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5–6 OCTOBER

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Escuela Superior de Arquitectura de San Sebastián
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International Congress on Energy Efficiency and Sustainability in Architecture and Urbanism

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[EU]
Gure ohiko kolaboratzaileak eta biltzarraren hamahirugarren edizioan parte hartu nahi lukeen oro gonbidatzen dugu beren proposamenak aurkeztera. Aurreko edizioetan bezala eta bere alderdi akademikoan oinarrituta, biltzarra bereziki ikasle, profesional eta ikertzaileei zuzenduta dago.
EESAP8/CICA1 ediziotik, zientzia eta teknikaren zabaltze-eremua eraikuntza berrikuntzetara zabaldu da eta baita enpresa mundura ere, enpresa berrikuntzak indartzeko dauden gizarte beharrei erantzuna emateko, eta era berean, horiek hiritar guztien bizi kalitate maximoa lortzeko bidean jartzeko.
Antolakuntza batzordeak, CAVIAR (UPV/EHU) ikerketa taldeak osatua, gaurkotasuna duten eta berritzaileak diren gaiak lantzen dituen antolaketa baten aldeko apustua egin du. Espazio honetan, horrela, adituek, ikertzaileek, ikasleek eta enpresek ezagutzak elkarbanatu ditzakete eta elkar eragin dezakete hitzaldi magistraletan, mahai-inguruetan, komunikatu libreetan eta berrikuntzarako lankidetza tailerretan (networking).

[ES]
La decimotercera edición del Congreso Internacional sobre Eficiencia Energética y Sostenibilidad en Arquitectura y Urbanismo (EESAP 13) abordará el tema de afrontar la oportunidad. En línea con el plan de recuperación de la Unión Europea, el objetivo se centrará en fomentar la mejora de la calidad de vida de las personas con modelos más ecológicos, digitales, resilientes y mejor adaptados a los retos actuales y futuros.
Invitamos a todos nuestros habituales y a quienes quieran acompañarnos en la próxima edición de nuestro congreso a exponer sus propuestas. Como en las anteriores ediciones y dada su faceta I+D+i+t, el congreso se dirige especialmente a profesionales, investigadores y estudiantes.
Desde la edición EESAP8/CICA1, el congreso amplía el ámbito de la difusión científica y técnica al conjunto de la innovación en la construcción y se abre al mundo empresarial, con el que se vincula para atender a la demanda social de fortalecer la innovación empresarial y encauzarla hacia la consecución de la máxima calidad de vida para todos los ciudadanos.

[EN]
]The thirteenth edition of the International Conference on Energy Efficiency and Sustainability in Architecture and Urban Planning (EESAP 13) will address the theme of addressing opportunity. In line with the European Union’s recovery plan, the focus will be on fostering the improvement of people’s quality of life with models that are greener, more digital, resilient and better adapted to current and future challenges.
We invite all our regulars and those who want to join us in the thirteenth edition of our conference to present their proposals. As in the previous editions and given in its academic facet, the conference is especially aimed at professionals, researchers and students.
Since the EESAP8/CICA1 edition, the conference has extended the scope of scientific and technical diffusion to the entire innovative construction sector. Furthermore, it is opened to the business sector, due to their close relationship to meet current social demands on business innovation for achieving a higher quality of life.
Once again, the Organizing Committee, composed of CAVIAR Research Group (Spanish abbreviations for Quality of Life in Architecture, UPV/EHU), has opted for innovative and current interest subjects to promote an atmosphere in which professionals, researchers, students and companies will be able to interact and exchange knowledge with the aid of lectures, round-tables, research communications and collaborative innovation workshops (networking).

9:00 Presentation

9:30 **Belinda López Mesa**
What is this thing called decarbonisation and digitalisation of buildings?

10:00 **Victor Echarri Iribarren**
Ceramic panels with capillary tube systems in buildings: Energy savings and investment

10:30 **Madelyn Marrero**
Control Ambiental a través de los presupuestos. Aplicación a la construcción de naves

11:00 Coffee

PRESENTATION

11:30 **Francisco Javier Díez Trinidad**
Resilient energy performance prediction system

11:50 **Markel Rueda Esteban**
Environmental and economic life cycle evaluation of residential buildings refurbishments by the calibration with monitored data

12:10 **Madelyn Marrero Meléndez**
Projecting sustainable design with PREDICE: Economic and environmental budgeting tool for Buildings Life Cycle

12:30 **María Jesús González Díaz**
Applying sustainability to existing architectural heritage. A practical example: adaptive reuse in a 1960s building in Valladolid (Spain)

12:50 **Arrate Hernández Arizaga**
Reference state temperature influence in the thermoeconomic costs of a building thermal facility

13:10 **Marta Gómez Gil**
European Digital Building Logbook: definition of its functionalities to maximize its potential

13:30 Lunch

POSTER SESSION

14:30 **Camila Andrea Ludueña**
Monitoring and simulation of thermal confort and air quality in social dwellings built in Bogotá-Colombia

Mª Isabel Romero Gómez
Sustainable solution as alternative to polypropylene reinforcement fibres used y gypsum composities

Filomena Pérez Gálvez
Sustainable energy rehabilitation model in rural areas of Andalusia as tool to alleviate depopulation

15:00 **EIBHO**
Ejes de actuación para conseguir un parque edificatorio eficiente y sostenible

WORKSHOP

15:20 **WORKSHOP 1 -**
Strategies for decarbonization of the building stock towards European Union objectives

Indicators presentation and activity of relevance

16:20 Coffee

WORKSHOP

16:40 **WORKSHOP 2**
The importance of monitoring and life-cycle perspective in social housing retrofitting

Introduction to "Zero Plana" of Alokabide and Steckhome: monitoring relevance

Presentation on the value of calibration, perspective life cycle analysis and activity of relevance.

18:00 Session end

9:00 Presentation

	Daniele La Rosa *The effects of urban green infraestructure in dense urban contexts: performance simulations for urban planing*	9:30
	Elma Durmisevic *Circular reversible buildings - Performance measurement and design tools*	10:00
	Pablo Martí Ciriquián *La aportación del BIG data a las estrategias de desarrollo urbano sostenible*	10:30

11:00 Coffe

PRESENTATION	Ekhiñe Eguiguren Azcune *Towards sustainable urban regeneration of industrial areas in the Basque Country: Case studies in Donostia - San sebastián and Pasajes.*	11:30
	Daniel Torrego Gómez *Rethinking Summer Energy Poverty from the south: debates and frontiers of an overlooked issue*	11:50
	Marta Gayoso Heredía *Summer energy poverty in southern Europe: a public policy perspective*	12:10
	Maddi Garmendia Antin *Progress towards sustainable stormwater management: Field monitoring of permeable pavement*	12:30
	Carlos Beltrán-Velamazán *Estimation of the solar potential of cities' roofs and façades from 3D city models and from bi-dimensional GIS models in Spain*	12:50
	Milagros Álvarez Sanz *Development of Simple Model for the Estimation of the Heating Demand at District Level*	13:10

13:30 Lunch

PRESENTATION	Markel Rueda Esteban *Monitoring and energy management strategy during the energy refurbishment plan of the social rental housing stock of the Basque Country*	14:30
	Francisco Valbuena García *Improving the urban environment through a zero energy university building: the R&D + i in Soria campus*	14:50
	Zhineng He *Simulation-based parametric analysis of control key-factors in building thermoelectric system*	15:10
	Darya Tretyakova *Digital twin as a tool to travel from A-class to NZEB*	15:30

15:50 Break

PRESENTATION	Jairo Posada Gómez *Calibration of energy simulations using real conditions of air quality, temperature and humididty, methodological proposal*	16:05
	Miriam Martinez Trinidad *The IA Zero methodology: A roadmap to sustainable refurbishment of buildings through energy simulation*	16:25
	Irati Prol Godoy *Thermoeconomic analysis of a thermal system supplied with Heat Pump and auxiliary boiler for DHW and heating*	16:45
	Chris Merveille *SmartLivingEPC, Advanced Energy Performance Assesment at Building and District Level*	17:05

17:25 Session end

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PRENERGET, framework for energy forecasting

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Key Words: Energy, Forecast, Machine learning, Artificial intelligence, Framework

Abstract

For the optimisation of energy management, it is crucial to be able to make decisions in advance. For this decision making it is necessary to have reliable predictions. In a building, there can be different types of predictions related to energy management; demand, production, temperature, price, occupancy, etc. Machine learning algorithms are a good technology to make these predictions, but they must be adapted to each variable and context, so many algorithms are needed running in parallel. In this paper a framework that allows to facilitate the execution of these predictions is presented. The boundary conditions on which these algorithms are based change over time and the predictions become less reliable. The presented framework allows to adapt to these changes in order to maintain the reliability of the predictions.

Introduction

PRENERGET is a framework for programming and executing machine learning algorithms to make predictions related to the energy efficiency of buildings. The recent energy crisis shows the need to increase renewable energy production. This implies a greater importance of active demand management in order to synchronise demand with production. Algorithms to perform this optimisation need to make predictions of different variables such as energy demand in different systems [1]. Machine learning (ML) based models have proven their importance in making accurate predictions [2][3][4]. Although there are a variety of environments that facilitate the development of ML models, when it comes to their deployment and exploitation it is necessary to move to a different approach. Data analysts are used to working in modelling environments whereas deployment environments are used by systems analysts and programmers.

The value provided by models is hindered in many cases by inadequate application logic. Additionally, under normal conditions the accuracy of ML-based forecasting models [5]. degrades over time due to changes in the environment that modifies the original assumptions of the models. Consequently, deployed models need to be regularly evaluated and updated to ensure the robustness of the solution they are part of [6].

The seamless exploitation, adaptation and evolution of ML-based models remains an open question today. In particular, the main contributions of the developed framework are:

-Facilitate the exploitation of ML models for energy efficiency related predictions.

-Maintain and, if possible, improve the accuracy of the predictions over time.

The rest of the article is structured as follows. Firstly, the motivation for the development of the environment is presented, followed by a summary of previous work found in the literature in the related work section. The theoretical and practical approach to the solution is shown in the strategy section for the control and continuous improvement of ML models. This is followed by the use cases that have been used to validate the environment. The final part shows the results obtained and the conclusions and ends by outlining the lines for future work.

Motivation

Today, the energy consumption of the building sector accounts for almost one third of total energy consumption and its share of emissions has risen to almost 30% [7]. In fact, energy consumed in the building sector is responsible for almost 3 Gt of direct CO_2 emissions. Space heating, cooking and other everyday activities account for the largest share of overall CO_2 emissions in the buildings sector, and demand side management (DSM) and demand response (DR) programmes have emerged in an effort to minimise these figures [8].
One of the ways to improve the energy efficiency of a building is to automate the operation to achieve energy management optimisation based on active demand side management. This optimisation is not simple because it depends on many factors such as the characteristics of the equipment, functionalities of the systems, activity, meteorology, building envelope, etc. In addition, in many cases there is an inertia that means that the actions taken do not have an immediate effect. For all these reasons, it is necessary to make predictions that allow us to take decisions in advance so that the effect of the actions carried out is applied at the right time, neither before nor after.
As we have said, there are many factors that influence energy management, some of which are static and others dynamic. The a priori dynamic factors are all predictable. This means that there are many variables that can be predicted. Some of these variables are energy consumed, energy produced, power, temperature, humidity, occupancy or luminosity. In addition, many of these variables must be aggregated or disaggregated by space, system and equipment. Consequently, a good optimisation in a large infrastructure requires many predictors running in parallel at time intervals that can vary from 15 minutes to a day.
We are then faced with the need to be able to run several different predictors in a stable and scheduled manner so that the optimisation of energy management can be automated. At this point, integration with other systems must be taken into account. In some cases, a classical integration via synchronised read and write to a database may be sufficient. For this it is necessary to synchronise the execution of the predictor in advance of its use, considering the time needed for the execution. In many cases, the prediction cannot be done much in advance either, as the results would be worse. The ideal synchronisation occurs when the optimisation algorithm is able to invoke the prediction algorithm when it needs the data. In this case it is not necessary to schedule the prediction, but it is necessary to define an interface that allows communication between the two modules. Service-oriented architectures (SOA) and web service interfaces have greatly facilitated the interoperability and integration of software systems.
PRENERGET aims to build a development environment that facilitates the generation, execution and maintenance of predictors of all these variables based on machine learning algorithms. For this, it is necessary to have easy access to the historical data of the monitored variables with different time horizons, as these periods will be very relevant in the results of the algorithms. It is also necessary to be able to make different schedules for the execution of the predictors given that depending on the variable and objective the intervals between predictions may be greater or lesser. Another aspect to consider is the integration of the results. PRENERGET stores the results in a normalised database in such a way that both the latest and previous predicted values are available to other software systems. In addition, PRENERGET incorporates a REST web service interface that allows the asynchronous invocation of any predictor in real time. The results of the execution, in addition to being recorded in the database, are returned in the call so that they can be used by the invoker directly.
After the generation and controlled execution of the predictors, they must be kept operational with good accuracy. It is normal for machine learning-based predictors to lose accuracy due to changes in the trend of any of the variables on which they are based. This has been particularly evident in the recent COVID 19 crisis in which there have been abrupt changes in normality that have significantly affected predictions made using pre-COVID data. Maintaining the accuracy of predictors generally involves periodic retraining and evaluation to determine whether the new predictor data is better than the old predictor data. This maintenance is tedious for the analyst and time-consuming and does not provide value. PRENERGET has automated this operation so that the prediction models are updated periodically without the need for manual retraining and evaluation.

Finally, it should be noted that another of PRENERGET's motivations is that it is a scalable system as well as improvable and updatable. To this end, in addition to modularity and interoperability, the advantages of each programming language/environment have been taken into account. Thus, a Java-based environment is used for programmatic tasks and an R-based environment for analytical tasks.

Related work

In recent years, AI has seen a strong advance that can be largely attributed to advances in modern computing and the increasing availability of data. The implementation of technology in buildings has led to the concept of 'Smart Building' where intelligent buildings collect, process and analyse data to efficiently manage energy resources and other supplies. Buildings can, for example, forecast the energy consumed and generated by the systems and based on this maximise energy efficiency through load restrictions or reallocation as explained in [1].

In the literature review, we can find numerous works aimed at forecasting energy from renewable or non-depletable sources that provide different approaches and mechanisms, among which the use of ML algorithms stands out. Several works such as those presented by [9], [10] and [11] show the validity of these algorithms for forecasting the energy produced in photovoltaic panels, solar thermal collectors and wind farms, among others. The approach and algorithms used differ from one author to another: for example, [12] shows a regression model using support vectors to forecast hourly and daily electricity consumption in households, while [4] uses regression trees and neural networks.

On the other hand, it is not only necessary to develop and integrate ML models but also to be able to perform functional monitoring of them to ensure that they are still functional and the results they provide are good. This is known as the concept drift problem, which means that the statistical properties of the target variable that the model is trying to predict change over time in unforeseen ways [13]. As explained in the work by [14], a changing environment can lead to degradation in the performance of forecasting models. And in the face of such changes, forecasting models must adapt [15]. It is necessary to understand the effect of drift on ML performance and to define the most appropriate adaptation strategies to make them more robust. Indeed, depending on the type of change, different adaptation mechanisms can be implemented. The work presented by [16] proposes different adaptation strategies starting from an initial model trained at least once with an initial batch of data. However, the strategy to follow will not always be the same and will depend on many factors (e.g. the nature of the data, the application domain, unforeseen events, etc.).

In this respect, there are different approaches found in the state of the art. Google for example offers the open-source product TensorFlow that allows integration into local infrastructure. This suite includes the model implementation tool Pusher, as well as other tools for model evaluation and validation, such as Evaluator and InfraValidator. In this case, the developer is limited to using these libraries to generate the models and will not be able to use other programming languages (e.g. Python, R...). On the other hand, the automation of updates must be implemented in the programming code using the tools mentioned above. The infrastructure presented by Clipper [17] has been developed at a higher level of abstraction in order not to rely on certain frameworks to build the model. This framework is modular and allows you to invoke models developed in Apache Spark, Scikit-Learn, Caffe or TensorFlow. It facilitates model integration through a unified REST interface but lacks model update capabilities. Data and Learning Hub for Science (DLHub) [18] is another framework for developing ML models. One of its pillars is the use of a standard model invocation through the "funcX" function [19] and the use of Docker-based containers. It is an excellent environment with good model characterisation capabilities and good performance, but it is oriented towards research environments rather than production environments where resources have different limitations. [20] shows a layer that encapsulates ML models to provide a microservice interface that can be exploited in commercial applications. In this case, the model developer must be able to implement the defined interface. This interface provides functionalities to detect data drift and accuracy KPIs and therefore assesses the need for retraining, but updating the models is outside the scope of the work.

FinTo the authors' knowledge, existing approaches do not cover these requirements [21] and [22]. Therefore, defining and implementing the necessary infrastructure, mechanisms, channels, interfaces and workflows to facilitate the automation, implementation and execution of ML models under the same software architecture to streamline the process is still a necessity today.

Strategy for monitoring and continuous improvement of ML models

PRENERGET helps to deploy ML models and to perform functional monitoring of ML models in a flexible, adaptable and reconfigurable way.
Figure 1 shows the flow of tasks configured from the selected strategy for functional monitoring of the models and its adaptation for the use case of energy consumption prediction in a building block (the use case is shown in the following section).

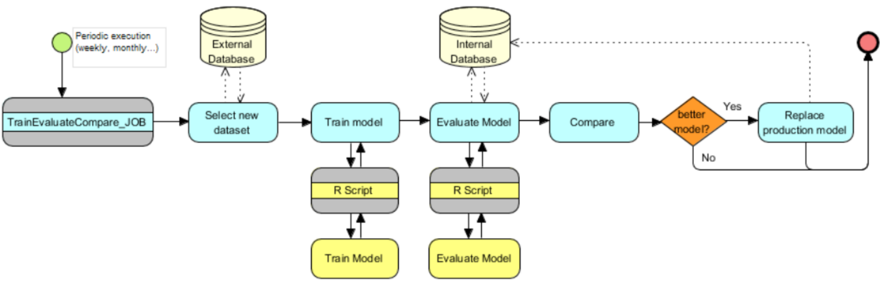

Figure 1. Data flow for model adaptation and updating.

We start from a time series database (TBS) in where the generated consumption data and the ML model are stored. The model has been initially trained with a 1-year dataset (hourly consumption) and has a starting accuracy adjustment (calculated in its validation phase). The strategy selected for drift detection and model adaptation is based on periodic scheduled monitoring of the error generated by the model during its life cycle and the use of moving time windows for updating the data used by the model in the retraining phase.
The 'Model Training' phase is executed daily, which trains the model with the most recent annual data obtained from the TBS from an R script. The algorithm searches and adjusts the hyperparameters of the model to maximise its accuracy. It returns as a result the error metric established and obtained by the new model.
Subsequently, the 'Model Evaluation' phase computes the error or drift obtained by the current running model using an R script, which currently compares the predicted values with the actual historical data values obtained and returns as a result the established error metric.
The drift detection of the model in production and its update by the new generated version is based on the improvement of these calculated error values by using error metrics that give us an idea of how good or bad our prediction model is (e.g. RMSE, MAE, etc.). It is in this last phase 'Comparison' where the errors of the new model and the previous one in production are compared, based on this whether the one in operation continues in use or is replaced.
As it is modular and configurable, PRENERGET allows different strategies to be programmed, both for the testing and evaluation of the models, as well as for updating and adapting them to changes, in a simple and agile way.

Use cases

The PRENERGET service has been tested in 4 scenarios in a technology research facility in Eibar (Spain). The different rooms chosen for the validation of the system have different energy consumption characteristics and the results obtained vary from one to another. The objective of the predictive task in the PRENERGET system is to provide hourly predictions of the power consumption expected for the next day using ML models trained with historical data. These data consist of univariate time series whose data are pairs of time records and records of electricity consumption measured in kWh.
In this case, through a previous comparative study, it was decided that the algorithm to be used was the k-nearest neighbours (KNN). The efficiency of KNN was found to be higher than that of ARIMA, linear regression and Support Vector Regression.
In order to choose the best explanatory variables in relation to the electricity consumption of the rooms, a set of variables was generated based on date and time. The contribution of each variable to the prediction was analysed and the following variables were chosen: time, day, month, season of the year,day of the week and a binary variable indicating whether the day is a working day or a public holiday, based on the local calendar. We observe that the numerical variables such as the time and the month have a cyclical behaviour. Since the KNN is based on the distances between instances, it is convenient to transform these variables to avoid erroneous conclusions. Therefore, the three variables were evaluated in the following function, where P is the period of each one (P=24 in the case of the hour, P = 12 in the case of the month) and obtaining two new variables corresponding to the sine and cosine of the initial values.

To pick the number of neighbours to be used, a cross-validation of 5 iterations on 70% of the data is used. This process is called training and is used to fit the model to the historical data. The process consists of dividing the training dataset into 5 equal parts and using 4 of them to fit a model by testing various values of k. Each of them is used to make predictions for the model. With each of them, predictions are made on the reserved set. By calculating the prediction errors in each of the tests, the k that gives the smallest average error is chosen. This choice is different for each dataset and once k is chosen a prediction is made on the remaining 30% of the data to evaluate the effectiveness of the decision taken. Both in the training process and in the final testing, the Root Mean Squared Error (RMSE) was the selected metric. This is a way of calculating the prediction error in the same units of measurement as the original data and is widely used as it is one of the most intuitive to interpret. Given a set of real values {y_t,t=1,…,T} and a set of values predicted by an ML model {y^_t,t=1,…,T }, the RMSE error is calculated as:

$$RMSE(y_t, \hat{y}_t) = \frac{1}{T}\sqrt{(y_t - \hat{y}_t)^2}$$

Once all the above decisions were made, the KNN model was trained with the latest year of historical data and a periodic task was scheduled to automatically run through the flow of Figure 1 every day at the same time, i.e. every 24 hours. Each time one of the iterations is run, the horizon of the training set is moved one day forward, so the oldest day is removed and data from the most recent day is added. Then, a model is trained with the newly updated data and the training error, i.e. the RMSE that has been used for the choice of the best k in the model fitting phase, is obtained. The update of the deployed model occurs in case the RMSE of the new model is lower than the one obtained in the current model fit. Each model update is labelled with an incremental numbering that marks the evolution of the model version.

Results

Some of the results obtained in the PRENERGET run for the 4 rooms mentioned above are discussed below. For all cases, the initial model labelled 0.0 was trained with historical data from 1 April 2020 to 31 March 2021. Consequently, the first prediction was made for the 24-hour consumption corresponding to 1 April 2021.
Table 1 shows the updated versions of the electricity consumption prediction model for the CGBT2 consumption point. Up to 17 August 2021, 10 more accurate versions of the predictive model were deployed. In the first two columns are the start and end dates of the data period used for training the model. The RMSE in the third column corresponds to the mean error obtained with the number of neighbours chosen in the cross-validation. In this case, the error is reduced from 16.481 kWh to 15.5 kWh, an improvement of 6%. The last column is the incremental label of the model version.

Initial date	End date	RMSE	Version
2020-04-01	2021-03-31	16.481	0.0
2020-04-02	2021-04-01	16.430	0.1
2020-04-03	2021-04-02	16.311	0.2
2020-04-09	2021-04-08	16.093	0.3
2020-04-10	2021-04-09	15.976	0.4
2020-04-13	2021-04-12	15.959	0.5
2020-04-20	2021-04-19	15.951	0.6
2020-04-29	2021-04-28	15.871	0.7
2020-05-02	2021-05-01	15.768	0.8
2020-05-03	2021-05-02	15.655	0.9
2020-08-18	2021-08-17	15.500	1.0

Table 1. Evolution of the RMSE of the training of the different deployed versions of the predictive model of electricity consumption for the CGBT2 consumption point.

The graph in Figure 2 shows the model updates from version 6 to version 9. In black the actual values collected are shown and the different colours are used to differentiate the predictions obtained with each of the running versions.

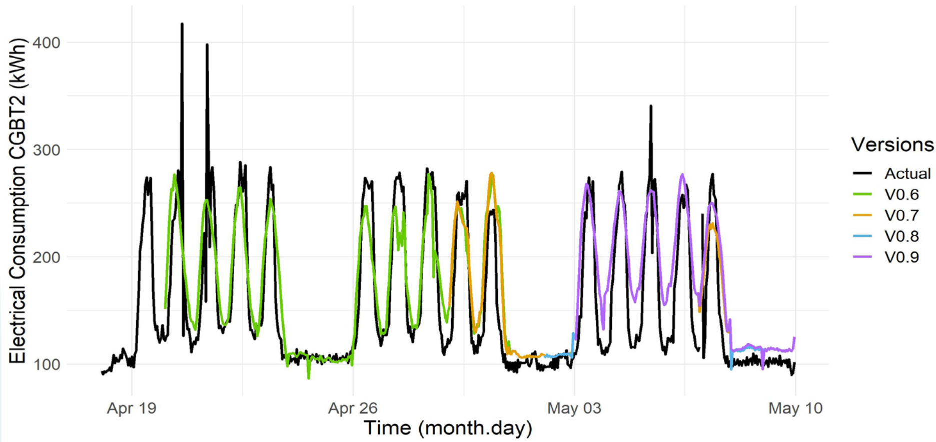

Figure 2. Evolution of predictions obtained by versions 6, 7, 8 and 9 of the deployed model.

The upgrade to version 10 that occurs on 17 August to start predicting values on 18 August is shown in Figure 3.

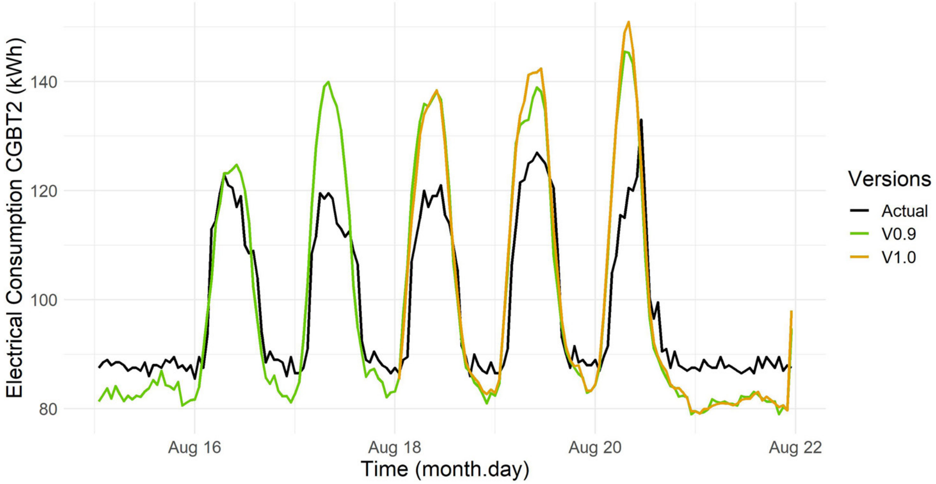

Figure 3. Evolution of the predictions obtained by versions 9 and 10 of the deployed models. The model update tables for the other 3 monitored variables are shown below.

Table 2 shows the update of the model deployed for the consumption point CGBT1. In this case the process was stabilised at version 12 reached on 5 June 2021, having reduced the RMSE of the model from 49.804 to 14.791. This improvement represents a 70% reduction in training error.

Initial date	End date	RMSE	Version
2020-04-01	2021-03-31	49.804	0.0
2020-04-02	2021-04-01	48.802	0.1
2020-04-07	2021-04-06	48.633	0.2
2020-04-08	2021-04-07	47.924	0.3
2020-04-10	2021-04-09	47.803	0.4
2020-04-11	2021-04-10	46.237	0.5
2020-04-17	2021-04-16	46.043	0.6
2020-05-23	2021-05-22	43.065	0.7
2020-05-28	2021-05-27	38.118	0.8
2020-06-03	2021-06-02	38.060	0.9
2020-06-04	2021-06-03	15.169	1.0
2020-06-05	2021-06-04	14.939	1.1
2020-06-06	2021-06-05	14.791	1.2

Table 2. Evolution of the RMSE of the training of the different deployed versions of the predictive model of electricity consumption for the CGBT1 consumption point.

The update of the model deployed for the clean room is shown in Table 3. In this room the consumptions are lower and more controlled. This is reflected in the slower improvement of the RMSE. The model was updated to version 8 on 20 June, achieving a 30% improvement in the RMSE.

Initial date	End date	RMSE	Version
2020-04-01	2021-03-31	3.016	0.0
2020-04-16	2021-04-15	2.972	0.1
2020-05-28	2021-05-27	2.843	0.2
2020-05-29	2021-05-28	2.811	0.3
2020-06-04	2021-06-03	2.141	0.4
2020-06-05	2021-06-04	2.129	0.5
2020-06-09	2021-06-08	2.121	0.6
2020-06-12	2021-06-11	2.115	0.7
2020-06-21	2021-06-20	2.103	0.8

Table 3. Evolution of the RMSE of the training of the different deployed versions of the predictive model of electricity consumption for the clean room.

Finally, Table 4 shows the update of the model deployed for the consumption point under cover. In this case, the final version was version 13 reached on 18 June, having lowered the training error from 17,511 to 5,456. This improvement represents a 69% decrease in the internal RMSE of the model.

Initial date	End date	RMSE	Version
2020-04-01	2021-03-31	17.511	0.0
2020-04-03	2021-04-02	17.192	0.1
2020-04-07	2021-04-06	17.183	0.2
2020-04-10	2021-04-09	16.263	0.3
2020-05-23	2021-05-22	13.969	0.4
2020-05-24	2021-05-23	13.522	0.5
2020-05-26	2021-05-25	13.424	0.6
2020-05-28	2021-05-27	12.383	0.7
2020-06-04	2021-06-03	5.548	0.8
2020-06-05	2021-06-04	5.502	0.9
2020-06-06	2021-06-05	5.480	1.0
2020-06-07	2021-06-06	5.467	1.1
2020-06-13	2021-06-12	5.459	1.2
2020-06-19	2021-06-18	5.456	1.3

Table 4. Evolution of the RMSE of the training of the different deployed versions of the predictive model of electricity consumption for the consumption point under cover.

Conclusions

ML models based on historical electricity consumption data are key for demand forecasting and for different energy efficiency strategies. PRENERGET is a system that contributes to the control and updating of the models developed for these tasks in an automatic, simple and efficient way. In this way, it is possible to maintain and even improve the error of the ML models that periodically provide estimates of future electricity demand values. The modular architecture of PRENERGET allows analysts to test different algorithms and evaluate them with different training and error measurement strategies. In a simple way, the different versions of the models are stored together with the information of each model that has been used during the course of the iterative tasks. PRENERGET is cost-saving, especially in terms of time, as its structure provides a simple way to change the prediction approach avoiding the effort of analysis from the beginning. In addition, model errors decrease over time, so having this automatic model re-training tool improves model resilience by automatically adapting to changes in the environment. In the examples analysed in this work, it has been shown that in about 3 months the RMSE of the models has been reduced by up to 70% in some cases. Future work PRENERGET is a system for periodically evaluating the effectiveness of electricity demand forecasting models based on historical consumption. The update of the models is given when a new adjustment with more recent training data obtains a lower error in the cross-validation. As a further evaluation, a module to evaluate model degradation by assessing the prediction errors obtained in the past is proposed as future work. That is to say, the error committed in the prediction of the past day would be collected by calculating a metric that compares the predicted values with the real ones and a Concept Drift detection system would be implemented. This method would detect deviations in the error distribution, which, by definition, should be normal.

Bibliography

[1] Esnaola-Gonzalez, I., Jelić, M., Pujić, D., Díez, F. & Tomasevic, N. (2021), 'An AI-Powered System for Residential Demand Response', Electronics 10.
[2] Gómez-Omella, M., Esnaola-Gonzalez, I., Ferreiro, S. & Sierra, B. (2021), 'k-nearest patterns for electrical demand forecasting in residential and small commercial buildings', Energy and Buildings 253, 111396.
[3] Tascikaraoglu, A. & Sanandaji, B. M. (2016), 'Short term residential electric load forecasting: A compressive spatio-temporal approach', Energy and Buildings 111, 380–392.
[4] Lusis, P., Khalilpour, K. R., Andrew, L. & Liebman, A. (2017), 'Short-term residential load forecasting: Impact of calendar effects and forecast granularity', Applied Energy 205, 654–669.
[5] Widmer, G.&Kubat, M. (1996), 'Learning in the presence of concept drift and hidden contexts', Machine learning 23(1), 69–101.
6] Žliobait˙e, I., Pechenizkiy, M. & Gama, J. (2016), 'An overview of concept drift applications', Big data analysis:
new algorithms for a new society pp. 91–114.
[7] International Energy Agency (2021), 'World energy outlook 2021'. URL: https://www.iea.org/reports/world-energyoutlook-2021
[8] Warren, P. (2014), 'A review of demand-side management policy in the uk', Renewable and Sustainable Energy Reviews 29, 941–951.
[9] Ahmed, R., Sreeram, V., Mishra, Y. & Arif, M. (2020), 'A review and evaluation of the state-of-the-art in pv solar power forecasting: Techniques and optimization', Renewable and Sustainable Energy Reviews 124
[10] Unterberger,V., Lichtenegger, K., Kaisermayer,V., Gölles,M. & Horn, M. (2021), 'An adaptive short-term forecasting method for the energy yield of flat-plate solar collector systems', Applied Energy 293.
[11] Juban, J., Siebert, N. & Kariniotakis, G. N. (2007), Probabilistic short-term wind power forecast
[6] Žliobait˙e, I., Pechenizkiy, M. & Gama, J. (2016), 'An overview of concept drift applications', Big data analysis:

new algorithms for a new society pp. 91–114.
[7] International Energy Agency (2021), 'World energy outlook 2021'. URL: https://www.iea.org/reports/world-energyoutlook-2021
[8] Warren, P. (2014), 'A review of demand-side management policy in the uk', Renewable and Sustainable Energy Reviews 29, 941–951.
[9] Ahmed, R., Sreeram, V., Mishra, Y. & Arif, M. (2020), 'A review and evaluation of the state-of-the-art in pv solar power forecasting: Techniques and optimization', Renewable and Sustainable Energy Reviews 124
[10] Unterberger,V., Lichtenegger, K., Kaisermayer,V., Gölles,M. & Horn, M. (2021), 'An adaptive short-term forecasting method for the energy yield of flat-plate solar collector systems', Applied Energy 293.
[11] Juban, J., Siebert, N. & Kariniotakis, G. N. (2007), Probabilistic short-term wind power forecasting for the optimal management of wind generation, in '2007 IEEE Lausanne Power Tech', IEEE, pp. 683–688.
[12] Zhang, X. M., Grolinger, K., Capretz, M. A. M.&Seewald,L. (2018), Forecasting residential energy consumption: Single household perspective, in '2018 17th IEEE International Conference on Machine Learning and Applications (ICMLA)', pp. 110–117.
[13] Lu, J., Liu, A., Dong, F., Gu, F., Gama, J. & Zhang, G. (2018), 'Learning under concept drift: A review', IEEE Transactions on Knowledge and Data Engineering 31(12), 2346–2363.
[14] Gomez-Omella, M., Esnaola-Gonzalez, I. & Ferreiro, S. (2020), Short-term forecasting methodology for energy demand in residential buildings and the impact of the covid-19 pandemic on forecasts, in 'Proceedings of 40th SGAI International Conference on Artificial Intelligence', Vol. 12498, pp. 227–240.
[15] Gama, J., Žliobait˙e, I., Bifet, A., Pechenizkiy, M. & Bouchachia, A. (2014), 'A survey on concept drift adaptation', ACM computing surveys (CSUR) 46(4), 1–37.
[16] Celik, B. & Vanschoren, J. (2021), 'Adaptation strategies for automated machine learning on evolving data', IEEE Transactions on Pattern Analysis and Machine Intelligence 43(9). URL: https://ieeexplore.ieee.org/document/9366792
[17] D. Crankshaw, X.Wang, G. Z. M. J. F. J. E. G. I. S. (2017), Clipper: A low-latency online prediction serving system, in '14th USENIX Symposium on Networked Systems Design and Implementation (NSDI)', pp. 613–627.
[18] Zhuozhao Li, Ryan Chard, L. W. K. C. T. J. S. Y. B. A. W. S. T. B. B. M. J. F. I. F. (2021), 'Dlhub: Simplifying publication, discovery, and use of machine learning models in science', Journal of Parallel and Distributed Computing 147, 64–76.
[19] R. Chard, Y. Babuji, Z. L. T. S. A. W. B. B. I. F. K. C. (2020), funcx: A federated function serving fabric for science, in 'Proceedings of the 29th International Symposium on High-Performance Parallel and Distributed Computing'.
[20] Muthusamy, V., Slominski, A. & Isahagian, V. (2018), Towards enterprise-ready ai deployments minimizing the risk of consuming ai models in business applications, pp. 108–109.
[21] Simmhan, Y., Aman, S., Kumbhare, A., Liu, R., Stevens, S., Zhou, Q. & Prasanna, V. (2013), 'Cloud-based software platform for big data analytics in smart grids', Computing in Science & Engineering 15(4), 38–47.
[22] Choi, T.-M., Chan, H. K. & Yue, X. (2016), 'Recent development in big data analytics for business operations and risk management', IEEE transactions on cybernetics 47(1), 81–92.

Environmental and economic life cycle evaluation of residential buildings refurbishments by the calibration with monitored data

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Abstract

Buildings are responsible of about the 40% of the energy consumption and the 36% of the greenhouse gas emissions of the European Union (EU), taking into account all the stages of the buildings' life; in response, the energetic refurbishment of buildings is one of the main keys to pursue the decarbonisation targets of the EU. Following this, numerous scientific studies, recommendations of the EU and recent publications such as the "Roadmap for the decarbonisation of buildings throughout their life cycle" published by GBC in 2022; where the integration of the life cycle assessment (LCA) is defined as one of the pillars to be able to assess and quantify the decarbonisation of the building stock. Moreover, studies found the high influence of non-operational stages of the buildings' life on the environmental and economic sustainability of building refurbishment, and according to the literature, the LCA is the prioritizing analysis on building refurbishment studies. Besides, regular energetic assessments, like energy performance certificates (EPC), are not considered reliable due to the standard input, presenting the need of calibration of inputs by real data calibration. Furthermore, other studies also showed the importance of the occupant behaviour for the energetic calculations, and the high influence of base temperature input for heating and cooling energy demand simulations.
The aim of the study is to provide a methodology to assess the environmental and economic sustainability of energy refurbishment of residential buildings taking into account all the stages of the buildings' life and the occupant behaviour. Therefore, the methodology is based in the environmental and economic LCA applying the calibration of input parameters by monitoring real data.
The proposed analysis evaluates the environmental and economic sustainability of energy refurbishment strategies related to the heating and domestic hot water (DHW) energy consumption. The methodology is developed in six stages: (1) Building data collection: building typology characteristics related to the energetic performance and monitoring of temperature of the dwelling; (2) Input parameters calibration according to the thermal performance of the building by the monitored data; (3) Modelling and simulation of the scenarios data (baseline scenario and scenarios with retrofitting strategies); (4) Energy consumptions calculation related to heating and DHW; (5) Environmental and economic impact indicators calculation in all the stages of the building's life for each scenario; (6) Prioritizing indicators calculation according to the environmental and economic impact.
As a result, the methodology evaluates the environmental and economic impact of the buildings' life cycle for different scenarios applying refurbishment strategies, taking into account all the stages of the buildings' life and the occupant behaviour by the calibration of input parameters by monitoring data. Thus, it provides a more accurate calculation in comparison to the regular methodology that is limited to quantifying the impact (economic and/or environmental) only during the use stage and by standard input parameters without reflecting the occupant behaviour.

1.Introduction

Buildings are responsible for about 40% of energy consumption and 36% of greenhouse gas emissions in the European Union (EU), taking into account all stages of the building life cycle; this makes them one of the major contributors to the greenhouse effect [1]. According to the European Commission, today about 75% of the EU building stock is inefficient, and only 0.4% to 1.2% of them are retrofitted per year [1]. To meet the challenge of drastically reducing energy consumption and greenhouse gas emissions, this rate should at least double [1]. To achieve such an increase in the rate of retrofitting, the main tool available to Member States (MSs) is the implementation of legal mechanisms.

The main legal mechanism concerning building retrofitting at the European level is the Energy Performance of Buildings Directive (EPBD), first introduced in 2002, (Directive 2002/91/EC) [2], updated in 2010 (Directive 2010/31/EU) [3], and in 2018 the latest update was added by Directive (EU) 2018/844 [4]. The regulation promotes policies that will help to achieve a highly energy efficient and decarbonized building stock by 2050 in order to reach EU energy and environmental targets, promoting decarbonisation, improved energy efficiency and also the quality of life of citizens along with additional benefits for the economy and society [4].

In order to provide guidelines to facilitate the implementation of the main measures enacted by Directive 2018/844, Commission Recommendation (EU) 2019/786 was published on 8 May 2019 [5]. The document focuses on the provisions related to building renovation and refers to Articles 2a, 10, 20 and Annex I of the EPBD, which include provisions on long-term renovation strategies, financing mechanisms, incentives, information and calculation of the energy performance of buildings [5]. Article 2a (2) added, establishes a framework for Long Term Renovation Strategies (LTRS) to support the renovation of the national building stock into highly efficient and decarbonized buildings, including: a) measurable progress indicators, and b) indicative milestones [5].

The so-called Measurable Progress Indicators (MPIs) defined in the “Commission Recommendation (EU) 2019/786 of 8 May 2019 on building renovation” document [5] are the main common framework to evaluate the decarbonisation of the building stock of the MSs. One of the main scopes referring to the point (b) of the Article 2a of the EPBD (Directive (EU) 2018/844) evaluates the “identification of cost-effective approaches to renovation relevant to the building type and climatic zone, considering potential relevant trigger points, where applicable, in the life-cycle of the building” [5]; this scope evaluates the energy saving potential of refurbishment strategies to ensure the decarbonisation of the building stock and the cost effectiveness of these measures. Moreover, the scope (g) of the Commission Recommendation (EU) 2019/786, about the “evidence-based estimate of expected energy savings” also evaluates the energetic and environmental aspects by the MPIs of “actual energy savings”, “reduction of emissions” and the “reduction of whole life carbon” [5]. According to this EU’s evaluation framework proposed in the Commission Recommendation (EU) 2019/786 regards the evaluation of the environmental and economic sustainability of the refurbishment strategies of the buildings taking into account the life cycle of the buildings.

The integration of the life cycle perspective is also remarked as the main methodological approach to assess and quantify the decarbonisation of the building stock in many other reports such as Level(s) [6], the European framework for sustainable buildings, and the recent published report “Roadmap for the decarbonisation of buildings throughout their life cycle” by GBCe in 2022 [7]. Moreover, studies found the high influence of non-operational stages of the buildings’ life on the environmental and economic sustainability of building refurbishment [8], and according to the literature the LCA is the prioritizing analysis on building refurbishment studies [9].

The environmental and economic indicators are also the most applied ones by the European research and technological development (RTD) projects, but these evaluations present barriers as the a previous study showed [10] showed, regarding the need of more accuracy and reliability of the evaluation indicators; however, the investigation also proposed opportunities like the calibration of input data of the energetic simulation by monitored data. Furthermore, many studies reported that regular energetic evaluations regular energetic assessments, like energy performance certificates (EPC), are not considered reliable [11] due to the standard input, presenting the need of calibration of inputs by real data calibration [12].

Furthermore, other studies also showed the importance of the user behaviour for the energetic calculations [13], and the high influence of base temperature input for heating and cooling energy demand simulations [14].
In summary of the requirements about the environmental and economic evaluation of the decarbonisation of the building stock by refurbishment strategies, the integration of the life cycle perspective as well as the calibration of calculation inputs by monitored data is essential for an accurate and reliable result.

2.Objective

The aim of the study is to provide a methodology to assess the environmental and economic sustainability of energy refurbishment of residential buildings taking into account all the stages of the buildings' life and the occupant behaviour. Therefore, the methodology is based in the environmental and economic LCA applying the calibration of input parameters by monitoring real data. This methodology will be useful, on the one hand, to answer to the requirements of the main evaluation scopes proposed by the Commission Recommendation (EU) 2019/786 concerning the indicators about the economic cost effectiveness and environmental impact; and in the other hand to prioritize the optimal refurbishment strategies according to the environmental and economic sustainability.
In the present paper, the methodology to assess the economic and environmental sustainability with the life cycle approach by the calibration with monitored data will be explained, developed in six stages. The study understands this methodology applicable to any collective residential building from Europe.

3.Methodology for the environmental and economic evaluation of building refurbishment strategies

The methodology is focused in the analysis of the environmental and economic life cycle of the buildings and the scenarios with refurbishment strategies related to the heating and domestic hot water (DHW) energy consumption. The methodology is developed in six stages: (1) Building data collection; (2) Calibration by read data; (3) Modelling and simulation; (4) Definition of LCA parameters; (5) Environmental and economic impact calculation; and (6) Prioritizing of the refurbishment strategies. The Figure 1 summaries the proposed methodology for the environmental and economic evaluation of building refurbishment strategies with life cycle approach and calibration by real data.

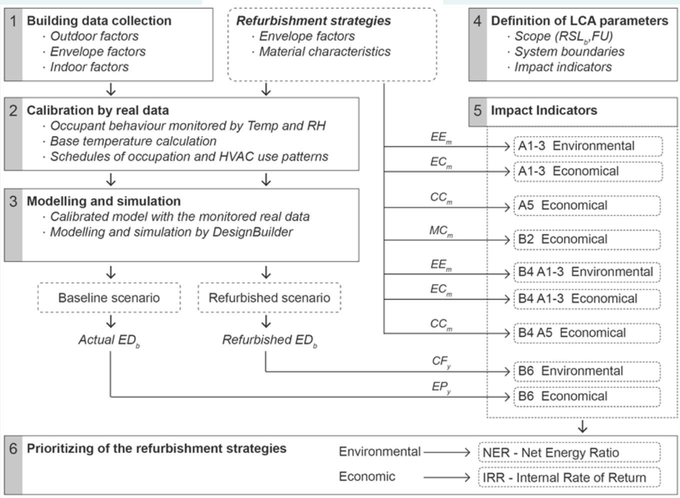

Figure 1. Graphical summary of the proposed methodology for the environmental and economic evaluation of building refurbishment strategies with life cycle approach and calibration by real data

3.1 Building data collection

The data for the calculation of the energetic operation of the buildings is collected. This data is divided in three groups according to the type of factors following the study made by Cuerda et al [15] that studied the calibration of energy simulations: the outdoor factors, the envelope factors, and the indoor factors.
Firstly, for the collection of the outdoor factors, the climatic files developed by different entities can be used, with at least the hourly data about the hygrothermal, solar radiation and weather conditions during the natural year. For instance, the database of ASHRAE can be a correct source as well as the data from local climatic stations or entities.
Secondly, for the envelope factors the building constructive characteristics are studied theoretically and empirically. The information about the geometry and the material composition of the construction elements related to the thermal performance are collected from the construction project; moreover, also the detailed description of the HVAC systems of the building is studied, including the technical data of the system. In addition, in site verification of the building constructive materials has to be done, as well as a visual inspection is done to identify possible pathologies that can disrupt on the energetic performance. Moreover, for the final check of the envelope factors a thermographic analysis needs to be done by a passive qualitative infrared thermography (IRT); this allows to analyse the hygrothermal behaviour of construction and the joints. The identification of thermal bridges and possible pathologies of the construction that can differ the theoretical thermal transmittances of the construction elements.
Thirdly, the internal factors are ruled by the occupant behaviour, and for the interpretation of it the data is collected quantitatively by monitoring the indoor thermal conditions with high technology and accuracy monitoring equipment. For the monitoring of the indoor thermal conditions, the equipments are placed in the day and night zones of the houses (living room and bedroom) in the height of the human chest (120cm aprox.) and the monitoring period is at least one natural annual cycle, recording the temperature and relative humidity (RH) at least every hour.

3.2 Calibration by read data

In order to reflect occupants' interaction with the building, the heating activation temperature is determined, aligned with the methodology of a previous work [16]. To do this, the outdoor temperature is analysed and the coldest month of the monitored period is determined. The corresponding analyses are performed on the monitored data of a given month for a selected dwelling. Since there may be a differentiated use of heating between rooms, with varying activity and temperatures, the living room temperature is used for calibration. The activation temperature of a dwelling is defined as the average of the relative minimum temperatures of the analysed period, corresponding to the most adverse month.

3.3 Modelling and simulation

The model of the building is created using the collected data together with the calibrated parameters for the simulation of the energetic analysis by the calculation engine EneryPlus using the interface of DesignBuilder. The accuracy of the needs to be precise, but mostly the thermal conditions and parameters as the parameters with the highest influence. The dynamic stationary simulation will calculate the energy demand related to heating and domestic hot water (DHW) for the baseline scenario and each refurbishment.
Different refurbishment strategies can be evaluated, proposing different types of refurbishment strategy in many levels of efficiency and materials with different embodied environmental impact and price. Each building will demand specific types of refurbishment strategies, applying both active and passive solutions. It is important to have the environmental impact data and the economic costs of the materials and systems of the refurbishment strategies to be evaluated, specified in the section 3.5; these data can be found in construction materials environmental product declaration (EPD) and databases about LCA assessment of products (for instance INIES, Ecoinvent) for the environmental impact, and in construction costs databases for the economic costs.

3.4 Definition of LCA parameters

In this stage, the LCA calculation parameters are defined to set the evaluation condition variables: the scope, the system boundaries, and the impact indicators.
The scope specifies the parameters of the Refurbished building Reference Service Life (RSLb) and the Functional Unit (FU): the RSLb defines the period for which the time-dependent characteristics of the evaluated object are analysed and the FU defines the reference unit where all the impacts will be measured, for a normalized evaluation. For this methodology, the following values are defined for the RSLb and FU parameter:

- RSLb: 50 years
- FU: [m2/year]

The system boundaries define the limits of the evaluation in terms of the stages of the life cycle. The stages of the LCA are defined in the standard EN 15978. However, for optimizing the calculation the limits of the system has been studied, not taking into account the stages that affect with less than 1% the results of the LCA according to the study of Oregi et al. (Oregi et al., 2017), demonstrating the low reliability of certain stages. For the environmental LCA the stages of A1-3 (Production), B4 A1-3 (Production of the replacement) and B6 (Operational) are included; and for the economical LCA the stages of A5 (Construction), B2 (Maintenance) and B4 A5 (Construction of the replacement) are added (see Figure 2).

Figure 2. System boundaries of the LCA based methodology.

The impact indicators measure directly the individual impact of each refurbishment strategy following the normative EN 15978. The methodology proposes the three most significant impact indicators, two for the environmental LCA and one for the economic LCA:

Environmental LCA:

-NRPE: Non-renewable primary energy [MJ-eq/m2·yr]
-GWP: Global Warming Potential [kgCO2-eq/m2·yr]

Economic LCA:

-Full-Cost: Full cost accounting [€/m2·yr]

3.5 Impact indicators calculation

To measure the effect of the strategies as well as the baseline building the impact indicators are calculated following the LCA calculation parameters defined in the previous stage. For the calculation of each impact factor for each life cycle stage, the equations of the Table 1 are used with the acronyms of the Table 3.
For the calculation of the impact, indicators during the different life cycle stages the results of the energetic simulations will be used, together with the environmental and economic data about the materials and systems of each refurbishment strategies.

Impact Indicators		
A1-3. Production of refurbishment strategies		
Environmental	$NRPE_{A1-3} = \sum_{m=1}^{m=k} EE_m \cdot Q_m \big/ FU$	$GWP_{A1-3} = \sum_{m=1}^{m=k} EE_m \cdot Q_m \big/ FU$
Economic	$FC_{A1-3} = \sum_{m=1}^{m=k} EC_m \cdot Q_m \big/ FU$	
A5. Construction process of refurbishment strategies		
Economic	$FC_{A5} = \sum_{m=1}^{m=k} (Q_m \cdot CC_m)/FU$	
B2. Maintenance of refurbishment strategies		
Economic	$FC_{B2} = \sum_{n=1}^{RSL_b} \left(\sum_{m=1}^{m=k} \frac{MC_m \cdot Q_m}{EMP_m} \right) \cdot (1 + IR_n) \big/ FU$	
B4 A1-3. Replacement of refurbishment strategies (Production)		
Environmental	$NRPE_{B4(A1-3)} = \sum_{m=1}^{m=k} EE_m \cdot Q_m \cdot \left((RSL_b / ESL_m) - 1 \right) \big/ FU$	$GWP_{B4(A1-3)} = \sum_{m=1}^{m=k} EE_m \cdot Q_m \cdot \left((RSL_b / ESL_m) - 1 \right) \big/ FU$
Economic	$FC_{B4(A1-3)} = \sum_{m=1}^{m=k} EC_m \cdot Q_m \cdot \left((RSL_b / ESL_m) - 1 \right) \cdot (1 + IR_{ESLm}) \big/ FU$	
B4 A5. Replacement of refurbishment strategies *(Construction process)*		
Economic	$FC_{B4(A5)} = \sum_{m=1}^{m=k} \left(([Q_m \cdot CC_m]) \cdot [(RSL_b / ESL_m) - 1] \right) \cdot (1 + IR_{ESLm}) \big/ FU$	
B6. Operational energy use of the building		
Environmental	$NRPE_{B6} = \sum_{n=1}^{RSL_b} \left(\sum_{m=1}^{m=k} \left[\left(\frac{ED_b}{\rho} + DL_b \right) \cdot CF_y \right] \right) \big/ FU$	$GWP_{B6} = \sum_{n=1}^{RSL_b} \left(\sum_{m=1}^{m=k} \left[\left(\frac{ED_b}{\rho} + DL_b \right) \cdot CF_y \right] \right) \big/ FU$
Economic	$FC_{B6} = \sum_{n=1}^{RSL_b} \left(\sum_{m=1}^{m=k} \left[\left(\frac{ED_b}{\rho} + DL_b \right) \cdot EP_y \right] \cdot [1 + EPI_y^n] \right) \big/ FU$	

Table 1. Equations for the calculation of impact indicators for each life cycle stage.

3.6 Prioritizing of the refurbishment strategies

For the prioritizing and comparison, the prioritizing indicators are calculated as the relative results of the environmental and economic sustainability of the refurbishment strategies evaluated. The prioritizing indicators show the environmental and economic sustainability of each refurbishment strategy relative to the baseline, calculated from the impact indicators:

Environmental LCA: Net Energy Ratio (NER)

Economic LCA: Internal Rate of Return (IRR) (%)

For prioritization according to the environmental aspect the indicator of NER has been used, developed for the environmental evaluation of buildings with life cycle approach by Hernandez & Kenny [17]. This indicator determines the energy efficiency over the life cycle of each retrofit strategy; this indicator is unitless and simply indicates how many times each retrofit strategy saves "internal energy" during its life cycle.

For the economic prioritizing, the applied indicator is the IRR, reflecting the value that equals the initial difference (net present value) between the initial payment and the income generated by the project. This indicator is generally used to assess the economic investment attractiveness of different projects; if the implementation of a rehabilitation project or strategy exceeds the IRR values defined by the researcher, the project becomes economically attractive. In the Table 2 the equations to calculate both prioritizing indicators are expressed, and the acronyms are defined in the Table 3.

Prioritizing Indicators	
Environmental	$NER = \frac{AEU1 - AEU2}{AEE2 - AEE1}$
Economic	$IRR\ (\%) = r_a + \left[\left(\frac{NPV_a}{NPV_a - NPV_b}\right) \times (r_b - r_a)\right]$

Table 2. Equations for the calculation of prioritizing indicators

Acronyms	*Definition*	*Unit*
Q_m	Quantity	[unit]
FU	Functional unit	[$m^2 \cdot yr$]
RSL_b	Reference Service Life of the building	[yr]
ESL_m	Estimated Service Life of the material	[yr]
EE_m	Embodied environmental impact of the material	NRPE[MJ/unit] - GWP [$kgCO_2eq$/unit]
EC_m	Economic cost of the material	[€/unit]
CC_m	Installation process cost of material	[€/unit]
MC_m	Maintenance cost of material	[€/unit]
ED_b	Energy demand of the building	[MJ]
P	Energy efficiency of the system	-
DL_p	Heat losses	[MJ]
CF_y	Conversion factor	NRPE [MJ/MJ] - GWP [$kgCO_2eq$/MJ]
EP_y	Energy price	[€/MJ]
EPI_y	Energy price increase coefficient	-
IR_{ESLm}	Economic inflation rate during the RSL_b	-
AEU	Annualized energy use	[$MJ/m^2 \cdot yr$]
AEE	Annualized embodied energy	[$MJ/m^2 \cdot yr$]
NPV	Net Present Value	[€/m^2]

Table 3. Acronyms of the equations of the impact factors.

Conclusions

The proposed methodology allows evaluating the environmental and economic sustainability of different refurbishment strategies to apply in a residential building, as well as to evaluate the impact of the planned or executed refurbishment.

On the one hand, the methodology can aid the decision-making on the possible refurbishment, according to the environmental and economic performance. The methodology will reflect the improvement than can provide each refurbishment strategy in terms of environment and economy, leaving the interpretation of the results to the different stakeholders involved, and assess if it is necessary or not to refurbish the building.

On the other hand, the methodology can address the challenge of answering to the evaluation indicators to measure the decarbonisation and cost effectiveness of the refurbishment of the residential building stock regarded by the Commission Recommendation (EU) 2019/786, mentioned before. This research emphasizes the importance of the life cycle perspective to evaluate the decarbonisation of the building stock, together with the occupant behaviour, in terms of decarbonisation effect and the economic cost effectiveness.

To conclude, the calibration by monitored data and the life cycle approach provide a more accurate result as all the effect of all the stages of the life cycle of the building are evaluated, both environmental and economical, taking into account the occupant behaviour going beyond the theoretical and standardized input data energetic calculations that doesn't make possible to get reliable results, and can lead to incorrect results.

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Bibliography

[1]European Commission, “Energy efficiency in buildings,” 2020. [Online]. Available: https://ec.europa.eu/info/sites/default/files/energy_climate_change_environment/events/documents/in_focus_energy_efficiency_in_buildings_en.pdf
[2]European Commission, “Directive 2002/91/EC of the European Parliament and ofthe Council of 16 December 2002 on the energy performance of buildings.”
[3]European Commission, “Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings.”
[4]European Commission, “Directive (EU) 2018/844 of the European Parliament and of the Council of 30 may 2018 amending directive 2010/31/EU on the energy performance of buildings and directive 2012/27/EU on energy efficiency.” [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L0844&from=EN
[5]European Commission, “Commission Recommendation (EU) 2019/786 of 8 May 2019 on building renovation,” 2019. [Online]. Available: https://data.europa.eu/eli/reco/2019/786/oj
[6]European Union, “Level(s).” https://ec.europa.eu/environment/topics/circular-economy/levels_en (accessed May 18, 2022).
[7]Green Building Council España, “Hoja de ruta para la descarbonización de la edificación en todo su ciclo de vida,” 2022. [Online]. Available: https://gbce.es/wp-content/uploads/2022/02/BuildingLife_Hoja-de-Ruta-para-la-Descarbonización-de-la-Edificación.pdf
[8]X. Oregi, P. Hernandez, and R. Hernandez, “Analysis of life-cycle boundaries for environmental and economic assessment of building energy refurbishment projects,” Energy Build., vol. 136, pp. 12–25, 2017, doi: 10.1016/j.enbuild.2016.11.057.
[9]A. Vilches, A. Garcia-Martinez, and B. Sanchez-Montañes, “Life cycle assessment (LCA) of building refurbishment: A literature review,” Energy Build., vol. 135, pp. 286–301, 2017, doi: 10.1016/j.enbuild.2016.11.042.
[10]M. Arbulu, X. Oregi, L. Etxepare, and R. Hernández-Minguillón, “Barriers and challenges of the assessment framework of the Commission Recommendation (EU) 2019/786 on building renovation by European RTD projects,” Energy Build., 2022.
[11]Y. Li, S. Kubicki, A. Guerriero, and Y. Rezgui, “Review of building energy performance certification schemes towards future improvement,” Renew. Sustain. Energy Rev., vol. 113, no. February, 2019, doi: 10.1016/j.rser.2019.109244.
[12]F. Pagliaro et al., “Assessing building energy performance and energy policy impact through the combined analysis of EPC data – The Italian case study of SIAPE,” Energy Policy, vol. 159, no. September, p. 112609, Dec. 2021, doi: 10.1016/j.enpol.2021.112609.
[13]C. Jimenez-Bescos and X. Oregi, “Implementing User Behaviour on Dynamic Building Simulations for Energy Consumption,” Environ. Clim. Technol., vol. 23, no. 3, pp. 308–318, 2019, doi: 10.2478/rtuect-2019-0097.
[14]X. Oregi, N. Hermoso, E. Arrizabalaga, L. Mabe, and I. Munoz, “Sensitivity assessment of a district energy assessment characterisation model based on cadastral data,” Energy Procedia, vol. 147, pp. 181–188, 2018, doi: 10.1016/j.egypro.2018.07.053.
[15]E. Cuerda, O. Guerra-Santin, J. J. Sendra, and F. J. Neila, “Understanding the performance gap in energy retrofitting: Measured input data for adjusting building simulation models,” Energy Build., vol. 209, p. 109688, Feb. 2020, doi: 10.1016/j.enbuild.2019.109688.
[16]S. Perez-Bezos, A. Figueroa-Lopez, M. Etxebarria-Mallea, X. Oregi, and R. J. Hernandez-Minguillon, “Assessment of Social Housing Energy and Thermal Performance in Relation to Occupants’ Behaviour and COVID-19 Influence—A Case Study in the Basque Country, Spain,” Sustainability, vol. 14, no. 9, p. 5594, May 2022, doi: 10.3390/su14095594.
[17]P. Hernandez and P. Kenny, “From net energy to zero energy buildings: Defining life cycle zero energy buildings (LC-ZEB),” Energy Build., vol. 42, no. 6, pp. 815–821, Jun. 2010, doi: 10.1016/j.enbuild.2009.12.001.

Projecting sustainable design with PREDICE: Economic and environmental budgeting tool for Buildings Life Cycle

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Abstract

Construction in recent decades in Europe has represented a significant environmental impact, covering approximately 40% of energy consumption, and 25% solid waste generated. To all this, it must be added that many of the natural resources used are finite, and some are close to being exhausted. In order to achieve sustainability in the sector, it is necessary to replace the linear model based on “pick, use and throw away” by a circular one. In 2015, the European Commission approved the “circular economy package” that establishes guidelines to guarantee sustainable growth using resources and waste in a more intelligent and responsible way. The objectives are to optimize the use of construction products, consumption of water and energy, minimize construction and demolition waste (CDW) and promote the use of modular and industrialized elements that facilitate their reuse and recycling. Taking all these into consideration, and in order to improve the environmental performance of buildings, it is necessary to analyze them through environmental and economic indicators that quantify the magnitude of the impacts, from the extraction of raw materials, through the manufacture of products, their transport, placement, use and maintenance, and finally its management as waste.

To carry out these analyses, it is necessary to keep in mind that the construction sector is made up of multidisciplinary teams, which makes it unavoidable to develop methodologies that are easy to implement and adaptable, facilitating the export and import of data in standardized exchange formats such as bc3 (FIEBDC). This makes it possible to centralize all project information, an essential aspect in the implementation of circular economy strategies from the design phase. In this line, the PREDICE tool is presented, under development and financed by the Ministry of Development, Infrastructure and Territory Planning of the Junta de Andalucía, within the 2020 call for grants for the development of research projects in housing matters, rehabilitation and architecture.

The work generated responds to the complete evaluation of buildings´ life cycle (BLC): from design, urbanization, construction, through the maintenance and rehabilitation phases, until reaching its end of life. Various environmental indicators are used, such as the footprint family, embodied energy and construction and demolition waste. The methodology is based on the projects´ quantity surveying, and to those quantities environmental coefficients corresponding to the aforementioned indicators will be applied. They are economically evaluated based on the Andalusian Construction Cost Database (ACCD). With this idea of an environmental budget (where not only the materials are evaluated, but also the workforce and the machinery), the aim is to promote good management and study from the design phase, in order to opt for solutions that reduce the environmental impact of the building life span. The results of the evaluation of an actual project, representative of the buildings in Andalusia, are presented. The sources of impact have been identified and the first conclusions of the research work carried out so far are presented.

Introduction

Construction activity in recent decades in Europe has represented a significant environmental impact, covering approximately 40% of energy consumption and 25% of solid waste generated [1]. To all this, it should be added, that many of the natural resources used are finite, and some are close to being depleted. To achieve sustainability in the sector, it is necessary to replace the linear model based on “take, manufacture and pull” with a circular one. In 2015, the European Commission approved the “circular economy package” which sets out guidelines to ensure sustainable growth by using resources and waste in a smarter and more responsible way. [2]. The objectives are to optimize the use of construction products, water and energy consumption, minimize the production of construction and demolition waste (CDW) and the use of modular and industrialized elements, which facilitate their reuse and recycling. In order to improve the environmental performance of buildings, it is necessary to analyse them through environmental and economic indicators, which quantify the magnitude of the impacts throughout life, from the extraction of raw materials, through the manufacture of the products, their transport, placement, use and maintenance, and finally their management as waste.
There is no doubt about the need for continuous improvement that construction procedures and processes must have in an increasingly global and competitive landscape. Professionals are faced daily with a multitude of issues in decision-making, which makes it necessary to resort to appropriate instruments that allow them to carry out this work in an effective and orderly manner. To carry out these analyses, it is necessary to bear in mind that the construction sector is made up of multidisciplinary teams, which makes it essential to develop easy-to-implement and adaptable methodologies, facilitating the export and import of data in standardized exchange formats such as bc3 [3]. This allows to centralize all the information of the project, an essential aspect in the implementation from the design phase of circular economy strategies. It is in this framework, where we find the bases of construction costs in Spain, which facilitate the preparation of budgets for building projects. There are several construction databases established in our country, for example: PREOC in Madrid, Construction Cost Base of the Community of Madrid [4], ITEC in Catalonia [5], CYPE in Alicante [6], BDC-IVE in Valencia [7], BDEU in the Basque Country [8], PRECIOCENTRO in Guadalajara [9] and the ACCD in Andalusia [10]. The use of cost bases in building projects is presented as capable of calculating environmental impacts in addition to monetary impacts due to their decomposition and cost hierarchy that makes it possible to introduce a standardized process [11], which would facilitate decision-making in the improvement of each building project. In this line works the basis of the ITEC that already incorporates energy, CO2 emissions and quantifies construction waste [5]. The bases are proposed as the ideal vehicle to quantify not only the economic cost but also the environmental one and as an integrating element.
This paper responds to the complete life cycle assessment of buildings (CVE): from design, urbanization, construction, through the maintenance and rehabilitation phases, until reaching their end of life. Various environmental indicators are employed such as the Footprint Family, embodied energy, and construction and demolition waste. The methodology is based on the measurements of the projects, to whose items environmental coefficients corresponding to the aforementioned indicators will be applied, and are economically evaluated from the Construction Cost Base of Andalusia (ACCD). With this idea of environmental budget (where not only materials are evaluated, but also labor and machinery) we want to promote good management and study from the design phase, to opt for solutions that reduce the environmental impact of the CVE. The PREDICE tool is presented, in development and financed by the Ministry of Development, Infrastructure and Territorial Planning of the Junta de Andalucía, within the 2020 call for grants for the development of research projects in the areas of housing, rehabilitation and architecture through the results of the evaluation of a real project, representative of the buildings in Andalusia. The sources of impact have been identified and the first conclusions of the research work carried out so far are presented. Therefore, design is promoted with the choice of renewable, recyclable or recycled materials and with low energy cost in its implementation.

2.Methodology

The proposed methodology is valid for any construction cost base, but in the present analysis the BCCA [10] is used to obtain the inventory of resources consumed in the life cycle. The BCCA result from the intention that all construction professionals use the same lexicon, in order to seek a better understanding and avoid conflictive situations. By defining a flexible and adaptable work unit organization and classification system, it facilitates the use of computer systems and data mechanization [12]. The ACCD is a document in constant development due to the interaction of multiple factors, among which are changes in materials, work procedures, economy, technology, legislation, and social, cultural and environmental aspects. It is based on a structure and decomposition of costs, adapting and organizing itself according to new needs. The analysis is carried out in several stages.
First of all, the families and subfamilies of units or basic costs are identified by their nature. Secondly, it is necessary that the different measurement units in which construction materials appear be transformed into a homogeneous unit, kg. The third step corresponds to determining the environmental impacts, in the case of the materials, the necessary energy and emissions from its extraction until it is ready to be used in the work. The workforce generates an energy consumption per worker following the philosophy of previous works [13] [14]. And for the machinery, the energy consumption is calculated, whether they work with a combustion engine or an electric one. Obtaining results will be specified by analyzing various unit costs, in such a way as to verify that the methodology works and that the proposal for determining the footprints for each basic cost can be transferred to higher levels as a result of the sum of the lower levels. Finally, the quantity surveying of a case study is evaluated and the results are presented.

2.1. Andalusia Construction Costs Database

The building model on which the entire cost structure of the ACCD is based is a new construction project, located in an open area, with no problems on the site in terms of access, communications and supplies, the floor area is 5,000 m², and the execution period is 12 months. The units of measurement follow the criteria established by the Association of Writers of Construction Databases [3].

The cost structure is created by virtue of a hierarchy that, starting from the lowest level, grows and by joining the lower unit costs that make up more complex costs. There are three large groups of costs which, ordered from lowest to highest, would be: basic costs (PB) distributed mainly according to three types: machinery, labor and materials, auxiliary costs (PA) formed by the union of the basic costs previously described with the quantities appropriate to their type and function, and unit costs (PU) formed by the union of basic costs and/or auxiliary costs, see Fig. 1

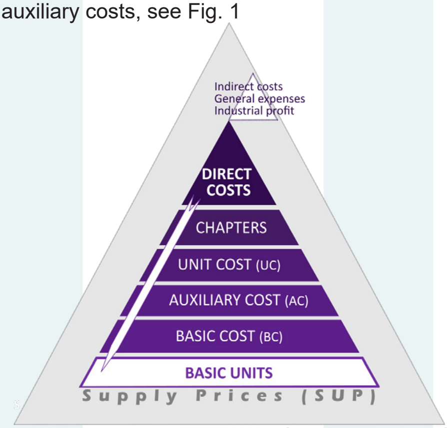


Figure 1. Hierarchical price structure. Own elaboration from [12].

Each cost is identified with an alphanumeric code, which has twenty-six characters in the alphabetic blocks and ten in the numerical ones. This leads to shorter codes with great encoding capacity. The letters, if carefully chosen, can provide complementary information and help powerfully in the translation of the code and its assignment in the coding phase. Each type of cost is defined according to Fig. 2, where "A" refers to alphabetic characters and "N" to numeric characters [10].

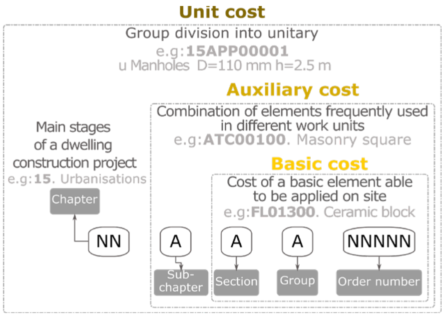


Figure 2. Price coding in the BCCA. Own elaboration from [12].

All costs are expressed in a specific unit of measure and with a measurement criterion. This criterion takes into account compensations that are representative of the traditional execution. The binomial cost - unit of work is reinforced by univocally establishing an indissoluble and rigid relationship between the measurement criteria a and its cost. Common metrics are used for similar costs. The concepts described above jointly constitute what is called a cost heading, with the result that all costs have a heading and that this is different for each element of the system.

2.2. Determination of environmental impacts

To determine the environmental impact, life cycle analysis (LCA) is data is used. According to the most widespread theories, there is a tendency to establish four life periods [15]: from the cradle to the gate, from the cradle to the site, from the cradle to the grave and from the cradle to the cradle. From the cradle to the gate considers all the processes within the life cycle until leaving the finished product at the gate of the factory where it was produced. From the cradle to the site includes the transport of the materials to their place of use. It is considered as the eminently productive phase. Following the reasoning of the ACCD, the phase to be addressed is from the cradle to the site, the production phase, which coincides with the costs in the database model. In this way it can be established that all the materials that the ACCD uses in its model building are ready to be incorporated in its construction.

In order to obtain the environmental data, there are databases that may contain information from multiple sectors or may be specific. It is recommended that they be well defined, with a degree of knowledge of the available data depending on their format, and with a regular update period, because technological advances cause data to become obsolete [16].

Starting from the systematic cost classification of the ACCD, its cost structure is used to carry out the first transformation with the aim of classifying each of the materials types in which it is organized. Once the families and subfamilies of materials of the ACCD have been determined, another of the characteristic concepts of each cost must be included: the measurement unit, since this data is fundamental and individual. Next, Table 1 presents the result after the contribution of this new information, in the construction family of Coatings. It can be seen in this table that each basic cost has its description, summarized in this case, its unit of measure, its code and it belongs to a subfamily of materials, which in turn belongs to a family. The alphanumeric code facilitates the identification of the various raw materials that make up each of the basic costs and allows their location within each subfamily, as well as the establishment of their degree of "kinship" with the rest of the basic costs.

In order to determine the volume and weight, the columns named “Dim X”, “Dim Y” and “Dim Z” will be used. Then, in cases where it is necessary, their corresponding density will multiply the previous volumes; this data in turn will if formed by a numerical value and a unit of measure (columns “CC” and “MD”). “CC” is the density of the material and “MD” expresses the destination measurement unit, in our case it is kilograms and “MO” the origin measurement unit in the ACCD. On certain occasions, the basic cost are formed by a number of equal units and this column will be used as a multiplier for this repetition; or on other occasions the density or weight data obtained is expressed in tons (t) or Newtons (N) and they need one more step to obtain kilograms (kg).

ACCD code	Cost (€)	Unit (Mo)	Description	Volume (m3)			CC. Density (kg/m3)	MD. Weight (kg)
				X	Y	Z		
AG00100	10.86	m3	Gravel	1.00	1.00	1.00	1,784.00	1,784.000
CA00320	0.81	kg	Steel B 500 S	1.00	1.00	1.00	1.00	1.000
CH02910	59.53	m3	HA-25/B/20/IIa concrete, supplied	1.00	1.00	1.00	2 549.25	2,549.250
FL00100	87.50	mu	ceramic brick triple hole 24x11.5x12 cm	0.24	0.115	0.12	1,223.64	4,052.696
IE02600	4.43	m	Copper cable 1x16 mm2 H07V-K(AS)	1.00	16.00	10-6	880.00	0.0144
PA00500	1.71	Kg	Acrylic paint	1.00	1.00	1.00	1.00	1.000
RA03900	82.40	m2	2cm gray granite slab, standard size	1.00	1.00	0.02	2,855.15	57.103
RA00200	0.17	u	White tile 15x15 cm	0.15	0.15	0.01	2,300.00	0.518
SB01000	4.33	m	PVC downpipe Diam. 125 mm	3.142	0.125	0.003	1,390.00	1.638

Table 1. Homogenization units of measurement of basic costs. Examples. Own elaboration from [17].

The ARDITEC research group [13] has developed a calculation model with some innovative hypotheses, such as including the food consumption of the operators, or the water consumption on the construction site. With the inclusion of food, footprints of crops, pastures and fishing are determined. In [18] they advanced the methodology for the construction phase. Then [19] designs a method for calculating the costs and environmental impact of buildings during the use and maintenance phase, based on the execution project. Next, [20] proposes a methodology that allows knowing the environmental feasibility of the recovery of buildings against their demolition. In [11], the methodology is developed basing the evaluation on the resources inventory of construction cost databases, focusing it from a new perspective of “environmental budget”. Finally [21], makes a methodology that encompasses all the phases of the CVE, to obtain a complete evaluation of the impacts from the design of the building project. These works give rise to the equations presented in Table 2.

Labor	equation number
HE_{FOOD}: HE produced by the consumption of food (hag)	
$HE_{FOOD\,i} = (H_{TRAB} / H_D) \times (PC/100) \times (HE_i/365)$	1
H_{TRAB}: Number of hours worked (h)	
H_D :Number of hours worked per day (8h/day/person)	
PC: Percentage representing breakfast and lunch of the worker's meal (60%)	
HE_i: Footprint of food consumption in category i of HE (hag/person) [18]:	
Categories: Crops (1.45x10-3 hag) · Pastures (0.27X10-3 hag) · Fisheries (0.41X10-3 hag) · Fossil (0.49X10-3 hag)	
365: days in a year	
HE_{RSU}: HE produced by municipal solid waste (hag)	
$HE_{RSU} = (H_{TRAB} \times R_{RSU} \times E_{RSU} \times 0.72)/W_F) \times FE_B$	2
$_{MSW}$: Quantity of MSW produced per hour of work (0.000077 t/h per person) [23];	
E_{MSW}: waste emissions factor (0.244 t CO_2/tRSU) [24];	
0.72:$_{CO2}$ absorbed by forests. The remaining 28% are ocean absorption [25];	
A_F: forest absorption factor (3.59t CO2/ha) [18];	
FE_B: forest equivalence factor (1.26 hag/ha) [18];	

Materials	
HE_{MAT}: He of building materials (ha)	
$HE_{MAT} = ((\Sigma_i\ Cm_i \times E_{MAT}) \times 0{,}72)/W_F) \times FE_B + HE_{TRAN} \times Cm$	**3**
Cm_i: consumption of material i (kg)	
E_{MAT}: emissions per material (kg CO_2/kg material)	
HE_{TRAN}: ecological footprint of the transport of building materials (ha/kg)	
I_{MAT}: EI,HC,HH of building materials (MJ; tCO_2eq; m^3)	
$I_{MAT} = (\Sigma_i\ Cm_i \times IU_{MAT}) + (IU_{TRAN} \times Cm_i)$	**4**
Cm_i: consumption of material i (kg)	
IU_{MAT}: unit impact per material (MJ; tCO_2eq; m^3/kg material)	
IU_{TRAN}: unit impact of the transport of building materials (MJ; tCO_2eq; m^3/kg material)	
Machinery	
V: fuel consumption (liters)	
V = (Pot x TU x Rend)	**5**
Pot: motor power of electrical machinery (kW)	
TU: time used according to measurements (hours)	
Rend: fuel consumed by the engine depending on whether diesel or gasoline (l/kWh)	
HE_{COMB}: HE fuel consumption (fossil) of machinery (hag)	
$HE_{COMB} = ((V \times E_{COMB} \times 0.72)/W_F) \times FE_B$	**6**
E_{COMB}: fuel emission factor (kg CO_2/litre): 2,616 kgCO_2/l [26];	
HE_{ELEC}: HE electricity consumption of machinery (hag)	
$HE_{ELEC} = ((Pot \times TU) \times E_{ELEC} \times 0.72)/W_F) \times FE_B$	**7**
E_{ELEC}: emission factor of the energy mix (kg CO_2/kWh): 0,248 kgCO_2/kWh [27] y [28]; Spanish data: 0,248 kg CO_2/kWh (REE 2014)	
IM_{COMB}: Impact fuel machinery (MJ; tCO_2eq; m^3)	
$IM_{COMB} = V \times UI_{COMB}$	**8**
IU_{COMB}: unit environmental impact of fuel (MJ; tCO_2eq; m^3/l fuel) LCA dates: [29] y [30];	
IM_{ELEC}: Impact electrical machinery (MJ; tCO_2eq; m^3)	
$IU_{ELEC} = (Pot \times TU) \times IU_{ELEC}$	**9**
IU_{ELEC}: unit impact of electricity, according to energy mix (MJ; tCO_2eq; m^3/kWh). 27], [28] y [31];	
Area consumed	
HE_{sup}: HE of consumed surface (hag)	
$HE_{sup} = S \times FE_x$	**10**
S: area of direct occupation (ha)	
FE_x: equivalence factor of the constructed area (2,51 hag/ha) [18].	

Table 2. Summary of equations for calculating the impacts (EF, CF, WF and EE) of the resources. Compiled from [22].

For the application of environmental indicators to the basic costs expressed in kilograms, materials are grouped into “Environmental families”, some examples are presented in Table 3.

MATERIAL	***HH (m^3/t)***	***HE (hag/t)***	***HC (t CO_2 eq /t)***	***EI (MJ/t)***
Soil	0	0,005	0,004	0
Wood	2,62	-0,483	-0,990	14.010
Concrete	1.68	0,057	0,112	616
Asphalt	3,0	0,098	0,21	7.040
Ceramics	1,0	0,107	0,22	2.840
Aggregates and stones	1,2	0,005	0,004	136
Metals	81	0,907	2,01	36.200
Plastics	456	0,898	1,97	60.300
Glass	17	0,30	0,669	15.200
Mortars and pastes	67	0,294	0,610	3.590

Table 3. Mean per reference unit of environmental indicators by family of materials. (Rivero, 2020).

2.3. Incorporation of the Exchange Format.

The FIEBDC Foundation [3] regularly publishes a report with the specifications relating to the definition of the standard exchange format for construction databases, so that with proper programming by trained technicians, it is easily adaptable to the proposal presented here. The “Technical Information Type Record” section, for example, facilitates the possibility of including energy consumption in said base expressed in MJ, and defines said consumption as “Energy cost (MJ). The unit energy cost of a composite element is obtained from the sum of the energy cost of the components of the cost justification (which is obtained from performance * unit energy cost of the component). The energy cost of simple elements is a “direct value”. In order to determine energy consumption, it must have the mega Joule (MJ) as the unit of measure. The energy consumption of a higher rank element is obtained by adding the components of lower ranks, by multiplying the amount in which each element participates in the element in question by its energy consumption. In a similar way, other indicators such as kgCO2 and construction and demolition waste, CDW, can be represented.

The nomenclature to be used to express the energy consumption of an element belonging to the ACCD according to the FIEBDC in its exchange format could be expressed as an example:

~X| | ce \ energy cost \ MJ \|[3]

Also to define the energy consumption of a basic cost such as that corresponding to the code FB00600 “CONCRETE BLOCK 40x20x15 cm”:

~X | FB00600 | ce \ 30.45 \ |[3]

The PB and PU would result in being able to represent economic and environmental information simultaneously as shown in Table 4, a unit cost of ventilated facade.

14FVL00001 | m² | VENTILATED FACADE WITH NATURAL STONE FINISH

Main sheet of perforated ceramic brick masonry. Thermal insulation of 60 mm thick mineral wool panel, placed between the uprights of the load-bearing structure. Internal lining of walls with plasterboard for self-supporting cladding, galvanized steel profiles with mechanical fixings. External cladding of mechanized limestone plates, placed using the continuous horizontal anchoring system on an adjustable support substructure made of aluminum alloy. Measure the executed surface.

Code	Q	u	Description	Cost/u	Cost (€)	EF (hag)	WF (m^3)	CF (tCO_{2eq}.)	EE (MJ)	CDW (t/m^3)
TO02100	2.72	h	1st Officer	19.85	53.99	0.0007	---	---	---	---
TA00200	2.52	h	Specialist assistant	19.04	47.98	0.0006	---	---	---	---
TP00100	0.50	h	Special pawn	18.80	9.45	0.0001	---	---	---	---
MW00300	0.26	h	Lifting platform	7.50	1.94	0.087	0.039	0.0108	177.3	---
06LHM00005	1.00	m2	Factory 1 foot brick H/D	29.64	29.64	12.029	0.443	0.0717	832.4	264.26
09TPP00161	1.00	m2	Mineral wool insulation	11.14	10.14	1.286	0.349	0.0183	282.3	12.386
QP01100	1.00	m2	Aluminum Profile	19.06	19.06	0.018	0.587	0.0231	372.4	1.93
10LWW90201	1.00	m2	Cast self-supporting	18.18	18.18	3.122	1.993	0.0860	1457.4	19.97
RA05300	1.00	m2	Limestone plate 3 cm	37.87	37.87	0.0036	63.036	0.0003	1.5	28.55
WW00400	2.00	u	Small material	0.30	0.60	0.00003	0.007	0.0003	5.3	0.00
				Total	**229.85**	**16.55**	**66.454**	**0.2105**	**3128.7**	**327,09**
					€	HE	HH	HC	EE	RCD

Table 4. Example of PU created from the “PREDICE” Economic and Environmental Database: HE, HC, HH, EI and RCD, based on the project budget. Own elaboration, 2022.

The established procedure and the proposed methodology adapt perfectly to any type of ACCD cost, allowing the calculation of the impact of each of the proposed items and the calculation of the total impact of any building project with the simple repetition of the method in each one of the unit costs in it.

3. Case study

An actual project of single-family housing is evaluated, with reinforced concrete structure and foundation formed by isolated footings. The total floor area of the project is 6,833.17 m2 and an urbanized area of 115,370 m2. The number of people living per dwelling is defined by the CTE [33], 3 occupants in single-family homes. The applied CVE has been designed from the limits established according to UNE-EN 15978 [34] and the methodology developed in [21].

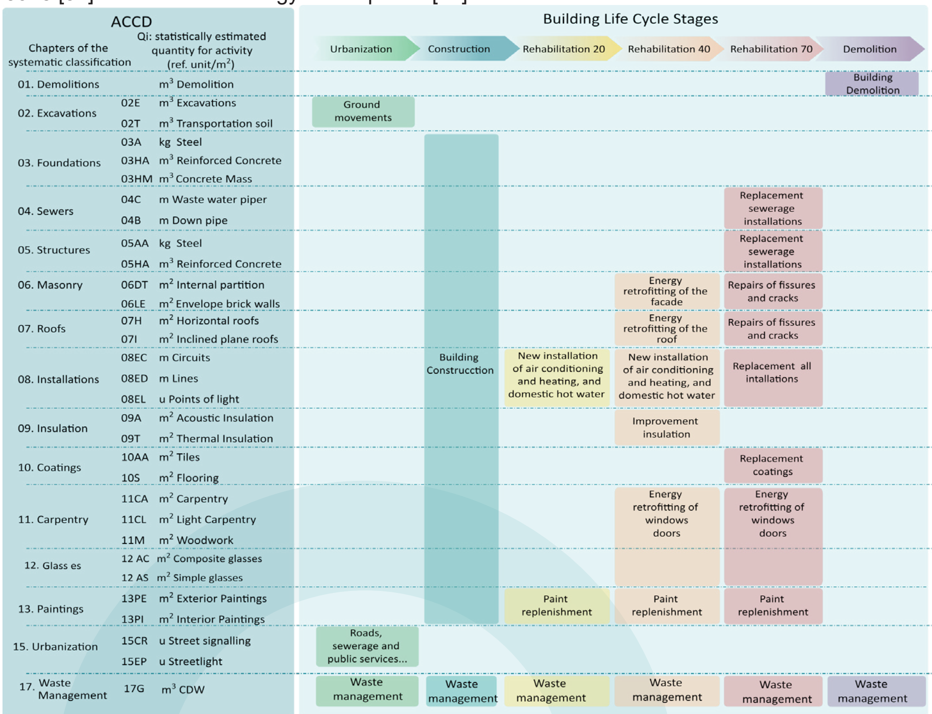


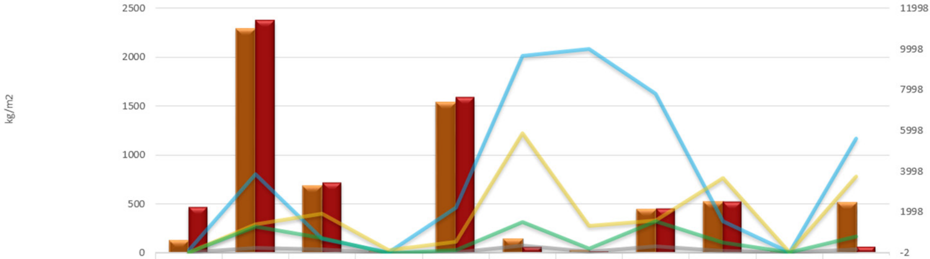
Figure 3. Chapters of the bank of economic and environmental costs [10] considered in each phase of the CVE designed [32].

The selected project begins its stage of urbanization and construction in the years 2008-2009, establishing the beginning of the stage of use in 2010. At the 100th year of the life of the building, and considering that the building does not meet the conditions of habitability, the demolition project of the building is executed. Following the structure of the chapters defined in the ACCD, you can select the costs of each item of work the tool developed to obtain the budget in your CVE (Fig. 3). The construction works carried out at each stage of the life cycle are summarized in:

•Urbanization: road works, sewerage and installations, public services, etc.
•Construction: The construction of the building.
•Renovation 20: Renovation of air conditioning and DHW generation installations.
•Renovation 40: Energy retrofitting of the roof and facades (including windows), including their insulation. Renewal of air conditioning installations, ACS. Wet cores, floors, doors. Renovation of elevators.
•Renovation 70: Structural repairs, fissures and cracks. Replacement of all installations: electricity, water and sanitation.
•Demolition: Complete demolition of the building.

4. Results:

The results of the evaluation of the case study project are presented, where the sources of impact have been identified both by phases of the CVE and by the different resources consumed, see Fig. 4 and 5. As the main material in the CVE (Fig. 4), concrete stands out, followed by aggregates and stones, and in a third position brick. On the contrary, the least representative materials are glass, wood and plastic, in order of lowest to highest consumption in the CVE. The results show more quantities of CDW than original materials in all families.



	Soil	Concrete	Brick	Wood	Aggregates and stones	Metals	Plastics	Plasters and pastes	Asphalt	Glass	Others
MATERIALS (kg/m2)	118,445	2283,668	678,117	7,899	1534,630	139,567	21,925	439,464	518,354	0,500	511,339
CDW (kg/m2)	472,902	2378,688	718,550	8,817	1590,818	70,563	23,021	461,437	529,083	0,515	72,069
CF (kg co2eq/m2)	0,515	256,193	149,186	-7,820	16,546	338,046	43,192	323,450	108,854	0,278	181,977
WF (dm3/m2)	142,134	3840,016	678,117	20,732	2227,817	9680,826	9986,667	7792,474	1555,063	7,000	5613,921
EE (MJ/m2)	16,108	1407,008	1925,852	110,670	543,581	5851,209	1322,055	1574,300	3649,215	6,450	3756,913
EF (m2g/m2)	6,464	1299,537	724,204	-38,157	129,850	1496,943	196,873	1558,406	505,684	1,285	790,759

Figure 4. Analysis of total indirect consumption by families (materials and CDW) of the CVE and its associated impacts [31].

These results are justified considering that the entire CVE is being evaluated, from conception to demolition. Therefore, all the materials that one day had their commissioning to form the building, when the time comes for its end of life, all that same amount of materials, will be considered CDW in the demolition. So why are the same RCD not generated as materials required for the construction of the building? The answer lies in the renovation works proposed in the CVE. In the execution of each of them, new materials are added to the building, with the corresponding losses due to breakages that these may have during the works, but also all the CDW generated by the debris and damaged materials that are removed from the building must be added. Therefore, more CDW will always be generated than materials consumed in construction, in cases where the complete BLC is evaluated.

Highlight the results of the urbanization stage in the case study (Fig. 5). For this building typology, the results corroborate how single-family homes are less sustainable than multi-family homes because the latter require less urbanized area with respect to floor area. This phase represents values 20% of the total BLC, and doubles multifamily buildings [21], that the stage represents only 10% of the impact. These data reaffirm that high-rise buildings help minimize environmental impacts by significantly reducing those associated with their urbanizations.

		RESOURCES (kg/m²)	CDW (kg/m²)	EE (MJ/m²)	EF (gha/m²)	CF (kgCO₂eq/m²)	WF (m³/m²)
Urbanisation	Materials (kg)	217,37	478,44	3513,01	0,09	201,65	5,49
	Machinery (h)	2,63	0,15	2709,20	0,081	0,16	0,63
	Labour (h)	9,51	0,25	0	0,002	0	0
Construction	Materials (kg)	3569,467	178,845	6309,746	0,266	543,216	14,273
	Machinery (h)	0,553	0,057	570,340	0,017	0,035	0,138
	Labour (h)	14,563	0,061	0	0,004	0	0
Renovation 20	Materials (kg)	10,067	10,116	256,448	0,006	14,247	0,655
	Machinery (h)	0,001	0,003	0,037	0,000001	0,003	0,0001
	Labour (h)	1,083	0,003	0	0,0003	0	0
Renovation 40	Materials (kg)	919,883	784,202	3118,592	0,119	253,682	9,376
	Machinery (h)	0,366	0,251	250,357	0,007	15,246	0,055
	Labour (h)	8,921	0,267	0	0,002	0	0
Renovation 70	Materials (kg)	1537,122	1413,255	6965,571	0,186	397,624	11,748
	Machinery (h)	0,564	0,452	325,526	0,010	19,891	0,098
	Labour (h)	10,936	0,481	0	0,003	0	0
Demolition	Materials (kg)	0	3569	0	0	0	0
	Machinery (h)	0,70	1,142	1895,47	0,057	35,992	0,46
	Labour (h)	2,42	1,215	0	0,001	0	0

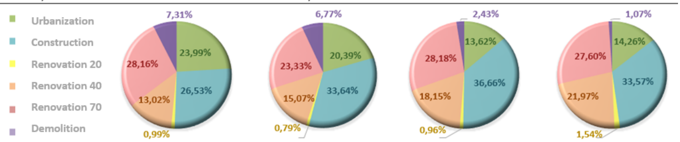


Figure 5. Results by phases of the CVE of the project and analysis of the HE of the types of resources consumed [31].

4.1. PREDICE tool.

With the tool developed it is possible to estimate the footprint that a building will have throughout its useful life. In addition, the tool (Figure 8), allows to locate those foci of greater impact in each of the stages, thus being able to manage them from the design of the project, so that the future footprint is reduced.

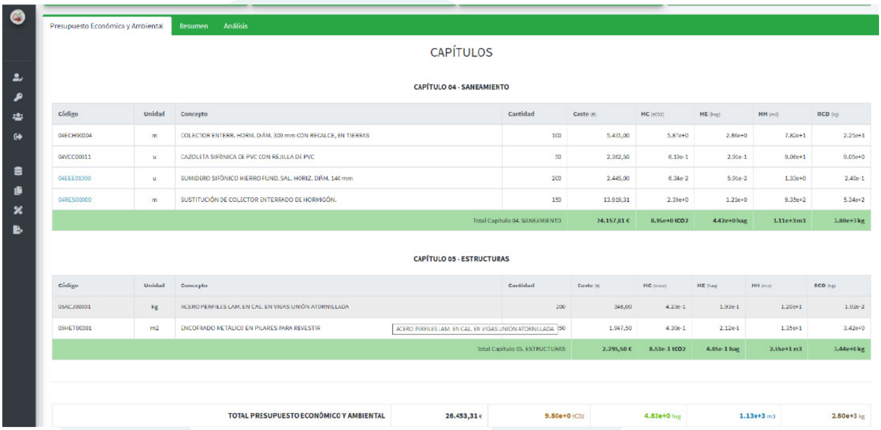


Figure 6. Interface of the tool where the BCCA chapters can be seen together with the economic and environmental costs of each resource. Own elaboration, 2022.

In the development of the tool, thanks to the use of the budgets of the building projects as a link for the incorporation of the environmental impact, the indicators are integrated in a standardized and re-producible way to the components of the budget of building projects. The methodology is similar to an “environmental budget”, facilitating its understanding by the technicians of the sector, which encourages its application. As the main innovation, an environmental construction database is created that allows systematic decisions to be made in project budgets. This is conversable into a publicly accessible exchange format (BC3) free of charge, allowing the environmental assessment of projects to all users

5. Conclusions

As stated in the objectives of this work, the challenge of finding an adequate procedure to calculate the impacts of BCCA materials and to be able to include them in the budgets has been raised. This has been achieved with a flexible proposal, oriented to future changes in the choice of the sources used or of the criteria and technical specifications of the chosen materials. The classification of basic prices and materials based on their impacts derived from the assignment of environmental families to each of them and the definition of reference data that allow comparison with projects with specific data, for example, has been made possible, obtained from environmental product declarations.
The methodology generated, robust and simple, as well as the tool developed, the main objective of this research, allows an easy evaluation of the environmental impact of the construction of residential buildings in their CVE through their budgets from the design phase, which translates into support for design and decision-making. Thanks to the budget structure, in the analysis of the results, it has been possible to focus on the fact that the most consumed material is not always also the most impressive. That is the case for stones and aggregates in terms of HC. In addition, low consumption materials, such as the family of plastics, have a high HH. The materials with the greatest impact on the HC and HH indicators are cement and concrete, as expected. The HE indicator reveals how materials are the most consumed resources and those with the greatest impact on results. However, it can be seen how machinery generates much more environmental impact than labor, even though labor is the second most consumed resource.
The evaluation carried out from the above perspective enables other of the stated objectives: that the agents involved in the building, and especially the project writers, make quantitatively based technical decisions, aimed at carrying out a more efficient and sustainable construction. In the future, due to the export of the databases to the bc3 exchange format, it can also be implemented in BIM, facilitating interdisciplinary work between technicians and professionals in the sector. Also in future works, the database created with machine learning tools will be evaluated to detect errors in the definitions or patterns in the constructive solutions.
It is stated that this publication has been the result of the research carried out in the research project (US.20-10): “Holistic model for the evaluation of the sustainability of the life cycle of social housing in Andalusia”, subsidized by “the Junta de Andalucía, through the Ministry of Development, Infrastructure and Territory Planning”, within the 2020 call for grants for the development of research projects in the areas of housing, rehabilitation and architecture, to the University of Seville.

6. References

[1] Unión Europea, 2019. Directiva relativa a la eficiencia energética de los edificios. Recomendación de la comisión de 7.6.2019 relativa a la modernización de edificios.
[2] Comisión Europea, 2015. Cerrar el círculo: un plan de acción de la UE para la economía circular.
[3] FIEBDC-3/2020. Definición del Formato De Intercambio Estándar de Bases de Datos de Construcción. https://www.fiebdc.es/web2/datos/uploads/Formato-FIEBDC-3-2020.pdf, the last accessed data 06/2022.
[4] PREOC/PREMETI, 2022. Base de precios, base de datos y programa de mediciones y presupuestos en la construcción. Madrid.
[5] ITeC, BEDEC - Banco Construcción 2022-04. Barcelona, Spain. https://metabase.itec.es/vide/es/bedec, the last accessed data 06/2022.
[6] Generador de precios de la construcción, 2022. CYPE Ingenieros, S.A. España. http://www.generadordeprecios.info/#gsc.tab=0, the last accessed data 06/2022.
[7] BDC-IVE, 2021. Base de datos IVE. Banco de precios y herramientas para el cálculo de costes de la construcción. Valencia.
[8] BDEU, 2015. Base de precios de edificación y urbanización en el País Vasco.
[9] PRECIOCENTRO, 2022. Base de Datos de la construcción editada por el Gabinete Técnico del Colegio Oficial de Aparejadores, Arquitectos Técnicos e Ingenieros de Edificación de Guadalajara.
[10] BCCA, 2021. Memoria Base de Costes de la Construcción de Andalucía. Sevilla.
[11] A. Freire Guerrero, Mª D. Alba Rodríguez, M. Marrero, A budget for the ecological footprint of buildings is possible: a case study using the dwelling construction cost database of Andalusia, Sustainable Cities and Society (2019) Vol. 51. https://doi.org/10.1016/j.scs.2019.101737, the last accessed data 06/2022.

[12] J. L. Barón Cano, J. Conde Oliva, M. Osuna Rodríguez, A. Ramírez de Arellano Agudo, J. A. Solís Burgos. Memoria de la clasificación sistemática de precios básicos, auxiliares y unitarios. Sevilla, 2017.
[13] J. Solís-Guzmán, M. Marrero, A. Ramírez de Arellano, Methodology for determining the ecological footprint of the construction of residential buildings in Andalusia, Spain, Ecological Indicators 25 (2013) 239-249.
[14] J. Solís Guzmán, M. Marrero Meléndez, D. Guisado García, Modelo de cuantificación y presupuestación en la gestión de residuos de construcción y demolición. Aplicación a viales, Carreteras (2014) Vol. 4. Núm. 195. 6-18.
[15] W. McDonough, M. Braungart, Cradle to Cradle: Remaking the Way We Make Things. North Point Press. 2002 p.p 193. ISBN 0-86547-587-3.
[16] A. Martínez-Rocamora, J. Solís-Guzmán, M. Marrero, LCA databases focused on construction materials: A review. Renewable & Sustainable Energy Reviews (2016) 565-573. https://doi.org/10.1016/j.rser.2015.12.243
[17] M. Marrero Meléndez, C. Rivero Camacho, A. Martínez Rocamora, M. D. Alba Rodríguez, J. Solís Guzmán, Life Cycle Assessment of Industrial Building Construction and Recovery Potential. Case Studies in Seville. Processes (2022) Vol. 10. 76-95. 10.3390/pr10010076
[18] P. González Vallejo, M. Marrero Meléndez, J. Solís Guzmán, The ecological footprint of dwelling construction in Spain. Ecological Indicators (2015). Núm. 52. 75-84. 10.1016/j.ecolind.2014.11.016
[19] A. Martínez Rocamora, J. Solís Guzmán, M. Marrero Meléndez, Toward the Ecological Footprint of the use and maintenance phase of buildings: Utility consumption and cleaning tasks. Ecological Indicators (2016) Vol. 69. 66-77. 10.1016/j.ecolind.2016.04.007
[20] M. D. Alba Rodríguez, A. Martínez Rocamora, P. González Vallejo, A. Ferreira-Sánchez, M. Marrero Meléndez, Building rehabilitation versus demolition and new construction: economic and environmental assessment, Environmental Impact Assessment Review (2017) Vol. 66. 115-126. 10.1016/j.eiar.2017.06.002
[21] C. Rivero Camacho, J.J. Martín del Río, J. Solís Guzmán, M. Marrero Meléndez, Ecological Footprint of the Life Cycle of Buildings, in: Assessment of Ecological Footprints. Springer. Singapur 2021, pp. 1-39. ISBN 978-981-16-0095-1
[22] C. Rivero Camacho, A. Ferreira-Sánchez, M. Marrero, Aplicación de la Footprint Family para la Evaluacion Ambiental de Edificios Publicos en España. Estudio de Caso: Centro Educativo. Hábitat Sustentable (2021) Vol. 11. Núm. 1. 72-85. 0.22320/07190700.2021.11.01.06
[23] European Union. Eurostat regional yearbook 2015. ISSN 2363-1716
[24] AM. Almasi, L. Milios, Gestión de residuos municipales en España, 2013, Spain.
[25] M. Borucke, D. Moore, G. Cranston, K. Gracey, K. Iha, J. Larson, E. Lazarus, J.C. Morales, M. Wackernagel, A. Galli, Accounting for demand and suppy of the biosphere's regenerative capacity: The National Footprint Accounts' underlying methodology and framework. Ecological Indicators (2013) 24:518:533.
[26] Instituto para la Diversificación y Ahorro de Energía: 'Factores de Emisión de CO2 / CO2 Emission Factors' 2011. Spain.
[27] Sistema Red Eléctrica Española (REE) / Spanish Electric System. 2015-2020,Spain.
[28] Machinery costs manual (in Spanish: Manual de costes de maquinaria). SEOPAN, 2008. Available:http://www.concretonline.com/pdf/07construcciones/art_tec/SeopanManualCostes.pdf, last accessed data 06/2022.
[29] SimaPro UK. (2014). Software ACV. About SimaPro 8, de SimaPro The world's most widely used LCA software: http://www.simapro.co.uk/aboutsimapro.html, last accessed data 06/2022.
[30] Ecoinvent Centre (2013) Ecoinvent database v3 ecoinvent report. www.ecoinvent.org, last accessed data 06/2022. Economía «BOE» núm. 85, de 9 de abril de 2003.
[31] Water Footprint Network. 2011. ISBN: 978-1-84971-279-8. www.waterfootprint.org, last accessed data 06/2022.
[32] C. Rivero Camacho, Tesis doctoral: Estudio de huellas en el ciclo de vida del edificio residencial. Universidad de Sevilla, 2020.
[33] Real Decreto 314/2006, de 17 de marzo, por el que se por el que se aprueba el Código Técnico de la Edificación. Texto refundido con modificaciones del RD 1371/2007, de 19 de octubre, y corrección de errores del BOE de 25 de enero de 2008. España. Revisión vigente desde 13 de septiembre de 2013. Boletín Oficial del Estado, 28 de marzo de 2006, núm. 74, pp.11816-11831, http://www.boe.es/boe/dias/2006/03/28/pdfs/A11816-11831.pdf, last accessed data 06/2022.
[34] UNE-EN 15978:2012. AENOR, 2012. Sostenibilidad en la construcción. Evaluación del comportamiento ambiental de los edificios. Métodos de cálculo. Informe técnico. Asociación Española de Normalización y Certificación. Madrid, España, 2012.

Applying sustainability to existing architectural heritage. A practical example: adaptive reuse in a 1960s building in Valladolid (Spain).

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Key Words: adaptative reuse, sustainable heritage, applied art, housing, Valladolid

Abstract
How should sustainability be applied in an existing building situated in a consolidated, dense urban context? Could sustainable criteria be adapted at any scale? Are those criteria opposed to the values of architectural heritage? Is that possible to maintain the original design values, simultaneously modernize and revitalize it, improving its biodiversity and quality? What is the role of its urban image when confronted with ecological awareness?
All these questions arose when the owners of an existing building of the 60s decided to intervene and adapt the building to present-day standards. The building is representative of its time: highly dense, with a steel structure, with expressive horizontal lines, long galleries and terraces and yellow brick façades. New use patterns arising from the last crisis pushed the owners to renovate and adapt the building, by changing the program of the two first stories, while keeping the original 68 dwellings. The former offices on the ground and first floors have been converted to 12 new apartments. The challenge covers various matters, which have been approached through the three pillars of the New European Bauhaus:
Environmental tasks optimizing the bioclimatic performance, oriented towards improving, air quality and reducing energy demands: by means of strong insulation systems as well as mechanical cross ventilation strategies, 55 % of energy demand has been saved. Embodied energy in building materials and circular economy have been considered as well.
Social improvements: the new apartments cover current living standards, with flexible as well as large, common spaces with equipment, greenery, and improving the accessibility for all.
Special attention was placed on showcasing and reinforcing the original architectural values of the building. The original aesthetic choices of the building have served as an inspiration for the new interventions. The use of similar yellow brick in the internal and external surfaces maintain the original patterns, as well as the glazed band that clads the first floor. The open connection between the existing courtyards (patios) conforms an open, spacious corridor which enlarges the common areas, improving lighting and ventilation, and introducing biophilia in the previous density of the block. The relationship between applied arts and architecture, common in the 1960's, has been revitalized and enhanced through this intervention, by researching the original typographies, and introducing site-specific artworks commissioned to local artists.
The intervention will be finished on 15th July 2022. It will be evaluated through the VERDE-GBCe (Green Building Challenge- Spain) method.

1.Introduction: representativeness and uniqueness

This case study is placed in a complex scenario. On one hand It has unique characteristics and on the other hand just the opposite. As the intervention affects only two of its eleven stories, it is neither a strict refurbishment nor a complete adaptive reuse, but rather the adaptation of existing heritage to a new socioeconomic reality. [Fig. 1].

Figure 1. Intervention c/ Muro 16, before / after. a) Before. Photo. P. Iván, 2018. b) After. Photo Ana Matos. 2022

On the other hand, the developer is a private and small community. Homeownership constitutes 76.7% of the housing stock, while 17.5% are rentals. The remaining 5,9% comprises other property systems. 2.4 million of rented apartments, (95.6%), are owned by private individuals and small businesses. In other words, ownership is highly fragmented and mainly inhabited by the owner. This sector makes small to medium-sized investments. In this respect, this case study is representative.
At the same time, adaptive reuse of offices is needed. Average rental prices in retail and office spaces are going down. The Covid-19 and new work habits too, have made bigger the empty stock of retails in the market.
The Renovation Wave funds aim to renovate 35 million homes in Europe by 2030, including 1.2 million in Spain. That is renovating 27.4% of its housing stock by 2050. The Next Generation Funds estimate that the renovation of 250,000 dwellings would produce 135,000 direct jobs per year. These projections should include the adaptive reuse, as this case study, even if it is not strictly that of housing renovation, facing the tension between demolition or reuse of buildings that affects the aging of cities.

2.Description and objectives

This intervention affects 890 m2 from the 5,000 m2 of a building dating from the late 1960s. The building is in the intersection of two centrally located streets, and it occupies its entire plot, with seven small internal courtyards. The new 12 apartments, ranging between 45 m2 to 50 m2, will be placed on the (split) ground and first floor. The 68 original apartments will remain in function and fully occupied, and so will the semi-interred garage. The energy system, which is centralised and supplies the air conditioning for the entire building, will be modified intervention later on. The objectives of this intervention are:

- An adequate return on investment
- An appropriate and up-to-date housing, according to current standards
- An environmentally and socially conscious intervention
- Improvement of the building as a whole

The owner and the architects aim for a combination of those five criteria above. Finding the balance between them poses difficulties: one is the application of rules, regulations, new requirements (such as the building passport) and norms in this intervention, which is unconventional, as it straddles the line between rehabilitation and new construction. The other one is the application of sustainability criteria in a heritage building whose architectural values are to be maintained.

3.Intervention criteria

3.1 Applying sustainability

Sustainability encompasses more criteria tan merely energy efficiency. According to Informe País, “The sector needs to concentrate its efforts in the next decade on 6 urgent fields of action: decarbonisation, health, holistic renewal, a resilient society, biodiversity, and the circular economy.” This intervention has focused on actions that combine these fields, in accordance with this scale. Maintaining as much as possible of the existing building is the main strategy followed in this project in order to prevent unnecessary consumption of energy and to get closer to an optimal LCA.

3.2 External certification

The best way to verify a comprehensive sustainability performance is to measure it through external certification. This guarantees independence and objectivity. For this case, we will apply the VERDE-GBCe method, whose indicators are aligned with European policies, the LEVEL(s) European framework . It also establishes the relationship of each of its indicators with the SDGs, specifying their contribution to every goal and target. In the Sustainable Finance Disclosure Regulation, and it’s Action plan (the so-called “Taxonomy Regulation”) this intervention is included and meets the requirements in terms of substantial contribution to the environmental impact of “climate change mitigation”.
The usual VERDE-GBCe tool requires a reinterpretation in this case too, due to the singularity of the intervention. The 12 apartments are not strictly new construction; they need to adapt to the existing structure, modulation, ceiling heights, courtyard layout, that limit them spatially. There are various topics involved, and it is important to combine their dependence upon one another, and their interactions.
There are other aspects of this project favourable to a good result in the VERDE-GBCe method: the building’s central location, fitting the “15-minute city” concept, easy access to all kind of services and public transport; a previous structure with more than 50 years in use; the recovery of building elements such as facades, etc. These are very positive issues in any sustainable construction strategy.

3.3 Respecting and improving heritage.

The image of the city, an asset to be preserved, is more than monumental heritage collection. This building is representative of the architecture of the 60s and 70s, closely related to late Modernism. The building’s architect, Julio González, was a representative of this movement in Valladolid, according to DoCoMoMo. The value the building as a complete element is preserved in all its cultural aspects, as far as possible. In this case, modulation, expressive relationships between horizontals and verticals, the sincere exhibition of construction materials, among other characteristics, should be preserved. That is the idea of the Intervention Project. It is not about nostalgia but about respect and culture. According to Casciato, “Modern architecture is Durable: Using Change to Preserve.” Modernist architecture was rational, functional, and innovative, and legitimate preservation implies authenticity of performance criteria and fidelity to the original experience. Behind the principles of the New Bauhaus lies the opportunity for sustainable restoration, and specifically that of the Modern Movement: “Sustainability is a Modern Movement.” [Fig. 2]

Figure 2. Intervention: Expressive relationships between horizontals and verticals. Photo: Ana Matos. 2022.

3.4. A new housing style.

The housing of the 1960s tended towards a compartmentalized type of dwelling, distributed in cells and small and individualized rooms, designed for a traditional family of two parents and several children. There is a mismatch between this typology and that of the 21st century. A new type of housing is desirable, for different lifestyles. We need different other: a flexible internal layout with open, accessible, and minimum compartmentalization. The target group of these new apartments, comprising young singles and couples, requires a greater number of common spaces.
Local and technical regulations have undergone major changes since the 1960s: these are logically much more demanding in terms of volumetric implantation, especially in the regulation of courtyards and accessibility to open spaces. [Fig. 3].

Figure 3. First Floor. Muro 16. a) Before, offices. b) After, apartments. New livingstyle and open courtyards. Authors of Proyecto de Ejecución. 2020.

4. ACTIONS BETWEEN UPGRADE AND RECOVERY

4.1. Bioclimatic and courtyards

The basic criteria about sunlight and orientation are pre-set by the existing volume and there are no collective spaces. The only open spaces are small internal courtyards. However, the Project emphasizes the opening and improvement of the existing interior courtyards in the block, connecting them by opening passage galleries. This increases the ventilation of the entire building, producing microclimates and facilitating air currents. The existing courtyards are also extended vertically, creating glazed courtyards that contain greenery and biophilia. In addition to adding natural regulation with their microclimates, they create quality collective spaces, favouring social communication. [Fig. 4].

Figure 4. Ground Floor. Muro 16. a) Before, offices. b) After, apartments. New livingstyle and extended courtyards. Authors of Proyecto de Ejecución. 2020.

4.2 Comfort, Health, and Accessibility

The previous structure of the building had good natural lighting, with large windows along the facades to Muro and Bailén streets. However, the interior of the plot could be improved. The opening and connection between the courtyards have significantly improved natural lighting and ventilation.
The distribution of window frames (mix of fixed, hinged and tilt-and-turn elements) allows for lighting, cross ventilation, and security, without the need for bar or defences. It also allows the view of the street from a seated position, at a height of 0.70 m, as an improvement in terms of accessibility. Excess sunlight is screened with sun protection elements, with technical fabrics.
A 100% of the inhabitable spaces (rooms and bedrooms) have natural lighting and ventilation as well as views to the exterior. 80% of the new apartments have natural cross ventilation, due to the pressure difference between the outside street and the microclimates created in the galleries and courtyards. In addition, they have forced ventilation, as required by local building regulations, consisting of an individual Siber system, 182 m3/h flow, to guarantee natural air quality, there are individual ventilation outlets to the roof from bathroom and kitchen, which operate individually.
The introduction of vegetation in the courtyards is a sensory resource. Considering that the building is a volume block which occupies the entire plot, with great density, this greenery naturalises the densely conceived block.
This strategically placed vegetation helps improve air quality. A low or zero VOC content has been demanded for all the finishing construction materials, in accordance with the VERDE-GBCe criteria, which involves the assurance of air quality within the building.

The level of noise protection has been improved in comparison to the CTE. Doors with acoustic insulation certification have been used. The ventilation system has a special device for acoustic insolation. The dividing walls are high density facing brick walls, with plasterboard and insulation. The same brickwork and colour wall construction has been used as a functional and aesthetic resource, on the exterior façade as well as the interior of the galleries and in the interior of the dwellings. This was a typical feature of the building from the 1960s. [Fig. 5]

Figure 5. Extended courtyards , galeries and construcción materials. Photo: Ana Matos. 2022.

Given the depth of the interventions undertaken in the building, the opportunity was taken to install an elevator that exceeded the requirements for increased accessibility, reaching a 1.100 x 1.400 m cabin and a 0.90 m door. Braille commands were integrated into the elevator, as well as tactile flooring in the accesses to the lift, Braille signage in the access and handrails and the numbering of the flats were also designed. The interior of the dwellings could be adapted, if necessary, due to the design of the toilets and flexible interiors. [Fig. 6].

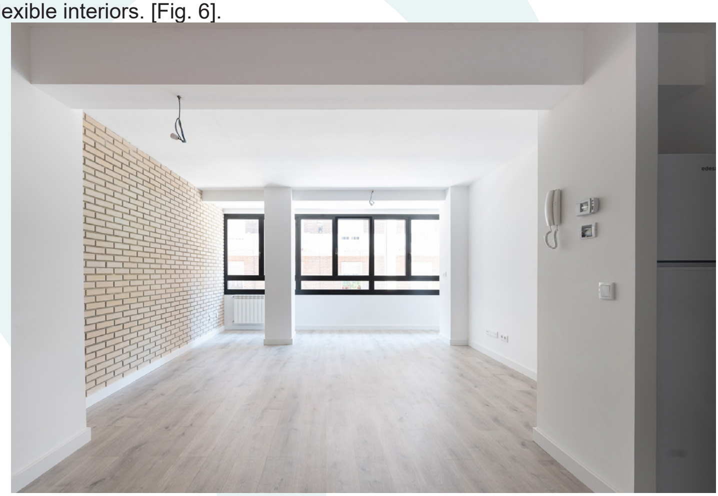

Figure 6. Interior, windows, bricks and fluent spaces. Photo: Ana Matos 2022.

4.3 Energy efficiency.

The energy strategy focuses on the drastic reduction of demand, and the tactical intervention focuses on the coherent application of passive and semi-active systems. This strategy will achieve a balance between energy efficiency and heritage preservation, as suggested by specific methods, which proposes to start with a thorough study of the building and its possibilities.
Thermal insulation is the principal action, carried out with regards to the existing architectural structure itself. This measure has been sufficiently tested in cases of preservation. On the façade, it has been added to the internal face of the wall. Horizontally, it has been placed on the lower part under the overhangs to the street and projected on the lower face of the existing floor slab over the garage area.
Originally, the external facade consisted of brickwork with cavity, light thermal insulation (Kraft from the 60s) and single brick wall cladding. In the Project, brickwork matching the existing one in colour and size similar to the existing one has been built and improved with thermal insulation with mineral wool in the existing façade wall linings, U= 0.28 W/m2ºK.

-New interior enclosures of dwellings in contact with unheated areas; U= 0.35 W/m2ºK.
-The lower part of overhangs and in external slabs. U=0.46 W/m2ºK

The original glazed band of the building has been renewed with code-compliant glazing that matches the colour, distribution, and modulation of the original situation. Windows are aluminium with RPT (no thermal bridge) and semi-concealed and practicable leaf IT-72HO RPT U=1.54 W/m2ºK. Low-emission glazing.
Natural ventilation and lighting help to reduce energy demand. Any case forced ventilation has been diverted towards the roof, in accordance with regulations, which can be individually controlled with different options, with an independent outlet to the roof for ventilation and the kitchen hood. The heating system (connected and depending on to the existing centralised system of the whole building) has sensors, control, and weekly programmers. The lighting in the galleries is automatic, with presence sensors, timers, LEDs and power reduction. The elevator is energy efficient A and the domestic appliances are low consumption, mostly A class.
With regard to the water system, actions are taken to reduce water consumption (double flushing, taps “cold open system,” etc.), which indirectly affect the centralised energy consumption of the building.
Eventually, due to this bioclimatic, passive and semi active measures, energy certification arises from an original E classification to a C, by 75.4 kWh/m2 per year, and CO_2 emissions of 19.1 kg CO_2/m2 per year. Those measures involve the reductions of 55 % reduction of energy demand. This exceeds the 30%, a requirement established in the European Taxonomy regulation as a substantial contribution to the environmental impact of “climate change mitigation”.

4.4 LCA and circular economy.

The result of a whole LCA of the Project, in this case, is ensured as a result of maintaining the foundations, the load-bearing structure, the floor slabs and a large part of the façade. That is obvious: all those elements of the building have been in use for more than 50 years. All new elements, the construction materials used in enclosures, partitions, flooring, and finishes, 90.92 % have EDP; 87.34 % are locally sourced (less than 200 km away); 70.60 & are recyclable material; and 1.63 % have recycled materials among their components. Some elements (guttering, bars, covers) have been reused. The final result of the VERDE-GBCe assessment (expected in November 2022) will present the final result, being the pre-assessment of “3 hojas” (maximum 5), which could mean a significant reduction of environmental impacts.

4.5 Respect for heritage and applied art.

The value of the heritage and related technologies goes beyond a mere external image; it requires knowledge of its function, its architectural criteria of modulation and expression, its dynamic relationships with the sun and the wind. It also requires knowledge of its construction elements and respect for small details, fittings, iron works, finishes, joints, etc. It is essential to understand the aesthetics, colours, materials, and applied art, when present.
A study of the typography from the origins of the building has been carried out and replicated. A prominent internal wall will be provided with a work of art, a mural, a site-specific piece, which aims at recovering the tradition of the time of including art and architecture in perfect coordination. .[Fig. 7]

Figure 7. Mural (Belén González) and Typography (A. Samaniego)

At specific points there may be contradictions between heritage preservation and upgrading: the balance must be solved on a case-by-case basis. At other points, an interpretation of the original technologies will be necessary, but not a simple replacement.
The structure of the building is made of steel pillars and steel overhanging beams, as well as one-way concrete joist slabs, a construction system typically used in the 1960s. In the opening and vertical extension of the courtyards, the existing joists have been left exposed and protected.
The original structural system causes specific problems. However, its preservation is very important, as other similar Modernism heritage cases. The interior height is 2.50 m (the minimum required by housing regulations), but the overhanging beams reduce this height in some cases. It is therefore not possible to install a horizontal chamber to house the new facilities, nor is it possible to install a raised floor that would reduce this minimum height. The final solution has been a combination of different solutions of false ceilings, very carefully studied, only in places that are essential for the passage of installations. Thus, the areas with a height of less than 2.50 m are only occasional, in coherence with the original structure, occupying less than 15 % of the living area. The conflict between exposed beams on the façade and the elimination of thermal bridges has been solved in each case by assessing priorities. [Fig. 8]

Figure 8. Structure and internal ceillings a) Photo Geo2, 2020. B) Photo Ana Matos 2022

The distribution and thickness of window frames is another challenge in the heritage-sustainability debate. The requirements regarding thermal insulation demand thicknesses far larger than the original ones. In this case, it is possible to maintain the original image of a modulated continuous element due to the scale. Nevertheless, the thickness of window frames remains an unresolved issue.

5. Conclusions

The lessons learned from this practical and real-life example of heritage upgrading adaptative reuse show:

•The potential of the existing heritage for the objectives of the Renovation
•The understanding between the Modernism and the upgrade of housing units, making compatible Heritage and Sustainability, in application of the New Bauhaus criteria,
•The equivalence between adaptive reuse and rehabilitation in the Renovation Wave housing programmes, sustainable investment targets through the "EU taxonomy", and other similar objectives.
•The specific actions that can be representative of the application of sustainability in the built heritage,
•The opportunities arising from the introduction of sustainability criteria at any scale of intervention, even in partial elements of a building, and especially in adaptative reuse, which will be much needed and demanded in the coming years.
•The capacity of bioclimatic, passive, and semi-active measures to activate energy efficiency: they alone can achieve remarkable improvements in energy demand, in this case from an E classification to a C, by 75.4 kWh/m2 per year, and CO2 emissions of 19.1 kg CO2/m2 per year.
•The favourable position of built heritage in the reduction of environmental impacts, especially in circular economy criteria, LCA of buildings, energy embodied in materials,
•The deepening of knowledge of environmental assessment methods for buildings in non-conventional cases.

6.References

[1]Green Building Council España, GBCe. VERDE- Valoración de Eficiencia de Referencia de Edificios. https://gbce.es/certificacion-verde/que_es_verde/. 2022.
[2]Instituto Nacional de Estadística. INE BASE. Hogares por régimen de tenencia de la vivienda. 2017. 6
[3]I. Benedito. ¿Quiénes son los gigantes de la vivienda en España? Caixabank, Testa o Lazora aumentan su peso y ya tienen casi 100.000 pisos de alquiler. Business Insider. 8/02/2022
[4]Banco de España 204 informe anual 2020 2. Los retos estructurales de la economía española tras el covid-19 y las políticas para abordarlos. 2020
[5]Bullen, P,Love, P E D. The rhetoric of adaptive reuse or reality of demolition: Views from the field. Cities . Volume 27, Issue 4, August 2010, Pages 215-224 https://doi.org/10.1016/j.cities.2009.12.005
[6]Espinoza-Zambrano, P. Marmolejo-Duarte, C. Hacia un Pasaporte de Renovación de Edificios en España: necesidades y oportunidades a la luz de experiencias europeas Towards a Building Renovation Passport in Spain: needs and opportunities in light of European experiences. Informes de la Construcción Vol. 74, 565, e424 enero-marzo 2022 ISSN-L: 0020-0883 https://doi.org/10.3989/ic.86195
[7]GBCe y KREAB. Informe País GBCE 2021 Sobre el estado de la edificación sostenible en España. 2021. P. 4 https://gbce.es/documentos/Informe_Pais_GBCe_2021.pdf
[8]Level(s) European framework for sustainable buildings. https://environment.ec.europa.eu/topics/circular-economy/levels_en
[9]Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment and amending Regulation (EU) 2019/2088. http://data.europa.eu/eli/reg/2020/852/oj
[10]McMullan, Randall. Environmental Science in Building. Red Globe Press. 2017 ISBN 978-1137605443 pp. 305 y 306

[11]Fundación DoCoMoMo Ibérico. Registros del Movimiento Moderno: Base de datos Julio González Martín. 2022. https://www.docomomoiberico.com/index.php?option=com_content&view=article&task=search&id=43&Itemid=61
[12]Lessa, A., Arez, Tostoes, A. Ferreira, Z., L14th International DoCoMoMo Conference"Adaptive Reuse. The Modern Movement Towards the Future"Lisbon, Portugal
[13]González, Geo2 Arquitectos, Sánchez, Vaquero, Ruipérez, de la Fuente, Proyecto de Ejecución de Intervención en edificio residencial. Valladolid. 2020.
[14]W. Quist, K. Bierman. .Inside,mo.mo- Het moderne interieur:hoe Lang gaat het mee? Nº 4. April 2014. Bestuur Stichting DOCOMOMO Nederland & Organisatie inside.mo.mo seminar. 2014
[15]M. Casciato, Modern Architecture is Durable: Using Change to Preserve. The Challenge of Change: Dealing with the Legacy of the Modern Movement. Proceedings of the 10th International CDoCoMoMo Conference. 2008
[16]H. Torrent. Issues of Temporality- Paradoxes and Changes of Modern heritage. The Challenge of Change: Dealing with the Legacy of the Modern Movement. Proceedings of the 10th International CDoCoMoMo Conference. 2008
[17]N. Rapppaport. Sustainability, A Modern Movement. The Challenge of Change: Dealing with the Legacy of the Modern Movement. Proceedings of the 10th International CDoCoMoMo Conference. 2008
[18]García Vázquez, C. La obsolescencia de las tipologías de vivienda de los polígonos residenciales construidos entre 1950 y 1976. Desajustes con la realidad sociocultural contemporánea Housing typologies obsolescence of the residential estates built between 1950 and 1976. Mismatches with contemporary socio-cultural reality. Informes de la Construcción Vol. 67, EXTRA-1, m020 marzo 2015 ISSN-L: 0020-0883 doi: http://dx.doi.org/10.3989/ic.14.045
[19]C. M. Joppolo, D. Del Curto, A, Luciani, L.P. Valisi, M. Bellebono. Keeping it modern, making it sustainable. Monitoring and energy retrofitting the Urbino University Colleges. Energy Procedia Volume 133, October 2017, Pages 243-256 Https://doi.org/10.1016/j.egypro.2017.09.363
[20]G. Galbiati, F. Medici, F. Graf, G. Marino. Methodology for energy retrofitting of Modern Architecture. The case study of the Olivetti office building in the UNESCO site of Ivrea. Journal of Building Engineering Volume 44, (December 2021) 103378. Https://doi.org/10.1016/j.jobe.2021.103378 2021
[21]Método CE3X. Proyecto de Ejecución de Intervención en edificio residencial. Valladolid. 2020. Memoria de Certificación Energética. 2020
[22]DGNB, DK-GBC, GBCe, ÖGNI. EU Taxonomy Study - Evaluating the market-readiness of the EU taxonomy criteria for buildings. 2021.
[23]A.P. Pinheiro, "BREEAM and LEED in Architectural Rehabilitation", in Industry 4.0 – Shaping the Future of the Digital World, 2nd S2M – Sustainable Smart Manufacturing International Conference 2019, 9th-11th April 2019, in Manchester, Bártolo P. (Ed.), Routledge, Taylor & Francis Group. ISBN 9780367422721. 2020
[24]Palomares Figueres, M.T. DOCOMOMO. Arquitectura moderna y patrimonio. December 2018 Loggia Arquitectura & Restauración DOI:10.4995/loggia.2018.7968
[25]A. Baladrón Carrizo. De focas, liebres y gatos. Aproximaciones al proyecto de la Central Lechera CLESA de Alejandro de la Sota desde una dialéctica entre lo industrial y lo humano. III Congreso, "Análisis crítico de una obra" Actas digitales 2016. ISBN: 978-84-608-7409-9, págs. [50 - 66]. 2016
[26]J. García-Gutiérrez Mosteiro Consideraciones sobre algunos caracteres de la arquitectura del siglo XX y su incidencia en los criterios de salvaguardia patrimonial. Criterios de Intervención en el Patrimonio Arquitectónico del Siglo XX Conferencia Internacional CAH20thC. Documento de Madrid 2011

Reference state temperature influence in the thermoeconomic costs of a building thermal facility

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In 2018, residential buildings were responsible for 17.1% of the energy consumption in Spain. To improve the energy efficiency of buildings, several actions have been taken by the European Union and later transposed by national governments. In our environment, located in the north of Spain, buildings have three main types of energy demand: electricity, DHW and heating demand. Usually, the proposals for reducing the primary energy consumption consider just the first law of thermodynamics that establishes the principle of energy conservation. Although energy quantity is conserved, energy quality degrades in energy exchange processes as the second law of thermodynamics establishes. Therefore, both the first and second laws must be taken into account to achieve an improvement in energy efficiency and the consequent energy savings. Exergy analysis applied to buildings allows quantifying the energy quality degradation, this is, the exergy destruction, since exergy is the thermodynamic property that characterizes the energy quality. Nevertheless, exergy is a relative property, in the sense that its value depends on the reference state chosen. Further, thermoeconomics allows quantifying the exergetic, economic and environmental costs of the exergy destruction.

This work analyses a thermal facility that supplies DHW and heating of 26 social dwellings located at Durango (northern Spain). It consists of a 68 kW ground source heat pump (GSHP) and a 120 kW natural gas condensing boiler. The average hourly unit exergy cost ($\bar{k}_j^{*,h}$), economic cost ($\bar{c}_j^h$) and environmental cost ($\bar{a}_j^h$) of the product of the ground source heat pump (GSHP) is calculated considering the dynamic outdoor environmental and the dynamic soil temperature as reference state temperatures, according to the data obtained from a TRNSYS simulation during a year. Average hourly exergy values ($\bar{B}_i^h$) of each *i*-th flow are used to build a functional diagram (FD) inside a software developed in Matlab that combines symbolic thermoeconomics and specific exergy costing (SPECO) approach, to calculate the $\bar{k}_j^{*,h}$, $\bar{c}_j^h$ and $\bar{a}_j^h$ costs of each *j*-th flow. These costs vary along the year, due to the dynamic behaviour of the thermal installation and the dynamic nature of the reference state temperatures used to calculate the exergy values. The highest values obtained correspond to August with $\bar{k}_{26}^{*,Aug.}$= 3.4, $\bar{c}_{26}^{Aug.}$= 74.08 c€/kWh and $\bar{a}_{26}^{Aug.}$= 2.12 gCO_2/kWh, whereas the smallest correspond to January with $\bar{k}_{26}^{*,Jan.}$= 2.3, $\bar{c}_{26}^{Jan.}$= 50.09 c€/kWh and $\bar{a}_{26}^{Jan.}$= 1.43 gCO_2/kWh. The main conclusion of this work is that the dynamic reference temperatures used significantly influence the dynamic productive structure configuration as well as the exergy values of the flows and consequently the cost values.

1.introduction

In April 2022, the Intergovernmental Panel on Climate Change (IPCC), has published the Working Group III report as a contribution to the IPCC sixth assessment report (AR6). Among its main conclusions are that over the last decade, greenhouse gas emissions have continued to rise and the rise can be attributed to urban areas [1]. Therefore, further action is urgently needed to mitigate the dramatic consequences of climate change, and one of the main actor in urban areas are buildings. In the European Union (EU), buildings are responsible for the 36% of the greenhouse gas emissions and of the 40% of the energy consumption.

In Spain, only residential buildings were responsible for the 17.1% of the energy consumption [2]. To improve the energy efficiency of the existing building stock and the energy performance on new buildings, several actions have been taken by the EU [3] and transposed by national governments [4]. In our environment, north of Spain, the main types of energy demand in buildings are electricity and heat (this last one used for thermal comfort and domestic hot water (DHW) supply).
Energy demand can be satisfied with passive or active elements [5]. The most frequent proposals for reducing the primary energy consumption that involves passive and active systems are the renovation of façades, roofs and windows along with the intervention in heating and DHW systems.
On this matter, the heat pump is a device capable of covering the energy demand exploiting renewable low enthalpy energy sources. The types, technical characteristics, and applications of heat pumps are described in the works [6]-[7]. The energy on the surface of the earth, in temperatures below 25-30 °C feeds ground source heat pumps (GSHP). Low enthalpy geothermal energy [8] is anywhere, for 365 days per year and 24 hours per day.
Proposals for reducing the primary energy consumption that consider just the first law of thermodynamics, use the energy efficiency value as an energy performance indicator. It is obtained after applying energy analysis in thermal facilities. Although energy quantity is conserved, energy quality degrades in energy exchange processes as the second law of thermodynamics establishes. Therefore, both the first and second laws must be taken into account to achieve a real improvement in energy efficiency and the consequent energy savings. Exergy analysis
applied to thermal facilities aims quantifying, locating and explaining the energy quality degradation, this is, the exergy destruction [9], since exergy [10] is the thermodynamic property that characterizes the energy quality. Nevertheless, exergy is a relative property that its value depends on the reference state chosen.

Thermodynamics establishes the physical relation between society and environment through the thermodynamic property, exergy. Thermoeconomics, in its widest possible sense, is the science which connects thermodynamics with economics; explains the physical bases of the cost and links the cost with the physical processes where the sacrifice of physical resources are located, and it causalizes and quantifies in terms of exergy destruction [11].
The exergy cost considers the amount of exergy required to produce a mass flow or energy flow, whereas the monetary or exergoeconomic cost [12] takes into account the economic cost of the fuel consumed, as well as the cost associated with the equipment items. Meanwhile the exergoenvironmental costs allocate the environmental impact to every flow of the energy conversion processes [13].
Therefore, using thermoeconomics as a tool for the study of domestic thermal facilities makes it possible to understand the behaviour of the facilities from an exergetic, economic and environmental perspective through the calculation of the costs of the flows. It is a tool that offers an opportunity to define the most efficient domestic thermal facilities, taking into account energetic, economic and environmental aspects. In short, it is a powerful tool for decision making to improve people's quality of life.
Exergy Cost Theory (ECT) [14], proposes methods to determine the amount of resources required for obtaining a product. ECT is based on cost assessment rules, which attribute to the useful product the resource cost of each component, and distribute its costs proportionally to its exergy. Symbolic thermoeconomics (ST) [15] appears as a technique, based on the ECT to be implemented into computer software applications [16]. In the Specific Exergy Costing method (SPECO), [17] , fuels, products and costs are defined by systematically registering exergy and cost to each material and energy stream.

The comprehensive effort to apply thermoeconomics to the analysis, optimization and design of power plants did not start until the 1980s and the application of thermoeconomics in buildings is still in its beginnings. The most remarkable publication refers to the book published in 2019 [18].

The application of thermoeconomics in building environment adds some difficulties comparing to the application of thermoeconomics in power plants. Power plants can be considered as stationary systems that operate in temperature conditions far away from the environmental ones. However, exergy values of the flows in a building thermal facility are very dynamic, due to changeable energy demand conditions and changeable environmental temperature conditions used as reference temperature. There is a quite good agreement in the literature about the identification of the outdoor environment as the reference state temperature in buildings and the soil temperature when GSHPs appear [19].
In addition, the effect of the dynamism of the reference temperature in the exergy values of the flows is not negligible, because of temperature values of the flows in a building facility are close to the environmental ones. Therefore, building system implementation must be dynamically considered through the series of quasi-steady states.
A work that faces the dynamic nature of building thermal facilities with the dynamic calculations of the exergetic, exergoeconomics and exergoenvironmental cost is in [20]. In this work, the costs are showed on a monthly basis, being the productive structure (PS) of the facilities [21] the key to understand the cost formation process [22]. In [23] thermoeconomics is used as a decision-tool for evaluating some thermal system design options.
In [24] thermoeconomics is applied to a cogeneration engine, an aerothermal heat pump and a natural gas condensing boiler. It is concluded that thermoeconomics is capable for analysing innovative and complex systems that incorporate renewable energy sources.
In a parametric study where the reference state temperature varies, the values of some exergetic and exergoeconomic performance indicators of a GSHP are obtained in [25]. The study is applied at a component level, in steady state and following the SPECO method.

2.Objective

The objective of this work is to analyse the influence of the reference temperature chosen in the thermoeconomic costs of a building thermal facility. Therefore, the scope is to analyse the influence on the thermoeconomic costs of two reference temperatures : outdoor air and soil temperatures. In turn, the contribution of this work aims to fill the gap in the application of thermoeconomics in a facility configuration that is scarce, as the literature review shows [26].
The document is divided into 6 main sections. After the introduction of Section 1, Section 2 addresses the objective and Section 3 describes the case study. Section 4 contains the methodology. In the beginning of Section 4, the tool used to obtain the results that allows achieving the objective of this work is presented. Then, in sequence, the inputs that the tool requires to obtain the results are specified. In Section 5 there are the commented results, where the numerical values obtained are included. Finally, Section 6 includes the conclusions and future works.

3.Case study

The case study is a domestic thermal facility placed in the ground floor of a building consisting of 26 social dwelling units, located at Durango (northern Spain). Figure 1 shows a partial view of the thermal facility and the building.

Figure 1. A partial view of the thermal facility and the building.

The facility supplies domestic hot water (DHW) during the year and heating from 15 October to 14 May. The generation system consists of a water-water reversible 68 kW ground source heat pump (GSHP) and a 120 kW natural gas condensing boiler (B). Besides, there are three buffer tanks with an accumulation capacity of 2,000 l each, which make up the storage system. Two of those storage tanks are connected in series and store DHW.
Thus, the water coming from the supply network is preheated with the energy provided exclusively from the GSHP; while in the other, the preheated water is heated with the energy provided exclusively by B until it reaches the DHW consumption temperature (40°C - 55°C) and the third tank stores heat for heating. The heating set-point temperature of the third tank depends on a specific heating curve described in [27]. The supply temperature for B is 62 °C while the GSHP has two working temperatures depending on the supplied demand: the supply temperature for DHW is 49 °C and for heating, 46 °C. These temperatures are kept constant throughout the year.
The control of the facility prioritize covering the DHW demand rather than the heating demand, so it was designed to supply the baseline DHW and heating demand with the GSHP, and to use B to reach the DHW consumption temperature and to cover peak heating demands.
Figure 2 shows the physical diagram (PD) of the facility described above in which 14 elements and 30 incoming and outgoing (i-flows) are numbered of which 28 are mass flows (from i=1 to i=28) and 2 are energy flows, electricity and natural gas (i=29 and i=30, respectively).

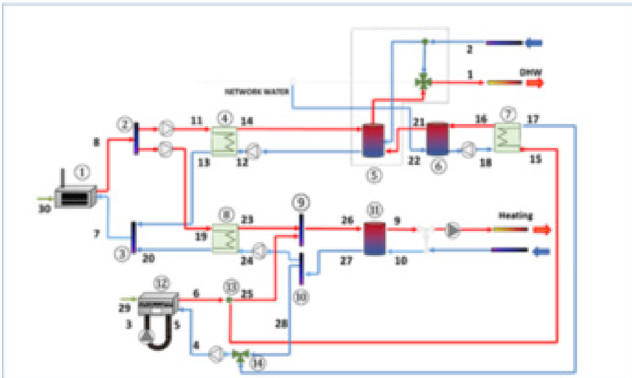

Figure 2. Physical diagram of the facility.

The elements considered in the PD are described in Table 1.

no.	Symbol	Description	no.	Symbol	Description
1	B	Boiler	8	HX3	Heat exchanger for heating and boiler
2	DV1	DHW/heating diverter from B	9	MX2	Heating mixer from B and GSHP
3	MX1	DHW/heating mixer from B	10	DV2	Heating diverter from B and GSHP
4	HX2	Heat exchanger between DHW and B	11	ST3	Heating storage tank
5	ST2	DHW final temperature storage tank	12	GSHP	Ground Source Heat Pump
6	ST1	DHW preparation storage tank	13	DV3	DHW and heating diverter
7	HX1	Heat exchanger between DHW and GSHP	14	V3V	DHW and heating 3-way valve

Table 1. Elements considered in the physical diagram.

4.Methodology

A software developed in Matlab [18], that combines ST and specific exergy costing (SPECO) approach is used to obtain the following values:

- for the elements, the vector of unit exergy consumptions $(\boldsymbol{k})$
- for the flows, the vector of unit exergy costs $(\boldsymbol{k}^*)$, unit economic costs $(\boldsymbol{c})$ and unit environmental costs $(\boldsymbol{a})$.

In order to apply a thermoeconomic software in the facility, a productive structure or functional diagram (FD) is needed which considers the system as a box-diagram interconnected by different flows. Apart from the FD, the software requires to include the dynamic exergy values of the fluxes, the acquisition, operation and maintenance costs of the facility and the unit economic and environmental costs of the external resources.

4.1.Productive structure of the facility

Based on the physical diagram, a FD of the facility is built, which reflects graphically its productive structure. In order to obtain a FD, the physical flows are interrelated and the flows are classified into fuels (F) and products (P). F refers to the amount of resources needed to consume in order to produce a specific useful objective, called product P. Therefore, P represents the productive objective of each component. Fictitious elements, rhombuses and junctions, are incorporated to the FD, where rhombuses (m) represent junctions and circumferences (d) bifurcations. Each element is represented by a square with an incoming arrow, F, and outgoing arrow, P. Figure 3 shows the FD of the system where the productive structure of the GSHP is highlighted. As can be seen, in this diagram there are:

-Number of elements: 33.
-Number of flows: 50.
-Number of incoming flows: 6.
-Number of outgoing flows: 6.

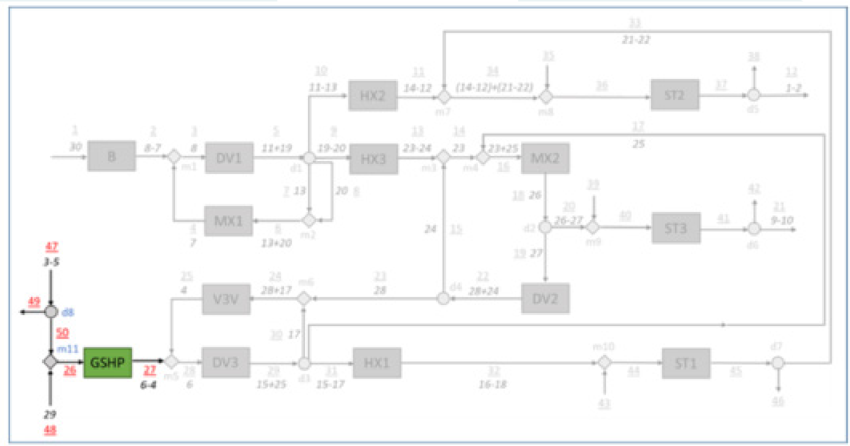

Figure 3. Functional diagram of the facility.

Table 2 relates the F and P with the physical flows of the GSHP. The re-numbering may seem a bit complicated but it makes the application of the thermoeconomic equations much easier.

Symbol	F	P
GSHP	26	27
		6-4
d8	47	49 + 50
	3-5	
m11	50 + 48	26
	29	

4.2. Dynamic exergy values

A transient model in TRNSYS v17 is generated following the description of the facility described in Section 3. This model was calibrated in [28]. Type 15-1 and Type 501 are used to introduce the dynamic outdoor temperature $T_{env.}$ and the dynamic soil temperature T_{soil} in the model. Type 15-1 uses weather data provided by Meteonorm for Sondika-Bilbao. The same weather data is used to define parameters 2 and 3, mean surface temperature and amplitude of the surface temperature of the Type 501. The network water monthly temperature is introduced according to [29]. A DHW and a heating demand profiles are generated with the tool developed in [30] and because of simplifying reasons, DHW daily demand profile has being considered constant for all months. Figure 4 shows $T_{env.}$, T_{soil} and DHW and heating values over the year.

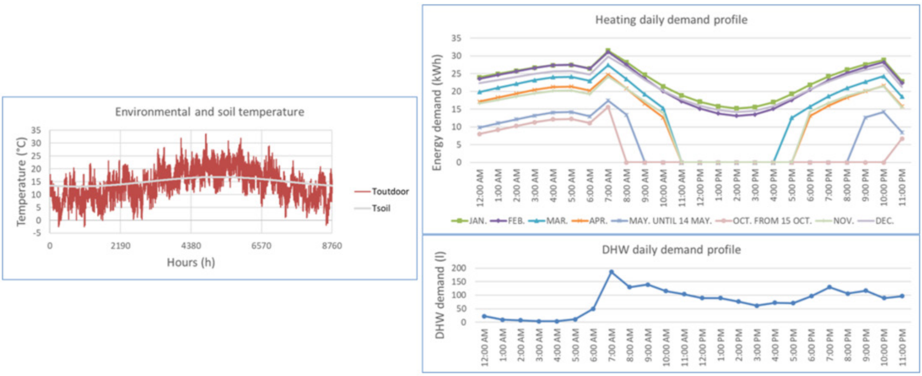

Figure 4. Temperature values and DHW and heating demand profiles over the year.

The model is simulated over a year (8760 h) with a time step of 0.01 hour (36 seconds) so the outputs of the simulation at each time (t) are used to calculate the instantaneous exergy values, $\dot{B}_i$, of the i-th flow numbered in the FD. The following equations are used to get the $\dot{B}_i$ values of the highlighted flows in Figure 3.

$$\dot{B}_i = \dot{m}_i \cdot c_p \cdot \left(T_i - T_0 - T_0 \cdot \ln\frac{T_i}{T_0}\right) \quad from\ i = 3\ to\ 6 \tag{1}$$

$$\dot{B}_i = \dot{W}_i \qquad i = 29 \tag{2}$$

where $\dot{m}_i$ is the mass flow rate, T_i is the thermodynamic temperature and $\dot{W}_i$ is the electricity consumption rate in the GSHP. For the specific heat of water c_p= 4.18 kJ/kgK is used. Usually, a mixture between water and antifreeze is used when the minimum outlet temperature of the evaporator will be less than 5 °C [31]; nevertheless, since the minimum evaporator outlet temperature is 7 °C, water is used in the ground heat exchanger.

T_0 refers to the reference state temperature needed to calculate the exergy value of an energy-flow. After all, a flow is capable to generate useful-work until it reaches the equilibrium with the reference state. As a novelty, in this work we evaluate the influence of T_0 in the GSHP analyzing two different cases:

- CASE 1 considers two different reference state temperatures ($T_0 = T_{soil}$ and $T_0 = T_{env.}$) for exergy calculation, according to the type of flow (T_{soil} for the “3 and 5” underground-flows in the evaporator and $T_{env.}$ for the rest of flows).
- CASE 2 considers that the reference state of all flows is the outdoor air ($T_0 = T_{env}$).

	Flow number *i*	T_0
CASE 1	*i*= 3 and 5	$\boldsymbol{T_{soil}}$
	i= 4 and 6	$\boldsymbol{T_{env.}}$
CASE 2	from *i*= 3 to 6	$\boldsymbol{T_{env.}}$

Table 3. Reference temperatures used in CASE1 and CASE2 for GSHP.

Figure 5 shows the average hourly temperature values $\bar{T}^h$, of the “3 and 5” flows that cross the evaporator side of the GSHP, together with the soil and the environment temperature according to each CASE. As it can be seen, in Figure 5 CASE 1, $\bar{T}^h_{soil}$ and $\bar{T}^h_3$ are overlapped . Due to simplification reasons, T_{soil} is used as the inlet flow temperature in the evaporator side of the GSHP. Obviously, a temperature jump between soil and the inlet flow temperature in the evaporator always exists.

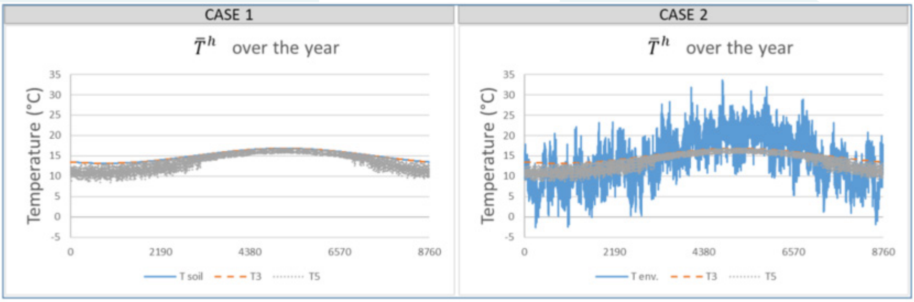

Figure 5. i=3 and i=5 flows and reference temperatures values in CASE 1 and CASE 2.

$\dot{B}_i$ values are averaged to obtain hourly exergy values $\bar{B}^h_i$ of each flow which are used for calculating the hourly averaged values for the products and fuels of the FD diagram.

4.3. Unit exergy consumptions and thermoeconomic costs

The unit exergy consumption in component n is the ratio between the fuel F_n and the product P_n:

$$k_n = \frac{F_n}{P_n}$$

The unit exergy consumption in component *n* is the ratio between the fuel F_n and the product P_n:

$$k_n = \frac{F_n}{P_n}$$

The unit exergy cost, $k^*_{F,n}$ $(k^*_{P,n})$ is the amount of exergy required to obtain an exergy unit of $F_n(P_n)$ and it is calculated as the quotient between the exergy cost $B^*_{F,n}(B^*_{P,n})$ and the exergy $B_{F,n}(B_{P,n})$:

$$k^*_{F,n} = \frac{B^*_{F,n}}{B_{F,n}}; \left(k^*_{P,n} = \frac{B^*_{P,n}}{B_{P,n}}\right)$$

The coefficients $k_{F,n}$, $k_{P,n}$ and k^*_n are related as follows:

$$k^*_{P,n} = k^*_{F,n} \cdot k_n$$

The unit economic cost, $c_{F,n}$ $(c_{P,n})$ is the amount of monetary resources required to obtain an exergy unit of the fuel *F,n* (product *P,n*). It is calculated as the quotient between the amount of monetary resources required $C_{F,n}$ $(C_{P,n})$ and the exergy $B_{F,n}$ $(B_{P,n})$:

$$c_{F,n} = \frac{C_{F,n}}{B_{F,n}}; \left(c_{P,n} = \frac{C_{P,n}}{B_{P,n}}\right)$$

$c_{P,n}$ can be divided into unit costs related exclusively to external resource consumption and the unit costs related to inversion, operation and maintenance. The following balance is satisfied at each *n* component in the facility:

$$c_{F,n} \cdot F + Z_n = c_{P,n} \cdot P$$

Where Z_n is the fixed cost per unit of time that includes investment costs, taxes and maintenance costs and it is calculated as follows:

$$Z_n = \frac{(I_n/I_{total}) \cdot C_{total}}{t}$$

I_n is the investment cost in the component *n*, I_{total} is the investment cost in the facility, C_{total} is the fixed cost of the facility and *t* is the operation time period of the *n* component. The value of *t* is obtained through the TRNSYS simulation and C_{total} is calculated as follows:

$$C_{total} = A + C_{Maintenance}$$

Where A is the annuity and $C_{Maintenance}$ is the maintenance cost estimated as 2.5% of the I_{total}.

$$A = I_{total} \cdot \frac{(1+i)^p - 1}{i \cdot (1+i)^p}$$

$$C_{Maintenance} = I_{total} \cdot 2.5\%$$

Being *p* the useful life and *i* the nominal interest rate. Hence, the Z_n value obtained for GSHP is 0.25 €/h and this information is entered into the software, as well as the unit cost of electricity (21.81 c€/kWh) and that of natural gas (5.07 c€/kWh):

Concept		Unit
I_{GSHP}	11082	€
I_{total}	35824	€
i	5	%
p	20	y
t	4692	h

A step further can be done and the unit environmental costs $a_{F,n}$ $(a_{P,n})$ can be calculated which are the amount of CO2 discharged to the environment to obtain an exergy unit of Fn(Pn). They are calculated as the quotient between the amount of CO2 discharged $A_{F,n}$ $(A_{P,n})$ and the exergy $B_{F,n}$ $(B_{P,n})$:

$$a_{F,n} = \frac{A_{F,n}}{B_{F,n}}; \left(a_{P,n} = \frac{A_{P,n}}{B_{P,n}}\right)$$

The values of 0.623 and 0.1962 kgCO2/kWh for the electricity and natural gas respectively are entered into the software.
After running the software, the k_n values for the n=33 elements and the k_j^*, c_j and a_j values for the j=50 flows are obtained. In order to avoid overloading the work presented, only the results referred to GSHP are shown. From now on we will call thermoeconomic costs to the set of these three types of costs.

5.Commented results

Before introducing the numerical results, the next Figure 6 is showed because it helps to understand the thermoeconomic costs formation process in CASE 1 and CASE 2. Besides, it is important to have Figure 5. in mind, showed in Section 4. In the following lines, the productive structure for CASE 1 and CASE 2 shown in Figure 6 is explained.
T_0 is used to calculate the $\dot{B}_i$ values required for the F and P calculation. The GSHP works in heating mode and $T_3 > T_5$ over the year. On the other hand T_0 is equal and higher than T_3 and T_5 respectively in CASE 1 and it fluctuates up and down the T_3 and T_5 values in CASE 2. According to Table 2, F in d8 is calculated as follows:

$$F_{d8} = \bar{B}_3^h - \bar{B}_5^h$$

Therefore, F_{d8} takes both positive and negative values. To solve this particularity, a "flexible" FD is proposed that adapts to both dynamic reference state temperatures of CASE 1 and CASE 2. The "flexible" FD has two configurations a) and b). Thus, CASE 1 has the FD configuration a), see Figure 6, because F_{d8} is always negative, meanwhile CASE 2 has both FD configurations a) and b), because F_{d8} could be positive and negative.

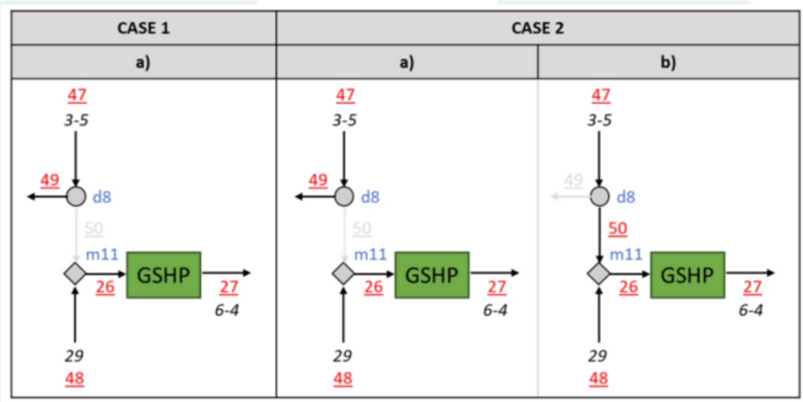

Figure 6. Productive structure in CASE 1 and CASE 2.

In the a) configuration, the energy and the exergy flows in the evaporator have opposite sense. In the b) configuration of the FD, the energy and the exergy flows in the evaporator have the same sense. Flow 49 represents the exergy flow when F_{d8} is negative and flow 50 represents the exergy flow when F_{d8} is positive.

5.1.Numerical results

The $\bar{k}^h, \bar{F}^h_{GSHP},$ and $\bar{P}^h_{GSHP}$ average hourly numerical values in each month over the year for GSHP in CASE 1 and CASE 2 are showed in Table 5.

Month	CASE 1			CASE 2		
	$\bar{k}^h$	$\bar{F}^h_{GSHP}$	$\bar{P}^h_{GSHP}$	$\bar{k}^h$	$\bar{F}^h_{GSHP}$	$\bar{P}^h_{GSHP}$
	-	kWh	kWh	-	kWh	kWh
Jan.	2.23	5.70	2.67	2.30	5.93	2.67
Feb.	2.28	5.55	2.55	2.34	5.74	2.55
Mar.	2.32	5.19	2.34	2.38	5.36	2.34
Apr.	2.32	4.64	2.08	2.39	4.79	2.08
May.	2.52	3.55	1.48	2.56	3.63	1.48
Jun.	2.99	3.00	1.03	2.99	3.00	1.03
Jul.	3.37	2.80	0.86	3.38	2.80	0.86
Aug.	3.39	2.79	0.85	3.39	2.79	0.85
Sep.	3.19	3.07	1.02	3.20	3.08	1.02
Oct.	2.57	3.34	1.35	2.60	3.41	1.35
Nov.	2.24	4.54	2.07	2.31	4.70	2.07
Dec.	2.26	5.35	2.48	2.33	5.57	2.48

Table 5. Unit exergy consumption, fuel and product numerical values in the GSHP for CASE 1 and CASE 2.

T_0 values used for calculating $\bar{F}^h_{GSHP}$ are different in CASE 1 and 2 but they are the same for $\bar{P}^h_{GSHP}$ calculation. Due to that, the $\bar{F}^h_{GSHP}$ values are different between CASE 1 and 2 whereas the $\bar{P}^h_{GSHP}$ values are the same for CASE 1 and 2 as indicated inTable 5.

The average hourly numerical values in each month over the year for the thermoeconomic costs for the F and P of the GSHP in CASE 1 and CASE 2 are showed in Table 6.

Month	CASE 1						CASE 2					
	$\bar{k}_F^{*,h}$	$\bar{k}_P^{*,h}$	$\bar{c}_F^h$	$\bar{c}_P^h$	$\bar{a}_F^h$	$\bar{a}_P^h$	$\bar{k}_F^{*,h}$	$\bar{k}_P^{*,h}$	$\bar{c}_F^h$	$\bar{c}_P^h$	$\bar{a}_F^h$	$\bar{a}_P^h$
	-	-	$\frac{c€}{kWh}$	$\frac{c€}{kWh}$	$\frac{kgCO_2}{kWh}$	$\frac{kgCO_2}{kWh}$	-	-	$\frac{c€}{kWh}$	$\frac{c€}{kWh}$	$\frac{kgCO_2}{kWh}$	$\frac{kgCO_2}{kWh}$
Jan.	1.00	2.23	21.81	48.54	0.62	1.39	1.00	2.30	20.37	47.13	0.58	1.35
Feb.	1.00	2.28	21.81	49.72	0.62	1.42	1.00	2.34	20.57	48.51	0.59	1.39
Mar.	1.00	2.32	21.81	50.56	0.62	1.44	1.00	2.38	20.60	49.36	0.59	1.41
Apr.	1.00	2.32	21.81	50.69	0.62	1.45	1.00	2.39	20.59	49.55	0.59	1.42
May.	1.00	2.52	21.81	54.89	0.62	1.57	1.00	2.56	21.00	54.06	0.60	1.54
Jun.	1.00	2.99	21.81	65.22	0.62	1.86	1.00	2.99	21.74	65.13	0.62	1.86
Jul.	1.00	3.37	21.81	73.57	0.62	2.10	1.00	3.38	21.77	73.52	0.62	2.10
Aug.	1.00	3.39	21.81	73.93	0.62	2.11	1.00	3.39	21.78	73.90	0.62	2.11
Sep.	1.00	3.19	21.81	69.57	0.62	1.99	1.00	3.20	21.69	69.44	0.62	1.98
Oct.	1.00	2.57	21.81	56.02	0.62	1.60	1.00	2.60	21.24	55.44	0.61	1.58
Nov.	1.00	2.24	21.81	48.94	0.62	1.40	1.00	2.31	20.46	47.58	0.58	1.36
Dec.	1.00	2.26	21.81	49.25	0.62	1.41	1.00	2.33	20.28	47.74	0.58	1.36

Table 6. Numerical values of the thermoeconomic costs in CASE 1 and CASE 2

The following conclusions are obtained:

The average hourly numerical values in each month over the year for the thermoeconomic costs for the F and P of the GSHP in CASE 1 and CASE 2 are showed in Table 6.

- $\bar{k}_F^{*,h}$ in CASE 1 and in CASE 2 is 1, since the elements downstream the GSHP, d8 and m11, are ideal so $k_{d8}=k_{m11}=1$. Due to the internal irreversibilities in the GSHP, the value of $\bar{k}_P^{*,h}$ increases in all months proportionally to the monthly $\bar{k}^h$ value.
- $\bar{c}_F^h$ and $\bar{a}_F^h$ in CASE 1 are equal to the electricity unit costs c and a entered into the software, whereas in CASE 2 $\bar{c}_F^h$ and $\bar{a}_F^h$ are smaller to those values. In CASE 2, the F of the element m11, is formed with flows <u>50</u> and <u>48</u>. Flow <u>50</u> has null economic and environmental cost values, although has exergy that is added to the exergy of the flow <u>48</u>. This makes that the P of the component m11 has $\bar{c}_P^h$ and $\bar{a}_P^h$ values smaller than in CASE 1.

In both cases, the irreversibilities in the GSHP and the economic costs associated with it makes the value of $\bar{c}_P^h$ higher than $\bar{c}_F^h$. Besides, in both cases, the irreversibilities in the GSHP makes the value of $\bar{a}_P^h$ higher than $\bar{a}_F^h$.

6.Conclusions

In building environment, the very dynamic performance of the thermal facilities due to variations in demand conditions makes the application of the thermoeconomic analysis a big challenge. Besides, the proximity of the temperature values of the flows in a domestic thermal facility to the environmental temperature causes the values of the exergy of the flows and consequently of their costs to vary significantly with the variations of that environmental temperature. This makes the study of the effect of T_0 variations on the results obtained from a thermoeconomic analysis an important issue.
The objective indicated in Section 2 has been achieved. As showed in the previous section, the dynamic T_0 values used over the year influence the thermoeconomic costs; as shown,these costs vary significantly over the year. Besides, T_0 values set the FD configuration.
In previous research works, the dynamic FD of a facility is linked with the on/off states of the components. However, the work presented here shows that, besides the on/off periods of the components, the selection of T_0 defines the FD configuration. Thus, a component could be on, but without contributing to the cost formation process. This is the main outcome of this work.
This work opens the way for future research about FD dynamic configurations, since T_0 is unique for each location.

7.Acknowledgments

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8.References

[1]Intergovernmental Panel on Climate Change (IPCC), 'WORKING GROUP III CONTRIBUTION TO THE IPCC SIXTH ASSESSMENT REPORT (AR6)'. May 2022. [Online]. Available: https://www.ipcc.ch/report/ar6/wg3/
[2]'Ministry of Transport Mobility and Urban Agenda, ERESEE 2020 Long-Term Strategy for Energy Rehabilitation in the Building Sector in Spain, 2020.' [Online]. Available: https://www.mitma.gob.es/recursos_mfom/paginabasica/recursos/es_ltrs_2020.pdf.
[3]THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION, 'DIRECTIVE (EU) 2018/844 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL', 2021. https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32018L0844&from=EN (2021)

[4]N. S. Ibañez Iralde, J. Pascual, and J. Salom, ‘Energy retrofit of residential building clusters. A literature review of crossover recommended measures, policies instruments and allocated funds in Spain’, Energy Build., vol. 252, 2021, doi: 10.1016/j.enbuild.2021.111409.
[5]International Energy Agency (IEA), ‘https://www.iea-ebc.org/Data/publications/EBC_Annex_37_Summary_Report_Heating_and_Cooling.pdf’, Sep. 2020.
[6]A. M. Omer, ‘Ground-source heat pumps systems and applications’, Renew. Sustain. Energy Rev., vol. 12, no. 2, Art. no. 2, 2008, doi: https://doi.org/10.1016/j.rser.2006.10.003.
[7]U. Lucia, M. Simonetti, G. Chiesa, and G. Grisolia, ‘Ground-source pump system for heating and cooling: Review and thermodynamic approach’, Renew. Sustain. Energy Rev., vol. 70, pp. 867–874, 2017, doi: https://doi.org/10.1016/j.rser.2016.11.268.
[8]Instituto para la Diversificación y Ahorro de la Energía (IDAE), ‘https://www.idae.es/uploads/documentos/documentos_11227_e9_geotermia_A_db72b0ac.pdf’, Sep. 2020.
[9]G. Tsatsaronis, ‘COMBINATION OF EXERGETIC AND ECONOMIC ANALYSIS IN ENERGY CONVERSION PROCESSES.’, 1985, pp. 151–157. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-0021899181&partnerID=40&md5=f5825f660ec4871eab89fb10cd455b2d
[10]Michael J. Moran, Howard N. Shapiro, Daisie D. Boettner, and Margaret B. Bailey, Fundamentals of Engineering Thermodynamics, 7th ed. Wiley.
[11]A. Valero, ‘THERMOECONOMICS AS A CONCEPTUAL BASIS FOR ENERGY–ECOLOGICAL ANALYSIS.’
[12]G. Tsatsaronis, ‘Definitions and nomenclature in exergy analysis and exergoeconomics’, Energy, vol. 32, no. 4, pp. 249–253, 2007, doi: 10.1016/j.energy.2006.07.002.
[13]L. Meyer, G. Tsatsaronis, J. Buchgeister, and L. Schebek, ‘Exergoenvironmental analysis for evaluation of the environmental impact of energy conversion systems’, Energy, vol. 34, no. 1, Art. no. 1,2009, doi: https://doi.org/10.1016/j.energy.2008.07.018.
[14]A. Valero, M. A. Lozano, L. Serra, and C. Torres, ‘Application of the exergetic cost theory to the CGAM problem’, Energy, vol. 19, no. 3, Art. no. 3, 1994, doi: 10.1016/0360-5442(94)90116-3.
[15]A. Picallo, C. Escudero, I. Flores, and J. M. Sala, ‘Symbolic thermoeconomics in building energy supply systems’, Energy Build., vol. 127, pp. 561–570, 2016, doi: 10.1016/j.enbuild.2016.06.001.
[16]A. Picallo-Perez, J. M. Sala-Lizarraga, and L. Portillo-Valdes, ‘Development of a tool based on thermoeconomics for control and diagnosis building thermal facilities’, Energy, vol. 239, 2022, doi: 10.1016/j.energy.2021.122304.
[17]A. Lazzaretto and G. Tsatsaronis, ‘SPECO: A systematic and general methodology for calculating efficiencies and costs in thermal systems’, Energy, vol. 31, no. 8–9, Art. no. 8–9, 2006, doi: 10.1016/j.energy.2005.03.011.
[18]Sala-Lizarraga, and Picallo-Perez, Exergy Analysis and Thermoeconomics of Buildings: Design and Analysis for Sustainable Energy Systems. Butterworth-Heinemann, 2019.
[19]H. Torío, A. Angelotti, and D. Schmidt, ‘Exergy analysis of renewable energy-based climatisation systems for buildings: A critical view’, Energy Build., vol. 41, no. 3, Art. no. 3, 2009, doi: https://doi.org/10.1016/j.enbuild.2008.10.006.
[20]A. Picallo-Perez, P. Catrini, A. Piacentino, and J.-M. Sala, ‘A novel thermoeconomic analysis under dynamic operating conditions for space heating and cooling systems’, Energy, vol. 180, pp. 819–837, 2019, doi: 10.1016/j.energy.2019.05.098.
[23]P. Catrini, A. Piacentino, F. Cardona, and G. Ciulla, ‘Exergoeconomic analysis as support in decision-making for the design and operation of multiple chiller systems in air conditioning applications’, Energy Convers. Manag., vol. 220, 2020, doi: 10.1016/j.enconman.2020.113051.
[24]A. Picallo-Perez, J. M. Sala-Lizarraga, C. Escudero-Revilla, J. M. Hidalgo-Betanzos, and I. Ruiz de Vergara, ‘Thermoeconomic Analysis in Advanced Cogeneration Systems in Buildings’, Front. Energy Res., vol. 9, 2022, doi: 10.3389/fenrg.2021.802971.
[25] Z. Erbay and A. Hepbasli, ‘Exergoeconomic evaluation of a ground-source heat pump food dryer at varying dead state temperatures’, J. Clean. Prod., vol. 142, pp. 1425–1435, 2017, doi: 10.1016/j.jclepro.2016.11.164.

[26]K. Menberg, Y. Heo, W. Choi, R. Ooka, R. Choudhary, and M. Shukuya, ‘Exergy analysis of a hybrid ground-source heat pump system’, Appl. Energy, vol. 204, pp. 31–46, 2017, doi: https://doi.org/10.1016/j.apenergy.2017.06.076.
[27]FEGECA, ‘Guía de Suelo Radiante’. La Fundación de la Energía de la Comunidad de Madrid (FENERCOM), 2017.
[28]A. Hernández-Arizaga, A. Picallo-Pérez, and J. M. Sala-Lizarraga, ‘Procedure for modelling and calibrating operating thermal systems in buildings’, J. Build. Eng., vol. 45, 2022, doi: 10.1016/j.jobe.2021.103530.
[29] Código Técnico de la Edificación (CTE), ‘https://www.codigotecnico.org/images/stories/pdf/ahorroEnergia/DBHE.pdf’, Sep. 2020.
[30] Iturriaga-Hidalgo, ‘Development of a simple method for the optimization of the design of installations in nearly zero energy residential buildings in the Basque Country. (In Spanish)’, UPV-EHU, Bilbao, 2017.
[31] Asociación Técnica Española de Climatización y and Instituto para la Diversificación y Ahorro de la Energía (IDAE), ‘Guía técnica Diseño de sistemas de intercambio geotérmico de circuito cerrado’. 2012.

European Digital Building Logbook: definition of its functionalities to maximize its potential

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Abstract

The building sector has a crucial role to achieve the climate goals set by the European Union for 2050. In this sense, renovating the existing building stock is a high-impact option to reduce energy consumption and CO2 emissions in the EU. However, to achieve the goals set by EPBD (EU) 2018/844, the renovation rate needs to move from the current value of 0.4–1.2% to 3%. One of the barriers that prevent renovation rate growth is the lack of open data about the building stock, which makes it difficult to analyse the real state of buildings. This barrier has hardly been addressed in the literature, but a new tool recently identified in the Renovation Wave, is called to solve this problem: the Digital Building Logbook (DBL). It is understood as a digital repository of all the relevant data on a building, collected throughout its lifecycle, to facilitate transparency, trust, informed decision making and information sharing among building owners and occupants, financial institutions and public authorities. Although the concept of a building logbook is not new in Europe (some initiatives have already been running at national and regional scale, such as the Woningpas in Flanders, the Hausakte in Germany or the Libro del Edificio in Spain), a common European Digital Building Logbook model does not exist so far. As the implementation of the DBL is a European priority, several groups have recently proposed DBL models, named the iBRoad-Log, the ALDREN BuildLog, the X-tendo Logbook and the Study on the Development of a European Union Framework for Buildings' Digital Logbook. Even though these proposals are an important contribution to the subject, there is no consensus regarding crucial aspects, such as its functionalities, the indicators or data fields that the DBL should contain or the way to collect them. Additionally, the potential of the DBL has not been fully addressed nor the operation and use stage has been solved. In this paper, the full potential of the DBL will be explored, starting from a critical analysis of the existing European DBL models, and going beyond by proposing and exploring new functionalities, such as the possibility to gather data that can be used to collect progress indicators to monitor the decarbonization in the building sector (as the ones proposed in Commission Recommendation (EU) 2019/786), or features, such as the connection to existing platforms e.g. the Energy Performance Certificates (EPC), and the upcoming data from other European initiatives related to the buildings sector, such as 'Renovation passports', lifecycle emissions calculation using the Level(s) framework, the Smart Readiness Indicator or the sustainable product passports for construction materials.

1. Introduction

One of the main objectives of the European Union in the medium term is the decarbonization of the economic and productive system by 2050. Currently, buildings are responsible for 40% of the energy consumption and 36% of CO2 emissions. Within this energy consumption, 80% is dedicated to space heating and cooling and domestic hot water (DHW) [1]. Thus, the intervention on existing buildings, which are very inefficient, acquires a crucial role in achieving the goal of decarbonization, even more considering that a considerable number of the buildings that currently exist will be standing in 2050. However, the current renovation rate is far from what is considered necessary to achieve the climate objectives, despite the efforts that, from the different public administrations, are being made to increase it.

In this sense, the proposal for the recast of the Directive of the European Parliament and of the Council on the energy performance of buildings [1], published in December 2021, includes a battery of measures to foster renovation, including the replacement of long-term renovation strategies by national building renovation plans or ensuring greater investment in renovation through the Recovery and Resilience Facility (RRF), the Social Climate Fund, Cohesion Policy funds, etc. In addition, new energy efficiency standards are proposed, and new concepts and definitions which were already addressed in different areas but were not covered by European legislation, are now included. This is the case of concepts such as ‘zero-emission building’, ‘staged deep renovation’, ‘renovation passport’ or ‘digital building logbook’, which are defined in Article 2 of the standard.
This work aims to make an approach to the digital building logbook, studying the advances made so far in this tool and identifying the next steps to take.

2. What is the digital building logbook? definition and status of the art

Europe is aware of the need to collect data on its building stock, since the lack of quality and reliable data is one of the many barriers that prevent renovation rate to grow [2]. In fact, several attempts have been made to create databases on buildings. Good examples of this are the INSPIRE Cadaster and the EU Building Stock Observatory (BSO). However, currently, none of them have reached a full development, mainly due to the lack of data on the building stock. On the one hand, the INSPIRE Cadaster, which aimed to homogenize the national cadasters of all the Member States by providing guidelines, is currently a conglomerate of disconnected contents. On the other hand, the BSO, created in 2016 with the aim of providing transparent, reliable and comparable information on buildings through the collection of 250 indicators, is practically empty and barely allows to visualize data about some topics from some countries. Given this situation, other hypotheses are being explored.
One of them is the digital building logbook (DBL), which is defined in the Proposal for the recast of the EPBD as a ‘common repository for all relevant building data, including data related to energy performance such as energy performance certificates, renovation passports and smart readiness indicators, which facilitates informed decision making and information sharing within the construction sector, among building owners and occupants, financial institutions and public authorities’. This tool acquires great relevance because it is supposed to serve to mitigate the current lack of data on the building stock, which is expected to increase the renovation rate.
Before being mentioned by the aforementioned Proposal for the recast of the EPBD, the digital building logbook had already begun to be outlined in the academia, where it used to be associated with a renovation roadmap to form the so-called ‘building renovation passport’ [3,4]. The renovation roadmap is intended to guide the building owner during the steps that must be taken to deep renovation the property.
Currently, there are some regional and national DLBs running in Europe. One of the most successful cases is the Woningpas, implemented in Flanders, Belgium, and developed by the Flemish Energy Agency. It is a model in permanent evolution and is applicable to single-family homes. The aim of the Woningpas it to minimize administrative burdens in the key moments of the building (construction, renovation, change of owner, etc.) and to provide users with information and advice on fundamental aspects of the building, including the generation of a roadmap for its improvement.
A common digital building logbook model has not been implemented in Europe so far. Nevertheless, there are four proposals, created before the DBL was mentioned in continental legislation. These proposals have been developed by research groups: three of them are outputs of H2020 research projects and the last one is a three-volume report commissioned by the European Commission. On the one hand, the outcomes of H2020 projects are the iBRoad-Log (focused on single-family homes), the ALDREN BuildLog (for non-residential buildings, mainly hotels and offices) and the X-Tendo Logbook (suitable for the whole building stock) [5-7]. On the other hand, the report entitled ‘Study on the Development of a European Union Framework for Buildings’ Digital Logbook’ [8] also seeks to be applicable to the entirety building stock.
These four proposals were studied by Gómez-Gil et al. [2] and constitute a very valuable first step for the implementation of the European DBL.

In the aforementioned work, a comparative analysis was carried out around 7 parameters: references used as a starting point, relevant stakeholders of the DBL, potential user needs, proposed structure, data sources, potential functionalities and operation and use. The following conclusions were obtained:

-Regarding the references used as a starting point for the definition of the DBL model there is no consensus among the proposals, but they all agree on having studied existing models of BRP and DBL. In addition, 3 of them considered models of energy performance certificates (CEE) and also 3 were based on surveys carried out with stakeholders of the sector.

-Regarding the stakeholders of the DBL, the most important of the agents are the owner and users of the building, followed by public authorities and financial institutions.

-Concerning the potential user needs, through participatory surveys conducted by the research groups, it was concluded that the most important topics are 'building's features/description', 'technical specifications of the elements', 'energy use, water consumption and energy bills' and 'energy performance certificate'.

-In relation to the structure -or indicators- of the DBL, there are large differences between the proposals. Only 4 out of 438 indicators were recommended by all the proposals and 21 out of 438 were recommended by 3 of them, which represents 6% of the total.

-Regarding the sources that should feed the DBL, the initiatives agreed that the building owner/user is the main source of information, along with the construction industry, public authorities, financial institutions, certified experts and auditors, service companies, existing databases and new information technologies.

-When it comes to the functionalities of the tool, there is consensus among the proposals that the main function of the DBL is to serve as a repository of the relevant information of the building. In addition, the assessment of the energy performance and smart readiness, the connection to the renovation roadmap and the link to external databases were also identified.

-Regarding the operation and use stage, no proposal defined it in sufficient detail. In fact, several proposals pointed out that the DBL would be prepared manually by a technician or auditor who, after collecting the existing information about the building in the existing databases (BD) and performing a visual inspection of the property, would fill in the document. On the other hand, it is also indicated that the connection with existing databases would be made automatically, but it is not detailed how.

Therefore, despite the value of these first initiatives, some key aspects are not solved yet, such as the set of indicators that must be collected, how they can be collected, how to manage them, how to interconnect existing databases or how their link with new tools, technologies and strategic frameworks that are emerging can be made.The Spanish Libro del Edificio Existente, emerged through Royal Decree 853/2021, of October 5 [9], can be framed on this 'first generation' of the DBL.

3. Next steps for the definition of a european digital building logbook model

In order to solve the key aspects that are still open about the tool and to be able to propose an efficient and consensual model, it is necessary to clarify, first, the objectives pursued by the DBL.

The authors of this paper think that the digital building logbook should be an instrument that contributes to promoting energy renovation of the building stock. To do so, in addition to the function of serving as a repository of data on buildings, the DBL must:

-Provide the necessary information to prepare a renovation roadmap, which allows the staged renovation of a building. As stated in the Proposal for the recast of the EPBD, the sequence of the indicated steps must guarantee the transformation of the building into a nearly zero energy building (nZEB) by 2030 and into a zero emissions building by 2050. In addition, other expected benefits should be specified.

-Make it possible to collect indicators to assess the progress of decarbonization, including building renovation, which currently cannot be assessed due to the lack of information. The mentioned Proposal for the recast of the EPBD specifies that national building renovation plans must contain a set of mandatory and voluntary indicators for this purpose. In addition, a voluntary framework of indicators for Member States had previously been provided in Recommendation (EU) 2019/786.

-Allow to elaborate a maintenance plan for the building. To ensure that the energy efficiency conditions of a construction are maintained over time, it is essential to create a maintenance plan that guarantees the proper functioning of the systems.

Secondly, after establishing the main functions of the DBL, the indicators that the DBL must collect to satisfy them can be defined:

-Regarding the functionalities 'definition of a renovation roadmap' and 'creation of a maintenance plan', the indicators should make it possible to know the current state of a building in terms of energy efficiency, health, comfort, resilience to climate change, living conditions, energy poverty, universal accessibility, safety, etc.

-With regard to the assessment of the progress of decarbonization and renovation, each of the evaluation indicators should be analyzed individually in order to identify what information should be gathered by the DBL to enable their collection.

Thirdly, since the DBL is a repository of data on buildings, all the approaches agree that the logbook should collect and link all the information that is already available in existing data sources (Fig. 1). Currently, in Spain the following data sources are running:

-The Cadaster, which contains general and administrative information.

-The Land Registry, which collects general and administrative information, as well as acts, contracts and administrative and judicial resolutions that affect the properties.

-Energy performance certificates registers, that are still regional, although they must be centralized at the national level.

-Building Assessment Report or Informe de Evaluación del Edificio (IEE) and Technical Inspection of Buildings or Inspección Técnica de Edificios (ITE) registers. Each Spanish region can decide to apply one, the other or both of them, which creates a great heterogeneity not only due to the different tools used, but also for the different models existing within each one.

-Building-scale documents, such as the Libro del Edificio and the new Libro del Edificio Existente.

-In addition, some municipalities count on local databases, which usually contain descriptive information.

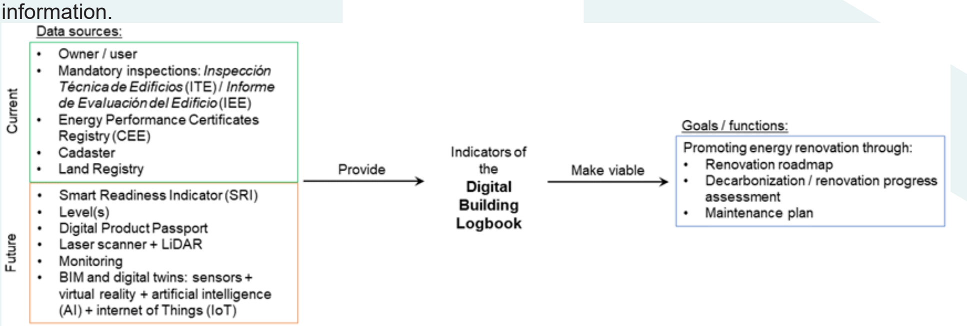

Figure 1. DBL concept scheme considering current Spanish databases

When all these issues are fully established, it will be possible to move on to the design phase of the digital application, where it will be necessary to:

-Define the architecture of the application, both its frontend -the user interface- and its backend -the internal operations, as well as the interconnection with other data sources-.

-Establish the permissions that each user of the application will have -viewing, editing, inserting, etc.-.

-Consider legal aspects on data protection.

However, to successfully conclude the design and implementation of the digital building logbook it is necessary, first of all, to overcome a series of burdens:

-One of the main ones lies in the availability of the data [10,11] that will feed the DBL. In this sense, the following barriers related to current data acquisition strategies stand out:

-Different administrations with different means are involved. The country's territorial organization means that institutions of different scales are responsible for collecting data on the building stock. There are data collected at the national, regional, and local levels, which makes it difficult to coordinate and symmetry the information.

-Data quality. The lack of up-to-date general guidelines and methodologies in relation to data gathering leads to a majority of non-operable and non-georeferenced data, which reduces its potential.

-Data privacy. There is a lot of data collected about the building stock. However, many of them are hosted in private databases, or are not even hosted in databases. This is the case of the Libro del Edificio, which is in possession of the building owner, which prevents data from maximizing their usefulness.

-Scale of the data. In many cases, aggregated data, used for statistical and political purposed, are available. However, these data are not useful for other purposes, such as the study of each building individually to establish renovation roadmaps.

-On the other hand, although there are some data satisfactorily collected and hosted in databases (DB), the DBs are rarely interoperable, which makes it difficult to exchange information. As an example, out of all the previously mentioned data sources -considering a case study located in Aragon- only the EPC registry has an API endpoint, that is, a communication channel from which other applications can contact it to request data.

-New data on buildings needs to be collected. To be able to plan efficient interventions on the building stock, it is necessary to gather data on the real performance of buildings (needs, consumption), their interior conditions, the user behavior, etc [12].

Solving these problems requires homogenizing the process of collecting and managing data, as well as modernizing the existing data infrastructures to adapt them to new needs, including improving their ability to interconnect with other applications or working with modern exchange formats.

4. Future of the digital building logbook

Although the European digital building logbook is not yet implemented and has not even been formally defined due to the previously mentioned barriers, the debate around a second generation of this tool has already begun. In this sense, in October 2021 the Horizon call for research projects called 'Demonstrate the use of Digital Logbook for Buildings' was launched. It aimed at exploring the maximum potential of the DBL, emphasizing the incorporation of new technologies to collect and process information, as well as for the creation of intelligent data environments at community level.

This 'second generation', that would solve some of the problems already identified, is characterized by the use of the latest technologies for the collection of data -in contrast to the more manual approach of the 'first generation'-, as well as for its storage and exchange. It is based on the automation of processes, the collection of real data and the creation of shared data environments.

In Table 1 a comparison between the first and the second generation of the DBL is shown.

FIRST GENERATION	SECOND GENERATION
STRENGTHS	
Simpler architecture	Dynamic (permanently updated)
Fast deployment	Automated processing
Lower cost	3D model format (digital twins)
More realistic considering the current means	Based on real data
	Implements the latest technologies
	It allows the creation of data environments of any scale
	The connection between the existing DBs is automated
WEAKNESSES	
Static (maintenance and updating are required)	Complex architecture and programming
Elaboration with a large manual component (a large amount of data is collected by the auditor)	Longer-term deployment
Based on calculated or estimated data	Higher cost
Text and 2D format (paper or digital)	Cutting-edge technology is needed
Focused on the building scale	It is utopian considering the current means
The information from existing DBs is not automatically incorporated	

Table 1. Comparison of the digital building logbook generations

European Commission Frameworks:

-'Smart Readiness Indicator' (SRI).

It is a certification system that measures the ability of a building to use information and communication technologies and electronic systems [13] to:

-Respond to users' needs (in terms of health, comfort, wellbeing, etc.).

-Optimize its energy performance.

-Interact and adapt to the network (flexibility, demand response, integration).

It arised with Directive (EU) 2018/844 and was extended in the Proposal for the recast of the EPBD. Its objective is to contribute to making buildings more efficient, healthy, and comfortable, optimizing and reducing their energy consumption, which also translates into economic savings for users.

It will provide administrative and general information on buildings as well as the preparation for intelligent applications class [14]. In addition, it will also allow to individually evaluate the different 'services' of the building: heating, DHW, cooling, ventilation, lighting, monitoring and control, electric vehicles, electricity, and dynamic envelope. They will be evaluated according to the energy savings they provide, flexibility with the network and storage, comfort, response and adaptability, health and well-being, maintenance and faults prediction, and information to users [15]. Where applicable, it will also assess the connectivity of the building, particularly the existence of high-speed networks, as well as interoperability, cybersecurity and data protection issues [16].

One of its main disadvantages is that it will be a voluntary framework, thus, Member States will decide if they want to incorporate it into their national regulations or not.

-Level(s).

This European framework, which has given rise to a free tool, aims to help professionals of the building sector to assess and monitor buildings' life cycle sustainability. To do this, it counts on a set of indicators that are structured in 6 macro-objectives: greenhouse gas emissions; resource efficiency and circular materials; efficient use of water resources; healthy and comfortable spaces; adaptation and resilience to climate change and cost and value of optimized life cycle [17,18].

-Digital Product Passport

The digital product passport, already mentioned in the European Green Deal [19], will also be included in the revision of the Regulation on Construction Products [20] as a tool that allows consumers to make more sustainable choices when purchasing products. This passport shall include information on origin, composition, repair and dismantling possibilities and end-of-life management.

Technologies applied to building analysis

-Laser scanner and Light Detection and Ranging or Laser Imaging Detection and Ranging (LiDAR):

The LiDAR system is a technology that allows generating high-precision point clouds using a laser emitter that determines the distance between the emitter and the object to be captured. To do so, LiDAR mainly uses a laser scanner and a drone or aerial airborne light scanner (ALS) that transports it. Flights that take place can be scheduled and automated, simplifying the process. In addition, the generated point cloud is usually accompanied by hundreds of ultra-high-resolution images.

With these elements, after a transformation process where the raw data must be converted into readable data and imported into a modeling program, it is possible to quickly generate the architectural survey of a building and to create a high-quality 3D model.

The laser scanner, without mounting on an ALS can also be used inside the building, providing a complete survey of the interior as well.

In addition, thanks to its ability to cover the entire building and to photograph it with extraordinary quality, it can be used to identify pathologies or to evaluate the state of conservation of inaccessible points [21].

-Monitoring

Monitoring through sensors is an effective method to gather data on operation, use and actual consumption of buildings [22]. Currently, there is a wide variety of sensors on the market that allow measuring, among other parameters, the ambient and surface temperature, CO2 concentrations, relative humidity, real energy consumption, opening time of the windows, etc. The data collected by the sensors can be sent in real time, using an internet connection, to any remote device for their storage and analysis.

-BIM and digital twins: sensors + Internet of Things (IoT)

Building Information Modelling (BIM) was a revolution in the way the architectural project is represented. It provides the advantage of allowing to include in a model all the information of the different elements (object-based system) that make up a project, and not only its geometry, becoming the most reliable database of the building.

Currently, a further step is being taken in this technology, trying to link to the BIM model the new technological advances, such as big data, cloud computing, artificial intelligence (AI), virtual reality (VR), augmented reality (AR), industry 4.0, and Internet of Things (IoT) [23], with the aim of expanding its capabilities. This way, an information flow is created between the model and the real object, in this case, the real building. When the flow of information is bidirectional, the model is called Digital Twin (DT) [24].

For the creation of a DT, technologies are installed in the finished/existing building to capture reality, such as sensors or cameras, which collect data that is transferred to IoT and machine learning platforms, where they are analysed and integrated in the model. The model returns feedback in the form of valuable information for the generation of a preventive maintenance plan, suggestions for improving the use phase -for example, to improve its efficiency- and performing “what-if” analysis [25,26]. In addition, the interconnection of different DTs (forming the so-called federated models) would allow to expand their scope of application to the scale of a neighbourhood or city [26].

Data that may be collected through these new technologies are listed in Table 2.

	SRI	Level(s)	*Product passport*	*Laser scanner +* LiDAR	Monitoring	BIM + DT
Planimetry				X		X
3D model				X		X
Building pathologies				X		
Energy performance	X				X	X
Fault prevention						X
Digitalization	X					
LCA		X	X			
Internal conditions					X	X
Maintenance plan						X
Improvement suggestions						X

Table 2. Information which would be gathered by new technologies

Despite the myriad benefits of incorporating these new technologies for building data collection, there are still barriers that will need to be overcomed for their application to the DBL. In addition to the aforementioned data protection and cybersecurity problems, it must be added that current databases are not prepared to deal with the growing heterogeneity and volume of data that will be handled by incorporating all these systems [27].

6. Conclusions

The digital building logbook has great potential to contribute to increasing the rate and quality of the building stock renovation. This potential has already been identified both at European and national level, and several countries have already implemented tools of this nature. At the continental level, there are only 4 DBL proposals that, however, have not been implemented yet. Meanwhile, the European Commission is trying to find a definitive model based on the latest technologies that would be implemented in the near future.

Nevertheless, the effective implementation of this tool still seems relatively distant, since there are many issues that need to be solved first. On the one hand, the design of the tool itself involves difficulties, such as the need to adapt to an entire very heterogeneous continent or the need to respect strict data protection laws. On the other hand, there are still conflicts of a technical nature, both with regard to the obsolete systems of collection, processing and dissemination of information and the challenges involved in the incorporation of the latest technologies, including the heterogeneity and the immense volume of data that would be collected, as well as its high cost.

7.References

[1] European Commission, Proposal for a Directive of the European Parliament and of the Council on the energy performance of buildings (recast). Belgium, 2021. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021PC0802&from=EN

[2] M. Gómez-Gil, A. Espinosa-Fernández, B. López-Mesa, Review and Analysis of Models for a European Digital Building Logbook, Energies 15 (2022). DOI: 10.3390/en15061994.

[3] M.M. Sesana, M. Rivallain, G. Salvalai, Overview of the available knowledge for the data model definition of a building renovation passport for non-residential buildings: The ALDREN project experience, Sustainability 12 (2020). DOI: 10.3390/su12020642.
[4] M.M. Sesana, G. Salvalai, D. Brutti, C. Mandin, W. Wei, ALDREN: A methodological framework to support decision-making and investments in deep energy renovation of non-residential buildings, Buildings 11 (2021). DOI: 10.3390/buildings11010003.
[5] "iBRoad Project." https://ibroad-project.eu/ (accessed Jun. 13, 2022).
[6] "ALDREN Project." https://aldren.eu/ (accessed Jun. 13, 2022).
[7] "X-tendo Project." https://x-tendo.eu/ (accessed Jun. 13, 2022).
[8] S. Dourlens-Quaranta et al., Study on the development of a European Union framework for digital building logbooks. Final report, 2020. Doi: 10.2826/659006.
[9] Gobierno de España. Ministerio de Transportes, Movilidad y Agenda Urbana, Real Decreto 853/2021, de 5 de octubre, por el que se regulan los programas de ayuda en materia de rehabilitación residencial y vivienda social del Plan de Recuperación, Transformación y Resiliencia, 2021. Available: https://www.boe.es/diario_boe/txt.php?id=BOE-A-2021-16233
[10] A. Cuchí, I. de la Puerta, Diagnóstico de la Rehabilitación en las Comunidades Autónomas. Luces y Sombras de un Sector que no Despega, 2016. Available: http://www.observatoriociudad3r.com/wp-content/uploads/2018/02/Informe-Rehabilitaci%C3%B3n-CCAA-Jul-2016.pdf
[11] B. Daniotti, et al., The Development of a BIM-Based Interoperable Toolkit for Efficient Renovation in Buildings: From BIM to Digital Twin, Buildings 12 (2022). DOI: 10.3390/buildings12020231.
[12] P. Mêda, D. Calvetti, E. Hjelseth, H. Sousa, Buildings Incremental Digital Twin Conceptualisations Targeting Data-Driven Circular Construction, Buildings 11 (2021). DOI: 10.3390/buildings11110554.
[13] European Parliament and Council of the European Union, Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018, Available: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32018L0844
[14] European Commission, Commission Implementing Regulation (EU) 2020/2156 of 14 October 2020 detailing the technical modalities for the effective implementation of an optional common Union scheme for rating the smart readiness of buildings. 2020. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32020R2156
[15] S. Verbeke, D. Aerts, G. Reynders, Y. Ma, and P. Waide, Final report on the technical support to the development of a smart readiness indicator for buildings, 2020. DOI: 10.2833/41100.
[16] European Commission, Commission Delegated Regulation (EU) 2020/2155 of 14 October 2020 supplementing Directive (EU) 2010/31/EU of the European Parliament and of the Council by establishing an optional common European Union scheme for rating the smart readiness of buildings, 2020. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2020.431.01.0009.01.ENG
[17] European Commission, Level(s): A common language for building assessment, 2021. Available: https://op.europa.eu/fr/publication-detail/-/publication/f5d52b58-2c95-11ec-bd8e-01aa75ed71a1
[18] European Commission, Level(s): Putting whole life carbon principles into practice, 2021. Available: https://op.europa.eu/en/publication-detail/-/publication/20761f2e-143f-11ec-b4fe-01aa75ed71a1/language-en/format-PDF/source-230076864
[19] European Commission, The European Green Deal, 2019. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1576150542719&uri=COM%3A2019%3A640%3AFIN
[20] European Commission, Proposal for a Regulation laying down harmonised conditions for the marketing of construction products, amending Regulation (EU) 2019/1020 and repealing Regulation (EU) 305/2011. 2022. Available: https://ec.europa.eu/docsroom/documents/49315
[21] M. Solla et al., A Building Information Modeling Approach to Integrate Geomatic Data for the Documentation and Preservation of Cultural Heritage, Remote Sensing 12 (2020). DOI: 10.3390/rs12244028.
[22] M. Lucas Bonilla, B. Muriel Delgado, and B. Montalbán Pozas, Implementing a monitoring system's proposal for the improvement of public buildings, Anales de Edificación, 6 (2020). DOI: 10.20868/ade.2020.4613.
[23] Q. Lu et al., Developing a dynamic digital twin at building and city levels: A case study of the West Cambridge campus, Journal of Management in Engineering, 36 (2019). DOI: 10.1061/(ASCE)ME.1943-5479.0000763.
[24] S. M. E. Sepasgozar, Differentiating Digital Twin from Digital Shadow: Elucidating a Paradigm Shift to Expedite a Smart, Sustainable Built Environment, Buildings 11 (2021). DOI: 10.3390/buildings11040151.
[25] S. Haghighat Khajavi, N. Hossein Motlagh, A. Jaribion, L. C. Werner, and J. Holmström, Digital Twin: Vision, Benefits, Boundaries, and Creation for Buildings, IEEE Access 7 (2019) 147406–147419. DOI: 10.1109/ACCESS.2019.2946515.
[26] M. Shahzad, M. Tariq Shafiq, D. Douglas, and M. Kassem, Digital Twins in Built Environments: An Investigation of the Characteristics, Applications, and Challenges, Buildings 12 (2022). DOI: 10.3390/buildings12020120.
[27] Q. Qi et al., Enabling technologies and tools for digital twin, Journal of Manufacturing Systems 58 (2019) 3–21. DOI: 10.1016/j.jmsy.2019.10.001.

Towards Sustainable Urban Regeneration of Industrial Areas in the Basque Country: Case Studies in Donostia and Pasajes.

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Key Words: sustainability, industrial heritage, urban regeneration, circularity.

Abstract

The industrial development of the 19th and 20th centuries brought with it, in addition to the impact on the economic, social and cultural spheres of Basque society, a profound transformation of the landscape, the urban fabric and the territorial planning of the Basque Country. From the 1970s onwards, the industrial crisis and the reconversion of industrial activities, together with the increasing presence of the service sector, led to the disappearance of most of the industry from the city centers and the creation of new productive fabrics in peripheral areas. This urban transformation, based on environmental justifications and the profitability of the resulting urban development operations, had two fundamental consequences. On the one hand, the loss of a large part of the built industrial heritage. This was due to the lack of social awareness of the heritage value of industrial facilities, the absence of legislation to protect these elements and the urgent need for land of great centrality for residential requalification.
On the other hand, the consequent zoning of large-scale uses. The segregation of residential and industrial uses decoupled population centers from industry, encouraged urban mobility based on the automobile and facilitated the artificialization of rural land. This urban sprawl strategy, still in force today, has given rise to a diffuse and unsustainable city model.

The municipalities of Donostia and Pasajes have not been alien to this reality. The aim of this paper is to analyze the industrial urban transformation of these two cities in the last years by means of the examination of reference bibliography, heritage cataloguing, urban plans of the area and field studies. The evolution and interventions in their industrial sites, the types of intervention applied and their degree of sustainability will be discussed, thus confirming that the actions carried out confirm the indicated trends. The main conclusion is that the urban regeneration of industrial areas must be approached from a metropolitan and territorial scale, facing the opportunity of a sustainable intervention on the existing city. To this end, it must seek the mix and diversity of uses, the proximity of the productive fabric and the enhancement of the industrial heritage.

This analysis is framed in the context of a broader research that consists of determining the bases of a new urban paradigm to combine the conservation of industrial heritage, sustainable regeneration and circularity criteria.

1.Introduction

According to the New Urban Agenda [1], urbanisation is one of the most transformative trends of the 21st century. SDG11 of the 2030 Urban Agenda, which sets out 17 Sustainable Development Goals [2], proposes to make cities and human settlements inclusive, safe, resilient and sustainable.
Land, in addition to being a basic natural resource, is a non-renewable resource and irreversible urbanisation, so it is urgent to optimise the occupation of the territory by the city. Urban and territorial planning play an important role as instruments for the adaptation of urban morphology to sustainability objectives. In addition to the density and diversity of uses, the regeneration and reuse of obsolete and underused urban fabric of the existing city is a determining factor in achieving these objectives.

Recently, within the framework of the Basque Green New Deal, the Basque Government has approved the first Land Protection Strategy of the Basque Country 2030; the reduction of land consumption and the management of land occupation are two of its strategic objectives.
Although urban regeneration interventions are already applied to residential areas in the Basque Autonomous Community [3], regeneration intervention in productive fabrics is not common. The extensive planning strategy, preferential in the last century, has led to the disappearance of industry from urban centres and its replacement by new residential developments.
This paper analyses the industrial urban transformation since the mid-20th century, seeking to assess whether the actions in Donostia and Pasajes follow the aforementioned trend and, if confirmed, to determine the criteria for sustainable intervention to which future urban planning actions should be adjusted, reversing the extensive dynamics of the city and optimising territorial occupation. Viable industrial activities in urban centres are those that are compatible with surrounding residential areas [4].

Having described the dynamics of industrial substitution and relocation in Gipuzkoa, the state of the art and the current legal framework for urban regeneration are summarised. The hypothesis, objectives and delimitation of the case study are defined and the results are shown. Finally, the conclusions and proposals are presented.

As a methodology, consultation of the existing bibliography has served to know the state of the art and the bases previously established by other authors. The study of urban planning has served to identify the areas that have been destined or will be destined in the future for industrial uses and the field study to analyse the evolution and types of intervention applied in industrial areas, their current state and sustainability.

This communication is framed in the context of a broader research that consists of reflecting on the bases of a new urban paradigm that combines the conservation of industrial heritage, sustainable regeneration and circularity criteria. The aim is to highlight and make visible these areas as a territory of opportunity for the achievement of a compact and sustainable city.

2.Dynamics of replacement and relocation of industrial areas in gipuzkoa.

Gipuzkoa is a territory with a long industrial tradition, one of the main characteristics of its territorial and urban development and transformation. From the first hydraulic forges in the 12th century [5] and especially from the mid-19th century onwards, the industrial growth of Gipuzkoa had a notorious impact on the economic, social and cultural spheres of Basque society.
However, from the 1970s onwards, the industrial crisis and the reconversion of industrial activities, together with the effects on health and the environment and the growing presence of the service sector, led to the disappearance of most of the industries in the urban centres and the emergence of new ones far from the urban centres. This urban and territorial transformation had two fundamental consequences.

On the one hand, the loss of industrial heritage due to: the lack of social awareness of the heritage value of industrial facilities and the consequent lack of legal protection; the need for central land for residential redevelopment and the high profitability of such operations; the negative perception of industrial ruins as an “image of degradation” [6]. For the latter, the GV developed a demolition aid programme between 1992-2013 [7].

On the other hand, the notable segregation of uses by moving industry to the periphery. Zoning meant the elimination of industrial activities from urban centres. It separated population centres from businesses, favoured car-based urban mobility and facilitated the artificialisation of rural land. This strategy of urban sprawl has led to a diffuse and unsustainable city model.

3.Sustainable urban regeneration of industrial areas

3.1.State of the art.

The urban regeneration of industrial areas involves the study of concepts that have a direct or transversal impact on the urban transformation of the city and territorial planning. The main ones are briefly listed below.

First of all, with regard to urban growth, a report commissioned by the Club of Rome from MIT, Limits to growth (1972) [8], exposed the limited capacity of the planet to accommodate population and economic growth and the increase in the ecological footprint. It concluded that the dynamics of exponential growth were not sustainable and that the Earth would soon, within 100 years, reach the absolute limits of growth.

With regard to industrial evolution and the implementation of the circular economy, on the one hand, since the Industrial Revolution, advances in society have led to the transformation of economic activities, especially industry. Jeremy Rifkin, in The Third Revolution [9] and in recent conferences, argues that we have reached the post-carbon era, where humanity must confront climate change, caused in part by pollution from industrial activities, through an urgent transition to renewable energies and the use of hydrogen as energy storage. It points to the obsolescence of infrastructures and facilities based on the use of oil derivatives and fossil fuels. Internet technology will transform the electricity grid and enable grid-based energy distribution. In mobility, the transition towards electric motor vehicle transport is necessary.

On the other hand, the production system is originally a linear process that produces at the cost of generating waste. This has resulted in the consumption of natural resources and the deterioration of the environment. As stated by McDonough and Braungart in “Cradle to cradle” [10], the transition to a circular model is necessary, where effectiveness (reuse of waste) prevails over efficiency (reduction of waste). With regard to urban regeneration, it should be pointed out that in contrast to the sprawl or expansive strategy of the city, the transformation of the built urban fabric, and specifically the regenerative intervention of the pre-existing fabric, is a relatively recent type of intervention. Limited to productive fabrics, the bibliography is smaller in comparison with other areas.

Francisco López Groh [11] stands out as an author who has dealt with the urban regeneration of industrial areas in Spain. He defends the “return of small manufacturing to the city” to guarantee a city of mixed uses. He stresses the need for pilot experiences and public-private collaboration, public initiative and the participation of the Administration, citizens and different agents, as well as the creation of associative entities for the prevention of obsolescence. It proposes collective facilities related to sustainability and industrial symbiosis. Along the same lines, the recent publication “The Industrious City: Urban Industry in the Digital Age” [12] advocates the location of the original industrial zones in urban centres, for more sustainable mobility and energy consumption.

Regarding the sustainability of regenerative interventions, the contributions of authors Sergio Zubelzu and Roberto Álvarez [13] to the study of the carbon footprint of industry and the relationship between urban planning and sustainability are relevant. Municipalities could significantly reduce the industrial carbon footprint through urban planning. They note that the pattern of land use has a clear effect on the mobility of a metropolitan area. The employment mix is increasingly peripheral and disconnected from residential space, leading to an increase in private car travel, which contributes significantly to GHG generation and climate change, as well as to high energy consumption [14].

In the regeneration of industrial areas, nature-based solutions (NbS) are relevant [15]. The EC defines them as actions inspired by, based on or copied from nature, which use or improve existing solutions to address various environmental, social and economic challenges in a sustainable and efficient way [16]. These include soil phytoremediation, permeability of development through filter strips, tree lining, rain gardens and greening of plots of land. [17]

Finally, also noteworthy is the work of Álvaro Cerezo and Ignacio Tejerina in the study of urban management in the regeneration of industrial areas. A recent publication [18] identifies the difficulties that the current legal framework creates for regenerative action in these areas.

3.2. Legal framework.

Law 3/2015 on Housing states that the reduction of travel needs, the reduction of the demand for consumption of services and infrastructures and less intervention in the territory are essential lines of public action. It underlines the social cohesion inherent in the diversity of uses, on which building renovation and urban regeneration must be based.

It defines urban regeneration [19] as a process of public intervention that integrates aspects related to the environment and physical, urban, social and economic conditions and proposes alternatives to improve the quality of life of the population and the conditions of the building, urbanisation and facilities of an urban area or population centre. As opposed to urban renewal, which avoids environmental or social aspects and the pre-existence, regeneration is of an integral nature.

It establishes the figure of Urban Regeneration Areas (ARU) [20] as an urban or rural building complex whose delimitation is approved by the Basque Government at the request of the corresponding town council and which must be subjected to special action by the public administration in response to the need to update or adapt its urbanised or built heritage, as well as the socio-economic conditions of the population at which it is aimed. Thus, public intervention in regeneration actions is defined. However, to date, no specific public aid has been determined for the regeneration of ARU of industrial areas, so this figure has not been developed in the case of productive fabrics.

The Revision of the Spatial Planning Guidelines refers to the regeneration of productive fabrics and considers it necessary to reflect on the life cycle of industrial land, the analysis of the existing problems of obsolescence and the adoption of renovation and reform strategies to enhance its value and reuse [21]. It considers supra-municipal planning as an appropriate instrument for their delimitation. However, the areas of urban regeneration of industrial areas have not been territorially delimited and their study as an intervention has been left for a later date.

The Sectoral Territorial Plan for Economic Activities establishes for general planning revision processes and for specific modifications, that the reclassification of industrial land to new residential qualifications, once the impossibility of maintenance has been justified, must incorporate in parallel an equivalent area of new land for economic activities in the municipality or Functional Area [22]. This determination favours the dynamics of substitution and relocation of industrial activities to the periphery and therefore the expansion of urbanisation in the territory. Therefore, although the territorial instruments in force enable the regeneration of these soils, the practice differs and the results are not aligned with the SDGs.

Within the integral nature of regeneration as an urban intervention, the consideration of industrial heritage is relevant for sustainability, as it has an impact on sustainable development. The first definition of sustainable development is contained in the Brundtland Report (1987) [23], based on the environment, the economy and the social. Since then, more and more voices have claimed the need for a fourth pillar, culture. Subsequently, SDG11.4 [2] called for intensified efforts to protect the world's cultural and natural heritage in order to achieve goal 11.

At the TICCIH National Assembly [24], the Nizhny Tagil Charter on Industrial Heritage was adopted. In addition to defining industrial heritage, it pointed out its social value as a "record of life and thus the creator of an important sense of identity for men and women" and the need to consider its preservation in spatial planning.

Among the novelties of Law 6/2019, on Basque Cultural Heritage, are the specific provisions relating to industrial heritage. After its specific definition, it establishes the criteria for intervention, with protection and use being compatible, even promoting other destinations if they comply with the conditions of conservation and protection. It establishes levels of special, medium and basic protection, depending on the characteristics and value of the buildings. It also determines the intangible heritage and its protection.

Finally, new urban developments in areas of industrial regeneration are subject to the determinations of Law 2/2006 on Land and Urban Planning of the Basque Country and Decree 123/2012 on urban development standards. A minimum building occupation of 30% of the total surface area is established in Unconsolidated Urban Soil areas and Developable Soil sectors [25]. Also as a minimum, a reserve of land for public facilities of the local systems network of no less than 12% of the total area of the sector [26]. The achievement of endowments, green areas, open spaces and car parks for areas in Unconsolidated Urban Land requires at least a land reserve equivalent to 6% of the surface area of the area (half of which may be used for public car parks) and the planting of one tree for every 100 m2 increase in building [27].

4.Hypothesis, objectives and delimitation of the case study.

The main objective of this research is to test whether the same dynamics of substitution of industrial activities by residential developments in urban centres, moving and locating industry to the periphery, together with the loss of part of the industrial heritage and the territorial segregation of uses, have been followed in the study area. If confirmed, this could point to future lines of research for sustainable urban regeneration solutions.

In terms of territorial delimitation, the study area covers Donostia and Pasajes, in Gipuzkoa, in the north of the Basque Autonomous Community. The former, with 182,088 inhabitants [28], is the capital of the province and the head of the region. The second, with 16,612 inhabitants [29], is a port municipality whose proximity to the capital has given rise to various synergies over time. At the beginning of the 19th century, the port of Pasajes emerged as a viable alternative to that of Donostia, whose limited capacity made it unsuitable for the transport of goods. From that time onwards, the whole of the bay of Pasajes was developed for port use. At present, the port industry and its auxiliary industries are the only ones located in the municipality and the urban extension of the capital to the east forms a residential urban continuum with Pasajes.

In the study area, 39 urban areas have been identified, which are those destined or which will be in the future, according to planning, for industrial use. 30 in Donostia and 9 in Pasajes.

With regard to the delimitation of the parameters studied, the following are to be found.

Location: central, peri-urban or peripheral. Centrally located areas are those in urban centres and peri-urban areas are those located on the edge of the city, close to urban centres and/or bordering on non-development land. Peripheral areas are those located in non-urban territory or close to smaller population centres, of a strategic nature or with accessibility to transport.

The surface area of the area, the year of industrial implantation and the urban planning in force.

The type of land, urban or developable, according to the Land Law 2/2006. The existence of industrial heritage and, if applicable, the legal protection it enjoys.

Functionality in relation to its accessibility conditions and the provision of open spaces, equipment and parking. Mobility according to the type of transport by which the area is accessed, with preference given to pedestrian routes, public transport or bicycles, as opposed to private fossil fuel vehicles.

For the state of urbanisation and building, 5 levels have been determined, depending on the current conditions, as well as the degree of industrial activity.

Finally, the original uses, the current uses and those established by the current planning and the public or private ownership of the properties.

5.Results

The case study has produced the following results, which differ from one municipality to another.

On the one hand, in Donostia, 26.67% of the industrial areas are located in urban centres, although more than half of these have already been replaced by residential fabric and the rest have the same destination according to the current planning. 40% of the areas are peri-urban, of which almost half are also destined to disappear as industrial use. The peripheral areas (33%) are reserves for the future, almost half of which have not yet been fully implemented.

The peripheral areas correspond to recent or future developments and have not been reclassified as residential. Therefore, in terms of the number of areas, almost half have residential use according to current planning and in a third of them this has already materialised.
It is worth mentioning here, due to its exceptional nature, the modification of use currently being processed in the PAPIN urban development area, reconsidering the residential development to which it is destined by the General Urban Development Plan (PGOU) in force and maintaining the current industrial use, which declares the area an Urban Regeneration Area (A.R.U.). Although it is noteworthy, this is a single case that has not yet been approved or materialised, so it does not affect the overall result.
In terms of surface area, the more distant the areas are from the urban centres, the greater the increase. Taking into account the surface areas earmarked for industrial uses by planning, the total peripheral surface area with 2.170.382 m2 is notably greater than the central area (22.186 m2, which is expected to be modified to residential) and the peri-urban area (890.054 m2). The peripheral intervention of Eskuzaitzeta stands out, a strategic territorial implantation, with a clearly larger surface area than the rest (1.052.528 m2) and located on the periphery.
In terms of the year of implementation of the areas, the peripheral ones are generally more recent than the central ones (40s-70s). Most of the land is urban and the land for development corresponds to the peripheral areas that have not yet been fully developed.
The industrial heritage has been located mainly in central areas corresponding to the aforementioned period. According to available sources, 40% of the areas studied had heritage of interest but without legal protection. The protected elements, which are those that are preserved, are three, the Gas Factory in Morlans with Special Protection and Tabacalera in Eguía and Norbega S.A. in Recalde II, with basic protection according to the PEPPUC of Donostia.
In general, the state of urbanisation and building is basic or deficient in areas with industrial uses in use, except in those recently created on the periphery or in periurban areas. The more central the location, the more deficiencies. The same applies to the degree of activity; in urban centres the use is residual, underused or abandoned, awaiting residential transformation.
In terms of original, current and planned uses, 60% of the total areas have been industrial and 33.3% are located on land that was not originally developed. However, 40% is currently used for industrial purposes and, according to planning, this will be reduced to 33.3% in the future, as 43.3% will be reclassified as residential land.
The industrial areas are privately owned, except for Eskuzaitzeta, part of which is publicly owned.

Sheet nº	Urban area	Location	Surface area	Year of establishment	Land classification	Industrial Heritage	State of urbanization	State of buildings	Act. level%	Origin use	Current use	Use in planning	Property
D-001	AL.02.01 TXINGURRI	CENTRAL	34.303,00	1960 - 1970									
D-002	AL.04. LARDI ALDE	CENTRAL	40.972,00										
D-003	AL.05. JOLASTOKIETA	CENTRAL	22.186,00	1957								*	
D-004	AL.12.01. SASUATEGI	CENTRAL	34.885,00	1940									
D-005	AL.14. PAPIN	PERI-URBAN	33.068,00	1960 - 1970								**	
D-006	AL.19. LANDARRO	PERIPHERAL	313.991,00	SIN EJECUTAR									
D-007	AM.09 MORLANS BEHEA	CENTRAL	105.744,00	<1945 IND/2005 RES									
D-008	AÑ.03.01 AÑORGAKO GELTOKIA	PERI-URBAN	32.265,00	1955 IND/2021 RES									
D-009	AÑ.04. CEMENTOS REZOLA	PERIPHERAL	105.512,00	1901									
D-010	AÑ.08 RECALDE I	PERIPHERAL	39.162,00	1957									
D-011	AÑ.09 BELARTZA I	PERIPHERAL	151.354,00	1998									
D-012	AÑ. 10. RECALDE II	PERIPHERAL	24.053,00	1950									
D-013	AÑ.12. ZUATZU	PERI-URBAN	137.923,00	1990									
D-014	AÑ. 13. BELARTZA II	PERIPHERAL	222.270,00	SIN EJECUTAR									
D-015	AO. 06. BENTA BERRI	CENTRAL	175.438,00	<1945 IND/1995 RES									
D-016	EG.03. TABACALERA	CENTRAL	27.769,00	<1945 INDS/ RES S.E.									
D-017	EG.18. ALDUNAENE	CENTRAL	26.722,00	1955 IND/2013 RES									
D-018	IB.13. IGARA	PERI-URBAN	265.286,00	1970								***	
D-019	IB.22. INFIERNO	PERI-URBAN	66.165,00	<1945 IND/2021 RES									
D-020	LO.05. TXOMIN ENEA	PERI-URBAN	163.525,00	1995 IND/2011 RES									
D-021	MA.01. ANTZITA	PERI-URBAN	87.151,00	<1945 INDS/ RES S.E.									
D-022	MA.02. TORRUA ZAHAR	PERI-URBAN	211.405,00	1960									
D-023	MA.03. MATEO GAINA	PERI-URBAN	53.141,00	2009									
D-024	MA.06. SARRUETA	PERI-URBAN	79.192,00	1970 IND/2020 RES									
D-025	MA.08. ANTONDEGI	PERI-URBAN	222.299,00	SIN EJECUTAR									
D-026	MZ.02. MIRAMON	PERI-URBAN	566.306,00	1995									
D-027	ZU.05 BUGATI	PERIPHERAL	71.274,00	SIN EJECUTAR									
D-028	ZU.06 MERCABUGATI	PERIPHERAL	28.467,00	2000									
D-029	ZU.07 CTRO TRNS. ZUBIETA	PERIPHERAL	161.771,00	2004									
D-030	ZU.08 ESKUZAITZETA	PERIPHERAL	1.052.528,00	2010									

* JOLASTOKIETA: Agreement for industrial development. Industrial in General Urban Development Plan.

** A Modification of General Urban Development Plan is currently being processed to maintain the current industrial use of PAPIN.

***A Modification of General Urban Development Plan is currently being processed for the residential rezoning of the DIARIO VASCO's urban parcel.

Land classification		
Urban land	Developable land	non-developable

Industrial Heritage				
uninteresting	with interest (no protection)	basic prot.	medium prot.	special prot.

State of urbanization					
optimum	good	basic	deficient	very deficient	non executed

State of building					
optimum	good	basic	deficient	very deficient	non executed

Activity level					
100%	75%	50%	25%	0% abandoned/without use	non executed

Origin use				
Non-developable land	industrial	tertiary	residential	infraestructure

Current use				
Non-developable land	industrial	tertiary	residential	infraestructure

Use in planning				
Non-developable land	industrial	tertiary	residential	infraestructure

Property	
public	private

Figure 1. Overview chart and legend. Author's own elaboration, 2022.

On the other hand, in Pasajes, the location of the port industry is linked to the seafront and has not changed. However, its building transformation has led to the loss of part of its built heritage. Currently, only the Jaizkibel Dredger is protected, having been classified as a monument in 1992, which has allowed it to be preserved and used as the Albaola shipyard-museum. Data has been collected in the rest of the areas for 13 elements of heritage interest according to available sources. Ownership corresponds to the port authority, a State body.

TYPE	SUBTYPE	Cult. Heritage's typification	Nº of urban areas	Urban area
I	A	P.E.	0	
		P.M.	0	
		P.B.	0	
		C.I.	4	AL.02.01. TXINGURRI
				AL.05 JOLASTOKIETA
				AL.12.01. SASUATEGI
				HERRERA NORTE
		S.I.	1	EG.03. TABACALERA*
	B	P.E./P.M./ P.B./C.I./S.I.	0	
II	A	P.E./P.M./ P.B.	0	
		C.I.	3	AL.14. PAPIN
				IB.13. IGARA
				MA.02. TORRUA ZAHAR
		S.I.	5	IB.22. INFIERNO
				AÑ.03.01 AÑORGAKO GELTOKIA
				MA.06. SARRUETA
				MA.01. ANTZITA
				MA.03. MATEO GAINA
	B	P.E./P.M./ P.B./C.I./S.I.	2	MZ.02. MIRAMON
				AÑ.12. ZUATZU
III	A	P.E./P.M./ P.B.	0	
		C.I.	2	AÑ.10. RECALDE II
				AÑ.02. CEMENTOS REZOLA
		S.I.	1	AÑ.08. RECALDE I
	B	P.E./P.M./ P.B./C.I./S.I.	5	ZU.05. BUGATI.
				ZU.06. MERCABUGATI.
				ZU.07. CTRO. TRS. ZUBIETA
				ZU.08. ESKUZAITZETA
				AÑ.09. BELARTZA I

*In terms of heritage, the building is not considered listed, as it has been the object of a previous intervention.

Note: those that have already been executed as residential (5) and those that have not been converted to industrial (3) have been excluded.

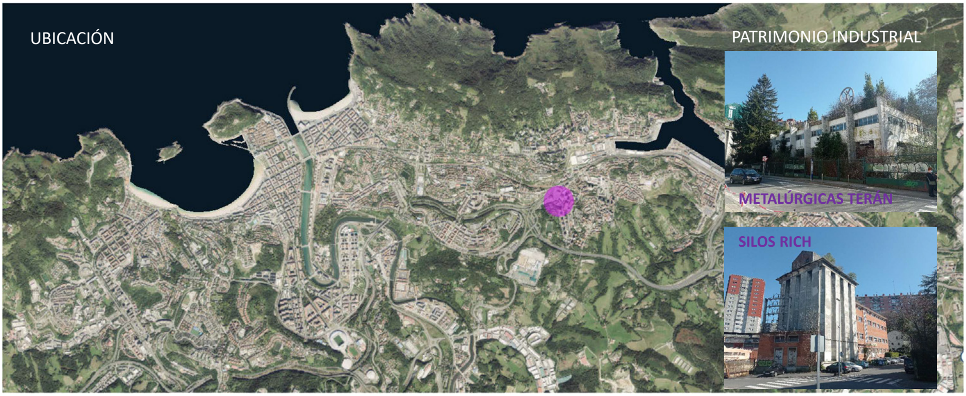
TYPE	LOCATION
I	CENTRAL
II	PERI-URBAN
III	PERIPHERAL

SUBTYPE	STATE OF URB. and/or BUILD.
A	not executed
	Very deficient
	Deficient
	Basic
B	Good condition
	Optimal condition

Cult.l Heritage's typification	Protection
P.E.	Special protection
P.M.	Medium protection
P.B.	Basic protection
C.I.	With heritage interest
S.I.	Without heritage interest

Figure 2. Selection table. Author's own elaboration, 2022

As a final result, 4 areas are preferential for urban regeneration; 3 in Donostia and 1 in Pasajes. The determining factors for the choice are: the central location, the basic or deficient state of the urbanisation/building and the existence of catalogued industrial heritage/interest.



AL.02.01. TXINGURRI

Superficie: 34.303 m²

Ubicación próxima a Pasajes y Pasai Antxo.

Primeras industrias implantadas en años 60.

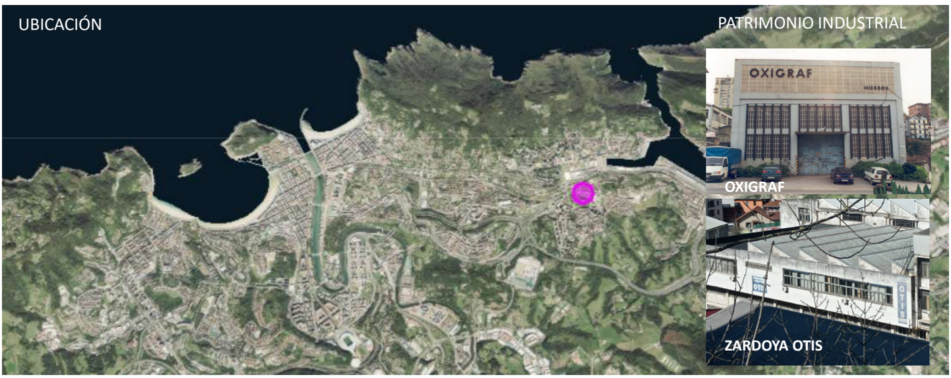
Planeamiento destina a residencial la zona más prxóima al barrio.

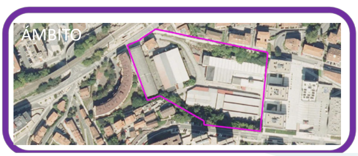
Edificios industriales infrautilizados y parcelas vacantes tras derribos.

Patrimonio industrial de interés sin protección.

AL.02.01. TXINGURRI	
ASPECTO	**INDICADOR**
Ubicación	I - CÉNTRICO
Superficie	34303 m²
Año de implantación	1960-1970
Clase de suelo	URBANO
Patrimonio industrial	de interés (no protegido)
Funcionalidad	básico
Movilidad	básico
Estado urbanización	deficiente
Estado de la edificación	deficiente
Grado de actividad	25%
Uso en origen	industrial
Uso en la actualidad	industrial
Uso en planeamiento	residencial
Propiedad parcelas	privada

Figure 3.1. Txingurri.





AL.05. JOLASTOKIETA

Superficie: 22.186m²

Ubicación próxima a Pasajes, al sur de Paseo de Herrera.

Primeras industrias implantadas en años 60.

Planeamiento mantiene uso industrial, pero convenio entre propiedad y Ayto SS para modificación, traslado y recalificación residencial.

Patrimonio industrial que podría tener interés y está sin protección.

AL.05.JOLASTOKIETA	
ASPECTO	**INDICADOR**
Ubicación	I - CÉNTRICO
Superficie	22.186 m²
Año de implantación	1957
Clase de suelo	URBANO
Patrimonio industrial	de interés (no protegido)
Funcionalidad	básico
Movilidad	básico
estado urbanización	deficiente
estado de la edificación	básico
grado de actividad	50%
uso en origen	industrial
uso en la actualidad	industrial
uso en planeamiento	industrial *
propiedad parcelas	privada

Figure 3.2. Jolastokieta.

AL.12.01. SASUATEGI

Superficie: 34.885m²

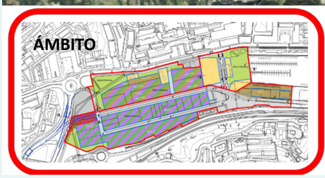
Ubicación limítrofe con Pasai Antxo.

El PGOU vigente destina el subámbito a usos residenciales.

Patrimonio industrial de interés sin protección.

A.12.01. SASUATEGI		
ASPECTO	INDICADOR	
Ubicación	I - CÉNTRICO	
Superficie	34.885 m²	
Año de implantación	1940	
Clase de suelo	URBANO	
patrimonio industrial	de interés (no protegido)	
Funcionalidad	nula/sin ejecutar	
Movilidad	básica	
Estado urbanización	sin ejecutar	
Estado de la edificación	muy deficiente	
Grado de actividad	0% abandonado	
Uso en origen	industrial	
Uso en la actualidad	industrial	
Uso en planeamiento	residencial	
Propiedad parcelas	privada	

Figure 3.3. Sasuategi.



LA HERRERA

Superficie: 50.327 m²

Ubicación céntrica en Pasaia.

Se destina a usos complementarios portuarios y para la interacción puerto-ciudad según la Revisión del Plan Especial de Ordenación de la zona de servicio del Puerto de Pasaia.

Patrimonio industrial de interés sin protección.

LA HERRERA		
ASPECTO	INDICADOR	
Ubicación	I - CÉNTRICO	
Superficie	50.327 m²	
Año de implantación	ppios SXIX	
Clase de suelo	URBANO	
patrimonio industrial	de interés (no protegido)	
Funcionalidad	básica	
Movilidad	básica	
Estado urbanización	deficiente	
Estado de la edificación	deficiente	
Grado de actividad	25%	
Uso en origen	industrial	
Uso en la actualidad	industrial	
Uso en planeamiento	residencial	
Propiedad parcelas	privada	

Fig 3.4. La Herrera.

6.Conclusions and proposals.

The main conclusion confirms the hypothesis put forward at the beginning in Donostia; the main trend has been the replacement of industrial activities by residential developments in urban centres, transferring and locating industry to the periphery. No urban regeneration interventions have been carried out in industrial areas. This expansive dynamic has made it difficult to mix uses, favouring the segregation and artificialisation of peripheral land, and relocating industry to the southwest of the city.

Figure 4. Image of the city of Donostia with industrial zones to the south-west. Author's own elaboration, 2022

In Pasajes, the pattern is different; industry is a port infrastructure of general interest belonging to the State. This has marked its maintenance and development, with special funding from the Administrations for the execution of various actions for the integral regeneration of Pasaialdea (Adinberri, the New Fish Market, etc.). This condition is not comparable to the rest as it is a particular case of regeneration.

Figure 5. Image of Pasajes with industrial areas. Author's own elaboration, 2022

The loss of industrial heritage is confirmed. In Donostia, only three elements have been catalogued, having detected the existence of buildings of heritage interest in all the areas of urban centrality. Legal protection has made the conservation and reuse of these heritage elements possible. In Pasajes, one element has been protected and a large part has disappeared.
The segregation of uses has also been influenced in both municipalities. In Donostia, by eliminating the productive fabric of the urban centre and transferring it to the south-west. In Pasajes, except for industry in its port location, the rest is mainly residential.
Therefore, the expansive tendency of the city and the occupation of the territory by urbanisation is still in force in territorial and urban planning. To reverse this dynamic, it is necessary to face the opportunity of a sustainable intervention on the existing city through urban regeneration. To this end, based on criteria and concepts reviewed in the state of the art, the following is proposed.

From a general perspective:

-Address urban regeneration interventions in industrial areas from a metropolitan and territorial scale. Both from the PGOU or PC, as well as from territorial figures. A revision of the current PTS of AAEE should prioritise the regeneration and optimisation of central industrial land as opposed to the artificialisation of the periphery, questioning the possibility of requalifying central areas for residential use and determining the regulations for industrial regeneration actions.
-Draw up an inventory of industrial zones and their classification based on different parameters, among which the location, the state of buildings and urban development, the existing industrial heritage and the functionality and mobility of the areas will be determining factors.
-Promote the mixture and diversity of uses in urban centres, favouring the relationship and proximity of residential and productive uses.
-Prior to the transformation and urbanisation of land in the periphery, regenerate and optimise preferably the central or peri-urban industrial areas, intensifying their use and buildability as far as possible.
-Integrate the study, conservation and reuse of industrial heritage in urban regeneration.
-Create pilot experiences to detect specific difficulties, advance in regeneration processes and configure a catalogue of good practices.
-Integrate public-private collaboration and the participation of different agents.
-Promote associative figures of resident companies for the prevention of degradation.
-Promote the initiative and participation of public administrations in the process and subsequent monitoring.
-Incorporate BDS, community renewable energy installations and energy efficiency.
-Adapt the legal framework to the regeneration of industrial fabrics.

The regeneration of selected industrial areas, in addition to the impact on the area and its surroundings, has an impact on a larger scale, favouring the territorial balance of productive uses currently concentrated in the south-west of Donostia.

From a detailed urban perspective, it is proposed:

In Txingurri, Jolastokieta and Herrera Norte, to maintain the industrial activity compatible with the residential uses of the surroundings, as well as the conservation, integration in the new development and reuse of the industrial heritage of interest. Generation of local employment and improvement of accessibility to the neighbourhood. Resolution of the shortcomings of the residential area through the provision of green areas, public spaces and car parks. The incorporation of NbS (e.g.: trees in line, permeability of soils, phytoremediation for decontamination of vacant plots until their definitive use), together with energy efficiency and community provisions for the generation of renewable energies.

In Sasuategi to conserve and enhance the industrial heritage of the Luzuriaga building. The recovery of the half-buried part of the ground floor façade and the integration of the building into the urban development and residential fabric, improving the urban quality of Eskalantegi street and its surroundings. In view of its surface area, in addition to public uses, the possibility of implementing smaller industrial activities adaptable to the building can be studied, leaving the rear slope for green areas and public spaces. The integration of NbS, energy efficiency and community generation of renewable energies in buildings of heritage value is presented as a line of future research.
Finally, it is worth considering circularity criteria in the selected areas, both in the building actions and in the activity itself. The possibility of industrial symbiosis between regenerated areas, so that the waste from some can be used for the production of others, is another possible line of research.
In conclusion, this study points to the need for a methodology that will be worked on in the future for the enhancement and protection of obsolete industrial fabrics in the CAPV, defending the practice of urban regeneration based on the SDGs and the concepts analysed in the state of the art.

7.References.

[1] UN Conference on Housing and Sustainable Urban Development, Habitat III. Quito, Ecuador, 20-10-2016.
[2] Sustainability Goals. Accessed 18-06-2022:https://ggim.un.org/documents/A_RES_71_313.pdf
[3] Integrated Urban Regeneration has been, to date, a regeneration action aimed mainly at residential neighbourhoods in vulnerable situations.
[4] Industries (CNAE 2009) of 1st, 2nd and 3rd category, according to Appendix 1 - Classification by categories of industrial uses in terms of discomfort and effects on health and the environment of the Development of the Third Final Provision of Law 2/2006 on Land and Town Planning of the Basque Country. Standardised classification of land uses.
[5] M. Urteaga Artigas. El homo faber (I). La cultura del hierro en el País Vasco: de don Julio Caro Baroja a la actualidad. Cultura y patrimonio de los pueblos de España. Ministerio de Cultura y Deporte, Madrid, 2019. Pp 86-107.
[6] Decree 75/1998, on subsidies for the drafting or execution of industrial ruins (BOPV 07-05-1998).
[7] Total of 21.205.463,14€. Accessed on 18-06-2022: https://www.euskadi.eus/ruinas-industriales/web01-a2lurral/es/
[8] D.H. Meadows. The Limits to Growth. Universe Books. New York, 1972. DOI 10.1016/B978-0-444-63768-0.00630-2
[9] J. Rifkin. La tercera revolución industrial: cómo el poder lateral está transformando la energía, la economía y el mundo. Paidós. Barcelona, 2011.
[10] W. McDonough, M. Braungart. Cradle to cradle: Remaking the Way We Make Things. North Point Press. New York, 2002.
[11] F. López Groh. La regeneración de las áreas industriales. SEPES Ministerio de la Vivienda, Madrid, 2011.
[12] H. Hosoya, M. Schaefer. The Industrious City. Urban Industry in the Digital Age. Lars Müllers Publishers, Zürich, 2021.
[13] S. Zubelzu, R. Álvarez. Urban Planning and industry in Spain: A novel methodology for calculating industrial carbon footprints. Energy Policy nº83 (2015) 57-68.
[14] A. Leboreiro Amaro. Occupation of the Territory and Sustainability in Transport in Madrid. Carbon Footprint and the Industrial Life Cycle. R. Álvarez Fernández et al. (eds.), Green Energy and Technology, Springer International Publishing AG 2017, pp 107-155. DOI 10.1007/978-3-319-54984-2_6
[15] M. Masiero, A. Biasin, G. Amato; F. Malaggi, D. Pettenella, P. Nastasio, S. Anelli. Urban Forests and Green Areas as Nature-Based Solutions for Brownfield Redevelopment: A Case Study from Brescia Municipal Area (Italy). Forests 2022, 13, 444. https://doi.org/ 10.3390/f13030444
[16] Nature-Based Solutions & Re-Naturing Cities. CE, 2015.
[17] M. R. del Caz Enjuto, S. Fernández Marín, I. Méndez Tovar.Aplicación de Soluciones basadas en la Naturaleza en áreas industriales para su contribución a la adaptación y mitigación del cambio climático. CONAMA 2020

[18] A. Cerezo Ibarrondo, J.I. Tejerina-González. La regeneración de los tejidos productivos, técnicas para el otro gran reto de la intervención urbana. Práctica Urbanística nº176 (2022).
[19] Art 3. ñ) Law 3/2015 on Housing (BOE 13-07-2015).
[20] Art. 3.b) Law 3/2015 on Housing (BOE 13-07-2015).
[21] Section 6.4. of the Report of the Revision of the DOT (Decree 128/2019, of 30 July).
[22] Art. 10.2. Planning Regulations. PTS de AAEE. Consulted 18-06-2022: https://www.euskadi.eus/contenidos/informacion/ptsa_original/es_def/adjuntos/texto/punto_8_mod_c.pdf
[23] "Development that meets the needs of the present without compromising the ability of future generations to meet their needs".
[24] TICCIH Moscow 17/07/2003 (TICCIH world organisation in charge of industrial heritage and special advisor to ICOMOS).
[25] Art. 77.5. Law 2/2006 SyUPV.
[26] Art. 79.3. Law 2/2006 SyUPV.
[27] Art.6.2. Decree 123/2012 on urban development standards.
[28] Eustat data. Consulted 20-08-2022:https://www.eustat.eus/municipal/datos_estadisticos/donostia_san_sebastian_c.html
[29] Eustat data. Consulted 20-08-2022:https://www.eustat.eus/municipal/datos_estadisticos/pasaia_c.html

Rethinking Summer Energy Poverty from the South: debates and frontiers of an overlooked issue

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Key Words: Summer Energy Poverty, methodologies, Urban Heat Island, Health plans, heatwaves, passive.

Abstract

Summer Energy Poverty is becoming a more concerning issue in southern European countries. Besides the growing interest in monitoring heatwaves and implementing prevention plans for vulnerable population, different municipalities have driven specific analysis of the Urban Heat Island (UHI) phenomenon and promoted projects for its mitigation. Scientific literature has grown in the last decade on topics such as urban microclimate, passive urban cooling or assessing dwellers adaptability to high temperatures. However, there is still a gap between scientific knowledge and local policies when dealing with overheating, especially targeting people under summer energy poverty conditions and promoting mitigation measures. This work aims to bridge this scientific and policy knowledge gap by gathering existing methodologies and approaches to summer energy poverty in the context of Southern Europe.
A collaborative collection and revision of nearly 200 resources was conducted from Italy, Greece, Bulgaria and Spain by screening, examining and incorporating the main ideas, current debates, as well as limitations and frontiers in summer energy poverty related issues. Three different approaches were identified within the documents to develop a common framework for southern EU countries:
• Resources that incorporate technical discourses: exploring UHI or simulating cooling needs and building/urban performance.
• Resources that explore the socio-economic dimension: including thermal comfort adaptive approach and qualitative research methods to explore lived experience in relation with the heat.
• Resources focused on health and recommendations for heat waves events.
Results show that, although authorities have developed local plans to tackle summer vulnerability and energy poverty as a whole, a cross-sectional vision is needed in order to incorporate scientific knowledge focused on summer conditions. By doing so, specific indicators related to UHI, building and urban characteristics should be defined to better address summer energy poverty characterization.

1. Introduction

A household is considered to be in energy poverty when it cannot access basic energy services to maintain the dwelling in habitable conditions. Energy poverty occurs as a consequence of the low energy efficiency of buildings, high energy prices and low households' income. Traditionally, the phenomenon has been studied more closely linked to winter conditions, due to the associated heating costs and because it is a subject of study initiated in Anglo-Saxon countries with colder climates [1] [2]. In southern European countries, however, according to the latest Eurostat survey (2012), more than 20% of households state that they are unable to keep their homes in comfortable conditions in summer. This situation is expected as heat waves increase their intensity and frequency due to climate change [1] [3].
Summer energy poverty (SEP) is associated with significant health risks. In recent years, mortality associated with heat waves has increased [4], leading to greater interest and development in research related to the microclimatic performance of urban environments and specific summer conditions [5] [6]. It is also notorious the appearance of successive action plans at the municipal level to deal with heat waves and address the problems of vulnerability of the population. However, there is a gap between scientific knowledge between urban microclimate and summer energy poverty assessment methodologies, and urban planning practices and municipal prevention plans.
Although in recent years the scientific knowledge applied to the study of SEP has increased, it is still insufficient and the findings derived from these studies are still premature [7]. In addition to its incipient nature at the academic level, its implementation in the development of policies and action plans is even lower. It enjoys little representation at the European level [2] and the existing catalogues of measures to improve comfort in high temperatures are very brief. In this sense, they fail to integrate scientific advances and academic dissemination into practice [8]. Furthermore, SEP is limited to certain latitudes and is not associated with other possible geographies, which increases the imbalance of knowledge and characterization of the problem between different regions [9]. However, as noted below, we find some 'green shoots' in terms of integrating the phenomenon into public plans and policies.
This communication summarizes a report carried out in the framework of the Cooltorise project, in which a compilation of the body of knowledge on urban microclimate, heat experiences and characterization of summer energy poverty in four southern European countries was carried out, with the aim of identifying the state of the art, fundamentals and areas of development, for subsequent public presentation.

Notes:
COOLTORISE – Raising summer energy poverty awareness to reduce cooling needs, is a Coordination and Support Action financed by the European Commission under the H2020 Call Mitigating household energy poverty (H2020-LC-SC3-EC-2-2020). The original document corresponds to the deliverable D1.1 – Methodological action framework: energy poverty definition, understanding and policy framework and summer energy poverty specificities. This paper presents a summary of that deliverable.

2. Methodology

2.1. General description

A collaborative collection and revision of nearly 150 resources was conducted from Italy, Greece, Bulgaria and Spain by screening, examining and incorporating the main ideas, current debates, as well as limitations and frontiers in summer energy poverty related issues. It is a subject that is still poorly addressed, whose scientific research development is still premature. However, the increase in the intensity and frequency of heat waves has resulted in the proliferation of heat control plans. For this reason, the document collection was not limited to scientific sources, but covered all official documentation dealing with any of the aspects that conform SEP (i.e. scientific papers, research projects and/or plans and policies). The collaboration of the different entities of the participating countries favoured a greater diversity of documents as well as overcoming language barriers.

2.2. Compilation of documents

All the project consortium members were asked to contribute to a common database with the found documents related to summer energy poverty or any other documents that would contribute to stablish the initial framework within their territory. By sharing a common database, members were asked to specify for each document its name, year of publication, short characterization -a triple choice question for identifying methodologies, reports or health and energy plans- and whether the document had a local focus or not. The search engines used were Scopus, ResearchGate and Google Scholar. For plans and policies, a specific research was carried out in the websites of the participant municipalities. The keywords used are listed in Figure 1. This first exercise was committed to incorporating different views from different countries, considering that it would have been more challenging to assess documents in a foreign language for a single member and taking advantage of the consortium diversity, also in terms of specialization.

After a first round, more than 120 documents were collected, ranging from scientific papers, guides and manuals, to plans and policies in the contexts of Spain, Italy, Greece and Bulgaria. A first screening process was performed in order to evaluate the correct classification of the documents in the different countries. Apart from these types of documents, a list of research projects being carried out in the European context and focusing on similar topics was incorporated into the database. The identified projects were related to vulnerable population suffering thermal stress, climate change in the city, financial education to tackle energy poverty, energy saving plans, identification of poor households, and tailor-made solutions to improve SEP situations.

This first process resulted in a wider variety of studies, scales and outcomes. First research lines when identifying a methodology for assessing SEP were drafted, which enabled the review to be structured according to 3 big families of approaches, taking into consideration the sub-tasks previously announced:

-Approach 1: Summer energy poverty methodologies.
-Approach 2: Urban climate and building characterization.
-Approach 3: Health and policies.

Approach 1	Approach 2	Approach 3
Adresses energy poverty characterization and/or social dimension of urban overheating, i.e. vulnerable population targetting.	**Adresses** urban thermal characterization, building summer energy simulation or urban cooling needs and strategies.	**Adresses** overheating risks, action plans and/policies related to health and thermal stress.
Keywords: Vulnerability, indicators, energy poverty, incomes, population, adaptability, comfort, summer	**Keywords:** Microclimate, urban, simulation, efficiency, modeling, Urban Heat Island, cooling strategy	**Keywords:** Heatlh, public, policies, heatwaves, alarm, prevention.

Figure 1. Compilation of documents and distribution according to approach.

2.3. Categorization of documents

For each approach, an analysis sheet was created for every approach, in order to evaluate the contributions made by the project partners (Figure 2). Regarding urban climate and building characterization approach, they were mainly quantitative and focused on the urban microclimate and UHI characterization, temperatures and humidity measurements, and the evaluation of different cooling strategies. Within SEP methodologies approach, the body of knowledge mainly targeted energy poverty indicators in the EU context, with papers focusing on adaptability of users under overheating, and interviews and surveys, conformed by qualitative research and closer to ethnography and social studies. Finally, and on a general basis, policies and health plans documents focused on heatwaves events, as well as on energy consumption and vulnerable population. No specific plans for tackling summer energy poverty were found, but some approaches were significant. These documents presented a higher level of integration of various factors related to summer energy poverty: the microclimatic conditions of the city, building conditions, passive cooling measures, energy use and income level by neighbourhood .

In order to analyse the documents and with the objective of establishing first comparisons and provide an argumentative structure for the report, a series of categories were created. First, categories were created related to: the seasonality referred to in each document, to identify those oriented to summer conditions; the location of the document, to identify those from southern latitudes of Europe; and the type of document, among the three variables introduced by the collaborators.

Second, other categories allowed to disaggregate the results and to have more precise information that would allow better comparisons between similar documents and the structuring of the report. Three families of categories were created: nature of the document, methodologies present in the document, and the presence or not of a specific focus. Within the nature of the documents, it was possible to differentiate repositories, guides, evaluations, reviews and case studies. Among the methodologies, four subcategories were created: use of data, policy analysis, simulation and modelling, and qualitative studies (surveys, questionnaires, interviews, etc.). Finally, within the specific focus category, five fields were identified: material performance, simulation and/or monitoring of the Urban Heat Island, local public health needs, gender perspective and focus on the covid-19 context.

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[3] The documents we refer to are climate change adaptation plans with a focus on vulnerable population, as in the case of Barcelona, the Action Plan for the climate emergency 2030, (Barcelona Municipality, 2021). In the case of Madrid, Madrid Recupera plan (Madrid Municipality, 2018) presented an attempt to prioritize vulnerable areas that are overexposed to thermal stress for the creation of green and fresh corridors, among other adaptation measures.

Approach 1: Summer energy poverty methodologies

	CAT. PROCESS (1)					CAT. PROCESS (2)													
Ref. Number	Location			Time period		Nature					Method				Focus				
	SE	E	NE	SU	YE	R	G	E	CS	RW	D	P	S	Q	GN	VP	MP	UH	HN
[1]		•		•		•													
[4]			•		•									•					
[10]			•	•					•										
[13]	•			•					•										
[14]			•	•					•					•					
[15]			•	•					•		•								
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[32]			•	•			•				•			•					
[35]			•		•								•						
[37]			•	•									•					•	
[38]			•	•					•				•						
[42]			•	•				•						•					
[44]			•	•					•		•								
[45]				•									•					•	
[46]	•				•								•						
[55]	•				•				•				•						
[58]	•				•				•		•			•					
[71]	•			•		•		•				•							
[72]	•				•							•					•		
[74]	•				•			•											
[85]		•		•				•			•		•	•					
[96]		•			•					•									

Figure 2. Analysis matrix for Approach 1. The array distribution facilitates to evaluate correspondences and similarities

3. Results

In terms of general characterization, a predominance of documents not concerning specifically summer conditions were identified. This fact, although it could be seen as a weakness, wasn't considered so as many of the documents that referred to the whole year where specifically structured attending also to summer conditions, but not only [10]. For example, thermal comfort evaluation or building performance simulations consider separately both winter and summer seasons. Studies mainly followed technical or sociological approaches, with less presence of health and policies related topics. It was identified a certain bias across the contributions from partners, being more prone to incorporate documents closer to their speciality. This was again not considered as a limitation, as the consortium is integrated by different experts from different fields, and the collection exhibited that diversity. Considering the type of documents consigned by the partners (plans, reports and methodologies) it was identifiable a generalized determination of the methodologies type. This circumstance was related to the fact that the other two options (reports or plans) are easier to identify, while methodologies are not presented normally as so, but appear in different studies and formats. Regarding the location of the documents, an equilibrated division was found between south of Europe (generally integrated by texts from the consortium countries) and those for the whole European territory. Less documents were found that specifically pointed to other parts of the planet or to the world as a whole.
In addition, a second characterization exercise made it possible to identify predominance of case study documents among other types, such as repositories, guidelines or general evaluations. The characterization of the nature of the document was key to understand the diversity of information gathered after the call for contributions. Case studies were generally related to scientific papers, offering up-to-date knowledge on specific fields and experiments.

Despite the high number of case studies founded, repositories were considered especially relevant for their content, in which specific plans and policies from European countries were indicated. When analysing methodologies present in the available documents, it is relevant to note that many of the documents with a technical approach used simulations as methodology to address the objectives of the study. Many other documents, especially those related to sociological or political approach, used data and statistics for the specific contents. Special analysis on political issues was found less often, and methodologies to target specific population (for example, vulnerable or exposed to heat) were found the least. When analysing specific focus on each document, a predominance of technical characteristics was found, expressed in UHI focused documents, as well as those related to building simulation and thermal performance, or specific material performance in the context of urban microclimate. Many documents were also marked as locally focused, generally containing local prevention plans for heat waves or energy national plans.
After this first phase of viewing and categorizing, the documents were reread by thematic blocks, and by similarity in their contents. Through the extraction of a series of key words for each resource, a diagnosis was made with the information obtained. Thus, the results were structured by recurring themes:

1)In the case of summer energy poverty methodologies, the most relevant aspects were the lack of a common definition for energy poverty, and the variety of assessment methods and approaches to the phenomenon. In addition, a growing interest in qualitative assessment methods in winter was identified, even though these approaches are very infrequent in summer.

2)Considering the urban climate and the characterization of buildings, two approaches related to the problem of characterizing summer energy poverty were identified. On the one hand, a large number of sources specialize in the analysis and quantification of passive cooling strategies in the city. On the other hand, a growing interest in urban and building energy simulation is identified. The question that emerges from these studies is how these studies and strategies can be transferred to public initiatives.

3)Regarding the specific health plans and policies related to summer energy poverty, large projects have been identified at the European level, but a greater lack of them in the participating countries. In any case, as a result of the increased intensity and frequency of heat waves, the consequences on public health are becoming more relevant in the political and administrative sphere, as observed in the documents.

4. Analysis and discussion

4.1. Measuring and defining summer energy poverty

Energy poverty is a multi-dimensional phenomenon that currently does not have a commonly agreed definition. In the European context, through the Energy Poverty Advisory Hub and the Energy Poverty Observatory, a series of indicators are proposed for its characterization. To date, each member country has its own definitions of energy poverty, having been formalized in only five of them [11]:

-(2M): Share of (equivalised) energy expenditure (compared to equivalised disposable income) above twice the national median.

-(HEP M/2 EXP): The absolute per capita spending on energy is less than half of the median equivalised spending.

-Ability to keep home adequately warm: percentage of households that are unable to keep their home in an adequately temperature

-Arrears on utility bills: percentage of households that are unable to pay the utility bills.

Secondary indicators are related to energy prices, based on consensus (on comfort conditions in summer and winter conditions), building conditions (energy certification, urban density, availability of heating and/or air conditioning, occupancy level) and poverty or health risks (poverty risk and excess mortality).

It is precisely in these secondary indicators that there are differences between the documentation collected. In the case of Spain, energy poverty is measured following the primary indicators proposed by EPOV [12]. It is striking that, for the "ability to keep the home at an adequate temperature" (referring for the rest of the countries only to keeping the home adequately warm), data are available for summer conditions only for the years 2007 and 2012. Regarding secondary indicators, not all of them are implemented in the Spanish context. For example, energy prices and the presence of pathologies in buildings are not included in their characterization.
In Italy energy poverty measurement is developed by analysing some proposed indicators and a special indicator derived from the Low-Income High Cost approach adapted to the Italian context [13]. The measure of energy poverty is focused on heating.
The indicators proposed by Greece to characterise the phenomenon are based in households' ability to accommodate their energy needs and the percentage of income spent on accommodating these needs [11].
In Bulgaria, energy poverty is measured through three national indicators: number of households experiencing restriction on heating their homes; number of households that cannot meet unexpected financial expenses with their own funds; households that cannot pay dwelling-related expenses on time [14]. Cooling needs are not included as primary indicators.

4.2. The integration of the summer dimension in the definition and measurement of energy poverty.

The review of methodologies and definitions of energy poverty allows us to identify the lack of the summer dimension in the studies of the phenomenon. This is largely due to the fact that the expenditure is very relevant, being present in many measurement indicators of the countries analyzed. Heating costs are higher than cooling costs. For this reason, in order to analyze the phenomenon of summer energy poverty in the participating countries, sources of information that analyze other fundamental aspects of the phenomenon were incorporated: the experience of the inhabitants and the thermal performance of urban environments.
Regarding occupant behaviour and households' experiences, some studies within Europe are carried out. The countries of the Cooltorise consortium present a lower efficiency of the cooling systems of the dwellings (Figure 3). Focused on interviews and qualitative research methods, some researches deepen strategies coping with heating [15] or cooling [2]. Results show that, although there is a growing body of energy poverty studies focused on inadequate indoor heating, yet there are not such a body of literature for indoor cooling.

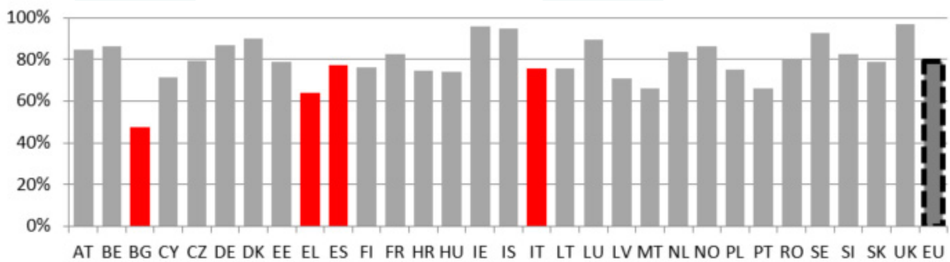

Figure 1. Share of population, based on question "Is the cooling system efficient enough to keep the dwelling cool?" and/or "Is the dwelling sufficiently insulated against the warm?", 2012. Source: EPAH, Eurostat

When the issue is to measure adequately indoor cooling, a framework analysis based in three aspects related to vulnerability to excessive heat arises as the more suitable strategy to characterise the phenomenon [2]. These three groups of indicators are: the risk of excessive indoor warmth (measure by size and orientation of windows, presence or absence of shading, number and orientation of windows, building material and presence of absence of insulation), the capacity to adapt (based on the size of home, the accessibility of cool spaces, the incomes, tenancy relations and built environment flexibility) and the sensitivity to harmful consequences (based on age and health status).
After analysing these three dimensions (based in quantitative and qualitative data), some insights arisen. Those households located in warmer countries are not necessary more exposed to excessive indoor heat, but those under a combination of natural weather and the influence of the Urban Heat Island. Moreover, those dwellings with more deprived orientations (south or west) find in windows able to be shaded, trees or neighbourhood buildings a help to reduce the risk of overheating. Respondents reported that insulation in walls and/or ceiling could also help to prevent overheating.
Regarding participant's physical health and sense of wellbeing, this research confirms what it was developed by other work before: that morbidity and mortality risk of people with pre-existing medical conditions get worse during heat waves episodes [16]. Also, that young children and older people are more affected by high indoor temperatures.
In relation with strategies to cope with indoor heat, short-term measures are preferred (because there are more accessible) than long-term solutions. Those outdoors places that stay cooler than dwellings are also a resource for those households who experiment disconfirmed indoor temperatures. However, when summer energy poverty is framed by analysing strategies to cope with heat, socio-economic status and restrictive tenancy relations are the most important factors which conditioned the phenomenon.
Within the documentation analysed for this report, only Greece and Spain contribute with qualitative studies to characterise energy poverty. Nonetheless, there are not qualitative studies regarding specifically summer energy poverty carried out.
Feminisation of energy poverty in the city of Madrid [17] brings some results related to summer energy poverty by use of qualitative analysis through interviews. Here, people (the sample was represented mostly by women) lack of knowledge about air conditioning maintenance, which conditioned its use. Low electricity contracted power together with high electricity prices were also reasons for not to use air conditioner. Related to the air conditioner usage, countries of the consortium present a penetration of AC systems over the European average (Figure 4).

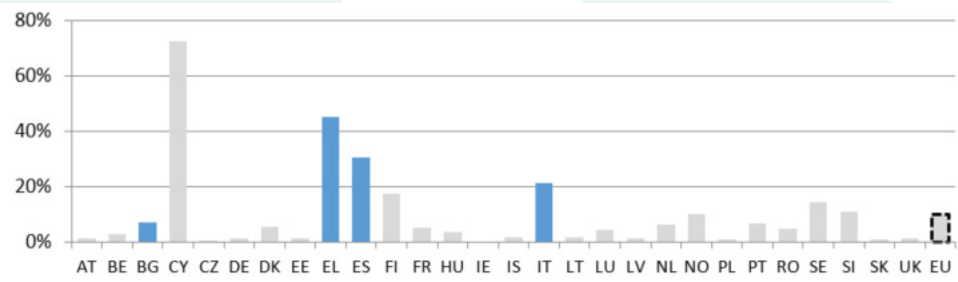

Figure 2. Share of population living in a dwelling equipped with air conditioning facilities, 2007. Source: EPAH, Eurostat

When focusing on housing stock performance in summer, two main research fields have been identified among the gathered information. Firstly, it is importance to notice that every participant has contributed with studies oriented to urban summer heat analysis.

Under this concept are located the documents that identify and analyse the Urban Heat Island phenomenon [3] [18], as well as those that tackle microclimate conditions of the urban scape, not necessarily related to the UHI. Secondly, related housing stock performance in summer, we also find documents that analyse specifically building performance in summer, offering various approaches to it: from energy efficiency measurements, heating and cooling loads simulations [19] to adaptive comfort evaluation [20].

4.3. Summer energy poverty public policies

The European Commission has taken initiatives in the energy field, starting by establishing requirements in energy legislation [21] [22]. The Clean Energy for all Europeans Package agreement (2016) aims to facilitate the transition to a cleaner energy through an energy policy framework. Specifically, for the purpose of reducing energy poverty, it contemplates actions in energy efficiency, protection against supply cuts and monitoring. The Governance Regulation (2018/1999) contains that Member State must include in national plans indicative objectives to reduce energy poverty and to integrate reporting such as data, information, policies, measures, and others; the Electricity Directive (2009/72) establishes the need to define a set of criteria to measure energy poverty at each Member State.

The Energy Poverty Observatory (EPOV) financed by the European Commission, aims to collect and analyse information at the European level on energy poverty, broadening knowledge in this area. This allows networking, disseminating knowledge and providing technical assistance. As a result, each Member State has a Report containing information on policies, Observatory publications and indicators on energy poverty. Now, this observatory is transitioning to the Energy Poverty Advisory Hub (EPAH) whose mission is to provide direct support, online trainings and research results in order to take informed action-making to reduce energy poverty.

In the matter of public policies, actions and interventions, Wellbased report gathers information from the EU countries. Italy, for instance, from a governance perspective, has proposed their own definition of energy poverty and had established specific objectives and policies to tackle energy poverty in their National Energy and Climate Action Plan. At the national level they offer subsidies for building insulation; heating installation subsidies; household appliances; financial aids for energy bills; grants for self-generation with renewable energy.

According to the Wellbased report [22], Greece and Spain stand out in the southern countries regarding energy poverty. Greece has a general social approach, providing grants to those households that cannot pay their energy bills. As a national strategy, they set up the Greek Energy Poverty Observatory and specific measures for EP, including obligations for energy companies and a social tariff. Interventions are implemented for financial aids for energy bills; subsidies for insulation of buildings; heating installation; self-generation with renewable energy; information and education. In the Energy Poverty in Greece document [23], the developments the European and national level are indicated, highlighting for the latter the “Saving at Home II” programme, and the market-based instruments. It also lists a number of proposals to address energy poverty that encompass new policy lines; public awareness and training; increasing building’s efficiency and renewable energy sources utilisation.

Spain has linked the energy poverty to energy inefficiency and the government pursues “ensure access to affordable, safe, sustainable and modern energy for all”. At national level, financial aids are available to pay bills; insulation of buildings; heating installation; protection from disconnection; self-generation with renewable energy. Spain has a National Strategy against Energy Poverty (2019-2024) [21], one of its objectives being to reduce each of the EPOV indicators by 25% for 2025.

Bulgaria current situation is different with respect to the above-mentioned countries. They have not developed a legal definition of energy poverty, although the European REACH project carried out a report on a national scale. There is no specific national strategy and they presented an undeveloped energy poverty policy, although the issue is generally included in social policies focused on financial aid and renewable energies poverty policy.

In order to collect the energy poverty initiatives carried out in Bulgaria, Greece, Italy and Spain, a repository of the projects, contained in the “Atlas of energy poverty initiatives in Europe” (2018), has been elaborated in the work that gives rise to this communication.

5. Conclusions

Regarding energy poverty definition, there is a current debate around this topic, that has been intensified by the urgency for designing new policies in the context of climate change and sustainable development. In addition of lacking a common definition for several countries, the official definitions of energy poverty do not include summer energy poverty as an issue to have into account. Related to the analysed documentation, only Italy registers a proposed definition of the summertime phenomenon as the condition for those households who fall below the poverty line trying to satisfy a minimal requirement of energy to get the “minimal thermal comfort” during summertime [24].
Analysing indicators and measurement of energy poverty, some insights arisen. Within the primary indicators proposed by EPOV it is not possible to measure summer energy poverty. Only secondary indicators enable to measure the phenomenon. Those secondary indicators which allows to characterise summer energy poverty are: the consensual-based indicator based on question “Is the cooling system efficient enough to keep the dwelling cool/ Is the dwelling sufficiently insulated against the cold?”, the household electricity prices, the expenditure-based indicator, some of the building stock features indicators and the poverty risk indicator. Besides, not all data is available within these secondary indicators; for instance, data related with building and dwelling equipped with air conditioning is only available in 2007 period, for 20 countries. Despite the fact that some of indicators take into account wintertime associated problems (as winter mortality/deaths or specific question “Can your household afford to keep its home adequately warm?”) there are not available for all countries such specific questions related to summertime conditions.
The revision of health plans and energy policies review reveals an interest on the part of the European Union to address the problem of energy poverty, reflected in directives such as 2009/72/EC or in large-scale projects such as EPOV and the current EPAH, giving member countries the opportunity to develop their own national policies in this area. In general, the policies implemented focus on financial aids for energy bills; grants for self-generation with renewable energy; subsidies for building insulation and heating installation.
In relation to methodologies and approaches to measure SEP from households’ lived experience and stakeholders’ reports info, it is remarkable the lack of studies focused on evaluate summertime conditions. From analysed documents, insights show that energy prices and type of tenancy determine using or even having air conditioner system at home. Some studies present how to cope with heating using passive strategies (from shading windows to the influence of urban vegetation).
Summer urban microclimatic conditions seem to be experiencing growing concern among the participant countries, with studies that relate different features of the urban scape with the final experiences of heat. However, it has been identified a total absence of urban indicators that could serve for policy makers and regulators to address summer energy poverty and heat exposure vulnerability.
Several studies show the negative impact of rising temperatures on people’s health, and the existence of vulnerable groups has also been identified. Energy poverty, being a multidimensional problem, plays a key role in that it can exacerbate these vulnerabilities, directly affecting people’s health.

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7.References

[1] C. Sánchez-Guevara, M. Núñez Peiró, J. Taylor, A. Mavrogianni, & J. Neila González. Assessing population vulnerability towards summer energy poverty: Case studies of Madrid and London. 2019. Energy and Buildings, 190, 132–143. https://doi.org/10.1016/j.enbuild.2019.02.024

[2] H. Thomson, N. Simcock, S. Bouzarovski, and S. Petrova, "Energy poverty and indoor cooling: An overlooked issue in Europe," Energy and Buildings, vol. 196, pp. 21–29, 2019, doi: 10.1016/j.enbuild.2019.05.014.

[3] M. Núñez-Peiró, C. Sánchez-Guevara Sánchez, A.Sanz-Fernández, M. Gayoso Heredia, J. López-Bueno, J. Neila González, C. Linares, J. Díaz, J., & G. Gómez Muñoz, Exposure and Vulnerability Toward Summer Energy Poverty in the City of Madrid: A Gender Perspective. Springer International Publishing, 2021. doi: 10.1007/978-3-030-57332-4_34.

[4]Ministerio de Ciencia e Innovación, "Aclimatarnos: el cambio climático un problema de salud pública. Guía didáctica sobre adaptación al calor."

[5]M. Palme, A. Salvati, eds. Urban Microclimate Modelling for Comfort and Energy Studies. Springer Nature, 2021.

[6]E. Waltz. Beating the heat. Nature biotechnology, 2014, vol. 32, no 7, p. 610.

[7]Bienvenido-Huertas, David, Daniel Sánchez-García, and Carlos Rubio-Bellido. 2021. "Adaptive Setpoint Temperatures to Reduce the Risk of Energy Poverty? A Local Case Study in Seville." Energy and Buildings 231: 110571. https://doi.org/10.1016/j.enbuild.2020.110571.

[8]L. Nicholls and Y. Strengers, "Heatwaves, cooling and young children at home: Integrating energy and health objectives," Energy Research and Social Science, vol. 39, pp. 1–9, 2018, doi: 10.1016/j.erss.2017.10.002.

[9]C. Morgan, J. A. Foster, A. Poston, and T. R. Sharpe, "Overheating in Scotland: contributing factors in occupied homes," Building Research and Information, vol. 45, no. 1–2, pp. 143–156, 2017, doi: 10.1080/09613218.2017.1241472.

[10] J. Allegrini, V. Dorer, and J. Carmeliet, "Influence of the urban microclimate in street canyons on the energy demand for space cooling and heating of buildings," Energy and Buildings, vol. 55, pp. 823–832, Dec. 2012, doi: 10.1016/j.enbuild.2012.10.013.

[11] A. Corovessi, S.-N. Boemi, T. Tsoutsos, M. Aryblia, and E. Touloupaki, Energy Poverty in Greece: policy developments and recommendations to tackle the phenomenon. 2020.

[12] C. Foronda, R. Charo, and J. Tobías. ECODES Dos Años de Estrategia Contra La Pobreza Energética. https://www.un.org/es/spotlight-initiative/. 2021.

[13] I. Faiella and L. Lavecchia, "Energy poverty. How can you fight it, if you can't measure it?," Energy and Buildings, vol. 233, no. September, 2021, doi: 10.1016/j.enbuild.2020.110692.

[14]E. Turai, S. Schmatzberger, and R. Broer, "Overview report on the energy poverty concept," 2021.

[15]Horta, Ana et al. 2019. "Energy Poverty in Portugal: Combining Vulnerability Mapping with Household Interviews." Energy and Buildings 203: 109423. https://doi.org/10.1016/j.enbuild.2019.109423.

[16] J. López-Bueno,. et al. "The Impact of Heat Waves on Daily Mortality in Districts in Madrid: The Effect of Sociodemographic Factors." Environmental Research 190(June). 2020.

[17]Sánchez-Guevara, Carmen et al. Feminización de La Pobreza Energética En Madrid. Exposición a Extremos Térmicos. Feminisation of Energy Poverty in the City of Madrid. ed. Fundación Arquitectura y Sociedad. Madrid. 2020

[18] E. Vardoulakis, D. Karamanis, A. Fotiadi, and G. Mihalakakou, "The urban heat island effect in a small Mediterranean city of high summer temperatures and cooling energy demands," Solar Energy, vol. 94, pp. 128–144, Aug. 2013, doi: 10.1016/j.solener.2013.04.016.

[19] A. Vallati, S. Grignaffini, M. Romagna, L. Mauri, and C. Colucci, "Influence of Street Canyon's Microclimate on the Energy Demand for Space Cooling and Heating of Buildings," in Energy Procedia, Nov. 2016, vol. 101, pp. 941–947. doi: 10.1016/j.egypro.2016.11.119.

[20] D. Bienvenido-Huertas, D. Sánchez-García, C. Rubio-Bellido, and J. A. Pulido-Arcas, "Applying the mixed-mode with an adaptive approach to reduce the energy poverty in social dwellings: The case of Spain," Energy, vol. 237, 2021, doi: 10.1016/j.energy.2021.121636.

[21]Ministerio para la Transición Ecológica. 2019. Estrategia Nacional Contra La Pobreza Energética 2019-2024.

[22]E. Soriano, V. Pellicer, P. Jordá, and A. Muñoz, "WELLBASED Deliverable 2.1. Review of public policies and interventions to reduce energy poverty," 2021.

[24] I. Faiella, et al. La Povertà Energetica in Italia. 2020.

[23] H. Böll Stiftung: The Green Political Foundation. Energy Poverty in Greece: Policiy Developments and recommendations to tackle the phenomenon 2.0. 2020.

Summer energy poverty in Southern Europe: a public policy perspective

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Key Words: Summer Energy Poverty, heat vulnerability, policies, energy efficiency, space cooling.

Abstract

Since the negative effects of rising temperatures on people's health have been noted at the administrative and political level, the implication of climate change on people´s health has become more relevant. Thus, subjects such as summer energy poverty are now part of the focus of action.

This work has been developed within the framework of COOLTORISE Horizon 2020 project, focused on raising summer energy poverty awareness to reduce cooling needs and carried out in the Southern Europe. Regarding Italian, Bulgarian, Spaniard and Greek contexts, specific policy and good practices focused on tackling summer energy poverty were analysed in order to define a state of art for policy makers. To this aim, different documents, regional policies, good practices and local agendas from these countries were collected and analysed. Three categories were stablished to facilitate a diagnostic process.

-Policies, good practices, and political agendas focused on measuring energy poverty.
-Reports that deepen in wellbeing conditions and urban scale.
-Health-related policies.

When considering the specific policies related to summer energy poverty at the European level, results show that legislation on the transition towards cleaner energy has already been introduced. Several reports, policies, good practices and agendas consider the energy poverty perspective and the importance of conducting studies and monitoring.

Existing large-scale projects were analysed too. Although projects as Energy Poverty Observatory (EPOV) have been carried out, there is still a long way to go, since not all European Union countries have managed to deepen their energy poverty policies.

Regarding public health policies, the implications for people's health have taken on greater importance in the political and administrative spheres because of the increase in temperature observed in recent decades, and the consequent concatenation of heat waves that occur every summer.

Conclusions present a set of proposals which provide policy makers and different stakeholders with a toolkit to address summer energy poverty and to guarantee a just transition with a people-centred approach.

1. Introduction

Recent years have experienced the rise of a growing public awareness in energy poverty, and this problem has attracted many political, academic and policy interests. Although there is not yet a common definition of energy poverty within EU, it could be characterised through different indicators where affordability, income and energy prices, energy efficiency, lived experience and energy spending have special importance [1]. Either through an income-based approach or using subjective indicators, measurement and characterisation of energy poverty reflect the complexity and multidimensional nature of the phenomenon.

Those studies which deepen on energy poverty are usually associated with cold climates [2]. Thus, the knowledge about how people struggle to stay warm is further superior to research focused on coping with the heat and cooling homes during summertime. For some population groups, it can be particularly difficult to cool their homes, and the drivers of Summer Energy Poverty (SEP) are not always the same as the ones detected for wintertime. Besides, it is also known that extreme hot weather and heat waves are increasing due to climate change. Different reports and studies, such as those developed by IPCC [3], point out that these extreme events are predicted to have an important impact on public health. In cities and dense urban areas, extreme events will be combined with the Urban Heat Island (UHI) effect which is going to worsen city centre temperatures [4].
In Southern European and low latitude countries, these challenging conditions are particularly relevant, and SEP is becoming a concerning issue [5]. COOLTORISE is a project focused on summer-specific energy povertyin the context of four countries located in the south of Europe: Italy, Spain, Bulgaria and Greece. COOLTORISE is the first project to be funded by the European Commission to deepen and widen the understanding of SEP.
One of the first outputs of COOLTORISE consisted of developing a policy brief focused on strategies to tackle SEP. It provides key inputs for different actors to formulate responses to summer-specific challenges. The policy brief was divided into three categories and a collection of diagnoses and measures was provided for each category.
This communication is structured into the following four sections: the first one shows the methodology applied to identify, group and analyse the scientific literature on SEP; the second section focuses on the results for each category, defining three subcategories to carry on a more specific diagnosis; following this section, the third one compiles the recommendations designed to overcome detected limitations and challenges finally, a set of main conclusions synthesize categories, diagnosis and recommendations included in this policy brief.

2. Methodology

A wide variety of documents from Italy, Greece, Bulgaria and Spain were collected. The analysed documents included not only scientific papers, but also other works that explore technical aspects, socio-economic dimensions, health, policies and good practices. A collaborative collection and revision of 150 different documents was conducted attending three proposed categories and focusing on extracting insights to reveal diagnosis and recommendations. Revision methodology and the complete catalogue of documents are included in the final version of the report “Methodological action framework: energy poverty definition, understanding and policy framework and summer energy poverty specifities” [6] uploaded on the COOLTORISE’s website for public access to the information. Part of the analysis resulted in a policy brief developed for COOLTORISE project, and this communication introduces some ideas on how to tackle the challenge of summertime energy poverty.
A table of the references that provide more information for the policy brief is included at the end of this communication to establish a clearer relationship between the issues mentioned and the documents.
These are the three categories that were identified as recurrent and important topics within the documents analysed:

2.1. Measuring Summer energy Poverty

Several limitations are founded when measuring SEP [7]. For this category, an analysis of methodologies, indicators and definitions of SEP was included in order to improve the recognition of the summertime phenomenon as a problem with structural drivers. From the national to the local context, the following aspects were analysed as challenges to overcome: 1) the creation of a common framework that would include one or multiple definitions of SEP; 2) the inclusion of SEP impact indicators within policies; and 3) the need for research to deepen on the household lived experience that would allow designing more suitable countermeasures.

2.2. Wellbeing Summer Energy Poverty

Assessing and evaluating summer heat stress in specific urban environments is a milestone for the implementation of effective policies and urban plans to tackle SEP [4]. Plans and policies analysed in this scenario were review in order to identify two key aspects regarding summer thermal comfort: on one hand, the definition of wellbeing conditions for summer-time periods and the promotion of cooling strategies in order to look deeper into adaptive comfort evaluation and the capacity of citizens to cope with high temperatures; and on the other hand, the analysis of specific urban thermal conditions, and the correspondence between heat exposition and heat vulnerability among the different areas of the city, in order to understand how urban features relate with local microclimate.

2.3. Health

The rapid increase in temperatures observed over the last century has set off multiple health alarms, revealing groups of people that are more vulnerable to climate change and whose vulnerability is exacerbated by other exposure variables [8]. Documents focused on public health recommendations were collected with the aim of describing the trends of public administration in identifying the most vulnerable groups, integrating policies that go beyond financial aid and a comprehensive approach by different actors.

3.Results

Regarding proposed thematic categories, a set of subcategories arose to allow a more specific diagnosis. Each category has been divided into three aspects to organize results.

3.1. Measuring summer energy poverty

3.1.1. Lack of common definition

It is known that instead of creating a common definition for all Member States, the Energy Poverty Advisory Hub gives them the opportunity of establishing its own definition of energy poverty[1]. Only few of them have adopted a formal definition to the date [9]. Although energy poverty is a shared problem during winter for all Member States, it is not the same situation during summertime.
Defining Summer Energy Poverty for those countries that suffer the problem involves a double work burden. Moreover, Summer Energy Poverty remains double invisible for those countries that have not a definition neither for energy poverty nor for Summer Energy Poverty.
Review of indicators
Some limitations arose when indicators and measurement of Summer Energy Poverty were analysed [10]. It is not possible to measure the problem regarding primary indicators proposed by EPOV, only by using secondary indicators. Within this secondary indicator, not all data is available for all periods. Thus, measuring some drivers of Summer Energy Poverty is impossible.
The lack of information exists also within some indicators that consider specific problems associated to wintertime (as winter/deaths or questions as “Can your household afford to keep its home adequately warm?”) but there are not available such specific questions or indicator regarding summertime.

3.1.2. Review of indicators

Some limitations arose when indicators and measurement of Summer Energy Poverty were analysed [10]. It is not possible to measure the problem regarding primary indicators proposed by EPOV, only by using secondary indicators. Within this secondary indicator, not all data is available for all periods. Thus, measuring some drivers of Summer Energy Poverty is impossible.

The lack of information exists also within some indicators that consider specific problems associated to wintertime (as winter/deaths or questions as “Can your household afford to keep its home adequately warm?”) but there are not available such specific questions or indicator regarding summertime.

3.1.3. Deepen households lived experience

During last years, a growing body of literature focused on analysing energy poverty from the lived experience has been developed [11]. Qualitative methods have been applied to discuss different drivers and the specific impacts of suffer energy poverty from household’s experience [12]. Currently, there are a lot of interviews and narratives that deepen this problem. However, qualitative researches are not specifically focused on summer time narratives. Thus, personal strategies to cope with hot weather are still unknown.

Summer Energy Poverty has a different relation with outdoor spaces than winter energy poverty due specific cultural drivers that give public space a special value during this season [13].

3.2. Wellbeing conditions and urban scale

3.2.1. Setting wellbeing conditions for summer time

Specific summer comfort conditions are closely related to adaptiveness of citizens [14]. By promoting measures and strategies to cope with overheating, people under Summer Energy Poverty situations can alleviate their overheating experience [15]. Unlike winter wellbeing conditions, where the indoor temperatures are mainly depending on heating devices and isolation of buildings, in summer there is more that people can do by implementing low energy-based thermal regulative habits. However, evaluation of building thermal performance and overheat risk is still far from incorportating such aspects, as buildings and inhabitants are commonly considered as passive agents in thermal simulations.

3.2.2. Summer urban microclimate conditions

Summer urban microclimatic conditions is a concerning issue for southern European cities [16]. Different municipalities and local universities have develop specific plans for monitoring and evaluating Urban Heat Island phenomenon [17]. However, the inexistance of useful data is a limiting aspect of such attemps. Some municipalities have develop their own network of stations to collect local climate data, but there is a lack of meteorological-based criteria for their instalation, being located in diverse and no comparable positions, for instance.

3.2.3. Indicators for policy makers

Although summer specific conditions are still not being correctly analysed, due partly to its novel character in energy poverty evaluations, there is an increasing concern on urban cooling and Urban Heat Island from local authorities and academic research. However, challenges point precisely to the gap from scientific knowledge to plans and policies relating overheating [18]. There is a growing number of prevention health plans for heatwaves events, but those same strategies seem to focus solely on the effects of summer urban conditions on health, rather than better integrating decisions on urban planning agendas or raising awareness on Summer Energy Poverty conditions among the citizens.

3.3.3. Integrative approach between actors.

Energy poverty, being multifaceted and multidimensional problem, must also be addressed through a variety of key actors. In this sense, in addition to administrations at national and European level, local public administrations, as well as civil society, the private sector entities and the academic sector, should be considered as key actos to tackle energy poverty [22]. These synergies have been observed in projects within the EU in which key actors have worked together

4. Discussion: recommendations

After thematic categories were defined and results in the form of diagnostics for each subcategory were collected, a set of recommendations has been prepared to encourage good practices and offer stakeholders a guide to improving policies related to summer energy poverty. Recommendations follow the results section structure exploring thematic categories and giving advice focused on each sub-category.

Defining problematics ensures that they are recognised within policies. If the European Union wants to truly leave no one behind, an integrated strategy against energy poverty should be developed. One of these strategies should be that Europe leads a recognition of how energy poverty works for each Member State, regarding different seasons too and giving them a definition to create future frameworks and guide policymakers. EU-funded projects should include the creation of this kind of knowledge for each context instead of tackling problems that have not been defined yet.

To improve available data and design suitable indicators to characterise Summer Energy Poverty arises as an urgent need [23]. As it is known, the drivers of energy poverty are structural, also drivers of Summer Energy Poverty are: it requires deepening and measuring housing, health policies, urban space, energy, employment and incomes, climate change…Including specific questions and recognising Summer Energy Poverty as a problem that should be possible to measure directly from new primary indicators, not only regarding secondary ones.

Summer Energy Poverty should be characterised by lived experience and cease being an overlooked issue in Europe. There are cultural drivers that shape Summer Energy Poverty and differentiate it from energy poverty during other seasons. Understanding the differences between territories [24], a map of experiences and initiatives addressing energy poverty should be created to link local, regional, national and international levels.

Regarding this specific articulation between Summer Energy Poverty and outdoor spaces [25], further research should be developed to get a better characterisation. Qualitative methods should reach collective experience, apart from individual indoor interviews.

In order to better address specific summer thermal experiences and the ability of dwellers to cope with thermal stress, a better understanding of cooling strategies and measures is needed. To do so, there is a need to gather qualitative data, and to better consider local microclimatic differences. Thermal comfort conditions can vary from one place to another in the same building, and relate to such aspects as age, economic conditions or vulnerability to overheating. By carrying out surveys and collecting data related to users' habits and socioeconomic profiles, and by identifying different heat cultures for a certain location [26] (in which passive strategies [27], adaptive measures and usages of building and energy supplies should be identified) it would be possible to better understand summer wellbeing conditions [28].

National meteorological agencies can play a central role in the promotion of monitoring campaigns, in order to better address urban microclimatic conditions. To do so, it is necessary to establish standardized criteria that make it more feasible to compare and relate some situations to others. Municipalities can interact with state-level agencies by facilitating knowledge and resources for the installation of devices. At the same time, specific studies and data collection can be carried out in order to better identify different features of the urban scape that relate to microclimatic conditions: types of pavements, green and blue infrastructure, building typologies and age, presence of AC systems, etc. In the end, what is needed is to better understand the relation of local microclimate [29] with different urban scenarios, in order to support urban cooling measures at different levels [30].

It is feasible to grow specific Summer Energy Poverty awareness by developing, on one hand, public projects for UHI monitoring and mitigation and, on the other hand, information campaigns on how to deal with overheating situations [31]. In order to target vulnerable populations and better adjust such campaigns, traditional indicators on energy poverty need to be complemented with those exclusively relating to summer, specialized in urban features and the possibility of citizens to promote cooling strategies [32]. These studies can also help to promote urban cooling plans at different levels, from city-whole scale to building or housing scale [33].

It is important to incorporate the identification of the most vulnerable groups in fuel poverty plans, in order to improve: the type of possible solutions to be applied; decision making; plan elaboration and the development of better policies to reduce fuel poverty [34]. To achieve this, as a first step it is necessary to collect data so that public administrations have statistical information to identify these vulnerable groups (e.g. socioeconomic data, household composition, among others).
Some of the practices observed in public administrations that can be very useful have been the development of health plans for heat prevention [35]. These plans [36] include an alarm system for heat waves to alert the community, and in health centers a protocol is activated to contact vulnerable groups already identified according to their medical history and/or age [37].
Urban initiatives such as the Urban Action Initiatives are also being carried out, with energy poverty as a central theme, in which not only vulnerable groups are identified and tailor-made solutions are established, but also include interventions in public spaces, understanding that these are spaces that can have an impact on the thermal comfort of nearby homes [38].
In the social sphere, protection for consumers in vulnerable situations has been legislated to prevent them from being deprived of basic services due to non-payment of their energy bills. Along the same lines, it has been proposed to eliminate historical debts in their bills to avoid a progressive increase in interest.
The public administration should therefore explore the implementation of policies not only in the economic sphere, but also in the social, health and urban spheres [39].
For a better integrative approach between actors, and considering the recommendations of other studies and reports [40], the following actors should be at least considered:

1. Civil organizations: they work closely with people and can help identify those groups most vulnerable to energy poverty, they can provide direct and specific assistance, share work experience, play an intermediary role between policies, plans and concretize changes.
2. Public Administrations: they have the capacity to finance actions, monitor, measure, involver citizens, plan and conduct awareness-raising campaings [41].
3. Private sector: it can be implicated through the participation in international agreements, adopt measures that favour gender equity. Furthermore, they can invest in research and share knowledge and experiences.
4. Academic sector: Plays a key role in generating knowledge, establishing methodologies for studies, analysis and implementation. Expand knowledge networks to the communities, and being able to inolve society and the administration

5. Conclusion

This work shows the results extracted from the policy brief developed within the COOLTORISE European-funded project. Focused on summer-specific energy poverty, the aim of this project is to improve awareness about this problem and to reduce cooling needs in Southern Europe. To do so, the first stages of the project are focused on a better understanding of methodologies, approaches and policies to characterise and contribute to the literature and knowledge on the phenomenon. Specifically, the objective of developing a policy brief within this project is to provide stakeholders and policymakers with a guide to address summer energy poverty as it is yet an overlooked issue.
Regarding the context of the project participant countries (Italy, Bulgaria, Greece and Spain) nearly 150 resources related to energy poverty and summer energy poverty were collected and analysed from the policy design point of view. Having into account that summer energy poverty is still an under-explored problem from a scientific perspective, not only scientific papers were included, but also different scales of policies, good practices, and political agendas, reports focused on wellbeing conditions and urban scale and health-related policies. To help with the analysis, three thematic categories have been identified that are common to document compiled: measuring summer energy poverty, wellbeing conditions and urban scale and health.

Results are shown as a diagnosis of the three categories defined. In order to organize more specifically the different aspects within these thematic categories, the diagnosis was divided into another three subsections for each principal thematic category. When analysing measurement/indicators design and approaches to defining Summer Energy Poverty, diagnosis reflects that the lack of a common definition, the current underdeveloped indicators and the dearth of available data, together with the absence of narratives about the lived experience are aspects to be improved. When regarding wellbeing and urban scale, the analysis of resources reveals that all the passive measures that could alleviate high temperatures indoors are far from being included within the evaluation of building thermal performance and overheating risk. Municipalities have to be able to measure the Urban Heat Island phenomenon with their own network of stations to a better characterisation and designing of effective outdoor interventions that mitigate outside temperatures that could influence indoor comfort. Indicators at the urban scale need to be improved too. From a perspective of public health, identification of vulnerable groups, integrative policies apart from economic investment and connection between actors to overcome this multidisciplinary problem should be boosted.
Recommendations collected within this research aim to ensure a just energy transition which leaves no one behind. Understanding summer energy poverty for each context should be the first step, as the phenomenon still receives little attention. Improvement of indicators should be done, as indoor cooling should look beyond the air conditioner and integrate also urban microclimatic conditions and passive adaptive measures. Protection and empowerment of vulnerable consumers should be incorporated within programmes and projects to protect those who could be deprived of basic services. Finally, the dissemination of different analyses and literature as policy briefs could guarantee an improvement in awareness and implementation of integrative approaches to overcoming the summer energy poverty problem.

Appendix I

Catalogue of documents identified as relevant from a policy making perspective focused on summer energy poverty alleviation within the 150 documents analysed.

Reference	Year	Type of document	Country
EPOV indicator Dashboard: Methodology Guidebook	2020	Methodology Guidebook	EU
Estrategia nacional contra la pobreza energética 2019-2024	2019	Methodology Guidebook	Spain
Energy poverty. How can you fight it, if you can't measure it?	2021	Scientific paper	Italy
BEATING THE HEAT: A SUSTAINABLE COOLING HANDBOOK FOR CITIES	2021	Methodology Guidebook	World
The urban heat island effect in a small Mediterranean city of high summer temperatures and cooling energy demands	2013	Scientific paper	Greece
Climate Change 2022 - Impacts, Adaptation and Vulnerability - Summary for Policymakers. 2022.	2022	Policy brief	World
Aclimatarnos: el cambio climático un problema de salud pública. Guía didáctica sobre adaptación al calor	2020	Prevention Guidebook	Spain
Inventory of energy efficiency technical measures for energy-poor households. ComAct project	2020	Methodology Guidebook	Central and Eastern European (CEE) region

WELLBASED Deliverable 2.1. Review of public policies and interventions to reduce energy poverty	2021	Policy brief	Europe
Comparing different methodological approaches for measuring energy poverty: Evidence from a survey in the region of Attika, Greece	2019	Scientific paper	Greece
LINEE GUIDA PER PREPARARE PIANI DI SORVEGLIANZA E RISPOSTA VERSO GLI EFFETTI SULLA SALUTE DI ONDATE DI CALORE ANOMALO	2006	Prevention Guidebook	Italy
Energy Poverty in Greece: policy developments and recommendations to tackle the phenomenon	2020	Policy brief	Greece
The summertime energy poverty problem	2022	Policy brief	Europe
National Policy Recommendations in energy poverty.	2016	Policy brief	Bulgaria
Health and Environment Alliance (HEAL) briefing	2020	Prevention Guidebook	Bulgaria

5. References

[1]J. Thema and F. Vondung, “EPOV indicator Dashboard: Methodology Guidebook,” Wuppertal Institut für Klima, no. April, pp. 5–24, 2020, [Online]. Available: https://energy-poverty.ec.europa.eu/system/files/2021-09/epov_methodology_guidebook_1.pdf
[2]H. Thomson, N. Simcock, S. Bouzarovski, and S. Petrova, “Energy poverty and indoor cooling: An overlooked issue in Europe,” Energy and Buildings, vol. 196, pp. 21–29, 2019, doi: 10.1016/j.enbuild.2019.05.014.
[3]IPCC, “Climate Change 2022 Summary for Policymakers,” 2022.
[4]S. Tsoka, T. Leduc, and A. Rodler, “Assessing the effects of urban street trees on building cooling energy needs: The role of foliage density and planting pattern,” Sustainable Cities and Society, vol. 65, Feb. 2021, doi: 10.1016/j.scs.2020.102633.
[5]M. Marí-Dell’Olmo et al., “Geographical inequalities in energy poverty in a Mediterranean city: Using small-area Bayesian spatial models,” Energy Reports, vol. 8, pp. 1249–1259, 2022, doi: 10.1016/j.egyr.2021.12.025.
[6]M. Gayoso, D. Torrego, P. San Nicolás, M. Núñez-Peiró, and C. Sánchez-Guevara Sánchez, “Methodological action framework: energy poverty definition, understanding and policy framework and summer energy poverty specificities.” Accessed: Jun. 15, 2022. [Online]. Available: http://cooltorise.eu/
[7]E. Turai, S. Schmatzberger, and R. Broer, “Overview report on the energy poverty concept,” 2021
[8]M. Núñez-Peiró et al., Exposure and Vulnerability Toward Summer Energy Poverty in the City of Madrid: A Gender Perspective. Springer International Publishing, 2021. doi: 10.1007/978-3-030-57332-4_34.

[9]Ministerio para la Transición Ecológica, “Estrategia nacional contra la pobreza energética 2019-2024,” 2019.
[10]I. Faiella and L. Lavecchia, “Energy poverty. How can you fight it, if you can’t measure it?,” Energy and Buildings, vol. 233, no. September, 2021, doi: 10.1016/j.enbuild.2020.110692.
[11]N. Willand and R. Horne, “‘They are grinding us into the ground’ – The lived experience of (in) energy justice amongst low-income older households,” Applied Energy, vol. 226, pp. 61–70, 2018, doi: 10.1016/j.apenergy.2018.05.079.
[12]V. Burholt and G. Windle, “Keeping warm? Self-reported housing and home energy efficiency factors impacting on older people heating homes in North Wales,” Energy Policy, vol. 34, no. 10, pp. 1198–1208, 2006, doi: 10.1016/j.enpol.2004.09.009.
[13]U. The Cool Coalition, BEATING THE HEAT : A SUSTAINABLE COOLING HANDBOOK FOR CITIES. 2021. [Online]. Available: http://www.un.org/
[14]D. Bienvenido-Huertas, D. Sánchez-García, C. Rubio-Bellido, and J. A. Pulido-Arcas, “Applying the mixed-mode with an adaptive approach to reduce the energy poverty in social dwellings: The case of Spain,” Energy, vol. 237, 2021, doi: 10.1016/j.energy.2021.121636.
[15]L. Nicholls and Y. Strengers, “Heatwaves, cooling and young children at home: Integrating energy and health objectives,” Energy Research and Social Science, vol. 39, pp. 1–9, 2018, doi: 10.1016/j.erss.2017.10.002.
[16]E. Vardoulakis, D. Karamanis, A. Fotiadi, and G. Mihalakakou, “The urban heat island effect in a small Mediterranean city of high summer temperatures and cooling energy demands,” Solar Energy, vol. 94, pp. 128–144, Aug. 2013, doi: 10.1016/j.solener.2013.04.016.
[17]C. Brandenburg et al., “Urban Heat Island Strategy: City of Vienna,” Stadt Wien, p. 116, 2018.
[18]Z. Z. I. (Malaysia) Hans-O. Pörtner (Germany), Debra C. Roberts (South Africa), Helen Adams (United Kingdom), Carolina Adler (Switzerland/Chile/Australia), Paulina Aldunce (Chile), Elham Ali (Egypt), Rawshan Ara Begum (Malaysia/Australia/Bangladesh), Richard Betts (United Ki, Climate Change 2022 - Impacts, Adaptation and Vulnerability - Summary for Policymakers. 2022.
[19]Ministerio de Ciencia e Innovación, “Aclimatarnos: el cambio climático un problema de salud pública. Guía didáctica sobre adaptación al calor.”
[20]M. de Luxán García de Diego, C. Sánchez-Guevara Sánchez, E. Román López, M. del M. Barbero Barrera, and G. Gómez Muñoz, Re-habilitación exprés para hogares vulnerables. 2017.
[21]M. Petrovic, “Inventory of energy efficiency technical measures for energy-poor households. ComAct project,” 2021. [Online]. Available: www.comact-project.eu
[22]E. Soriano, V. Pellicer, P. Jordá, and A. Muñoz, “WELLBASED Deliverable 2.1. Review of public policies and interventions to reduce energy poverty,” 2021.
[23]F. Martínez Navarro, F. Simón-Soria, and G. López-Abente, “Valoración del impacto de la ola de calor del verano de 2003 sobre la mortalidad ,” Gaceta Sanitaria , vol. 18. scieloes , pp. 250–258, 2004.
[24]E. Ntaintasis, S. Mirasgedis, and C. Tourkolias, “Comparing different methodological approaches for measuring energy poverty: Evidence from a survey in the region of Attika, Greece,” Energy Policy, vol. 125, no. November 2018, pp. 160–169, 2019, doi: 10.1016/j.enpol.2018.10.048.
[25]L. Papada, A. Balaskas, N. Katsoulakos, D. Kaliampakos, and D. Damigos, “Fighting energy poverty using user-driven approaches in mountainous greece: lessons learnt from a living lab,” Energies (Basel), vol. 14, no. 6, 2021, doi: 10.3390/en14061525.
[26]S. N. Boemi and A. M. Papadopoulos, “Energy poverty and energy efficiency improvements: A longitudinal approach of the Hellenic households,” Energy and Buildings, vol. 197, pp. 242–250, 2019, doi: 10.1016/j.enbuild.2019.05.027.
[27]H. Campaniço, P. Hollmuller, and P. M. M. Soares, “Assessing energy savings in cooling demand of buildings using passive cooling systems based on ventilation,” Applied Energy, vol. 134, pp. 426–438, Dec. 2014, doi: 10.1016/j.apenergy.2014.08.053.
[28]C. Morgan, J. A. Foster, A. Poston, and T. R. Sharpe, “Overheating in Scotland: contributing factors in occupied homes,” Building Research and Information, vol. 45, no. 1–2, pp. 143–156, 2017, doi: 10.1080/09613218.2017.1241472.

[29]J. Allegrini, V. Dorer, and J. Carmeliet, “Influence of the urban microclimate in street canyons on the energy demand for space cooling and heating of buildings,” Energy and Buildings, vol. 55, pp. 823–832, Dec. 2012, doi: 10.1016/j.enbuild.2012.10.013.
[30]I. Gaetani, P. J. Hoes, and J. L. M. Hensen, “Estimating the influence of occupant behavior on building heating and cooling energy in one simulation run,” Applied Energy, vol. 223, no. March, pp. 159–171, 2018, doi: 10.1016/j.apenergy.2018.03.108.
[31]M. Núñez-Peiró, S.-G. Sánchez, and J. Neila, “Actualización de la isla de calor urbana de Madrid y su influencia en la simulación energética de edificios,” Sevilla, 2015.
[32]K. Tamminga, J. Cortesão, and M. Bakx, “Convivial greenstreets: A concept for climate-responsive urban design,” Sustainability (Switzerland), vol. 12, no. 9, May 2020, doi: 10.3390/su12093790.
[33]A. Vallati, S. Grignaffini, M. Romagna, L. Mauri, and C. Colucci, “Influence of Street Canyon’s Microclimate on the Energy Demand for Space Cooling and Heating of Buildings,” in Energy Procedia, Nov. 2016, vol. 101, pp. 941–947. doi: 10.1016/j.egypro.2016.11.119.
[34]D. Bienvenido-Huertas, D. Sánchez-García, and C. Rubio-Bellido, “Analysing natural ventilation to reduce the cooling energy consumption and the fuel poverty of social dwellings in coastal zones,” Applied Energy, vol. 279, Dec. 2020, doi: 10.1016/j.apenergy.2020.115845.
[35]Ministerio della Salute and Direzione Generale Prevenzione Sanitaria, “LINEE GUIDA PER PREPARARE PIANI DI SORVEGLIANZA E RISPOSTA VERSO GLI EFFETTI SULLA SALUTE DI ONDATE DI CALORE ANOMALO,” 2006.
[36]A. de Barcelona, “Pla Clima. Resum executio efecte illa de calor,” 2017. [Online]. Available: http://lameva.barcelona.cat/barcelona-pel-clima/ca
[37]E. Cámera Díez, “Variables Meteorológicas y Salud,” 2006.
[38]J. Matin-Vide, V. M. Artola, Mj. Cordobilla, and Mc. Moreno, “La isla de calor en el área metropolitana de Barcelona y la adaptación al cambio climático,” 2015.
[39]A. Corovessi, S.-N. Boemi, T. Tsoutsos, M. Aryblia, and E. Touloupaki, Energy Poverty in Greece: policy developments and recommendations to tackle the phenomenon. 2020.
[40]L. Živčič, “The summertime energy poverty problem,” 2021.
[41]M. J. N. Oliveira Panão, S. M. L. Camelo, and H. J. P. Gonçalves, “Assessment of the Portuguese building thermal code: Newly revised requirements for cooling energy needs used to prevent the overheating of buildings in the summer,” Energy, vol. 36, no. 5, pp. 3262–3271, 2011, doi: 10.1016/j.energy.2011.03.018.

Progress towards sustainable stormwater management: Field monitoring of permeable pavements

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Key Words: SUDS, monitoring, urban drainage, rainfall-runoff modeling.

Abstract

The use of sustainable urban drainage systems (SUDS) in cities is becoming increasingly widespread. Partly, because of concerns about climate change and the associated flood risks, and partly, because of increasingly strict requirements regarding the quality of discharges and the insufficient capacity of our wastewater treatment plant systems. However, there is still much uncertainty in their design and implementation: costs, life-cycle, modelling, etc.
One of the most widely used tools in the management of urban drainage networks is hydrological-hydraulic modelling. Almost all water utilities have models that allow them to understand the operation of the network, prioritize investments, and estimate the impact of changes in the network. However, these models can only be realistic (and useful) if we provide real data for their calibration. In this sense, very little information is available to integrate sustainable urban drainage systems into the models.
This research consists of the field monitoring of both rainfall events and SUDS behaviour. Specifically, the SUDS technique analyzed are permeable pavements. For this, the first step is the construction of a 1-1 scale model, integrated in the urbanization of the city. Then, a monitoring system is designed to collect data continuously. Obtained data shows not only the effectiveness of the monitoring site for gathering SUDS data, but also the ability of SUDS to control precipitation.
Also, collected data allows evaluating the behaviour of the permeable pavement under real operating conditions and will be used later to carry out the calibration of the model. This calibration is fundamental to properly apply rainfall-runoff models and, therefore, to better understand SUDS performance and adequately plan the future implementation of new SUDS.

1. Introduction

The traditional urbanization process has a negative impact on the urban hydrological cycle: it increases surface runoff, increases runoff velocity, decreases the concentration time, and reduces water quality (Dietz, 2007). Sustainable Urban Drainage Systems (SUDS) replicate the natural hydrologic cycle (infiltration, filtration, storage, lamination, evapotranspiration) and thus reduce the flood risk and pollution risk (Woods Ballard et al., 2015).
Most SUDS have layers prepared to collect rainwater runoff that falls on them or on nearby areas. Depending on the characteristics of the ground, rainwater can be infiltrated (recharging aquifers), reused, or simply retained in order to be discharged into the underground drainage network. Specifically, permeable pavements can reduce runoff by 50-90% on average (Shafique and Reeho, 2015). Moreover, it has been found that for small intensities, permeable pavements can achieve up to 95% reduction in peak flow and up to 90% reduction in runoff volume (Liu et al., 2017).
Some of the research conducted with permeable pavements place great value on hydraulic-hydrologic models, where such modeling can only represent the actual runoff once calibrated (Andrés-Doménech et al., 2018).

While computational models show high accuracy in replicating laboratory data, they overestimate hydrograph discharge and their accuracy decreases with rainfall intensity (Sañudo-Fontaneda et al., 2018). Therefore, although the benefits of SUDS in general, and permeable pavements in particular, are evident, there is still some uncertainty surrounding the parameters that define such hydraulic-hydrologic models, as well as their calibration and validation."

The objective of this work is to continue this line of research, and specifically, to establish a methodology for monitoring SUDS in relation to the hydraulic response of permeable pavements. To this end, the first step is the construction of a 1-1 model integrated in the urbanization of the city and the design of a monitoring system that allows continuous data collection.

2. Background

Natural hydrological processes, such as infiltration and surface runoff, are altered in urban environments, as the urbanization process modifies the physical environment and, therefore, water dynamics. The lack of knowledge of these new, more complex urban hydrological processes is the main reason that has prevented the standardization of these hydrological models adapted to the urban environment. Today, one of the main problems making the development of such models difficult is the lack of data (Salvadore et al., 2015). Therefore, the collection of full-scale data that improves the understanding of hydrological processes related to SUDS is crucial.

Despite the fact that the SUDS concept is not new, there is still resistance to adopt them as a common solution, being the lack of monitored projects one of those reasons (Rodríguez-Rojas, 2020). At the state level, the first project related to permeable pavements dates back to 2003 (Castro-Fresno et al., 2013), a project that has been joined during these years by other projects where field data were monitored (Andrés-Doménech et al., 2021). Even so, there are few permeable pavements where data on their hydraulic response or quality performance are collected. As an added difficulty, the great climatic variability existing at state level makes it difficult to apply such data in areas with a completely different pluviometric regime (Abellán García et al, 2021).

In recent years, several SUDS have been built in different municipalities of the Basque Country. However, in most cases, these SUDS have been built in isolation and without measurement elements that could yield data on the actual performance of the SUDS in terms of peak flow reduction, time delay of peak flow, or runoff pollution reduction.

In this research, a permeable pavement pilot plant has been designed where different modules of permeable pavement and conventional pavement (used as a control environment) have been built specifically for the purpose of the research, as well as a series of manholes to collect and monitor filtered and runoff rainwater. In this way, the aim is to characterize the hydraulic behavior of permeable pavements on a real scale and under real conditions. These data will allow the calibration of a hydraulic-hydrological model, which is essential to adequately plan the future implementation of new SUDS.

3. Design of the works and monitoring

The experimental area of permeable pavements occupies 180 m², is located in the recently built urbanization of Txomin-Enea, in San Sebastian (see Figure 1) and its layout is shown in Figure 2. Half of the area is a sidewalk, built with tiles or pavers (called P surfaces) and the other half is a parking area, built with asphalt (called A surfaces).

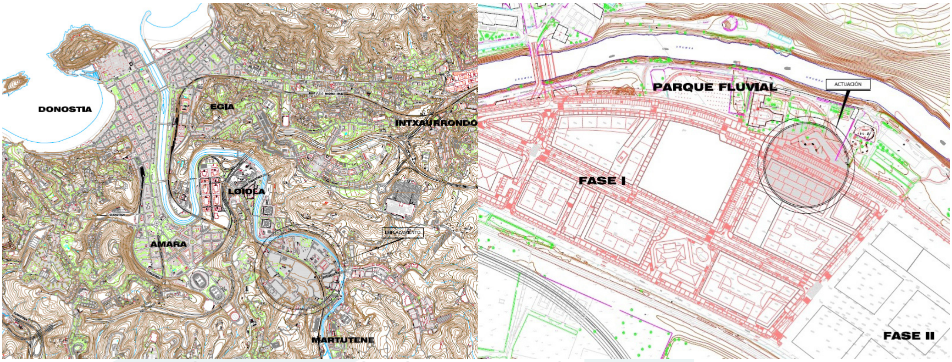

Figure 1. Location of Txomin-Enea in San Sebastian and of the experimental area in the new urbanization executed in Txomin Enea.

1.The pavement package used in each case has been made independent of the grading; i.e., the surface in contact with the natural soil has been waterproofed, in order to control the volume of water managed by the different sections. Specifically, three different sections or configurations were used (see figure 2):

2.The first section, called the control zone, has been built with conventional materials, and therefore, impermeable. Thus, in the sidewalk area, the typical hexagonal tiles used by the city of San Sebastian (Pimp) have been used, and in the parking area, traditional asphalts (Aimp) have been used.

3.In the second section, permeable pavers (P) and porous asphalt (A) have been used over the usual gravel layers in permeable pavements.

4.The last section is identical to the previous one, except that plastic cells have been placed at the bottom to increase the hydraulic capacity of the section. These sections have been identified as Pcell and Acell respectively.

Figure 2. Scheme of the different configurations installed in Txomin-Enea (Madrazo et al., 2022) and image of the finished work.

In order to evaluate the performance of the permeable pavements installed in their different configurations as well as that of the control section, six manholes have been installed on site. Two of them collect the surface runoff water and have been named R: Rimp collects the surface runoff water corresponding to the control area (Aimp and Pimp) and Rperv collects the surface runoff corresponding to the permeable pavement areas (A, P, Acell and Pcell).

The other four boxes collect the infiltrated water for each type of permeable pavement and section, that is:

-Dp: Subsurface drainage of the permeable pavers of the first section (P).

-Da: Subsurface drainage of the porous asphalt of the first section (A)

-Dpcell: subsurface drainage of permeable pavers with cells in the subbase of the second section (Pcell)

-Dacell: Subsurface drainage of porous asphalt with cells in the subbase of the second section (Acell).

A thin-walled weir with a rectangular geometry has been installed in each of these pits to measure the outflow. In addition, in order to carry out continuous monitoring, 6 pressure sensors have been installed, one in each chamber, which allow the level, and therefore the flow rate, to be determined remotely. To collect rainfall data, a rain gauge was used, which could not be installed safely in the urbanization itself, and was installed on the roof of the School of Engineering of Gipuzkoa, which is located just 2 km from the study area.

Figure 3. Three of the manholes built in Txomin-Enea. Weirs can be noted as well as the pressure sensors located in each manhole. Pluviometer installed on the roof of the School of Engineering of Gipuzkoa.

4. Results and discussion

The period analyzed runs from July 2021 to December 2021. During this period, the sensors take data every 10 minutes and the most intense storm occurs on November 15 (see Figure 4). As an example, the data obtained for a rainfall episode of Imax=4.8mm/h and 3h duration on September 3rd is shown (see figure 5).

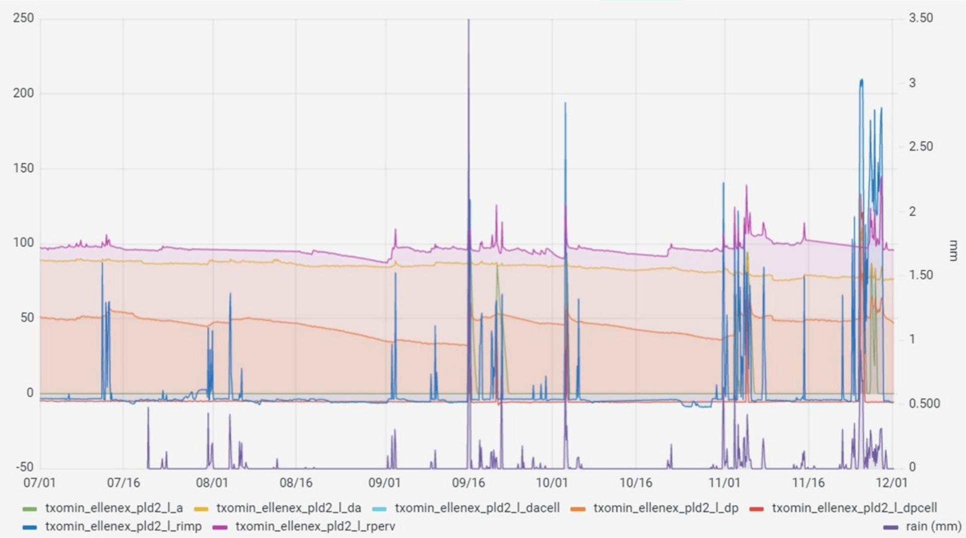

Figure 4. Raw data collected by the pressure sensors and the rain gauge.

As can be seen in the data obtained from the rain gauge (Figure 5, right), the maximum rainfall intensity on September 3 is between 7:20 and 7:40am, although from 9:10 to 9:30am there is another peak, just before the end of the episode at 9:50am. This rainfall generates a surface runoff on the impervious surface (Rimp) that can be seen in Figure 5 (left). Likewise, the sensors located in the other five manholes, which record water level data in the permeable sections (Rperv, Da, Dacell, Dp, Dpcell) hardly record any measurements, and when they do, it is towards the end of the period analyzed, at values much lower than the surface runoff in the control zone.

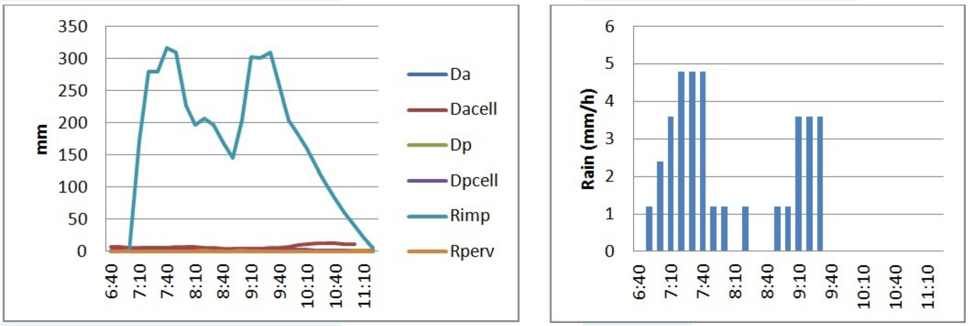

Figure 5. Water levels in the Txomin water boxes and rainfall collected by the rain gauge during the rainfall event analyzed on September 3, 2021.

It is evident that all the rainwater is filtered by the permeable pavements, hardly generating any outflow. The infiltrated rainwater is absorbed by the material itself and retained in the manholes, without generating subsurface runoff at any time.

5.Conclusions and future research

This work has made it possible to establish a methodology for monitoring SUDS in relation to the hydraulic response of permeable pavements. The work carried out and its monitoring makes it possible to measure the infiltrated flows and determine the retention capacity of the infrastructure with real rainfall data. From the data obtained, it is possible to conclude the capacity of a permeable pavement to reduce peak flow and laminate runoff. In any case, it will be necessary to analyze the data over a longer period of time and with higher rainfall intensities in order to have more conclusive results, although the preliminary results are consistent with the results published to date.
The final objective of this project is the development of a generalized model for urban catchments to analyze the hydraulic and pollutant retention behavior of any urbanization project where the use of permeable pavements is foreseen through the application of SUDS techniques. The data obtained in this work will serve as the basis for a more exhaustive study that will feed and validate the modeling to be carried out. As a future line of research, the storage of infiltrated rainwater by permeable pavements for subsequent reuse is proposed, especially as an alternative in areas where for various reasons (clayey or impermeable soils, high groundwater level, contaminated soils, etc.) the water captured by SUDS cannot or should not infiltrate into the natural ground.

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Refereneces

[1] M. E. Dietz, Low impact development practices: A review of current research and recommendations for future directions, Water, air, and soil pollution, 186 (1-4), 351-363, 2007.
[2] B. Woods Ballard, S. Wilson, H. Udale-Clarke, S. Illman, R. Ashley, R. Kellagher, The SUDS manual (C753). Ciria, London, 2015. Available at: https://www.ciria.org/
[3] M. Shafique, R. Reeho, Low Impact Development Practices: a Review of Current Research and Recommendations for Future Directions. Ecological Chemistry and Engineering, 2015 https://doi.org/10.1515/eces-2015-0032
[4] C.Y. Liu, T.F.M. Chui, Factors Influencing Stormwater Mitigation in Permeable Pavement, WATER, 2017. https://doi.org/10.3390/w9120988
[5] I. Andres-Domenech, S. Perales-Momparler, A. Morales-Torres, I. Escuder-Bueno, Hydrological performance of green roofs at building and city scales under mediterranean conditions, Sustainability 10 (2018). https://doi.org/10.3390/su10093105.
[6] L. A. Sañudo-Fontaneda, D. Jato-Espino, C. Lashford, & S. J. Coupe, Simulation of the hydraulic performance of highway filter drains through laboratory models and stormwater management tools. Environmental Science and Pollution Research, 25(20), 19228-19237, 2018.
[7] E. Salvadore, J. Bronders, O. Batelaan, Hydrological modelling of urbanized catchments: A review and future directions, Journal of Hydrology 529 (2015) 62–81. https://doi.org/10.1016/j.jhydrol.2015.06.028
[8] M.I. Rodríguez-Rojas, F. Huertas-Fernández, B. Moreno, G. Martínez, Middle-Term Evolution of Efficiency in Permeable Pavements: A Real Case Study in a Mediterranean climate, International Journal of Environmental Research and Public Health 17 (2020). https://doi.org/10.3390/ijerph17217774
[9] D. Castro-Fresno, V.C. Andrés-Valeri, L.A. Sañudo-Fontaneda, J. Rodriguez-Hernandez, Sustainable drainage practices in Spain, specially focused on pervious pavements, Water (2013). https://doi.org/10.3390/w5010067
[10] I. Andrés-Doménech, J. Anta, S. Perales-Momparler, J. Rodriguez-Hernandez, Sustainable Urban Drainage Systems in Spain: A Diagnosis, Sustainability 13 (2021). https://doi.org/10.3390/su13052791
[11] A.I. Abellán García, N. Cruz Pérez, J.C. Santamarta, Sustainable Urban Drainage Systems in Spain: Analysis of the Research on SUDS Based on Climatology, Sustainability 13 (2021). https://doi.org/10.3390/su13137258
[12] E. Madrazo-Uribeetxeberria, M. Garmendia, M. Meaurio (2022) Zoladura iragazkorrak hirietako drainatze sarean txertaturiko elementu gisa, Ekaia, DOI: https://doi.org/10.1387/ekaia.23083

Estimation of the solar potential of cities' roofs and façades from 3D city models and from bi-dimensional GIS models in Spain

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Key Words: Solar potential, 3D models, 2D GIS models

Abstract

The use of renewable energies is a key aspect in the construction of cities of the future. Spain's Integrated National Energy and Climate Plan (ENCP) of the Ministry for the Ecological Transition and Demographic Challenge highlights the relevance that renewable energies are increasingly taking, in particular photovoltaic and thermal solar, hoping to achieve a use of renewable energies of 42% of the total by 2030. To achieve this objective, its strategy highlights self-consumption, distributed generation of energy and the promotion of local energy communities. In these approaches, the integration of photovoltaic panels in buildings is particularly important, generating energy in the buildings where it is consumed.

In order to analyze the opportunities offered by sunlight on roofs, it is necessary to carry out extensive analysis of the solar potential of roofs with a sufficient degree of precision. There are several tools to calculate solar potential; the two most common ways to calculate solar potential in buildings are: with 3D models and specific software for their calculation and with Digital Surface Models and energy calculation plugins in GIS software such as ArcGIS. This communication analyzes both calculation methodologies to assess whether there are significant differences between them, applying them to the case of a neighborhood in the city of Zaragoza (Spain), called Ruiseñores. Two models are used for this task: a 3D city model generated automatically from the Cadaster data and a GIS-based model from ArcGIS using the Digital Terrain Model with the available LiDAR.

The results of the solar access of the roofs and façades at urban scale could be used to find out the photovoltaic potential of an entire area to be renovated, to incorporate photovoltaic production or to generate energy communities. This urban approach would be particularly useful to determine districts where energy networks can be implemented by analyzing suitable solar energy producer buildings surrounded by potential energy consumers, such as dwellings, shops and offices that can be connected to the first one.

1. Introduction

The use of renewable energies is a key aspect in the construction of cities of the future. Spain's Integrated National Energy and Climate Plan (ENCP) of the Ministry for the Ecological Transition and Demographic Challenge [1] highlights the relevance that renewable energies are increasingly taking, in particular photovoltaic and thermal solar, hoping to achieve a use of renewable energies of 42% of the total by 2030. To achieve this objective, its strategy highlights self-consumption, distributed generation of energy and the promotion of local energy communities. In these approaches, the integration of photovoltaic panels in buildings is particularly important, generating energy in the buildings where it is consumed.

In order to be able to analyze the opportunities offered by energy production in buildings, it is necessary to carry out a comprehensive analysis of the solar potential with a sufficient degree of precision. There are several tools to calculate solar potential; the two most common ways to calculate solar potential in buildings are: with 3D models or with 2D models. The first one, in general, uses three-dimensional models generated from different software tools such as Rhinoceros, Revit, ... and simulates them using specific software such as Ecotect Analysis, EnergyPlus, among others. To generate the 2D models Geographic Information Systems (GIS) are often used, with software tools such as ArcGIS that includes a plug-in with the calculation of solar radiation. Incident solar radiation at urban scales can be calculated in different ways, for example, using GRASS GIS to obtain solar radiation on facades from 2D (r.sun) and 3D (v.sun) models, as done by Kolečanský, Š. et al. [2] for a neighborhood in Slovakia.

The 2D and 3D models work differently. The 3D methodology uses three-dimensional models to calculate the shadow masks of the buildings and calculates the incident solar radiation. In our case, the Ecotect Analysis 2011 software tool was used to calculate the shadow mask, the solar path and solar radiation, as performed in similar analysis [3] [4] [5]. The bi-dimensional model uses a Digital Surface Model (DSM), a 2D image where each pixel contains the elevation value of this pixel with respect to sea level. The software uses the Area Solar Radiation tool to calculate the solar radiation in each image following a series of formulas to obtain the direct and indirect radiation, based on, among other parameters: the latitude, longitude, diffuse proportion and transmissivity of the atmosphere, and the angle of incidence between the sky and the intercepting surface [6].

To generate these models, the use of GIS tools is helpful, both to handle 2D images and to work with LiDAR point clouds or models, such as OpenStreetMap, in order to generate 3D models, as performed in similar analysis [7] [8] [9].

Of the above parameters, it should be noted that the vast majority of them can be taken by default in the software tool: latitude, longitude and the angle of incidence between the sky and the intercepting surface. These parameters are already included if the raster is georeferenced and the angle is part of the raster information, allowing to obtain its orientation and slope with the information it already contains. However, the parameters of diffuse proportion (the proportion of diffuse global normal radiation flux, which depends on the atmospheric conditions) and transmissivity (the fraction of radiation that passes through the atmosphere, which also depends on the atmospheric conditions) are fundamental. For these parameters, ArcGIS default values are 0.3 and 0.5, respectively, related to a generally clear standard sky. In this communication, the simulation in ArcGIS is studied, maintaining these default values and calibrating them for the specific case of the Ruiseñores neighborhood in Zaragoza (Spain). As we will later on observe, once the model is calibrated, the results of solar radiation get significantly more precise.

2. Materials and Methods

This communication studies the strengths and weaknesses of both approaches, as well as the synergies that can be found when working with both methodologies according to the desired application. A comparison of the analysis of the solar potential of a neighborhood is carried out using both methodologies, 3D and 2D, observing their degree of precision, the time consumption to undertake the analysis, and the strengths and weaknesses of each analysis, such as the possibility of incorporating facades, different levels of detail or working at different scales, among others.

For this comparison the following set of data were generated:

-Data from a three-dimensional model.
-Data from a two-dimensional model.
-PVGIS data, used as reference, to compare results.

2.1. Neighborhood selected as a case study

The study presented in this communication is carried out on the case study of the Ruiseñores neighborhood of Zaragoza (Spain). This neighborhood, which was analyzed in previous studies [10], combines multiple types of buildings and urban solutions, for example: residential towers, large blocks, closed and open blocks, terraced houses, single-family homes, as well as unique buildings such as four schools, three health centers and a hospital, a church, two retirement homes and two office buildings, using abundant flat and pitch roofs with different slopes. It is considered a relevant neighborhood due to the breadth of cases that it includes for its study in a reduced environment. This variability of the typologies allows a better evaluation of the accuracy of the 3D and 2D modeling used.

Figure 1. Aerial view of the city of Zaragoza and location of Ruiseñores neighborhood. From: A Method for the Automated Construction of 3D Models of Cities and Neighborhoods from Official Cadaster Data for Solar Analysis [10]. Derivative work of PNOA 2021 CC-BY 4.0 scne.es [11].

This neighborhood, built at the beginning of the 20th century, is located in the southern part of the city, within the University district. The neighborhood is next to one of the main expansion axes of the city at the time. Currently, the district to which it belongs is one of the best communicated and equipped areas of the city. The neighborhood occupies 400,000 m2 and has approximately 450 buildings that occupy an area of 158,500 m2 [12]. The buildings have a constructed area of 680,000 m2. Figure 1 shows the location of this neighborhood in the city of Zaragoza and Figure 2 a general view of the Ruiseñores neighborhood.

Figure 2. Aerial view of Ruiseñores neighborhood. From: A Method for the Automated Construction of 3D Models of Cities and Neighborhoods from Official Cadaster Data for Solar Analysis [10]. Derivative work of PNOA 2021 CC-BY 4.0 scne.es [11].

2.2 Information sources

The information sources to carry out the models studied in this communication are:

-Buildings and their heights from the INSPIRE Cadastre [13].
-Digital Surface Model and Digital Terrain Model from the Spanish National Geographic Information Center (CNIG) [14].
-Horizontal Radiation and Ratio of diffuse to global radiation from the PVGIS tool of the European Solar Test Installation (ESTI) [15].

As can be seen in Table 1, the three-dimensional model is made with QGIS 3.16, ArcScene 10.7.1 and AutoCAD 2019, and Ecotect Analysis 2011 is used for solar radiation calculations. For the two-dimensional model ArcGIS Desktop 10.7.1 is used with the Spatial Analyst plug-in.

Model	Fuentes de information	Software
3D Model	Cadastral INSPIRE, CNIG	QGIS, ArcScene, AutoCAD, Ecotect
2D Model	Cadastral INSPIRE, CNIG, PVGIS tool	ArcGIS with Spatial Analyst plug-in

Table 1. Sources of information and software used.

In order to know the real solar radiation that the neighborhood has and to be able to establish the comparison, the data provided by the PVGIS tool has also been studied. It is a tool developed by the European Solar Test Installation (ESTI), a reference laboratory for calibration of photovoltaic devices and verification of their energy generation. Their data are taken as the correct ones in the present study. Regarding the photovoltaic potential, its tool, PVGIS, allows to know the incident horizontal global radiation, as monthly sum of the energy of solar radiation that falls on a square meter of horizontal plane, measured in kWh/m2. This data, as well as the atmospheric diffuse ratio parameter (Ratio of diffuse to global radiation) is provided for each of the months from 2005 to 2020 currently. However, this tool does not consider the buildings and their associated shadows on elements, but the flat terrain without obstacles, so it will be useful to compare the areas of flat roofs without surrounding shadows.

2.3 Comparison

To compare the two-dimensional model and the three-dimensional model, the following steps are performed:

-In the first place, the solar radiation of the flat roofs without major obstacles around is studied. The PVGIS data are taken as the correct values. This study is necessary to calibrate the diffusivity and transmissivity in ArcGIS. Later on, we present the difference in the results between the models with the default and calibrated values.

-Secondly, the three-dimensional model is compared with the two-dimensional model, studying the radiation obtained on the roofs of the neighborhood in both models.

-Finally, the potential of including facades in the analysis is explored, combining both models and the potentialities that each model possesses and the synergies between them, as well as their limitations and requirements to be able to generate the models.

2.4 Model creation process

2.4.1 3D model

To automatically generate the 3D models we use the methodology developed by Beltrán-Velamazán et al. [10], where the INSPIRE cadastre is used in GIS to export it and generate three-dimensional models through the “3D-Model” algorithm, developed for AutoCAD and freely available in the GitHub repository. In addition, the terrain has been incorporated and the buildings located at the corresponding height so that it is a more faithful model of the neighborhood. The model obtained is a 3D model with a Level of Detail 1 (LOD 1), constituted by the polygons of the Buildings_parts layer of the INSPIRE cadastre extruded by the height they contain. This generates 3D models of extruded surfaces, to which the terrain is added.
To incorporate the terrain, the Digital Terrain Model (DTM) provided by the Spanish National Geographic Information Center (CNIG) was used. By means of the GIS software ArcScene, the model is converted into a 3D surface with the corresponding slope. Subsequently, by making a spatial union between the DTM and the INSPIRE cadastre lines, their height can be included in the terrain, and when exporting them and generating the 3D model in AutoCAD, a 3D model compatible with the terrain surface is generated, which is included in the same coordinates to generate a more complete model. This model has an advantage over the previous one developed since it incorporates the terrain and buildings at their relative height, however, the generation of sloping roofs is pending for later development. This model uses QGIS and AutoCAD for the generation of the buildings, and for the generation of the terrain, a GIS software that allows exporting the model in 3D, such as ArcScene, is required.

Figure 3 shows the entire city of Zaragoza made in 3D and the model of the neighborhood incorporating the terrain in 3D.

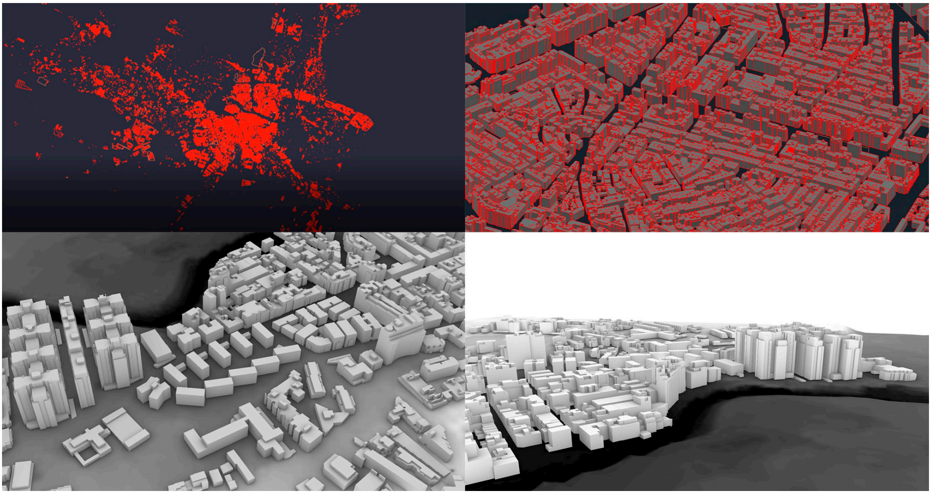

Figure 3. Above: Automatically built model of Zaragoza city without the terrain based on INSPIRE cadaster data. From: A Method for the Automated Construction of 3D Models of Cities and Neighborhoods from Official Cadaster Data for Solar Analysis [10]
Down: Automatically built model Ruiseñores neighborhood with the terrain.

Regarding the definition of the model and its limitations, it must be said that the model consists of the extrusion of the INSPIRE Cadaster surfaces at their corresponding height. To obtain a greater degree of precision, the Buildings_parts layer is used, allowing to obtain the parts of the building instead of only its general surface. This significantly improves the quality of the model, although it increases the number of surfaces, from 328 footprints for buildings to 2,589 surfaces for the Buildings_parts layer. This change means that the final model that is imported into Ecotect is much larger, as it extrudes a much larger number of surfaces, generating many more surfaces in the process. The final 3D model is composed of a total of 61,829 surfaces, divided into:

-Roofs: 2,589 surfaces.
-Facades: 53,412 surfaces.
-Terrain: 5,828 surfaces.

This procedure results in a model with a high number of surfaces that requires high calculation times. This is why it is not feasible to calculate all the roofs in the neighborhood. Just the most representative ones were calculated, leaving out of the study the roofs inside interior courtyards and the areas that, either due to their small size or because they have a disadvantageous position, it is safely assumed that they will not be suitable for photovoltaic production. This way, the number of roofs to calculate is reduced as well as calculation times.

2.4.2 2D model

This model uses ArcGIS software, with the Spatial Analyst plug-in. The data to generate the model are taken from the Spanish National Geographic Information Center (CNIG). From its download page the files of 3D point clouds are accessible. The so-called Lidar 2nd coverage are used, with a resolution of 1x1 meters, and with LAStools, the point clouds are transformed into Digital Surface Model (DSM) in .tif format. Using the DSM of the CNIG allows to work with the ArcGIS Solar Radiation Area tool to know the solar radiation in the neighborhood.

The same INSPIRE Cadaster was used to obtain the same roofs in both models. As indicated by Kausika et al. [16], it is essential to correctly calibrate the parameters of transmissivity and diffuse proportion in the simulation of solar radiation to obtain accurate results.

Regarding the calibration of the model in ArcGIS, it is important to point out that due to the lack of real and precise data in the neighborhood, the values obtained by PVGIS have been taken as the correct ones for flat surfaces and without surrounding shadows. The PVGIS tool allows downloading the radiation obtained and the diffuse proportion by months during the last 15 years (from 2005 to 2020 currently), being able to obtain through these data the diffuse proportion and transmissivity to calibrate the model.

We obtained for our case study that the values corresponding to 2020 are:
- Diffuse ratio: 0.35
- Transmissivity: 0.61.

Table 2 shows a comparison of the results obtained by calibrating the diffuse ratio and transmissivity and leaving the default data (diffuse ratio 0.3 and transmissivity 0.5).

The values obtained from PVGIS in the neighborhood for flat roofs without shadows are taken as correct and the error is calculated by comparing the average results obtained in the flat roofs without shadows of the models. All the months of the year 2020 and the year as a whole are taken, so that the differences can be seen
both in cold and warm months and in the annual average.

Figure 4 shows the different components for the energy simulation, the DSM and the INSPIRE cadastre, as well as the radiation map of the neighborhood and the incident radiation on the roofs of the neighborhood

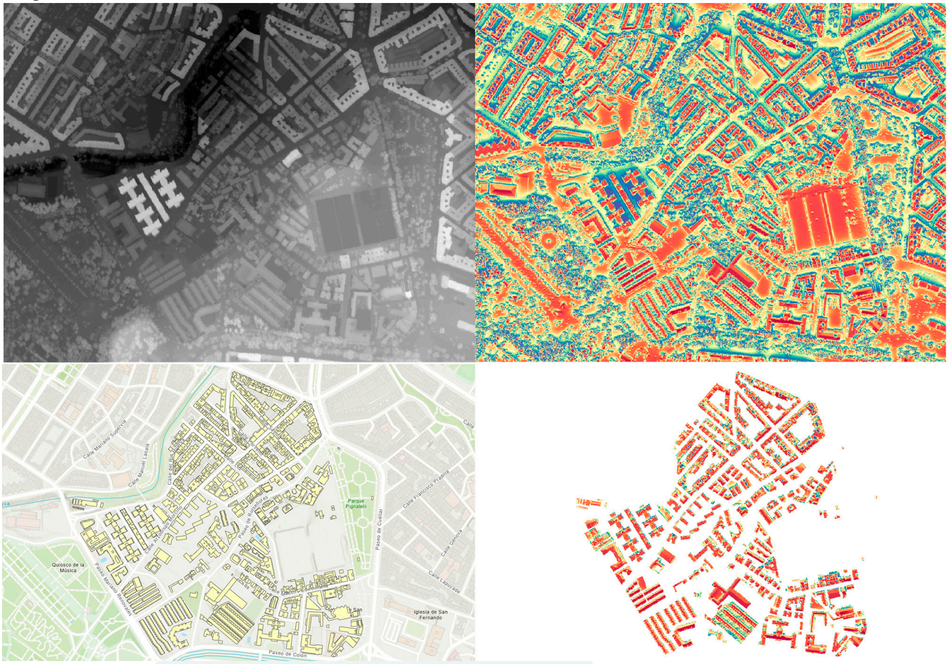

Figure 4. Above: Digital Surface Model and Solar Radiation of the entire neighborhood
Down: INSPIRE cadaster data and Solar Radiation of roofs

Months of 2020	PVGIS radiation values kWh/m²	Radiation values - ArcGIS default values kWh/m²	% Error	Error Radiation values - calibrating ArcGIS kWh/m²	% Error	Diffuse proportion - Transmissivity
January	61.44	27.5	-55.2	62.5	1.7	0.46-0.62
February	103.2	46.6	-54.8	103.7	0.5	0.29-0.74
March	127.62	88.3	-30.8	131.8	3.3	0.37-0.6
April	159.72	126.2	-21.0	161.2	0.9	0.41-0.54
May	211.29	161.7	-23.5	206.8	-2.1	0.3-0.6
June	217.74	166.4	-23.6	212.1	-2.6	0.3-0.6
July	236.24	166.5	-29.5	238	0.7	0.26-0.67
August	204.26	141.3	-30.8	203.3	-0.5	0.29-0.65
September	155.1	97.7	-37.0	154.5	-0.4	0.33-0.65
October	112.81	59.7	-47.1	108.5	-3.8	0.36-0.65
November	67.91	30.6	-54.9	68.4	0.7	0.42-0.67
December	58.18	19.4	-66.7	55.3	-5.0	0.44-0.7
Annual average	142.96	98.3	-31.2	142.8	-0.1	0.35-0.64

Table 2. Comparison between the solar radiation values obtained in ArcGIS with the default values and calibrating the model.

From these differences in solar radiation, it follows the importance of calibrating the ArcGIS model so that its results are similar to those of models with reliable results such as PVGIS, so that approximations can be made in the calculation with an acceptable degree of reliability.

2.5 Comparison of models

In order to establish a comparison between the 2D and 3D models presented, it is decided to compare only the 2D model of ArcGIS calibrating the values, since it is the model that presents results that are much more consistent with those given as correct than the model without calibrating.

Due to the excessive time it takes to calculate all the roofs of the 3D model, it has been decided to eliminate the roofs of the ground floors of the interior courtyards, roofs that are assumed not to be suitable for photovoltaic production, eliminating them in both models to reduce the calculation time of the 3D model. This being one of the limitations of the 3D methodology used, the automatic system allows the generation of three-dimensional models of entire cities in acceptable times, but the calculation time required by the software tools to calculate solar radiation is considered excessive for large scales.

3. Results and Discussion

To compare the incident radiation in the 2D and 3D models, the neighborhood was divided into 26 zones (Figure 5), so that the average solar radiation in both can be compared. For the comparison, the average daily radiation of a full year was used, in Wh/m2 (Table 3 and Figure 6).

Figure 5. The Ruiseñores neighborhood divided into 26 zones. From: A Method for the Automated Construction of 3D Models of Cities and Neighborhoods from Official Cadaster Data for Solar Analysis [10]

No. of zone	Radiation Wh/m² day 3D Model	Radiation Wh/m² day 2D Model	Difference Wh/m²	% Difference
1	3718.90	3722.30	3.40	0.09
2	3569.47	3602.61	33.14	0.93
3	3499.87	3472.37	-27.49	-0.79
4	3759.08	3802.87	43.79	1.16
5	3855.19	3807.21	-47.98	-1.24
6	4153.16	4338.25	185.09	4.46
7	3824.76	4022.92	198.16	5.18
8	3668.58	3714.54	45.96	1.25
9	3740.42	3447.91	-292.50	-2.27
10	3412.54	3377.62	-34.92	3.72
11	3556.92	3406.97	-149.94	-2.33
12	3474.71	3370.72	-103.99	-2.99
13	3100.78	3265.01	164.23	5.30
14	3792.68	4211.77	419.08	11.05
15	3847.31	3631.62	-215.69	-5.61
16	3757.18	3641.44	-115.74	-3.08
17	4008.77	3763.95	-244.82	-6.11
18	3717.95	3651.92	-66.03	-1.78
19	3374.77	3463.40	88.63	2.63
20	3600.85	3336.46	-264.39	-3.92
21	3740.62	3557.75	-182.87	-4.89
22	3841.40	3639.43	-201.97	-5.26
23	3921.81	3699.93	-221.88	-5.66
24	3680.67	3471.50	-209.18	-5.68
25	3988.25	4026.09	37.83	0.95
26	3893.48	3836.53	-56.94	-1.46

Table 3. Comparison between the solar radiation values obtained in Ecotect with the 3D model and with ArcGIS calibrating the model.

Comparing the results, 18 of the 26 sets of buildings present differences between both models of less than 5%. On average, in the total of the sets, a mean error of 0.63% is obtained between the models, and a mean absolute error of 3.45%, obtaining in general a value with Ecotect slightly higher than that obtained with ArcGIS. This is consistent with the generated models, since as the 2D model is a DSM with a resolution of 1x1 meters, and the 3D model is a model of extruded surfaces, the 2D model includes a higher level of detail in the analysis, including chimneys, terraces, and other shadows that are real and in the 3D model do not appear to be simplified in volume.

The main differences occur in groups 14 and 17, with errors between 11 and 6%, respectively.

These errors occur in zones with more variability in geometry, multiple heights, types of sloping roofs. Zone number 14, has particularly well-oriented sloping roofs and different heights, causing the greatest discrepancies between the models. Zone number17, with an error of 6%, reflects the opposite case, as it is an area that has multiple typologies, heights and very varied construction solutions. The shadow map of the roofs is much more complex than the simplification of the 3D flat roofs, which omits multiple existing shadows in the area, this is why the 3D model gives higher results than the 2D model with a more precise level of detail.

Studying the rest of the covers with errors greater than 5%, it is observed:

-Zone 7, with a 5% error, shows differences in its radiation as it contains buildings, all of them with roofs with a marked slope and an ideal orientation for solar radiation. Both factors combined cause that the 2D model gives higher results than the Ecotect model with its flat roofs.

-Zones 13, 15, 21, 22, 23, 24, with errors of approximately 5%, are the blocks with the greatest variability of solutions for roofs, sloped, flat, terraces, etc., generating differences in the 3D model when represented as extruded surfaces since they are not rendered in the same detail as in the 2D model, thus producing different shadow maps.

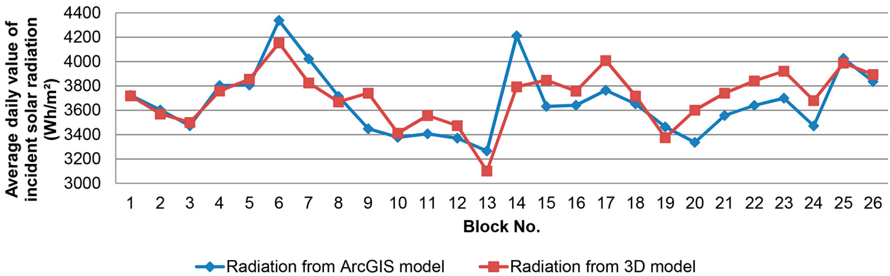

Figure 6. Comparison between the results obtained in both models

In general, these discrepancies are due to two factors: there are differences in the degree of detail of the models, the 2D model being more precise as it has a resolution of 1x1 meter, whereas the 3D model contains a simplified volume of the building. In addition, the 3D model lacks slope on the roofs, which the 2D model does have, which is decisive, especially on roofs with a strong slope and optimal orientation of the roofs.

As can be seen, in zone 2, made up entirely of residential towers and blocks with flats roof, the models yield very similar results, with a difference of less than 1%. Zone 4, which contains low and flat-roofed buildings, also presents a very similar radiation, with around 1% error. Zones 1, 3 and 5, with errors close to 1%, are made up of flat and sloping roofs with a very slight slope, yielding very close values the two models.

Analyzing the consumption of time, the preparation time of the models is in general very reduced. As all the online information is open, the process of acquiring the necessary information is very short for both models, and the generation of the models following the previous specifications requires little time.

However, there are big differences in computation time, the much lighter 2D model has a much shorter computation time compared to the much longer 3D computation processes (Table 4). This high time consumption makes the complete model with terrain very inefficient when calculating neighborhood-sized areas due to the large number of surfaces to be calculated and a calculation time that increases as the number of surfaces increases. The 3D model without land is very successful for relatively flat land, as is the case in this neighborhood, and it takes half the calculation time, so its use can be more optimal depending on the needs. This time difference increases as the scale of the models increases, making the chosen 3D methodology impractical for calculating much larger areas without strong computing power.

Model	Time for model generation	Computing time
2D Model	1h	15 min
3D Model	1.30h	900 h, 1.91h per surface on average
3D model without terrain	30 min	450 h, 0.96h per surface on average

Table 4. Time required by the models

A potentiality that the 2D model does not have is the analysis of solar radiation on facades, being an opportunity to complement photovoltaic production on roofs (Figure 7).
This fact, linked to the fast times of the 2D analysis, allows studying large areas in 2D and complementing the 2D analysis with 3D analysis facades studies at specific points that are considered especially relevant for photovoltaic production.

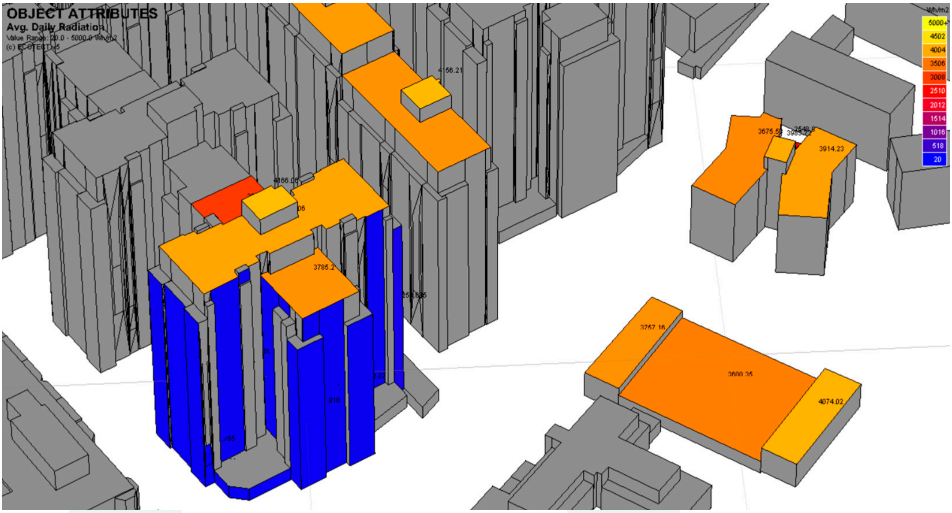

Figure 7. Analysis of roofs and facades of the 3D model

4. Conclusions

This paper presents a comparison of two methodologies for calculating solar radiation in a neighborhood; both use official open data and allow knowing the incident solar radiation on roofs in environments of a certain amplitude such as the Ruiseñores neighborhood. The compared models are a three-dimensional model based on the GIS information from the INSPIRE cadastre, and a two-dimensional model based on the DSM with the information published by the CNIG. They have also been compared with PVGIS data.
From the comparison between the non-calibrated and the calibrated two-dimensional model with the PVGIS data, we observe the importance of calibrating the diffusivity and transmissivity of the model so that it is consistent with the available verified data or reliable sources of information such as PVGIS.
The comparison between the three-dimensional and the two-dimensional model highlights the importance of modeling buildings as accurately as possible. It is observable that when the real geometry of the neighborhood begins to be complex, the results vary more and more.

Carrying out the comparisons, it can be seen that the use of the 3D models used, models called LOD 1, extruded surfaces, yields accurate results in flat roof areas, with the exception of perimeter parapets and small obstacles not included that cause shadows, and in areas with small slopes the results have a degree of precision generally less than 5%. However, these results worsen as the set of buildings becomes more complex and with more elaborated roofs, especially the well-oriented roofs, to the South and with a steep slope, which are the most optimal parameters of orientation and slope to maximize their solar radiation. In this case, the 3D models with LOD 1 undervalue the solar potential. In addition, it is important to highlight the difference in terms of time and resource consumption to calculate the models: the 2D model is very effective for calculating the radiation solar on roofs, leading to much shorter times. Both models strongly increase the time needed for their calculations as the scale to be studied increases, but the 2D model remains at acceptable values up to much larger scales than the 3D model. So that for a neighborhood scale model or higher, a 2D model presents better potential to study its solar radiation, and the 3D model has great potential to study solar radiation on smaller scales, being able to incorporate facades. If the LOD 1 is surpassed, and the model incorporates a higher level of detail, the 3D model would be able to include sloping roofs, windows, chimneys and any other singular element, improving its results.
There are important synergies between the models, for example, the possibility of combining both analyses, due to the reduced generation time of both models, it is possible to combine the capabilities of analyzing large urban areas with 2D models, and incorporate the analysis of the radiation of the facades with the 3D model, so that combined data from both analyzes is obtained. In addition, with the 2D analysis it is possible to obtain the slope and orientation values of the roofs, as well as to detect the presence of small elements, which means that in the future it could be a source of information to automatically generate 3D models with a greater degree of detail.

5. Abbreviations

2D	Two-dimensional
3D	Three-dimensional
CNIG	Spanish Nacional Centre for Geographic Information
DSM	Digital Surface Model
DTM	Digital Terrain Model
ENCP	Spain’s integrated National Energy and Climate Plan
ESTI	European Solar Test Installation
GIS	Geographical Information System
INSPIRE	Infrastructure for Spatial Information in Europe
LiDAR	Light detection and ranging
LOD	Level of Detail

6. Acknowledgements

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7. References

[1] Ministerio para la Transición Ecológica y el Reto Demográfico. Plan Nacional Integrado de Energía y Clima. 20 de enero de 2020.
[2] Kolečanský, Š.; Hofierka, J.; Bogľarský, J.; Šupinský, J. Comparing 2D and 3D Solar Radiation Modeling in Urban Areas. Energies 2021, 14, 8364. https://doi.org/10.3390/en14248364
[3] D Trisnawan. Ecotect design simulation on existing building to enhance its energy efficiency. 2nd international Tropical Renewable Energy Conference (i-TREC) 2017. 2018. doi :10.1088/1755-1315/105/1/012117

[4] Romero Rodríguez, L.; Duminil, E.; Sánchez Ramos, J.; Eicker, U. Assessment of the photovoltaic potential at urban level based on 3D city models: A case study and new methodological approach. Sol. Energy 2017, 146, 264–275.
[5] Brito, M.C.; Redweik, P.; Catita, C.; Freitas, S.; Santos, M. 3D Solar Potential in the Urban Environment: A Case Study in Lisbon. Energies 2019, 12, 3457. https://doi.org/10.3390/en12183457
[6] ESRI web. How solar radiation is calculated. https://pro.arcgis.com/es/pro-app/2.8/tool-reference/spatial-analyst/how-solar-radiation-is-calculated.htm (accessed on 19 June 2022).
[7] Liang, J.; Gong, J.; Zhou, J.; Ibrahim, A. N.; Li, M. An open-source 3D solar radiation model integrated with a 3D Geographic Information System. Environmental Modelling & Software 2015, 64. https://doi.org/10.1016/j.envsoft.2014.11.019
[8] Desthieux, G.; Carneiro, C.; Camponovo, R.; Ineichen, P.; Morello, E.; Boulmier, A.; Abdennadher, N.; Dervey, S.; Ellert, C. Solar Energy Potential Assessment on Rooftops and Facades in Large Built Environments Based on LiDAR Data, Image Processing, and Cloud Computing. Methodological Background, Application, and Validation in Geneva (Solar Cadaster). Front. Built Environ. 4:14. 2018. doi: 10.3389/fbuil.2018.00014
[9] Liang, J.; Gong, J.; Xie, X.; Sun, J. Solar3D: An Open-Source Tool for Estimating Solar Radiation in Urban Environments. ISPRS Int. J. Geo-Inf. 2020, 9, 524. https://doi.org/10.3390/ijgi9090524
[10] Beltran-Velamazan, C.; Monzón-Chavarrías, M.; López-Mesa, B. A Method for the Automated Construction of 3D Models of Cities and Neighborhoods from Official Cadaster Data for Solar Analysis. Sustainability 2021, 13, 6028. https://doi.org/10.3390/su13116028
[11] PNOA. Plan Nacional de Ortofotografía Aérea. Available online: https://pnoa.ign.es/ (accessed on 19 June 2022).
[12] Ayuntamiento de Zaragoza. Cifras de Zaragoza: Datos Demográficos del Padrón Municipal de Habitantes. Available online: https://www.zaragoza.es/cont/paginas/estadistica/pdf/Cifras-Zaragoza-2020.pdf (accessed on 19 June 2022).
[13] General Directorate of Cadastre. INSPIRE Services of Cadastral Cartography. Available online: http://www.catastro.minhap.es/webinspire/index.html (accessed on 19 June 2022).
[14] Página web del Centro Nacional de Información Geográfica, Centro de Descargas, https://centrodedescargas.cnig.es/CentroDescargas/index.jsp (accessed on 19 June 2022).
[15] PVGIS tool web, https://re.jrc.ec.europa.eu/pvg_tools/en/ (accessed on 19 June 2022).
[16] Kausika BB, van Sark WGJHM. Calibration and Validation of ArcGIS Solar Radiation Tool for Photovoltaic Potential Determination in the Netherlands. Energies. 2021; 14(7):1865. https://doi.org/10.3390/en14071865

Development of a Simple Model to Estimate Heating Demand at a District Level

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Abstract

The energy rehabilitation of buildings has great potential to significantly reduce energy consumption in the building sector. In this sense, the Energy Performance of Buildings Directive 2010/31/EU, recently updated in Directive 2018/844/EU, represented a turning point in the promotion of energy efficiency in buildings in the EU, introducing legal requirements for both new and existing buildings. This directive introduced important concepts such as the optimal cost of investments and the nearly zero energy building (nZEB). For this purpose, it becomes necessary to develop extensive design processes with an optimization perspective that covers all possible aspects in matters of building design (envelope, shading, components of cooling and heating systems, regulation criteria, among others), starting from the most initial design phases, to comply with the prescriptions of the Directive, ensuring the thermal comfort of the occupants. In addition, the need of speeding up the emissions reduction rate associated with buildings has led to transcending the individual limit of each building, applying the nZEB principle at the neighborhood or district scale, from both an architectural and urban planning perspective. This has given rise to the concept of Net-Zero Energy Districts. Software tools for the energy simulation of buildings allow estimating the thermal demand of different alternatives and obtaining optimal designs. However, they require many evaluations at a high computational cost, making the analysis practically impossible when the object of study is entire neighborhoods. Therefore, there is a need for simple methods for estimating energy demands that offer sufficiently accurate results. One of the main steady-state methods for calculating energy demand is the degree-days method. However, this model has limitations that must be known to consider its scope and applicability. Among the main uncertainties of this method is the selection of the base temperature, which in practice will be affected by the level of efficiency of the evaluated building. Although there have been approaches for calculating a variable base temperature, the tendency is to use a generic base temperature, without considering the specific characteristics of the analyzed building. This has a significant impact on the demands estimated using this method, which tend to be significantly overestimated. In this sense, the present work aims to develop a simple model for calculating district heating demand. To this end, the most relevant design and operational aspects for residential buildings were taken into consideration, leading to the selection of 7 independent parameters. A total of 5,000 simulations have been carried out, based on a multi-family building located in the neighborhood of Otxarkoaga (Bilbao). Using linear regression techniques, a relationship between these independent variables and the base temperature has been determined. The heating demand can be consequently determined by applying the degree days formula. The results show the potential of this prediction method as an effective alternative tool to support decision-making on energy rehabilitation solutions through an initial estimation of heating demand with good precision.

1. Introduction

The energy rehabilitation of buildings has great potential to significantly reduce energy consumption in the building sector. In this sense, the Energy Performance of Buildings Directive 2010/31/EU [1], recently updated in Directive 2018/844/EU [2], represented a turning point in the promotion of energy efficiency in buildings in the EU, introducing legal requirements for both new and existing buildings. This directive introduced important concepts such as the optimal cost of investments and the nearly zero energy building (nZEB).

For this purpose, it becomes necessary to develop extensive design processes with an optimization perspective [3] that cover all possible aspects in matters of building design (envelope, shading, components of cooling and heating systems, regulation criteria, among others), starting from the most initial design phases, to comply with the prescriptions of the Directive, ensuring the thermal comfort of the occupants [4].

In addition, the need of speeding up the emissions reduction rate associated with buildings has led to transcending the individual limit of each building, applying the nZEB principle at the neighborhood or district scale, from both an architectural and urban planning perspective. This has given rise to the concept of Net-Zero Energy Districts [5]. By establishing the goal of zero energy for an entire neighborhood, the strategy of integrating the contributions of different energy yields and different production capacities makes it possible to take advantage of this diversity by optimizing the aggregation of different production and consumption profiles, which opens the possibility of share needs, resources, and costs [6].

Software tools for the energy simulation of buildings allow estimating the thermal demand of different alternatives and obtaining optimal designs. However, the high casuistry involved in putting forward rehabilitation actions requires many evaluations at a high computational cost, making the analysis practically impossible when the object of study is entire neighborhoods, which can contain from tens to hundreds of buildings. Therefore, there is a need for simple methods for estimating energy demands that offer sufficiently accurate results, without the need to recourse to dynamic simulations with a high computational cost.

One of the main steady-state methods for calculating energy demand is the degree-days method. Scientific literature points out that weather severity can be properly characterized in terms of degree-days [7]. Specifically, degree-days are the addition of positive differences between a reference temperature, known as base temperature, and the daily mean temperature over a given period [8]. The outdoor temperature variations explain, to a great extent, heating demand variation, but that relationship is not linear [9]. However, generally, these methods allow nothing but a first exploratory calculation, with an accuracy below that obtained from the application of more complex dynamic simulation tools.

In the case of using degree-days to estimate demand, it must be considered that this method can only provide approximate results based on the series of simplifications that its calculation entails [8]. Among the main uncertainties of this method is the selection of the base temperature, which in practice will be affected by the level of efficiency of the evaluated building. The base temperature, Tb, is defined as the outdoor air temperature at which heating or cooling systems do not need to operate to maintain comfort conditions [8]. Base temperatures of buildings are not constant, even in a climatically homogeneous location [10]. The definition of the base temperature depends on the thermal characteristics of the building, such as thermal transmittance, thermal capacity, and heat loss mechanisms (ventilation and infiltration flow rates) [8], in addition to the local climatic conditions and the type of use of the building [10].

The base temperature generally used are standard values found in norms, published by official bodies. However, there is no single globally accepted base temperature value, on account of the variations of the parameters that influence its definition.
To estimate the base temperature, analytical or experimental methods can be used. However, fully controlled experimental verification in real buildings is prohibitively expensive. In this sense, Kusuda et al. [19] proposed in 1981 a purely theoretical model with variable base temperature, based on the physical observation that the gains of a building offset the need for heating, until the outside temperature is lower than the setpoint temperature, by a magnitude equal to the ratio of the gains between the global heat loss coefficient of the building [11]. Thus, the base temperature is calculated based on parameters such as the setpoint temperature (Tsp), the solar gains (Qsol), the internal gains (Qin), and the global heat loss coefficient of the building (UAeff).
Due to the need for simple methods that offer more accurate estimates and the need to apply global approaches to energy analysis that act at a neighborhood scale, this paper aims to develop a simple model for calculating district heating demand. For this purpose, the development of a regression model is proposed to determine the base temperature and consequent heating demand of a building through the degree-day method.
As a result of programming a battery of energy simulations and obtaining an extensive database, a quadratic linear regression model is defined that allows the base temperature to be analytically related to the operational and design parameters established. Then, the heating demand can be easily obtained using the degree-day method once the base temperature, unique for each building, has been determined. The model thus developed makes it possible to determine the impact of various energy rehabilitation actions on heating demand through a series of easily obtainable geometric, construction, and climatic indicators.
The first results in this line of research were previously published at the 10th European Congress on Energy Efficiency and Sustainability in Architecture and Urbanism (EESAP 10) [12]. The work presented here is the first phase in the development of a tool for estimating energy demands in buildings that will allow its application at a neighborhood or regional scale.
The rest of the work is classified as follows. In Section 2 the methodology developed for obtaining the regression model is presented. This methodology is applied to a reference building as presented in Section 3, consisting of a social multifamily building located in the Otxarkoaga district (Bilbao). The obtained model, as well as the interpretation of the results, are presented in Section 4 where additionally the validation of the model is carried out by comparing the estimates of energy demand calculated with those obtained from detailed dynamic simulations through the combined use of Python programming with the Energy Plus software. Finally, the main conclusions are summed-up in Section 5.

2. Methodology

The energy behavior of a building will be taken as a reference to determine the model, specifically the monthly energy needs that are necessary for maintaining adequate indoor thermal comfort. To have a sufficiently large sample of cases for the definition of the simple model, the energy demands of a building will be obtained based on different geometric, constructive, and use combinations. Thus, to determine the input variables of the model, the effect of different aspects of the building design such as shape, conditioned volume, glazing characteristics, and insulation level is analyzed. As a starting point for the analysis, the parameters that are most mentioned in literature as influential in the heating demand and the base temperature were selected.
To observe the gains and losses through the building envelope and based on the application of the physical principles of energy balances in the building, the simple model to be developed intends to ponder gains/losses due to the transmission through the envelope, solar gains, internal gains and gains/losses from infiltration and ventilation.

Thus, the exchange of heat through the envelope will be considered through the U values of different elements that compose it (wall, windows, and roof) and its corresponding area (A), which, along with air exchanges by infiltration and ventilation, are included in the global coefficient of heat loss (UAeff). Similarly, the effect of solar gains is included through the introduction of the south equivalent surface (SES), which include data on the glazing area, its distribution, and orientation. Internal gains, dependent on the use and operation of the building, are also included (Qi). These exchanges (especially those related to heat transfer through the envelope and those associated with ventilation and infiltration) will be affected by the demanded interior comfort conditions, which are also considered in the model through the setpoint temperature (Tsp).
The SES is a parameter proposed by Catalina et al. [13] that represents in a single parameter the glazed area and its distribution by the different orientations of the facades. This parameter is calculated by the sum of the multiplication of the area of a glazed surface by the coefficient of its orientation. These coefficients represent the percentage of solar incidence that a vertical surface oriented in a certain orientation receives compared to what it would receive in a south orientation. In this way, an estimate of the effective solar irradiation received by a certain building can be made by using these coefficients and knowing the southern vertical irradiation of the study site.
The parameters proposed are easily obtainable from cadastral databases, vector maps, raster maps, orthophotos, as well as meteorological stations. In this way, the characterization of the building's parameters can be obtained more automatically to extend the replicability and generalization of the model.
Table 1 presents the values of the orientation coefficients calculated for Bilbao climatology in January, obtained by simulating a simple model in Design Builder and utilizing the weather data file from the Meteonorm Data Base [14].

NORTE	ESTE	SUR	OESTE
0,26	0,47	1,00	0,45

Tabla 1. Coeficientes de orientación para la climatología de Bilbao en el mes de enero

The case matrix is obtained by combining the mentioned parameters, assuming different intermediate values within the most frequent ranges found in the building: Uwall (0.122 – 1.336 W/m²K), Uwindow (1.225 – 5.639 W/m²K), Uroof (1,107 – 1,767 W/m²K), Tsp (18 – 22 ºC) and Qi (0 – 15 W/m²). For the calculation of the SES, window ratios were modified only in the south orientation between 30 and 70%, and the building was rotated between 90º and 270º. Finally, the air exchanges by ventilation and infiltration were varied between 0 and 2 ACH. Thus, the case matrix results in a combination of 937,500 cases or simulations.
To reduce the high computational effort that would require covering this number of simulations, as well as to facilitate the analysis of the data and therefore the determination of the coefficients of the model, a fraction of 5,000 cases selected independently of each other from the original case matrix has been selected.
The simulation cases are carried out by combining the dynamic simulation software EnergyPlus with Python programming language. Specifically, the Eppy [61] library, based on Python, allows the manipulation and generation of EnergyPlus simulation input files. In addition, the Design-Builder software was also used to export the file with building modeling data that is used for model determination.
The objective behind this model is to determine the base temperature, unique for each case, which must be applied to the degree-day method to obtain, through the degree-day equation (1), the same heating demand that was estimated by energy simulations. That demand, therefore, applying equation (1), is transformed into degree-days for each case.

$$T_b = C + \sum Comp_i \cdot Coef_i \tag{2}$$

Q represents the heating demand, in kWh. As mentioned above, UAeff represents the global coefficient of heat loss, in kW/K. DDp, are the degree-days that contemplate the weather effect and represent the total number of heating or cooling degree-days in a month p.
The results obtained from the dynamic simulation of the 5000 selected combinations will be used as the basis for an initial determination of the simple model. A preliminary analysis of the results leads to the decision to work first with the determination of a monthly demand model, based on the data obtained for the month of energy, due to its greater correlation with the annual demand. One of the hypotheses launched is that the form of the correlation that explains the annual demand will surely be very similar in form to the correlation that explains the demand in the months of greatest use of heating.

3. Reference building

Although the final goal of this research work is to apply the proposed methodology to different building types that can make up a neighborhood, the model presented in this work was obtained by analyzing a single building (with a specific geometry) and one climatic zone. To do this, a multi-family building located in a significant district of Bilbao, known as Otxarkoaga, is used as a reference. Even though the existing heterogeneity of the building stock, this building has representative features of the building stock of the region, and a high possibility of replicability [16], as has been analyzed in detail in previous research pieces [17]. It consists of social housing, a 6-story multifamily building from the 1960s, which contains 36 dwelling units, each of them with a net floor area of 50–55 m2 (Figure 1).

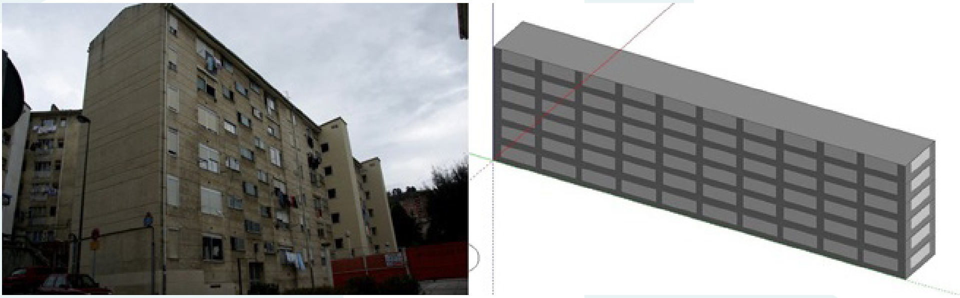

Figure 1. General view of the building (left) and Design-Builder thermal model (right)

En lo referente a características constructivas del modelo de referencia, las paredes externas del edificio están compuestas por dos capas de ladrillo hueco separadas por una cámara de aire, una capa de aislamiento de fibra de vidrio y una tercera hoja de ladrillo, presentando una U de 0,74 W/m2.K, mientras que en cubierta el escenario base presenta una U de 2,842 W/m2.K. Como material aislante, tanto en la fachada como en la cubierta del edificio, se consideró la lana de vidrio (U=0,04 W/m.K). Con respecto a las ventanas, se consideraron marcos de PVC (U=3,476 W/m²K) para todos los casos y la variación del porcentaje de ventanas es aplicado únicamente a fachada de orientación sur, manteniendo las demás orientaciones con 20% de superficie acristalada. (Se puede encontrar una descripción detallada de la envolvente térmica de este edificio en [17]) .
Por otro lado, se realizaron algunas simplificaciones en el diseño del edificio para realizar las simulaciones, que en cualquier caso no influyen en la representatividad de los resultados. En vez de considerar una cubierta inclinada con una bajo-cubierta no habitable, se ha supuesto una cubierta plana, con el objetivo de aumentar la generalización de modelo resultante.

4. RESULTS

Through the evaluation of the results obtained, it is possible to determine, through linear regression techniques, an analytical expression that explains a relationship between the independent variables – that is, the parameters presented above – and the dependent variable – that is, the base temperature. Different models have been evaluated and it has been identified that the best results are obtained by quadratic linear regression of 7 variables, as can be verified in Table 2. Even though other parameters also showed a small influence in the resulting model, they were maintained since their elimination from the regression does not reveal improvement in the adjustment.
Therefore, the resulting regression model equation is presented in equation (2), where Tb represents the base temperature, in ºC/month. In turn, C is the constant of the equation, Compi represents component i multiplied by its respective coefficient, Coefi

$$T_b = C + \sum_{i=0}^{n} Comp_i \cdot Coef_i \qquad (2)$$

Comp.	Coef.	Comp.	Coef.	Comp.	Coef.	Comp.	Coef.
Constante	-8,94	g_{glass}^2	-3,45E-02	$SSE \cdot g_{glass}$	-6,27E-04	Tsp^2	-1,27E-02
UA_{muro}	6,76E-04	Q_{int}	-1,22E+00	$SSE \cdot Q_{int}$	4,58E-05	UA_{eff}	3,39E-03
UA_{muro}^2	-1,74E-07	$Q_{int} \cdot UA_{muro}$	-2,78E-05	SSE^2	2,39E-05	$UA_{eff} \cdot UA_{muro}$	2,57E-07
UA_{cub}	1,34E-03	$Q_{int} \cdot UA_{cub}$	2,92E-05	Tsp	1,31	$UA_{eff} \cdot UA_{cub}$	-3,57E-08
$UA_{muro} \cdot UA_{cub}$	-1,80E-07	$Q_{int} \cdot g_{glass}$	-8,71E-03	$Tsp \cdot UA_{muro}$	-7,36E-06	$UA_{eff} \cdot g_{glass}$	8,52E-05
UA_{cub}^2	7,56E-08	Q_{int}^2	-2,29E-03	$Tsp \cdot UA_{cub}$	-7,44E-05	$UA_{eff} \cdot Q_{int}$	1,16E-04
g_{glass}	-6,50E-02	SSE	-4,16E-02	$Tsp \cdot g_{glass}$	-8,63E-03	$UA_{eff} \cdot SSE$	2,64E-06
$g_{glass} \cdot UA_{muro}$	-5,62E-05	$SSE \cdot UA_{muro}$	-2,04E-06	$Tsp \cdot Q_{int}$	1,18E-02	$UA_{eff} \cdot T_{sp}$	-2,20E-06
$g_{glass} \cdot UA_{cub}$	-4,43E-05	$SSE \cdot UA_{cub}$	9,89E-07	$Tsp \cdot SSE$	5,47E-04	UA_{eff}^2	-3,53E-07

Table 2. Summary table of the components and coefficients of the quadratic linear regression model for the prediction of heating demand

The resulting model offers an adjusted R2 of 93.04% and a residual standard error of 0.828ºC, which is considered a good adjustment. In addition, this model has passed the normality test with a significance level of 0.01 and it can be concluded that the result is statistically significant. The graphs of the base temperatures and consequent heating demands obtained through the model in comparison with the values obtained through energy simulations are shown in Figure 2.

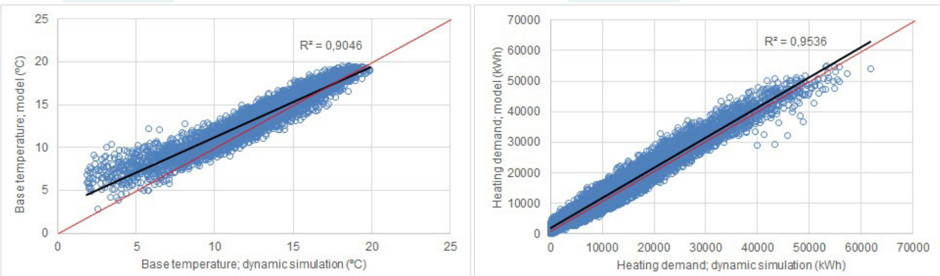

Figure 2. Comparación de las temperaturas de base (izquierda) y demandas de calefacción (derecha) obtenidas por simulaciones con las estimaciones ofrecidas por el modelo

The red line in both graphs serves as a reference to carry out a visual analysis of the results. First, the inclination of the trend line in the base temperature graph allows us to observe that for small values of Tb error is more considerable than for higher values (>15ºC) and this error is more accentuated the lower is Tb. These values, for the most part, represent the cases whose monthly heating demands are lower than the average.
For the development of the model, the cases whose monthly demands were close to zero were discarded because they were considered outliers (abnormal observations) and had the potential to affect the estimation of the model. Therefore, in extreme cases, the model's prediction does not have such an optimal fit. However, the analysis of the heating demand graph shows an almost constant tendency to overestimate the demand, when the results are compared with the values found in the dynamic simulations.
After this first analysis, the model validation can follow. This is possibly the most important step when trying to determine a prediction model, especially when multiple parameters are involved. Validating and analyzing cases other than those considered to obtain the model will provide good estimations of the model's accuracy [18].
Even though the final objective of the model proposed in this work is for the application at a neighborhood or regional scale and in different climates, a building with a different typology from the reference model is considered for validation. It consists of a multifamily building in the same climatic zone, also located in Otxarkoaga, Bilbao, with type H typology (Figure 3).

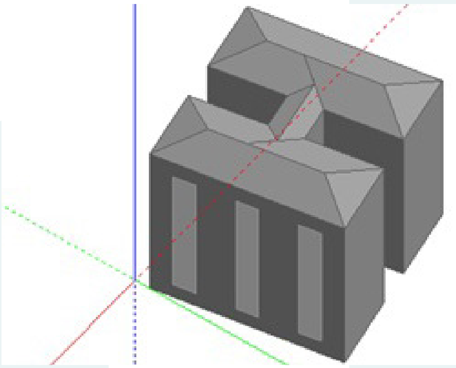

Figure 3. General view of the thermal model of the building in Design-Builder, used for validation

Thus, for the validation, cases that would correspond to façade rehabilitation measures are proposed. For this, the Uwall, the infiltrations, and the SSE are modified, the latter being changed through a variation in the percentage of windows and the orientation of the building. In this way, the variables that depend on the use and operation of the building, such as Qi and Tsp, remain constant. The roof will not be modified either.
Regarding the modifications to the façade, 3 different values of Uwall are considered, one referring to the building in its reference state, without refurbishment (U=2.65 W/m²K), and two other values that would represent refurbished cases (0 .22 and 1.04 W/m²K). Two values were considered for infiltrations: 0.23 and 1 ACH. In addition, a ratio of 20% for windows is considered in the west orientation and 40% in the east orientation. The building in these configurations was rotated between 90 and 270º, to analyze the effects of solar incidence in different cases. The other parameters (Uroof, gglass, Qi, and Tsp) were not changed, maintaining the building's original configuration values. In this way, 18 validation cases were generated (12 rehabilitation cases and 6 without façade rehabilitation, with only the other parameters varying).
To calculate the demands by the degree-day method considering a fixed base temperature, a 15ºC value is taken as a reference, as defined by the UNE 100-002-88 standard [19]. The results obtained for the monthly demand for January can be seen in Figure 4.

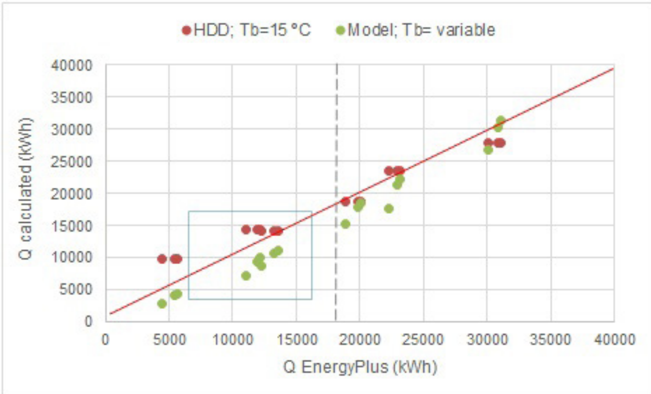

Figure 4. Comparison between the demands obtained from the simulations (Q Energy Plus) with the estimates offered by the degree-day method and by the proposed model

In the graph, demands calculated by the degree-day method are shown in red while those obtained by applying the model proposed in this work are shown in green. Both predictions are contrasted with the demands obtained from the energy simulations carried out with the EnergyPlus software.
Once again, the red line serves as a reference to carry out a visual analysis of the results. In general, the predictions obtained with the model are below the reference line and thus, underestimated. On the other hand, the predictions obtained with the degree-day method below 18,000kWh (identified in the graph by the vertical dashed line) present greater errors, overestimating the demand. These values represent 9 of the 12 rehabilitation cases, with errors greater than 120% for cases in which the monthly demand is around 5,000 kWh. With the variable base temperature model, in these rehabilitation cases, the maximum error is 35%. The other three rehabilitated cases have higher demands because they correspond to the largest infiltration cases. The average of errors obtained by the degree-day method is 23.7% while the average obtained by the method proposed in this work is 16.8%.
Also, the predictions obtained by the degree-day method are separated into small blocks in which the demands are practically the same, forming small horizontal lines on the graph, although the predictions obtained through the energy simulations vary for all the cases. This behavior can be observed in Figure 5.

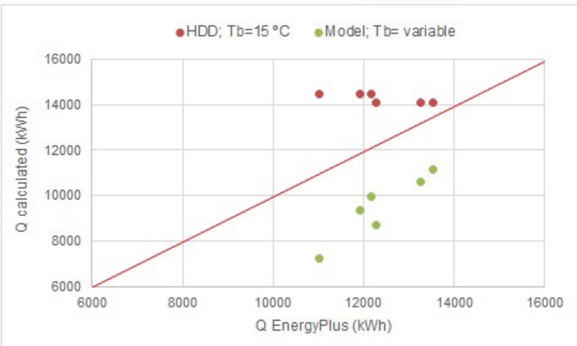

Figure 5. Zoom of the square identificated in the Figure 4.

As Figure 5 shows, for different demand values calculated by the energy simulation software, the degree-day method obtains results that are very close to each other. This is expected considering the series of simplifications that the calculation by this method supposes, one of them being that the same heating demand will be obtained for cases in which the UAeff coincide, although each building has other peculiarities, both constructive and use. In addition, the degree-day method does not consider variables such as internal gains and solar gains, which can have a considerable impact on heating needs.
Figure 5 also shows how the model is sensitive to the variation of parameters such as SSE. Two groups of 3 cases can be identified, corresponding to cases in which only the SSE is varied and the other parameters remain constant. The higher the SSE, the lower the demand for heating will be since solar gains offset part of that demand. By taking into account this parameter, the effect of the glazed surface layout along the building's facades can be analyzed. This can be very useful during the design process of new construction buildings. In general, the results obtained by the model follow a line with a trend close to the reference line marked in red, although most of the values are underestimated.

5. Conclusions

This paper has presented the development and validation of a model for determining the base temperature and consequent prediction of the heating demand of a building through the degree-day method for the climatology of Bilbao, in the north of Spain. For this purpose, the most relevant design and operational aspects of residential buildings were taken into consideration. Independent design parameters and an interval of design that is wide enough to contain a high casuistry in real building designs were selected. The model contemplates the gains and losses by the envelope, as well as the effect of solar and internal gains and comfort conditions. Through statistical techniques, the results allowed obtaining an analytical relationship between the base temperature and the operational and design parameters identified. Thus, a quadratic linear regression model is defined. This model is applicable in different scenarios, allowing estimating the heating energy demand, both during the design phase of a new building or when assessing retrofitting actions for existing buildings.
The resulting quadratic linear regression model allows for obtaining base temperature predictions with an adjusted R2 of 93.04% and a residual standard error of 0.828ºC. The model was validated for 18 cases by comparison of the demands obtained by dynamic simulations with the estimates offered by the degree-day method and by the proposed model, using a building with a different typology than the reference building that was considered in the modeling.
In conclusion, there is a better agreement between the model estimations and those obtained by dynamic simulation than the values obtained by the degree-day method. In addition, the model considers variables such as internal gains and solar gains, which can have a considerable impact on heating needs. Despite its potential, the exclusive estimation of heating demands and specific climatic conditions constitute a major limitation of the actual version of the model.
To conclude, the proposed prediction model shows promising functionalities, which can be used by the different agents involved in the design phase of energy rehabilitation projects, serving as support in the identification of efficient energy solutions. In the future, the extension of the methodology presented here is intended to develop a tool for estimating energy demands in buildings with an application at neighborhood or regional scale.

6. Acknowledgment

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7. Bibliography

[1]European Parliament, “Directive 2010/31/EU of the European Parliament and of the Council on the Energy Performance of Buildings,” 2010.
[2]European Parliament, “DIRECTIVE (EU) 2018/844 of the European Parliament and of the Council,” 2018, [Online]. Available: https://eur-lex.europa.eu/legal-content/ES/TXT/?uri=CELEX%3A32018L0844.
[3]A. T. Nguyen, S. Reiter, and P. Rigo, “A review on simulation-based optimization methods applied to building performance analysis,” Appl. Energy, vol. 113, pp. 1043–1058, 2014, doi: 10.1016/j.apenergy.2013.08.061.
[4]L. Yang, H. Yan, and J. C. Lam, “Thermal comfort and building energy consumption implications - A review,” Appl. Energy, vol. 115, pp. 164–173, 2014, doi: 10.1016/j.apenergy.2013.10.062.
[5]E. Iturriaga, A. Campos-Celador, J. Terés-Zubiaga, U. Aldasoro, and M. Milagros´ Milagros´alvarez-Sanz, “A MILP optimization method for energy renovation of residential urban areas: Towards Zero Energy Districts,” Sustain. Cities Soc., vol. 68, p. 102787, 2021, doi: 10.1016/j.scs.2021.102787.
[6]A. R. Amaral, E. Rodrigues, A. Rodrigues Gaspar, and Á. Gomes, “Review on performance aspects of nearly zero-energy districts,” Sustain. Cities Soc., vol. 43, pp. 406–420, Nov. 2018, doi: 10.1016/J.SCS.2018.08.039.
[7]M. Christenson, H. Manz, and D. Gyalistras, “Climate warming impact on degree-days and building energy demand in Switzerland,” Energy Convers. Manag., vol. 47, no. 6, pp. 671–686, Apr. 2006, doi: 10.1016/J.ENCONMAN.2005.06.009.
[8]T. CIBSE, Degree-days: theory and application. 2006.
[9]D. Lindelöf, “Bayesian estimation of a building’s base temperature for the calculation of heating degree-days,” Energy Build., vol. 134, pp. 154–161, Jan. 2017, doi: 10.1016/J.ENBUILD.2016.10.038.
[10]Q. Meng and M. Mourshed, “Degree-day based non-domestic building energy analytics and modelling should use building and type specific base temperatures,” Energy Build., vol. 155, no. September, pp. 260–268, 2017, doi: 10.1016/j.enbuild.2017.09.034.
[11]D. Ruch and D. E. Claridge, “A four-parameter change-point model for predicting energy consumption in commeroial buildings,” J. Sol. Energy Eng. Trans. ASME, vol. 114, no. 2, pp. 77–83, 1992, doi: 10.1115/1.2929993.
[12]M. Álvarez-Sanz, Á. Campos-Celador, J. Terés-Zubiaga, and P. Larrinaga-Alonso, Development of a Simple Model for the Estimation of the Space Heating Demand Reduction due to Retrofitting Actions. 2019.
[13]T. Catalina, V. Iordache, and B. Caracaleanu, “Multiple regression model for fast prediction of the heating energy demand,” Energy Build., vol. 57, pp. 302–312, 2013, doi: 10.1016/j.enbuild.2012.11.010.
[14]Meteonorm, “Meteonorm Data Base,” 2022. https://meteonorm.com/en/ (accessed Jun. 20, 2022).
[15]S. Philip, “eppy 0.5.52 Documentation,” Github Repository, 2019. https://github.com/santoshphilip/eppy.
[16]J. Téres-Zubiaga, K. Martín, A. Erkoreka, and J. M. Sala, “Field assessment of thermal behaviour of social housing apartments in Bilbao, Northern Spain,” Energy Build., vol. 67, pp. 118–135, Dec. 2013, doi: 10.1016/J.ENBUILD.2013.07.061.
[17]J. Téres-Zubiaga, A. Campos-Celador, I. González-Pino, and C. Escudero-Revilla, “Energy and economic assessment of the envelope retrofitting in residential buildings in Northern Spain,” Energy Build., vol. 86, pp. 194–202, 2015, doi: 10.1016/j.enbuild.2014.10.018.
[18]T. Catalina, J. Virgone, and E. Blanco, “Development and validation of regression models to predict monthly heating demand for residential buildings,” Energy Build., vol. 40, no. 10, pp. 1825–1832, 2008, doi: 10.1016/j.enbuild.2008.04.001.
[19]AENOR, “UNE 100002:1988 Climatización. Grados-día base 15 grados centígrados.” 2007, Accessed: Jun. 20, 2022. [Online]. Available: https://www.une.org/encuentra-tu-norma/busca-tu-norma/norma?c=N0007753.

Monitoring and energy management strategy during the energy refurbishment plan of the social rental housing stock of the Basque Country

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Key Words: Building and environmental monitoring, Building energy retrofitting, Indoor air quality, Occupant behaviour, Social rental housing.

Abstract
Energy efficiency of buildings is one of the main concerns in the sector given the current objectives of decarbonizing the built stock. Furthermore, within this stock of buildings, there is an important type of social rental housing of out in this building typology within the framework of a collaborative project. The aim is to establish the necessary means to guarantee the interior conditions of hygrothermal well-being and control of energy consumption on a social renting housing block. The paper shows the overview of the proposed platform, based on a preload system in which a series of enabling technologies have been combined. Results of the research showed the correct behaviour of the implemented system leaving open the research line for long-term monitoring in order to correlate the effect of different occupant profiles and the behaviour of the building.

7. Introduction

Buildings are responsible for 40% of energy consumption in Europe [1]. In this context, the energy refurbishment becomes the cornerstone in order to update and adapt existing buildings to current energy and comfort requirements. With that aim, several solutions can be identified in order to improve buildings energy efficiency, from the addition of thermal insulation in facades [2] or the improvement of airtightness [3] to reduce the energy losses produced by the envelope to the integration of renewable energy systems (RES) [4] for the implementation of monitoring solutions [5].
Nowadays, we live in the information society where data is increasingly becoming an indispensable asset. Due to this, and given the scope that concerns us, the new models known as Smart Cities or Smart Buildings take on vital importance with the ultimate purpose of improving the quality of life of citizens through the information that surrounds us [6]. As previously indicated, buildings monitoring becomes a useful alternative in order to improve energy efficiency of buildings. The advantages it offers, among others, is the quantification of relevant indicators such as energy consumption, interior comfort, air quality or characteristics of the thermal envelope.
As stated by various authors [7-9], residents become the cornerstone in the behavior of the building. Furthermore, monitoring technologies are presented as key tool for real data collection, thus understanding occupants' behavior and allowing improving buildings performance. In this sense, monitoring and automation allows the user to offer direct information on their energy consumption to later make them aware of habits that are more efficient and finally be able to observe and understand the effect that these changes have had thanks to the feedback received. According to Darby's research [10], this feedback can lead to a reduction in energy consumption of up to 15%. In line with this issue, this research proposes to implementation of a technological platform in order to detect the existing relation between occupants behavior and buildings performance.

With this purpose, this study presents the work that the authors are developing within the framework of a collaborative project between the university (University of the Basque Country), the public administration (Alokabide) and a private company (STECHome). Alokabide manages social rental housing in the Basque Country, northern Spain; through its previous project, “Plan Zero Plana” diagnosed the building stock according to building model, construction system, accessibility and energy systems. The innovative energy management system “AuGe” developed by STECHome has been implemented in 15 buildings managed by Alokabide, with centralized heating and DHW. This system uses temperature and humidity sensors located in the living rooms of the dwellings and consumption measurement units that transmit the information live to a data visualization system accessible to the occupants and managers. The aim is to measure occupants’ interaction with the building in order to achieve energy savings and reduce energy inequality and poverty.
On this basis, this research aims to present the project framework to be able to analyze the current situation of social rented housing from a comfort, energy consumption and social profile perspective, in order to analyze different improvement strategies from a life-cycle perspective.

2. Background

a. Social assessment and occupants behavior in buildings

User behavior refers to their presence, movement and interaction within the building with its elements and appliances. Monitoring this behavior provides insight into the occupant’s behavior, needs and attitude towards more sustainable strategies [11]. Including their behavior allows for a broader understanding of the building’s performance.
User behavior is a variable that has to be taken into account already at the design stage as the author Guerra-Santil points out in the developed study [11]. As result, applied in two case studies, the author finds that the level of activity of the residents together with employment conditions or the household position have a direct effect on occupant behavior. In further studies [12] has proposed a method of how to include occupant behavior in the performance of nZEB buildings.
Regarding which methods to use to consider user behavior, it has been found that using oversimplified methods makes the results between simulation and reality more distant [13]. It is important to combine qualitative and quantitative methods based on data collection and modelling. The International Energy Agency (IEA) Energy in Buildings and Community (EBC) Program Annex 66 [13] defines a methodological structure for this approach, which includes the full process from data collection, behavior model representation, and modelling and evaluation approach.

b. Monitoring technologies

Building monitoring has long been a tool for monitoring multiple parameters with the aim of knowing their real behavior. However, with the recent arrival of the digitization process that the sector is experiencing and the new technological paradigms, an important revolution is taking place in this area [14]. In this sense, specifically the Internet of Things (IoT) [15] takes on a fundamental role as an enabling technology for the interconnection between the physical and digital world.
Nowadays, there is a plethora of IoT technologies applicable to the construction sector [16]. Among them, solutions based on Wi-Fi technology stand out due to their high availability in buildings or ZigBee and Z-Wave given the many technological solutions available in the field of building automation and industrial applications. However, in recent years, other promising solutions based on Low Power Wide Area Network (LPWAN) technology have also emerged, with a forecast of 11% of IoT connections by 2025 [17]. In addition, these technologies are mainly characterized by meeting two of the most important requirements in building monitoring, offering low energy consumption of the devices and a long transmission range [18].

3. Material and methods

This section provides the general overview of the more relevant details of the project and carried out steps in the research. For it, the section is divided into the following subsections: Project framework and case study, Social assessment and Deployed technology.

a. Project framework and case study

As previously indicated, the public company Alokabide, member of the project, is responsible for an important stock of social rental housing in the Basque Country, owning 136 buildings that bring together 7408 dwellings.
In line with current strategies and with the aim of pursuing a decarbonized park, Alokabide has implemented an innovative system called Plan Zero Plana for the energy management of 15 of its buildings, thus reaching 1388 homes. The objective of the system is to control and measure the behavior of users with the building in order to achieve the desired energy savings and improve the health and well-being of its users.
Due to the large stock of buildings considered in the program and with the aim of narrowing the scope of work, this research will focus on the presentation and analysis of a case study. For this, a case study of all the buildings has been selected, Figure 1, which forms a representative example of the existing building stock.

Figure 1. Analyzed case study.

The building is located in the municipality of Vitoria-Gasteiz and was built in 2010. It has 6 C-shaped floors, although the ends of the building have eight floors. In total, the building houses, 155 homes with one, two or three bedrooms and an average surface area of 76.18m2. The Energy Performance Certificate (EPC) rate is D (primary energy consumption of 122 kWh/m2 year and emissions of 25 kg CO2/m2 year). The heating system is central by means of a gas boiler and the interior of the houses use hot water radiators. In addition, the building has a low-temperature solar collector system for the production of DHW to support the central system and hygro-adjustable controlled mechanical ventilation system.

b. Social assessment

In this case, it has been used the classification defined by the INE in the Household Budget Survey [19], which takes into account the number of people living in the household, their ages and family relationships, classifying them into the most relevant or representative ones. Single person aged 65 or more, single person aged under 65, couple without children, couple with one child, couple with two children, couple with three or more children, an adult with children or other types of households.

In this classification, we have added those variables that allow us to define more complete profiles beyond the number of people, age and family relationships living in the household. But also their presence throughout the day and the net monthly income of the family unit.
Therefore, two profiles have been chosen for this research, considered opposed in number of inhabitants and occupancy profile, one a couple with three or more children (P1) and a single adult (P2). The results show the average of the dwellings of each profile chosen so that patterns and differences between profiles can be detected while protecting the anonymity of each family unit.

Occupants social profile	
Profile	***Number of dwellings***
No. couple with a child dwellings	21
No. couple with two children dwellings	16
No. couple with three or more children dwellings	20
No. single adult with children dwellings	13
No. other dwellings	0
Unknown	34

Occupants social profile	
Profile	***Number of dwellings***
No. single person (⩾65years) dwellings	0
No. single person (<65years) dwellings	33
No. couple dwellings	18

Table 1. Social profile of case study

c. Deployed technology

Figure 2 shows the deployed general IoT architecture for the present project, considering the physical or perception layer, the transmission layer and the application layer. Implemented temperature and relative humidity (T/RH) sensors are the model RFM-AMB, of the Bmeters manufacturer, with a typical accuracy of ± 0.4ºC and ± 3% respectively. For consumption measurements, Sontex Superstatic 789 were implemented for the heating consumption of each home based on the flow rate and the temperature difference. Additionally, the device offers two additional pulse inputs, one of which has been used to read the volume of DHW consumed by each home. Regarding to the communication system, it was deployed a gateway C300 and a series of R300 repeaters of Usanca manufacturer in order to establish the Wireless M-Bus communication protocol inside the building, for both sensors and meters. Furthermore, both the heating system and the DHW system can be remotely controlled through solenoid valves governed by Selekron Xikra230 control modules connected in this case via Ethernet that activate the relays using http commands.
Finally, so that users can interact, keep track of all the information and proceed to make payments for the preload system, each of the homes has a tablet where they can manage the Plan Zero Plana system through a Graphical.User Interface (GUI), Figure 3 The entire platform works on the servers that the company has in its facilities. In relation to the data, it is stored through the phpMyAdmin tool that manages the MySQL database.

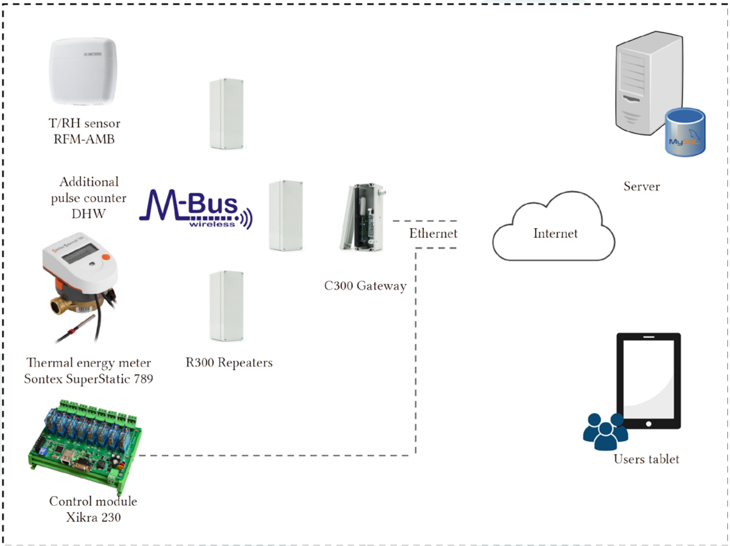

Figure 2. IoT architecture of the AuGe energy management system

Figure 3. GUI of the AuGe system through te tablet

4. Results and discussion

a. Analysis of the monitoring results and occupant profiles

This section shows the first results that are being collected from the monitoring of the dwellings. Given that the monitoring system has been implemented gradually, the data obtained correspond to two intervals, on the one hand to the period 19/02/2019-31/12/2020 for the temperature and relative humidity profiles, Figure 4, and on the other hand to the period 16/06/2020-30/04/2021 for the case of heating and DHW consumption, Figure 5.

In order to show anonymous data and thus save the required privacy of users, they have been reflected according to the previously presented P1 and P2 profiles, reflecting the daily mean value of each of the profiles. In relation to the thermal comfort data, the results show daily mean values of the entire interval for the P1 and P2 profiles of 20.56 ± 3.05 ºC and 21.50 ± 3.21 ºC respectively. These first averaged results do not clearly show the difference. However, if the graph Figure 4 is observed during the winter periods, the difference between the two profiles can be more easily appreciated, as well as the temperatures obtained below the minimum value of 18ºC recommended by the WHO for the P1 profile. In this sense, the daily mean heating consumptions, Figure 5, allow to corroborate this circumstance since there is a notable difference between both profiles P1 and P2, being 2.51 kWh and 9.07 kWh respectively.
Users have been aware of the purpose of the study from the time the sensors were installed. However, awareness of the measurements has not led to changes in energy use. Regarding the influence of Covid 19 disease, the confinement from March to May 2020 and the subsequent partial restrictions in autumn 2020 and winter 2021 have not led to a change in relative humidity and temperature or in heating and DHW consumption.
Due to the complexity of measuring the radiant temperature and due to the limitations of the technology used, this study focuses on measuring the air temperature of the spaces previously mentioned.

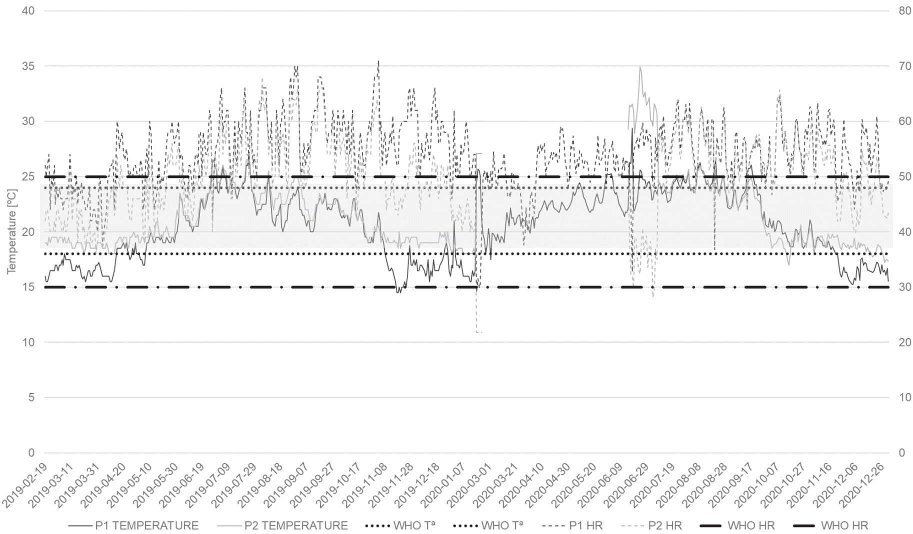

Figure 4. Monitored temperature and relative humidity mean values according to profiles

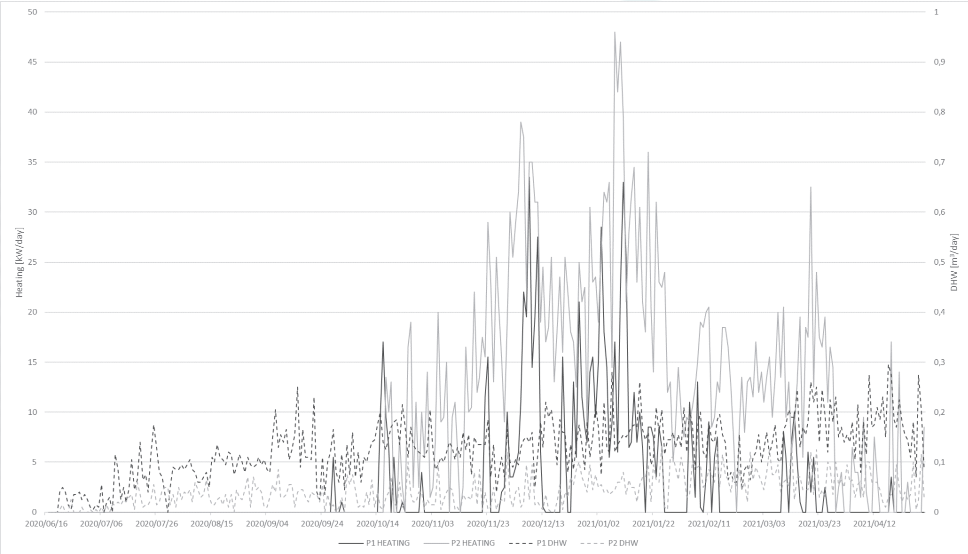

Figure 5. Monitored heating and DHW consumption mean values according to profiles

5. Conclusions

The results obtained in this study have made it possible to demonstrate the reliability of the deployed monitoring and energy management system. The study has made it possible to highlight the notable differences obtained between the user profiles of the analyzed case study, thus being able to glimpse the first relationships between these profiles with the thermal and energy behavior of the buildings. However, it is worth noting the limitations of the present research caused by the slightly different measurement periods between comfort and consumption values. That is why in order to be able to show more clearly these first conclusions obtained in the present investigation, future works will focus on collecting a greater volume of data as well as from the same periods in order to be able to be comparable all the results.

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6. References

[1] European Parliament, '"Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast), Official Journal of the European Union." Dir. 2010/31/EU, pp. L 153/13.
[2] M. Andreotti, D. Bottino-Leone, M. Calzolari, P. Davoli, L. Dias Pereira, E. Lucchi and A. Troi, '"Applied Research of the Hygrothermal Behaviour of an Internally Insulated Historic Wall without Vapour Barrier: In Situ Measurements and Dynamic Simulations," Energies, vol. 13, no. 13, pp. 3362.
[3] A. Martín-Garín, J.A. Millán-García, J.M. Hidalgo-Betanzos, R.J. Hernández-Minguillón and A. Baïri, '"Airtightness Analysis of the Built Heritage–Field Measurements of Nineteenth Century Buildings through Blower Door Tests," Energies, vol. 13, no. 24.
[4] E. Lucchi, C.S. Polo Lopez and G. Franco, '"A conceptual framework on the integration of solar energy systems in heritage sites and buildings," IOP Conf. Ser. Mater. Sci. Eng., vol. 949, no. 1.
[5] M.W. Ahmad, M. Mourshed, D. Mundow, M. Sisinni and Y. Rezgui, '"Building energy metering and environmental monitoring – A state-of-the-art review and directions for future research," Energy Build., vol. 120, 5/15, pp. 85-102.
[6] L.G. Anthopoulos, '"Understanding the smart city domain: A literature review," Transforming City Governments for Success. Smart Cities, pp. 9-21.
[7] J. Kim, T. Hong, J. Jeong, M. Lee, M. Lee, K. Jeong, C. Koo and J. Jeong, '"Establishment of an optimal occupant behavior considering the energy consumption and indoor environmental quality by region," Appl.Energy, vol. 204, pp. 1431-1443.
[8] E. Delzendeh, S. Wu, A. Lee and Y. Zhou, '"The impact of occupants' behaviours on building energy analysis: A research review," Renewable Sustainable Energy Rev, vol. 80, pp. 1061-1071.
[9] B.F. Balvedi, E. Ghisi and R. Lamberts, '"A review of occupant behaviour in residential buildings," Energy Build., vol. 174, pp. 495-505.
[10] S. Darby, '"The effectiveness of feedback on energy consumption. A Review for DEFRA of the Literature on Metering, Billing and direct Displays," Oxford Environmental Change Institute, vol. 2019, no. September 15.
[11] O. Guerra-Santin, N. Romero Herrera, E. Cuerda and D. Keyson, '"Mixed methods approach to determine occupants' behaviour – Analysis of two case studies," Energy Build., vol. 130, pp. 546-566.
[12] O. Guerra-Santin, H. Bosch, P. Budde, T. Konstantinou, S. Boess, T. Klein and S. Silvester, '"Considering user profiles and occupants' behaviour on a zero energy renovation strategy for multi-family housing in the Netherlands," Energy Effic., vol. 11, no. 7, pp. 1847-1870.
[13] T. Hong, D. Yan, S. D'Oca and C.-. Chen, '"Ten questions concerning occupant behavior in buildings: The big picture," Build.Environ., vol. 114, pp. 518-530.
[14] L. Grosso Sategna, D. Meinero, M. Volontà, '"Digitalising the Construction Sector. Unlocking the potential of data with a value chain approach.".
[15] L. Atzori, A. Iera and G. Morabito, '"The Internet of Things: A survey," Computer Networks, vol. 54, no. 15, 10/28, pp. 2787-2805.
[16] A. Martín-Garín, J.A. Millán-García, A. Baïri, M. Gabilondo and A. Rodríguez, '"IoT and cloud computing for building energy efficiency (Ch. 10)," Start-Up Creation 2nd Edition: The Smart Eco-Efficient Built Environment, 2020, pp. 235-265.
[17] M. Arnott, E. Buckland, M. Ranken and P. Owen, '"IoT Global Forecast and Analysis, 2015-2025.", vol. G00325939.
[18] K. Mekki, E. Bajic, F. Chaxel and F. Meyer, '"A comparative study of LPWAN technologies for large-scale IoT deployment," ICT Express, vol. 5, no. 1, March 2019, pp. 1-7.
[19] Instituto Nacional de Estadística (INE), '"Encuesta de Presupuestos Familiares (EPF). Metodología.," Instituto Nacional de Estadística.

Improving the urban environment through a zero energy university building: the Soria campus R&D + i.

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Key Words: NZEB, Urban NZEB, Valladolid, Health and comfort.

Abstract

The Universidad de Valladolid (UVA) has built a 3,500 m2 R&D + i (Research & Development + Innovation) building on the Soria University Campus, for R&D + i activity and training. It is designed to adapt to educational changes. The UVA has been investigating how to improve the sustainability of its new buildings for the last ten years or so. In the Soria building, we have also tried to improve the urban connections between its location – in the outskirts of Soria – and the same small town of around 39,000 inhabitants.
With this approach, the new building covers three objectives: to achieve a nearly zero-energy building (NZEB) performance; to make it functionally adaptable to an educational and changeable use; and to improve the nearby urban landscape. The three objectives must coordinate with each other to achieve a coherent and harmonious solution.
Three strategies have been used for obtaining the NZEB objective. They are: (a) multiple design solutions that minimise energy demand, (b) the incorporation of selected technologies with strict energy efficiency criteria and (c) the generation of on-site energy.
For this, the external conditions and the location have been studied and assessed, to make the site its own energy resource (through geothermal energy, solar wall, and photovoltaic production). The dynamic simulation carried out with Design Builder version 5 showed a reduction in final energy consumption of 84% compared to the current requirements of the Spanish CTE regulation, and 81% in non-renewable primary energy, which represents an 86% reduction in emissions of CO2. Its energy certification is A, and it is being evaluated through the international LEED and national VERDE-GBCe certifications.
We have also designed a building which is capable of continuous adaptation to the changing needs of education, taking into consideration both its spatial and geometric possibilities and its internal conditions of use. We have considered variables such as air quality, humidity, temperature, comfort, hygiene, lightning, and ventilation with the aim of making them optimal at all times. The building opened its doors during the Covid-19 pandemic. Since then, it has proven its characteristics of adaptability to the ever-changing conditions of the pandemic and health protocols, being fully operational during this hazardous time. In summary, the building proved its comfort and security during such an unexpected situation.
The original site was a semicircular plot bordering a vacant area in the form of embankment, just on the edge of the urban area. It was next to sports facilities, and nobody had planned any specific use for the site or any specific urban norms for it. However, it was decided to locate the research centre there - basically on wasteland - because use can be made of the energy possibilities (especially geothermal) of the embankment and improve the connection of this area with the rest of the town. Hence, the building offers a sense of community and increases the green feeling of the area.
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1. Introduction

1.1.Programme and location

The new building has an area of 3,500 m2, made up of two areas. The first is of 900 m2, for laboratories or pilot plants that require large spaces, both in terms of floor area and height, to accommodate large machinery. Structurally, it is covered by wide-span beams, made of local wood, the area having abundant forest. The other area, parallelepiped, is distributed over four floors, consisting of laboratories (300 m2), research and specialised classrooms (600 m2), offices and headquarters (600 m2), classrooms and other dependencies making up a total of 2,600 m2. (Figure 1).

Figure 1. Laboratory and classroom areas. Photo: Antonio V. 2022

The site planned for the construction of the multipurpose building closed out a semicircular shaped plot, terminating a group of aligned areas for different university uses. In addition, this plot bordered an embankment plot on the edge of the urban area, at the time a wasteland for which no specific use had been designated, next to sports fields. In the design phase, however, it was decided to place the new building on the wasteland and not to finish off the arc of the planned plot in order to take advantage of the energy benefits of this terracing. The new building on the plot is connected to the rest of the Campus buildings by means of an access walkway. The green space is thus accessible from the perimeter, at different heights, opening onto the sports fields. (Figure 2).

Figure 2. Location of the building in the complex. Project. 2018.

This change of location has created a space that closes off the Campus space centrally, creating a whole and giving a sense of community, while at the same time completing the plot on the edge of the city with a well-conditioned and finished area alongside the sports areas, adding quality to the spaces on the edge of the city and forming a coherent, controlled, permeable, green and, most importantly, usable space[1].

Previous holistic experiences

The building was constructed between 2018 and 2020. The University of Valladolid had previous NZEB experience (Nearly Zero Energy Building). This was in the form of the LUCIA[2] building, built 2014, intended for technology transfer laboratories; and the IndUVA classroom building, built 2018.[3] Both obtained optimal results in terms of sustainability, certified by external institutions (platinum results in the LEED international certification and 5 leaves in the VERDE-GBCe national certification).
The aim for this building on the Soria Campus was to continue researching and improving on the previous results, adapting them to changing circumstances and to be specific to the location and the town, Soria, expanding their social aspects in terms of health, air quality, comfort and accessibility and the decarbonisation of architecture through the use of wood. At the same time, the insertion of the building in the plot was intended to finish off and provide a solution to the urban edge of the city, previously somewhat degraded. Enabling a barren field and opening it to the widely used sports field can provide a real example of how a building can create and improve urban space and reduces the heat island effect.[4]

2. Discussion: measures applied

2.1. Health and comfort.

Accessibility, air quality, natural lighting and acoustic and comfort levels were calculated in such a way that they exceeded those required by Spanish regulations and in accordance with recognised environmental assessment systems. Views of the landscape, natural lighting, a good level of acoustic control and guaranteed air quality through ventilation are key elements for achieving comfort and improving the health of the occupants.[5]
The building is located in an area on the outskirts of the town of Soria and is of excellent quality (ODA 1 with 0 dp). In addition to natural ventilation, indoor air quality was planned for with continuous centralised ventilation, classified as IDA-C1. The heat recovery unit is included in the ventilation system. In addition to this, the use of non-VOC materials (Volatile Organic Compounds) was insisted on, in addition to other requirements, such as the Environmental Product Declaration, EPD, for each product along with their complete environmental definition, together with the use of local materials to the extent possible.[6]
The acoustic levels were also planned to be stricter than Spanish regulations, to ensure comfort consistent with a facility intended for teaching or learning, as well as to allow uses generating more noise such as pilot plant workshops.
Natural lighting is considered to improve health, in addition to reducing energy demand.[7] Offices and classrooms have large light areas, with views to the outside and to the green areas. The stairs, corridors and toilets also have direct natural lighting. The upper floors have skylights for the introduction of natural light, and the semi-basement floor receives light from components that introduce natural light with "solatube" type amplification elements.

2.2. Energy efficiency

The first action in the conception of the NZEB building was the geographical and geomorphological study of the plot, its sunlight, winds, and peculiarities of the environment. The embankment takes advantage of its geothermal characteristics, supporting renewable energy systems, while at the same time its earthworks create its own shielding with gabions and stone.

Two of the levels of the building, workshops and laboratories have been built against the hillside, taking advantage of the fact that the site has two natural platforms. This reduces the energy demand for these spaces, allowing the implementation of a passive conditioning strategy in the building through the accumulation of energy in the retaining walls and in the ground.[8] The slope can be considered an important reservoir or accumulator of temperature.

2.3. Passive design – orientation

The walls of the facade have been selected based on the orientation, the volume, the sunlight and the zones to which they give use. Each facade, including floor and roof, has its own strategy in reference to the capture of renewable energy.
On the Southeast facade, one of the faces of the laboratory must be windowless due to its use as an entrance for materials, so a solar wall was placed on it, consisting of a hot air accumulator that runs through a large part of its facade surface. It is a mainly passive system that allows the heating of the air chamber by radiation on the facade wall material. This aids in reducing energy demand, preheating the air for the interior circuit.[9] (Figure 3)

Figure 3. Solar wall for air preheating, and green roof . Photo: MJGD.2021

The Northeast facade houses the classes and laboratories, open to views, solar radiation and natural lighting, protected from direct radiation with solar control glass. (Figure 4)

Figure 4. The semi-buried Southwest facade connects with the corridor area, and facilitates views, natural ventilation and also houses the facade with vertical photovoltaic panels.10

2.4. Envelope

Thermal transmittances:

- Sheet metal facade (workshops): 0.168 W/m²K (including substructure thermal bridges)
- Photovoltaic facade: 0.232 W/m²K
- Composite facade: 0.227 W/m²K
- Composite facade (workshops): 0.255 W/m²K
- Blind panel curtain wall facade: 0.335 W/m²K
- Workshop roof (green roof): 0.18 W/m²K
- Classroom block roof (green roof): 0.157 W/m²K
- Access hall roof: 0.292 W/m²K
- Floor machine workshop: 0.313 W/m²K
- Floor classroom building: 0.308 W/m2K
- Roof skylights: 0.5 W/m²K
- Aluminium framings: Model COR 70 IND. U frame = 1.9 W/m²K
- Glazing: Double with 16mm Argon chamber and Planitherm 4S low-emission treatment or Guardian Sun on face 2. Characteristics Ug = 1.1 W/m²K, g = 0.38 Tl = 0.65. (In the programme 1.4 W/m²K has been introduced, according to NFRC regulations)

2.5. Energy systems

The various passive strategies of bioclimatic design and renewable energy production are combined with other semi-active ones to reduce demand. Among them, the pre-treatment of air with geothermal tubes (also erroneously called Canadian wells) and the solar wall. The active ones include the geothermal heat pump, high-efficiency heat recovery and the production of photovoltaic solar energy. All this is controlled by intelligent lighting control systems, HVAC systems and a Building Management System (BMS). The result is a complete system based on the coordination of passive, semi-active and active systems, with a preponderance of energy production in situ.
The solar wall acts as a preheating system with a new technical and experimental solution, composed as follows: Thickness: 0.7 mm - Material: galvanised steel S220 GD + ZA 255 - Finishes: - Outer side: hot-dip metallic coating base of 95% Zinc and 5% Aluminium. - Inner side: 10 µm polyester. Reaction to fire: A2 - S1 - d0 according to EN 13501 - 01. - Width: 1000 mm - Colour: Black
The photovoltaic wall is made up of Photovoltaic cells: Onyx Solar, 283 units of Amorphous Silicon Photovoltaic Glass with dark transparency have been supplied in standard measurements of 1245 x 635 mm and 3 + 4 mm configuration.

2.6. Energy design and simulation

The energy behaviour of the building was simulated in the Execution Project using EnergyPlus 8.5.011. Project data was entered into the program to assess compliance with the required regulations, and the improvements achieved with respect to Spanish regulations and other regulations and standards. To include the combination of active and semi-active components, simplifications or interpretations of the model had to be made to capture the coordination complexity of the energy systems. However, it is considered that these simplifications or hypotheses do not substantially alter the results obtained in the simulation, which is valid and representative of the Project. They are as follows:

-The occupancies and loads of equipment have been considered conventional for offices and classrooms (from 8 a.m. to 8:00 p.m., Monday to Friday), and lighting values in accordance with the instructions and VEEI (Value for the Energy Efficiency of the Installation) of regulations for each of the rooms of the building, individualised, according to the project.

-The planned ventilation is somewhat higher than the ASHRAE 62.1 standard (0.18 ACPH during non-operation hours).

-The composite cladding of the ventilated facade has been entered as a surface thermal resistance material corresponding to still air. This thus takes into account the non-convection on the insulation of the ventilated chamber.

-The green roof is considered as a layer of topsoil, without specifying the type of plant, taking into account the dry climate of Soria (Cfb - Köppen Climate Classification subtype).

-The trapezoidal geometry of the curtain wall of the large workshops space has been simplified into simple elements, so that the surface of the sandwich panel is equivalent to the real one.

-Geothermal wells have been modelled in a simplified way as pre-cooling and pre-heating batteries, as the program does not consider their direct use in association with an air conditioner.

-In the same way, the effect of the solar wall has been considered, as it is a variation not foreseen in the program. An air outlet temperature has been considered after pre-heating of the wall according to the detailed calculation12 of the Execution Project, by months and by hours.

-The cooling floor has been simulated as a cooling ceiling of a lower floor. For this, a buffer floor (unconditioned transition space) between both floors has been considered, and with a false ceiling height of the lower floor.

-In winter, a comfort temperature of 18ºC has been considered for the workshops, sufficient for light industrial work with a higher metabolic rate than the rest of the building, instead of the temperature of 21ºC, which is less adequate and would present many hours outside of range.

3. Results

3.1. Use of materials

The pre-assessment regarding the use of materials, in accordance with the pre-certification with the VERDE-GBCe tool, analyses the construction materials for the structure, walls, load-bearing elements and partitions, flooring, cladding and fixed elements, regardless of the installations[13]. This is an advance in the circular economy and regionality criteria to reduce the impact of materials on the environment. The pre-assessment carried out indicates that 41.36% of the materials used in the building, by weight, are of local origin, travelling a distance of less than 200 km. 63.59% are elements that have an Environmental certification (in general EPD, Environmental Product Declaration). 7.6% are recycled elements, and 17.75% are recyclable elements.

3.2. Seasonal energy results

Various results are extracted from the energy simulation in a simplified manner: With respect to energy consumption, on a typical winter day, the highest consumption comes from equipment, IT and utilities (miscellaneous), followed by fans. (Figure 5)

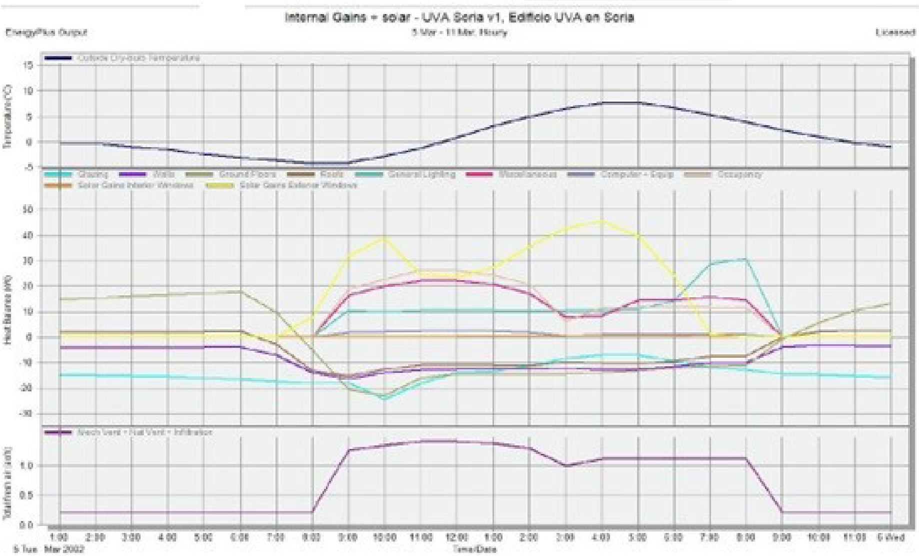

Figure 5. Winter gains- Temperature (ºC) and heat balance (kWh). DanielPascual. 2017

With regard to a typical summer day, the greatest gains are direct solar radiation, hence the importance of solar control glass. In daily use, the biggest load is again that of the equipment, fans and lighting. Refrigeration consumption is low thanks to evaporative cooling. (Figure 6)

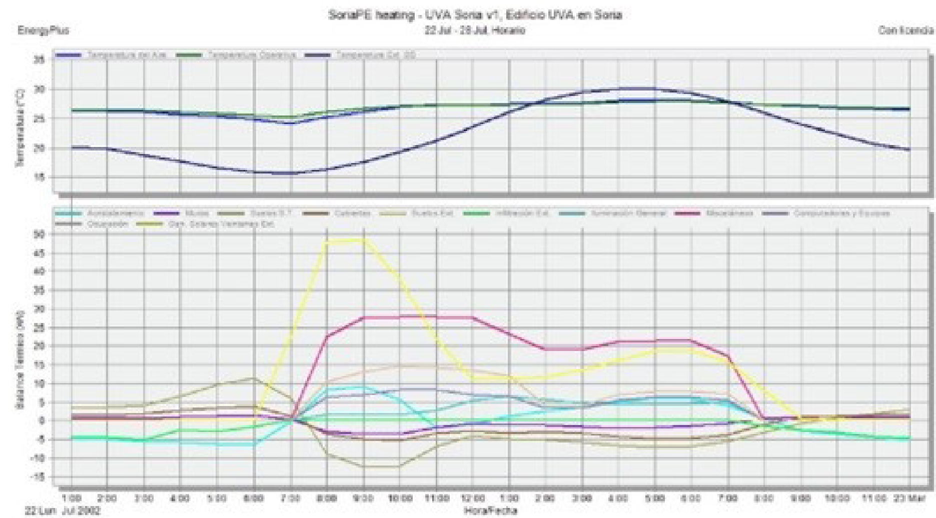

Figure 6. Summer gains- Temperature (ºC) and heat balance (kWh). DamielPascual. 2017

As a whole, the significant annual energy consumption of the building is in the equipment and, secondly, in the fans. Compared to the consumption of these, that of the heat pump in heating and cooling is low. (Figure 7)

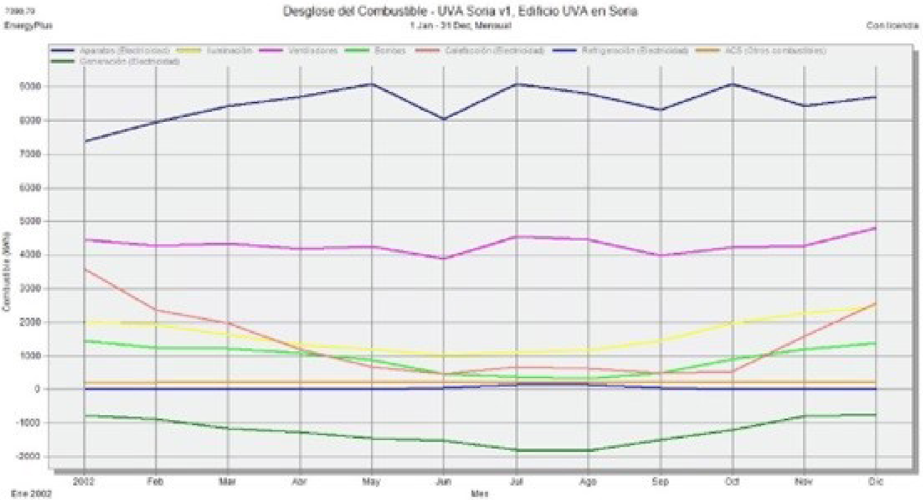

Figure 7. Fuel breakdown based on the year. DaniePascual. 2017

Compared to the equipment in the building (computers, etc.), the consumption of heating and cooling is very low. This is due to the projected passive measures and the correlation between envelope and orientation, already described, and ventilation with high efficiency recovery and variable flow controlled with CO2 probes. The geothermal tube and solar wall systems provide great support to the system to thermal storage.[14]

3.3. Energy results in absolute terms

The total expected energy consumption is 202,950 kWh per year, without considering Domestic Hot Water (DHW), which represents an impact per built m2 of 77.0 kWh/m2, of which 42% corresponds to equipment, 21.69% to fans and 14.07% to heating production (Table 1). The estimated production of the photovoltaic installation is 14,916 kWh/year, and the percentage covered by the photovoltaic installation of the electrical energy demanded is 7.35%.

Final energy consumption			
FINAL USES	Electricty (kWh)	Geothermic tubes - Cold (kWh)	Geothermic tubes and solar wall - Heat (kWh)
Heating	12,557.80		21,052.69
Cooling	4,546.20	11,895.80	
Interior lighting	19,510.20		
Equipment	102,033.20		
Fans	51,591.94		
Pumps	10,973.94		
Heat recovery	1,595.20		
Water system	2,615.47		
TOTAL FINAL USES	205,423.95	11,895.80	21,052.69

Table 1. Final energy consumption

Finally, energy system efficiency is estimated by comparison with the LEED standards and in comparison, with the Spanish CTE, summarised in the following table (Table 2)

CTE Reference building (Spanish Code -2017)							
	Demand	FE	PE coef.	no renov. PE	CO2 coef.	CO2 Emissions	
	kW/h	kW/h	kWh/kWh	kW/h	kgCO2/kWh	kgCO2	
Heating	330,103,7	471.576,8	1,179	555.989,0	0,311	146.660,4	
Cooling	69.888,20	41.110,7		80.330,3		13.607,6	
Lighting		131.557,60	1,954	257.063,6	0,331	43.545,6	
Equipment		102.033,2		199.372,9		33.773,0	
TOTAL		746.278,3	kWh	1.092.755,8	kWh	237.586,6	kgCO2
		283,1	kWh/m2	414,6	kWh/m2	90,1	kgCO2/m2
Reference building LEED							
	Demand	FE	PE coef.	no renov. PE	CO2 coef.	CO2 Emissions	
	kW/h	kW/h	kWh/kWh	kW/h	kgCO2/kWh	kgCO2	
Heating		182.114,3		355.851,3		60.279,8	
Cooling		52.820,8		103.211,9		17.483,7	
Fans		115.912,6		226.493,2		38.367,1	
Lighting		91.300,9		178.402,0		30.220,6	
Equipment		102.033,2		199.372,8		33.773,0	
TOTAL		544.181,8	kWh	1.063.331,2	kWh	180.124,2	kgCO2
		206,4	kWh/m2	403,4	kWh/m2	68,3	kgCO2/m2
I+D+i Soria Building							
	Demand	FE	PE coef.	no renov. PE	CO2 coef.	CO2 Emissions	
	kW/h	kW/h	kWh/kWh	kW/h	kgCO2/kWh	kgCO2	
Heating		12.557,8		24.537,9		4.156,6	
Cooling		4.546,2		8.883,4		1.504,8	
Fans		51.734,3		101.088,9		17.124,1	
Pumps.		10.973,9		21.443,1		3.632,4	
H. Recovery		1.595,2		3.117,0		528,0	
Lighting		19.510,2		38.123,0		6.457,9	
Equipment		102.033,2		199.372,8		33.773,0	
PHV Genertaion		- 14.916,6		- 29.147,1		- 4.937,4	
TOTAL		188.034,2	kWh	367.419,0	kWh	62.239,4	kgCO2
		71,3	kWh/m2	139,4	kWh/m2	23,6	kgCO2/m2

Table 2. Comparison of the R+D+i building on the Soria Campus with the LEED and CTE building.

3.4. Context of the obtained results.

EnergyPlus 8.5.0. has been the dynamic simulation program used to model both energy consumption (heating, cooling, ventilation, lighting and plug and process loads, and water use) in the building. This international and known dynamic energy simulation program is a basic element to evaluate environmentally the building according to LEED and VERDE methods, but not the only one to complete the whole environmental evaluation.
The singularity on construction study cases makes unusual the comparison in absolute terms. Habitual building environmental evaluation methods used in Spain, (such as GREEN, LEED, VERDE, BREEAM, DGNB) establish not absolute terms but self-competition. Only Passivhaus standard (not a building environmental evaluation method) establishes absolute levels, focused on energy efficiency and thermal performance. It is not applicable in this case due to its own characteristics and limitations. Taking in account the purpose of the building (educational aulas and mechanical workshop), there are no comparable newly built buildings in national and international platforms specialized on sustainable construction (Construction21, LEED certified cases, VERDE and others). There are diversity of circumstances and situations between buildings, such as variety of purposes, location, targets, performances, intervention scale, uses, calculation methods and other, that make unscientific to make a comparison in absolute terms. Nevertheless, some references can be reported only as a guide.
According to the previous statement, some cases can be reported from the Construction21 platform. These show the scatter in absolute results, and the results regarding the primary energy of the realized building and the building itself in a hypothetical conventional standard performance:

- IME (Medical Educational Institute) -SESSAD La Fleuriaye. France, 2,092 m2. Year 2018. [15]

  -Primary energy need :79.10 kWhep/m2.year
  -Primary energy need for standard building :104.10 kWhep/m2.year

-URMA de Bruay / Saint-Saulve- France, 9,395 m2. Year 2018. [16]

  -Primary energy need :13.10 kWhep/m2.year
  -Primary energy need for standard building :7.,20 kWhep/m2.year

-Climate-positive zero-energy technical classroom wing in Aalen, Germany, 1100 m2. Year 2019. [17]

  -Primary energy need :47.00 kWhep/m2.year
  -Primary energy need for standard building :81.20 kWhep/m2.year

-LUCIA building. Valladolid. Spain. 5,356 m2. Year 2014. [18]

  -Primary energy need :285.00 kWhep/m2.year
  -Primary energy need for standard building: 339.00 kWhep/m2.year

-IndUVa Building, Valladolid. Spain. 5,539 m2. Year 2018. [19]

  -Primary energy need :307.00 kWhep/m2.year
  -Primary energy need for standard building: 431.00 kWhep/m2.year

As a conclusion, the best reference to know the performance of the building, in reliable terms, is making comparison with the building itself. It has been made in three different situations: a) having been carried out with the regulatory requirement criteria of the CTE (Spanish Code Regulations); b) in its comparison in case of having been carried out with LEED normative criteria; c) as it has been really built. The results are in the Table 2

4. Conclusions

The introduction of this building into the University fabric of the town, closing the urban edge with a building that represents the new environmental discipline, has had a two-fold effect. The first is increased environmental awareness across the town, the building being widely publicised in the local media. The second is the example set in the midst of the student population, who have a practical illustration proven with daily use, and whose scope in terms of sustainability will form part of their educational curriculum.
In summary, the design team has understood the implementation of this building to be another step that follows on from the previous ones already mentioned. The conclusions obtained will be used to improve knowledge in terms of sustainability in order to propose, in the next step, an extension of this with respect to local materials and the circular economy.
Energetically, the results evaluated allow us to conclude reductions in functional energy demand of 84% in lighting, 98% in heating and 56% in cooling, obtaining a total reduction in final energy consumption of 68% with respect to the current CTE requirements. This has been possible through the combination of several passive, semi-active and active systems, and they represent a further step in the investigation of building energy systems.
The general and global sustainability of the implementation can only be estimated and specified, today, through the environmental evaluation of the building with external and comparison tools, such as LEED, VERDE-GBCe and other systems. As the UVA has been doing in other previous buildings (the aforementioned LUCIA and IndUVA), sustainability will be evaluated and verified
by third parties through the LEED international sustainability and national VERDE-GBCe certifications, estimating the optimal ratings in the pre-evaluations.
The other health and comfort objectives can be verified through user satisfaction surveys (mostly of students), verified within the University's protocols.
One of the prerequisites of the programme for the building was adaptation to changing educational patterns. The achievement of the objective was proven with the outbreak of COVID-19: the building opened precisely during this pandemic, immediately verifying its adaptability to new circumstances and recent health and air quality demands. The laboratory hall was temporarily converted into classrooms and the ventilation system worked in accordance with the new health, social distancing and safety regulations without major difficulties. In this way, the protocols prior to the COVID-19 pandemic verified the adaptability of the building and its operation in unforeseen circumstances, to which the flexibility of the building and its efficient systems allowed it to adapt.

5.Reference

[1] Akbari H. and Konopacki S. 2005. Calculating energy-saving potentials of heat-island reduction strategies, Energ. Policy, vol. 33 , No. 6

[2] F. Valbuena, M.J. González La experiencia del edificio LUCIA: estrategias imprescindibles para conseguir el edificio de equipamiento de cero energía y en sostenibilidad. LUCIA Building experience: essential strategies for sustainability to achieve Near Zero Energy Building". 5th European Conference on Energy Efficiency and Sustainability in Architecture and Planning. EESAP5.ISBN 978-84-9082-003-2. San Sebastián 7-9 /07/2014 Pp.211-218.

[3] F.Valbuena, M.J.,González, R.Borja, Edificios inteligentes de alta ocupación con patrón discontinuo y variable: el aulario IndUva de la Universidad de Valladolid. III Congreso de edificios inteligentes. Madrid 20-21 Junio 2017. 21-23/07/2015. Pp 19-24. ISBN 978-84-697-3491-9

[4] Levermore G., Parkinson J., Leeb K., Laycock P. and Lindley S. 2018. The increasing trend of the urban heat island intensity, Urban Climate 24

[5] Farley, K. M., & Veitch, J. A. (2001). A room with a view: A review of the effects of windows on work and well-being. Institute for Research in Construction, National Research Council Canada

[6] Kephalopoulos S., Geiss O., Barrero-Moreno J., D'Agostino D., Paci D., 2016. Promoting healthy and energy efficient buildings in the European Union - National implementation of related requirements of the Energy Performance Buildings Directive (2010/31/EU)

[7] Boyce P., Hunter C. and Howlett O. 2003. The Benefits of Daylight through Windows. Rensselaer Polytechnic Institute, Troy. 2003

[8] Paksoy, H.; Snijders, A.; Stiles, L. State-of-the-art review of aquifer thermal energy storage systems for heating and cooling buildings. In Proceedings of the Effstock Conference, Stockholm, Sweden, 5–17 June 2009

[9] Ascione F., De Masi R.F., de Rossi F., Ruggiero S., Vanoli G.P. 2016. Optimization of building envelope design for nZEB in Mediterranean climate: performance analysis of residential case study, Applied Energy 183, 938–957.

[10] Montoro D.F., Vanbuggenhout P., and Ciesielska J. 2011. Building Integrated Photovoltai cs: An overview of the existing products and their fields of application (6th Framework programme for Research and Technological development of the European Commission).

[11] D.Pacual, Simulación de un edificio universitario en el Campus de Soria para la Universidad de Valladolid.. Danielpascual.com

[12] F.Valbuena García, M.J.González Díaz, M.J. Gutiérrez Cid, C. Cero energía en edificios de alta ocupación con patrón discontinuo y variable: el aulario IndUVa de la universidad de Valladolid. Comunicación Técnica. CONAMA 16. Noviembre 2016.

[13] GEA- VERDE NE Equipamiento V 1.g. "Green Building Council España", GBCe.

[14] Roos, I. (2015, May 9). Thermal energy storage in buildings makes district heating more climate friendly. From http://phys.org/news/2015-05-thermal-energy-storage-district-climate.html

[15] Construction21. IME (Medical Educational Institute) -SESSAD La Fleuriaye. https://www.construction21.org/case-studies/fr/ime-medical-educational-institute-sessad-la-fleuriaye.html

[16] Construction21. URMA de Bruay / Saint-Saulve https://www.construction21.org/case-studies/fr/urma-de-bruay-saint-saulve-en.html

[17] Construction21. Climate-positive zero-energy technical classroom wing https://www.construction21.org/case-studies/de/climate-positive-zero-energy-technical-classroom-wing.html

[18] Construction21. LUCIA (Lanzadera Universitaria de Centros de Investigación Aplicada) https://www.construction21.org/espana/case-studies/h/lucia-lanzadera-universitaria-de-centros-de-investigacion-aplicada.html

[19] Construction21. Aulario IndUVA. https://www.construction21.org/espana/case-studies/h/aulario-induva.html

Simulation-based parametric analysis of control key-factors in thermoelectric frames

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Key Words: Electricity, Efficiency, Strategy, LabVIEW, Window

Abstract

The thermoelectric systems (TE) have been studied for years as a potential energy efficient system in buildings due to its good integration with solar system and building structures. However, compared to the conventional air-conditioning system, the TE has lower COP, which negatively affects its applications in buildings. To improve the COP of the TE, control strategies against the dynamic working conditions would be critical for the future development of building integrated TE. Changing the key-factors of control strategies would affect the performance of the TE to different degrees under the same working condition. In this work, the numerical model of the TE window system is established on LabVIEW based on the Peltier effect, heat transfer and fluid mechanics. The simulation results indicate that the temperature difference between two sides and the total heating capacity increase, but the COP drops with the driving current of Peltier cells increases under certain condition. More working Peltier cells for the same heating capacity under certain condition means less driving current and better COP. In addition, higher air flow mass rate decreases the temperature difference between two sides and increases the temperature difference between object side and indoor space, which improves the COP.

1. Introduction

In recent years, a significant number of researchers have explored various materials for making high-performance Peltier cell, and report that the material having higher figure of merit ZT would enhance the application possibilities of Peltier cells [1]. Except for the high-performance materials, the configurations inside are also essential to their improvement. Wang et al. [2] analysed the effect of number of thermoelectric elements (TEEs), TEE leg length, and TEE cross-sectional area on the performance of TE (thermoelectric), and suggested their optimal value range for a better COP. On another hand, Montecucco et al. [3] indicated that the electrical configuration, such as in series and in parallel, of TEEs would affect the performance of the TE in certain level.

These studies above mainly focus on the Peltier cell itself, namely realizing a high-performance unit by improving its nature and configuration. However, considering the challenges of the material innovation, how to improve the performance on the perspective of the optimization of the whole TE system is urgent to the application of the thermoelectricity in building. For example, after installing heat sinks with thermal conductance of 30 W/K, both COP and thermal capacity of TE increase, but remain stable even if the thermal conductance is more than 30 W/K [2]. Hagenkamp et al. [4] suggested that an additional heat recovery system is beneficial for the system with few Peltier cells. Martín-Gómez et al. [5] also emphasized the importance of fans and heat sinks to the system performance. In addition to these improvements with strengthening heat transfer or applying heat recovery, the dynamic control system further improves the performance by optimizing the system under various working conditions. Irshad et al. [6] designed an IoT management framework to control the indoor climate based on outdoor conditions by means of the modulation of supplied current to the TE. Through these, the COP and cooling capacity of the TE got a substantial improvement.

This work develops a numerical model for parametric analysis of a thermoelectric window frame that could be integrated with the building envelopes. This model is designed on LabVIEW based on an ongoing experimental system, namely the TE window system. In order to analyse the effect of some factors, such as the power strength to Peltier cells, the power strength to fans, and the number of working Peltier cells on the system performance, we develop the numerical experimental system to realize the optimal design for the TE control system under certain working conditions and the results of experiments would be used for validating the numerical model.

2. Thermoelectric window frame

In this current work, the TE is considered to be integrated in a window frame for space heating or cooling. It is installed in an adiabatic box which is taken as a room, as shown in Fig. 1. The TE prototype consists of 4 Peltier cells, 2 heat sinks, 2 fans, framework, and 10 cm insulation layer, and recovers the heat from indoor exhausted air. The current to Peltier cells and fans could be modulated, then the thermal capacity and air flow mass rate could be changed respectively. The heat sinks could install up to 20 Peltier cells. The parametric details of the experimental system are listed in table 1.

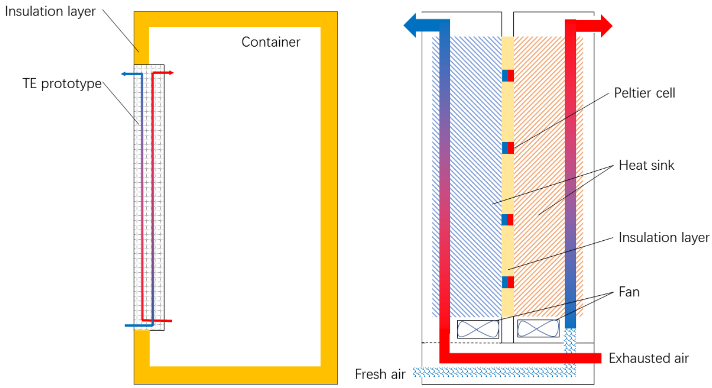

Figure 1. The schematic of the conceptional model of the experimental system in the thermal process.

Regarding the thermal process, firstly, fresh air and exhausted air powered by fans flow into two chamber of air ducts respectively, the fresh air is pre-heated or pre-cooled by the exhausted air at the beginning part of the frame. Then, the fresh air is heated up by powered Peltier cells (and the Joule heat). At the same time, the exhausted air cools down the outer chamber, helping to absorb or dissipate heat from the other side of the Peltier cell. Therefore, powered Peltier cells could absorb the heat from exhausted air, then emit to fresh air, as a heat pump with heat recovery. To improve its performance, one hand, the heat sinks, and fans for strengthening heat transfer are applied. On another hand, we also pay attention to the optimal control strategies under certain conditions for the control system based on the adjustment of input power to Peltier cells and fans, and the number of working Peltier cells.

Table 1 Property parameters of the components of the experimental system.

Components Componentes	Properties Propiedades	Values Valores
Box Caja	Dimensions (L*W*H) Dimensiones (L*W*H)	720 mm*795 mm*1520 mm
	Thickness of plates Espesor de placas	2 mm
	Heat conductivity of plates Conductividad térmica de las placas	15 W/(m·K)
	Thickness of insulation (XPS) Espesor del aislamiento (XPS)	10 mm
	Heat conductivity of insulation Conductividad térmica del aislamiento	0.032 W/(m·K)
Frame Marco	Dimensions (L*W*H) Dimensiones (L*W*H)	1200 mm*86 mm*58 mm
Heat sinks Disipadores de calor	Dimensions (L*W) Dimensiones (L*W)	870 mm*86 mm
	Thickness of plate base Espesor de la base de la placa	45 mm
	Longer fin (L*W*H) Aleta más larga (L*W*H)	870 mm*2 mm*55 mm (4 units)
	Shorter fin (L*W*H) Aleta más corta (L*W*H)	870 mm*2 mm*29 mm (5 units)
	Distance between fins Distancia entre aletas	4 mm
	Heat conductivity Conductividad de calor	237 W/(m·K)
Peltier cell Células Peltier	Dimensions (L*W*H) Dimensiones (L*W*H)	40 mm*40 mm*3 mm
	Thickness of ceramic plates Espesor de placas de cerámica	0.4 mm
	Heat conductivity of ceramic plate Conductividad térmica de la placa de cerámica	220 W/(m·K)
	Maximum current Corriente máxima	6.4 A (Th=25℃) and 6.4 A (Th=50℃)
	Maximum voltage Voltaje máximo	14.4 V (Th=25℃) and 16.4 V (Th=50℃)
	Maximum power Potencia máxima	50 W (Th=25℃) and 57 W (Th=50℃)
	Seebeck coefficient α Coeficiente de Seebeck α	0.05 V/K (Th=25℃) and 0.05 V/K (Th=50℃)
	Resistance Re Resistencia Re	1.98 Ω (Th=25℃) and 2.3 Ω (Th=50℃)
	Thermal transfer coefficient K_{te} Coeficiente de transferencia térmica K_{te}	0.52 W/K (Th=25℃) and 0.54 W/K (Th=50℃)
	Number of TEEs Número de TEEs	1-4
Fan Ventiladores	Maximum air flow volume Volumen máximo de flujo de aire	38 m³/h
	Maximum rotation speed Velocidad máxima de rotación	17250 r/min
	Maximum power Potencia máxima	6.9 W
	Number Número	2

3. Numeral model

The heat released Qh,t and the heat absorbed Qc,t of Peltier cells are shown in the equations(1)-(2) [7]. The thermal capacity of the Peltier cell depends on the Peltier heat, the Joule heat, and the heat conductance inside.

$$Q_{h,t} = N(\,\alpha I T_h + \frac{1}{2} I^2 R_e - k(T_h - T_c)) \quad (1)$$

$$Q_{c,t} = N(\alpha I T_c - \frac{1}{2} I^2 R_e - k(T_h - T_c)) \quad (2)$$

Therefore, if N Peltier cells are used, the total thermal capacity should be expressed as shown in equations (3)-(6).

$$Q_{h,t} = \frac{T_h - T_{fh,m}}{U_{h,t}} \quad (3)$$

$$Q_{c,t} = \frac{T_{fc,m} - T_c}{U_{c,t}} \quad (4)$$

$$T_{fh,m} = \frac{T_{fh,in} + T_{fh,out}}{2} \quad (5)$$

$$T_{fc,m} = \frac{T_{fc,in} + T_{fc,out}}{2} \quad (6)$$

Here, the total thermal resistance at hot side Uh,t includes the conductance resistance of ceramic plate, the contact resistance between ceramic plate and heat sink which could be obtained from the work of Ritzer et al. [8], and whose value is 0.03 W/K, the conductance resistance of heat sink and the convection resistance between heat sink and air flow. Similarly, the total thermal resistance at cold side Uc,t also includes these resistances, as shown in the equations (7)-(8).

$$U_{h,t} = {U_h}/{N} = (\frac{\delta_{cp}}{\lambda_{cp} A_{cp}} + U_{cont} + \frac{\delta_{hs,sub}}{\lambda_{hs} A_{cont}} + U_{conv,h})/N \quad (7)$$

$$U_{c,t} = {U_h}/{N} = (\frac{\delta_{cp}}{\lambda_{cp} A_{cp}} + U_{cont} + \frac{\delta_{hs,sub}}{\lambda_{hs} A_{cont}} + U_{conv,c})/N \quad (8)$$

Combining the equations (1)-(8), we would know the temperature at hot and cold side Th, Tc depends on the average temperature of fresh air and exhausted air, the total thermal resistance at two sides, the driving current and the properties of Peltier cells, as shown in the equations (9)-(10) [9].

$$T_h = \frac{\left(\frac{T_{fh,m}}{U_h} + \frac{1}{2} I^2 R_e\right)\left(\frac{1}{U_c} + \alpha I\right) + \kappa\left(\frac{T_{fc,m}}{U_c} + \frac{T_{fh,m}}{U_h} + I^2 R_e\right)}{\left(\frac{1}{U_h} - \alpha I\right)\left(\frac{1}{U_c} + \alpha I\right) + \kappa\left(\frac{1}{U_c} + \frac{1}{U_h}\right)} \quad (9)$$

$$T_c = \frac{\left(\frac{T_{fc,m}}{U_c} + \frac{1}{2} I^2 R_e\right)\left(\frac{1}{U_h} - \alpha I\right) + \kappa\left(\frac{T_{fc,m}}{U_c} + \frac{T_{fh,m}}{U_h} + I^2 R_e\right)}{\left(\frac{1}{U_h} - \alpha I\right)\left(\frac{1}{U_c} + \alpha I\right) + \kappa\left(\frac{1}{U_c} + \frac{1}{U_h}\right)} \quad (10)$$

On the perspective of air heat flow, in heating mode, the heat received by the fresh air Qfh, and the heat loss of the exhausted air Qfc are shown in the equations (11)-(12).

$$Q_{fh} = c_p m_{fh}\left(T_{fh,out} - T_{fh,in}\right) \quad (11)$$

$$Q_{fc} = c_p m_{fc}\left(T_{fc,out} - T_{fc,in}\right) \quad (12)$$

The total electrical consumption of Peltier cells is expressed in equation (13).

$$Q_{e,t} = N(\alpha I(T_h - T_c) + I^2 R_e) \tag{13}$$

The power consumption of fans and the air flow rate are relevant to the rotate speed, as shown in equations (14)-(15) [10].

$$\frac{Q_{fan,0}}{Q_{fan}} = \left(\frac{n_{fan,0}}{n_{fan}}\right)^3 \tag{14}$$

$$\frac{m_0}{\mathrm{m}} = \frac{n_{fan,0}}{n_{fan}} \tag{15}$$

The overall COP for heating and cooling of the TE would be calculated as shown in the equations (16)-(17).

$$COP_h = \frac{Q_{h,t}}{Q_e + Q_{fan,t}} \tag{16}$$

$$COP_c = \frac{Q_{c,t}}{Q_e + Q_{fan,t}} \tag{17}$$

4. Methodology

The numerical model is established on LabVIEW based on the above formulas for the parametric analysis of the TE control system. The constant inputs are material properties and geometry values of Peltier cell, box, framework, fans, and heat sinks and the indoor set point. The variable inputs include the temperature of incoming fresh air and exhausted air, the supplied current to Peltier cells, the rotation speed of fans, and the number of working Peltier cells. Here, the input power could be adjusted by means of manipulation of supplied current via pulse width modulation (PWM) [11]. And the outputs are the two-side temperature of Peltier cells, the total heating and cooling capacity, the total air heat flow, the electrical consumption of Peltier cells and fans, and the COP.

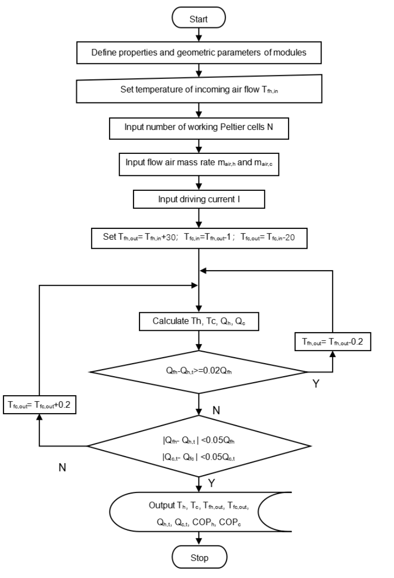

Figure 2. The schematic of the flow chart of the computational calculations in heating mode.

The experimental system will be simulated under different ambient conditions [12]. As shown in the Fig 2, firstly, assuming the temperature of outcoming fresh air and exhausted air, the two-side temperature could be calculated, and the total thermal capacity and the total heat flow could be gained under certain driving current of Peltier cells and rotation speed of fans. Assuming there is a good insulation for the framework, the total thermal capacity and the total heat flow should be the same. Therefore, the model would iterate until the error between the total thermal capacity and the total heat flow is no more than 5%, if not, the temperature of outcoming fresh air and exhausted air would be adjusted gradually until the iteration condition is met. When the calculation under a certain current and rotation speed is completed, the current could be adjusted gradually until the tested current is over maximum current. Then, the rotation speed is also changed step by step until the working air flow mass rate is over the maximum air flow mass rate. At last, the iteration calculation of the number of working Peltier cells is also done.

The numerical model could be used for calculating the temperature and thermal capacity of the Peltier cell under different driving current to Peltier cells, air mass flow rate and number of working Peltier cells. Then, the effect of the above factor on the COP could be compared and analysed. Therefore, under certain heat load, it would be understood what the optimal combination of the driving current, the air flow mass rate and the number of working Peltier cell for a better COP is.

5. Discussion

In those simulations, the airflow mass rate is adjustable based on ventilation rate of 15, 25, 35, 45 and 55 (the volume of the test space is 0.8 m3) whist the air density is considered as 1.225 kg/m3. At the heating mode, the ambient temperature is assumed to be 0ºC. The indoor temperature is set as 20ºC. The total number of installed Peltier cells is 4. The controllable range of the driven current is 0-6.4 A. The COP decreases, but the temperature difference between two sides and the total heating capacity increase with the driving current of Peltier cells increases under certain condition. In the simulation, 2 Peltier cells works under ambient temperature of 0ºC and air flow mass rate of 0.0098 kg/s. As shown in the Fig. 3, when the current is changed from 1 A to 6 A with the steps of 0.5 A, the total heating capacity increases from 26 W to 252 W and the temperature difference between two sides rises from 3.29ºC to 9.07ºC. The heat conductance of the Peltier cell itself increases because of the rising temperature difference of two sides, therefore, the COPh drops from 3.25 to 1.45.

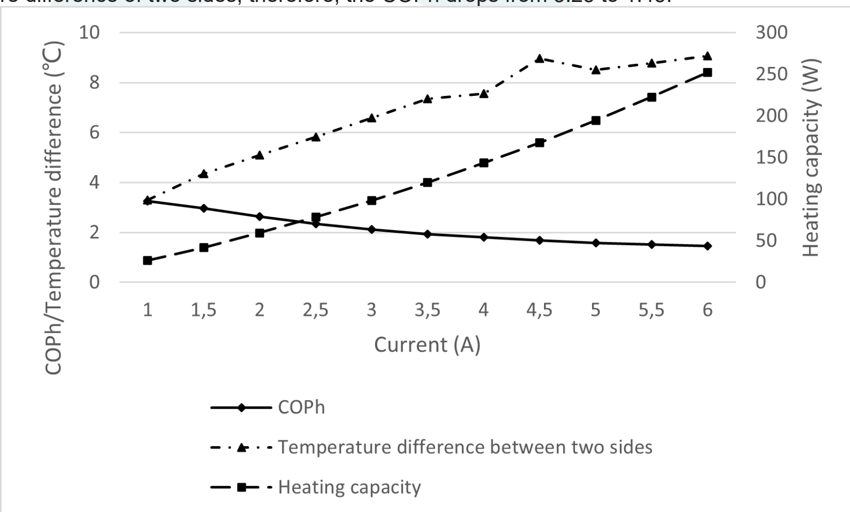

Figure 3. COPh, temperature difference between two sides and heating capacity variations versus current.

More working Peltier cells for the same heating capacity under certain condition means less driving current and better COP. Under the ambient temperature of 0ºC, just 1 Peltier cell cannot provide supply air of 20ºC with air flow mass rate of 0.0098 kg/s. Nevertheless, 2, 3 and 4 Peltier cells with the driving current of 5ºC, 3.7ºC, and 2.9ºC respectively could gain the total heating capacity of 193 W and reach air supply temperature of 20ºC. The temperature difference between two sides decreases from 10.85ºC to 6.06ºC, and the COPh rises from 1.56 to 2.30, as shown in the Fig. 4.

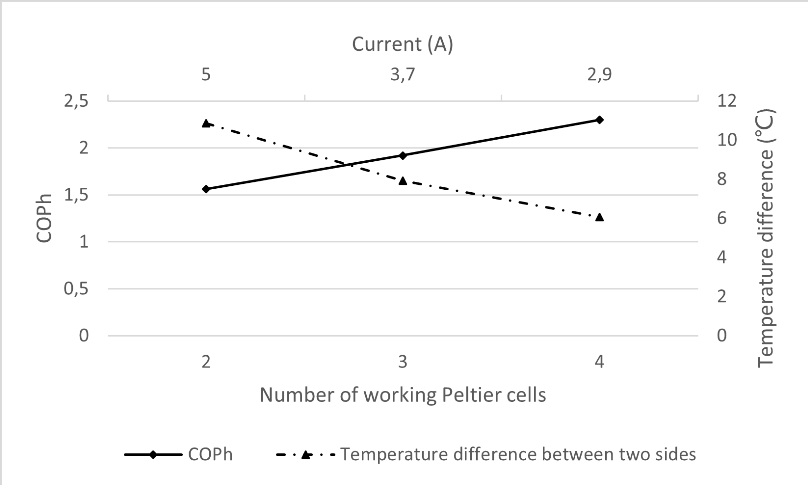

Figure 4. COPh and temperature difference between two sides variations versus number of working Peltier cells.

Higher air flow mass rate decreases the temperature difference between two sides and increases the temperature difference between object side and indoor space, which improves the COP. Here, 4 Peltier cells works with 2.9 A (heating capacity of 193 W) in order to meet the indoor temperature of 20ºC. At this condition, when the air flow rate rises from 0.008 kg/s to 0.0122 kg/s, the temperature difference between hot side and air flow drops from 6.22ºC to 2.7ºC, the temperature difference between two sides drops from 8.77ºC to 2.45ºC and the COPh rises from 2.23 to 2.39.

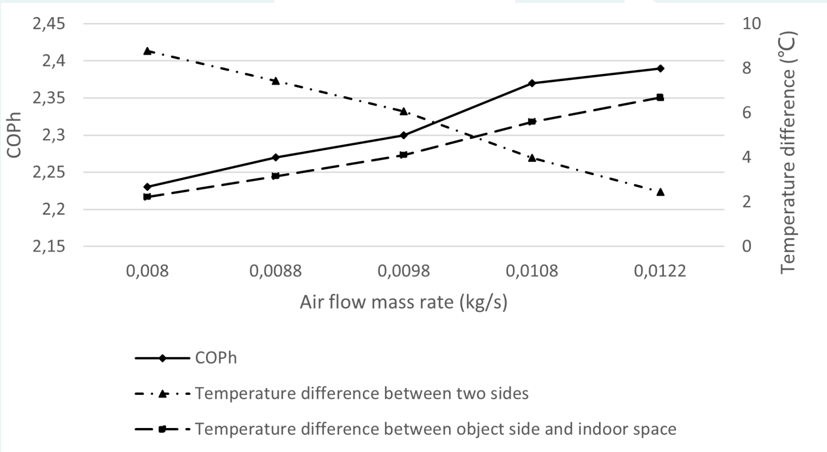

Figure 5. COPh and temperature difference between two sides variations versus air flow mass rate.

6. Conclusions

In this work, the numerical model of the TE window system is established on LabVIEW based on the Peltier effect, heat transfer and fluid mechanics. According to the relationship between the total thermal capacity and the total heat flow, iteration calculations are implemented for the driving current to Peltier cells, air mass flow rate and number of working Peltier cells until the error between the total thermal capacity and the total heat flow is no more than 5%. Based on the simulation results, we can find that:

1)The COP drops, but the temperature difference between two sides and the total heating capacity increase when the driving current of Peltier cells increases under certain condition.

2)More working Peltier cells for the same heating capacity under certain condition means less driving current and better COP.

3)Higher air mass flow rate decreases the temperature difference between two sides and increases the temperature difference between object side and indoor space, which improves the COP. About next steps, the numerical model of the experimental system will be validated based on the experimental results, further will be used for designing and analysing the control methods for the TE window system.

7. Reference

[1]S. Twaha, J. Zhu, Y. Yan, and B. Li, "A comprehensive review of thermoelectric technology: Materials, applications, modelling and performance improvement," Renew. Sustain. Energy Rev., vol. 65, pp. 698–726, 2016, doi: 10.1016/j.rser.2016.07.034.
[2]P. Wang, Z. Liu, D. Chen, W. Li, and L. Zhang, "Experimental study and multi-objective optimisation of a novel integral thermoelectric wall," Energy Build., vol. 252, p. 111403, 2021, doi: 10.1016/j.enbuild.2021.111403.
[3]A. Montecucco, J. Siviter, and A. R. Knox, "The effect of temperature mismatch on thermoelectric generators electrically connected in series and parallel," Appl. Energy, vol. 123, pp. 47–54, 2014, doi: 10.1016/j.apenergy.2014.02.030.
[4]M. Hagenkamp, T. Blanke, and B. Döring, "Thermoelectric building temperature control: a potential assessment," Int. J. Energy Environ. Eng., 2021, doi: 10.1007/s40095-021-00424-x.
[5]C. Martín-Gómez, A. Zuazua-Ros, K. Del Valle de Lersundi, B. Sánchez Saiz-Ezquerra, and M. Ibáñez-Puy, "Integration development of a Ventilated Active Thermoelectric Envelope (VATE): Constructive optimization and thermal performance," Energy Build., vol. 231, 2021, doi: 10.1016/j.enbuild.2020.110593.
[6]K. Irshad, A. Almalawi, A. I. Khan, M. Alam, M. H. Zahir, and A. Ali, "An IoT-Based Thermoelectric Air Management Framework for Smart BuildingApplications: A Case Study for Tropical Climate," SUSTAINABILITY, vol. 12, no. 4, Feb. 2020, doi: 10.3390/su12041564.
[7]N. Korprasertsak and T. Leephakpreeda, "Mathematical modeling and validation of cooling/heating effects in thermoelectric module coupled with heat sinks," Proc. 2016 7th Int. Conf. Mech. Aerosp. Eng. ICMAE 2016, pp. 95–99, 2016, doi: 10.1109/ICMAE.2016.7549515.
[8]T. M. RITZER and P. G. LAU, "Economic optimization of heat sink design," in THIRTEENTH INTERNATIONAL CONFERENCE ON THERMOELECTRICS, 1995, no. 316, pp. 177–180.
[9]T. Han, G. Gong, Z. Liu, and L. Zhang, "Optimum design and experimental study of a thermoelectric ventilator," Appl. Therm. Eng., vol. 67, no. 1–2, pp. 529–539, 2014, doi: 10.1016/j.applthermaleng.2014.03.073.
[10]M. Teitel, Y. Zhao, M. Barak, E. Bar-lev, and D. Shmuel, "Effect on energy use and greenhouse microclimate through fan motor control by variable frequency drives," Energy Convers. Manag., vol. 45, no. 2, pp. 209–223, 2004, doi: 10.1016/S0196-8904(03)00147-X.
[11]G. A. Mannella, V. La Carrubba, and V. Brucato, "Peltier cells as temperature control elements: Experimental characterization and modeling," Appl. Therm. Eng., vol. 63, no. 1, pp. 234–245, 2014, doi: 10.1016/j.applthermaleng.2013.10.069.

[12]E. Ibáñez-Puy, C. Martín-Gómez, J. Bermejo-Busto, and A. Zuazua-Ros, “Thermal and energy performance assessment of a thermoelectric heat pump integrated in an adiabatic box,” Appl. Energy, vol. 228, pp. 681–688, Oct. 2018, doi: 10.1016/j.apenergy.2018.06.097.

8. Abbreviations

Nomenclature		Subscript	
A	Area (m²)	0	Rated value
B	Interval between fins (m)	air	Air flow
c	Specific heat capacity (J/kg•℃)	c	Cold side
COP	Coefficient of performance	cp	Ceramic plate
h	Convection coefficient (W/ m²•℃)	cont	Contact
I	Driving current (A)	conv	Convection
m	Air flow mass rate (kg/s)	e	Electric
n	Rotation speed of fan (rpm)	fh	Air flow at hot side
N	Number of working Peltier cells or fins	fc	Air flow at cold side
Q	Heat flow rate or electric power consumption (W)	fin	Fin of heat sink
R	Electric resistance (Ω)	fan	Fan
T	Temperature (K or ℃)	h	Hot side
TE	Thermoelectric system	hs	Heat sink
U	Thermal resistance (K/W)	in	Incoming
α	Seebeck coefficient (V/K)	m	Average value
κ	Coefficient of thermal transfer (W/K)	out	Outcoming
δ	Thickness (m)	p	Pressure
λ	Thermal conductivity (W/m•℃)	t	Total value
η	Fin efficiency		
ρ	Density (kg/m³)		

Digital twin as a tool to travel from a-class to nzeb

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Key Words: NZEB, Energy Modelling, Digital Twin, Renewable Energy Sources, Photovoltaics.

Abstract
Broad development and implementation of Net Zero Energy Buildings (NZEB) can support reducing energy consumption and associated carbon emission rates drastically. This paper presents a case study carried out on La Balma which is a recently built A-class energy-rated multifamily building located in Barcelona, Spain.

The analysis is performed on a dynamic building energy model using IES VE simulation software, which acts as a Descriptive Digital Twin, prior to adding operational and sensor data. This tool is used to assess potential strategies for converting a high-efficiency building into an NZEB, by means of deploying onsite energy generation from renewable sources coupled with building energy systems optimization. The building is a low embodied energy cross-laminated timber featuring six-story construction finished in 2021 under very high energy standards. The low energy demands suggest that it could be possible to achieve an annual positive balance. The discussion reflects on which services can be included in this assessment.

A big share of renewable energy sources leads to a necessary shift from traditional supply control to a more flexible demand control in terms of energy production, distribution, and storage. Therefore, the energy flexibility approach is also considered in the study. This approach explores the benefits of utilizing PV generation together with energy-storing in batteries and buying electricity from the grid during low-tariff hours. All these strategies aim to become less dependent on intermittent energy generation patterns typical for renewable energy sources.

Furthermore, the building's future performance and resilience to Climate Change is analysed under the weather of Barcelona in 2050 and 2100 for the key IPCC predicted scenarios.

1. Introduction

As stated by United Nations Secretary-General António Guterres, the world has reached a climate emergency [1]. It refers to drastic temperature deviations, sea level rise, extreme weather events causing threats to living organisms not being able to adapt to changing climate [2]. Considering human health, it also gets affected directly and indirectly by food supply chain failure, clean air and water shortage, heat strokes, etc. Climate change also affects infrastructure including buildings, bridges, roads, grids as these were designed for old weather conditions that are no longer maintained. Human-related high concentration of greenhouse gases in the atmosphere is directly related to these events. As predicted by Intergovernmental Panel on Climate Change (IPCC) to prevent greater changes from happening, the global average temperature rise compared to pre-industrial time should be restricted to 1.5 degrees. Countries must reduce greenhouse gases by cutting out 30 gigatons of emissions annually [3].
Broad implementation of Net Zero Energy Buildings (NZEB) can support reducing energy consumption and associated carbon emission rates considerably. As achieving net-zero predominantly comes to balancing energy production and consumption, detailed information of building's energy performance is essential for defining the generation system. Dynamic simulation tools deliver various capabilities providing detailed building's energy consumption and onsite generation data, thermal comfort parameters, and cost figures for new and existing buildings. Correct input of the parameters allows creating a Digital Twin – a virtual model that performs the same way as the considered physical building. Using the data acquired from the simulation one can test and assess the feasibility of project decisions in terms of energy consumption, economic benefits, carbon emissions, and other impacting factors [6].
This paper illustrates an example of utilizing a Descriptive Digital Twin, or level 1, of a newly built A-energy class residential building with photovoltaic (PV) panels, named La Balma (Figure 1), located in Barcelona [4]. This level of a digital twin is the first step before adding added a layer of operational and sensory data, which provides a "live, editable version of design and construction data of a built asset" [7]. The goal of this research is to estimate the capacity and limitations of transforming La Balma into an NZEB.

Figure 1. La Balma exterior view [4]

2. Methodology

Firstly, a detailed profile for building's energy consumption is necessary for the assessment. This is obtained from the digital twin of the building, created via Integrated Environmental Solutions - Virtual Environment (IES VE) dynamic modelling tool. This research incorporates IES-VE as a means of obtaining a digital twin due to its various capabilities and being widespread in the industry [5]. It provides qualitative and quantitative approaches to determine overall performance of the building, systems, lighting, natural ventilation, and thermal comfort. Furthermore, this software package provides possibilities of simulating grid-displaced electricity allowing to include renewable energy sources (RES) into the model with a great level of detail [6].
IES-VE is a plugin-based software, with each plugin dedicated to specific model aspects:

-ModelIT – models building geometry and surrounding buildings. La Balma building is a five-story building, with the ground floor dedicated to commercial, equipment and community spaces, while floors one to five having four apartments and one community space each. Every apartment was modeled as a single thermal zone (Figure 2), commercial spaces and equipment location spaces were merged by groups since these are thermally unconditioned, while the community spaces were defined as individual thermal zones.

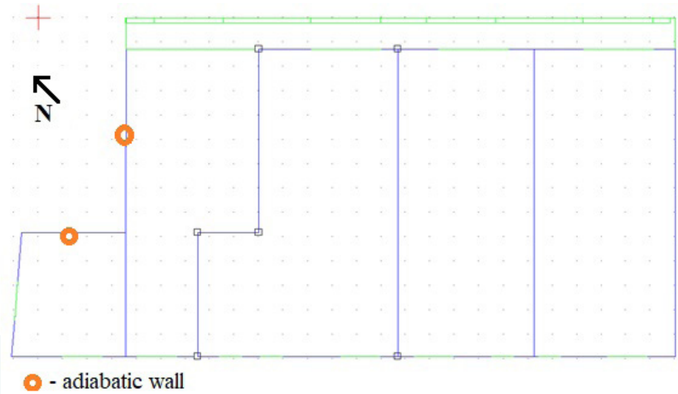


Figure 2. Typical floor plan in IES-VE

-SunCast – estimates shading effect and produces solar intensity scheme based on building geometry, location and simulation weather data.

-MacroFlo – simulates natural ventilation in the building by querying coefficients related to wind path and openings geometry. Also used to set up windows opening time profiles.

-Apache – main thermal simulation plugin, also, it enables assigning thermal properties for the envelope and on-site energy generation sources which were taken from the project data.

-ApacheHVAC – detailed input of HVAC components and their settings for air- and water-source loops using a component-based approach. This way, several generic components can be programmed and assembled into a system in any desired way, not restricting its complexity (see Tab. 1).

System type	Actual Component	ApacheHVAC Representation
Heating	Geothermal heat pump	Part-load curve boiler
Cooling	Passive water-source cooling	Water-source heat exchanger
Domestic Hot Water (DHW)	*same source as Heating*	*same source as Heating*
Ventilation	*- (not specified in the documents)*	simple exhaust ventilation

Table 1. Building Systems

-VistaPro – results visualization and post-processing.

Having obtained and verified the building energy consumption data, the next step is to assess the capacity of the on-site energy generation to cover the demand. In this case, there are PV panels and battery storage. Annual battery performance simulation was carried out using a separate Python script based on IES-VE simulation results. To evaluate the resiliency of this building towards the climate emergency, the building model was tested with future weather data, under Representative Concentration Pathway (RCP) scenarios created by IPCC [8].

3. Results

First step of building energy simulation resulted in obtaining annual energy demand and consumption data. Total energy consumption for La Balma building comes from electricity, there are no gas or other fuels powered systems in the building. It equals to 32 MWh per year, with the biggest share of it spent on domestic hot water (38%) and space heating (27%), both served by the geothermal heat pump. Building's energy consumption split by services is provided in Fig. 3.

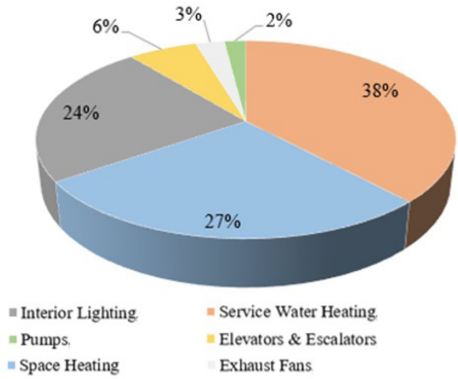


Figure 3. Annual energy consumption by services

Investigation of the monthly electricity consumption (Figure 4) can help understanding the base load, the season changes for this building, and so achieving a better adjustment with RES integration. The base load occurs in summer, with around 1.8 MWh from June to September. In winter, average of 3.5 MWh from November to March and maximum of 3.7 in December. Only space heating exceeds the base load significantly and varies from month to month depending on the outdoor temperature.

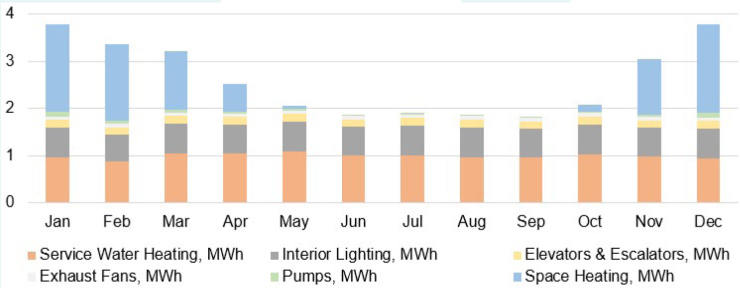


Figure 4. Monthly electricity consumption

After obtaining the detailed consumption profiles, onsite electricity generation is assessed by the same IES-VE simulation engine. Installing the project specified model and number of PV panels (around 21 MWh/year) does not allow to generate sufficient energy to cover all the building electricity needs (32 MWh/year). So, this analysis focuses on the possibility of covering the Heating, Ventilation and Air Conditioning (HVAC) services only, as these services are essential for the building, predictable, furthermore only these are included within the Spanish building Energy Performance Certification (EPC). The monthly balance of these HVAC systems consumption and the PV obtained with the simulation of the digital twin are summarized below (Table 2).

	Consumed by HVAC, MWh	Produced by PVs, MWh
Jan	2.77	1.01
Feb	2.43	1.20
Mar	2.19	1.69
Apr	1.68	2.11
May	1.35	2.49
Jun	1.20	2.32
Jul	1.20	2.67
Aug	1.17	2.36
Sep	1.15	1.70
Oct	1.33	1.38
Nov	2.06	0.88
Dec	2.76	0.87
Annual	**21.30**	**20.68**

Table. 2 PV generation

The annual numbers show how PV generation equals to 97% of the annual HVAC consumption. However, if applying the net balances monthly the percentage lowers down to 78% (Figure 5), it is obvious that the system is not reaching net zero in any of the cases: it is significantly underproducing during winter season and overgeneration in the summer season.

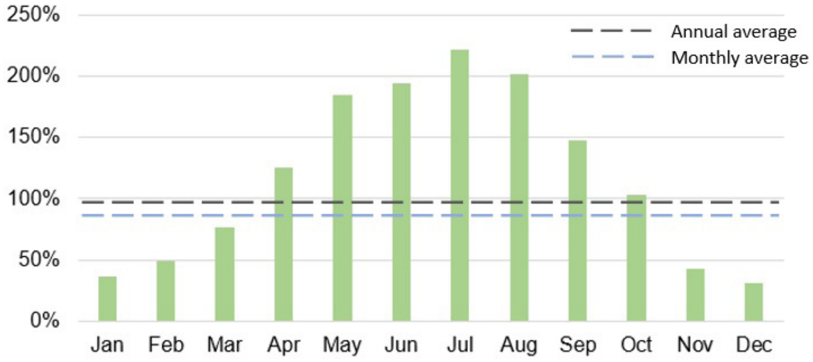
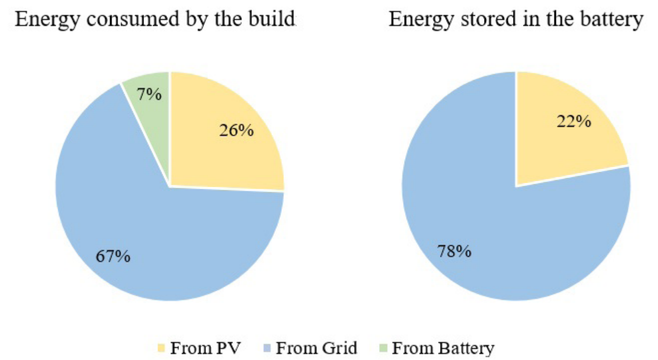


Figure 5. Monthly ratio of PV production over the building consumption

4. Analysis and discussion

Achieving Net Zero

Indeed, aiming for a real electricity balance is far more difficult. The previous monthly balances do not reflect the energy actually being consumed by the building, as there is energy consumption at early mornings, evenings, night hours, while there is no PV generation. Additionally, peak generation (summer afternoon hours) happens at the same time as the lowest energy consumption of the building because of low occupancy and passive cooling system during afternoon hours. An investigation on whether battery storage can tackle this imbalance was carried out using the data extracted from the digital twin and a created Python script for battery simulation.
The project of the case study assumes energy arbitrage performing: the battery is being charged from PV generation surplus and also from the power grid during low electricity tariff hours (covering weekdays night hours, from 0:00 to 7:59, and all weekend hours), to be later discharged during the expensive tariff hours. This way, there are three sources of electricity for the building: from the PV panels, from the battery storage (when the demand is not covered by the panels), and from the grid (when the demand is not met by the PV and battery). Fig. 6 illustrates the distribution between these sources for the annual consumption.



It shows that even with battery storage the biggest share of electricity used for the building needs comes from the power grid (67%). If looking at the battery storage, it is obvious that it is mainly (78% of the time) charged from the grid, while around 23% of total energy generation is not getting consumed by the building and is sold to the grid.
After analyzing the hourly battery simulation data, the following conclusions regarding the implemented charging scheme were reached:

-Charging the battery from the grid during low tariff hours (at night and the weekends) shows the expected performance, allowing to discharge the battery in first one or two hours of the expensive tariff time when the panels are not generating yet, allowing some economic savings;

-However, as lower tariff covers the whole weekend the battery is not being utilized at all during this time, neglecting all the PV generated energy;

-Furthermore, the benefits get reduced in summer because PV starts generating around 6:00 – 8:00, that is the battery that is fully charged from the grid during the night does not have enough time to discharge fully prior to PV peak generation; as a result the amount of energy bought from the grid is not fully consumed and it would have been gained from the panels at no additional costs in the first hours of expensive tariff anyway.

A new charging scheme to improve the indicated issues was proposed. The optimized scheme has three different algorithms depending on the season:

-For the weekdays of winter season (October to March) the battery is charged as proposed in the project: charged fully from the grid at night (low tariff) discharged during high prices time (morning), excess PV is stored in the battery, if it is not full;

-During the weekends of winter season it is getting charged from the surplus PV generation and not getting discharged (as it is low tariff time), also, if by the last hour of the weekends it is not fully charged, it is getting charged from the grid;

-During summer season (May to September) the battery is not getting charged from the grid at all, and it only stores the surplus PV generated energy.

Climate Change Scenarios

An average life span of a building is often considered up to 100 years and since La Balma was finished in 2021, it would possibly continue in use even after 2100 and it should still be able to provide comfort for the occupants. As disclosed in the introduction, climate is subject to massive changes within the next decades, which will oblige buildings to adapt.
While there are various methods of future weather prediction, this research focuses on RCP scenarios created by IPCC [8]. These represent different greenhouse gas (GHG) concentration pathways. For this study simulation weather files for the years 2050 and 2100 according to the RCP 2.6, RCP 4.5, RCP 8.5 corresponding to low, medium and high concentration.
A comparison of heating and cooling degreedays was performed in order to see how much each scenario is different from present climate (Tab. 3).

	Present	2.6 2050	4.5 2050	8.5 2050	2.6 2100	4.5 2100	8.5 2100	Present	2.6 2050	4.5 2050	8.5 2050	2.6 2100	4.5 2100	8.5 2100
	HDD 20	**HDD 20**	**HDD 20**	**HDD 20**	**HDD 20**	**HDD 20**	**HDD 20**	**CDD 25**	**CDD 25**	**CDD 25**	**CDD 25**	**CDD 25**	**CDD 25**	**CDD 25**
Units	°Cd	°Cd	°Cd	°Cd	°Cd	°Cd	°Cd	°Cd	°Cd	°Cd	°Cd	°Cd	°Cd	°Cd
Annual	**1769**	**1612**	**1553**	**1454**	**1667**	**1342**	**968**	**127**	**207**	**257**	**293**	**202**	**348**	**683**
Jan	368	346	333	323	353	306	247	0	0	0	0	0	0	0
Feb	303	288	279	265	301	252	198	0	0	0	0	0	0	0
Mar	240	225	217	206	240	187	131	0	0	0	0	0	0	0
Apr	154	136	130	120	148	104	60	0	0	0	0	0	0	0
May	47	32	28	23	37	18	4	0	0	0	1	0	1	11
Jun	2	0	0	0	1	0	0	16	25	31	37	21	46	103
Jul	0	0	0	0	0	0	0	56	86	105	120	88	136	234
Aug	0	0	0	0	0	0	0	52	86	109	119	83	140	241
Sep	8	2	2	1	2	0	0	2	10	12	16	11	24	87
Oct	70	47	47	34	47	23	5	0	0	0	0	0	0	7
Nov	234	213	206	185	216	176	113	0	0	0	0	0	0	0
Dec	343	322	311	297	321	277	210	0	0	0	0	0	0	0

Table 3. Future weather degreedays comparison

As indicated in the table, heating degreedays (left side of Table 3) are reduced by different percentages from 9% to 18% in 2050 and from 6% to 45% in 2100 resulting in lower heating loads and it could be easier for the building systems in terms of adaptability – it will be over-sized but still capable of supplying the heat required.
For cooling (right side of Table 3), one can notice a shift in the hottest month from July in present climate to August in cases of high (RCP 8.5) and medium (RCP 4.5) emissions. There is also a massive increase in cooling degreedays compared to present value: best case it goes up by 63% in 2050 and 59% in 2100, while the worst case experiences a rise of 130% in 2050 and 440% in 2100.
The most important test is to verify whether the HVAC system is capable of providing the future demands or not. Heating and cooling systems need to be carefully examined, while ventilation and DHW, remain the same as these are not impacted by the climate directly.

The evaluation of building performance under the changed climate scenarios is carried out based on the examples of RCP 8.5 for 2050 and 2100, as these represent the worst conditions where the heating load is going down and the cooling load is rising.
Looking into simulation results (Figure 7) for air temperature inside most exposed apartment 5A (corner, top floor), one can see that for both future scenarios (blue line for RCP 8.5 2100 and red line for RCP 8.5 2050) heating is provided, mainly keeping the temperature within the setpoints limit (17°C – 20°C) in winter. In summer the indoor temperatures exceed 30 ºC and may require additional cooling.

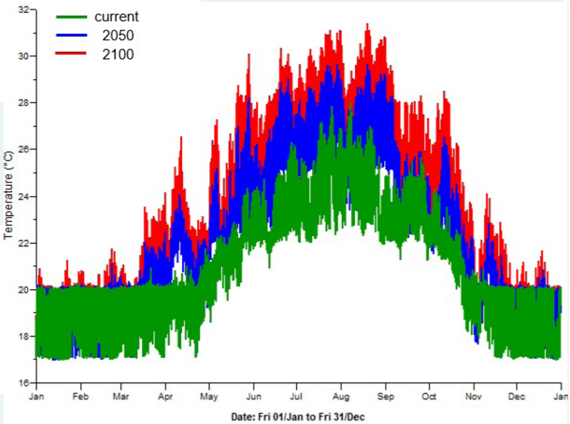


Figure 7. Future weather simulation – annual indoor temperature

The model was simulated according to the temperature setpoints of the Spanish Building Technical Code (CTE of 2019 [9]) which turns off cooling from 7:00 to 15:00. According to the observed results the operation should be more regular during all hours to be able to guarantee summer comfort. For this, a daily profile is analyzed (Figure 8).

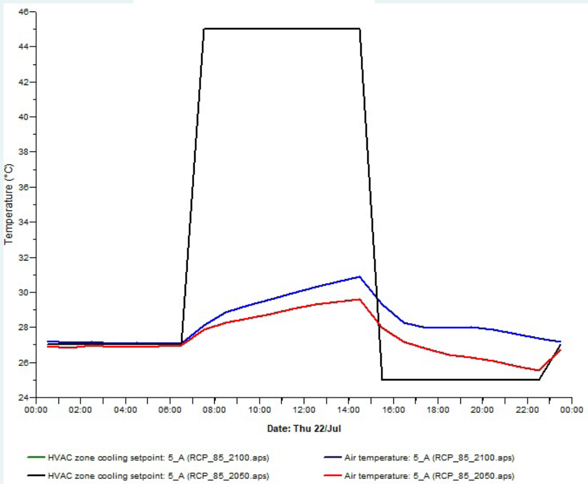


Figure 8. Future weather simulation – detail of typical summer day indoor temperatures

In both cases (year 2050 and year 2100) the morning design temperature of 27°C is satisfied, however the afternoon one of 25°C is exceed by 1 to 4 degrees. The typical long time of response of hydronic radiative terminal units takes too long to cool the room down.

5. Conclusions

The conducted literature review underlined the importance of adopting Net Zero approach in all the new constructions, as well as for the existing building stock, in order to combat the negative impact of changing climate. A digital twin model of the actual building proved to be a key tool to understand the current situation and reduce the operational carbon emission from the buildings in different ambition scales. In other words, one could include a balance only HVAC consumptions or add also lighting and equipment uses, getting a very different outcome.
As shown by its Digital Twin, La Balma is capable of achieving Net Zero Energy having HVAC annual energy consumption balanced by the annual onsite electricity generation from the PV panels: around 21 MWh per year.
However, in reality the building would hardly be self-sufficient in terms of energy even during the peak PV panels production season due to the intermittent nature of this type of renewable energy source.
Regarding the future adaptability, simulating a Digital Twin of La Balma had also shown that under future climate scenarios the current passive cooling system would fail to deliver thermal comfort and it would require operational improvements of the geothermal heat pump.

6.Bibliography

[1]'Facts about the climate emergency', UNEP - UN Environment Programme, Jan. 25, 2021. http://www.unep.org/explore-topics/climate-action/facts-about-climate-emergency (accessed May 09, 2022).
[2]Hoegh-Guldberg, O., D. Jacob, M. Taylor, M. Bindi, S. Brown, I. Camilloni, A. Diedhiou, R. Djalante, K.L. Ebi, F. Engelbrecht, J. Guiot, Y. Hijioka, S. Mehrotra, A. Payne, S.I. Seneviratne, A. Thomas, R. Warren, and G. Zhou, 2018: Impacts of 1.5ºC Global Warming on Natural and Human Systems. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. In Press.
[3]Rogelj, J., D. Shindell, K. Jiang, S. Fifita, P. Forster, V. Ginzburg, C. Handa, H. Kheshgi, S. Kobayashi, E. Kriegler, L. Mundaca, R. Séférian, and M.V. Vilariño, 2018: Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. In Press.
[4]'La Balma: habitatge cooperatiu a Poblenou', Sostre Cívic. https://sostrecivic.coop/projectes/la-balma/ (accessed May 13, 2022).
[5]E. Kayleigh, M. Abdellatif, A.-A. Joseph, S. S. Alquzweeni, and K. Hashim, 'Mitigating the impact of climate change on UK buildings through zero energy strategies', in IOP Conference Series: Earth and Environmental Science, 2021. doi: 10.1088/1755-1315/877/1/012018.
[6]'IES Virtual Environment', IES. https://www.iesve.com/software/virtual-environment (accessed May 13, 2022).

[7]‘What Is a Digital Twin? How Intelligent Data Models Can Shape the Built World‘, Redshift by Autodesk. https://redshift.autodesk.com/articles/what-is-a-digital-twin (accessed Aug 16, 2022).
[8]D. P. van Vuuren, J. A. Edmonds, M. Kainuma, K. Riahi, and J. Weyant, ‘A special issue on the RCPs’, Clim. Change, vol. 109, no. 1–2, pp. 1–4, Nov. 2011, doi: 10.1007/s10584-011-0157-y.
[9]‘Documentos CTE’, Código Técnico de la Edificación de España. https://www.codigotecnico.org/DocumentosCTE/DocumentosCTE.html (accessed Dec. 11, 2021).

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The IA ZERO methodology: A roadmap to sustainable refurbishment of buildings through energy simulation

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Abstract

For years, Spain has faced the need of renovating its old building stock to address energy efficiency in existing buildings and to meet the targets set by the European markets and standards. Now, in an uncertain post-pandemic era, Spain is starting to react to this need and 6.8 billion euros from the Next Generation funds have been allocated to urban regeneration and building energy retrofits. In this scenario of recovery and sustainable transformation, the IA ZERO methodology is postulated as an alternative to the traditional refurbishment process.

Supported by the Basque Professional Association of Energy Managers (APROBASGE) and Biscay's School of Building Administrators (CAFB) and generated under the ERAIKAL/20 lines of the Government of The Basque Country, the IA ZERO methodology promotes a comprehensive and advanced energy management model for residential buildings and their energy refurbishment. The goal is to provide a systemic procedure and tools that allow developing a diagnosis of the starting point, determining the transformation itinerary, and generating systems or processes to more effectively manage all aspects related to building energy. The IA ZERO approach relies on initial energy audits of the existing conditions and whole-building energy simulations to guide sustainable refurbishments towards Nearly Zero Energy Buildings (NZEB). This paper describes how energy models are used in the IA ZERO methodology to identify weaknesses, to investigate retrofit alternatives, to combine scenarios and to compare them with the performance of the existing building. Energy simulation is a very powerful decision-making tool used to identify synergies that lead to significant energy performance improvements such as the ones that IA ZERO aims to achieve. presented in this paper.

This paper presents the goals of the IA ZERO methodology and how energy simulation is used as a key guiding tool to achieve those goals in the retrofit process. The IA ZERO methodology is undergoing a refining and consolidation process through four pilot projects, two of which are exposed in this paper. These projects serve as illustrative case studies for future projects and to better understand the scope, the caveats and the benefits of this innovative approach. It is concluded that IA ZERO stands out from conventional refurbishments and provides a comprehensive roadmap to more sustainable energy retrofits that aims to guide neighborhood communities towards the optimal renovation strategy.

1.Introduction

Buildings are responsible for 40% of the energy consumed in the European Union [1]. Since the publication of the first Energy Performance of Buildings Directives with Directive 2002/91/EC adopted in 2002, the European Union has implemented strategies to address the energy efficiency improvement of European buildings. Subsequent legislation has gradually increased energy efficiency obligations, even introducing in Directive 2010/31/EU the requirement for Nearly Zero Energy Consumption Buildings (NECB) for new construction. In contrast to this commitment to sustainability, between 81% and 86% of European residential buildings date from before 1990 [2] and were built under regulations with little to no energy efficiency requirements. In Spain, 65.7% of the buildings are residential, and 51% of these date from before 1980 [3]. Current regulations and the latest modifications of the CTE HE contribute very positively to achieving the energy saving objectives in newly constructed buildings. However, with a building stock as old as Spain's, refurbishing existing residences can be even more important than building new efficient ones. The Spanish building stock has great potential for improvement and reduction of energy consumption through renovation.
In the Basque Country, the housing stock is very old (46.2 years on average) and has poor accessibility (26.9% of the buildings do not have an elevator) [4]. Data collected in the 2019 Survey on Housing Needs and Demand ENDV, 7.7% of Basque households expressed the need to refurbish their homes or buildings [4]. In order to respond to this reality, in the last decade a large number of strategies, laws and subsidies have been implemented to promote the energy rehabilitation of buildings, among which the Strategic Plan of the Basque Country for Building Renovation and Urban Regeneration 2010-2013 and the Basque Housing Act 3/2015 stand out. These rehabilitation policies aim to avoid disturbing more new land by intervening on the already built surface and thus contribute positively to the global objectives of sustainable development; the reduction of CO2 emissions and energy consumption.

1.1 IA ZERO ETXEBIZITZA background

According to the Spanish Institute for Energy Diversification and Saving (IDAE), buildings in Spain consume 30% of the total final energy, and only 0.3% of existing buildings have undergone energy retrofits. In order to improve this low percentage, the PREE fund program for energy refurbishment was created. This program was developed within the framework of the Recovery, Transformation and Resilience Plan and is financed by the Next Generation EU funds to help repair the social and economic damage caused by the COVID-19 pandemic. Following the trend of energy rehabilitation initiatives prior to the pandemic and to make use of the Next Generation EU funds, the IA ZERO ETXEBIZITZA project has been launched in the Basque Country. The lockdown established during the COVID-19 pandemic has served to give visibility to the importance of good thermal comfort and energy efficiency in residential buildings. As a result, energy retrofits and ecological transition are considered key elements in the recovery after the pandemic. In this context, the IA ZERO ETXEBIZITZA initiative aims to be a tool to develop energy renovations of residential buildings, which facilitates a transformation itinerary towards Nearly Zero Energy Buildings (NZEB).

2.IA ZERO ETXEBIZITZA CONCEPTS AND GOALS

The key ideas and objectives of the IA ZERO ETXEBIZITZA (hereinafter IA ZERO) project are developed in this section, focusing on the importance of energy simulation in this initiative.

2.1 The IA ZERO ETXEBIZITZA initiative

"The IA ZERO ETXEBIZITZA project is an initiative of the Basque Professional Association of Energy Managers- APROBASGE generated under the ERAIKAL/20 lines of the Basque Government and aims to promote a comprehensive and advanced energy management model for residential buildings and their transformation into NZEB, assuming the figure of the property manager and the maintenance company as essential agents for this change in the energy model due to their link with the owners and the operational management of the buildings, their facilities and their energy supplies." [5]
The IA ZERO initiative is a tool that serves to guide energy renovation processes in residential buildings by developing a whole-building rehabilitation strategy to achieve maximum levels of energy savings. This holistic approach to retrofits focuses on improving energy efficiency, improving accessibility and improving fire protection, according to LINE 3 of the ORDER of 21 July 2021, of the Regional Ministry of Territorial Planning, Housing and Transport. The IA ZERO methodology differs from traditional energy rehabilitation and incorporates innovative techniques such as energy simulation, which plays an essential role in the IA ZERO rehabilitation process together with the initial energy audit. Energy simulation is crucial for analyzing energy performance and for optimizing decision making and comprehensive processes.
In order to achieve energy efficiency targets as demanding as those of the NZEBs, it is necessary to implement mechanisms and solutions that are just as demanding, if not more. To this end, IA ZERO promotes cooperation between small and medium-sized companies from the building renovation sector to encourage the sharing of knowledge, resources and skills, and to avoid competing on price. The basis of the IA ZERO project is to create a climate of understanding and cooperation between professionals, organizations and agents in the sector that promotes good energy renovation practices. IA ZERO provides communities and property managers with a guide for the transformation of residential buildings into NZEBs, detailing the starting point, technical solutions, processes, savings and all aspects of NZEBs related to energy and comfort.

2.2 Whole-building energy simulation

Whole-building energy simulation is an analysis process that virtually replicates through energy models, the characteristics and factors that make up and affect the building. Energy models consider all aspects of the building and assess their impact on energy and economic performance. Energy models take into account the intrinsic components of the building (mass, orientation and shape), its constructive and architectural components, energy systems, environmental conditions (climatological and geographical), conditions of use and occupancy. Elements such as household appliances, which can be more or less efficient, and electricity, water and fuel rates are also taken into account. These elements are called inputs and by adjusting these variables different design alternatives can be analyzed using iterative simulations. Ideally the outcome of this iterative process will be an efficient building that guarantees user comfort.
Energy simulation makes it possible to obtain and compare consumption results immediately, which is of great value in retrofit projects such as those under the scope of the IA ZERO initiative. The energy retrofit of an existing building can be understood as the combination of several energy efficiency improvement strategies. The impact that these strategies will have on the total energy consumption of the building and on its overall performance can be estimated with simulation tools, as described later in this paper.
Integrated from the beginning of the project, energy simulation optimizes the design process and identifies synergies that increase the energy efficiency of the building and reduce costs. The IA ZERO initiative relies on the results of the energy simulation to determine the most favorable combination of energy conservation measures for the building. The more demanding the target, the more necessary it is to conduct an energy analysis that ensures the positive impact of the strategies that will be implemented. For this reason, energy simulation is a fundamental part of the IA ZERO renovation methodology.

2.2.1 Energy modelling tools

The software used in this initiative are Autodesk Revit to build the geometry and TRACE 700 for the energy simulation. To create the geometry, only areas and volumes of the spaces and their enclosures and openings are considered, but not their construction characteristics (these will be defined later in TRACE 700). Autodesk Revit allows to easily create a simple geometry and then export a gbxml file that can be imported into TRACE 700. The simulation software TRACE 700 allows to perform both load calculations and integral energy simulation using the well-known EnergyPlus egine. TRACE 700 has been used in this initiative because of its versatility to model different conditions and systems and to adjust a large number of variables (more than most software), thus being able to create highly accurate energy models.

2.3 IA ZERO target

The main objective of the IA ZERO initiative is to facilitate a roadmap for the transformation of a conventional residential building into a nearly zero consumption one. The project seeks to define a methodology that allows a diagnosis of the initial conditions and that proposes technical solutions and designs retrofit strategies that will be agreed with the owner. IA ZERO promotes energy empowerment of homeowners. The aim of the process is that the retrofitted building benefits from a better thermal comfort, reduction in energy consumption and therefore cost reduction in energy bills, greater accessibility and an increased value of the building. IA ZERO promotes a pathway towards more sustainable buildings and towards energy empowerment of homeowners using energy simulation throughout the renovation process to identify and analyze the best solutions and to verify results.

3.Description of the methodology

The methodology developed below describes the implementation and scope of energy simulation in the IA ZERO retrofit process. The IA ZERO project is supported by energy models throughout its different phases, which will provide valuable information for each stage of the project. This section presents the IA ZERO proposal for the optimal incorporation of energy simulation in the energy rehabilitation of residential buildings.

3.1 Phase 1: Information gathering, geometry and initial diagnosis

The first step to refurbish a building is to understand how it behaves, and to study its energy performance in order to identify which elements need to be improved. The way to obtain this information is to carry out an energy audit of the building, which will mainly consist of compiling plans of the building and relevant energy documentation (energy bills, energy studies or previous audits, energy certificate, etc..), and carrying out technical visits to the building. It is especially important to check the veracity and timeliness of the information collected as it is the basis of the initial energy model. The energy model starts with the creation of a virtual replica of the building geometry, which determines the mass, orientation and shape of the building. The geometry must define the areas of the envelope (facades and roofs), areas of openings (windows, doors and any other openings in the envelope), floor to floor heights, balcony areas, shading elements and the topography of the site. Interior spaces are then categorized as adiabatic spaces, exterior spaces, spaces adjacent to the ground, or spaces adjacent to unconditioned areas. The geometry also serves to identify parts of the building that require special attention, such as cantilevered floors, floors in contact with the ground, ceilings adjacent to the roof, and walls adjacent to unconditioned spaces, among others.
Once the geometry is built, existing conditions are defined, which may vary depending on the type of analysis and the simulation software used. In the case of a whole-building simulation for a residential building, such as the ones conducted in the IA ZERO initiative, at least the following parameters are taken into account:

-Environmental conditions: climatological and geographical conditions
-The building components: floors, slabs, structural materials, envelope and construction materials
-The energy systems: heating, cooling, domestic hot water, ventilation and renewable energy systems.
-The conditions of use and occupancy: number of occupants, usage profiles and comfort ranges.
-Energy and water consuming systems: appliances, lighting, plumbing fixtures, swimming pools, etc.
-Electricity, gas and fuel rates.

The characteristics of these parameters that are introduced in the energy model are called inputs. Some of the most important and influential inputs are the thermal transmittance of envelope elements, types and wattage of luminaires, and the nominal power and efficiency of HVAC systems. A first energy simulation is performed by introducing the inputs of the existing conditions. This initial energy model will be the baseline model and the results obtained for the baseline are analyzed and compared with energy consumption bills. Creating an initial energy model that rigorously aligns with existing consumption data requires meticulous refinement and calibration of the initial inputs. Outputs generated by the simulation provide valuable information to understand the energy consumption of the building, and the correct interpretation of these simplifies the identification of weak points in the building's behavior.

3.2 Phase 2: Technical solutions, iterative process and strategic analysis

In this phase different technical solutions and design strategies are evaluated using the baseline model as a starting point. Inputs can be easily and quickly modified in the energy model, and the effect of each of these changes can be studied. Design variables and inputs are adjusted and an iterative process is generated, through which the impact of each adjustment is quantitatively and qualitatively predicted. Iteration is one of the most powerful processes used in energy simulation, and there are many ways to approach it but ultimately iteration is simply a trial-and-error method that aims to find the design strategy that best suits project goals. Generally, the results of each iteration are compared with the outputs of the baseline model, especially in renovation projects. The main outputs used for performance comparison are energy demand, energy consumption and CO_2 equivalent emissions.
The IA ZERO project bases its final design proposal on the results of this strategic analysis. While it is usually the energy modeler or the architect who proposes and analyses different design strategies, in the IA ZERO methodology specialized companies generate the proposals. The IA ZERO initiative relies on the experience of these companies to create strategic solutions that are studied using energy simulation. Each technical solution represents a design alternative that is initially studied independently and after identifying the most beneficial ones, combinations of several alternatives are studied.

3.3 Phase 3: Combinations of alternatives and the IA ZERO Solution

The result of phase 2 is the final design proposal, which will be a combination of different energy efficiency measures. It is important to investigate through energy simulation the impact that combinations have on the whole-building energy performance. Combining different alternatives can sometimes result in energy efficient synergies. Alternatively, there can be conflicting measures that do not contribute to reducing energy consumption as expected because their benefit is not additive or because of incompatibility of execution. Using energy simulations to understand synergies and conflicts is one of the key benefits of the IA ZERO initiative.
Since the intention of the project is to transform the buildings into NZEB, the IA ZERO design proposal tries to include as many beneficial solutions as possible. The combination of all of them is called the “IA ZERO Solution”, which typically consists of a more efficient envelope, high performance HVAC systems and the inclusion of renewable energies, as it will be seen in the case studies. However, the suitability and applicability of the strategies will be different for each building. It is worth remembering that the IA ZERO Solution is a holistic retrofit that addresses not only the improvement of energy efficiency, but also the improvement of accessibility and fire protection; according to LINE 3 of the ORDER of 21 July 2021. Although accessibility and fire protection are not parameters that can be analyzed through energy simulation, they must be included in the final proposal and be present in the decision-making process.

3.4 Phase 4: Performance verification

Design decisions are especially important in early stages of a project. The appropriate specification of design features and processes during early phases of the project will reduce costs and the inconvenience of possible alterations in the future. Energy simulation analysis becomes more valuable in these early design phases because it optimizes decision making by trying to avoid modifications later in the process. However, it is difficult to avoid updates from the preliminary design, and it is necessary to consider whether the project can absorb these changes. In this scenario, energy simulation can also be used as a verifying agent throughout the project, by assessing impacts derived from possible changes. Energy simulation allows to check if design alterations compromise the performance objectives of the project. The energy model of the proposed final design is a project audit tool that serves to evaluate changes, to verify that the constructed or retrofitted building is faithful to the construction documents and to compare the real final performance with the simulated one. For the IA ZERO initiative the energy model of the IA ZERO solution is a fundamental piece for quality assurance. Any modifications to the proposed technical solutions must be evaluated by energy simulation to ensure that they do not compromise the energy performance of the building. IA ZERO uses energy simulation as a monitoring element to ensure that the savings percentages estimated in the initial phases are transformed into reality.

3.5 Limitations of the methodology

The results of the simulations are estimates and do not represent actual consumption. They can predict how the building will perform in the future and identify opportunities for improvement, but the accuracy of the results will depend on the accuracy of the data and parameters entered, and the level of experience of the energy modeler. Achieving reliable results requires specialized energy modelers and simulation software that provides an appropriate level of detail.
Many of the buildings considered for the IA ZERO project do not have drawings and access to energy consumption information may be limited. Many of the inputs for the baseline model will be assumed values that will be defined as close as possible to reality.

4.Case studies

The IA ZERO methodology is being put into practice through 4 pilot projects, two of which are presented below. These case studies are pilot projects that serve to test the suitability of the methodology and also to help define aspects such as managing the collaboration between companies, evaluating the results, the prioritization of strategies and financing options for the communities. The cases presented in this article have been developed in the neighborhood communities of Zumalakarregi 93-99 and Zumaia 22 in Bilbao and the Jauregizahar neighborhood in Amorebieta.
The software used to build the energy models of these projects are Autodesk Revit for the geometry and TRACE 700 for the energy simulation.

4.1 1 Case 1: Neighborhood Community of Zumalakarregi 93-99 and Zumaia 22

The neighborhood community of Zumalakarregi Av. 93-99 and Zumaia St. 22 is the first pilot project of the IA ZERO initiative and is composed of 5 multi-family buildings with garages in the basement. The scope of this analysis only includes floors dedicated to residential use and common areas, excluding the garages mainly because no energy conservation measures have been proposed for those spaces. An energy audit has been carried out to assess the current state of the property, which includes visits to the building and the review of drawings, energy consumption data and documentation on previous studies. Table 1 summarizes the conditions found both during the site visits and in the documents provided by the community. These data are used to determine the inputs assumed for the baseline energy simulation.

Existing conditions		
Envelope		
Roof	Uninsulated concrete roof, R-0,625 m^2.K/W[i] (U- 1,6 W/ m^2.K[i])	
Facade	Uninsulated brick facade, R-0,74 m^2.K/W[ii] (U-1,35W/ m^2.K[ii])	
Windows	Climalit windows, U-3,08 W/ m^2.K[iii], SHGC-0,635[iii]	
Doors	Glazed patio doors, U-5,7 W/ m^2.K	
Lighting	Fluorescent and incandescent lighting	
HVAC systems	**Type**	**Fuel**
Heating	Boiler 1 + radiators – 1120kW nominal power and 87,6% efficiency Sedical circulating pumps	Gasoil-C Electricity
Cooling	None	-
Ventilation	Natural ventilation	-
Domestic Hot Water	Boiler 2 – 370kW nominal power and 85,5% efficiency Sedical circulating pumps	Gasoil-C Electricity
Appliances	Standard	Electricity

Table 1. Summary of the existing conditions in Zumalakarregi and Zumaia.

i)Values estimated by Hinojal Arquitectos and calculated using the simplified software CE3x 2.3
ii)Values estimated by Hinojal Arquitectos and calculated using the simplified software CE3x 2.3
iii)Estimated values from the building's technical inspection report from 2019.

Two main conclusions have been obtained from the energy audit. On the one hand, the building needs to improve the envelope, because both facades and roofs are uninsulated. On the other hand, heating equipment must be replaced, not only to improve its energy efficiency but also because the existing gasoil boiler must be removed, by law, before 2030.

Figure 1. Exterior view of the building at Zumalakarregi 93 (Miriam Martínez, 2021).

Figure 2. Boiler room located in the basement of Zumalakarregi 93 (Miriam Martínez, 2021).

The Energy Conservation Measures (ECMs) proposed for this community and shown in Table 2 are the consequence of the conclusions drawn after the energy audit.

ECM #	ECM Type	ECM Description
1	Envelope - Windows	New double-pane VEKA windows, U-1,3W/m².K[iv] y SHGC-0,4[iv]
2	Envelope – Ventilated facade	Ventilated facade with 10cm Knauff mineral wool insulation, U-0,273 W/ m².K[v]
3	Envelope – ETICS facade	ETICS with 10cm EPS NEOPOR insulation, U-0,254 W/ m².K[vi]
4	Envelope - Roof	Expended XPS insulation above deck, U-0,31 W/ m².K[vii]
5	HVAC	New hot water natural gas boiler (Efficiency: 106,5%[viii]) + new circulating pumps + heat pump water heater (COP 3,7[viii])
Renewable Energy		
RE	Photovoltaic system	PV panels, installed power 196kWp[ix]

Table 2. Energy Conservation Measures proposed for Zumalakarregi 93-99 and Zumaia 22.

In order to study the different ECMs, a preliminary energy model for each one has been built based on the baseline energy model. The analysis focuses on providing an estimate of the energy savings after independently implementing each measure. The electricity and gasoil bills provided by the community set the starting point to compare energy consumptions derived from the different ECMs. Note that window replacement has been included in the analysis, but it will be optional for each homeowner. Note also that studying the inclusion of renewables goes beyond the scope of the preliminary simulation and has been analyzed independently (not through whole-building energy simulation).
The predicted energy savings for each ECM obtained from the energy simulation are shown in the following graphs.

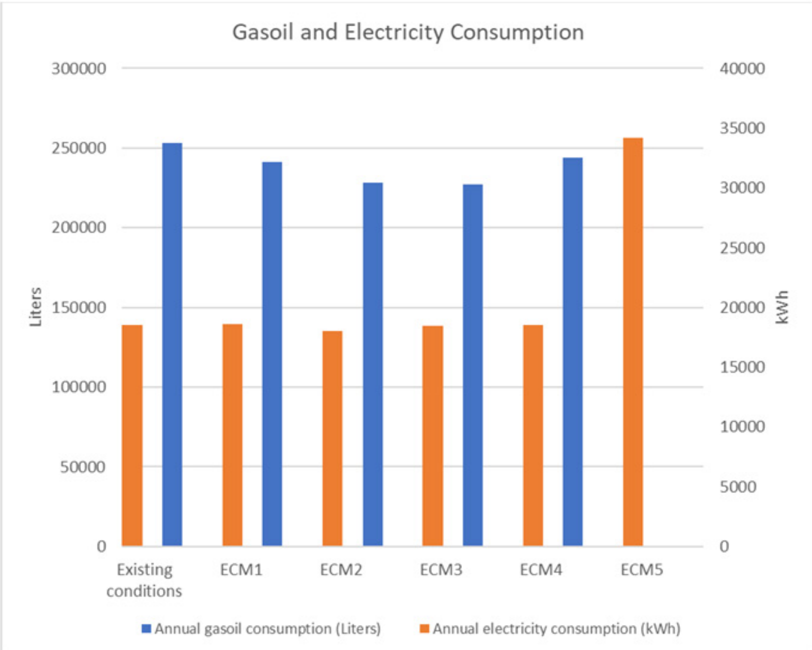

Figure 3. Estimated gasoil and electricity consumption for Zumalakarregi and Zumaia based on 2020 data.

iv)Values provided by VEKA
v)Values provided by ULMA
vi)Values provided by Beissier
vii)Values estimated by Hinojal Arquitectos and calculated using the simplified software CE3x 2.3
viii)Values provided by Efiner Soluciones Energéticas
ix)Value provided by CEC Energía y Edificación

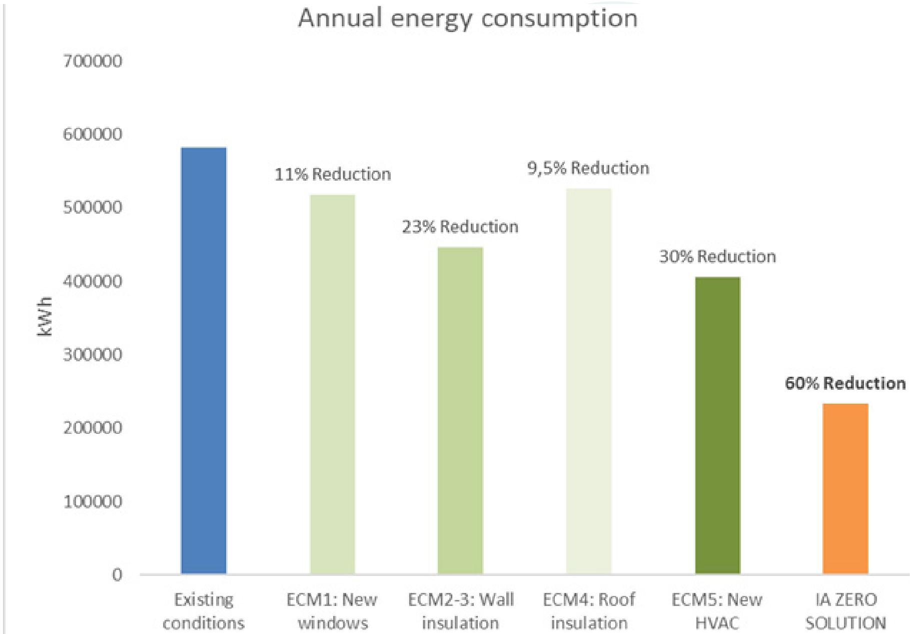

Figure 4. Estimated annual energy consumption and savings by ECM for Zumalakarregi and Zumaia based on 2020 utility data.

Finally, a simulation of the IA ZERO solution has been conducted, which combines all the previous ECMs, and a 48% reduction of the total energy consumption has been estimated. IA ZERO seeks the transformation of the existing building into a NZEB, and therefore the final strategy addresses improvements for all aspects of the building.

4.2 Case 2: Neighborhood Community of Jauregizahar 10-14

The second pilot project has been carried out in the neighborhood community of Jauregizahar in Amorebieta, which is composed of 5 multi-family buildings (portals 10 to 14) and it has garages in the basements of the buildings. As in Case 1, garages are excluded from the preliminary analysis. Data on existing conditions is obtained from the energy audit and it is represented in the baseline energy model with the values shown in the table below.

x)Note that between the two façade strategies the one with the best performance has been selected (ECM3)

Existing conditions		
Envelope		
Roof	Uninsulated concrete roof, R-0,625 m^2.K/W[xi] (U- 1,6 W/ m^2.K[x])	
Facade	Uninsulated brick facade, R-0,74 m^2.K/W[xii] (U-1,35W/ m^2.K[xii])	
Windows	Residential units: SGG Climalit doble-pane windows U-3,08 W/ m^2.K[xiii], SHGC-0,635[xiii] Stairs and common areas: Glass blocks, U-5 W/ m2.K[xiv], SHGC-0,8[xiv]	
Doors	Glazed patio doors, U-5,7 W/ m^2.K	
Lighting	Fluorescent and incandescent lighting	
HVAC systems	**Type**	**Fuel**
Heating	Boiler 1 + radiators – 588.200 kcal/h nominal power and 85% efficiency Smedegard circulating pumps	Gasoil-C Electricity
Cooling	None	-
Ventilation	Natural ventilation	-
Domestic Hot Water	Boiler 2 – 212.000 kcal/h nominal power and 85% efficiency Sedical circulating pumps	Gasoil-C Electricity
Appliances	Standard	Electricity

Table 3. Summary of the existing conditions in Jauregizahar.

The strategy proposed for this pilot project is very similar to the one followed in Zumalakarregi due to the similarity of the initial conditions of both communities. The main improvements proposed also focus on improving the envelope, currently without insulation, and the HVAC heating equipment, which also consists in diesel boilers that will be obsolete in 2030.

Figure 5. Exterior view of the facades of one of the buildings (Miriam Martínez, 2021).

Figure 6. Boiler room located in the basement of Jauregizahar 12 (Miriam Martínez, 2021).

xi)Values estimated by Hinojal Arquitectos and calculated using the simplified software CE3x 2.3
xii)Values estimated by Hinojal Arquitectos and calculated using the simplified software CE3x 2.3
xiii)Estimated values from Zumalakarregi's building technical inspection report from 2019
xiv)Values provided by VEKA

The following table summarizes the ECMs proposed for this community.

ECM #	Tipo de MCE	Case 1: Zumalakarregi & Zumaia	Case 2: Jauregizahar
ECM1	Windows	4,3%	11%
ECM2	Ventilated facade	9,4%	23%
ECM3	ETICS facade	9,6%	23,3%
ECM4	Roof	3,7%	9,6%
ECM5	HVAC	37%	30,3%
ECM1-5	IA ZERO Solution	48%	60%
Renewable Energy			
RE	Photovoltaic system	320%[xxii]	180%

Table 4. Proposed Energy Conservation Measures for Jauregizahar 10-14.

Following the reasoning of the previous case the replacement of the windows has been included in the analysis but it will be optional for each owner, and the photovoltaic system has not been included in the whole-building energy simulation. The estimated energy savings for each ECM have been compared with the existing data obtained from electricity and diesel bills provided by the community. The following graphs show this comparison.

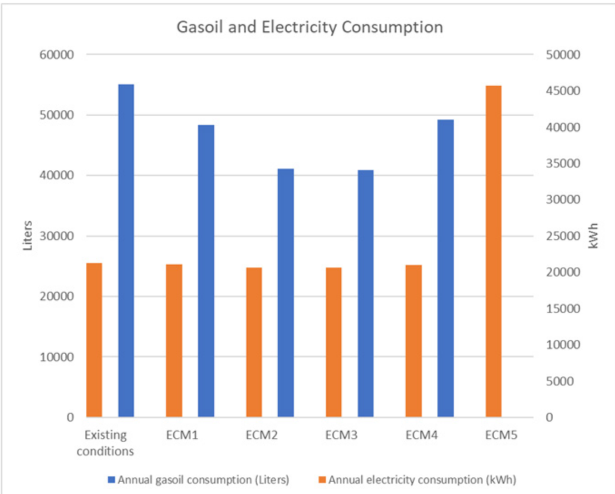

Figure 7. Estimated gasoil and electricity consumption for Jauregizahar based on 2020 data.

xv)Values provided by VEKA
xvi)Values provided by ULMA
xvii)Values provided by Beissier
xviii)Values estimated by Hinojal Arquitectos and calculated using the simplified software CE3x 2.3
xix)Values provided by Efiner Soluciones Energéticas
xx)Values provided by CEC Energía y Edificación

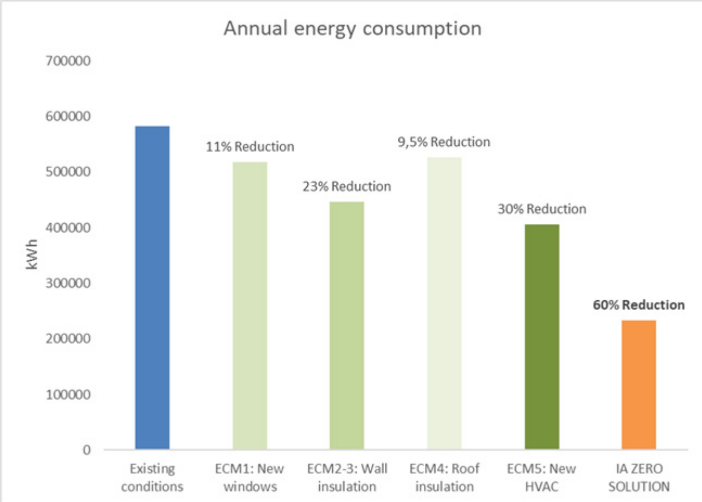

Figure 8. Estimated annual energy consumption and savings by ECM for Jauregizahar based on 2020 utility data.

Finally, an energy model that includes all ECMs has been created, which will be the IA ZERO Solution, and which is estimated to achieve a 60% reduction in the total energy consumption.

5.Conclusions

To conclude, a summary of the total energy consumption savings estimated for each case and ECM is shown.

ECM #	Tipo de MCE	Case 1: Zumalakarregi & Zumaia	Case 2: Jauregizahar
ECM1	Windows	4,3%	11%
ECM2	Ventilated facade	9,4%	23%
ECM3	ETICS facade	9,6%	23,3%
ECM4	Roof	3,7%	9,6%
ECM5	HVAC	37%	30,3%
ECM1-5	IA ZERO Solution	48%	60%
Renewable Energy			
RE	Photovoltaic system	320%[xxii]	180%

Table 5. Summary of total energy savings percentages for each case study and MCE.

xxi)Note that between the two façade strategies the one with the best performance has been selected (ECM3)

Energy savings in the four envelope strategies are mainly due to a lower heating demand, which results in a lower consumption of diesel oil and a lower electricity consumption derived from the distribution equipment. Improvements on the building envelope present consumption reduction percentages worthy of consideration, but they are far from being able to compete with the improvements proposed for the HVAC equipment, which are the ones that show the greatest expected savings.
The energy conservation measures considered for these communities have been analyzed independently and then a single combination of all of them has been studied. Iterative analysis is beyond the scope of the preliminary analysis of the pilot projects, but the study of different combinations between measures is highly recommended and will be included in future IA ZERO projects. The total percentages of energy savings achieved with the IA ZERO Solutions, although high, are not NZEB. However, note that these percentages have been obtained without accounting for the benefit of photovoltaic installations, which will contribute very positively to achieving the NZEB target.
The methodology proposed by IA ZERO is currently being refined and promoted through the four pilot projects, which are establishing the foundations for a roadmap for building retrofits that is a set of coherent decisions supported by energy simulation. IA ZERO promotes that these decisions derive from a collaborative deliberative process bringing together different actors in the sector around a common vision and objectives. This project promotes a more transformative, long-term, inclusive and resilient urban development that can benefit from energy savings as considerable as the ones presented in this paper.

xxii) Percentage of photovoltaic contribution to the estimated annual electricity consumption

6.Bibliography

[1] Official Journal of the European Union, DIRECTIVE 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings, 2010.
[2] Buildings Performance Institute Europe (BPIE), Europe's Buildings under the Microscope—A Country-by-Country Review of the Energy Performance of Buildings, Brussels, October 2011.
[3] Ministry of Transport, Mobility and The Urban Agenda, ERESEE 2020. 2020 Update of the Long-term Strategy for Energy Renovation in the Building Sector in Spain, June 2020.
[4] Basque Housing Observatory, Evaluation Report on the Basque Country's Rehabilitation Policy 2020, July 2021.
[5] https://www.iazero.es/objetivo/

Thermoeconomic analysis of a thermal system supplied with heat pump and auxiliary boiler for heating

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Abstract
The European Directives promote the use of energy from renewable sources and defines a common system to promote energy from renewable sources in all sectors. These efforts are transposed to the Spanish legislation by the National Integrated Energy and Climate Plan 2021-2030, in which Spain has set out to improve its energy efficiency and reduce primary energy consumption. Therefore, reducing energy consumption is in the spotlight of many researchers, especially in the sectors with the greatest potential for consumption savings, which are buildings, along with transport and industry.

Because of that, one of the important new features of the Building Technical Code (CTE in Spanish) 2019 has been the widening of the technologies allowed for compliance with section DB-HE4, and Heat Pumps become eligible to reach the minimum renewable share in DHW and heating production.

The Department of Territorial Planning, Housing and Transport of the Basque Government has a Laboratory of Quality Control of Buildings (LCCE) to carry out diverse testing on construction materials, components, systems and construction sites to assess compliance and enhance the quality of mechanical properties, acoustics and energy efficiency. The ENEDI Research Group of the University of the Basque Country (UPV/EHU) works in the Thermal Area of the LCCE improving the energy efficiency in new developments, existing buildings and refurbishments, as well as promoting the use of renewable energies; through experimental tests, research activities, training and advising society on the energy performance of buildings. An experimental facility bench allows testing of different configurations of thermal systems, by emulating real thermal and DHW demands.

The main objective of this work is to show the results of an experimental test carried on LCCE's system laboratory that reflects the dynamic behaviour of an Air Source Heat Pump (ASHP) thermal facility to cover the heating demand of a multifamily house. The smart control gives priority to the ASHP according to the dynamic demand and external conditions, so the auxiliary condensing boiler is activated in peak demands. A thermoeconomic analysis is applied, that is, an analysis that considers the two laws of thermodynamics and uses exergy as a basis. Thus, cost-sharing along the system is performed and the cost formation in each operation mode is evaluated in depth. The most inefficient equipment and the equipment that generates the most overcosts for the installation have been identified. This extensive analysis is very useful for further implementation of heat pumps in thermal refurbishments as well as for energy savings in buildings.

1. Introduction

The energy demand of a building is the energy required for a user to enjoy certain comfort conditions inside the building. This energy includes the energy needed to supply heating, cooling, ventilation, domestic hot water (DHW) and lighting. In Spain, the energy demand of buildings is increasing steadily, for example, from January to June 2021 the demand is 5.1% higher than that recorded in the same period in 2020, according to Red Eléctrica Española [1]. The increase in energy consumption not only has an impact on resources, but also on the emission of polluting gases into the atmosphere. The excessive use of some raw materials is leading to their rapid depletion, so that they do not have enough time to regenerate. In Europe, 40% of the energy consumed is in buildings, thus causing more than 50% of the CO2 emissions [2].These high levels of consumption, among others, have led the planet into a climate crisis. In order to find a solution, the Energy Union has been set up, which establishes partial targets for 2030 and final objectives for 2050. This Energy Union is to encompass five dimensions: energy security, internal energy market, energy efficiency, decarbonisation and research, innovation and competitiveness. In Regulation (EU) 2018/1999, the governance of the Energy Union and Climate Action was discussed for the first time [3].
Today, the climate situation continues to be worrying, which is why, in May 2021, the Official State Gazette (BOE) [4] communicated the European Union's decision to establish a new strategy, with the goal of becoming the first climate-neutral continent by 2050. The obligation to limit emissions conditions sectoral policies and implies changes in consumption patterns. The primary energy intensity is expected to improve annually by 3.5% until 2030, so that the country's energy dependence is estimated to fall from 74% to 61% by 2030, as a consequence of falling coal and oil imports. One way of achieving the aforementioned objectives is through the use of technologies such as heat pumps, mainly aerothermal, considered as high- efficiency equipment by the CTE DB-HE 2019 [5].
In addition, the maintenance of thermal installations in buildings is key to ensure the proper functioning of equipment and systems and to promote their energy efficiency. Because of this, studies and subsequent diagnostics are carried out to detect and evaluate faults. An adequate maintenance system guarantees the improvement of services, thus providing a preventive system based on the knowledge of the state of each of the equipment in an installation. The behavior of each piece of equipment is described by parameters that represent the consumption of resources from other equipment or the environment. This maintenance has changed over the years; according to Torne et. al. [6] maintenance has evolved into a preventive and predictive system. However, the basis of maintenance is to inspect equipment at regular intervals, to prevent failures and to avoid the consequences of failures.
In this context, especially since 2010, Thermoeconomics started to be applied in buildings and in particular in their installations. As developed in Ref. [7], thermoeconomic analysis combines thermodynamic analysis with economic analysis, calculating the cost of the resources used, the investment in equipment and the operating and maintenance costs. The data obtained makes possible to locate the real losses, i.e. irreversibilities, through the destruction of exergy and thus quantify the possible energy savings that can be achieved.

2. Objectives

The aim of this work is to show the results of the test carried out on an experimental heat pump installation at the LCCE and to analyse the results by means of a thermoeconomic analysis. For this purpose, a description of the installation and, in particular, of the control system implemented is given first.
In order to achieve this objective, the study covers the following stages:

-Analysis of the operation of the LCCE test bench, comprising the following phases:

- -Definition of the heating and DHW demands to be tested, according to the type of building.
- -Definition of control.
- -Characteristics of the test carried out and data obtained.
- -Calculation of thermodynamic variables.
- -Development of the thermal model of the system.

-Analysis of the test results from the perspective of the First and Second Principles of Thermodynamics.
-Application of thermoeconomics for cost calculation.
-Drawing conclusions and discussing them.

3. Materials and methods

This section shows the materials and methods used for this work.

3.1 Laboratory of Quality Control of Buildings of the Basque Government

The LCCE experimental plant is characterised by being a flexible installation that makes it possible to configure different installations depending on the required demand. For this purpose, the installation can be divided into different zones or islands, as can be seen in the following Figure 1: (1) low temperature zone, (2) high temperature zone and (3) solar collector zone. These three zones correspond to the different generation equipment, the (4) distribution equipment zone, the (5) heating/ACS terminals, and finally, the (6) thermal storage zone.
A thermal and electrical load simulation system, control systems, visualisation and automated recording of the different variables are available.

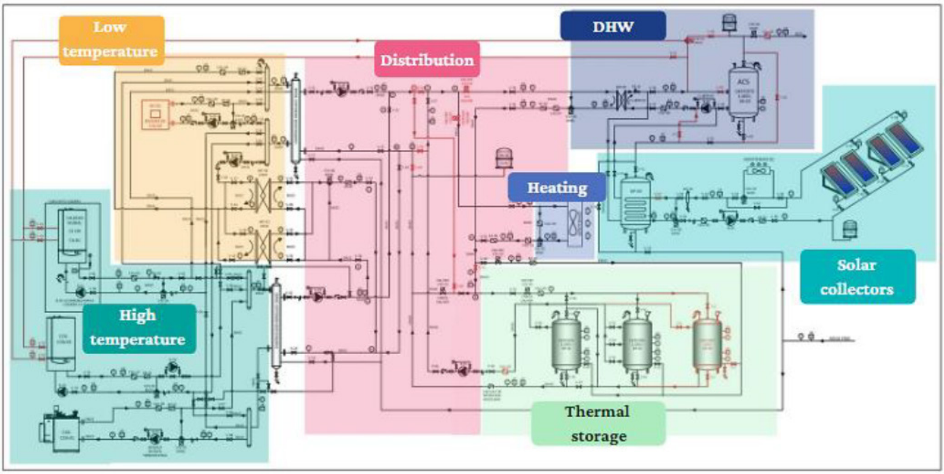

Figure 1. Schematic diagram of the LCCE experimental facility

The installation consists of more than 100 signals to control and monitor the variables to be evaluated. For this purpose, 46 high-precision temperature probes Pt 100 class 1/10 are used, 40 of them located in pipes and the rest in tanks, 1 SIEMENS F M electromagnetic flowmeters (MAG 3100 and 5100W sensors and MAG 6000 transmitters), 2 pressure switches, one in the general circuit and the other in the solar circuit. It also has ambient temperature, humidity and pressure sensors both inside and outside the laboratory. The boiler and the micro-cogeneration equipment have gas and electricity meters to monitor the cogeneration generation and the consumption of the heat pump.

3.2 Methods for thermoeconomic analysis

The Exergy Cost Theory is based on a series of Propositions, the systematic application of which makes it possible to determine unambiguously the value of the costs (in units of energy, monetary and environmental impact) of each of the flows of the system under analysis, Ref. [8].
In order to carry out a productive analysis of the installation, the flows are classified according to the function they perform in the equipment. The approach of the structural theory of thermoeconomics goes beyond the physical structure of the system and defines its productive structure in a matrix form. This representation considers each piece of equipment i as a black box with an input arrow, called fuel (Fi [kWh]), and an output arrow, product (Pi [kWh]). The Fi of a component i represents the resources (measured in exergy) needed to run the specific energy process and the Pi contains the target of the process itself. Therefore, the difference between the two represents the irreversibility of the process (Ii =Fi -Pi) and the ratio (ki =Fi /Pi [-]) reflects the unit exergy consumption of the component and is related to the rest of the components through the specific interrelationships F and P, given by a matrix (KP). Likewise, a product of one piece of equipment can be part of the fuel of another piece of equipment, or also part of the final product, P_s.
Consequently, the vector P containing the product of each equipment and the vector F containing the fuel of each equipment, are related through the following equations [9]:

$$\mathbf{P} = \mathbf{P_s} + (\mathbf{KP}) \cdot \mathbf{P} \quad (1)$$

$$\mathbf{F} = \mathbf{I} + \mathbf{P} = \mathbf{K_D} \cdot \mathbf{P} \quad (2)$$

where the end product vector is P_S; K_P is a diagonal matrix containing the total unit exergy consumption of the components; I corresponds to the vector of irreversibility, the matrix (KP)reflects, as we have said, the productive structure.
The total fuel consumption of the system,F_t, is calculated by adding the total irreversibilities and the final product of the system; or by multiplying the vector P, with the consumption of external resources, K_e , i.e. electricity and fuels consumed in the installation.
The elements K_{ij} and K_{ej} of the matrix (KP) represent the amount of resources of component i and of external resources that are necessary to obtain one unit of output of component j. Therefore, they are referred to as marginal exergy consumption and marginal external exergy consumption. For each piece of equipment, the unit exergy consumption, K, is equal to the sum of all marginal exergy consumptions of the equipment.
In addition, the unit exergy cost (K^*_j) takes into account the resources needed to generate flow i in the energy chain. Therefore, K^*_j increases as the irreversibilities along the energy chain increase. The unit exergy costs of equipment products (K^*_p [kWh/kWh]) are related to the unit exergy costs of the external resources $K^*_{e,i}$ of component i and to the marginal exergy consumption associated with the external resources $K^*_{e,i}$ and represent the amount of exergy required to obtain one unit of exergy from that flow.
On the other hand, the exergoeconomic cost of a flow Ci represents the economic resources necessary to obtain this flow i. The economic costs of internal flows and final products depend on the thermodynamic efficiencies of the processes, as well as on the investment and maintenance cost of the equipment. In order to calculate the costs of the flows, it is necessary to know the acquisition cost of each equipment (*C A E* i [€]), the active hours of each piece of equipment per year (t [h/year]), the useful life (n [year]), the effective interest rate (i [-]) and the costs of the resources used. The total costs are broken down into fixed costs and variable costs.
Variable costs are those that depend directly on the level of production, while fixed costs are the costs of investment, maintenance and operation of the equipment, which are represented by the vector Z [€]. Also, $C_{F,i}$ [€] represents the exergoeconomic cost of fuel for equipment i and indicates the economic resources necessary to obtain fuel for this equipment. Similarly, $C_{P,i}$, is the exergoeconomic cost of the product of this equipment and represents the economic resources necessary to obtain this product; therefore the following relationship is fulfilled:

$$C_{P,i} = C_{F,i} + Z_i \quad (3)$$

Similarly, the exergoeconomic unit costs of fuel and products ($C_{F,i}$ and $C_{P,i}$ [€/kWh]) are:

$$c_{F,i} = \frac{C_{F,i}}{F_i} \qquad (4)$$

$$c_{P,i} = \frac{C_{P,i}}{P_i} \qquad (5)$$

If we call C_F and C_P the fuel and product cost respectively for each of the equipment, the following matrix equation is satisfied:

$$\mathbf{c_P} \cdot \mathbf{P} = \mathbf{c_F} \cdot \mathbf{F} + \mathbf{Z} \qquad (6)$$

3.3 Software used

In order to carry out this work, we have used software for the control and diagnosis of thermal installations, which is based on Thermoeconomics. The software calculates the thermoeconomic costs of each of the installation's flows, and detects the equipment with the greatest irreversibilities, which are those that most increase the cost along the energy chain.
This software combines Matlab software [10], where the calculations are performed, and Excel, where the data are recorded and the results are displayed.
The results obtained, explained in Ref. [11] depend on the quality of the data, which requires accurate and well-calibrated probes, so that the greatest difficulties are related to the analysis and the filtering of the measured data. The costs are obtained from the productive structure that interconnects all the equipment according to (1) the distribution ratios, b_y (2) the unitary exergy consumption of each equipment, k_i and (3) external resources, F_e. This is very useful information for future diagnostic analyses, given that when a parameter of a piece of equipment varies, its unitary exergy consumption varies, and so do the costs related to that component.

4. Case study

This section explains the configuration of the experimental installation, the productive structure, other economic data and the application of these data in the software used to carry out the case study.

4.1 Configuration of the experimental facility

The installation supplies heating to a building of 1 dwelling located in Burgos (Table 1), using a 17.9 kW air-to-water heat pump with a seasonal COP of 2.5 and a 28 kW condensing boiler.

Location	Burgos
Climate zone	E1
No. of dwellings	1
Floor dimensions	10 m
Building height	4 m
Height between floors	2.7 m
Glazed surface	40%
Usable area	200 m^2
Comfort temperature	21ºC
Minimum outdoor temperature	-4.2ºC
Q_{peak}	45900 W
UA	1821.429 W/K

Table 1. Building characteristics

The main equipment of the designed installation is as follows:

-Generation: air-to-water heat pump and condensing boiler.

-Distribution: hydraulic pumps, hydraulic compensator, thermal collectors, three-way valves.

-Supply: Fan heater.

The heating demand profile has been calculated using the simplified Degree-Day method, considering the guidelines and limitations required by the Technical Building Code (CTE). Once a typical profile has been obtained, it has been implemented in the LCCE test bench platform to dissipate the heating in real time by means of the fan heater.

4.2 Productive structure

The configured installation in the LCCE consists of 6 equipment and 15 flows, as shown in the Figure 2. For the thermoeconomic analysis, the pumps are not considered, as their consumption is very small, and only the thermal energy of the water flows is considered and the mechanical part related to pressure changes is not included.

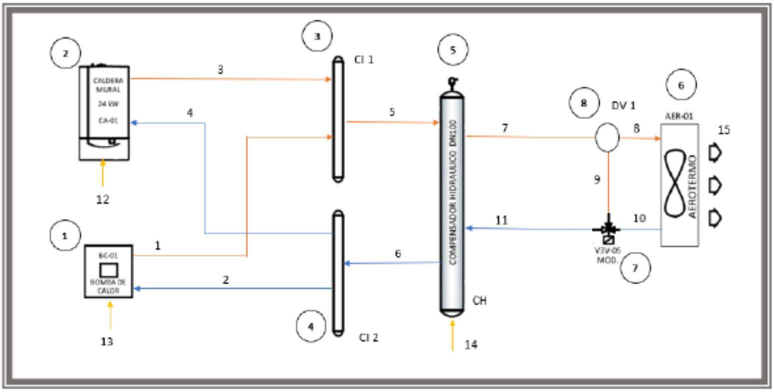

Figure 2. Schematic diagram of the installation

In order to define the productive structure, it is necessary to add “virtual” equipment (grey in the Figure 3) in order to represent the fuel and the product of each team. In addition, the flows are renumbered (Table 2), resulting in 14 equipment and 19 fuels, see Table 2.

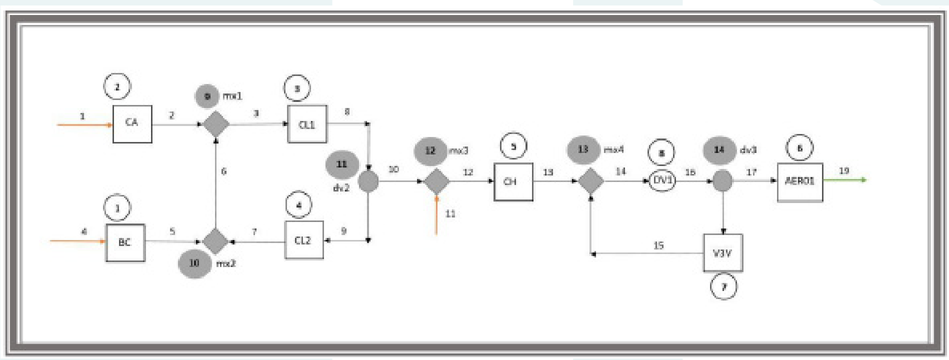

Figure 3. Simplified productive structure

Nº	NAME	FUEL	PRODUCT
1	BC (Heat pump)	4	5
2	CA (Boiler)	1	2
3	CI 1 (Impulse collector 1)	3	8
4	CI 2 (Impulse collector 2)	9	7
5	CH (Hydraulic compensator)	12	13
6	AER-01 (Fan heater)	17	19
7	V3V-05 (3 way valve)	18	15
8	DV 1 (Divider 1)	14	16
9	mx1 (mixer 1)	2+6	3
10	mx2 (mixer 2)	5+7	6
11	dv2 (divider 2)	5	10+9
12	mx3 (mixer 3)	10+11	12
13	mx4 (mixer 4)	13+15	14
14	dv3 (divider 3)	16	17+18

Table 2. Simplified productive structure

4.3 Other economic data

In order to calculate the economic cost, it is necessary to know the cost of the external resources used (electricity, natural gas). The unit costs of both resources presented in the Table 3 shows the unit costs of both resources.

c_{elec} [€/kWh$_{ex}$]	0.286
c_{GN} [€/kWh$_{ex}$]	0.081

Furthermore, Table 4 presents the fixed costs of acquisition, operation and maintenance, Z, of the main equipment, according to their operating hours and their acquisition, operation and maintenance price.

Nº	NOMBRE	Acquisition cost of each equipment (CAE) [€]	Fixed costs (CF) [€/period]	[hON/period]
1	BC (Heat pump)	4396	15.21	196.75
2	CA (Boiler)	1899	6.57	0.75
3	CI 1 (Impulse collector 1)	900	3.11	288.00
4	CI 2 (Impulse collector 2)	900	3.11	288.00
5	CH (Hydraulic compensator)	1334	4.62	288.00
6	AER-01 (Fan heater)	4502	15.58	212.43
7	V3V-05 (3 way valve)	80	0.28	288.00
8	DV 1 (Divider 1)	80	0.28	288.00
	TOTAL [€]	14091		

Table 4. Economic data of the installation components

4.4 Thermoeconomic software

The workflow of the software consists of 3 phases, from which the first two ones define the installation and the third one consists on solving matrixes:

-Definition of the general parameters of the installation:
In this phase the productive structure of the installation is established, as well as the economic data previously developed.

-Numerical values and calculations:
It is divided into different procedures:
-Transfer, noise filtering and validation of monitored data (Excel): The data collected from the test bench are transferred to Excel, where noise is filtered and data are validated.
-Energy and exergy calculations (Excel): Energy and exergy values are calculated for the defined flows.
-Matrix calculations (MATLAB): Matrix calculations based on Thermoeconomics are performed.

-Obtaining results:
The results are extrapolated to Excel for further analysis.

5 Results and discuss

This section shows the data obtained from the test and the results of the thermoeconomic analysis carried out.

5.1 Test results

The following Figure 4 shows the heating demand calculated and implemented in the LCCE. As mentioned above, it corresponds to the heating demand of a building of 1dwelling in Burgos. This demand profile has been calculated hour by hour based on the simplified Degree-Day method and the standard temperatures of the site. However, the experimental installation of the LCCE updates the demand every 15 seconds, so it interpolates the hourly demands, obtaining consumptions in the corresponding period.

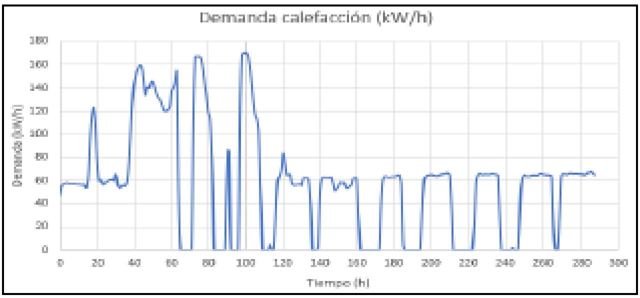

Figure 4. Real demand of the LCCE installation

The control has been designed in such a way that it prioritises the operation of the heat pump over the boiler. Therefore, whenever there is a heating demand, the BC is activated to supply it; the boiler only comes on as auxiliary equipment at peak demand. The graphs in the Figure 5 describe the operating modes of the generation equipment. They show the boiler fuel and product energy as well as its efficiency on the one hand, and the values for the heat pump on the other hand. The following can be seen:

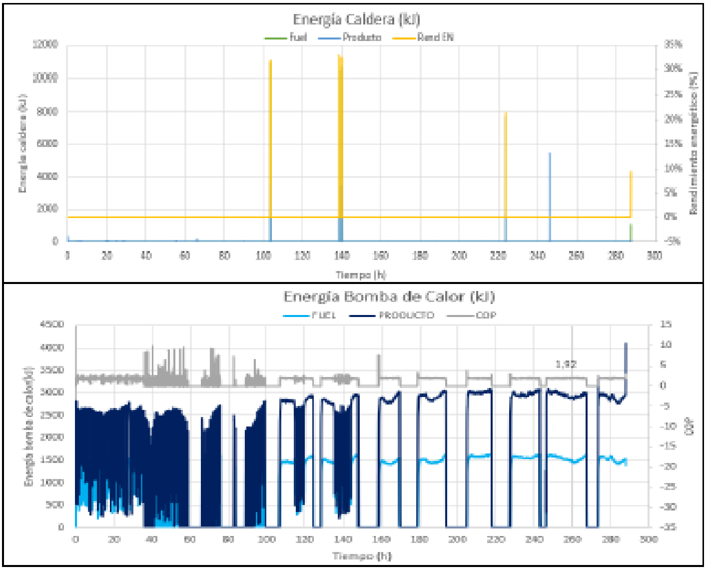

Figure 5. F-P and efficiencies of generation equipment

-As for the boiler, it can be seen that the efficiency is very low (around 30%), much lower than its nominal efficiency of 90%. This may be due to the short activation period between start-up and shut-down, which does not allow it to reach steady states. This is of course an unfavourable scenario, which causes the boiler to consume more than it should. Furthermore, the boiler hardly participates in the generation of demand.

-In the case of the heat pump, the energy of the product is higher than that of the fuel, because its operation is measured through the COP, which has a value greater than unity. The COP of this heat pump in steady state is 1.92, slightly lower than the nominal COP.

5.2 Thermoeconomic results

The Table 5 contains the thermoeconomic results over the 288 hours of the test. The following conclusions are drawn:

Nº	NAME	F_{ex} [kWhex]	P_{ex} [kWhex]	k $\left[\frac{kWh_{ex}}{kWh_{ex}}\right]$	k^*_F $\left[\frac{kWh_{ex}}{kWh_{ex}}\right]$	k^*_P $\left[\frac{kWh_{ex}}{kWh_{ex}}\right]$
1	BC (Heat pump)	892.11	92.60	9.63	1.00	9.63
2	CA (Boiler)	13.80	0.20	69.88	1.00	69.88
5	CH (Hydraulic compensator)	276.85	166.11	1.67	3.94	6.57
6	AER-01 (Fan heater)	73.76	15.04	4.90	14.78	72.50
7	V3V-05 (3 way valve)	260.62	168.27	1.55	14.78	22.90

Table 5. Exergy results of the components of the installation

-As expected, as one moves up the energy chain: (1) exergy decreases between the fuels and products of each piece of equipment (due to exergy efficiency), and (2) exergy decreases as one moves downstream between the components, see Figure 6.

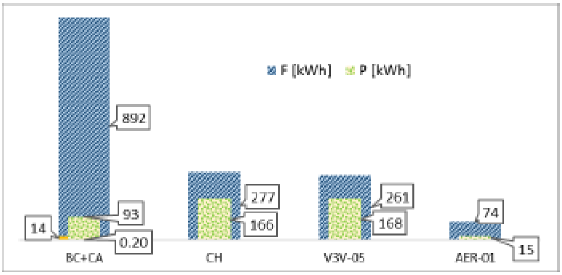

Figure 6. Evolution of the Fuels and Products of each equipment in the energy chain

-The equipment with the highest unit exergy consumption, K_i, are the generation equipment, i.e. the heat pump and the boiler, with values of 9.68 [-] and 69.88 [-] respectively. This shows that it are the generator equipment that has the greatest exergy destruction in the system, with the boiler's being the highest.
-On the other hand, it is observed that the unit exergy costs of fuels, $k^*_{F,i}$ of the generating equipment have a value of 1, as these two input flows are external flows. It is also observed that the ratio between the unit exergy costs of the fuels and the products of these two generators, $k^*_{F,i}$, is proportional to the irreversibilities that occur.

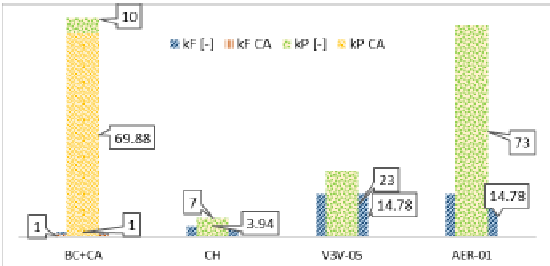

Figure 7. Evolution of unit exergy costs along the energy chain

-As you move up the energy chain, the costs increase, due to the accumulation of irreversibilities, see Figure 7.
-Furthermore, the total boiler product, Pex = 0.20 [MWhex], is low. This is due to the fact that the boiler has been in operation for 0.26 % of the total time.

For the exergoeconomic results of the installation, a first analysis has been made without taking into account the operating, acquisition and maintenance costs included in vector Z, i.e. only the costs due to the external consumption of gas and electricity of the installation have been considered, as shown in the last column of Table 6. It is concluded as follows:

Nº	NOMBRE	c_F $\left[\frac{c€}{kWh_{ex}}\right]$	c_P $\left[\frac{c€}{kWh_{ex}}\right]$	c_Z $\left[\frac{c€}{kWh_{ex}}\right]$
1	BC (Heat pump)	21.81	210.11	0.00
2	CA (Boiler)	5.07	354.36	0.00
5	CH (Hydraulic compensator)	70.53	117.55	0.00
6	AER-01 (Fan heater)	264.74	1298.27	0.00
7	V3V-05 (3 way valve)	264.74	410.03	0.00

Table 6. Exergoeconomic results of the components without taking into account the costs of Z

-On the one hand, the exergoeconomic costs of fuels, cF, take into account the irreversibilities accumulated up to that point in the energy chain; it can be seen that, as one moves up the energy chain, these costs increase.
-On the other hand, in terms of the exergoeconomic costs of products, only the unit costs due to the exclusive consumption of external resources are taken into account, cP; therefore, in the same way as for fuel costs, the costs of products increase as one moves up the energy chain.

The Table 7 presents the exergoeconomic costs of the fuels and products of the plant equipment, including the costs of Z for this second test. The following comments can be made:

Nº	NAME	c_F $\left[\frac{c€}{kWh_{ex}}\right]$	c_P $\left[\frac{c€}{kWh_{ex}}\right]$	c_Z $\left[\frac{c€}{kWh_{ex}}\right]$
1	BC (Heat pump)	21.81	210.11	16.42
2	CA (Boiler)	5.07	354.36	3327.55
5	CH (Hydraulic compensator)	80.65	117.55	19.64
6	AER-01 (Fan heater)	309.72	1298.27	324.16
7	V3V-05 (3 way valve)	309.72	410.03	69.83

Table 7. Exergoeconomic results of the plant components taking into account the costs Z

-Obviously, the costs increase compared to the previous case. Thus, for example, in the case of the fan heater, the fuel cost increases from $c_{F,aer}^{withoutZ}$ = 264.74 $\frac{c€}{kWh_{ex}}$ to $c_{F,aer}^{withZ}$ = 309.72$\frac{c€}{kWh_{ex}}$.
-On the other hand, the cz of the boiler is very high, due to its few hours of operation. This cost is passed on to the rest of the equipment, as it is linked to the previously established productive structure and the boiler is one of the first pieces of equipment in the energy chain. Therefore, both the cz and cF increases in the rest of the downstream equipment.

Given the high costs of low use of the boiler and low energy input, the case of no boiler has been analysed, i.e. the thermal comfort in the building is sacrificed due to the lack of boiler input for 0.26% of the total time.

		WITH BOILER			WITHOUT BOILER		
Nº	NAME	c_F $\left[\frac{c€}{kWh_{ex}}\right]$	c_P $\left[\frac{c€}{kWh_{ex}}\right]$	c_Z $\left[\frac{c€}{kWh_{ex}}\right]$	c_F $\left[\frac{c€}{kWh_{ex}}\right]$	c_P $\left[\frac{c€}{kWh_{ex}}\right]$	c_Z $\left[\frac{c€}{kWh_{ex}}\right]$
1	BC (Heat pump)	21.81	210.11	16.42	21.81	210.11	16.42
2	CA (Boiler)	5.07	354.36	3327.55	0.00	0.00	0.00
5	CH (Hydraulic compensator)	80.65	117.55	19.64	78.02	117.13	15.68
6	AER-01 (Fan heater)	309.72	1298.27	324.16	299.86	1293.61	280.47
7	V3V-05 (3 way valve)	309.72	410.03	69.83	299.86	408.56	56.04

Table 8. Exergoeconomic results taking into account the costs of Z with and without boiler back-up

The Table 8 compares the exergoeconomic costs with and without a back-up boiler. As mentioned above, the considerable increase in the unit cost of the equipment due to the cost of amortisation, operation and maintenance of the boiler is once again highlighted cz,CA.

		C_P
REGARDLESS OF Z (fuel cost only)	HEATING	195.27 $[€/_{12\ days}]$
TAKING INTO ACCOUNT Z	HEATING	244.00 $[€/_{12\ days}]$
TAKING INTO ACCOUNT Z, WITHOUT BOILER	HEATING	236.75 $[€/_{12\ days}]$

Table 9. Comparison of total system product cost

The Table 9 shows the costs of heating production for the three cases analysed. On the one hand, it is clear that the costs of acquisition, maintenance and operation represent an additional cost in the thermal installations. On the other hand, it shows how not using the boiler and “sacrificing” 0.26% of the total time of the building’s thermal comfort, means a saving of 7.27 € in 12 days, which is equivalent to a saving of 3% of the total.

6 Conclusion

This work analyses from a thermoeconomic point of view a heating installation powered by an aerothermal heat pump and a natural gas condensing boiler. It has been seen that the most inefficient equipment is the boiler due to its unitary exergy consumption of k=69.88 [-]. Furthermore, using the exergoeconomic costs, it has been seen that the cost Z of the boiler generates a significant extra cost to the products of the installation, due to its low operating hours; and that in short, not including the boiler in the system generates a 3% saving in 12 days, and it guarantees thermal comfort in the building almost completely, 99.74% of the total time.
Ultimately, it has been demonstrated that a thermoeconomic analysis is capable of identifying irreversibilities and cost overruns in a thermal installation.

7 Discussion

It should be recalled that the analysis of this work has been carried out with the thermoeconomic software developed in 2019. This software provides the user with flexibility in terms of being able to carry out different casuistry of the installations and can represent an important advance in the field of the management of thermal installations in buildings. In this way, the effect on cost and comfort of incorporating or not incorporating the boiler in the installation has been proved.
For future lines, work will continue on heat pump-based installations for buildings, and highlights the need to further study its control in order to take advantage of the most efficient COP, as it is a technology capable of achieving the objectives in line with European legislation, i.e. the development of the intelligent building and decarbonisation by 2050.

8 Acknowledgements

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9 Referencias

[1] R. CÓRDOBA HERNÁNDEZ, A. HERNÁNDEZ-AJA. Revisión de la best practice" red española de ciudades por el clima", desde la estrategia europea medioambiental. Revista INVI, 2013, vol. 28, no
[2] L. MAZZARELLA. Energy retrofit of historic and existing buildings. The legislative and regulatory point of view. Energy and Buildings, 2015, vol. 95, p. 23-31.ç NOUICER, Athir; MEEUS, L. The EU clean energy package. Florence School of Regulation, 2019.
[3] A. NOUICER, L. MEEUS. The EU clean energy package. Florence School of Regulation, 2019.
[4] BOE-A-2021-8447
[5] Código Técnico de la Edificación (CTE) Documento Básico HE de Ahorro de energía. 2019 (ht-tps://www.codigotecnico.org/pdf/Documentos/HE/DBHE.pdf)
[6] I. GONDRES TORNÉ, S. LAJES CHOY, A. DEL CASTILLO SERPA. Gestión del mantenimiento a interruptores de potencia. Estado del arte. Ingeniare. Revista chilena de ingeniería, 2018, vol. 26, no 2, p. 192-202.
[7] A. PICALLO-PEREZ, et al. Reflexiones sobre la termoeconomía como una herramienta metodoló-gica para la sostenibilidad en edificios. DYNA-Ingeniería e Industria, 2021, vol. 96, no 1.
[8] E. Querol, J. Garcia Torrent, A. Cámara, J. Mª. Montes. Termoceonomía y Optimización Energéti-ca, Universidad Politécnica de Madrid, 2011.
[9] V. Verda, , L. Serra, A. Valero, Thermoeconomic Diagnosis Zooming Strategy Applied to Highly Complex Energy Systems Part II- On the Choice of the Productive Structure, ASME Paper IMECE 2002-33185, 2002.
[10] MATLAB. (2018). 9.7.0.1190202 (R2019b). Natick, Massachusetts: The MathWorks Inc.
[11] A. PICALLO-PEREZ, J.M. SALA-LIZARRAGA, L. PORTILLO-VALDES. Development of a tool based on thermoeconomics for control and diagnosis building thermal facilities. Energy, 2022, vol. 239, p. 122304.

The potential for improvement in the new generation of Energy Performance Certification with an integrated approach to assessment at neighbourhood level. SmartLivingEPC Project- case study of Leitza

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Key Words: EPC; renewable energy community; building complex scale; BIM; digital twin.

Abstract

A significant amount of valuable information about energy consumption in buildings can be gleaned from databases with Energy Performance Certificates (EPC). However, the literature shows that there are many challenges to be overcome in next generation EPC schemes. In this respect, this communication presents the SmartLivingEPC project, funded by the European Commission's Horizon Europe programme, whose aim is to develop a new method for calculating an EPC. To this end, the project will be based on the use of digital tools (BIM, digital twins, etc.). In addition, it will integrate various indicators that until now have not been included in the methodologies, such as life-cycle analysis, air quality, acoustic quality, water consumption, level of building intelligence (SRI) or the actual operation of the facilities. An assessment methodology will be proposed both at

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the level of theoretical calculations (asset rating) and at the operational level (operational rating). Moreover, in addition to developing the rating system at building level (Building EPC), another rating scheme will be obtained at the level of building complex level (Complex EPC). This extension to the neighbourhood level and energy communities is one of the most important innovative aspect of SmartLivingEPC. To this end, the small town of Leitza in Navarre, Spain, will participate as pilot community with a mix of private residential dwellings, small commerce and public buildings such as a school, a sports centre and the town hall. Community-owned assets such as a PV plants providing electricity for collective self-consumption add tangible benefits which will be reflected in the EPC score. In a first phase, the potential of energy communities to provide knowledge about energy measures to its members, and empower them to participate in a just energy transition has been observed. And It is hoped that more targeted community-led refurbishment activities can be triggered as a result of the participation in the project. Therefore, it can be said that the integration of the Renewable Energy Communities in EPC Schemes could improve the capacity of the EPCs to encourage energy saving measures.

The project, which receives co-funding from the Horizon Europe programme, started on the 1st of July 2022, will run for three years and involves 15 partners from 12 different countries.

1. Introduction

The building Energy Performance Certificate (EPC) is the EU's core policy instrument to attain European Directive targets in the area of energy efficiency [1], [2]. The EPC database has become the main source of information on the energy consumption of the building stock. However, studies show that there are some concerns and misgivings about its applicability and data reliability [3]–[6] and that there is a need for more reliable and cost-effective calculation methods. Furthermore, the large disagreement between the EPC and the actual energy demand does not allow policymakers to successfully design future energy plans, nor for property owners to confidently invest in energy-efficiency measures.

Despite the progress made in the past years towards more energy-efficient buildings, challenges brought about by the introduction of technical innovations in the building industry and by an increasing demand for smarter and more sustainable living still need to be overcome. In the same way, EPC functionalities and uses could be extended with innovative features for users [7].

Li et al point out many challenges for the next generation of EPCs based on a review of 18 studies [3]. Some of them are key to the present study: (i) Integration with BIM models to speed up the data consolidation process; (ii) Inclusion of more key performance indicators to enrich the EPC; (iii) Taking human intervention and building smart readiness into account.

Novel tools for assessing a building's energy performance such as Building Information Modelling (BIM), digital twins, smart-sensor data and digital building logbooks (DBL) offer rich and dependable information. At the same time, they make the EPC data as well as the information exchanged between building owners, contractors and other stakeholders more transparent. Pereira et al highlighted that BIM tools are a good support for Life Cycle Analysis (LCA) and building energy certification [8].

Moreover, Reiter et al state that neighbourhood design and its impact on energy performance of both individual buildings and of the entire neighbourhood is often overlooked [9]. If we add to this the increase of Renewable Energy Communities (RECs) and, as a consequence, the improvement of energy efficiency performance at the whole building complex or neighbourhood scale, there is a significant gap in the EPCs, as they do not consider the impact of performance beyond those of the building unit itself.

The SmarLivingEPC project responds to these challenges posed by the literature. This project is co-funded by the European Comission's Horizon Europe programme. It started on the 1st of July 2022 and will run for three years. 15 partners from 12 different European countries are involved.

This communication provides an overview of this project, with special attention to the methodology and the case study of an REC that is being carried out by project partner Goiener, a citizen energy cooperative in the Basque region of Spain, and is beginning to show its first results, despite being in a preliminary phase. This case study is located in Leitza (Navarra) and it is detailed in Section 3.

2. Objectives and scope of smart living epc

The SmartLivingEPC project aims to develop a new methodology for issuing energy certification of buildings focusing on aspects that have not been considered so far, such as the use of digitised tools and BIM models, data from the actual operation of HVAC installations, neighbourhood scale performance, LCA and other non-energy aspects (air quality, water consumption and noise pollution). To this end, the project defines 8 key objectives which will be available on the project's website and form the subject of future publications by project partners. GoiEner will contribute to the development and demonstration of a new rating scheme for neighbourhood scale, based on the assessment of individual building units and on additional building complex parameters. The scope of the proposed work is detailed in the following pharagraphs.

The first phase will lay the conceptual and contextual foundations for the development of the project in Leitza. Information will be collected through surveys and on-site data collection in order to know, on the one hand, the experience of the users and their needs at an individual level, but above all paying special attention to the community level; and, on the other hand, the existing conditions of the buildings and of the whole: their energy performance, services on a neighbourhood scale, structural, constructive and geometric definition and the heating and DHW, ventilation and photovoltaic facilities.
Another phase of work aims at developing an energy rating methodology based on calculation conditions of various indicators at both building and neighbourhood level. For its development, in Leitza we will obtain relevant data on the life cycle of buildings and non-energy aspects (water consumption, air quality and noise pollution), but mainly, research will be carried out on aspects more related to the building complex (energy community, the energy services network, charging points for electric vehicles and others) to help in the development of the new methodology. It will be studied how collective energy performances and services affect the individual and collective rating.
In another project phase, a new energy rating methodology will be obtained that includes experimental data at both building and neighbourhood level. To obtain real data (energy consumption, temperature, relative humidity, CO2 and occupancy), the buildings in the Leitza case study (see Table 1) will be monitored. The necessary instrumentation will be installed, the data will be collected on a platform in real time and the results obtained will be studied and evaluated.
To carry out all this work, the use of digital tools will be necessary. The 6 buildings in Leitza will be modelled in BIM will serve to lay the foundations for the evaluation of the energy efficiency of buildings and decision making. Digital twins of the pilot buildings will also be developed with data collected in real time. And finally, DBL will also be used to collect detailed information on the performance of buildings based on the digital data.
Artificial intelligence and benchmarking tools designed in the project will be used for all of these processes. And through the set of pilot buildings, validation activities and tests will be carried out that will eventually lead to the definition of the SmartLivingEPC digital platform.
Para todo ello, se emplearán herramientas de inteligencia artificial y de evaluación comparativa diseñadas en el proyecto. Y mediante el conjunto de edificios piloto se llevarán a cabo actividades y pruebas de validación que conllevarán finalmente a la definición de la plataforma digital SmartLivingEPC.
All this global work has a significant impact on the end user and/or the owner of the pilot buildings in Leitza. Therefore, it requires coordination and organisation with them both to respect their privacy and other sensitivities and to meet their requirements and needs, so that the SmartLivingEPCs solutions can be used effectively. Once the project methodologies have been applied, the impact obtained and the effectiveness of the methodology to promote citizen- led energy saving measures will be evaluated. And, once the case study and its evaluation have been completed, training and guidelines will be provided for the implementation of SmartLivingEPC solutions in other replicable cases.

3. New rating scale for building complex scale and the case study: Leitza

As explained in the previous section, one of the innovations that this new generation of CEEs intends to bring is the introduction of a new rating scale considering the assessment of performance at the neighbourhood scale in addition to the building unit scale. One of the aspects to be studied at the neighbourhood scale are the Renewable Energy Communities and their influence on this new rating scale. The main mission we are undertaking in Goiener is to follow up a real case from the creation of an energy community, technical and legal advice, technical proposals, implementation follow-up, monitoring, data collection, etc. to the application of SmartLivingEPC solutions. To this end, Leitza will participate as a pilot community case.
Leitza is a small town of 3,000 inhabitants in Navarra. The town council of Leitza, on its way towards energy transition, has promoted the creation of a citizen-led REC, financing the costs of accompaniment, technical and legal advice for the co-design process of the REC. This accompaniment has been carried out by Goiener. Currently, more than 120 families have joined the community.

Among the participants in the REC, 6 buildings will be analysed that are located relatively close to each other (<500m radius) (see Fig. 1) and have different uses: a single-family house, a flat, the town hall, a school, the sports centre and a mixed-use building (residential and commercial). The current characteristics of the buildings are detailed in the following Table 1.

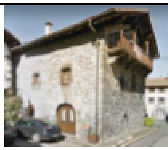
	Imagen	Año constr.	Sup. Constr.	Calif. en CEPnr	Demanda de energía	Energía renovable
1.- Vivienda unifamiliar		2001	450m^2	B	Calef: 43 kWh/m^{2}año ACS: 11.5 kWh/m^{2}año Iluminación+others: 15 kWh/m^{2}año	-
2.- Vivienda en un piso		1895	130m^2	E	Calef: 94 kWh/m^{2}año ACS: 16 kWh/m^{2}año Iluminación+others: 16 kWh/m^{2}año	-
3.- Edificio de uso mixto (residencial + comercial)		1860	348m^2	B	Calef: 72 kWh/m^{2}año ACS: 0.9 kWh/m^{2}año Refrig.: 8.8 kWh/m^{2}año Iluminación+others: 17 kWh/m^{2}año	-
4.- Ayuntamiento		1917	1800m^2	D	Calef: 103.83 kWh/m^{2}año ACS: 2.27 kWh/m^{2}año Iluminación+others: 25.30 kWh/m^{2}año	3.4 kWh/m^{2}año
5.- Colegio		1968	5425m^2	E	Calef: 115 kWh/m^{2}año ACS: 2.51 kWh/m^{2}año Iluminación+others: 28.38 kWh/m^{2}año	-
6.- Polideportivo		2001	2548m^2	F	Calef: 143 kWh/m^{2}año ACS: 10.28 kWh/m^{2}año Refrig: 1.67 kWh/ m^{2}año Iluminación+others: 29.13 kWh/m^{2}año	-

Table 1. Characteristics of the case study buildings in Leitza

Figure1. Location map of the case study buildings

At the moment there is a proposal, led and approved by the community in the project phase, for the execution of a PV installation on the roof of the sports centre that will allow the users of the facilities, as well as the 120 families that make up the REC, to consume on the basis of collective self-consumption. The REC is a useful tool for disseminating knowledge about energy [10], and consequently empowering and raising people's awareness. In addition, the SmartLivingEPC project is expected to conclude more understandable and accessible EPC models for people in order to improve people's perception of their usefulness. This also helps to raise public awareness of the importance of energy efficiency. As a result of the participation of these buildings in the project, it is expected that more community-led renovation activities will be launched to improve energy savings at district level.

Proof of this is that currently, without having started to implement the methodologies of the SmartLivingEPC project, only as a result of the participation in the REC, other needs or possible future initiatives are already being identified in addition to the PV installation. These possible interventions are mentioned below:

-Collective management of municipal forest biomass, of which each household has the option to apply for approximately 3 Tn per year (so called wood allotments).

-Work on mobility and strengthen public transport, as well as tools to facilitate car sharing.

-To look for solutions to cover the thermal demands of homes, currently covered by gas combustion.

-Work to improve the energy efficiency of homes, businesses, buildings and their equipment.

These initiatives are totally linked to collective initiatives for saving measures that are being studied in other European projects in which Goiener is participating, so these synergies will be used to build on the results and experiences of these projects. In the BeCoop project [11] solutions are being studied for residential heating by means of bioenergy boosted through energy communities.

The Why project [11] is investigating user motivations to change energy consumption behaviour. And finally, the Powerpoor project [11] promotes collective investment within an energy community as a way of combating energy poverty and social exclusion, as people in this situation are unlikely to be in a position to get out of it alone, but within a REC it is more likely.
Therefore, as a main result in this first phase, it has been observed that the consideration of RECs in EPCs has a great potential to improve the efficiency of the EPC in terms of its capacity to promote energy refurbishment, which is the main objective of this tool.

4. Conclusiones

The EPC is a tool that aims to have an impact on increasing the renovation of the building stock. The methodology developed in the SmartLivingEPC project will allow to conclude a new and more effective EPC methodology in this sense, as it aims to conclude more understandable and accessible EPCs for the general population. This in turn will improve the credibility and trustworthiness of EPCs. In order to develop the methodology, several case studies will be tested throughout Europe, both at building and neighbourhood level. One of the case studies, in which we will work from Goiener, consists of 6 buildings integrated in a CER in Leitza. The new methodology proposed in SmartLivingEPC will integrate aspects of current and general interest that were not considered so far: BIM modelling, building and neighbourhood scale assessment, SRI analysis, life cycle analysis, air quality, acoustic characteristics and actual operation of the facilities. The project considers a combined assessment based on theoretical calculation methodologies as well as experimental data. Artificial intelligence tools and digital twins will be obtained as a result of the project. Goiener has started the process in the REC of Leitza and although it is in a preliminary phase, favourable results are already being obtained in the promotion of renovation measures for energy saving. This demonstrates the potential of integrating the energy performance of RECs into EPCs to improve the effectiveness of this tool in terms of its ability to promote retrofitting.

5. Acknowledgement and disclaimer

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6. References

[1] European Commission, DIRECTIVE (EU) 2018/844 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 30 May 2018, vol. 276 LNCS, no. May. Official Journal of the Eiuropean Union, 2018, pp. 98–107.
[2] European Commission, Directive 2010/31/EU of the european parliament and of the council of 19 may 2010 on the energy performance of buildings. 2010, pp. 13–35.
[3] Y. Li, S. Kubicki, A. Guerriero, and Y. Rezgui, "Review of building energy performance certification schemes towards future improvement," Renewable and Sustainable Energy Reviews, vol. 113, no. June, 2019, doi: 10.1016/j.rser.2019.109244.
[4] A. Arcipowska, F. Anagnostopoulos, F. Mariottini, and S. Kunkel, "Energy Performance Certificates Across the EU. A mapping of National Approaches," 2014
[5] A. Hardy and D. Glew, "An analysis of errors in the Energy Performance certificate database," Energy Policy, vol. 129, pp. 1168–1178, Jun. 2019, doi: 10.1016/J.ENPOL.2019.03.022.
[6] B. Hårsman, Z. Daghbashyan, and P. Chaudhary, "On the quality and impact of residential energy performance certificates," Energy Build, vol. 133, pp. 711–723, Dec. 2016, doi: 10.1016/J.ENBUILD.2016.10.033.
[7] S. Zuhaib et al., "Next-generation energy performance certificates: End-user needs and expectations ," Energy Policy, vol. 161, 2022.
[8] V. Pereira, J. Santos, F. Leite, and P. Escorcio, "Using BIM to improve building energy efficiency – A scientometric and systematic review," Energy Build, vol. 250, 2021, doi: https://doi.org/10.1016/j.enbuild.2021.111292.
[9] S. Reiter and A.-F. Marique, "Toward Low Energy Cities. A Case Study of the Urban Area of Liége, Belgium," J Ind Ecol, vol. 16, no. 6, pp. 829–838, 2012.
[10] F. H.J.M. Coenes and T. Hoppe, "Renewable Energy Communities as a New Actor in Home Energy Savings," Cogitatio, vol. 7, no. 2, pp. 108–122, 2022, doi: https://doi.org/10.17645/up.v7i2.5088.
[11] "Goiener- European projects." [Online]. Available: https://www.goiener.com/en/european-projects/. [Accessed: Aug. 25, 2022]

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