The first step towards a change of mentality was taken on 11 December 1997, when the Kyoto Protocol (ONU, 1998) was approved, with its subsequent entry into force on 16 February 2005, an international agreement in which 192 countries committed themselves to reducing emissions of gases into the atmosphere that cause the greenhouse effect and global warming. Following this initiative, the governments of each country have progressively implemented increasingly restrictive regulations, with the aim of reducing the impact of human-generated emissions on the environment.

Given that this project is focused on a building located in Burgos (Spain), it is necessary to contextualise from a legislative point of view, how it affects its development.

International reports on energy consumption indicate that buildings account for approximately 50 % of energy consumption (IEA, 2019), as well as being responsible for 30 % of greenhouse gas emissions (GBPN, 2013), mainly generated during use and construction. For this reason, on 17 March 2006, Royal Decree 314/2006 was published in Spain, approving the Technical Building Code (CTE) (Min. Vivienda, 2006) and subsequently, through Royal Decree 1027/2007, the Regulation on Thermal Installations in Buildings (RITE) (Min. Presidencia, 2007) came into force. With this regulation, which has been updated in subsequent years, the aim has been to achieve a rational use of energy, the reduction of demand, consumption, and emissions, as well as the implementation of renewable energies in newly constructed buildings. However, these types of buildings only account for a minor percentage of total energy consumption and gas emissions into the atmosphere. The bulk of these percentages occur in existing buildings, some of which are more than 60 years old.

Consequently, the Spanish Government, supported by European financial aid, has created the Energy Rehabilitation Programme for Buildings (PREE), approved by Royal Decree 737/2020 of 4 August (Min. Trans. Ecológica, 2020). This plan allocates a total of 300 million euros for the energy refurbishment of existing buildings, through actions ranging from changes in the thermal envelope, energy efficiency in lighting and replacement of thermal generation facilities using fossil fuels with facilities that use renewable energies such as biomass, solar energy, electricity generation for self-consumption, etc.

For the case study presented here, we are going to opt for a centralised biomass generation installation, with the support of solar energy. The conditions of the city of Burgos allow it to have sufficient solar radiation and nearby biomass sources, which implies a lower cost for this energy, given that the closer the consumption points are to the production points, the lower the energy costs will be.

It is also worth mentioning that biomass and solar energy are not energy sources sensitive to international tensions, as is the case with natural gas. The consequences of having built practically the entire energy supply of the population based on an energy source that is impossible to obtain in our country can be seen on the international scene.

During this project, first, an energy certification of the building was carried out using the CE3X tool (Efinovatic, 2022). This step is of vital importance to obtain as accurately as possible the values of demands, consumption, and emissions of the building in its current state. Next, a sizing of the new heat generation installations based on renewable energies has been carried out, following the requirements of the Regulation on Thermal Installations in Buildings (RITE).

Finally, the same building was re-certified in its refurbished state, to determine the possible improvements in demand, consumption, and emissions due to the intervention carried out. An economic study of costs and feasibility has also been carried out.

As previously mentioned, use was made of the CE3X programme, which is a tool validated and recognised by the Ministry of Ecological Transition and Demographic Challenge of the Spanish Government. This energy calculation programme makes it possible to justify the Basic Document on Energy Saving (DB-HE) (Min. Fomento, 2019) of the Technical Building Code and to carry out a detailed study of the different variables of the thermal behaviour of buildings.

II. MATERIALS AND METHODS

To carry out this study, a large base of information was used as a starting point. Initially, information was searched for at the Municipal Archive of Burgos City Council (Archivo Municipal de Burgos, 2022) and on websites, such as the Cadastre (Min. Hacienda, 2022) or satellite images of the city, such as Google Maps (Google, 2022) or Google Earth (Google, 2022). With this information, it has been possible to make certain initial decisions, which have allowed the initial research to begin with a search for possible candidate buildings.

To determine which buildings would be suitable for energy refurbishment, different factors were considered: (i) year of construction, (ii) volume of dwellings, (iii) orientation, (iv) free space on the roof and the possibility of installing solar collection devices on it, (v) availability of plots, land, or neighbouring premises on which to locate the energy production installations.

To obtain economic savings after the improvement and to guarantee the profitability of the project, through the shortest possible amortisation periods, a large building has been always sought. This is one of the restrictive conditions for the selection of the candidate. In this way, it is possible to divide the cost of the project over a larger number of owners, thus reducing the investment per dwelling. The costs of centralised boilers are not very different above certain capacities.

Another criterion was the improvement potential of the buildings. This fact is very relevant, since it excludes from the range of action all those modern buildings in which the current legislation (DB-HE and RITE) has been complied with or even improved on the requirements of said legislation. It would not be cost-effective to spend a certain amount of money on buildings where the margin for savings and emission reductions is very small. Also, buildings with a considerable number of years of age and very poor insulation properties would also be excluded. The work with this type of buildings is delicate, since they require important investments, such as improvements in the thermal envelope or possible changes in the DHW and heating distribution installation in each dwelling, among others.

A recent renovation was a reason for exclusion from the list of candidates, since, according to the authors, the only improvement measure required and evaluated is the replacement of individual heating and DHW production equipment powered by natural gas with a centralised biomass installation supported by solar collectors. Thus, if this measure were to be considered in a building in which the façade insulation has been improved, the façade is planned, an investment has been made in the installation of modern condensing boilers given the age of those present after the building was constructed, or the building has been replaced by aerothermal equipment (among other available technologies), it would be unreasonable to select it. The chosen building should have, as far as possible, the same properties as at the time of its construction to be able to precisely quantify the influence of the measures taken to improve its energy performance.

Once these criteria had been established and the search for candidates had begun using the sources of information, it was necessary to obtain further information to determine which of the candidates might be suitable.

At this point, the main source of information was the documents available in the Municipal Archive of Burgos City Council. From this source, we obtained both plans and reports of the building construction projects, from which we were able to obtain detailed geometry and the list of materials used in each of the building envelopes, given that these are fundamental parameters when it comes to knowing the energy demand of a building and its thermal losses, which modify this demand in a proportional manner.

At this point, after making comparisons between the candidates, it was possible to reach an agreement and determine which of them would be chosen. As can be seen in Fig. 1, this building is in a large area and there are no higher blocks around it that could affect the hours of daylight it receives.


Fig. 1. Housing Building selected.

This building has 217 dwellings spread over seven floors, from the ground floor to the sixth floor. The building under study is the one finished in green and yellow. The interior green area is intended for recreational use, given that the garage is located underneath it and it is not available land for building.

At this point, it is necessary to start with the energy rating, which allows us to know the current state of the building. The non-renewable primary energy consumption has been calculated in [kWh/m^{2}·Year], as well as its carbon dioxide emissions in [kg CO$_2$/m^{2}year]. A simplified calculation tool recognised by the Ministry for Ecological Transition and Demographic Challenge of the Spanish Government for the energy certification of buildings, CE3X, was used for this purpose. This programme also makes it possible to justify the DB-HE and carry out a detailed study of the different thermal performance variables of buildings.

This application initially requires a series of data on the geometry of the building. These are the useful surface area for dwellings and the surface area of each envelope. The calculation of the surface area of the dwellings was carried out using the AutoCad programme (Autodesk, 2022), scaling the plans obtained in the File and redrawing the outlines of the dwellings, excluding the surface area belonging to the enclosures, as can be seen in a detail of this process shown in

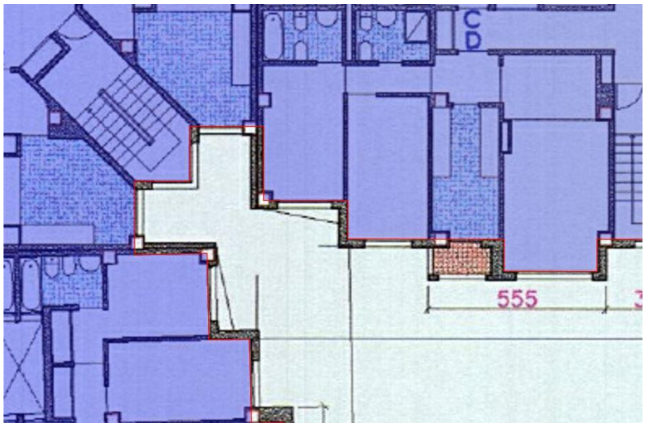

Fig. 2. Detail of the criteria used to obtain the surface area of the building.

Obtaining the necessary data to define the enclosures is somewhat more complex, given that it has been necessary to measure the surface of the façade, always differentiating each of its finishes, given that there may be constructive differences between them. Likewise, a distinction has been made between vertical and horizontal partitions that delimit the exterior, commercial premises, and non-habitable spaces. To complement this information, it has been necessary to specify the composition of each of the different types of enclosures available in the building. Similarly, the surfaces of each of the partitions have been divided into new groups according to their composition. To all these classifications, another one has been added, the location. In the proposed case, eight different facades can be distinguished. Each of them has a different solar incidence and different shading patterns, among other considerations, so it has been necessary to distinguish in each type of enclosure to which façade they belong.

To finish with the introduction of data relating to the geometry of the building, it has been necessary to establish what type of solutions are used to make the window enclosures. At this point, it was necessary to know the measurements of the windows installed in the building, the type of carpentry, the thermal properties of the frames and the glass, always distinguishing the façade on which each one of them is located.

As mentioned above, the shading patterns of each of the building's façades were calculated. To do this, the elevation angles and the azimuths have been introduced into the CE3X program so that it considers the shadows cast on each façade. An example of one of these shadow patterns can be seen in Fig. 3, as well as the process of obtaining the azimuth angles in Fig. 4.

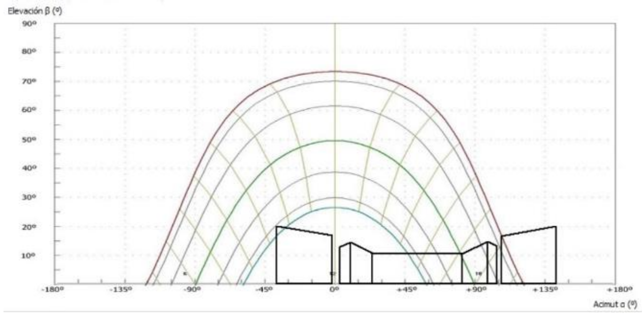

Fig. 3. Shading pattern obtained for the façade shown in Figure 4.

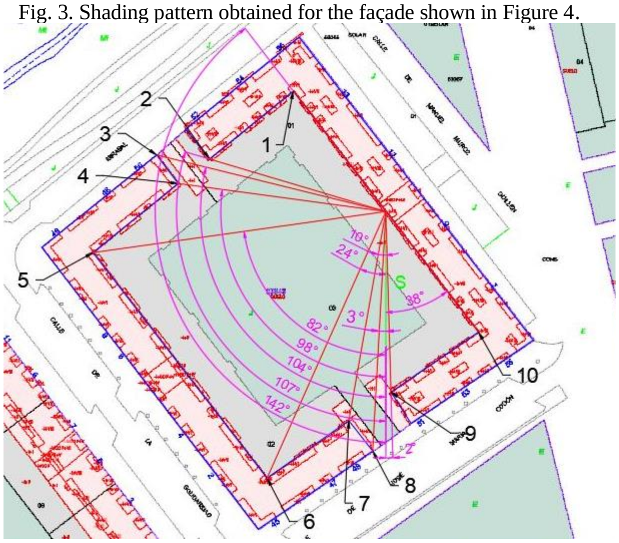

Fig. 4 Method used to obtain the azimuthal angles of each body casting a shadow on one of the building facades.

The methodology followed to size the heat generation equipment consists of calculating two main elements, on the one hand, the heating needs and, on the other, the DHW needs.

This first group includes all the losses generated in the thermal envelope, both heat transmission and ventilation, and therefore includes losses in roofs, overhangs, windows, interactions of dwellings with ground floor premises and garages, etc.

On the other hand, there are the DHW needs, which are calculated following the tables provided by the RITE and the DB-HE. These demands are covered in a percentage by the solar panels installed on the roofs, this minimum percentage is fixed by the current legislation and its calculation is carried out following these regulations.

Therefore, as previously mentioned, in order to calculate the losses in the thermal envelope, the thermal gap between the external and internal surfaces of the block of flats under study must be established, so that the calculation of heat transmission losses can be carried out. According to the Regulation of Thermal Installations in Buildings (RITE), the heat generating equipment must be sized to cover the demand of 95 % of the coldest days of the year. So, according to Table 1, the indoor comfort temperature for winter would be 21.00 °C, and - 1.57º C for the outdoor temperature, which is a value obtained by interpolating in Table 2, which represents the temperature values for the city of Burgos ordered according to probability. In this case, it would be a cumulative frequency of 5, which indicates that only 5 % of the time will the temperature be lower than the one shown. For unheated premises a temperature of 10 °C will be assumed.

TABLE I

COMFORT INDOOR TEMPERATURES AND HUMIDITY TABLE, OBTAINED FROM IT 1.1.4.1.2 IN RITE.

Season	Temperature (º C)	Relative Humidity (%)
Summer	23-25	45-60
Winter	21-23	40-50

TABLE II

CUMULATIVE FREQUENCIES FOR THE CITY OF BURGOS, TABLE OBTAINED FROM THE SPANISH TECHNICAL ASSOCIATION OF AIR CONDITIONING AND REFRIGERATION (ATECYR) HEATING INSTALLATION CALCULATION GUIDE (IN. S: OUTSIDE TEMPERATURE; FR. AC: CUMULATIVE FREQUENCY).

Cumulative frequencies for the town of Burgos									
IN. S	**FR. AC**	**IN. S**	**FR. AC**	**IN. S**	**FR. AC**	**IN. S**	**FR. AC**	**IN. S**	**FR. AC**
-9,5	0,09	0,5	11,36	10,5	61,30	20,5	91,76	30,5	99,60
-9,0	0,10	1,0	13,30	11,0	63,39	21,0	92,39	31,0	99,69
-8,5	0,14	1,5	15,86	11,5	65,97	21,5	93,19	31,5	99,80
-8,0	0,17	2,0	17,78	12,0	67,78	22,0	93,73	32,0	99,86
-7,5	0,22	2,5	20,47	12,5	70,30	22,5	94,40	32,5	99,91
-7,0	0,29	3,0	22,63	13,0	72,01	23,0	94,85	33,0	99,93
-6,5	0,40	3,5	25,39	13,5	74,22	23,5	95,48	33,5	99,97
-6,0	0,55	4,0	27,53	14,0	75,87	24,0	95,88	34,0	99,98
-5,5	0,75	4,5	30,41	14,5	77,86	24,5	96,42	34,5	99,99
-5,0	0,96	5,0	32,77	15,0	79,30	25,0	96,82	35,0	100,00
-4,5	1,23	5,5	36,13	15,5	81,07	25,5	97,25	35,5	100,00
-4,0	1,55	6,0	38,36	16,0	82,31	26,0	97,58	36,0	100,00
-3,5	2,05	6,5	41,63	16,5	83,73	26,5	97,95	36,5	100,00
-3,0	2,60	7,0	43,91	17,0	84,85	27,0	98,19	37,0	100,00
-2,5	3,30	7,5	46,84	17,5	86,18	27,5	98,45	37,5	100,00
-2,0	4,00	8,0	48,81	18,0	87,05	28,0	98,67	38,0	100,00
-1,5	5,15	8,5	51,61	18,5	88,36	28,5	98,93	38,5	100,00
-1,0	6,15	9,0	53,73	19,0	89,10	29,0	99,09	39,0	100,00
-0,5	7,47	9,5	56,61	19,5	90,08	29,5	99,30	39,5	100,00
0,0	8,98	10,0	58,75	20,0	90,86	30,0	99,45	40,0	100,00

With this data, both heat losses through the building envelope and ventilation losses are calculated.

With regard to the calculation of DHW demand, as stated in the DB-HE, certain factors are of vital importance, such as: (i) the centralisation factor, i.e. the number of dwellings in the building, which influences the total DHW consumptions, (ii) outside temperatures, (iii) minimum hot water temperatures to avoid the proliferation of legionellosis, (iv) the number of hours of use of this domestic hot water, (v) the climatic zone where the study is carried out, which directly influences the minimum percentage of solar contribution in the DHW demand (Ruiz Hernández, 2015).

Once losses in the thermal envelope have been calculated, as well as DHW demands and contributions, the following have been dimensioned: (i) the heat generating equipment, which are three biomass boilers, (ii) the boiler room, (iii) the biomass storage with their respective auxiliary systems, (iv) the distribution installations in garages and uprights (Pérez, 1999).

The conditions considered for the calculations are shown below:

i. Heat generating equipment, which, having a power of more than 400 KW, the RITE specifies a minimum number of two pieces of equipment. In addition, they must operate with a modulating burner, which allows the equipment to operate in different power ranges.
ii. Boiler room, which must have a minimum height of 2.50 m and 0.50 m clear height between the highest point and the roof, concrete walls with a minimum thickness of 20 cm, ventilation grilles that allow constant air renewal and metal doors with specific dimensions.
iii. Biomass store, which must have the capacity to withstand the maximum demand for 1,500 hours, i.e., operation of all equipment at 100 % during that time without having to replenish the store.
iv. Heating distribution installations, primary DHW, recirculation DHW (essential circuit so that the DHW temperature does not drop below 60° C and so that it is always moving, preventing the proliferation of Legionella), solar panels, tanks, and expansion vessels. In all these calculations, the RITE regulations have been followed both for the calculation of load losses (Aurelio Alamán, 2007) and construction materials:

$$\frac{1}{\sqrt{f}} = -2\,log\ \left(\frac{\varepsilon}{3.72 * D} + \frac{2,52}{Re * \sqrt{f}}\right.$$

where:

$\boldsymbol{f}$: is coefficient of friction of the pipe, [-].

$\boldsymbol{\varepsilon}$: is the absolute roughness of the material, [Kg/m3].

D: is the diameter of the pipe through which the fluid flows, [m].

Re: is the dimensionless Reynols number, [-].

III. Results

After performing the energy calculations explained in the previous section, the result of the energy demands and consumptions are shown together with the CO2 emissions of the building in its initial state, comparing them with the same indicators of the case relative to the improvement proposed in the building's thermal installations. This comparison can be seen in Table 3.

As expected, this shows the significant reduction in CO2 emissions because of the almost zero net emissions from the biomass used as fuel. This reduction affects both heating and DHW emissions, but it is important to emphasise the effect of solar support, as this is responsible for such a pronounced reduction in CO_2 emissions and non-renewable primary energy consumption in DHW production.

An economic study has been carried out including the fourteen main work units, resulting in the budget shown in Table 4.

TABLE IV
Comparison between the main indicators before and after the proposed improvement of the building.

Work Unit	Description of the unit	units	Unit price	Budget [€]
01	Combustion	3	60,558.08	181,674.24
02	pellet	3	3,711.25	11,133.75
03	pellet boiler	10	3.797.13	37,971.30
04	Pellet combustion boiler	10	8,298.21	82,682.10
05	boiler	133	1,599.80	212,733.40
06	boiler	20	406.52	8,130.40
07	Tank	10	114.71	1,147.10
08	DHW storage tank	10	221.17	2,211.70
09	Tank	10	446.10	4,461.00
10	DHW storage tank	10	507.64	5,076.40
11	Solar collector	35	56.62	1,982.05
12	Solar collector	105	57.62	6,050.10
13	DHW pumping station and	70	41.98	2,938.60
14	solar collector	720	79.22	57,038.40
	Material execution budget			615,230.54

TABLE III
Comparison between the main indicators before and after the proposed improvement of the building.

Energy indicators	Initial status	Improved status	Percentage of improvement
Non-renewable primary energy consumption [kWh/m2year].	206.70	11.50	94.40
Non-renewable primary energy consumption heating [kWh/m2year] [kWh/m2year].	173.68	10.73	93.00
Non-renewable primary energy consumption DHW [kWh/m2year] [kWh/m2year] CO2 emissions	33.01	0.77	97.00
CO2 emissions	43.80	2.43	94.00
emissions [kgCO2/m2year] [kgCO2/m2year	36.78	2.27	93.00
CO2 emissions heating	6.99	0.16	94.40

Table 5 below shows the Total Budget of the project including total costs and taxes:

TABLE V
TOTAL BUDGET

Concept	Amount [€]
Material Execution Budget (PEM)	615,230.54
Overheads (14,50 % PEM)	89,208.43
Industrial Profit (6,00 % PEM)	36,913.83
Quality Control (2.00 % of the PEM)	12,304.61
Work management (3,00 % of the PEM)	18,456.92
SUBTOTAL (TP)	772,114.33
V.A.T. (21,00 % of TP)	162,144.01
TOTAL BUDGET	934,258.34

Considering this total budget and the fact that the number of dwellings in the building is 217, the contribution per dwelling amounts to €4,305.34, which is an investment within acceptable limits. Furthermore, the economic study carried out by the CE3X tool itself, at a theoretical level, gives a payback period of 8.8 years, and a Net Present Value (NPV) of €985,222.40, for a calculation period of 15 years.

IV. CONCLUSIONS

With the data provided, it can be stated that the improvement measure proposed for the housing block is efficient in terms of achieving a more efficient use of energy and reducing CO_2 emissions.

Savings of 94.40% in overall non-renewable primary energy demand and a 94.00% reduction in CO_2 emissions have been achieved.

The economic viability of the transformation is also demonstrated. According to the economic study, a total investment of 934,258.34 € is estimated, and an investment per dwelling equivalent to 4,305.34 € is estimated.

The economic study carried out, at a theoretical level, gives a payback period of 8.8 years, and a Net Present Value (NPV) of 985,222.40 €, for a calculation period of 15 years.

These energy and economic results indicate the suitability of the proposed solution to the needs raised when planning this project.

The use of thermal energy stored in biomass, combined with solar energy, means a lower outlay than the use of natural gas. It also reduces the energy dependence of the building. Solar energy will always maintain relatively stable values at zero cost (obviously excluding the initial investment). Biomass, on the other hand, is a renewable energy source that can flourish if installations such as the one proposed are implemented, expanding demand in a virtually untapped market.

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