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Holistic approach for energy retrofit with volumetric add-ons toward nZEB target: case study of a dormitory in Athens

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Abstract

This paper proposes a novel multistep approach for comparing several architectural solutions with the aim to create additional volumes on existing buildings by means of the façade transformation. The nearly zero energy standard is the objective of the designing and the criteria for the comparison take into account the minimization of economic impacts and the maximization of comfort conditions for the occupants. An innovative SWOT matrix is proposed for evaluating, with multidisciplinary approach, the results of the refurbishment design. The internal strengths and weaknesses are referred to the building occupants, while external opportunities and threats are referred to the whole society.

The proposed approach is applied to the B Building FEPA of the student dormitory in the National and Kapodistrian University of Athens in the frame of a research project financed by HORIZON 2020 funds. With reference to the case study, an increment of around 22% of living space is achieved with energy saving and polluting reduction of around 90%; at the same time the amenity of the outdoor environment, the seismic security, the global comfort are improved.

The results of the case study allow to demonstrate how the volume add-ons technique can bring many benefits, not only on the energetic point of view, in the refurbishment of the existing building stock. The awareness of these advantages could encourage occupants, tenants and communities to participate actively in the designing process, and it could be accelerate the achievement of the nearly zero energy standard for the existing building stock. This is the future goal for the sustainable development of the building sector.

Keywords:

Volumetric add-ons, energy refurbishment, nZEB, Mediterranean climate

1. Introduction: studies about the effect of livable space addition

The building sector plays an important role in order to reduce the polluting emissions due to the energy consumptions. The most recent available data suggest that the final energy consumption of the EU-28 in 2016 has been 1'107'818 ktoe and the building sector has accounted for around 39.3% [1]. This is justified considering that the existing building stock is very old, with poor energy performance and very low comfort level. About 49% of dwellings are over 50 years [2] and almost 75% of the building stock is energy inefficient, with a very low percentage of refurbishment rate (around 0.4-1.2% per year) [3]. Thus, the renovation of existing buildings is strategic to achieve the target set by European Commission to 2050 [4].

The main legislative instrument, at European level, for increasing the building energy efficiency, has been the Energy Performance of Building Directive, (EU 2010/31) [5], and its amendment (Directive (EU) 2018/844) [6], which has identified the transition to nearly zero-energy building (nZEB) as a hinge element to achieve the Union's objectives. According to the EPBD recast [5], a 'nearly zero-energy building' is a building that requires nearly zero or very low amount of energy that should be covered to a very significant extent by energy from renewable sources, including the ones which produced on-site or nearby.

The nZEB standard can be easier accomplished for new constructions, whereas for the existing building stock this target is challenging and includes a big set of refurbishment interventions, which in most cases is associated with the limits (technical and economical) set by the state of fact. Instead, the new European legislation [6], in regards of building energy performance, requires the Member States to create a long-term strategy about the building stock refurbishment, in order to turn the existing buildings into nZEB.

The first aspect to point out about the nZEB definition [7] is the great variability among Europe of threshold value for the primary energy value that changes between 20 and 200 kWh/(m^{2}y) with the inclusion of different energy uses; moreover only some countries specify the amount of RES (between 25% to 56%). The national regulations have implemented different numerical indicators for certifying the achievement of nZEB target. D'Agostino and Mazzarella [8] have shown that most Member States have adopted the yearly energy balance for the evaluation of these indexes. The normalization procedure varies; it could be the net conditioned area, the gross floor area or the net volume or floor area. Some regulations, e.g. the Italian one [9], adopt technical standards in which semi-stationary approach is defined with the adoption of standardized boundary conditions for climate and kind of uses. Moreover, many scientific papers about the nZEB design are focused on new construction [10, 11] or on the suggestion of economically efficient solutions [12].

However, the most important consideration is that some socio-economical barriers against the nZEB diffusion are still present [13]. Probably, the evaluation of benefits due to a possible volumetric addition, seismic or even aesthetic improvement, could make an investment in energy refurbishment more attractive for occupant and owners.

About these aspects, Eliopoulou and Mantziou [14] have underlined the fact that the refinement of architectural space plays an important role in the building's energy balance. They have proposed an approach for minimizing the building energy needs by improving the architectural qualities and the users comfort. The application to an old school in Athens, has reduced the energy demand of around 44%. According to Ferrante [15], the volumetric addition may be conceived as powerful, energy generating and insulating buffer zones able to set to zero the energy demand of the original building and, at the same time, to improve the static and mechanical performance of existing structures.

On this point, several studies have confirmed that the addition of new sub-structures to an existing building can boost energy savings. In particular, Ferrante and Semprini [16] have found that the addition of greenhouse, combined with photovoltaic generation and geothermal heat pump, drastically reduces the Energy Performance index, e.g from 206 kWh/(m^{2}y) to 10 kWh/(m^{2}y) in historical buildings located in Bologna. Gaspari et al. [17] have shown that the building refurbishment with space addition strategy can provide primary energy savings of 89%, with floor area increase of 33% for a vertical wall. Meanwhile adding volumes on two façades and the roof the total energy saving can be 79%. For Athens, Fotopoulou et al. [18] have found that the window replacement and wall insulation, combined with a sunspace on the south oriented side and a buffer zone on the north one is the best energy refurbishment options.

The space addition by means of a sunspace can contribute to the increase of the solar gains; nonetheless its application must be evaluated also in summer conditions when the overheating problem could be verified.

The main design variables for a sunspace are: orientation, space configuration, natural ventilation, position and radiative properties of the shading devices, type and number of glazed surface layers [19], all dependent on the boundary conditions [20]. According to Bataineh and Fayez [21] the use of sunspace in the south orientation, in Amman-Jordan, causes an overheating problem during summer, that could be overthrown with night ventilation and internal shading devices. Monge-Barrio and Sánchez-Ostiz [22] for dwellings in different climatic zones in Spain, have found that if a proper ventilation is actuated (25% opening of the exterior sheet during daylight hours) and a solar protection system is designed, the active cooling system is not needed. In a comparable climatic condition, Aelenei et al. [19] have studied the energy performance of different types of sunspaces applied to an existing residential building. In four cities (Faro, Lisboa, Évora and Coimbra) the most appropriate configuration for energy demand reduction is the fully integrated with single glazed surfaces, without the increment of livable space. In addition, in Porto and Bragança the best configuration seems to be also the fully façade adjacent one, with double glasses. In order to mitigate the overheating problems the authors [16] have hypothesized that the new space should be open during the summer season. Muscio and Ferrari [23] have proposed to change a balcony into a ventilated sunspace, with transparent PVC sheets installed along the balcony perimeter during the cold season and removable during the hot period. Compared with a passive sunspace without ventilation, their solution could control the summer heat gains and outperform the wall insulation.

Moreover, Semprini et al. [24] have demonstrated the economic feasibility of the volumetric add-ons combined with the renewable energy sources in a district area in Bologna. Similarly, Cukovic-Ignjatovic and Ignjatovic [25] have explored the economic feasibility of different types of lateral and vertical extensions applied to the building structure.

Some real examples are also available. Druot [26], Lacaton and Vassal. Have designed the refurbishment of the Paris' Tower *Bois-le-Prêtre*. The retrofit of the envelope has been realized through the inclusion of a self-supporting structure with prefabricated elements; the surface of the apartments is increased (+3560 m^2) with terraces and winter gardens. It has been estimated an energy saving of about 50% mainly due to the addition of winter gardens and an economic saving of € 70'000 compared to the demolition and reconstruction. Blauraum architects have converted an office building of the '70s into a residential house in Hamburg (Germany) [27-29] obtaining fifteen new apartments through discontinuous external volumes added on the façade. The east-west orientation of the building has been developed with an opaque wooden façade facing the street and a fully glazed façade facing the courtyard. The Minimum Impact House in Frankfurt am Main, designed by architects Drexler, Guinand and Jauslin [30], consists in a mini-house developed in height built up to the bare façade of an existing building. It is characterized by natural construction materials (light wood) and passive envelope technologies (green roof). The building compared to a conventional construction located in the north of Frankfurt, results in a reduction of 63% in the total energy use, with a Global Warming Potential climate-change effect reduced by 68% per each house. Other projects characterized by envelope refurbishment with increment of living spaces are: the residential tower in Winterthur in Switzerland, completed in 2009 by Burkhalter Sumi and Albisetti and the housing in Saint-

Nazaire in France, completed in 2014 by the architects Lacaton&Vassal and Druot [31]. In Winterthur a new concrete volume has been built on the northern façade and two prefabricated vertical volumes made of concrete on steel supports have replaced the balconies on the southern façade new. The four small residential units located on each floor of the old building were grouped together into two apartments. For the residential block in Saint-Nazaire the new volumes were created through a dual system of loggias and balconies, with glass parapets, more a roofed flexible loggia, which is transformed into a winter garden during the cold season. The glass-enclosed areas are characterized by PVC blinds system.

By analyzing the literature review about existing building refurbishment with volume add-ons, some general conclusions can be made. First of all, only in recent years some refurbishment case studies with volumetric add-ons have been developed for the European climates. However, these are usually focused on demonstrative buildings of research projects supported by European funding frameworks. The authors are mainly focused on one of the following aspects: technological and typological renovation, urban and social implications. More in general, the real case studies deal with architectural aspect and technical feasibility, with few details about performance parameters of building envelope and thermal loads evaluation. The HVAC systems are often not defined in detail and the achievement of nZEB target is not discussed. Moreover, it is really important to take into account the dynamic behaviour of the building-HVAC system for correctly evaluating the incidence of innovative materials technologies, un-conventional HVAC systems with RES integration and intelligent control devices.

The main objective of this paper is to find out a methodological approach for studying the refurbishment design within the application of a new architectural appearance of the building façade with the final outcome of nZEB target. Even though many researchers were worked on the refurbishment of the building stock, very few researchers were reported about an integrated multidisciplinary approach for the evaluation of the capability of volumetric add-ons to support the nearly zero energy standard diffusion. This is the novelty of proposed research: evaluate the net zero energy standard taking into consideration the benefits also in term of esthetical appearance, environmental impact, improvement of building livability and incidence of new configuration on the occupant behavior, impact of working period in term of time and costs.

More in detail, the proposed approach is based on an optimization procedure that takes into consideration the indoor comfort aspects as well as the economic value of energy savings. It is easily replicable for researchers and designers. With the goal to give some general indications for retrofit interventions in Mediterranean climate, the proposed approach is applied to an existing typical 30-year-old building in Athens.

The paper is organized as follow: section 2 describes the proposed approach; section 3 presents the energy diagnosis of the case study and thus the student's dormitory owned by the National and Kapodistrian University of Athens, named B Building FEPA (Β΄ Κτήριο ΦΕΠΑ); sections 4 and 5 are dedicated at the application of the proposed method for comparing the refurbishment actions. Finally, in section 6 the results of previous section are discussed by means the proposition of an innovative SWOT matrix.

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2. Methodological approach

Figure 1 shows the schematization of proposed approach for evaluating the effectiveness of different architectural solutions for building facades. The proposed approach is new because it includes different aspects that concur to optimization of structural and energetic performance as well as to reach high environmental standard with reduced costs.

Here: Figure 1

Initially, a deep knowledge of the building with its real performance is needed; this step requires the energy diagnosis, which allows defining and calibrating the numerical model of the building. The collected data can be divided into five categories [32]: 1) architectural and historical investigations; 2) building envelope audit; 3) technical system and equipment characterization; 4) building uses and thermal zones definition; 5) trend of annual energy consumptions. The hourly energy simulation of a building, when properly performed, is a powerful tool for reliable estimation and quantification of energy benefits of different measures for the energy refurbishment. In order to simulate reliable energy performances, the numerical model can be calibrated by means of procedure proposed by M&V Guideline [33] by determining the deviation and the relevant uncertainty.

The calibrated model is used for evaluating (phase I) the impact of a geometrical modifications and new envelope characteristics on the heating and cooling loads; the comparison of different solutions take into account also the costs (investment and operating) and the indoor comfort conditions set as minimum requirement. More specifically, the thermo-hygrometric conditions are evaluated by means of the total hours, in occupied zones, in which the combination of humidity ratio and operative temperature is not within the region defined by ASHRAE Standard 55-2004 [34] that has been implemented in the international EN 15251 standard [35]. These are defined discomfort hours (TD). For the proposed case, two configurations of volume add-ons are examined the *Extra-Room* and the *Sun-Space* an attached sunspaces applied in loggia. These solutions are explained in detail in section 4.1.

The phase II consists in the designing of HVAC system with renewable sources integration and of lighting system. Finally, the annual or monthly energy balance is studied for verifying the respect of nZEB standard. Table 1 summarizes all the calculation hypotheses carried out for the proposed design approach.

Here: Table 1

For the proposed case study, the adopted dynamic simulation tool is EnergyPlus v.8 [38], through its interface Design Builder v. 4 [39].

3. Case study: a dormitory in the National and Kapodistrian University of Athens

The considered case study is a building owned by the National and Kapodistrian University of Athens, situated in the University campus of Zografou, about 5 km from the Athens city center (Lat. 37.98, Long. 23.73). The dominant feature of Athens's climate is alternation between prolonged hot and dry summers and mild to cool winters with moderate rainfall. According to the Koppen classification [40] it is included in the Csa zone.

3.1 Energy audit

The building hosts 138 single-bed rooms for students, and it was built in 1986. Figure 2a shows a global view of the site. The building is located near Taxilou street, Zografou, in area of around 4'500 m^2, with an altitude of 153 m on sea level. Near the building there is a football field and a park.

Here: Figure 2

3.1.1 Geometrical features

The building is composed of 4 floors (including the ground level) and a basement. It is accessible from a central staircase or two lifts. Figure 2b shows the cross sections of the floors. The net height of all rooms is 2.40 m with the exception of the basement floor where the net height is 2.60 m. The building has a rectangular profile (Figure 2c), 56.59 m length and 15.37 width. The gross building area is around 3'642 m^2 (725 m^2 for each floor and 742 m^2 for the basement) with 138 bedrooms that, in many cases, have a surface area of 9.50 m^2. The heated floor area is about 2'584 m^2. The global window to wall ratio (following WWR) is equal to 32 %.

3.1.2 Building envelope audit

The building skeleton is made of reinforced concrete not thermally insulated. The bearing body is made by two pillars, separated by a joint. On the base of the available design information, and several in-situ inspections, the composition of opaque envelope has been developed. Table 2 shows the thermo-physical proprieties of the main elements: thickness (t), thermal conductivity (λ), specific heat (cp), density (ρ). The calculation of thermal transmittance (U) has been done according to the EN ISO 6946 [41].

Windows and glazed doors are made of single glass with aluminum frame with thermal transmittance (U_f) of 5.9 W/m^2 K; these elements are not sealed. There are four types of windows, whose dimensions are given in table 2. The glass transmittance (U_g) is calculated according to the ISO 15099 [42] moreover solar factor (SF) and light transmission in visual spectrum (LT) are indicated in table 2; these are technical data of the installed glass.

Here: Table 2

The audit suggests certain interventions to improve comfort and energy efficiency of the building block. In particular, the external walls and slabs must be insulated since the values of thermal transmittances are very far from the minimum specifications imposed by the regulations, for climatic zone like Athens [43]; e.g. for the external wall the limit value is 0.50 W/(m^2 K), for the roof slab it is 0.45 W/(m^2 K) and for the basement 0.90 W/(m^2 K). The roof should be completely renovated, to address the lack of thermal and hydro insulation. The same applies to the window replacement and a few other internal modifications needed to meet the general construction requirements.

3.1.3 Audit of technical systems

For the heating needs, the building is equipped with centralized gas boilers, which provide the thermal vector fluid to in-room radiators. The thermal power plant is installed at the basement floor. There are two natural gas boilers, one with nominal power of approximately 988.6 kW and another one with nominal power of 732.7 kW, with nominal efficiency of about 94% The heating system is turned on for 7 hours each day, from

1st November until to 31 March (turned off during the Christmas holidays). The same boilers feed two newly installed storage tanks for hot water production.

The local emitters are old static radiators. Corridors and common areas have 12 radiators of 0.90 m height. The radiators installed in the bedroom have 1 body of 0.90 m height with 10 slices of 3 columns.

There are no thermostatic valves or zone thermostats; moreover, the pipes delivering hot water are not insulated. This decreases the efficiency of the system, as there are high distribution losses from the basement floor across each floor.

There is no central air conditioning system with the exception of few rooms (porter and living room at the ground floor) that have autonomous split systems. Natural ventilation is provided through the external frames when needed.

Regarding the lighting system, the dormitory is equipped with fluorescent lamps, with a total installed power of 26.5 kW in the rooms and 18.7 kW for common spaces. The mean estimated efficiency of installed lamps is 60 lm/Watt and these are connected to the supply grid with a traditional type of reactor.

More in detail, the internal lighting system consists of:

- Basemen: 52 x 2 lamps with power of 36 W;
- Other floors:
  - Public areas have 52 x 2 lamps with power of 36 W;
  - Bedrooms have 4 ceiling lamps with power of 18 W, one wall spot of 60 W, and one shower spot of 60 W.

The external lighting system on the façade of the building consists of 208 lamps with a power of 60 W (total 12.5 kW) mainly placed on the balconies.

3.1.4 Characterization of building uses and definition of thermal zones

The building includes the following functions:

- Ground floor: central entrance, staircase and 2 elevators, seating area, 30 single rooms, public bathroom (for men), common kitchen;
- 1st, 2nd, 3rd floor (typical): 36 single rooms and shared kitchens, living rooms;
- Basement: technical rooms and warehouses.

There is a call center area on the ground floor. A TV set is installed in the ground floor lounge. Electrical equipment consists of 6 washing machines per floor and 1 large refrigerator per floor in the kitchen.

The area of single-room is currently considered unsuitable for student's accommodation. Indeed, from a short interview, during the audit, the rooms result small and they have a douche corner on the same level, separated from the rest of the room by inconsistent booths, resulting to water leakage.

3.1.5 Energy building data

The energy bills of the whole building for each month are available. In particular electricity consumption refers to two different periods Jun 2014 -May 2015 and from Jan 2017 to Feb 2018. In the elaboration of energy billing, the most continuous periods have been considered. Indeed some uncertainties affects the missing months because the university has undergone administrative changes and because they have modified the management of the electricity supply system, with periods of adjustments difficult to elaborate. The natural gas boilers have been installed in the beginning of 2017 and the bills of natural gas are not yet available. The available energy bills have been used in order to calibrate the numerical model.

3.1.6 Calibration of building simulation model

The simulation model has been created according to the aforementioned surveyed details, and the operation schedules have been created according to manager and occupant information.

Regarding the thermal zone's characterization, through an accurate inspection, the use of each room has been verified. During the inspections, some questions have been proposed to office occupants and students, in order to describe, as accurately as possible the real conditions inside the building. These questions concerned: a) how many hours are daily spent in the building, b) how many hours are spent by working at a computer or anything else, c) if for the occupants there are conditions of comfort or discomfort for what concerns the indoor microclimate and d) if there are important criticalities of the building. All these information have been used to make an accurate modeling of the thermal zones.

More in detail, three thermal zones have been considered *Bedroom*, *Common area* and *Basement*. The main input information about occupants, lighting and electrical equipment have been set according to their answers and some typical schedules have been defined for describing the occupation patterns. A relax activity has been taken into account for *Bedroom* (104 W/people) while a light activity has been set for *Common area* (117 W/people). During the calibration procedure some adjustments of the schedules of appliances utilization, infiltration model and windows openings are been needed.

The rendering of the geometrical model and the comparison with the actual building behavior is shown in Figure 3a. The weather data file called "Athens 167160 (IWEC)", available on EnergyPlus web site, has been used.

The simulation outputs, in term of electricity requests, have been compared to values reported on the energy billings. The available data have been elaborated for defining a reference year; the average value of the data for the same month but for different years has been calculated.

The "Whole Building Level Calibration with Monthly Data" approach of the M&V Guideline [33] has been used. More in detail, the adopted indexes are the error in the annual energy consumption ($ERR_{average\ month}$), the mean bias error (MBE) and the coefficient of variation of the root mean squared error $CV(RMSE_{month})$. For the corresponding calculations the following equations were used:

$$ERR_{average\ month}(\%) = \frac{\sum ERR_{month}(\%)}{N_{month}} \quad (1)$$

$$MBE(\%) = \frac{\sum (M - S)_{month}}{\sum M_{month}} \times 100 \quad (2)$$

$$CV(RMSE_{month})(\%) = \frac{RMSE_{month}}{A_{month}} \times 100 \quad (3)$$

Where ERR_{month} is the error in the monthly energy consumption; N_{month} is the number of monthly utility bills in the year; M and S are the amount of energy measured and simulated respectively; $RMSE_{month}$ is the mean squared monthly error and A_{month} is the mean of the monthly utility bill.

The ERR_{month} plot is presented in figure 3 for the electricity consumptions; the threshold value is always respected and varies in the range of about ±15%. The other resulted indexes with the tolerance values are reported in figure 3b; these suggest that the model is a good representation of the actual building. Thus it can be concluded that for the available data, the model is well calibrated.

Here: Figure 3

3.2 Performance evaluation of actual building by means of simulations

The evaluation indices shown in table 1 are thoroughly discussed considering the building's actual configuration.

3.2.1 Thermal and cooling loads

The boundary conditions used for the heating load calculation are the following:

(1) 1.8°C is the outdoor dry bulb air temperature;

(2) 20°C is the indoor air temperature;

(3) there is no heat recovery.

According to these assumptions, the total heating load is equal to 227 kW (88 W/m^2).

The day taken into account for the cooling load calculation is the 15th of July which was characterized by a maximum external dry bulb temperature value of 35.6 °C at 14:00 p.m and by a minimum value of 26.6°C that occurs at 5:00 a.m. The global solar radiation reaches the maximum value (980 W/m^2) at 12.30 p.m. and the indoor air temperature is set equal to 26°C. In these conditions the whole cooling load is 208 kW (80 W/m^2). These two values are typical for the Athens climatic conditions.

3.2.2 Energy and environmental performance

Figure 4 reports the energy consumptions for the main building uses, normalized to the net heating area. In particular, the requests for heating and domestic hot water ones (DHW) include also the auxiliaries (electric energy) that have been converted into primary energy by means of national power plant efficiency; for Greece, considering the reference [36], it is 0.42 if also the national renewable energy sources are considered. On the contrary the electric consumptions for lighting and other equipment is reported.

It can be noted that the service with the greatest consumption is the artificial lighting. This is imputable to efficiency of actual system that is not very high compared with the best available technology; moreover, the lighting system is not equipped with occupancy sensor and the students are not very careful about switching off the devices in their absence, or in any case they have not the control of the optimal lighting level thus the lamps are turned on also when these are not needed.

Here: Figure 4

Synthetically, the global the primary energy need is 188 kWh/m^2y. The equivalent carbon emissions (CO_2) are equal to 54 kg/m^2y. These have been calculated assuming the polluting factor equal to 0.727 $kgCO_2$/ kWh_{el} for electricity [37] and 0.205 kg CO_2/ kWh_{gas} for natural gas.

3.2.3 Thermo-hygrometric comfort

The evaluation of indoor thermos-hygrometric conditions has been made according to the ISO 7730 [44] international standard. This protocol presents methods for predicting the general thermal sensation and the thermal dissatisfaction of people exposed to moderate thermal environments. It enables the analytical determination and interpretation of thermal comfort using calculation of PMV (predicted mean vote) and PPD (predicted percentage of dissatisfied), giving the environmental conditions, which are considered acceptable for general thermal comfort. The recommended comfort requirements are that the PPD must be less than 10% which corresponds to - 0.5 <PMV <+ 0.5.

Following this approach the comfort conditions are studied in four rooms placed at the second floor: *Bedroom AN*; *Bedroom S*; *Bedroom P*; *Bedroom AG* (see figure 5a). These have different exposure and about 3.7 m^2 of glazed envelope each one. For summer and winter periods, the days taken into account are: 20th January with an outdoor mean daily temperature (T_{out}) of about 9.0°C, and 20th July, with T_{out} equals to 28°C. In figure 5b, PMV and PPD are reported for different hours; also the mean daily operative temperature (T_o) is indicated.

Here: Figure 5

The PPD of wintertime is always higher than threshold value (10%) and more in particular the opinion of person is that the room is very cold. Indeed at 15:00, a typical hour with solar gains, in the bedroom with south exposure the PMV is -2.79. The less cold room is on the north west exposure, at any time. The evaluation of these data for all building has allowed to conclude that the actual heating system and its management cannot satisfy the comfort requirements.

The indoor condition are clearly not comfortable during the summer since the mean delay operative temperature is higher than 30°C and the PMV value correspond to the answer “very hot” by the occupants. This situation is identical for all room of each floor, and it is easy to conclude that the installation of a cooling system is needed in order to meet the users comfort.

Moreover, the discomfort hours (TD) are calculated. For these outputs the operative temperature is simplified to be the average of the air temperature and the mean radiant temperature. For summer, the 0.5 Clo level is used and, for winter, the 1.0 Clo level is used. It should be underlined that the calculation of discomfort hours at building level is a floor area-weighted average of all zones. For the considered case study, during the heating and cooling season TD is respectively 1966 h and 1100 h.

3.2.4 *Daylight evaluation*

In figure 6 the distribution map of daylight illuminance (ill) and of daylight factor (DF), on the working plane (0.7 m), is reported for the second floor. The sky model selected is an overcast day with luminance at the Zenith equal to 10000 lux. Considering the same rooms taken into account for the thermal comfort analysis, the minimum and average values of DF are shown and the working area where it is higher than 2.0%. This value has been chosen as the minimum acceptable value for visual comfort, following as prescribed by BREEAM standard [45] in the case of domestic buildings refurbishment. The assumed target for illuminance is 500 lux for rooms where reading and studying activities are performed and 300 lux in the other rooms. These choices are in accordance with the recommended minimum level specified in the new standard EN 17037 [47]. Indeed it prescribes an illuminance level of at least 300 lux over at least 50 % of the space for at least half of the daylight hours in the year; and an illuminance level of at least 100 lux over 95 % of the space for at least half of the daylight hours in the year. To meet the proposed new standard a median daylight factor of 2.1% is required.

Due to the high value of glazed surface, the results in terms of visual comfort are not bad since about 50% of the analysed room area has a DF greater than 2.1%. However, concerning the whole building, the total average DF weighted on the floor area of each zone is equal to 1.83% (index DL in table 1).

Here: Figure 6

4 Building envelope refurbishment (phase I)

Based on the above mentioned calculations, the addition of a new façade which provides the increment of livable space is evaluated. This additional façade is connected to the existing reinforced concrete frame by the column-beam joints and it consists of a steel frame for each floor. The effect of this solution on the overall building structural behavior has been studied in the past [46]. The added volume that increases the market value of the building and the occupant comfort is an *inteGrated Efficient Technology*, namely as GET.

4.1 Definition of GET layout

The added volume has width of 2 m (gross size) realized on the east and west side of the building of all floors, except for ground floor. The following configurations for the GET are shown in figure 7:

- *Extra-Room* (ER)*:* air-conditioned space with different percentage of WWR (20-40-70-100%);
- *Sun-Space* (SS)*:* an attached sunspaces applied in loggia not air-conditioned.

Here: Figure 7

For ER type, the existing external wall is eliminated in order to create a unique living space. As shading system, the external venetian blinds are chosen. For the cold period, they are considered to be always open, in order to maximize the contribution of solar gains. Meanwhile during the summer the blinds are closed during the hottest hours, in order to minimize overheat. Regarding the Sun-Spaces, a mixed system is developed for using both direct solar gains as well as the thermal storage effect. In this case, a complete glazed volume is added. The sunspace is not equipped with heating and cooling system. The internal windows are always considered closed, while the external ones are open in the summer and closed in winter. External roller blinds are considered as shading system. During the winter these are not used while in summer the blinds are rolled down between the 11:00 and the 16:00.

The present building will also be renovated based on the re-distribution of the internal spaces according to the layout proposed in figure 8 for a type floor. In particular, the hallway is restricted in order to create larger bedrooms, and two double rooms per floor are created.

Here: Figure 8

4.2 Selection of thermo-physical characteristics

Table 3 presents the thermo-physical parameters of selected solutions; herein the thermal transmittance, has been calculated according to EN ISO 6946 [41] and the dynamic parameters (periodic thermal transmittance Y_{IE}, thermal mass M_s, internal areal heat capacity χ) according to ISO 13786 [48].

The cross-laminated panels (X-LAM) with mineral wool insulation have been chosen, with strong correspondence to the nearly Zero Energy Building demonstration building built in Benevento and currently in the post-validation phase [10]. The use of wood façade brings several technical benefits as shown in recent studies [49, 50]. A triple glazed with low-emittance coating (Low-E) and spectral selective characteristics are considered for the windows.

Here: Table 3

The roof has also been considered in the refurbishment action for the whole optimization of the energy performance since it is characterized by U-value of around 1.05 W/m^{2}K (the required is 0.45 W/(m^{2}K) [43]). For this reason, the application of 7.0 cm of mineral wool insulation has been designed with which the thermal transmittance becomes 0.31 W/(m^{2}K).

Finally, when the installation of the sunspace is evaluated, the refurbishment of existing external vertical elements is taken into account. In particular the windows are replaced as described in table 3. For the wall, the insulation with 7.0 cm of mineral wool is applied; the thermal transmittance becomes 0.33 W/m^{2}K.

4.3 Economic analysis of designed GETs

An economic analysis is also carried out. The cost for new products have been calculated as the mean value between the costs proposed by different commercial producers available on their website and taking into consideration the proposals of the different industrial partners involved in the project. For the wall preparation, the scaffolding, the labour cost, data have been found some in Greek and Italian official price lists. More in detail, the GET systems have the same bearing structure; therefore, the common costs are not considered. Table 4 shows the detailed costs that include installation of the system and manpower needed. From the cost estimated below, it is clear that the Sun-Space is twice expensive than the Extra-Room.

Here: Table 4

The global investment is used for evaluating the simple pay-back time for each designed configuration. It is the ratio between the investment cost and the reduction of operating costs due to the improvement of energy efficiency.

4.4 Selection of GET for each room

Simulations have been conducted considering the application of the proposed GET systems to each room; the analysis is based on the evaluation of HL, CL and DF defined in table 1. The internal and external boundary conditions are the same for the real building and for the calibration of the numerical model meanwhile the layout is changed (according to figure 8) and the lighting system has been replaced with LED lamps equipped with presence and illuminance level sensors. All results for the 2nd floor are reported in figure 9 where ΔHL indicates the variation of the heating load for sunspaces (SS) and extra-room (ER) with different windows area, compared with the base case (BC); ΔCL is the variation in the cooling load. A negative value indicates a reduction. The base case is the present building and the nomenclature for each room is reported in figure 8; east and west orientations are indicated with "E" and "W" respectively. The DL value is indicated for each room.

Here: Figure 9

All indices have been calculated for each room of each floor. Furthermore, the highest values for the heating and cooling loads are obtained in the common area probably because of the high window to wall ratio and the very low thermal resistance. The bedrooms of the 2nd floor are characterized by the lower value of HL meanwhile for CL the minimum is obtained in the 1st floor. Regarding the average daylight factor (DL), the best values are achieved for the common areas.

Figure 9 suggests that the ER solution always offers a great reduction of the heating load (-40% ÷ -55%) even if the heated area is bigger than the base case due to volume add-ons. The energy saving is also due to improvement of insulation level of the building envelope of the simulated refurbished configuration compared with the building with is actual structure. No significant difference is observed between different values of WWR; however, the window to wall ratio of 20% maximizes ΔHL. Instead the CL is negatively affected by the increment in the WWR due to the increment of solar gains. In more detail, with WWR equal to 20% and 40% there is a reduction of CL but with WWR equal to 70% and 100%, there are no cases with increased cooling load. However, in some rooms the reduction can be obtained thanks to the designed shading systems. The highest reduction in the cooling load for the WWR configuration of 70% or 100% is obtainable in the common areas because these also have windows on the south and north sides, and lower surface to volume ratio (≈ 0.28 m^{-1}) with respect to the rooms (≈0.36 m^{-1}).

The daylight factor improves with high window to wall ratio thanks to natural lighting. On the other hand, for WWR configurations of 20% and 40%, the DF value is always less than 2%, except for the common areas because these have the windows also on the south side or north side. Finally, for each configuration of the Extra-Room, the DL index is lower than the base case. It is in part a consequence of DL definition

because the net are to be lighted is increased; on the other hand the solar factor of selected windows is lower (0.6) than the base case (0.89) and thus the solar but also visual radiation that enter in the room is reduced.
The addition of a Sun-Space results in a significant reduction of the heating load (-60%) in the 1st, 2nd and 3rd floors, and lower values for the 4th floor (around -35%). This is mainly because of the heat losses occurring through the roof. Moreover, the reduction of the cooling load is significant and in some rooms of the 2nd floor it reaches -50%. Surely it due to several concomitant factors, for instance: the space is completely open, the new balcony have bigger depth, the solar transmittance of refurbished glasses is lower. In addition, it reaches -39% in the 4th, -45% in the 3rd and -51% at 1st floor which is less influenced by solar radiation. For the sunspace solution, the DL is found to be lower than that of the base case.
The SS creates a "buffer zone" before the room and thus it has an impact not only on the solar gains but also on the heat losses. On the other hand, the ER determines a single indoor space acting mainly on the solar gains. For this reason, probably, the greatest reduction of HL is always achieved with the Sun-Space. As far as the summer behavior is concerned, the ER with WWR of 20% has comparable behavior with the SS, while the highest values of DL are achieved for the Extra-Room with WWR of 100% but these are comparable, in many cases, with the results obtained for SS.
Considering the obtained results, it is not possible to express a global and unambiguous preference judgment. In order to identify the best solution for each room, a decision making problem has been solved considering as objectives the maximization of heating and cooling design loads reduction and by setting the average Daylight Factor as constraint (DL ≥ 2%). This assumption is really important in the design process of façade add-ons. It affects not only the visual perception of occupants and therefore their comfort, but also the electric consumptions and thus the operating costs of the lighting system. Considering the results proposed in figure 9 and the considered constraints, for the 2nd floor the ER with WWR equal to 20% and 40%are not considered to be the best solutions for the rooms instead these could be admissible for the common area.
Furthermore, considering the results for the other floors, the most acceptable configuration, according to DL value, that provides maximum cooling and heating load reduction at the same time, is usually SS mainly for the rooms. On the contrary, the Sun-Space solution has twice as much investment costs as the Extra-Room solutions. For this reason, a decision criterion that takes into account investment and operational costs have been set, among the acceptable solutions (DL≥2%). In particular, the evaluation of economic profitability in terms of simple payback period has shown that the reduction of exercise costs allows to refund the investment costs for SS in an acceptable time (lower than 7 years) only when ΔHL and ΔCL are greater than 45%. Meanwhile the possibility to achieve a good reduction of both cooling and heating loads determines the selection on the ER GET type. Figure 10 shows the selection criteria method.

Here: Figure 10

More in detail, for the configurations that respect the lighting constraint, the reduction of heating and cooling load determines the most profitable solution. It is the Sun Space if the savings are higher than 45%, instead it is ER with WWR of 20% when the saving is at least 25%. In the other cases the solution is ER with WWR of 70%.

Figure 11a summarizes the global result of selection criteria application. 144 GET systems are added to the existing façade. Only for the common areas in the corners, the best solution is ER with WWR of 20%. The range of the achieved heating and cooling load reduction is also reported.

Here: Figure 11

Finally, Figure 11 b shows the new configuration where the dark grey indicates the opaque envelope and the light grey the transparent surfaces. The air-conditioned surface for this configuration is equal to 2'954 m^2, with an increase of 14% with respect to the present building configuration. The total heating load was 81 W/m^2 while the cooling one 93 W/m^2.

5 HVAC and renewable sources implementation toward nearly Zero Energy Building (phase II)

The goal of the proposed energy refurbishment is to achieve the nZEB target. With this aim, the designing of HVAC systems and plants powered by renewable energy sources (RES) has been carried out (phase II) starting from configurations selected by the minimization of heating and cooling loads.

In the present work the nZEB realization was achieved following best practices or legislative constraints of various Mediterranean countries are taken into account for designing performing HVAC with RES integration.

5.1 HVAC designed configuration for nZEB goal

The solution selected for the energy refurbishment takes into account the most critical observations recorded during the audit phase.

Taking into consideration the energy requests in Figure 4, it has been considered the replacement of the actual lamps with LEDs characterized by nominal efficiency of 110 lm/Watt. A continuous control is assumed; it allows the adjustment of light levels continuously according to the measured daylight illuminance. The simulation software allows the implementation of the logic control but the final output is the total electric consumption of the lighting service. For this reason the consumptions due to controllers (namely stand-by power and parasitic power) have not been declared.

Regarding the HVAC system, a mixed air-water system is proposed. For the heating period, a natural gas condensing boiler, assisted by climatic compensation is considered, starting from the total heating design load (240 kW), which is the best performing boiler available on the market. For the cooling of the building, an air cooled chiller (275 kW) with screw compressor is chosen. It is important to note here that in the base case there is no cooling system. Therefore the cooling period is set following the Greek report "TABULA" [51] according the climatic zone.

Here Table 5

The generation system consist of boiler and heat pump; for this system Botticella et al. [52] have performed a multi-criteria optimization analysis and some experiment about the use of unconventional fluids [53]. The two pipe fan coil units (FCU), placed in each room, are characterized be constant water flow and variable speed fan, in order to meet the load. These should balance only the sensible loads since for the control of ventilation and latent loads, for each floor, a centralized Air Handling Unit (AHU) is considered with duct's distribution for each room. For the chosen system configuration, the AHUs have to process only the external air in order to maintain the required level of air quality according to the standard UNI 10339 [54] and thus, according to the building kind of use, 11 l/s per person. The AHU is also provided with a Fixed-Plate-Cross-Flow Heat Exchanger that only recovers sensitive heat with a yield of 70%. The AHU and the heat recovery unit operate throughout the year according to the people occupation schedule.

Finally the free cooling mode is considered during the night of the cooling period (15 May - 15 September). It helps to improve the thermal energy performance of the HVAC system and the thermo-hygrometric comfort. This cooling technique is realized by activating the exhaust fans but only in common areas.

Table 5 reports all technical specifications as well as the operation mode and the boundary conditions for the considered renewable sources. Regarding the DHW, a combined solar assisted system with condensing boiler integration is taken into account. 32 solar collectors made by evacuated tubes with a size of 1640 mm x1927 mm and storage volume of 2000 l are considered. The number of solar panels has been chosen for satisfying the 55% of user demand (34'210 kWh/ year in the state of fact). This is a threshold value usually adopted in the European states for achieving the nZEB goal. Briefly, 365 panels with crystalline silicon cells can be installed; for the selected commercial modules the rated power is 250 Wp and the cell efficiency value is equal to 20.8%, thus the PV-system has nominal power of 91.3 kW. All technical data are in table 5.

In order to optimize the performance of solar collectors and photovoltaic modules, the South-East orientation has been chosen and the tilt angle is 31° according to the latitude of the building. The panels do not shade each other and these are not visible by the street, as shown in the rendering of figure 12.

Here: Figure 12

5.2 Renovation results and nZEB target verification

For evaluating the achievement of the nZEB standard, the dynamic simulation of the refurbished building has been carried out. Figure 13 shows the yearly energy needs for the main services. The total primary energy need is 133 kWh/(m^{2}y). Considering the commented Europe of threshold value for NZEB classification [7], it seems a good results for the proposed aim.

More in detail, the comparison with the state of fact in Figure 4 allows to conclude that the heating demand decreases of around -63% as well as the reduction of the consumptions for the lighting system is reduced of around -60%. These results are comparable with those proposed by Gaspari et al. [17] meanwhile the energy saving is higher than value calculated by Eliopoulou et al. [14] in the same climate because they take into account only architectural modifications while the proposed designed is also finalized to improve building envelope and HVAC system performance.

The energy balance for the refurbished configuration is characterized by the new term of cooling consumptions due to the requirement of improve indoor conditions during the summer.

Indoor electric equipment consumption remains practically the same of the base case. This study does not propose a deepening about the effect of the adoption of more efficient appliances because it is not a deterministic action; indeed the consumption for internal appliances is a random variable depending mostly on occupants' preference.

Here: Figure 13

Finally, the global primary energy saving is 29% but two new services have been added compared with the base case: cooling and mechanical ventilation.

Figure 14a shows the monthly energy balance considering the electricity request (equipment, lighting, fans and pumps, cooling) and the production of PV-system. The percentage with which the PV production is able to satisfy the requests ranges from 31% in January to 96% in July. The proposed configurations determines a big surplus of production in April, May and above all August and September; in these months the cooling service is turned off except for 15 days in May and September meanwhile the ventilation is turned on and the lighting consumptions are reduced due to natural lighting. This consideration underlines the great incidence of heat pump in the energy balance of summer period. For maximizing the self-consumption, a storage system has to be installed.

Figure 14b shows how much energy for DHW productions is supplied by solar collectors or by the boiler. At least 47% of the energy demand is covered by solar collectors' production every month; from June to September there is a full coverage. Annually, the integration of renewable source due to solar collector is around 72%. This result is better than normative prescription in many countries, as for instance Italy where the new and refurbished building must cover 50% of DWH production with renewable sources [9].

Here: Figure 14

Take in mind that in August, during the summer holiday, the model consider an occupation rate of 10% compared with the other months. For this reason the consumptions in figure 14a and 14b are low. However, considering the annual energy balance, the whole electricity demand is 54.4 kWh/m^2 and the coverage of photovoltaic system is around 88%, thus only 6.4 kWh/m^2 should be taken by the national grid. Moreover during the whole year the consumption of natural gas is only around 3.4 kWh/m^2.

These results confirm that the refurbished building has very low energy needs which are covered almost entirely by renewable energy systems. Indeed, the percentage incidence suggests a very good integration of renewable electric source that allows to reach the zero energy standard, according to the most diffused definition in Europe [10].

6 Discussion with SWOT matrix definition

Since the proposed refurbishment covers more aspects than the traditional energy, economic and environmental issues, a new way to represent the results is proposed by means of a SWOT analysis. It is, traditionally, a strategic planning tool used by organizations when making decisions for better understand business environment due to the analysis of the positioning an organization's resources and environment in four regions of a matrix: *Strengths*, *Weaknesses*, *Opportunities* and *Threats* [55] (Figure 15 a). Briefly, *Strengths* and *Weaknesses* are internal (controllable) factors that support and obstruct, respectively, organizations to achieve their mission; *Opportunities* and *Threats* are the external (uncontrollable) factors that enable and disable organizations from accomplishing their mission [56]. It is a method born in management research area and developed in other fields because it is really easy to understand also if some studies underline that sometimes this approach may lead to a wrong decision due to two bottlenecks [57]:

1. only qualitative factors are taken into account;
2. only the point of view of the decision maker is taken into account.

Here: Figure 15

In order to overcame the above problems an innovative qualitative and quantitative SWOT matrix is presented and applied to the case study with the aim to evaluate with a multidisciplinary approach the results of the energy refurbishment. First of all, the concept of SWOT matrix has been slightly modified: internal strengths and weaknesses are referred to the building occupants, while external opportunities and threats are referred to the community/society. Several aspects have been taken into account as shown in Figure 15 b and most of these can be quantified with numerical indexes showed in Figure 15 c. More in detail, the effect of the design on the living space is considered as beneficial for the occupants' perspective and it is included in the section of Strengths. This variable can be quantified with the percentage variation (ΔS) of livable surface. The impact on aesthetic improvement of refurbished building is qualitatively considered as well as on market and occupation due to retrofit working according to society perspective. Moreover, the variation of annual discomfort hours is calculated for evaluating the effect on occupant comfort (ΔTD) meanwhile the energy saving and the reduction of pollution emission are considered as opportunities for their benefit on the entire society. The adopted indexes are the total percentage of electricity covered by PV production [$\%RES_{EL}$]; the total percentage of thermal energy for DHW covered by solar collector production [$\%RS_{DHW}$]; the avoided CO_2 emissions [ΔCO_2]; the primary energy saving without the renewable energy sources [$\Delta EP_{TOTnren}$]; the primary energy saving considering the renewable energy sources [ΔEP_{TOTren}]; the energy saving for heating [$\Delta E_{HEATING}$ %]; the reduction of electricity consumption for lighting [$\Delta E_{LIGHTING}$].

The energy operating costs and the refurbishment investment costs are considered charged to the community, since this is a public building. Thus the reduction of operational cost (ΔOC) is an opportunity for the society. The index is calculated considering the difference with the base case over a period of one year. The costs, including taxes, for Greece are estimated equal to 0.078 €/kWh for natural gas [58] and equal to 0.160 [59] for electricity.

The only intervention to the building that can affect the occupants is the addition of some services that could improve the thermos-hygrometric and visual comfort. The same applies for the seismic security changes as well as the acoustic performance parameters. Another important benefit is that since they are prefabricated (the GET) the working period is very fast in comparison to conventional renovation.

Based on the previous considerations, the SWOT matrix for the case study is shown in Figure 14 c; positive values indicate an increment compared with the present building otherwise negative values indicate a reduction. More in detail, the living space is increased of more than 20% with better amenity of external environment; this means that students could have a more positive opinion on their accommodation and their comfort, regarding the personal space and their quality of life will increase highly. Regarding the thermo-hygrometric comfort there is a reduction of discomfort hours both in the summer than in winter. Indeed, during the winter the discomfort hours decrease from 1'966 h in the state of fact to 1'143 h in the refurbishment case; while during the summer, from 1'100 h to 850 h. Instead, the DL increases from 1.83%, in the base case, to 2.53%, in the refurbished case in almost all rooms. Some extra and important services are added, such as cooling, ventilation and automation for the lamps, these improve the quality of life inside the building but the energy saving object is reached. As regards the total primary energy, without taking into account the renewable sources, the saving is around 39%, a number which is relatively low, nonetheless this is due to the addition of two new energy-consuming services, ventilation and cooling. If the renewable sources are taken into account, the savings correspond to 90%, as well as the reduction of polluting emissions. This result underlines the zero energy target achievement. The operational costs are reduced of around 29’500 €/ y, this is an important result for community mainly considering the economic problems that often affect administrations. This money could be invested for further improving the student services.

Finally, although some factors have not been quantified, it can be concluded that the proposed redevelopment is certainly a beneficial action to be implemented. Indeed there are more helpful elements than the harmful ones and thus the refurbishment design can have a positive impact on both occupants and society.

It is important to underline that this can be used by designers during the comparison of several alternatives. Indeed, this is a simple method for judging an action that has to be implemented, assuming that all different aspects have the same impact on the building.

Conclusions

A holistic multidisciplinary approach is investigated and presented in this work for evaluating the optimal configuration of building’s refurbishment, using volumetric add-ons, with respect of the nZEB target. The application to the retrofit design of the student dormitory of University of Athens allows to obtain an increment of the living space of around 20% with improvement in term of thermal and visual comfort as well in the amenity of external environment. The building reaches the target of zero energy with energy saving and polluting emission reduction compared with the present configuration of around 90%. The operational costs are reduced to around 29’500 €/ y.

The results of the case study demonstrate the effectiveness of the proposed approach for identifying the best retrofit solution in Mediterranean climate and its replicability. At same time, it has been shown how, for the existing building stock, the volume addition strategy could be a way to reach the goals of help a more rapid diffusion of nZEB, also providing improvements of not energy related benefits. For instance it could be the solution to address the urbanization problem without the construction of new buildings; it can contribute to the increase of the real estate value of existing edifices, or to incentive their improvement the of architectural aesthetics features with the changed urban context compared to what it was when the building was built; it can be a method with which acoustics, visual and thermo-hygrometric comfort can be improved.

Moreover the results give important suggestions to the designers in Mediterranean climate about the most appropriate technologies for building envelope and plants in order to reach high energy efficient performances. Briefly, between the examined GET systems, the sunspace applied in loggia seems the best performing solution in terms of energy savings.

Finally, it has been shown the usefulness of the definition of a quantitative SWOT matrix; it can help designers and researchers to set a multidisciplinary evaluation by considering strengths and weaknesses according to occupants' point of view meanwhile opportunities and threats with reference to the society.

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References

1. Eurostat, Energy balance sheets 2016 DATA, 2018 edition, STATISTICAL BOOKS.
2. European Commission, EU Buildings Database, https://ec.europa.eu/energy/en/eu-buildings-database (accessed 8.03.19).
3. European Commission website available on line at https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings (accessed 19.10.18).
4. European Commission - Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: A policy framework for climate and energy in the period from 2020 to 2030, Brussels, 22.1.2014 COM(2014).
5. Directive (EU) 2010/31 of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast).
6. 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.
7. J. Kurnitski, T. Buso, S. P. Corgnati, A. Derjanecz, A. Litiu, nZEB definitions in Europe, REHVA Journal – March 2014.
8. D. D'Agostino, L. Mazzarella. What is a Nearly zero energy building? Overview, implementation and comparison of definitions. Journal of Building Engineering 21 (2019) 200–212.
9. DECRETO 26 giugno 2015 Applicazione delle metodologie di calcolo delle prestazioni energetiche e definizione delle prescrizioni e dei requisiti minimi degli edifici. (in italian) (GU n.162 del 15-7-2015 - n. 39).
10. Ascione F, Borrelli M, De Masi R F, de Rossi F, Vanoli G P 2016 A framework for NZEB design in Mediterranean climate: Design, building and set-up monitoring of a lab-small villa, Solar Energy, 184, 2019, Pages 11-29.
11. T. Karlessi, N. Kampelis, D. Kolokotsa, M. Santamouris, L. Standardi, D.Isidoric, C. Cristalli, The Concept of Smart and NZEB Buildings and the Integrated Design Approach, Procedia Engineering, 180, 2017, 1316-1325.
12. M. Kapsalaki, V. Leal, M. Santamouris, A methodology for economic efficient design of Net Zero Energy Buildings, Energy and Buildings, 55, 2012, 765-778
13. Fair Energy Transition towards Nearly Zero Energy Buildings European Public, Cooperative and Social Housing Providers Working for a Fair Energy Transition http://www.powerhouseeurope.eu/ Progress Report, March 2013.
14. E. Eliopoulou, E. Mantziou, Architectural Energy Retrofit (AER): An alternative building's deep energy retrofit strategy, Energy and Buildings 150 (2017) 239–252.
15. A. Ferrante, Energy retrofit to nearly zero and socio-oriented urban environments in the Mediterranean climate, Sustain. Cities Soc. 13 (2014) 237–253.
16. A. Ferrante, G. Semprini, Building energy retrofitting in urban areas, Procedia Engineering 21 (2011) 968-975.
17. J. Gaspari, A. Boeri, E. Antonini, D. Longo, Volumetric additions for sustainable refurbishment of residential buildings: from theory to practice, Central Europe towards Sustainable Building 2013: Sustainable Building and Refurbishment for Next Generations, GRADA Publishing, Prague, 2013.

18. A. Fotopoulou, G. Semprini, E. Cattani, Y. Schihin, J. Weyer, R. Gulli, A. Ferrante, Deep renovation in existing residential buildings through façade additions: A case study in a typical residential building of the 70s, Energy & Buildings 166 (2018) 258–270.
19. D. Aelenei, H. de Azevedo Leal, L. Aelenei, The Use of Attached-sunspaces in Retrofitting Design: The Case of Residential Buildings in Portugal, Energy Procedia 48 (2014) 1436-1441.
20. G. Mihalakakou , A Ferrante , Energy conservation and potential of a sunspace: sensitivity analysis, J. Energy Convers. Manage. 41 (12) (2000) 1247–1264.
21. K.M. Bataineh , N. Fayez, Analysis of thermal performance of building attached sunspace, Energy Build. 43 (2011) 1863–1868.
22. A. Monge-Barrio , A. Sánchez-Ostiz , Energy efficiency and thermal behaviour of attached sunspaces, in the residential architecture in Spain, Summer Conditions Energy Build. 108 (2015) 244–256.
23. A. Muscio, C. Ferrari, Ventilated greenhouses for energy retrofit of condominium buildings with balconies, Proceedings of the 13th Conference on Sustainable Development of Energy, Water and Environment Systems, Palermo, October, 2018.
24. G. Semprini, A. Ferrante, E. Cattani, A. Fotopolulou, New strategies towards nearly zero energy in existing buildings: the ABRACADABRA project, Energy Procedia 140 (2017) 151–158.
25. N. Cukovic-Ignjatovic, D. Ignjatovic, Some Possibilities of Extensions in Building Renovation, Proceedings of the 23rd Conference on Passive and Low Energy Architecture, Geneva, September, 2006.
26. http://www.druot.net/Book-Tour-Bois-le-Pr%C3%AAtre-FR.pdf, accessed on October 2018.
27. http://www.blauraum.eu/projekte/project/2/, accessed on October 2018.
28. http://www.convertiblecity.de/projekte_projekt31_en.html#showcase02, accessed on October 2018.
29. Minimum Impact House – Entwicklung eines nachhaltigen Prototyps Drexler Guinand Jauslin Architekten GmbH und Fachgebiet ee, TU Darmstadt
30. H. Drexler, M. Guinand, D. Jauslin, MINIMUM IMPACT HOUSE THE PROTOTYPE FOR SUSTAINABLE BUILDING IN THE CITY CENTRE AND WHAT'S BEYOND THE PROTOTYPE, Proceedings of the 4th International Conference of the International Forum on Urbanism (IFoU), Amsterdam/Delft, 2009.
31. S. Paris and R. Bianchi, La riqualificazione architettonica e ambientale dei quartieri moderni di edilizia residenziale pubblica: una opportunità per la città contemporanea. Un caso di studio a Roma. TECHNE 10 2015.
32. L. Bellia, M. Borrelli, R. F. De Masi, S. Ruggiero, Giuseppe Peter Vanoli, University building: Energy diagnosis and refurbishment design with cost-optimal approach. Discussion about the effect of numerical modelling assumptions, Journal of Building Engineering 18, 2018, 1-18.
33. Department of Energy Federal Energy Management Program, M&V Guidelines: Measurement and Verification for Federal Energy Projects Version 3.0, 2008, Boulder, CO.
34. ANSI/ASHRAE Standard 55-2004 - Thermal Environmental Conditions for Human Occupancy.
35. European Committe for Standardization EN 15251:2007. Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics
36. World Energy Council – Energy Efficiency Indicators. Efficiency of power generation.
37. http://www.terna.it/it-it/sistemaelettrico/statisticheeprevisioni/confrontiinternazionali
38. U.S. Department of Energy. Energy Plus simulation software 2013. Version 8.1.0.
39. Design Builder v.4.7. <http://www.designbuilder.co.uk/>; 2016.
40. M. Kottek, J. Grieser, C. Beck, B. Rudolf, F. Rubel, World Map of the Köppen-Geiger climate classification updated, Gebrüder Borntraeger, Berlin, Stuttgart 2006, DOI: 10.1127/0941-2948/2006/0130
41. International Organization for Standardization ISO EN 6946:2007, Building Components and Building Elements: Thermal Resistance and Thermal Transmittance, Calculation Method.
42. International Organization for Standardization ISO 15099:2003, Thermal performance of windows, doors and shading devices -- Detailed calculations.
43. Ministerial Decision Δ6/Β/οικ.5825/30-03-2010 ΦΕΚ Β΄ 407.
44. International Organization for Standardization ISO 7730:2006 - Ergonomics of the thermal environment -- Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria.

45. BREEAM Refurbishment – Domestic Buildings, Technical Manual, SD5077, Issue: 2.2, 2014. https://www.breeam.com/domrefurb2014manual/ (accessed 27.02.19)
46. A. Ferrante, G. Mochi, G. Predari, L. Badini, A. Fotopoulou, R. Gulli, G. Semprini A European Project for Safer and Energy Efficient Buildings: Pro-GET-onE (Proactive Synergy of inteGrated Efficient Technologies on Buildings' Envelopes), Sustainability 2018, 10, 812; doi:10.3390/su10030812 www.mdpi.com/journal/sustainability.
47. European Committe for Standardization EN 17037:2018, Daylight in buildings
48. International Organization for Standardization ISO 13786:2007, Thermal performance of building components- Dynamic thermal characteristics – Calculation methods.
49. C. Coupillie, M. Steeman, N. Van Den Bossche, Katrien Maroy, Evaluating the hygrothermal performance of prefabricated timber frame façade elements used in building renovation, Energy Procedia 132 (2017) 933–938.
50. K. Sandberg, T. Orskaug, A. Andersson, Prefabricated Wood Elements for Sustainable Renovation of Residential Building Façade, Energy Procedia 96 (2016) 756-767.
51. National Observatory of Athens. Greek report "TABULA", May 2012.
52. F. Botticella, F. De Rossi, A.W. Mauro, G.P. Vanoli, L. Viscito, Multicriteria (thermodynamic, economic and environmental) analysis of possible design options for residential heating split systems working with low GWP refrigerants, International Journal of Refrigertion 87 (2018) 131-153.
53. G. Lillo, R. Mastrullo, A.W. Mauro, L. Viscito, Flow boiling heat transfer, dry-out vapor quality and pressure drop of propane (R290): Experiments and assessment of predictive methods, International Journal of Heat and Mass Transfer 126 (2018) 1236-1252.
54. UNI 10339:1995, Impianti aeraulici al fini di benessere. Generalità, classificazione e requisiti. Regole per la richiesta d'offerta, l'offerta, l'ordine e la fornitura (in italian).
55. B. Phadermrod, R. M. Crowder, G. B. Wills, Importance-Performance Analysis based SWOT analysis, International Journal of Information Management 44 (2019) 194–203.
56. R.G. Dyson, Strategic development and SWOT analysis at the University of Warwick, European Journal of Operational Research, 152 (2004) 631-640.
57. Wilson, R. M., & Gilligan, C. Strategic marketing management: Planning, implementation and control. Routledge, 2005.
58. K. T. Papakostasa, G. Martinopoulos, A. M. Papadopoulos, Comparison of Various Heating Systems in Greece Based on Efficiency and Fuel Cost, 17th Symposium on thermal science and end Engineering of Serbia, Sokobanja, Serbia, October 20-23, 2015.
59. Eurostat, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity_price_statistics/it (accessed 8.03.19)

Figure captions:

Figure 1: Outline of the paper methodology

Figure 2: View building position (a); draw of cross section (b) and of internal plan (c).

Figure 3: a) Real and numerical rendering of the building; b) Calibration indexes

Figure 4: Energy consumptions of the real building

Figure 5: a) Selected rooms of 2nd floor for comfort analysis; b) PMV and PPD for selected rooms

Figure 6: a) Daylight analysis for the 2nd floor; daylight indexes for selected rooms

Figure 7: Architectural drawing of the GET systems

Figure 8: New layout distribution for a type floor

Figure 9: Results for the 2nd floor

Figure 10: Flow chart of the selection criteria

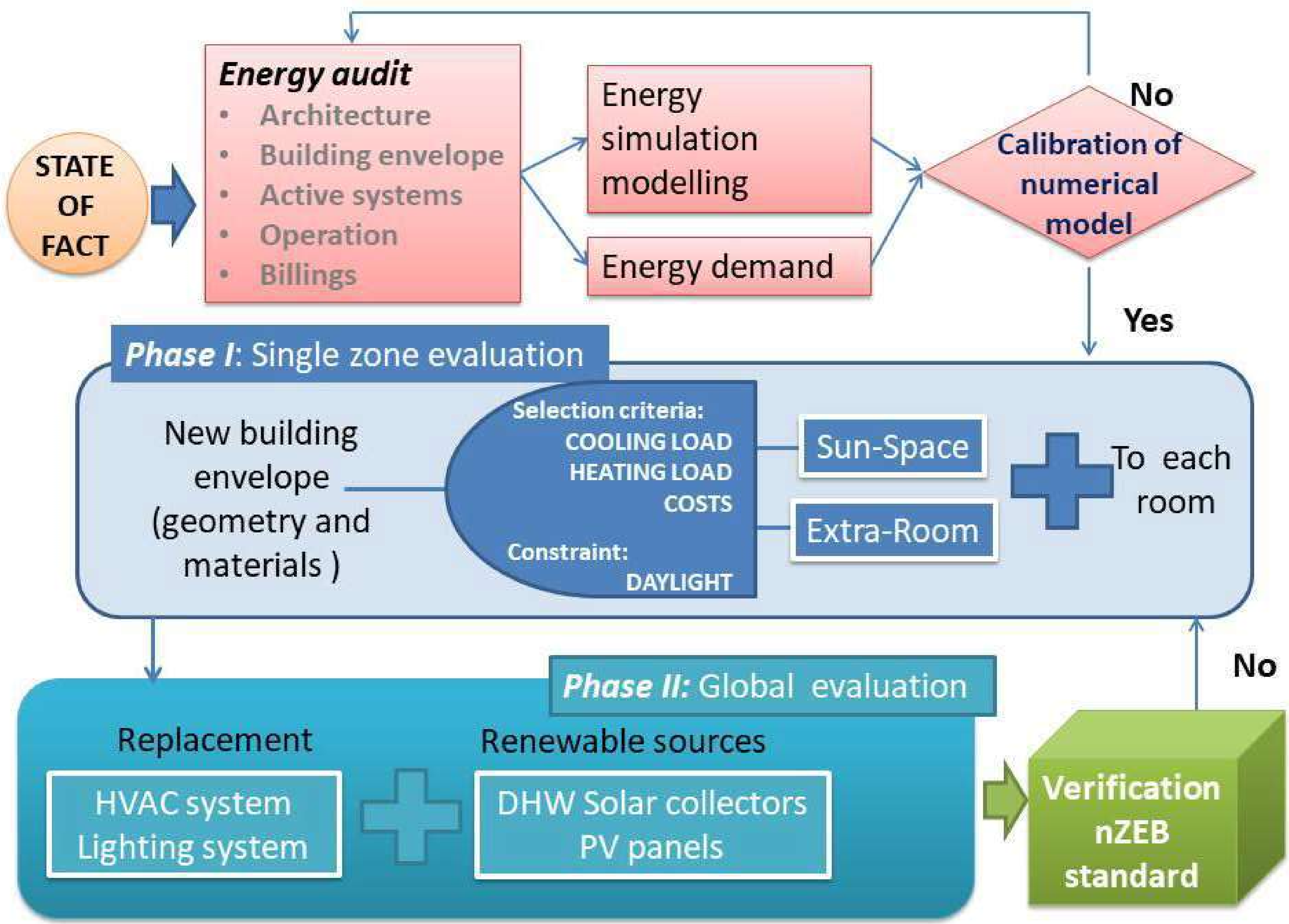
Figure 11: a) Selected solution; b) Final layout of new façade

Figure 12: Render view of refurbished building

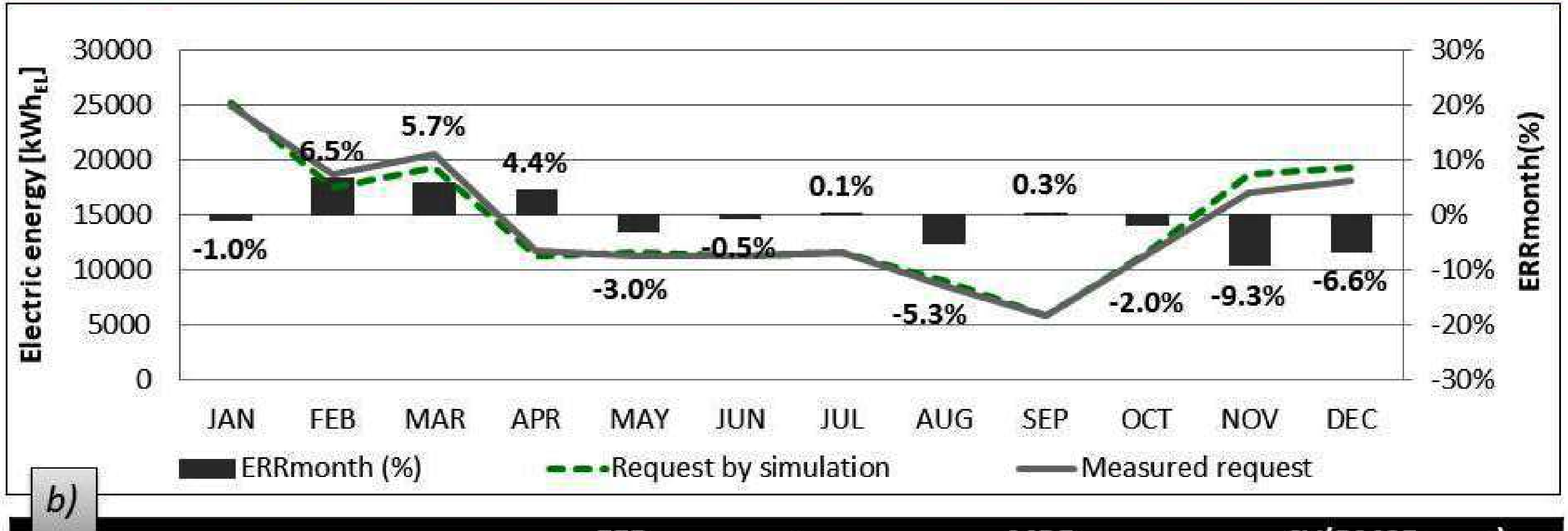
Figure 13: Energy consumption of refurbished building

Figure 14: a) Electricity requests and photovoltaic production; b) Gas request for DHW and rates supplied by boiler and solar collectors

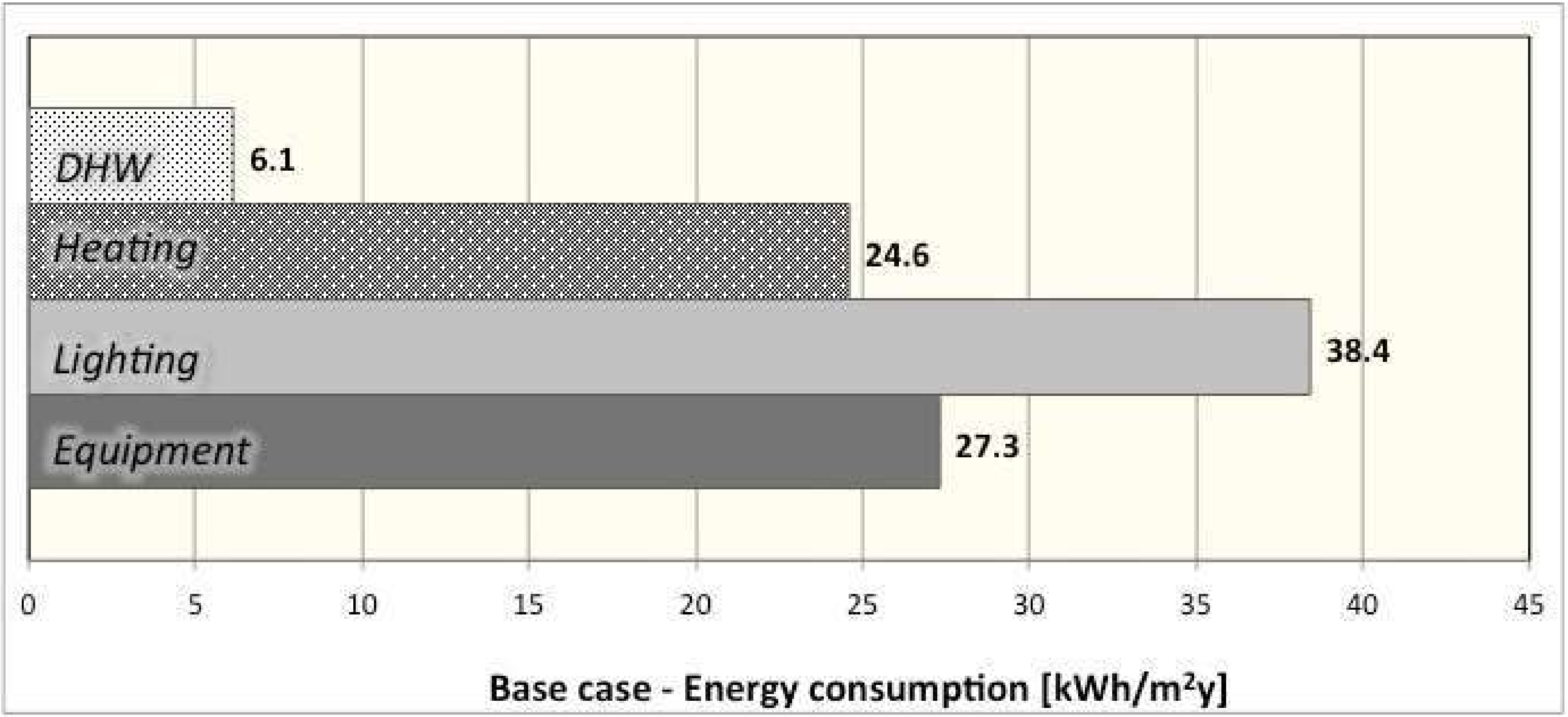
Figure 15: a) Traditional SWOT matrix; b) Qualitative SWOT analysis c) Quantitative results of the SWOT analysis obtained from simulations

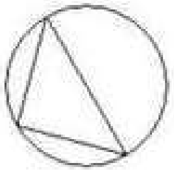

STATE OF FACT
Energy audit
Architecture
Building envelope
Active systems
Operation
Billings
Energy simulation modelling
Energy demand
Calibration of numerical model
No
Yes
Phase I: Single zone evaluation
New building envelope (geometry and materials)
Selection criteria:
COOLING LOAD
HEATING LOAD
COSTS
Constraint:
DAYLIGHT
Sun-Space
Extra-Room
To each room
Phase II: Global evaluation
Replacement
HVAC system
Lighting system
Renewable sources
DHW Solar collectors
PV panels
Verification nZEB standard
No


a)
Google
b)
North East- South West
Δ-Δ ΤΟΜΗ
c)
1st, 2nd,3rd Floor



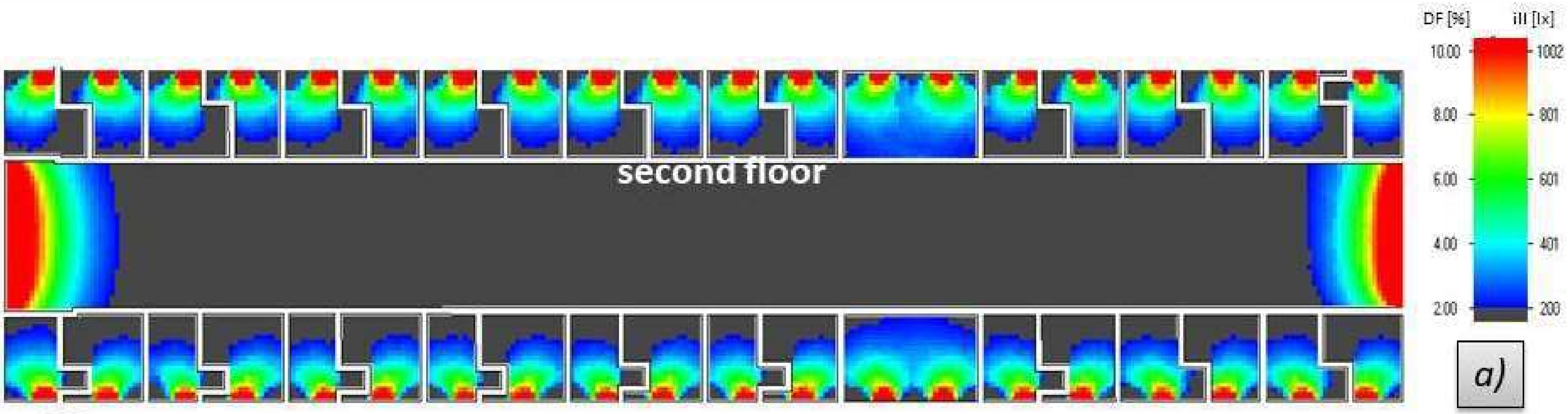
	$EER_{average\ month}$	MBE	$CV(RMSE_{month})$
Evaluated indexes	-0.9%	+3.5%	+5.6%
Tolerance values ***M&V Guideline***	±10	±5	±10


DHW
6.1
Heating
24.6
Lighting
38.4
Equipment
27.3
0
5
10
15
20
25
30
35
40
45
Base case - Energy consumption [kWh/m²y]

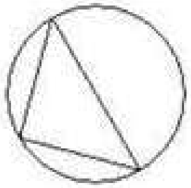


	Bedroom AN	Bedroom S	Bedroom P	Bedroom AG
20 January (T_{out} = 9°C)				
To [°C]	19.28	19.66	19.54	18.77
PMV (PPD) at 10:00	-1.77 (65%)	-2.60 (95%)	-1.75 (64%)	-1.82 (68%)
PMV (PPD) at 15:00	-1.86 (70%)	-2.79 (98%)	-1.76 (65%)	-2.07 (80%)
PMV (PPD) at 20:00	-1.81 (68%)	-2.66 (96%)	-1.78 (66%)	-1.84 (69%)
20 July (T_{out} = 28°C)				
To [°C]	34.61	35.49	35.05	33.86
PMV (PPD) at 10:00	3.18 (100%)	3.74 (100%)	3.01 (99%)	2.46 (92%)
PMV (PPD) at 15:00	3.38 (100%)	3.72 (100%)	3.36 (100%)	2.82 (98%)
PMV (PPD) at 20:00	3.44 (100%)	3.46 (100%)	3.73 (100%)	3.26 (100%)

b)

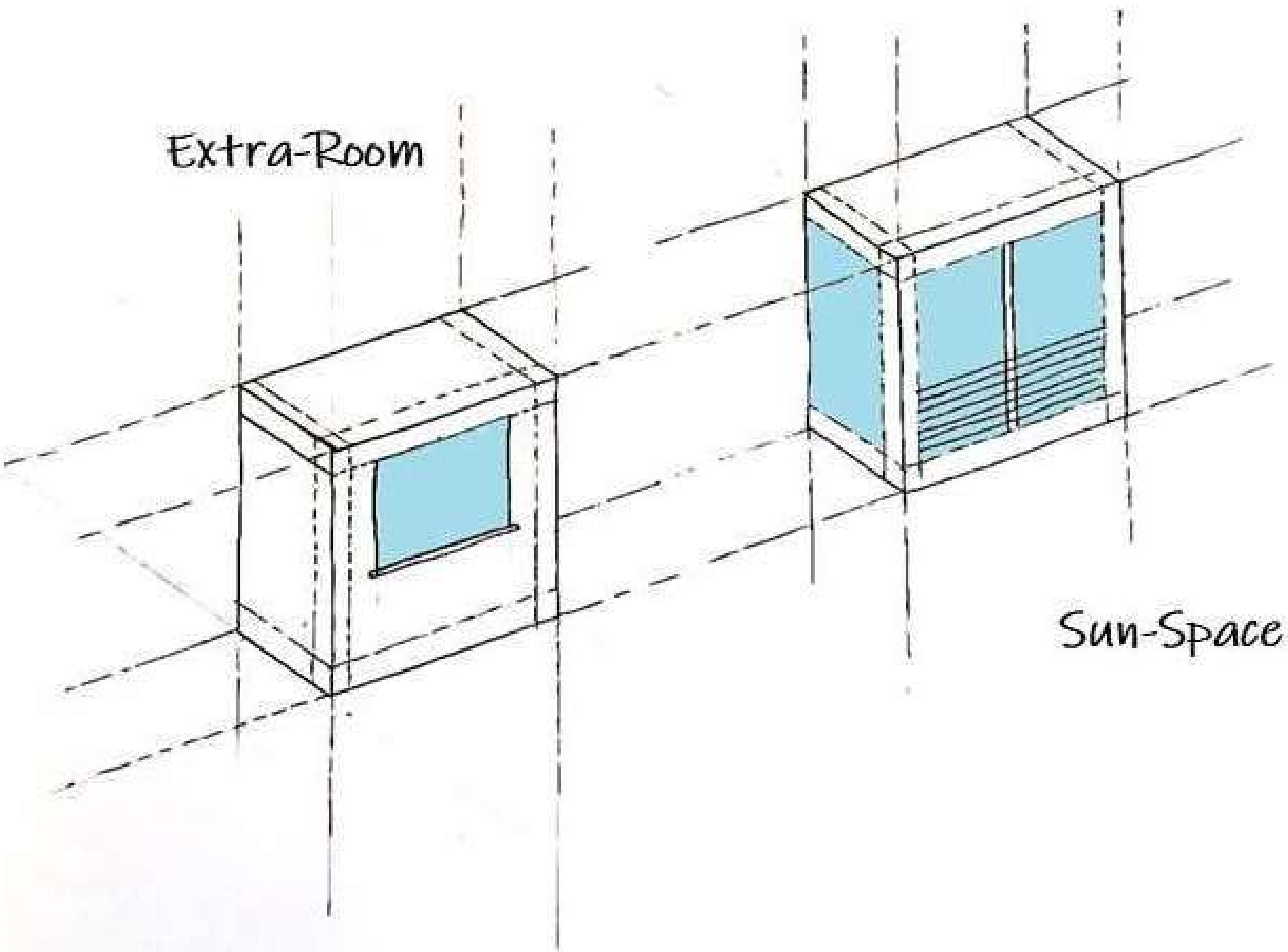


a)

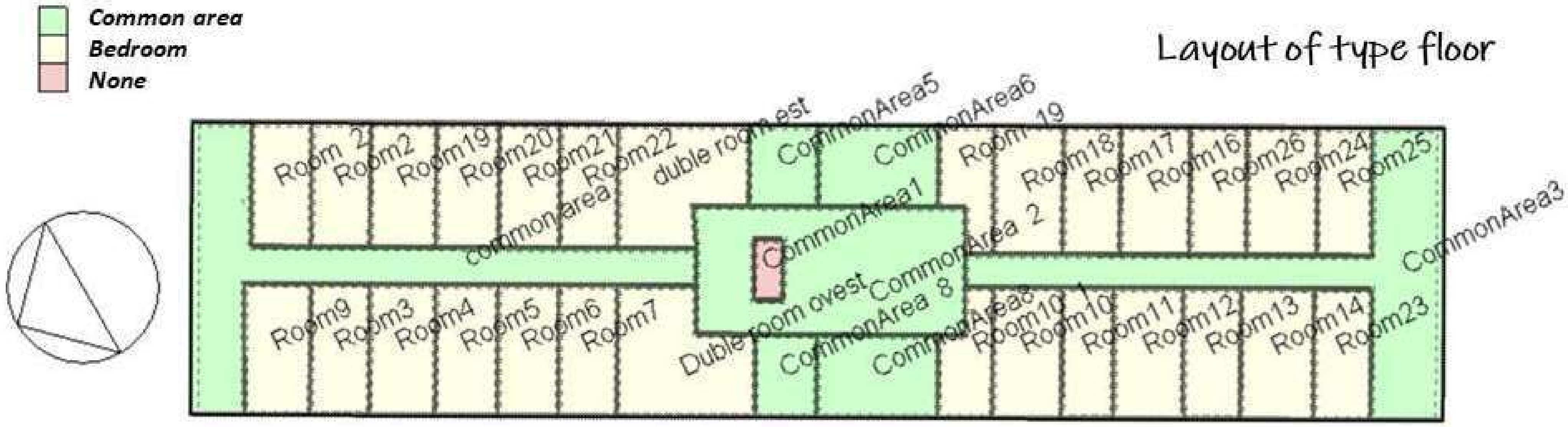


b)

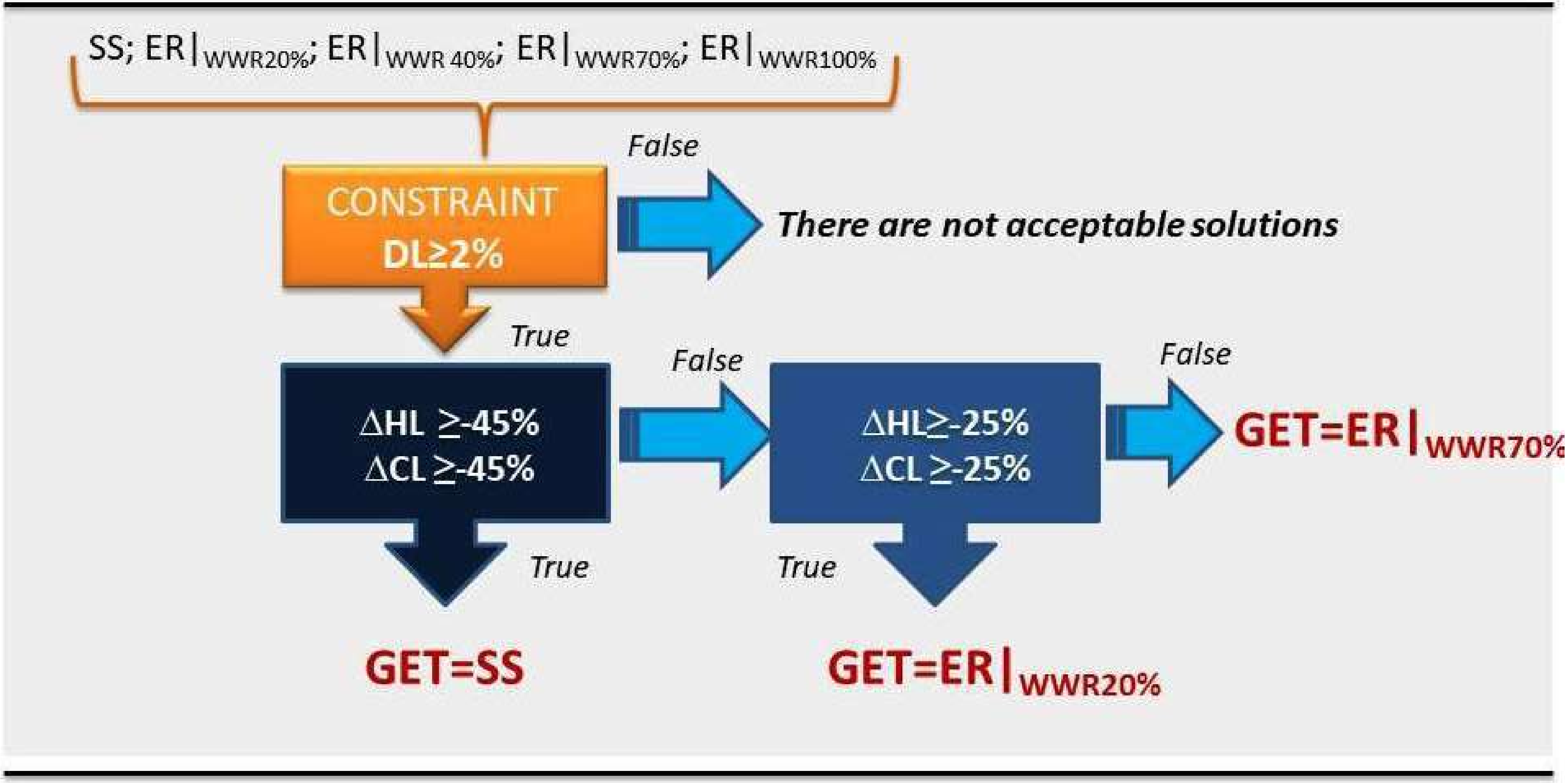
ROOM	Min DF [%]	Average DF [%]	Working plane area with DF>2% [m^2]
Bedroom AG	0.30	3.02	5.20
Bedroom P	0.33	3.11	6.06
Bedroom S	1.63	4.38	6.80
Bedroom AN	0.33	3.38	4.41

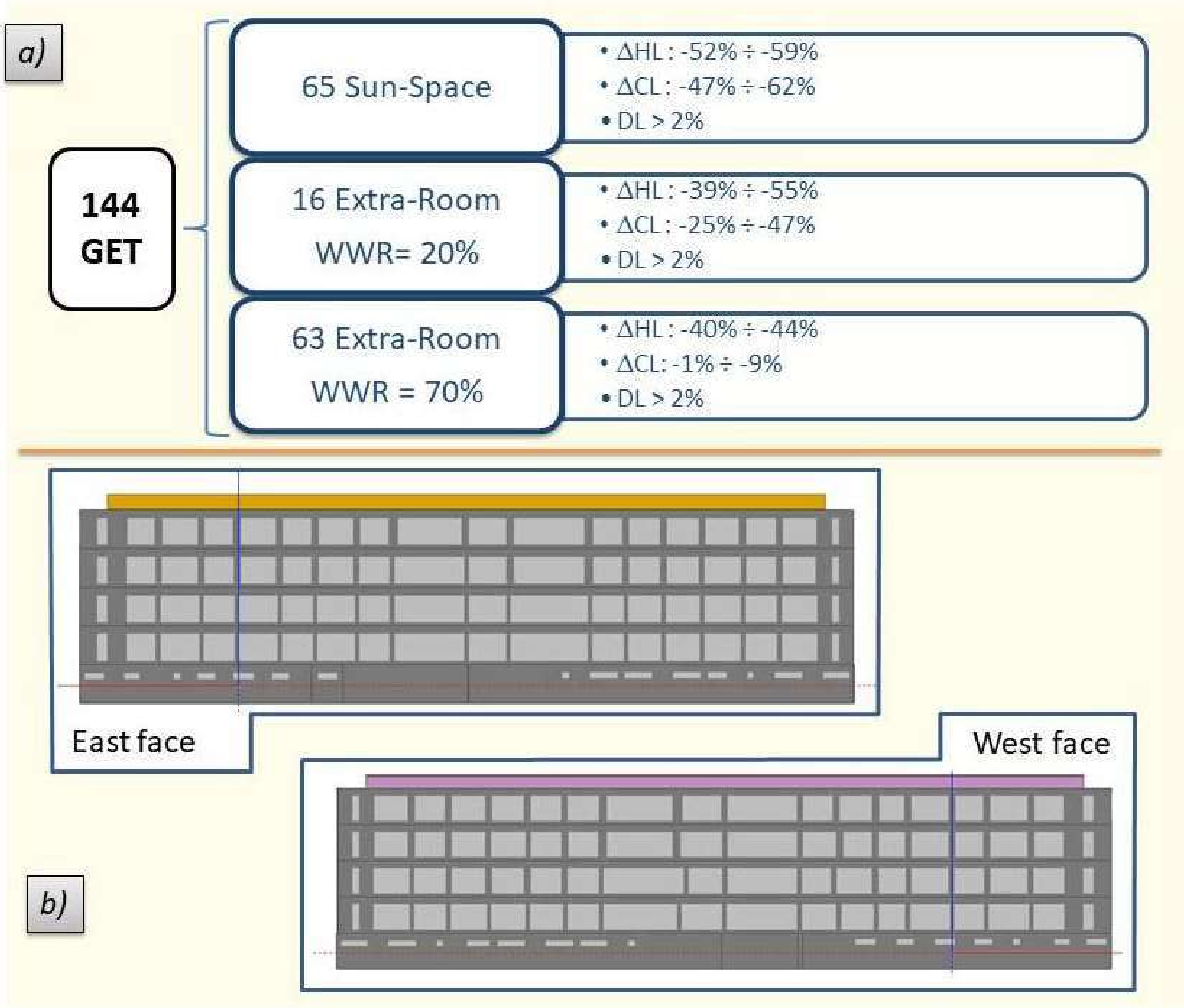

Extra-Room
Sun-Space

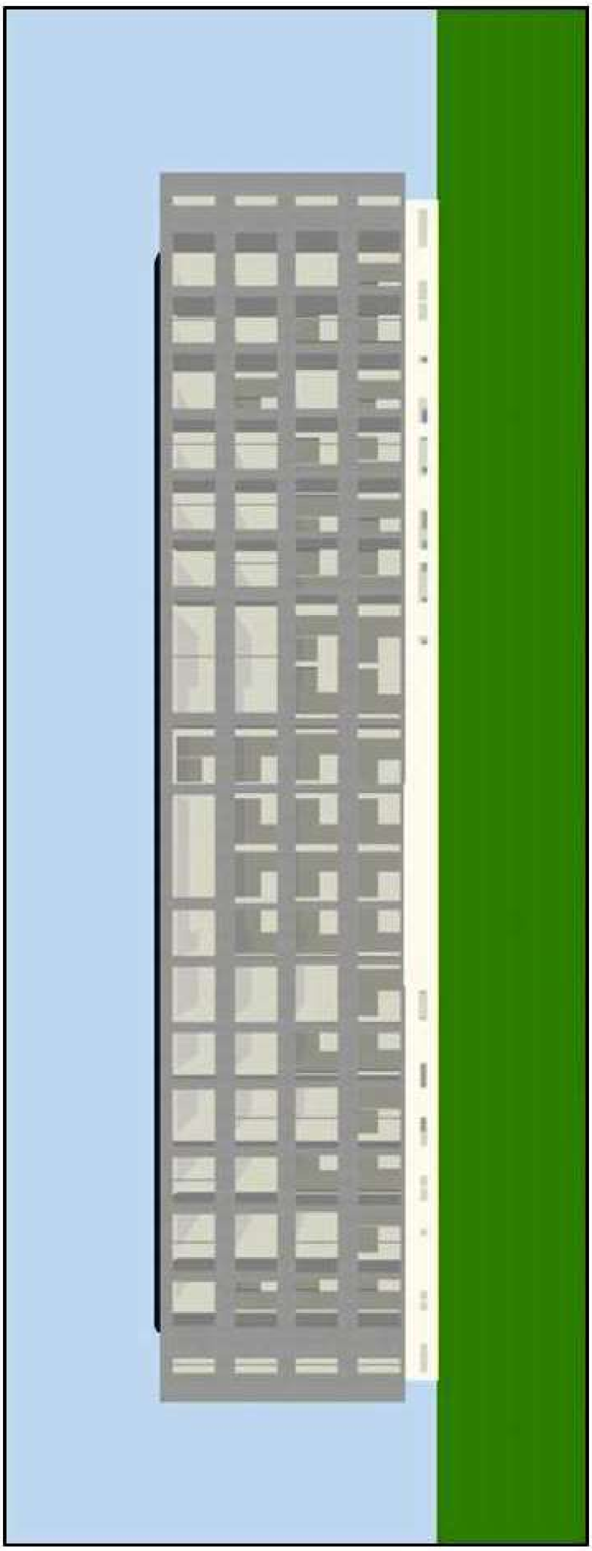
Layout of type floor

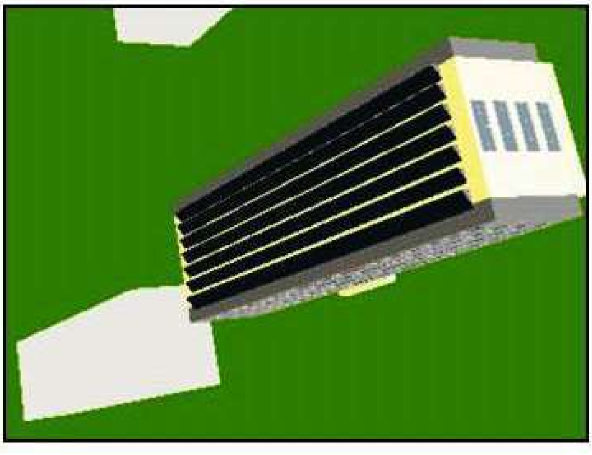


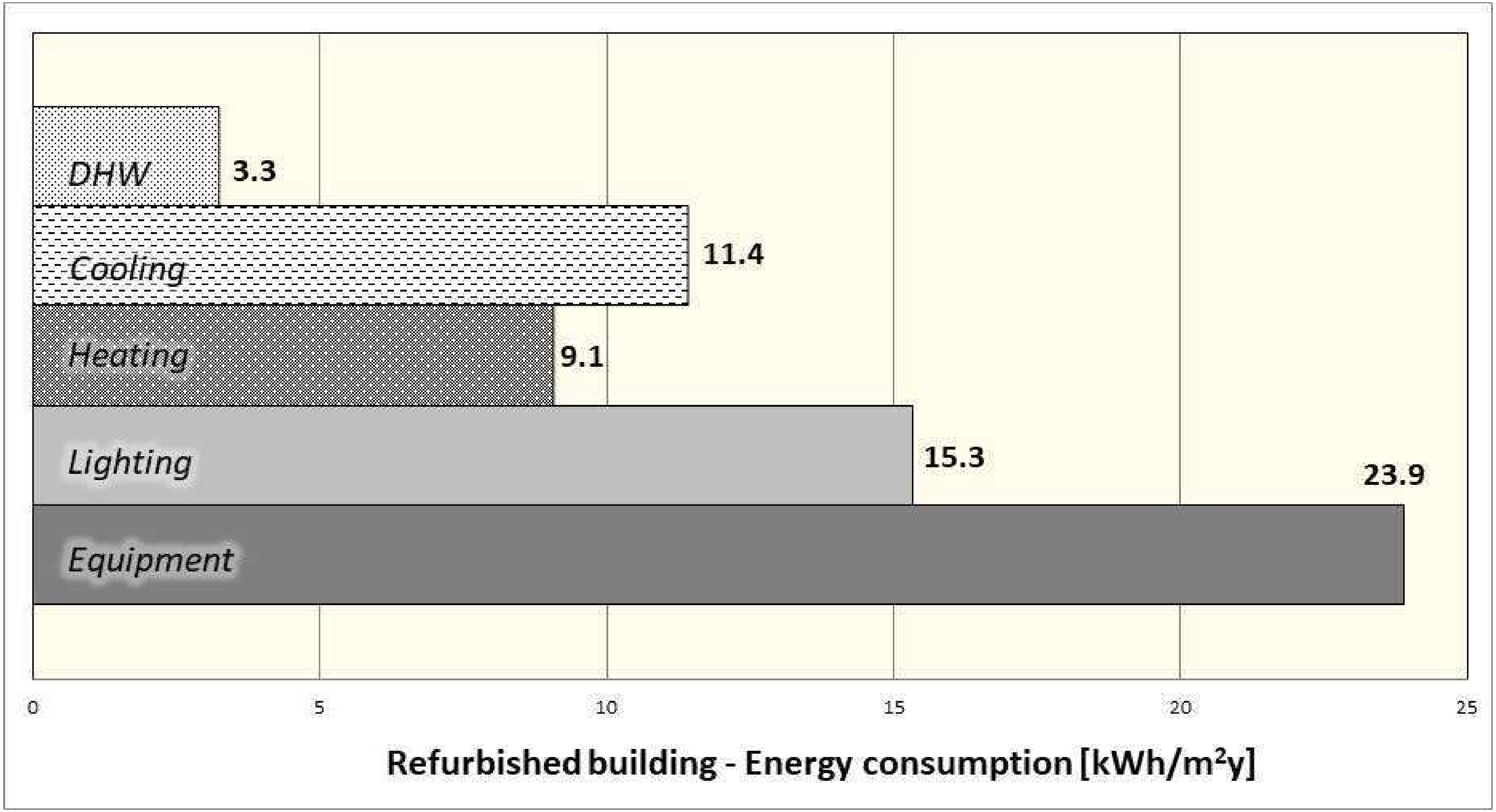
Zone	exp	HL [kW]	ΔHL [%]					CL [kW]	ΔCL [%]					DL [%]					
		BC	SS	ER WWR20%	ER WWR40%	ER WWR70%	ER WWR100 %	BC	SS	ER WWR20%	ER WWR40%	ER WWR70%	ER WWR100%	BC	SS	ER WWR20%	ER WWR40%	ER WWR70%	ER WWR100%
CommonArea8	W	1.68	-60%	-48%	48%	-44%	-43%	2.39	-50%	-44%	-44%	+2.0%	+8.0%	7.43	3.98	1.22	1.19	4.08	4.34
Room10 1	W	0.89	-60%	-49%	-49%	-46%	-46%	1.34	-49%	-46%	-46%	-10%	-6.0%	5.34	2.65	0.74	0.73	2.68	2.76
Room10	W	1.23	-55%	-46%	-46%	-42%	-42%	1.66	-43%	-37%	-37%	-1.0%	+3.0%	3.73	2.47	0.67	0.67	2.39	2.53
Room11	W	0.96	-57%	-49%	-49%	-46%	-46%	1.39	-47%	-45%	-45%	-12%	-9.0%	3.93	2.16	0.55	0.55	2.03	2.13
Room12	W	1.24	-55%	-45%	-45%	-42%	-42%	1.66	-43%	-36%	-36%	+2.0%	+6.0%	3.67	2.56	0.68	0.68	2.41	2.55
Room13	W	1.04	-56%	-48%	-48%	-45%	-44%	1.49	-46%	-43%	-43%	-10%	-7.0%	3.85	2.12	0.55	0.55	2.01	2.11
Room14	W	1.29	-54%	-45%	-45%	-42%	-41%	1.72	-42%	-35%	-35%	+2.0%	+6.0%	3.64	2.43	0.66	0.66	2.35	2.47
Room23	W	1.06	-57%	-47%	-47%	-44%	-44%	1.50	-46%	-42%	-42%	-9.0%	-5.0%	3.90	2.24	0.59	0.59	2.14	2.23
Common Area3	EW	5.29	-58%	-53%	-53%	-51%	-51%	6.07	-46%	-43%	-42%	-27%	-25%	5.51	3.91	2.81	2.81	3.93	4.01
Common Area 8	W	0.86	-60%	-49%	-49%	-45%	-44%	1.24	-52%	-45%	-45%	+1.0%	+5.0%	6.23	3.43	0.96	0.96	3.44	3.63
Common Area5	E	0.91	-63%	-47%	-47%	-43%	-42%	1.28	-62%	-48%	-47%	-2.0%	+2.0%	6.59	3.53	1.05	1.04	3.71	3.94
Common Area6	E	1.61	-59%	-47%	-46%	-42%	-42%	2.29	-53%	-49%	-48%	-5.0%	+1.0%	8.02	4.29	1.30	1.29	4.44	4.75
Room 19	E	0.86	-58%	-48%	-48%	-44%	-44%	1.27	-50%	-46%	-45%	-13%	-9.0%	5.68	3.05	0.86	0.86	3.10	3.26
Room18	E	1.19	-55%	-45%	-45%	-42%	-41%	1.54	-43%	-38%	-36%	-8.0%	-4.0%	3.87	2.63	0.72	0.71	2.57	2.71
Room17	E	1.01	-55%	-47%	-47%	-44%	-44%	1.40	-46%	-43%	-41%	-15%	-11%	4.31	2.50	0.65	0.65	2.36	2.49
Room16	E	1.19	-54%	-44%	-44%	-41%	-40%	1.55	-43%	-37%	-35%	-7.0%	-3.0%	4.12	2.67	0.74	0.74	2.62	2.76
Room26	E	1.01	-55%	-47%	-47%	-44%	-44%	1.40	-46%	-43%	-41%	-15%	-11%	4.18	2.53	0.63	0.64	2.30	2.41
Room24	E	1.20	-54%	-44%	-44%	-41%	-41%	1.56	-44%	-37%	-36%	-7.0%	-3.0%	4.06	2.67	0.72	0.71	2.54	2.70
Room25	E	0.99	-56%	-46%	-46%	-43%	-43%	1.39	-48%	-44%	-43%	-17%	-14%	4.40	2.48	0.65	0.65	2.39	2.49
Common Area	EW	5.14	-59%	-55%	-55%	-54%	-54%	5.31	-42%	-41%	-40%	-26%	-25%	4.95	3.64	2.70	2.69	3.50	3.53
Room9	W	1.19	-58%	-46%	-46%	-43%	-43%	1.62	-53%	-38%	-38%	-3.0%	+1.0%	3.82	2.29	0.63	0.62	2.30	2.39
Room3	W	1.08	-56%	-47%	-47%	-44%	-44%	1.52	-46%	-41%	-41%	-8.0%	-5.0%	4.01	2.37	0.60	0.59	2.21	2.30
Room4	W	1.18	-55%	-46%	-46%	-43%	-42%	1.60	-44%	-38%	-38%	-1.0%	+2.0%	3.76	2.34	0.62	0.62	2.29	2.40
Room5	W	1.13	-56%	-47%	-47%	-43%	-43%	1.56	-45%	-40%	-40%	-4.0%	-1.0%	3.82	2.30	0.62	0.61	2.22	2.33
Room6	W	1.10	-55%	-47%	-47%	-44%	-44%	1.52	-45%	-39%	-39%	-5.0%	-1.0%	3.77	2.29	0.61	0.61	2.19	2.32
Room7	W	1.07	-56%	-48%	-48%	-45%	-44%	1.52	-47%	-42%	-42%	-8.0%	-5.0%	3.93	2.24	0.59	0.59	2.14	2.25
Double room W	W	2.19	-58%	-45%	-45%	-42%	-41%	2.98	-54%	-35%	-35%	+6.0%	+11%	5.03	3.05	0.95	0.94	3.28	3.44
Double room E	E	2.01	-59%	-44%	-44%	-40%	-40%	2.66	-52%	-38%	-36%	-2.0%	+3.0%	5.53	3.32	1.05	1.05	3.62	3.84
Room02	E	1.02	-55%	-44%	-44%	-41%	-40%	1.40	-45%	-39%	-38%	-6.0%	-2.0%	4.28	2.87	0.76	0.77	2.75	2.91
Room2	E	1.12	-56%	-46%	-46%	-43%	-43%	1.50	-46%	-42%	-41%	-14%	-10%	4.42	2.60	0.67	0.67	2.43	2.56
Room19	E	1.07	-54%	-46%	-46%	-42%	-42%	1.45	-45%	-39%	-39%	-10%	-6.0%	4.31	2.72	0.70	0.70	2.54	2.65
Room20	E	1.05	-55%	-46%	-46%	-43%	-42%	1.43	-46%	-41%	-39%	-12%	-8.0%	4.36	2.66	0.71	0.72	2.57	2.73
Room21	E	1.02	-55%	-47%	-46%	-43%	-43%	1.43	-46%	-41%	-41%	-13%	-9.0%	4.42	2.63	0.72	0.72	2.57	2.71
Room22	E	1.68	-56%	-47%	-47%	-44%	-43%	2.39	-48%	-43%	-42%	-15%	-12%	4.57	2.59	0.69	0.69	2.50	2.63

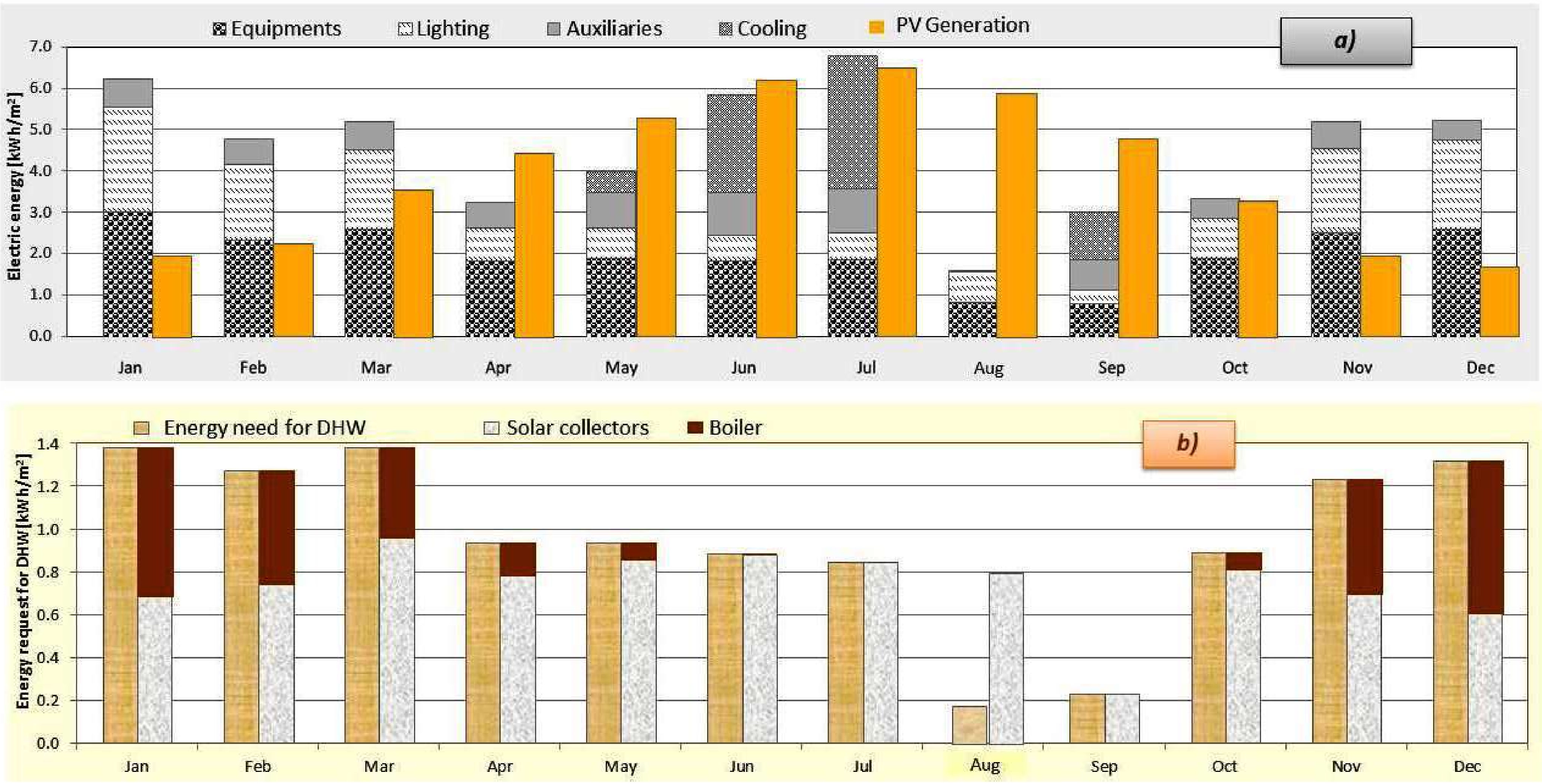

SS; ER|WWR20%; ER|WWR 40%; ER|WWR70%; ER|WWR100%
CONSTRAINT
DL≥2%
False
There are not acceptable solutions
True
ΔHL ≥-45%
ΔCL ≥-45%
False
ΔHL≥-25%
ΔCL ≥-25%
False
GET=ER|WWR70%
True
True
GET=SS
GET=ER|WWR20%

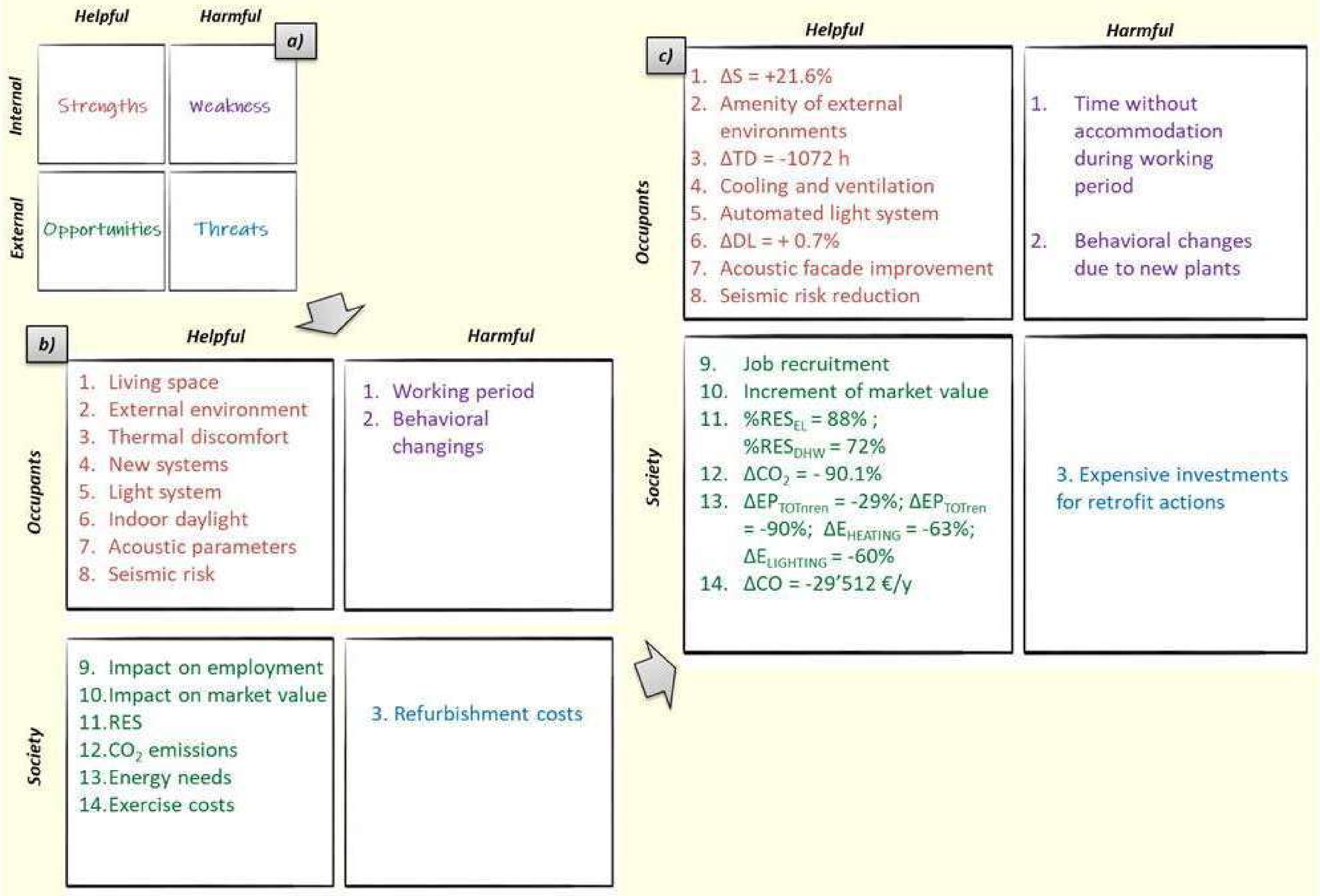

a)
144 GET
65 Sun-Space
• ΔHL : -52% ÷ -59%
• ΔCL : -47% ÷ -62%
• DL > 2%
16 Extra-Room
WWR= 20%
• ΔHL : -39% ÷ -55%
• ΔCL : -25% ÷ -47%
• DL > 2%
63 Extra-Room
WWR = 70%
• ΔHL : -40% ÷ -44%
• ΔCL: -1% ÷ -9%
• DL > 2%
East face
West face
b)






DHW
3.3
Cooling
11.4
Heating
9.1
Lighting
15.3
Equipment
23.9
0
5
10
15
20
25
Refurbished building - Energy consumption [kWh/m²y]


a)
Equipments
Lighting
Auxiliaries
Cooling
PV Generation
Electric energy [kWh/m²]
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
b)
Energy need for DHW
Solar collectors
Boiler
Energy request for DHW [kWh/m²]
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec



a)
Helpful
Harmful
Internal
External
Strengths
Weakness
Opportunities
Threats
b)
Helpful
Harmful
Occupants
Society
1. Living space
2. External environment
3. Thermal discomfort
4. New systems
5. Light system
6. Indoor daylight
7. Acoustic parameters
8. Seismic risk
1. Working period
2. Behavioral changings
9. Impact on employment
10. Impact on market value
11. RES
12. CO_2 emissions
13. Energy needs
14. Exercise costs
3. Refurbishment costs
c)
Helpful
Harmful
Occupants
Society
1. $\Delta S = +21.6\%$
2. Amenity of external environments
3. $\Delta TD = -1072$ h
4. Cooling and ventilation
5. Automated light system
6. $\Delta DL = +0.7\%$
7. Acoustic facade improvement
8. Seismic risk reduction
1. Time without accommodation during working period
2. Behavioral changes due to new plants
9. Job recruitment
10. Increment of market value
11. $\%RES_{EL} = 88\%$; $\%RES_{DHW} = 72\%$
12. $\Delta CO_2 = -90.1\%$
13. $\Delta EP_{TOTnren} = -29\%$; $\Delta EP_{TOTren} = -90\%$; $\Delta E_{HEATING} = -63\%$; $\Delta E_{LIGHTING} = -60\%$
14. $\Delta CO = -29'512$ €/y
3. Expensive investments for retrofit actions

Tables

Table 1: Indexes for the refurbishment design

Symbol	Unit	Parameter	Description	Note	Phase
S	[m^2]	Space	Total occupied building floor area		I
E	[kWh/m^2y]	Energy	Primary global energy normalized on the heated floor area	Dynamic calculation: • *Conduction Transfer Functions* algorithm; • 6 number of time step for an hour; • hourly climate file *(IWEC);* • electric efficiency conversion system values [36]	II
HL	[kW]	Heating Load	Design heating load	Steady-state calculation: • constant winter design external temperature; • constant design values of speed and direction of wind; • heated zones are heated constantly to achieve the heating temperature set point; • heat conduction and convection between zones of different temperatures; • safety factor equal to 1.25.	I
CL	[kW]	Cooling Load	Design cooling load Global design heating load	Steady-state calculation: • periodic steady-state external temperatures by using maximum and minimum design summer weather conditions; • no wind; • solar gains through windows and scheduled natural ventilation; • internal gains from occupants, lighting and other equipment; • heat conduction and convection between zones of different temperatures; • Safety factor equal to 1.15.	I
CO_2	[kg/m^2]	CO_2 emissions	Global CO_2 emissions normalized on the heated floor area	• electricity conversion factor taken from [37]; • natural gas conversion factor equal to 0.205 kg CO_2/ kWh.	II
TD	[h]	Thermal discomfort	Number of Discomfort hours	Dynamic calculation: • the operative temperature is simplified to be the average of the air temperature and the mean radiant temperature; • 0.5 Clo level for summer and 1.0 Clo level for winter; • the value is a floor area-weighted average of all occupied zones.	II
DL	[%]	Daylight	Global mean Daylight Factor	Steady-state calculation: • statistical *Monte Carlo* approach; • sky model is an overcast day with luminance at the Zenith equal to 10000 lux; • evaluation on the working plane (0.7 m above floor level) for each zone; • surface visible reflectance of the material on the innermost layer of constructions; window glazing transmittance; detailed geometry description and site ground reflectance taken from the model; • the value is a floor area-weighted average of all zones.	I

Table 2: Thermo-physical characteristics of the opaque and transparent building envelope.

Opaque envelope	**t** [m]	**λ** [W /(m K)]	**ρ** [kg/ m³]	c_p [J/(kg K)]
External wall				
t_{tot} = 0.25 m U = 1.69 W/(m² K)				
Plaster	0.025	0.35	950	840
Brick	0.200	0.72	1920	840
Plaster	0.025	0.35	950	840
Roof				
t_{tot} = 0.26 m U = 1.05 W/(m² K)				
Asphalt	0.006	0.70	2100	1000
Perlite-bitumen bonded	0.030	0.06	240	840
Concrete	0.200	0.75	2300	657
Plaster	0.025	0.52	1200	840
Ground floor				
t_{tot} = 0.22 m U = 2.07 W/(m² K)				
Marble	0.020	2.90	2750	840
Concrete	0.200	0.75	2300	657
Glazed envelope	**t** [mm]	U_g [W/(m² K)]	**SF** [-]	**LT** [-]
Clear glass	4	5.9	0.85	0.89
Gross dimensions	Type 1: 1.30 m x 1.10 m and Type 2: 1.00 m x 2.30 m in the rooms; Type 3: 5.70 m x 2.30 m balcony door in common used zone; Type 4: 2.16 m x 0.6 m in the basement.			

Table 3: Thermo-physical characteristics of new building envelope

Opaque envelope	t [m]	λ [W /(m K)]	ρ [kg/ m³]	c_p [J/(kg K)]	t_{tot} [m]	U [W/(m² K)]	M_S [kg/m²]	Y_{IE} [W/(m² K)]	χ [kJ/(m²K)]
External wall									
Aluminium coating	0.002	160	2800	880					
Mineral wool insulation	0.035	0.035	50	1030					
Cross laminated panels (XLAM)	0.090	0.120	420	1600	0.177	0.334	47	0.11	13.26
Mineral wool insulation	0.035	0.035	50	1030					
Drywall	0.015	0.200	680	1000					
Roof									
Bituminous membrane	0.008	0.130	2100	800					
Fiber cement board	0.020	0.350	1150	837					
Mineral wool insulation	0.070	0.035	50	1030	0.223	0.305	103	0.12	41.49
Cross laminated panels (XLAM)	0.090	0.120	420	1600					
Wooden listel	0.020	0.150	550	1600					
False ceiling	0.015	0.210	750	1000					
External floor									
Floating floor	0.020	0.200	700	1700					
Air gap	0.050	R=0.16 (m²K)/W							
Cross laminated panels (XLAM)	0.090	0.120	420	1600					
Wooden listel	0.020	0.150	550	1600	0.242	0.398	93	0.13	28.78
Mineral wool insulation	0.040	0.035	50	1030					
Fiber cement board	0.020	0.350	1150	837					
Aluminium coating	0.002	160	2800	880					

Transparent envelope	t [mm]	Gap	Coating	U_g or U_f [W/(m² K)]	SF [-]	LT [-]
Triple clear and selective glass	4-10-4-10-4	90% Argon	Low-E	0.81	0.51	0.60
Aluminium frame with thermal break	60	-	-	1.60	-	-

Table 4: Costs for GET systems

			TOTAL
Extra-Room			
Demolition of the external wall (thickness ≈ 0.30 m)		18.0 €/m^2	
Handling in the construction site area		2.10 €/m^2	
Transport to landfill sites and landfill charges		13.5 €/m^2	
External window (triple glazing)		280 €/m^2	455 €/m^2
Opaque structure	Drywall	13.1 €/m^2	
	Cross laminated panels (XLAM)	103.7 €/m^2	
	Mineral wool insulation	24.5 €/m^2	
Sun-Space			
Mineral wool insulation (0.07 m) and plaster remaking (0.015 m)		50.0 €/m^2	
Replacement of window: triple glazing and replacement cost		305 €/m^2	855 €/m^2
Glass wall		500 €/m^2	

Table 5: Characteristics of HVAC system and RES integration.

	TECHNICAL SPECIFICATIONS	OPERATION
	HEATING: Gas-fired condensing boiler Heating capacity: 240 kW Rated thermal efficiency at nominal power (80-60°C): 98% Rated thermal efficiency at nominal power (50-30°C): 104%	Weather compensation 1st Nov - 31st March (except Christmas holidays) 7:00-11:00 and 18:00 - 22:00 Set point temperature: 20°C Thermal zones: Bedrooms and Common spaces
	COOLING: Air-cooled chiller with screw compressors Cooling capacity: 275 kW EER: 3.5 (evaporator water temperature: 12/7°C, ambient temperature: 35°C)	15th May – 15th September (except August) 6:00 - 8:00 and 18:00 - 23:00 Set point temperature: 26°C
	DHW: Hot water tank connected with condensing boiler Tank volume: 2000 l Maximum tank temperature: 80°C	1st January - 31st December (no August, Christmas holiday) Consumption rate: 1.3 l/m^2 day Set point temperature of DHW tank: 55 °C
VENT	**AHU and recuperative section with fixed-plate-cross-flow heat exchanger** Heat recovery sensible effectiveness: 70% Frost Prevention at 1.7 °C	1st January - 31st December (no August, Christmas holiday) Winter time: 7:00-11:00 and 18:00 - 22:00 Summer time: 6:00 - 8:00 and 18:00 - 23:00 Night free cooling (only for common areas) 15th May – 15th September, 23:00 - 5:00.
RES	**Photovoltaic system** Cell type: crystalline silicon cells Cell efficiency: 20.8% N. modules: 365 Total PV area: 507.44 m^2 Maximum total power: 91.25 kWp DC Inverter efficiency: 98%	Orientation: south-east Tilt angle: 31°
	Solar thermal collector for DHW system Solar collector type: Evacuated tube collector Type Fluid: water and glycol mixture N° solar collector: 32 Total collector area: 101.4 m^2 Annual producible energy: 605.67 kWh/year	Availability all year