CAPABILITIES AND CHALLENGES IN BUILDING RENOVATION: APPLYING THE SUSTAINABILITY PRINCIPLES IN AN OFFICE BUILDING IN THESSALONIKI, GREECE

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ABSTRACT

The renovation of the existing building stock is regarded as key for advancing its energy performance and decarbonization, while driving the clean energy transition. Beyond the objectives of energy, environmental and economic gains that are pursued through the renovation of public and private buildings, the intended plans should address the user needs, health, and well-being. Following this concept, this paper attempts to highlight the process followed for the renovation of an office building in Greece. The objective of the renovation is the improvement of the energy and environmental footprint of the building, using a co-design approach. Within this context, the building users participated in the diagnosis of the problems encountered and proposed measures that would enhance its operation, with a focus on their special demands and desires. The building performance at its current state was extensively studied through the monitoring of the indoor conditions, as well as through the energy audit that was performed over a long period and focused on the actual energy consumed for covering the heating and the cooling needs. By combining the users' expectations, the results of the energy audit and the results of the building energy performance calculations the optimal interventions were identified that would lead to the improvement of the indoor conditions and to the minimization of energy consumption and emissions, not only during the operation phase, but within the building's life span. Although the perspectives from the renovation of the specific building are very promising, the paper would like to highlight the technical, economic, and legislative barriers that were raised during the project's implementation. The ambition of the specific study is to present a renovation process that follows a holistic approach, on the basis of sustainability principles, and at the same time to serve as an example for the renovation schemes of similar buildings. The latter is of particular importance, given that the studied building houses the offices of the Technical Chamber of Greece in Thessaloniki, so it has the potential to act as a paradigm for relevant actions to the technical world.

KEYWORDS _ *building renovation, energy performance, energy audit*

INTRODUCTION

Building sector nowadays is one of the most energy consuming, as in the European Union it is responsible for almost 40% of the total energy consumption and 36% of the total greenhouse gas emissions. This is mainly attributed to the old building stock, since 35% of the existing buildings surpass the age of 50 years, and the energy inefficient buildings are counting for 75% of the present building stock. Considering that 85%-95% of the existing buildings will still operate by 2050, intensive renovation strategies are urgent to achieve the climate neutral economy target set at the same year.

Building renovations in Europe have increased during the last decade, which is primarily associated with the subsidized European Union's programs. However, the vast majority of the occurring renovations can be characterized as "light renovations", with relatively low environmental benefits. An effective renovation strategy though, should not only direct at a slight increase of the examined building's energy performance, achieved by simple and common interventions, like the addition of thermal insulation or the replacement of the old windows with new, energy efficient ones, but should rather form a holistic approach. In fact, this holistic approach is vital considering that an average person spends about 90% of its life in an indoor environment (Klepeis et al., 2001). To this direction, energy audits have become mandatory in many countries. In brief, an energy audit is an inspection process, through which analytical data regarding the building's HVAC systems operation and its full energy consumption profile are collected, aiming at detecting the existing problems, finding optimum solutions and enhancing the building's energy performance.

The conduction of additional surveys is still not very accustomed and is often at the discretion of the engineer. For instance, questionnaires and interviews with the occupants is a common practice in Post Occupancy Evaluation (POE) studies, to evaluate the parameters affecting their comfort (Bavaresco et al, 2020) and identify problems that might not be detected during the energy audit. Key parameter for the selection of the most significant factors to study is the building type (Sanchez Leitner et al., 2020), the aim of the survey conduction (Izadyar et al., 2020), and the special characteristics a building presents, such as its size (Kalantari and Shepley, 2021). Office buildings are the most common building types for POE examination, as it has been proved that the users' performance is directly connected to their satisfaction from the work environment (Haapakangas et al., 2018) and performance. According to Leder et al., who studied the employees' perception of their working environment in open-plan and private offices in Canada and the U.S.A., the most important indicators are the acoustic and optical privacy, the existence of a window in the working space, the indoor air quality and the glare conditions (Leder et al., 2016). According to another study, which evaluated questionnaires' results from 663 office buildings around the world (Kent et al, 2021), privacy issues, the working space adequacy and cleanliness were found to affect the occupants' satisfaction.

In this study, the building of the Technical Chamber of Greece, Section of Central Macedonia, located in Thessaloniki, Greece, was investigated with regard to its present performance. A detailed energy audit was conducted, along with the collection of the occupants' perception of their work environment and an energy performance calculation in compliance with the national legislation, aiming at identifying the optimum renovation strategies to reduce the building's environmental footprint, enhance its energy performance and the users' satisfaction with the indoor environment. The scope of this research is to describe the main problems of a modern office building in the Mediterranean area, along with the difficulties that the engineer teams face due to various legislative and economic barriers.

METHODOLOGY

Building description

The investigated building houses the offices of the Technical Chamber of Greece, Section of Central Macedonia, located in Thessaloniki, northern Greece, and is dated to 2007. It consists of 3 floors above the ground and two basement floors, with two external staircases on the east and west facades. From its north, east, and south side it is surrounded by multi-storey buildings, whilst its west side has an unobstructed view to the seaside. The construction is regarded as composite, comprising of reinforced concrete and steel elements, while the facades encompass reflective double-glazed panels, as shown in Figure 1.

Figure 1: External and internal (1st floor) view of the building under examination.

Spaces of multiple uses are located in the different floors. So, considering the energy audit and the energy performance calculation requirements, the heating spaces were grouped into 8 distinctive thermal zones (auditorium, foyer, café, lecture halls, offices, library, common areas, and corridors. The categorization in thermal zones was based on the attributed use, the HVAC systems existing in each space, the demands for ventilation, the operation frequency of each space, and the occupants' concentration on them, in conjunction with the Hellenic guidelines, which recommend the division of the building into the least possible zones.

Although the building is rather modern, its thermal insulation is rather poor: It was found that the vertical elements were insulated with a 3cm thick extruded polystyrene, leading to U-values equal to 0,78 W/m^{2}K for the reinforced concrete elements and to 0,95 W/m^{2}K for the steel elements. The flat roof of the building is insulated with a 4 cm thick layer of extruded polystyrene and its U-value is equal to 0,67 W/m^{2}K. It is worth noting that these thermal transmittance values are almost double with respect to the ones applied for new buildings.

The glazed panels are formed by aluminium frames (U_f=7,0W/m^{2}K) and double glazing (6-12-6 mm, U_g= 2,8 W/m^{2}K, g-value=0,63, tv=0,58). Based on these values and the geometry of the panels, their U-value is equal to 3,65-3,70 W/m^{2}K and the total g value of the panel is 0,46.

Two gas boilers, 349 KW each, are used for heating the building spaces. Cooling is provided by an air-cooled water cooler. The mechanical ventilation is supported by 7 central air conditioning units (2 of which are all-air and 5 are combined with fan-coils). The preparation of hot water is made only for the café by an electric heater. The internal spaces are lit with fluorescent luminaires (mostly T8 and PL light bulbs).

Indoor environmental conditions evaluation

The assessment of the indoor climatic conditions contributes to the detection of the parameters affecting the users' thermal comfort feeling, along with the study of the building's energy behaviour. To this direction, sensors recording the basic parameters affecting thermal comfort (air temperature and relative humidity) and the Indoor Air Quality (CO2 concentration levels) were installed. The measurements for thermal comfort and air quality took place from 9/9/2021 to 22/12/2021, using autonomous Hobo U12 sensors for the indoor conditions, Hobo U23 for the external conditions, and EXTECH SD800 for the CO2 concentration respectively. Additionally, illumination and noise levels were measured in order to identify the visual and acoustic comfort during the building operation. The measurements were taken simultaneously with the users' interviews.

Occupants' personal opinion recording

The importance of acquiring the occupants' perception of their working environment has been already stated in the Introduction section. So, in this study apart from the findings obtained from the indoor environmental conditions' measurements, the users' opinions were collected in order to assess parameters beyond the thermal comfort perception. In this way, further drawbacks of the building could be detected and resolved.

The process was divided into three phases: the first one included anonymous questionnaires examining the comfort and well-being of the occupants, during the heating and the cooling period. The questionnaire was formed on the basis of recent studies and standards and targeted on the evaluation of parameters affecting thermal, acoustic, visual comfort and indoor air quality. The second phase included personal interviews with the users, who stated their opinion considering the prevailing conditions and their proposals for a possible improvement, in conjunction with some simultaneous measurements of the current environmental indices. Finally, on the third phase, the research findings were presented to the occupants aiming at discussing with them the renovation strategies that should be followed to enhance the building's performance along with their own well-being.

Energy audit & energy performance calculations

The energy audit was based on the national regulatory framework and international standards, such as ASHRAE's Guideline 14. The objectives of the energy audit were to understand how energy is used and where it is wasted, find alternative measures to reduce energy losses and improve the overall performance and perform a cost-benefit analysis for highlighting which energy efficiency measures are best to implement. For this purpose, real energy consumption data were collected for a period of 5 years, and all building components and systems were inspected. An in-depth analysis of energy usage, energy costs and system characteristics, along with the on-site energy demand was followed.

In parallel to the energy audit of the building, calculations for defining the building's energy performance were conducted, using the national software TEE KENAK, which employs the quasi-steady state (monthly) method of ISO 13790 for assessing buildings' energy performance. The modelling of the building's performance enabled the further study of its behaviour on the present state, while it allowed the comparative analysis of the impact that potential renovation measures will have on the building's energy and environmental footprint.

THE ASSESSMENT OF THE BUILDING PERFORMANCE

Indoor environmental conditions: measurements and user's opinions

The recording of the indoor climate conditions was conducted during the transition period from summer to winter and included days with different temperature variations, both warm and cold. The recorded data showed that there are notable differences in the indoor temperature prevailing at the various spaces of the building. This is attributed to their different exposure to the ambient environment, formed by the low thermal insulation levels of the opaque elements and the different shading settings caused by the surrounding buildings, along with the relatively low thermal mass of the building. Additionally, the different space uses and densities and the extensive use of natural ventilation (due to COVID19 habits) contribute to the non-homogeneous distribution of the air temperature. Accordingly, the non-uniform temperature distribution is not only observed among the building spaces, but also during the daily operation of the building: some very high temperatures (above 30°C) were recorded early in the morning, which coincided with the initial operation of the heating system.

These patterns were also detected in the users' evaluation process. More specifically, the questionnaire answers showed that during wintertime the main parameter causing thermal discomfort to the occupants is the heating system. In particular, the inability to regulate independently the temperature, the inadequate thermostat operation, and the misuse of the radiators, result in a too cold or too hot atmosphere and the lack of achieving the desired temperature. Similarly, during the cooling period, the main problems related to the occupants' thermal discomfort are associated with the cooling system. In fact, the users pointed out the lack of individual thermostat control, the inability to control the system's operation and the misuse of the cooling equipment. Apart from these, the lack of shading devices and the big transparent area seem to be additional discomfort sources.

Moreover, most of the occupants stated that they use natural ventilation both during winter and summer period, either during the whole working hours or intermittently. Regarding the building as a whole, the occupants are mostly satisfied; however, on the working space level, the users are pleased with their accessibility and size, while they feel rather discomfort with the view and the privacy.

The second stage of the users' evaluation process concerned the personal interviews, which were conducted on 21/12/2021, under a sunny weather and good environmental conditions. In general, the interviewed users are satisfied from the building's architecture and location, but they stated problems related to the heating system due to air's drought and noise, the artificial lighting which cannot be regulated depending on their needs, the excessively hot atmosphere occasionally occurring at summer, etc.

Daylight levels were considered adequate, although the measured levels at the working level often did not exceed 200 lx. However, the existence of windows on more than one walls contributed to the more uniform daylight distribution, which gave the users the impression that daylighting was sufficient. The acoustic environment was found satisfactory. Only when the external cooling units are operating, the noise levels range in high levels and cause discomfort to the users. A few users claimed that they are irritated by vibrations in the building interior.

The building energy behavior

The energy audit showed that the most significant consumer of electricity is the artificial lighting system, which is responsible for the 37,4% of the annual electricity consumption (61,1 MWh), followed by the cooler (17,7% - 28,9 MWh) and the circulator pumps (13,6% - 17,4 MWh). The analysis of the building energy balance indicated that most energy is used for covering the heating needs (54,7%), the lighting needs of the main spaces (18,4%) and the cooling needs (16,1%). According to TEE KENAK, the building belongs to the energy category D, as it consumes 1,7 times more primary energy than the reference building defined by the national regulation. It is noted that the energy category B+ is defined as the minimum for newly built constructions of the tertiary sector.

The Renovation Strategies

The analysis of the building energy performance indicated that the renovation measures should include the heating, lighting and ventilation installations, supported by the improvement of the building envelope. The national regulatory framework promotes the use of Renewable Energy Sources (RES) for covering a significant portion of energy needs.

The individual renovation measures that were studied included the replacement of the fluorescent luminaires with new LED ones; the replacement of the air conditioning units with ones with heat recovery; the adequate thermal insulation of the opaque building elements and the replacement of the glazing or the glazed panels; the replacement of the gas boiler with a central heat pump; the installation of a Variable Refrigerant Flow (VRF) system for heating and cooling; the installation of a PV system for electricity production, etc.

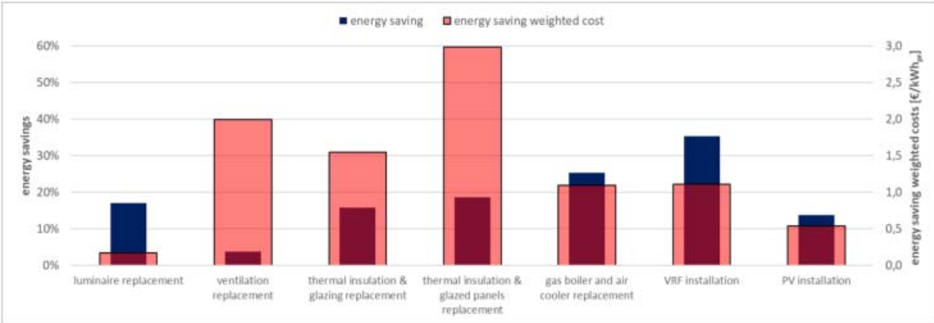

Figure 2: The energy savings and the costs of each measure weighted against the energy savings.

The impact of each individual measure on the building's energy performance is shown in Figure 2. It is obvious that the biggest impact with the minimum cost derives from the intervention on the lighting system. On the contrary, the lower energy impact with a relatively high cost is encountered with the replacement of the ventilation system. High energy savings are expected when the heating and cooling systems are replaced with either heat pumps or VRF.

On the basis of the above, several sets of measures can be discerned: Scenario1: replacement of luminaires, replacement of ventilation system, installation of heat pump, installation of PV; Scenario 2: replacement of luminaires, replacement of ventilation system, installation of VRF, installation of PV; Scenario 3: replacement of luminaires, replacement of ventilation, installation of heat pump; thermal insulation & replacement of glazing, installation of PV; Scenario 4: replacement of luminaires, replacement of ventilation system, installation of VRF; thermal insulation & replacement of glazing, installation of PV; Scenario 5: replacement of luminaires, replacement of ventilation system, installation of heat pump; thermal insulation & replacement of glazed panels, installation of PV; Scenario 6: replacement of luminaires, replacement of ventilation system, installation of VRF; thermal insulation & replacement of glazed panels, installation of PV.

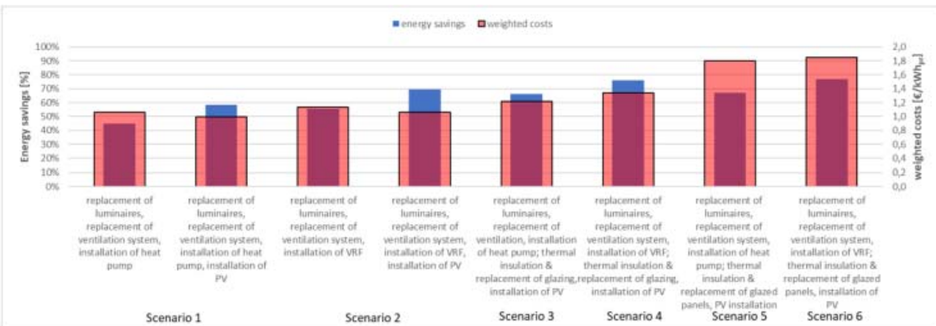

Figure 3: The energy savings and the costs of each examined set of measures, weighted against the energy savings.

For each set of measures, the energy savings and the relevant costs were calculated. Figure 3 presents the energy savings against the existing conditions, and the cost of each set of measures weighted against the energy savings. It is depicted that the higher reduction in primary energy consumption occurs when Scenario 4 or 6 is selected (76% or 77%), followed by Scenario 2 (69%), 5 (67%) and 3 (66%). The lower cost per saved energy unit is derived for Scenario 1, 2 and 3.

DISCUSSION AND CONCLUSION

In the previous section, the energy saving potential was presented for each measure and set of measures. Additionally, the cost of each measure and set of measures was calculated and weighted against the reduction of primary energy consumption, in order to enable a simple cost benefit analysis. The calculation results identified some sets of measures with the highest impact on energy consumption and others with the lowest cost per saved energy. One might say that the building owner should define its own criteria and take the decision on which set of measures to select. However, nowadays the trend is to consider the users' wills and desires, as well as the formation of a healthy and comfortable indoor environment.

That probably means that it would not be proper to replace the glazing (scenario 3), but the whole system of glazed panels, in order to minimize the water vapour concentration on the cold aluminium frame of the existing panels, which might lead to increased humidity and mold creation. Accordingly, the replacement of the whole transparent façade would provide better noise reduction levels and better daylighting, given that it would be appropriate to select glazings with high visible transmittance.

However, beyond the user-centric approach, there are also more factors to be considered when designing a deep renovation project, that constitute potential barriers. Some of them are merely technical: In this specific building, the solution of replacing the glazing units or the glazed panels is not easily supported, since they are not standardized and not available on the market. This leads to the need for further studies and additional costs. The necessity to elaborate specific studies taking into account the safety and seismic risk in order to get permission for the renovation may lead to a long process with the public authorities and discourage the owners. The disruption is another very significant factor and it is associated with the trouble caused to the users and the building operation due to the renovation works. In the specific case study, the time of the renovation is crucial, as the building will not be able to operate during the renovation works.

In order to step up the pace of building renovation in Greece and Europe, it is necessary to intensify the work towards raising the technical, regulatory, financial and social barriers that currently exist and may be responsible for the low rate of building renovation. Nevertheless, the deep renovation of the examined building will certainly raise awareness in the engineering community, as it houses the Technical Chamber of Greece in Thessaloniki.

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