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IEQ and energy improvement of existing buildings by prefabricated facade additions: the case of a student house in Athens

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Abstract. The aim of this paper is to evaluate and illustrate the energy saving potential and Indoor Environmental Quality (IEQ) performances of a façade addition on existing and low energy performing buildings. Different technical solutions are proposed and all IEQ indicators' simulation results are presented for the case of a students' building block of the 80's located in Athens. The building is the demonstrator of the "Pro-GET-onE" Horizon 2020 project, that aims to demonstrate the attractiveness and the energy efficiency of a renovation strategy based on new façade additions combining inteGrated Efficient Technologies (GETs). The research project proposes the highest transformation of the existing building's shell with external added volumes, which generate energy efficient buffer zones and at the same time increase the building's volume (with balconies, sunspaces and extra rooms). This strategy gives also the possibility to increase IEQ performance, in different ways depending on the architectural solutions, the selected materials and the adopted technological solutions. As a general statement, the facade addition solution leads to an increase of the thermo-hygrometric conditions (both for the cold winter season and the summer period), of the facade sound insulation and consequently the acoustic comfort, and of the indoor air quality. The lighting and the visual comfort are a critical point due to the enlargement of the existing surface of the rooms: specific light enhancement techniques have been studied to optimize indoor light, therefore minimizing the drawbacks of façade expansions, and will be suggested for the final design of the case study. The detailed analysis of individual units (additions) led to the formulation of hypotheses for targeted energy retrofitting interventions in different options; with different scenarios of integrated RES technologies, these options have been analysed both separately and in combination, to assess the technical, the energy feasibility and the IEQ performance in each scenario.

1. Introduction

Energy efficiency challenge in buildings in European countries mainly concerns the energy refurbishment and investments in its existing buildings stock [1]. The cost-benefit assessments of retrofit actions in this sector show excessive payback times, creating a strong and generalized lack of confidence by investors and final users. Furthermore, in the Mediterranean and seismic areas of the EU, this gap is even exacerbated by a perceived sense of safeness in most existing buildings [2]. In these areas, recent seismic events have shown how relevant is the issue of seismic vulnerability for existing buildings of reinforced concrete since many of these were designed without any reference to anti-seismic criteria.

Regarding the energy retrofit, several studies have been already carried out to overcome the barriers of high costs and long by technological solutions using prefabricated systems for low energy renovation (TES Facade, More Connect). Most of these solutions are generally founded on the load bearing capacity of the existing buildings, condition that is rarely applicable in the highly seismic areas of the Mediterranean countries. Thus, in many EU regions, it became imperative to couple energy retrofit with



structural safeness improvement, to make visible that higher initial investments of retrofit are more interesting in the long term than lower investments with higher paybacks [3].

Within this context Pro-GET-onE (EU H2020 project) aims to combine in a same holistic and integrated system based on pre-assembled components the highest performances in terms of energy requirements, safety, social sustainability and market attractiveness [4]. This goal is attained through the application of solutions for the building envelopes, as well as through an optimum climatic-structural-functional management, grounding on the substantial increase of the real estate value of the buildings through significant energy and architectural transformation. This incremented value will be the result of the development and application of integrated efficient technologies on existing buildings providing the increase of structural safeness and energy efficiency towards nZEBs standards with the implementation of renewable energy.

As important key factor is the improving IEQ performances according to actual standard. This requires more analysis on the defining technical systems and solutions in order to comply to acoustic, lighting, IAQ requirements and a special care on assembly procedures. In the paper different aspect of IEQ are analysed to a specific case study within the ProGETonE solutions.

2. The case study in Athens

2.1. Climatic data and geometrical characteristics

In the framework of ProGETone H2020 project the assessment of different retrofit scenarios combining deep energy retrofit and volumetric expansion with seismic improvement is being analyzed. This scenario includes the development and implementation of a metallic exoskeleton on the façade of the building, with the creation of the extra space to be used as sunspace. The building that has been selected is a 4 floors linear building hosting 138 single rooms for lower income students of the University of Athens.



Figure 1. Photographs of the Student house of the National and Kapodistrian University of Athens

Athens is characterized by hot and dry summers and mild to cool winters with moderate rainfall. The average annual temperature is 18.1 °C, the hottest month of the year is July with an average temperature of 27.9 °C, while the lowest average temperatures are found during January, which account to 9.5 °C. The amount of precipitation annually is about 397 mm. Input data were inserted in our model, designed by energy simulation software, EnergyPlus v8.4, with the graphical definition of the geometry, dimensions and positions of the thermal envelope assigned by means of the interface of Design Builder v4.6. The model was calibrated using actual data from collected bills from the building under investigation.

2.2. Main interventions: façade addition, envelope deep renovation, HVAC upgrade, RES

The proposed retrofit strategy is based on a new structural frame installed outside the existing building which guarantees both seismic reinforcement of the building and support the new façade addition.

Three main types of volumetric additions can be built (shown in Fig. 2), with different characteristics and functions, each studied to optimize the energy efficiency of the renovated building, and to increase the user's comfort:

- The extra-room addition foresees a volume addition which enlarges the existing rooms whom it is applied. This addition is built with prefab timber frame insulated walls and high-performance windows on the new external wall.
- The balcony addition guarantees the creation of a new livable space outside the rooms. This addition is provided with an integrated shading device, which increase the visual and the thermal comfort, especially during the summer period.
- The sunspace addition is a balcony with a full height window on the external side, which needs to be closed during cold seasons, creating a thermal buffer zone, and opened during warm periods.

This choice is left to the final user, depending on financial resources or just personal needs and tastes. Furthermore, each addition can be installed with different finishing. These possibilities lead ProGETonE strategy to a user-oriented approach, which gives to every building a unique architectural value.

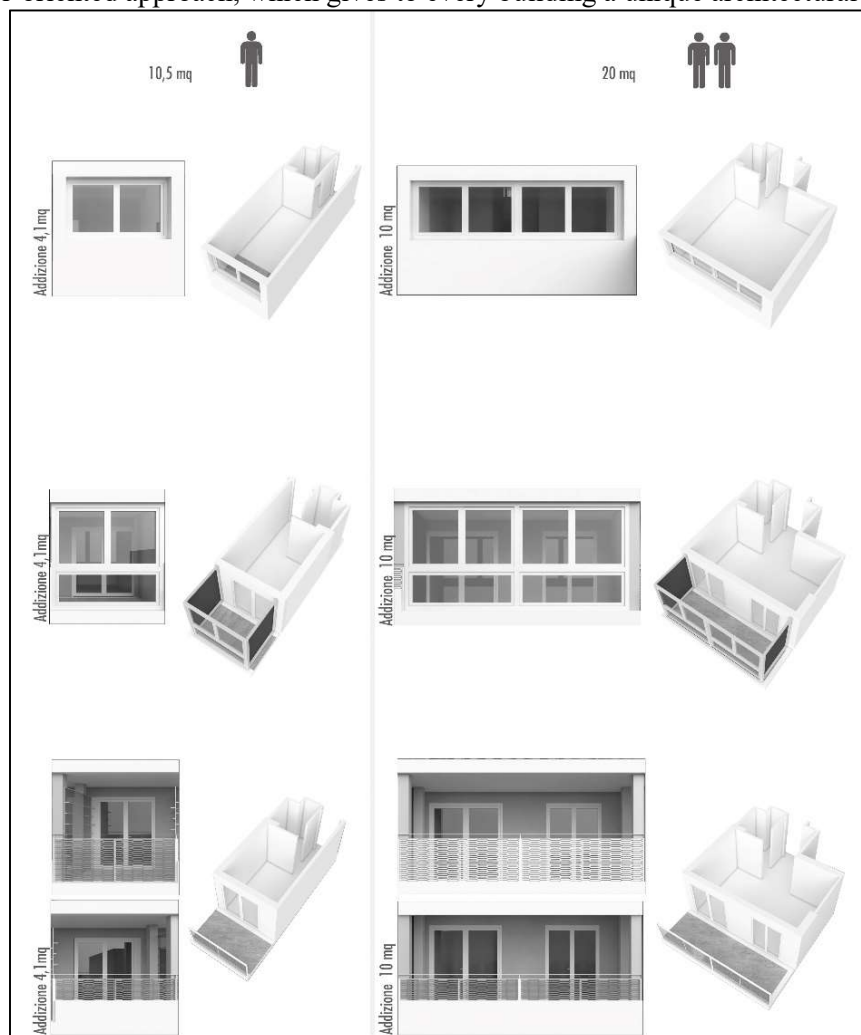


Figure 2. GET system abacus scenarios

2.3. HVAC system and RES

In order to renovate existing heating plants and to satisfy actual energy efficiency requirements, one of the main purposes of the project is to introduce new HVAC systems with a “plug-and-play” connection to internal devices and energy production by renewable sources (photovoltaic). The external allocation

of all main plant system (heat pumps, PV system, hydraulic pipes, electric lines) will allow the simple plant maintenance and/or substitution. The chosen HVAC system is a centralized hydronic system with rooftop inverter heat pumps and internal fan-coils. A mechanical controlled ventilation system with heat recovery is provided in each room for air changes and air quality control. Integrated photovoltaic solutions are installed on top of the building as a renewable energy source system.

Simulations of different scenarios of the additions on the existing building and of different extension of photovoltaic system resulted in corresponding diverse energy performances, from the very low grade of performance of the existing building, up to nearly zero energy demand, for selected technological solutions applied in specific climatic contexts.

3. Energy and Indoor Environmental Quality results

3.1. Energy Improvement

The adopted design solution for this case study plans a retrofitting procedure by external coating with insulation materials, new windows system, and façade addition creating sunspaces and balconies. The mean thermal transmittance of external opaque components is $0.35 \text{ W/m}^2\text{K}$ and that of windows is $1.2 \text{ W/m}^2\text{K}$. Effects of shadings due to balconies and external curtains are important elements for reducing the cooling energy need in summer period.

In Fig. 3 the final energy needs for heating, cooling, auxiliaries, lighting and other electrical equipment are shown before and after retrofit. Besides the high reduction of energy needs for heating (higher than 90%) and lighting (higher than 50%) due to adopted solutions, it is also interesting to point out that, in the after situation, the energy for cooling appears as a new consumption together with an increase on energy consumptions from auxiliary due to a more complex plant system, to a larger period which pumps work and also to introduction of mechanical ventilation. On the other hand, there is a reduction on energy needs for equipment due to end the use of electrical devices for local ventilation and cooling during summer period. In the retrofit case also the value of energy produced by PV system is also shown.

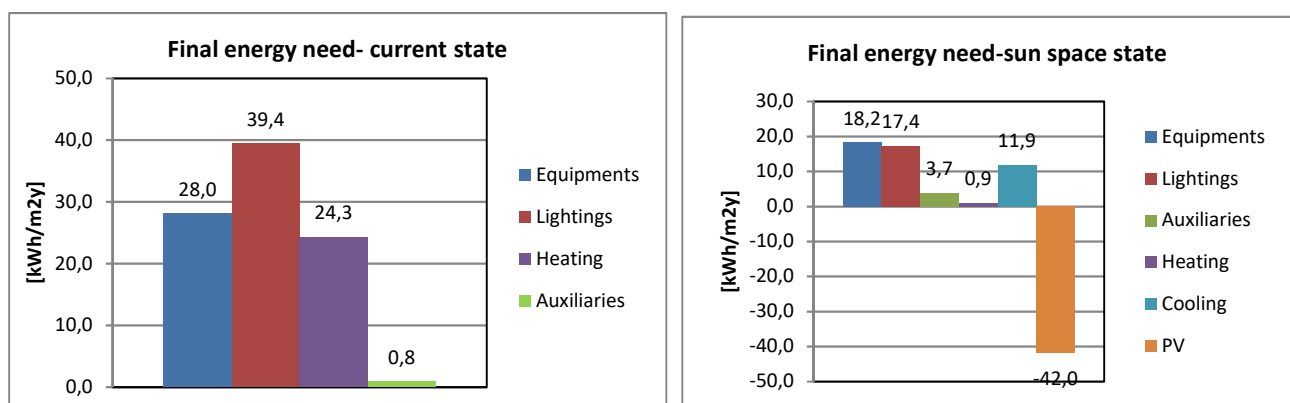


Figure 3. Final energy needs for different uses in the actual case (left) and after renovation with sunspaces (right).

In table 1 global results are reported. The total primary energy decreases from 186 to 25 $\text{kWh/m}^2\text{year}$ (86% of energy saving) because of the use of more efficient equipment and more performing envelope; CO_2 emission index decrease by 86%, accounting to 46.5 $\text{kg/m}^2\text{year}$ of CO_2 .

Table 1. Primary energy needs before and after renovation, energy saving and energy from renewable.

	unit	Before retrofit	After GET solutions
Primary Energy need	($\text{kWh/m}^2 \text{ year}$)	186	25

Renewable production	(kWh/m ² year)	--	42
Energy Savings (after/before)	(%)		86
CO2 emission	(kg/m ² year)	54	7.6

3.2. Thermal and light comfort

According to actual situation, Fig. 4 shows the percentage of reaching the temperature within the range of comfort zone, before the refurbishment, considering the comfort zone temperature 20-23 °C for winter months and 23-26 °C for summer months. It is obvious that the warm months (June- September) the percentage is too small because of the lack of shading systems, as well as the absolute lack of adequate cooling systems.

The increase of envelope performances in terms of thermal insulation and shading device solutions, the use of reversible heat pumps for both heating and cooling and, above all, the introduction of single room control systems, allows to increase considerably the internal operative temperature and thermal comfort during all day and all the year.

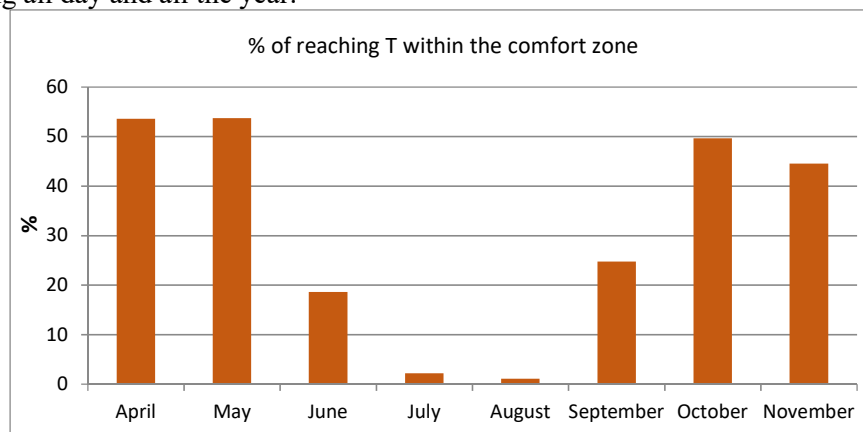


Figure 4. The percentage of temperature within the range of thermal comfort.

On the other hand the increase of the building density from the facade may result to significant difficulty in providing the adequate level of luminance from daylight. Nonetheless, even partial use of daylight can still significantly reduce lighting and cooling loads and improve occupants' preferences, visual relief, and pleasing effects [5]. Therefore, in order to achieve an improvement of indoor natural lightning, the installation of light shelves is proposed. The exploitation of daylight, commonly referred to as 'daylight utilization' or 'daylight harvesting', is recognized as an effective means to reduce the artificial lighting requirements of buildings. A light shelf is a passive architectural device used to reflect natural daylight into a building. They are often designed as part of a broader daylight and shading strategy [6].

3.3. Acoustics

Acoustic comfort inside buildings require technical solutions and special care in construction details in order to reduce the noise from external sources (road infrastructures, commercial activities, etc.) and from neighbours. Building deep renovation generally provide the increase of performances of sound insulations of internal partitions (walls and floors) and façade windows, the latter effecting also the increase of thermal insulation and reduction of air infiltration. Concerning the case study with façade addition, the presence of terraces and balconies cause a further improvement of noise reduction of external noise sources.

In EU countries national standards provide different descriptors, limits and classification schemes [7]. The most used indicator is the Façade Sound Insulation ($D_{2m,nT,W}$), that takes in consideration the acoustic insulations of all components of the façade (external wall, window, any air vent, shade and screen), as well as the geometry of façade, terrace and internal room. The calculated values in the actual

case, considering single glaze windows, is about of 30 dB, while after renovation, considering new standard windows and the effect of the large façade shape, the façade sound insulation rises to 41–42 dB which represents a high-performance value.

Special attention must be paid on the correct choice of HVAC components to avoid annoying noise inside rooms. According to EN15251 standard, the default design value of the sound pressure level is 30 dB(A) (considering our case as hotel room). Fan coils and mechanical ventilation systems are main noise sources inside the rooms and the sound levels vary according to fan rotational speed. The size of those components was carried out in order to minimize noise emission.

3.4. Air quality

The indoor air quality and the humidity level in actual situation is controlled by natural ventilation and it is strongly depended on student behaviour and how many times windows are opened during a day. In many cases, due to low occupation during day, especially in winter period, the air change inside small bedrooms are not frequent, and the air quality is generally poor. For this reason and considering that new high performing windows reduce consistently air infiltrations, a mechanical ventilation system with heat recovery will be used for each room with possibility to set a different air flow rate.

4. Conclusions

Façade addition combined with new technological HVAC systems can contribute highly to the primary energy savings and reduction of CO₂ emission, while ensuring the seismic strengthening of the building through the exoskeleton. However the sustainability of the economic investments of this solution must be analysed considering not only the energy aspects but also the improvement of IEQ along with the increase of space for the users.

The results from the proposed case study highlight that façade additions can be very effective. More particular the expected energy need for equipment will decrease from 28 to 18.2 kWh/ m² year, after retrofit. Moreover the energy need for lightings and heating will decrease from 39.4 and 24.3 kWh/ m² year before retrofit to 17.4 and 0.9 kWh/ m² year after retrofit respectively. Overall the energy savings are calculated to be 86%. Therefore the additional building envelope is a powerful technological solution combining the improved energy performance of the buildings with an increased real estate value and a renewed aesthetic quality.

5. References

- [1] Buildings Performance Institute Europe (BPIE), Belgium. Retrieved from <http://www.bpie.eu>
<http://www.buildingsdata.eu>
- [2] SHARE Project (Seismic Hazard Harmonization in Europe). Retrieved from <http://www.share-eu.org/>
- [3] Ferrante A, Mochi G, Predari G, Badini L, Fotopoulou A, Gulli R and Semprini G. 2018, A European Project for safer and energy efficient buildings: Pro-GET-onE, *Sustainability* **10**(3) 1–26.
- [4] ProGETonE H2020 project -Proactive synergy of inteGrated Efficient Technologies on buildings' Envelopes (grant agreement No 723747). Retrieved from <http://www.progetone.eu/>
- [5] Ghisi E, Tinker JA, An ideal window area concept for energy efficient integration of daylight and artificial light in buildings. *Building and Environment*, 2005, **40**(1) 51–61.
- [6] Kontadakis, A.; Tsangrassoulis, A.; Doulos, L.; Zerefos, S. A Review of Light Shelf Designs for Daylit Environments, 2017, *Sustainability*, **10**, 71.
- [7] Rasmussen B., Machimbarrena M., Existing sound insulation performance requirements and classification schemes for housing across Europe, 2014, *Cost Action TU0901Report*