Energy upgrading of existing collective housing with environmental and economic criteria: financial accessibility gap in cost-optimal energy retrofit of a ten-storey residential building in Athens, Greece.

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Abstract. The collective housing buildings developed during the construction boom of the 1970s and 1980s form the bulk of the contemporary urban fabric of Athens, Greece, the majority of which lack any intrinsic capacity of thermal protection. At the same time, unprecedented economic factors during the last decade depleted the disposable income of large parts of the population and threatened households’ ability to maintain conditions of thermal comfort. This original research focuses on a ten-storey collective housing unit of multiple owners, part of a larger 1972 complex, located in central Peristeri, one of the most densely populated areas at the west of the city-centre of Athens. Cost-optimality methodology was employed to compare the energy assessment of the current condition of the building and 15 energy retrofit scenarios consisting of four fundamental measures and all their possible combinations. This calculated the annual needs in primary energy and the total cost per square meter over a period of 15 years. A users’ questionnaire was employed as an additional methodological tool and a focus group of residents established their willingness to undergo a hypothetical energy retrofit of their residence and the amount of disposable income that each resident would be willing to dedicate to cover its costs. Findings demonstrate that although primary energy consumption could be reduced significantly from the current condition levels, self-funding is not sufficient to cover most of the energy retrofit scenarios’ initial investment costs, including the cost-optimal scenario, even if a common investment amount could be agreed among the multiple residents. This indicates the financial accessibility gap between sustainable retrofit of the existing collective housing stock and current household income.

1. Introduction

The building concerned is a representative example of a large part of the building stock of Greece due to its period of construction, i.e. 1971-1980, when most of the residential buildings in the country were built, as well as due to its typical, for the time, thermally unprotected structure [1]. Moreover, the building being exclusively residential in its use and situated in the centre of a densely-built urban fabric makes it a pertinent case study in reflecting the improvement of living conditions in modern urban centres, which is the broader context of this paper.
The data used, related to the geometry and construction of the building concerned were taken from the building permit as recovered from the archive of the Technical Service of the Ministry of Labour, Social Insurance and Social Solidarity, along with on-site measurements which were held during inspection of the building to document its current condition.

To determine an appropriate set of measures for the energy retrofit of the building concerned, several interviews were held with a focus group of residents who were asked questions so as to establish the degree of their environmental awareness, their energy consumption patterns, any interventions they have made to their apartments, and the cost they intend to bear in an assumed energy retrofit of the building concerned in the foreseeable future.

Four primary sets of energy retrofit measures were then identified:

- Thermal shielding of the building envelope through external thermal insulation
- Replacement of the existing windows with energy efficient ones
- Installation of solar domestic hot water heating systems
- Replacement of the central heating system and the several room cooling systems with an array of air-water heat pump systems for cooling and heating.

The above primary set of measures examined autonomously, along with all their possible combinations, constitute 15 energy retrofit scenarios for further analysis with environmental and economic criteria.

The calculation of the energy performance of the current condition of the building concerned and all retrofit scenarios was carried out through the official Energy Performance Certificate (EPC) software (TEE-KENAK v1.29.1.19) based on monthly quasi-steady state calculation method according to ISO 13790:2008 [2] standards and the relevant Technical Guidelines of the Technical Chamber of Greece (TOTEE 20701-1) [3]. The total cost for a retrofit life-cycle of 15 years was calculated for the current condition and all retrofit scenarios considering initial investment cost and annual cost consisting of energy, operational and maintenance costs while also considering the associated discount rate.

The results of the energy performance and the total cost calculations per retrofit scenario were compared based on the cost-optimal curve methodology [4]. Then, the initial investment cost of each scenario was compared separately with the answers of the residents in terms of their financial capabilities to draw conclusions about the feasibility of applying the interventions under consideration, through self-funding concurrently with further stimuli.

2. Methodology

2.1. Description of the reference building

The ten-storey collective residence building concerned [Figure 1] is located in the Municipality of Peristeri, on 72 Ethnarchou Makariou Street, and is part of a larger complex of tower blocks, constructed in 1972 by the Housing Department of the then Ministry of Public Works. It is an area which features a modern urban center, heavily built-up and with a population density of 13,000 inhabitants / km².

The plan is almost a square measuring 20x20.6 m [Figure 2] and consists of a ground floor with pilotis, of a 2.85 m high typical floor, and of four apartments arranged around a common-use corridor with a central staircase that leads to the roof. The building facades are oriented 40 degrees relative to the North-South axis. The building is shaded only at its southwest facade from a neighboring building of the complex.

Further on the construction of the building, the bearing structure is a reinforced concrete one, and the external masonry is made of double -shell stretch brickwork coated on both sides. The concrete slab of the first floor is in contact with external air as it is the ceiling of the pilotis, while the roof is a conventional flat one. The entire envelope is thermally unprotected without any thermal insulation. The windows and balcony doors are sliding, metal-framed, with single glazing and have external shades.

There is a central heating installation with an oil boiler of 350 kW thermal power and coefficient of 0.80 while the pipelines of the distribution network are not insulated. In most apartments the residents have installed split-system heat pumps (air conditioners) for cooling during the summer months while to produce domestic hot water most of the apartments are equipped with electric water heaters.
Figure 1. The ten-storey residential building.

Figure 2. Plan of the typical floor as retrieved by the building permit folder.

The energy model of the building concerns the ten floors of similar floor plans (typical floor) of four apartments each, with exclusively residential use. The stairwell including its exit at the roof, the ground floor entrance area and the common services area in the basement are unconditioned spaces. The data on the operating conditions affecting the energy efficiency of the building such as the desired indoor thermal comfort conditions (temperature, humidity, ventilation, natural light) the loads created due to the operation of electrical appliances and the presence of the users, are defined in the software calculations as appropriate for the building location and use [Table 1]. In few cases the residents have replaced the originally single-glazed windows with double-glazed ones or the electric domestic hot water heaters with solar ones. There has been no installation of any type of thermal insulation in any apartment. For the calculation phase, all the apartments are considered to share the same characteristics of the majority.

Table 1. Geometric and operational characteristics of the energy model

|                          | Operating hours / days / months | Heating period       | Cooling period       |
|--------------------------|--------------------------------|----------------------|----------------------|
| Number of floors         | 10                             | 18 / 7 / 12          | 15 Oct – 30 Apr      |
| Number of apartments     | 40                             |                      |                      |
| Floor height (m)         | 2.85                           |                      |                      |
| Total area (m²)          | 3,900                          | Avg. internal heating temp. (°C) | 20 |
| Total volume (m³)        | 11,115                         | Avg. internal cooling temp. (°C) | 26 |
| Heated area (m²)         | 2,800                          | Avg. winter internal relative humidity (%) | 40 |
| Heated volume (m³)       | 7,980                          | Avg. summer internal relative humidity (%) | 45 |
| Cooled area (m²)         | 1,400                          | Fresh air requirements (m³/h/m²) | 0.75 |
| Cooled volume (m³)       | 3,990                          | General illuminance (lux) | 200 |
|                          |                                | Annual consumption of DHW (m³/bed) | 27.38 |
|                          |                                | Avg. DHW temp. (°C) | 50 |
|                          |                                | Avg. annual water supply temp. (°C) | 16.4 |
|                          |                                | Heat gains by occupants (W/m²) | 4 |
|                          |                                | Avg. coefficient of occupant presence | 0.75 |
|                          |                                | Heat gains by appliances (W/m²) | 2 |
|                          |                                | Avg. coefficient of appliances operation | 0.75 |
2.2. Definition of energy retrofit scenarios

For the determination of the energy retrofit scenarios [Table 3], widespread technologies were chosen in compliance with the regulated minimum energy performance requirements for new or radically renovated buildings (Umax), while also maintaining a higher level of intensity to meet more ambitious energy targets in the upcoming years [5]. The primary intervention measures [Table 2] included:

- External thermal insulation of the building envelope: application of insulation stone wool panels 80 mm thick of $\lambda = 0.032$ W / mK on the outer masonry and the on the first floor pilotis concrete slab in contact with air, combined with 75 mm thick stone wool insulation panels of $\lambda = 0.038$ W / mK and optimized mechanical properties on the flat roof.
- Replacement of the existing metal-framed single glazing windows with new ones of synthetic frame, argon-filled double glazing with low –e coating.
- Installation of solar domestic hot water (DHW) systems featuring 2 m² solar collectors with selective absorbers per apartment to cover the annual 2,190.4 m³ needs of all 40 households.
- Installation of 2 air-water heat pump systems per floor in array through cooling/ heating controllers, inverter circulator and buffer tanks with COP 4.74 (operating limits from -20 to 43 °C) and EER 3.91 (with a minimum intake temperature of 7 °C) and autonomous fan coil units.

| External Insulation | Current condition | Retrofit values |
|---------------------|-------------------|-----------------|
| External walls      | $U = 2.20$ W/m²K  | $U = 0.35 < U_{\text{max}} = 0.40$ W/m²K |
| Pilotis slab        | $U = 2.75$ W/m²K  | $U = 0.40 < U_{\text{max}} = 0.45$ W/m²K |
| Roof slab           | $U = 3.05$ W/m²K  | $U = 0.40 < U_{\text{max}} = 0.45$ W/m²K |
| Windows             | $U = 5.89$ W/m²K  | $U = 2.10$ W/m²K |
| Domestic Hot Water (DHW) | Electric heaters (4 kw, 80 lt tank) | Solar heaters (2 m² selective absorber per household, 120 lt tank) |
| Heating and cooling systems | Central heating with oil boiler, room cooling with split-system units | Air-water heat pump systems, autonomous fan coil units for heating and cooling COP 4.74 / EER 3.91 |

Table 2. Summary of primary retrofit interventions
The combined application of the primary 4 interventions make up 15 energy efficiency upgrading scenarios with a gradually increasing intensity from the implementation of one measure (SC01 to SC04), to a combination of two measures (SC05 to SC10) and, three measures (SC11 to SC14), as well as the simultaneous implementation of all measures in SC15 which is also the most intensive scenario.

The results of the calculations per intervention scenario are given in comparative graphs with reference to the annual primary energy consumption per use in kWh/m² [Figure 3] and the annual consumption per energy source in kWh/m² [Figure 4]. At first reading, the results show that the increase of the scenarios intensity is proportional to the reduction in energy consumption with the most intensive scenario SC15 delivering the optimal energy behavior.

![Figure 3. Annual use of primary energy consumption per retrofit scenario kWh/m²](image3)

![Figure 4. Source of annual energy consumption per retrofit scenario kWh/m²](image4)
2.3. Total cost calculation of retrofit scenarios

To calculate the total cost of the interventions and make a comparison of their economic performance during a 15-year retrofit life-cycle based on the cost optimal methodology [10], several key assumptions are considered:

- For the calculation of the annual cost per ton of fuel oil a price of €0.1125 /kWh is set, taking into consideration i) the average 5-year retail price of 1.10 /lt after taxes [6], ii) the oil density of 0.83 kg/lt, iii) the oil calorific value of 10,200 kcal /kg or, when referred to kWh (1 kcal = 0.001163 kWh), 11,8626 kWh/kg.
- The cost of electricity for households in Greece which amounts to €0.177 /kWh including all taxes and other applicable charges [7].
- The annual increase in domestic heating oil at 0.55% and in electric energy at 0.5% [8].
- The calculations do not take inflation into account.
- The discount rate is set at 3% for Greece, lower than the 5.7% EU weighted average [9].
- Intervention measures have zero residual value.
- Replacement and disposal costs are not considered.
- Apart from the construction costs, no other costs have been included, for example costs for the temporary relocation of the residents.
- Implementation costs derived through market research without any discount that would be offered in a tendering process.
- The initial cost of the intervention regarding the application of external thermal insulation was determined at €202,730 including supply and transport of materials, placement costs and all related insurance contributions and taxes.
- The initial cost for the replacement of the windows amounts to €238,120 including removal works regarding the existing windows and balcony doors as well as the supply, transport and installation of new ones and all relevant contributions and taxes.
- The domestic hot water solar heating system initial cost per apartment amounts to €1,100 including the cost of supply, transport and installation as well as all related taxes. The annual maintenance cost is €25 per apartment including all relevant taxes.
- The initial cost of installation of the air-water pump system amounts to €238,000, including all costs for the supply, transport and installation of the equipment as well as all related taxes. The annual maintenance cost amounts to €2,500 including the cost of consumables and all corresponding taxes and levies.

The total cost (\(C_g\)) of each retrofit scenario is calculated as follows in Eq. (1)

\[
C_g = C_i + \Sigma [\Sigma (C_a \times R_d) - V_f]
\]

where:

- \(C_i\) is the initial cost of the interventions applicable as per retrofit scenario
- \(C_a\) is the annual running cost, including energy cost, maintenance cost, operation cost and replacement cost (not considered for this life-cycle)
- \(R_d\) is the discount rate per year \(n\) as it derives from the ratio \(1 / (1 + R)^n\) where \(R\) is the discount rate for the 15-year life-cycle excluding inflation
- \(V_f\) is the residual value of the retrofit components, not considered for this life-cycle

The total cost results refer to the 2,800m² of total living area and are expressed in €/m² [Figure 5]. It is made clear that as the intensity of the retrofit interventions increases, the initial investment cost \(C_i\) increases as well, while the total annual cost \(\Sigma C_a\) decreases.
Figure 5. Total cost breakdown per retrofit scenario €/m²

2.4. Boundaries
The assessment of the retrofit scenarios relied on energy simulation software in accordance with international standards regarding climatic data, thermal properties of building materials, and operational scenarios, which utilizes the monthly quasi-steady state calculation method. However, an energy simulation software using dynamic analytical methods of daily or hourly calculation may improve the reliability of the results. Especially for determining the energy behavior of the residents, the application of telemetering systems regarding real-time energy consumption can be used to investigate most effective and site-specific interventions.

The reliability of the total cost calculation results is based both on the quality of market analysis and the models used to predict future energy prices and other costs [11]. A sensitivity analysis can be performed using various discount rates and various forecasts of future energy costs to identify retrofit scenarios which respond better to different economic environments [10].

2.5. Definition of cost-optimal curve
The results from the energy efficiency calculations and the total cost calculations of the retrofit scenarios are shown in graphs with x-x axis in terms of total primary energy consumption per square meter per annum and y-y axis in terms of total cost per square meter [Figure 6].

In the case study the cost optimal scenario, found lower in the y-y axis, corresponds to the retrofit scenario SC10 in which solar domestic hot water heaters and air-water heat pump arrays are installed. The intervention scenarios SC02, SC05, SC09 and SC12 shift higher on the y-y axis as they require higher costs per square meter than the current condition for the time frame of the calculations, although they clearly show improved energy efficiency. Of interest is the correlation between the current condition SC00 and the most intensive retrofit scenario SC15 as although they are at almost similar total cost levels, SC15 requires only about a quarter of the current condition primary energy consumption.
2.6. Residents questionnaire

Representatives of 20 out of 40 households, or 51% of the 39 inhabited apartments (one being vacant), agreeing to take part in the survey were asked about how much they would be willing to spend to upgrade their apartment energy efficiency assuming that, for the foreseeable future, it would be more energy efficient and that heating and electricity costs would be scientifically reduced. Their responses ranged from 0 to €20,000 with €3,000 as the most prevalent price and €5,000 as the median which is considered the maximum limit for any larger amount is not within the financial capacities of the majority of the residents [Figure 7]. These amounts when referred to a total of 40 apartments sum to a potential initial investment capital ranging between €120,000-€200,000. To a question about the stimuli that would incentivize residents to engage in energy retrofit, almost all of them expressed their preference on a government subsidy, the second most popular answer regarded tax benefits, while at the same time, bank loan option was the least popular [Figure 8].
2.7. Feasibility of retrofit scenarios
It is noted that the cost-optimal retrofit scenario SC10 is beyond the financial capacities of the residents as it requires an initial investment capital of €282,000 or €7,050 per apartment [Figure 9]. At the same time, it results in 60% energy savings and a total cost of about 40% lower than the current condition SC00. Correspondingly, the most energy-efficient retrofit scenario SC15 requires €722,850, or €18,071 per apartment and results in 75% reduced energy requirements and 9% cost savings from the current condition SC00 levels, nevertheless without possibility for implementation by own financial means.

3. Conclusions
As initial investment costs rise on the most intensive retrofit scenarios, which lead to more efficient buildings, further research on the gradual implementation of the interventions, that make up the various retrofit scenarios, is proposed as part of a broader strategy within the life-cycle of the building. By focusing on the most beneficial sequence of implementing the individual interventions from the scope of the energy and financial gains, engineers can draw up appropriate strategies so that all the interventions required in the retrofit scenarios can be realized step by step and over time, making initial investment costs more accessible. This long-term approach leaves room for possible adjustments to the retrofit strategy which may arise from new economic, institutional or technological developments. Alternative ways of financing or further incentives should also be sought [12]. The currently unattainable initial costs, the lack of access to financial tools and the reluctance of the residents to take financial risks are the main obstacles to the implementation of energy retrofits.

![Figure 9. Financial accessibility gap per energy retrofit scenario](image)

References
[1] Hellenic Statistical Authority 2014 2011 Population and housing census: Characteristics and amenities of dwellings available on <http://www.statistics.gr/en/2011-census-pop-hous>
[2] ISO 13790:2008 International Organization for Standardization Energy performance of buildings -- Calculation of energy use for space heating and cooling
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