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Addressing the challenges of public housing retrofits

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Abstract

European directives are pushing EU member states to promote energy retrofits of their building stocks. Nevertheless, building renovation stagnates due to many issues, including financial, informational, behavioral, educational and other challenges. All of these increase for the public housing sector, where specific problems such as fuel poverty and social exclusion sum up to common problems such as the tenant-landlord dilemma. On the other hand, public housing represents an important asset for local governments, both in terms of economic and social value. By improving the quality of life and the economic resilience of inhabitant of public housing, local authorities may obtain long-term returns for social inclusion, and citizens' wellbeing. Following this perspective, the municipalities of Milan and Lisbon committed, within the larger framework of the EU funded Sharing Cities project, to promote the renovation of some pilot public housing estates. The design process, the objectives, the expected outcomes and the monitoring and assessment process are described in the paper, trying to highlight the potential benefit for tenants, local governments and, in the long run, for the whole society.

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Keywords: public housing; social housing; deep energy retrofit; energy efficiency; smart city; residential buildings

1. Introduction

The residential sector is one of the largest consumers of energy, accounting for around 25 % of the yearly final energy consumption in the European Union (EU) [1]. To reduce energy consumption in this sector, and the consequent

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environmental impacts that derive from it, the EU has designed and implemented the Energy Efficiency Directive [2] and the Energy Performance of Buildings Directive [3].

Several studies have identified that there is a significant potential to increase the energy efficiency of the residential sector through the investment in more efficient appliances, the retrofitting and construction of high performance buildings' envelopes and technical systems and also through changes in occupants' behavior [4-7]. In the particular case of building retrofits, the potential is justified by the aged building stock of the EU, with two-thirds of the existing buildings having been built before there were any energy performance standards [8,9]. As such, many residential buildings have low efficiencies, resulting in high energy demands to fulfill the occupants' needs, especially those that date between 1945 and 1980. However, despite the identified potential, energy reduction in the residential sector has only been decreasing slightly, with the renovation rate of buildings being only about 1 % per year [10]. To address this issue, the European Commission has identified that its member states need to further promote building retrofits by providing more information to consumers about energy efficiency options and to improve the investment conditions for private consumers. In addition, recognizing that some of its citizens still face fuel poverty and low living standards, the European Commission also urges member states to implement measures such as interest-free loans and to tackle the tenant-landlord dilemma, which are particularly relevant in social and public housing [11].

The aim of this work is to provide a better understanding of the challenges faced by local and national governments to promote building retrofits in public housing estates, by presenting how Milan and Lisbon are addressing the issue within the Sharing Cities project. In the paper we will refer to the distinction provided by the Oxford Dictionaries for public housing, i.e. housing provided for people on low incomes, subsidized by public funds; and for social housing, i.e. housing provided for people on low incomes or with particular needs by government agencies or non-profit organizations.

2. Challenges and barriers of retrofitting

Building renovation faces several barriers that have hindered the investment in energy efficiency improvement. Financial barriers originate from the high upfront costs that are inherent to building retrofits and lead to long payback periods [12]. Information barriers may affect all the stakeholders involved in the value chain of building retrofit, as they may have a lack of information regarding the regulatory framework, the most suitable measures, the available technologies, the installation, operation, and maintenance of efficient equipment and the quantification of future energy savings [13]. Behavioral barriers are also very relevant, as they derive from the willingness of the consumer to invest in energy efficiency improvements. Examples of behavioral barriers are the possible unavailability of individuals to leave their houses or endure the annoyance when works are required, the high discount rates that individuals have when assessing an investment, and the split-incentives issue that arises if the house is rented, with the tenant having immediate benefits and the property owner obtaining benefits in the long-run [14]. The split-incentives problem is very relevant in the EU as around 30 % the population lives in rented houses [15].

Another challenge is the quantification of non-monetary benefits that may be obtained through building retrofit. These include improved indoor air quality (IAQ), better thermal comfort and lower noise levels, i.e. a higher indoor environmental quality (IEQ). The inclusion of these factors in a building retrofit analysis could help convincing household owners to undertake renovations.

Between the behavioral and information barriers and the challenge of non-monetary benefits lays the so-called rebound effect [16], i.e. the reduction in expected energy savings, because of unfavorable occupants' behavior. The rebound effect can be better defined as the increase on energy consumption in services for which improvements in energy efficiency reduce the costs [7]. A typical example is occupants choosing to invest part of the economic operational saving obtained as consequence of the energy efficiency measures, in a not necessary energy service. Literature studies report that, although energy consumption is lower in energy efficient dwellings, their occupants tend to prefer higher indoor temperatures [7]. It is therefore plausible that lower energy costs for heating are offset by a demand for more heating-related benefits [7].

In order to surpass these barriers and increase renovation rates, governments have been pushing for more clear regulation, to drive investment and reduce uncertainty, and establishing energy performance certificates to bring attention to energy efficiency and provide more information concerning the benefits of building retrofits [17].

3. Retrofit of public housing

Public and social housing presents one of the most difficult environment where to promote buildings renovation [18]. First, there is generally a split-incentives issue, as the property owner is generally a local government and the tenants are responsible for paying energy bills [19]. Second, the relationship between the property owner and the tenants may not be proactive, resulting in an added difficulty to perform renovation works when buildings are occupied by tenants. Finally, occupants may be fragile persons or experience substantial economic and/or social problems, which may lead to rent arrears towards the property owner and the energy suppliers.

Nonetheless, building retrofit of public and social housing also presents many advantages for municipalities and residents [20]. From an economic perspective, the renovation of public and social housing results in an increase demand for labor, materials and additional services. From a societal perspective, residents may reduce their energy poverty and social exclusion, since cost-effective energy efficiency improvements increase the available income of a household, reducing their energy costs and increasing the available budget for other goods, services or to recover bills and rent arrears. Finally, the municipality may also obtain environmental benefits by decreasing the emission of local pollutants and CO_2 associated with energy use. For example, the Wales Government through the Arbed programme [21] made a high investment in social housing retrofits, expecting future cost savings in buildings maintenance and access to lower construction material prices, due to economies of scale. In addition, the programme boosted the local economy by taking advantage of local businesses to implement the energy saving measures, providing training and employment to local workers. About 27 000 houses benefited from this programme.

Considering this scenario, the municipalities of Milan and Lisbon agreed to renovate some public housing units, as pilot or case studies, within the context of the Sharing Cities project [22]. The experience gained with this activity may be the basis for future larger actions on the public and social housing stocks of the two cities. The next sections describe the plans from each city for the retrofit works.

3.1. Milan

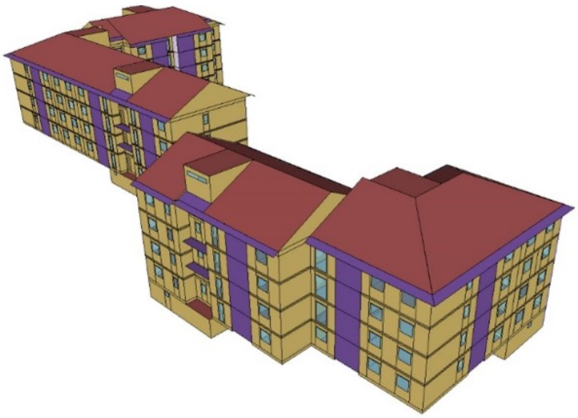
According to official data for the year 2015, 55.2 % of the Italian building stock is made of residential buildings, with 16.2 % of them being public housing [23]. This means that public housing represents about 9 % of the national building stock. Milan is the second largest city in Italy by population, after Rome, accounting for 1 337 155 citizens, of which 135 000 reside in public housing (i.e. 10 % of the city's population). There are 76 817 public residential units in Milan, representing about 13 % of the 606 328 residential units in the city [24]. The requests for public residential units received in Milan in 2014 were about 22 000 [25]. Public housing represents therefore a consistent part of the national and of Milan's building stock, affecting a relevant part of the urban population.

The Municipality of Milan considers a relevant priority the improvement of the energy and comfort conditions of these buildings and the wellbeing of their inhabitants. As part of the Sharing Cities project, it has thus decided to promote the deep energy renovation of a public housing estate built in the 1980's, consisting of two blocks with four stories each. The retrofit is meant to become a reference example to be replicated, improved or modified in future interventions; it will therefore become a source of information for future local policies on energy retrofit. The gross surface area of the buildings is 4 633 m^2, accounting for 66 residential units and an estimated population of 210 persons. The building envelope is made of prefabricated concrete elements, presenting almost no thermal insulation, and of low performance windows with no solar shading. The exiting centralized heating system uses fuel oil as energy carrier, whereas each apartment is equipped with a local boiler for domestic hot water (DHW) generation, using natural gas as energy carrier. Natural gas is used also for cooking, while all the other energy uses rely on electrical energy, supplied by the national grid.

The retrofit strategy focuses on the substantial reduction of the building's energy needs, providing, at the same time, adequate thermal comfort conditions for occupants. The building envelope is therefore the core object of the retrofit. The opaque part of the building façade and the roof will be insulated with 0.25 m of rook wool resulting in a U-value of 0.125 W/(m^2K) and 0.156 W/(m^2K), respectively. The exposed ground floor slab will be insulated with 0.10 m of phenolic resin resulting in a U-value of 0.225 W/(m^2K). The existing windows will be substituted with low-e double glazing windows and frame with thermal break (U_w equal to 1.653 W/(m^2K), g-value of 0.52). An exterior solar shading (louvres manually operated by occupants) will be installed on each window.

In order to control heat loss due to ventilation, allowing at the same time for an adequate level of IAQ, a centralized mechanical ventilation system with heat recovery and by-pass (to allow for free cooling in summer and mid seasons) will be installed, having an average specific fan power of 2.2 kW/(m^3/s). High-performance centralized heating and DHW generation systems based on heat pumps (seasonal coefficient of performance (SCOP) of 2.67) will be installed together with LED lamps for common areas lighting. The remainder final energy use will be partially complemented exploiting renewable energy source, i.e. a photovoltaic (PV) system for the production of electrical energy (127 m^2 producing 19 800 kWh/year) and a solar thermal system integrating the DHW system (20 m^2 producing 9 000 kWh/year). An energy management system, in combination with storage batteries (20 kWh), will contribute to maximize the building self-use of the PV generated energy, to contrast common uses such as elevators and lighting, and possibly also heat pumps and mechanical ventilation.

A model of the building has been prepared (Fig. 1) and dynamic energy simulations have been run in EnergyPlus [26] to optimize the envelope design, both in terms of energy performance and of investment costs.



Reference Building	
Heating Setpoint Temperature [°C]	20
Cooling Setpoint Temperature [°C]	n.a.
Weather file (source)	ITA_Milano-Linate.160800 (IGDG)
Number Thermal Zones	41 (Building 1) + 66 (Building 2)
Gross Floor Surface [m^2]	4633
Gross Volume [m^3]	13823
Window-to-Wall Ratio [%]	14
Surface-to-Volume Ratio	0.55

Fig. 1. Milan model of public housing reference building and boundary conditions

The energy simulations performed for the case study in Milan provided the building's overall energy needs for heating, whereas calculations for DHW, lighting and ventilation have been performed on the basis of standard procedures and values [27-30]. The energy needs for space heating and DHW have been transformed into final energy use by applying an estimated global seasonal energy efficiency for the baseline of 0.7, and a SCOP of 2.67 for the retrofit scenario. The adopted primary energy factor for fuel oil and natural gas is 1, whereas it is 2.42 for electrical energy [31]. An indoor set point temperature of 20 °C was used during the heating season, according to the national regulation [32], which also establishes a set point value for the cooling season of 26 °C. All the values are referred to the current level of design; however, since the detailed design is ongoing, some changes may still be expected.

The energy needs for heating evaluated in this paper refer to a data sets made on weather data from 1951 to 1971 (2661 heating degree days and 52 cooling degree days); however, other data sets have also been considered [33].

3.2. Lisbon

About 17 % of the social housing buildings and 22 % of the public housing dwellings in Portugal are located in the Lisbon municipality, corresponding to 4 463 buildings with an average number of 6 dwellings per building, usually with two or three bedrooms each. Public housing represents about 9.3 % in Lisbon municipal territory [34]. This means that a significant percentage of the residential building stock is presently occupied by a relevant part of population with financial difficulties.

More than half of the public buildings was built between 1946 and 1980, previous to any thermal regulation, having a great potential to improve the thermal conditions through buildings' retrofitting. Still, in 2011, according to national statistics, Lisbon only reported a share of 4.4 % in what concerns the entire buildings' refurbishment and 6.3 % in dwellings refurbishment in public housing.

Within this context, Lisbon municipality through the Sharing Cities project, made the commitment to retrofit two public housing blocks for a total built area of 20 609 m^2, corresponding to 10 buildings, with a total 248 dwellings and an estimated population of 437 persons. The main goal is to improve the thermal comfort and IAQ conditions of the population, through the improvement of the envelope insulation, which will have a positive impact in reducing the occupants' exposure to extreme temperatures and to mold that appears due to condensation on cold walls. According to a report from GEBALIS in 2012 [35], 20.9 % of the resident population in this area was illiterate, 20.1 % did not finished the primary school and only 45.2 % of the active population was employed, suggesting a population with very low levels of income.

In what concerns the building's envelope, the façade is composed of concrete blocks 0.2 m thick and extruded polystyrene for thermal insulation in the interior wall 0.04 m thick. The roof is a concrete slab 0.15 m thick with exterior extruded polystyrene insulation 0.03 m thick and asbestos tiles. The windows are composed by simple pane glazing 0.004 m thick and aluminum frames, with shutters for solar shading. There is no heating or cooling system centrally installed in the houses and DHW is provided through individual non-condensing boilers. Natural gas is the main energy carrier for hot water, and it is also used for cooking, while electricity is used by small portable heaters, lighting and other appliances.

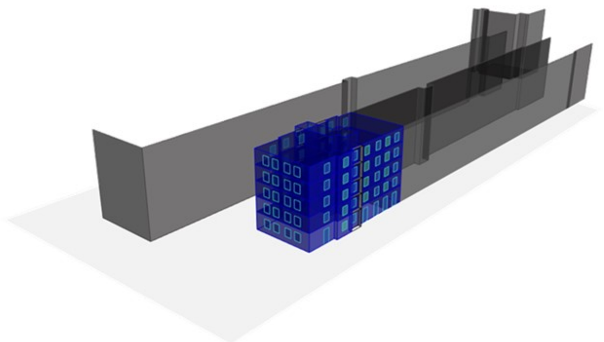
Although the selected buildings have been constructed in 1998, they are already a cause of concern regarding the thermal performance of the envelope as the implemented solutions were not sufficient to promote indoor thermal comfort. In fact, in the Portuguese context, energy consumption for heating and cooling houses is very low, mostly due to energy poverty issues, resulting in a very high thermal discomfort.

The retrofit strategy designed within Sharing Cities focuses on improving the quality of life of the current population. Regarding wall insulation, an external thermal insulation composite system (ETICS) with cork aggregate 0.06 m thick will be installed. It is particularly recommended in retrofit since, besides improving the overall energy performance of the building, it may reduce existent thermal bridges, and in terms of civil works it is not necessary to get inside the apartments. The roof will be renovated by replacing the roof insulation material with a cork aggregate 0.06 m thick and removing the asbestos tiles.

A total of 900 solar PV panels for electricity production are foreseen to be installed, with an expected total electricity production of 339 750 kWh/year. The existing windows, which have a very low thermal performance, will be replaced by double-glazing windows (4+16+4) with PVC framing. Finally, LED lamps will be installed in the common areas of the buildings.

A dynamic simulation of the building has been performed using EnergyPlus to assess the expected improvements due to the implementation of the retrofit measures. The improvements were calculated by comparing with a simulation model of the existing building. Since the case study accounts for 10 buildings that have similar geometry and construction characteristics, a detailed model was created for a representative building (as shown in Fig. 2).

Set point temperatures of 20 ºC as heating and 26 ºC as cooling were defined, which are higher than the reference comfort temperatures from the national standards [36] (18 ºC for heating and 25 ºC for cooling) but are in line with international standards such as ASHRAE [37] and CIBSE [38]. The adopted primary energy factor for electricity was 2.5 and 1 for all other fuels [39]. The weather data set adopted refers to measurements from 1951 to 1980.



Reference Building	
Heating Setpoint Temperature [°C]	20
Cooling Setpoint Temperature [°C]	26
Weather file (source)	EnergyPlus Lisboa 085360 (INETI)
Number Thermal Zones	15
Gross Floor Surface [m^2]	1412
Gross Volume [m^3]	3955
Window-to-Wall Ratio [%]	14
Surface-to-Volume Ratio	0.28

Fig. 2. Lisbon model of public housing representative building and boundary conditions

4. Methodology

Sharing Cities is an EU funded lighthouse Smart City project involving London, Milan and Lisbon as lighthouse cities and Bordeaux, Burgas and Warsaw as follower cities. The broad goal of this ambitious project is to develop smart cities solutions as regards building retrofit, e-mobility, smart lampposts, energy management systems, urban sharing platforms, and citizens' engagement. Within the project, which started in 2016 and is expected to end by 2020, building retrofit actions play a relevant role, since a large amount of cities' energy use and related harmful emissions are dependent on buildings' performance. To assess the impacts of the retrofit activities, a detailed monitoring plan will be deployed, mainly covering energy savings, thermal comfort and IAQ, which will be monitored and evaluated by means of smart meters, sensors and surveys. The pre-retrofit monitoring plan will include: delivered energy for space heating (Milan), delivered energy for electrical household and common uses (Milan and Lisbon), detailed thermal comfort monitoring in reference apartments (Milan) and outdoor weather conditions (Milan and Lisbon). The post-retrofit monitoring plan is meant to monitor: delivered energy for space heating, delivered energy for DHW, delivered energy for electrical household and common uses, delivered energy for centralized mechanical ventilation, electrical energy generated by the PV systems, thermal energy generated by the solar thermal system, detailed thermal comfort monitoring in reference apartments, basic thermal comfort and IAQ monitoring in each apartment, outdoor weather conditions. All of these performance indicators will be compared against the expected benefits evaluated by means of simulations as described in the following sections. Finally, the effect of occupants' behavior on the final performance will be established, to inform citizens and engage them in a better operation of the buildings.

5. Expected benefits and their assessment

Building energy retrofits may have different benefits depending on the actions taken, the time scale considered and the stakeholders involved. In this section, the total expected energy savings are presented and an analysis is performed on the type of benefits that can be obtained by tenants, local government (property owner) and the society.

5.1. Energy savings

Table 1 presents the primary energy demand for heating, cooling, hot water, lighting and ventilation, for the baseline (i.e. the pre-retrofit) and the retrofit scenarios. The heating values represent the demand to maintain thermal comfort conditions in the housing units, i.e. 20 °C, based on simulations and on the reference weather data sets, which may therefore be slightly different from the actual operational consumption of the building. The same consideration is valid for the cooling values, where a constant temperature of 26 °C is assumed as a proxy for comfort condition in the public housing in Lisbon. Since no cooling system is existing in the pre-retrofit and it is not included in the retrofit as well, cooling was not simulated in Milan.

Simulation results show a massive potential for energy saving, both in Lisbon and especially in Milan, where the climate is more challenging during the heating season. It should, nevertheless, be noticed that building performance is substantially influenced by occupants' behavior, which is not under the control of design, particularly in what concerns the energy consumption for heating and cooling due to ventilation and for lighting, which are subject to the occupants' operation of systems and windows. This is the reason why a lot of attention is given, in Sharing Cities, to the actual monitoring of energy and environmental performance, trying to assess the effect of occupants' behavior on the final consumption, eventually supporting inhabitants to improve it.

Table 1. Primary energy for baseline and retrofit scenarios

Primary Energy	Milan - Baseline	Milan - Retrofit	Lisbon - Baseline	Lisbon - Retrofit
Heating (kWh/m^2 yr)	214	17	95	59
Cooling (kWh/m^2 yr)	-	-	4	4
DHW (kWh/m^2 yr)	21	12	37	37
Lighting (kWh/m^2 yr)	15	10	12	10
Ventilation (fans) (kWh/m^2 yr)	-	17	-	-
Total (kWh/m^2 yr)	250	56	148	110

5.2. Benefits for tenants

The main benefit for tenants of public housing is the potential improvement of indoor thermal comfort. Many occupants of public housing experience low levels of thermal comfort due mostly to an inadequate mean radiant temperature, i.e. inadequate temperatures of surrounding walls, and to cold air draughts. By improving the envelope (both opaque and transparent) and by increasing the buildings' airtightness, the major reasons of discomfort complaints should be solved. Mechanical ventilation and education on how to properly operate windows should also guarantee adequate levels of IAQ. Better thermal comfort can improve the quality of life of occupants, physiologically and psychologically, which may reduce, in the long run, health issues related to a poor thermal environment [40]. In Lisbon, the removal of asbestos will also result in an improvement in health for occupants.

In order to assess the potential of comfort improvement achievable with the foreseen retrofit actions, further simulations were run, setting the models in free-floating conditions, i.e. without any active heating or cooling, all year long. A comfort analysis according to the standard EN 15251 and its adaptive model was then applied to the baseline and retrofit scenarios in order to assess if the retrofit scenario was able to rise up the number of hours falling within the comfort bands for category I, II and III respectively (Table 2). When the outdoor mean running temperature was below 10 °C for the upper boundaries and below 15 °C for the lower boundaries of the comfort bands, the limit values adopted for the calculation were maintained constant at the values calculated for 10 °C and 15 °C, respectively.

The output of this analysis shows the effect of the "passive" retrofit actions applied to the envelope, including mechanical ventilation in Milan, in increasing the comfort level in the public buildings. Referring to category II, we can account for a potential increased number of comfort hours of about 17.2 % in Milan and of about 5.9 % in Lisbon. The higher improvement in Milan is due both to a deeper retrofit approach and to a colder climate. Since the climate is much favorable in Lisbon, the baseline scenario shows less challenging conditions. This is furthermore confirmed by the increased number of hours falling in category I, the more restrictive, after the retrofit in Lisbon, which overtakes the improvement reached for category II, up to 7.8 %. It is moreover interesting to notice that, in the retrofit scenario, the percentage of comfort hours in all of the three categories are similar in Milan and in Lisbon.

Table 2. Comfort hours in category I, II, III, according to EN 15251, in the baseline and retrofit scenarios under free-floating

		Baseline		Retrofit		Comfort improvement
		% in	% out	% in	% out	%
Milan	cat I	25.2 %	74.8 %	39.0 %	61.0 %	+ 13.8%
	cat II	32.9 %	67.1 %	50.1 %	49.9 %	+ 17.2%
	cat III	40.7 %	59.3 %	54.5 %	45.5 %	+ 13.8%
Lisbon	cat I	33.3 %	66.7 %	41.0 %	59.0 %	+ 7.8%
	cat II	42.0 %	58.0 %	47.9 %	52.1 %	+ 5.9%
	cat III	48.4 %	51.6 %	52.7 %	47.3 %	+ 4.4%

Nevertheless, Fig. 3 shows that the actions on the building envelope, although effective, may not be sufficient to guarantee comfort conditions for a large part of the cold season. An energy efficient heating system coupled with systems for the production of energy from renewable sources is therefore required in the retrofit plan, especially in Milan. Results reported in Fig. 3 show moreover that during the warm season comfort conditions might be maintained just via passive systems and without recurring to active cooling systems. The continuous warming of local climate could nevertheless challenge this result [33].

A secondary benefit for tenants may result in the form of economic saving. If, after the energy retrofit, the energy delivered to the buildings for space heating and other energy uses decreases, the energy bills should decrease as well. However, due to the social-economic characteristics of the inhabitants, it may occur that some of the economic benefits will not be obtained, as people tend to not heat or cool their homes to the necessary comfort levels, especially in Lisbon. The distribution of savings across the residents is a crucial issue, yet under discussion in Milan, where ground floor apartments could experience a lower reduction of energy use, because the insulation layer applied to the floor slab can have only a limited thickness. The current Italian legislation requires energy metering at the apartment level in any building with a centralized heating system [41], to adequate bills to the real consumptions. However, forms of equalization are necessary to compensate technical limitation of the retrofit intervention.

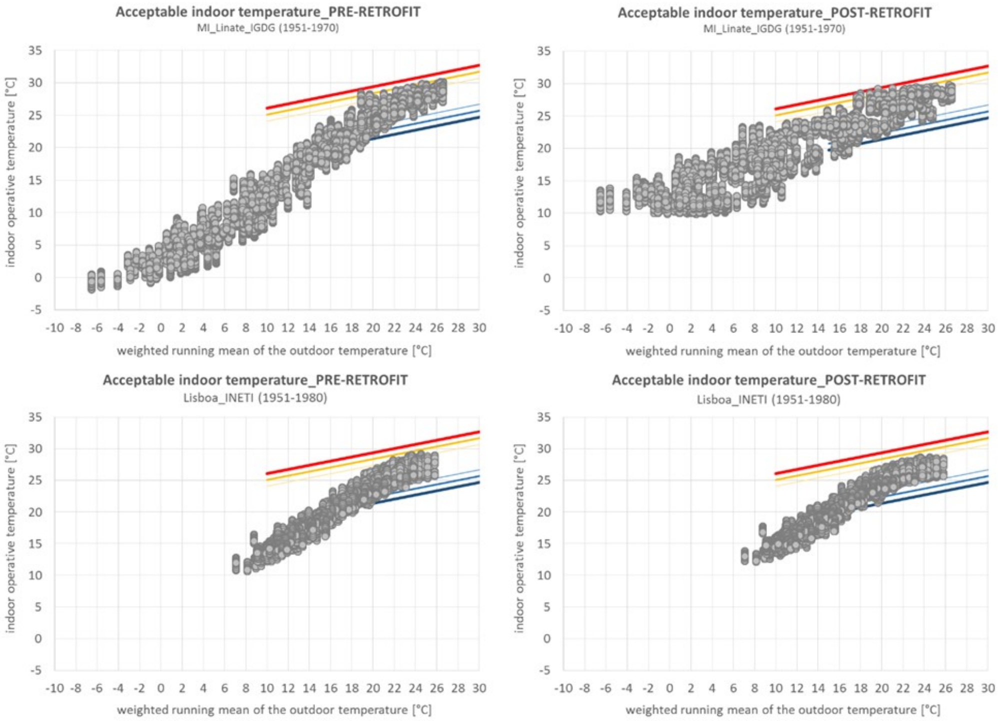


Fig. 3. Comfort analysis under free-floating condition for the baseline and retrofit scenario

5.3. Benefits for the local government

The direct economic benefits for the local governments in Milan and Lisbon are limited to the electric energy generated by the PV system that might be sold to the grid and to the reduced costs for energy uses in common areas. Indirect benefits, such as the improved wellbeing of occupants and an expected reduction of social tensions in the areas object of intervention, may also be obtained. The local governments may also benefit from the reduced rate of rent arrears, that may result in a substantial amount when heating and DHW are produced via a centralized system. Moreover, the maintenance of buildings is a fundamental activity to preserve the value of the public building stock.

5.4. Benefits for the society

If the retrofit approach will prove to be economically feasible and will be scaled up to the whole public housing stock, the social benefits will be scaled up as well. These benefits are both environmental and economic and include reduction of air pollution, carbon savings, waste reduction from avoidance of demolition and construction, new business opportunities, employment creation, increase of GDP, positive impacts in public finance, reduction of energy import dependency, and improved social welfare.

Most of these societal benefits cannot be easily estimated and evaluated, and they are therefore often neglected in technical reports. However, they might represent, in the long run, one of the most important effect of energy retrofits. Yearly carbon dioxide savings, which is one of the major global warming gas, may be nevertheless estimated on the basis of standard emission values, supposing to retrofit the entire public housing stock in Milan and Lisbon. The potential savings are summarized in Table 3. The conversion factors assumed from energy to CO_2 emissions in Lisbon are 0.144 $kgCO_2/kWh$ for electricity and 0.170 $kgCO_2/kWh$ for gas [39], whereas in Milan they are 0.4332 $kgCO_2/kWh$ for electricity, 0.1998 $kgCO_2/kWh$ for natural gas and 0.2642 $kgCO_2/kWh$ for fuel oil [42].

Table 3. Estimated yearly carbon savings in Milan and Lisbon when applying the proposed energy retrofit to the entire public housing stock

	Milan	Lisbon
CO_2 savings (tons)	259 262	17 304

6. Discussion

The results presented in this paper are based on simulations not including the effect of humidity and occupants' behavior on the final performance of the buildings. The literature [43] reports, however, examples where analogous retrofit actions did not work as expected, and the occupants were not taken out of fuel poverty due to both the increase in energy costs and the rebound effect. The detailed and real time monitoring that will be deployed by Sharing Cities, including both energy, thermal comfort and IAQ, is thus deemed to be a crucial element for the early detection of any deviations from expected benefits and to implement quick and effective actions to counterbalance them.

7. Conclusions

Buildings' energy retrofits, although promoted by European directives, did not yet become a common practice in the EU. Many practical and social challenges, including financial and educational aspects, hinder the process. To overcome these challenges is not easy, and it may be extremely difficult for the public housing sector, where specific problems such as fuel poverty and social exclusion sum up to common problems such as the tenant-landlord dilemma. The local governments of Milan and Lisbon decided to challenge the issue by promoting the deep energy retrofit of a few pilot public housing blocks. The main objective of the interventions is to improve occupant's thermal comfort and wellbeing, reducing at the same time the emission of local pollutants and CO_2 associated with energy use.

The energy performance of the buildings before and after the retrofit have been evaluated via a dynamic energy simulation software, allowing to estimate the potential energy savings under standard weather conditions and occupants' behavior, and the comfort effects of retrofit actions affecting the building envelope. If scaled up to the whole cities' public housing stock, the energy and comfort benefits could be significant, as well as the potential reduction of pollutants and CO_2 emissions. A detailed plan for monitoring and assessment of buildings' performance has been established and will be shortly deployed to assess the effectiveness of the energy retrofit and to inform and educate occupants about the effect of their behavior on the final energy performance of their dwellings.

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