Unveiling the social costs of fuel poverty in Lisbon public housing

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Abstract

Social costs derived by fuel poverty is too often neglected when determining the economic feasibility of building retrofits, which may lead to the exclusion of vulnerable groups from subsidy schemes and further degradation of the typically aged and inefficient public housing stock. Indeed, the renovation of low-income housing may result unprofitable under conventional methods due to multiple factors, such as the low price of energy caused by subsidised utility tariffs, the below-average energy consumption of residents and their inability to take charge of the investment. This paper assesses the viability of public housing retrofitting taking into account the social costs derived by fuel poverty, a situation of vulnerability driven by a combination of low income and poor living conditions regarding energy consumption and thermal comfort. Enhanced comfort conditions have positive effects on individuals' health and social life, which translates into economic relief for the National Healthcare Service (NHS). By monetising the hidden benefits of housing retrofitting, particularly on health, this paper introduces a paradigm shift when it comes to invest in the renovation of public housing. The results of this paper offer local authorities further clarity when it comes to understand the impact of building retrofit on fuel poverty, prioritise the renovations of the public housing stock and adequately allocate public funding.

Keywords: Thermal comfort; Fuel poverty; UBEM; Building retrofit; QALY; HRQLC; Public housing

1. Introduction

Energy-inefficient buildings are one of the main drivers of fuel poverty, a condition affecting between 50 to 125 millions Europeans (Atanasiu et al., 2014). In Southern Europe, mild winters typical of Mediterranean climate lead to a relevant share of households not using any heating (35% of Portuguese poorest income quintile) (INE, 2019). In conclusion, living in conditions of fuel poverty implies suffering thermal discomfort and poor levels of Indoor Air Quality (IAQ). The vulnerable population is more prone to suffer health conditions, physical (cardiovascular and respiratory) and mental (depression and stress) (Santamouris et al., 2014), as well as social exclusion, poor diets and development, educational and psychological problems in children (Barnett et al., 2005). These issues lead to societal problems like the poverty risk, the expenses for the National Health Service (NHS) and the dissolution of social fabric.

The last assessment of the Energy Efficiency Directive (EED) shows EU countries are moving slightly above the 2020 target (European Commission, 2019), calling for step up efforts on building retrofitting for the subsequent decade. Energy renovations would be very beneficial in Southern Europe, where around 65-75% of the housing stock ages back before the first regulations on energy performance on buildings (Escandón et al., 2017). The buildings erected before do not incorporate any specific measures for thermal insulation in their envelopes and are obsolete from an energetic point of view. Complementary benefits would be lower energy bills, better health and higher comfort (European Commission, 2019).

Passive architectural interventions improve the thermal properties of the envelope, decreasing the winter thermal load required to keep a comfortable temperature and eliminate the moisture. Retrofit actions increase thermal comfort (Curado and de Freitas, 2019; Monteiro et al., 2017) and reduce cold-related morbidity and mortality (Camprubí et al., 2016; Peralta et al., 2017). Various studies focusing on social housing in the Mediterranean climate have verified that passive measures can reduce the thermal load between 45% to 80% in winter and 30% to 48% in summer, with a reduction in the annual energy demand of 36-63% (Serrano-Lanzarote et al., 2017; Suárez and Fernández-Agüera, 2011) and a payback time using energy bill savings of around 11 and 25 years (Mancini et al., 2016; Semprini et al., 2017).

Investments in public building retrofits still encounter barriers, such as the inability for low-income households to participate in the investment. Public health and fuel poverty are not always the primary concern of energy efficiency policies, since the corresponding benefits are often neglected due to their non-monetary nature (Monteiro et al., 2017). This may result in the exclusion of vulnerable groups from subsidy schemes (Camprubí et al., 2016) and further degradation of the public housing stock. With their Index of Vulnerable Homes, Castaño-Rosa et al. (2020a) evaluate the money saved by the NHS after the retrofit of a social housing block in Southern Spain, concluding that those savings could pay for the investment in around three years (Castaño-Rosa et al., 2020b). This paper aims to extend Castaño-Rosa et al. (2020a) method to a larger sample, represented by seven social neighbourhoods in Lisbon in order to provide local authorities with a scalable and quick procedure. The originality of this work consists in the application of Urban Building Energy Modelling (UBEM) using reference buildings (or archetypes) to assess the energy performance of large samples of buildings in a fast way (Reinhart and Davila, 2016) and to identify energy policy implications on the allocation of funds.

2. Methods

2.1 Lisbon case study selection

Table 1 provides an overview of the chosen areas of analysis regarding the demographics and economic situation of the residents, aggregated at the neighbourhood level. The case study area hosts around 22,000 people living in 1,700 buildings. The simulation was run on a representative sample of 340 buildings, which host almost 15,000 residents in around 5,000 households.

2.2 District energy performance simulation

This project uses five archetypes, developed within the SusCity project, to represent the public housing stock of Lisbon. City Energy Analyst (CEA) was the software used to simulate the energy demand and thermal comfort of the case study, composed of seven social neighbourhoods.

Reference occupancy and use profiles for heating, appliances and lighting were defined separately for each neighbourhood by crossing data from Gebalis, a shapefile containing the basic geometry of all the buildings in Lisbon municipality (Fumega et al., 2014) and statistics on the ownership rate of heating and domestic appliances (INE, 2017).

The case study population was considered comparable to the first income quintile in Lisbon, a third of which do not own any sort of heating system (INE, 2017). This assumption was incorporated in the simulation by considering that a third of the buildings in each neighbourhood lacked a heating system.

Consequently, the individual energy consumption of each building was either over or underestimated. However, in the authors' opinion, the aggregation and analysis of the results at the neighbourhood scale compensate for this discrepancy and reflect the average ownership of the heating system.

The simulation provided for each building: a breakdown of energy and power loads by final use and by the source of supply; internal loads, indoor and outdoor temperatures for every hour of the year.

Three passive retrofit scenarios were proposed for all buildings: the substitution of existing windows (WINDOW); the insulation of external walls (WALL); the substitution of the external envelope as a whole (EPBD). The simulations were thus repeated after incorporating the three scenarios considered.

2.3 Index of Vulnerable Homes

Castaño-Rosa et al. (2020a) developed a novel index of vulnerable homes in terms of fuel poverty obtained by a combination of different existing fuel poverty indicators together with the energy efficiency of buildings. Three dimensions are included in the IVH: monetary poverty, energy and thermal comfort. 13 levels of vulnerability are thus defined and linked to the health-related quality of life of the households. The IVH was originally developed for Spain; this study thus adjusts the index to the Portuguese context. Finally, the dimension indicators proposed by Castaño-Rosa et al. (2020a) were adapted to the data available to this study; this simplification may have sacrificed rigour in favor of attainability.

2.3.1 Energy Indicator (EI)

The overall grid electricity consumption (*EC*), which includes lighting, appliances and heating, was the feature used to assess buildings' energy performance as compared to each other and to statistical data. The Energy Indicator (*EnI*) is calculated using equation 2:

$$EnI = \frac{EC}{AEC} \tag{2}$$

where EC is the simulated electricity consumption required, while AEC is the average per capita domestic electricity consumption of a Portuguese citizen, which was 1,220 $\frac{kWh}{p \cdot y}$ in 2017 (PortData, 2020)

2.3.2 Thermal Comfort Indicator (CI)

The evaluation of thermal comfort derives from the application of an adaptive model (ASHRAE, 2010) for which "admissible" conditions are reached if the average daily temperature falls in the comfort range for more than 80% of the time.

2.3.3 Monetary Poverty Indicator

Two poverty lines were proposed by Castaño-Rosa et al. (2020a): a monetary poverty threshold (MPT) and a severe monetary poverty threshold (SMPT). The MPT represents living with a low income, which is 60% of the median equivalised disposable income, equal to 5,607€ per person per year in Portugal (INE, 2019). The SMPT represents a more precarious level of poverty, which is set by the social benefit granted by the government to families in social exclusion, which in Portugal cannot earn more than 189.66€ per person per month ("Rendimento social de inserção," 2019). Both indicators are calculated dividing the household's net income (*NI*) by the respective poverty threshold (*T*), as shown in equation 3.

$$MPI = \frac{NI}{T} = \frac{I - (HE + EE)}{T} \tag{3}$$

where I is the household income, *HE* is the housing expenditure (monthly rent) and *EE* is the energy expenditure which derives from the simulation. A household is said to be in a situation of monetary poverty or severe monetary poverty if its net incomes fall below the respective threshold ($MPI < 1$).

2.3.4 Quality-Adjusted Life-Years and Health-related Quality-life Cost

Each of the 13 levels of vulnerability was given a specific score on a five-level European Quality of Life 5 Dimensions' questionnaire (*EQ-5D-5L*), a standard measure developed by the EuroQol Group to provide a generic measure of health status (EuroQol Group, 1990). A value of quality-adjusted life-years (*QALYs*) could be bound to the *EQ-5D-5L* scores, using specific coefficients for Portugal (Ferreira et al., 2019).

A *QALY* equal to 1 represents the best possible life condition, while values below 0 represent that the demeaning living conditions might cause the death of a household member. Finally, a monetary value portraying the NHS expenses related to the different *QALYs* was determined using the Health-related Quality-life Cost (*HRQLC*) (Threlfall, 2011). The *HRQLC* is a measure of the cost-effectiveness value of a human life, which represents what amount of money the NHS would have to pay to keep a person alive in perfect health for one year. The reference measure of this parameter for Portugal ($HRQLC_{ref,\,PT}$) is set by the NHS to 20,000€. The *HRQLC* of each IVH level was thus calculated using equation 4.

$$HRQLC = (1 - QALY) \cdot HRQLC_{ref,\,PT} \tag{4}$$

Diverging from Castaño-Rosa et al. (2020a), this paper proposes an alternative methodology to estimate pragmatic NHS savings by defining an average QALY for Portugal ($QALY_{avg,\,PT} = 0.524$), which is calculated as the average of the QALYs conferred to each IVH level. Hence, the average QALY is linked to the current expenditure on healthcare per capita ($NHS\_cost_{avg,\,PT}$), which in Portugal are equal to 1,784.8€ per year. A new reference value for NHS cost ($NHS\_cost_{ref,\,PT}$), associated with a null QALY, is then defined using equation 5.

$$NHS\_cost_{ref,\,PT} = \frac{NHS\_cosst_{avg,\,PT}}{(1-QALY_{avg,\,PT})} = 3,748\frac{€}{y} \tag{5}$$

Finally, the *NHS_cost* related to each IVH level is calculated using equation 5 after replacing $HRQLC_{ref,\,PT}$ with the $NHS\_cost_{ref,\,PT}$ just calculated. Table 2 presents the 13 IVH levels defined by Castaño-Rosa (2020a) and the respective values introduced in this chapter.

Table 2: Definition of the 13 IVH levels and the corresponding EQ-5D-5L questionnaire answers, through the combination of three indicators (Monetary poverty, Energy and Comfort), with the calculated QALY, HRQLC and NHS_cost for Portugal

IVH	Monetary poverty	Energy	Comfort	EQ-5D-5L	QALY	HRQLC	NHS_cost
1	No Monetary Poverty	Admissible	Inadmissible	11121	0.959	820€	154€
2	No Monetary Poverty	Inadmissible	Admissible	11122	0.899	2,020€	379€
3	No Monetary Poverty	Inadmissible	Inadmissible	11133	0.814	3,720€	697€
4	Monetary Poverty	Admissible	Admissible	11223	0.830	3,400€	637€
5	Monetary Poverty	Admissible	Inadmissible	11333	0.751	4,980€	933€
6	Severe Monetary Poverty	Admissible	Admissible	12333	0.703	5,940€	1,113€
7	Monetary Poverty	Inadmissible	Admissible	13333	0.681	6,380€	1,196€
8	Monetary Poverty	Inadmissible	Inadmissible	13433	0.609	7,820€	1,466€
9	Severe Monetary Poverty	Admissible	Inadmissible	14334	0.468	10,640€	1,994€
10	Severe Monetary Poverty	Inadmissible	Admissible	13344	0.401	11,980€	2,245€
11	Severe Monetary Poverty	Inadmissible	Inadmissible	14455	0.019	19,620€	3,677€
12	Monetary Poverty	Inadmissible*	Inadmissible	24455	-0.029	20,580€	3,857€
13	Severe Monetary Poverty	Inadmissible*	Inadmissible	25555	-0.295	25,900€	4,854€

*Represented by households who cannot afford minimum energy consumption due to a lack of monetary resources.

2.4 Economic analysis and energy policy implications

The benefits of the retrofit's scenarios were evaluated in economic terms, including the health gains embodied in the *HRQLC* index. The costs of retrofit (C_R) were calculated with standard maximum unit costs for the retrofit options and reference useful life years (Y) suggested by POSEUR (POSEUR, 2016). The Net Present Value (*NPV*) and the Return on Investment (*ROI*) were calculated, with a discount rate (*DR*) equal to 3% (Steinbach and Staniaszek, 2015), for each retrofit scenario under four conditions.

Public housing residents in Portugal pay a reduced social tariff for electricity, which in turn shrinks the margin of monetary savings in the electricity bill. The first condition examines if the modest savings obtained with the social tariff ($S_{el.,\,social}$) would be enough to appropriately cover the cost of retrofit.

Rather, the second condition wonders what the outcome would be, if, instead of being publicly owned, the same building was part of the housing market and its residents had to pay regular electricity tariffs.

Under the third condition, the cost of retrofit would be repaid by the savings obtained with the social tariff plus the annual NHS savings, calculated multiplying the *HRQLC* variation after the retrofits by the number of households in the respective buildings (N_{hh}), as proposed by Castaño-Rosa et al. (2020a). Lastly, the fourth condition is similar to the third, but it uses the pragmatic methodology proposed previously, replacing *HRQLC* with *NHS_cost*. The *NPV* and the *ROI* of each retrofit activity *i* were calculated by using equation 6 and Equation 7.

$$NPV_i = \left(\sum_{t=1}^{Y} \frac{1}{(1+DR)^t}\right) \cdot [S_{el., social} + (\Delta(NHS\_cost) \cdot N_{hh})] - C_{R,i} \tag{6}$$

$$ROI_i = \frac{C_{R,i}}{S_{el., social} + (\Delta(NHS\_cost) \cdot N_{hh})} \tag{7}$$

where: Y is useful life years (25 for Windows and EPBD; 35 for Wall); DR is the discount rate, equal to 3%; $S_{el., social}$ is the savings obtained in the subsidised energy bills; NHS_cost is the public healthcare expenses per household; N_{hh} is the number of households and $C_{R,i}$ is the cost of retrofit i per building.

3. Results and discussion

3.1 Energy performance

The annual end-use energy demand (ED), grid electricity (EL) and natural gas (NG) consumption of 340 buildings were simulated. Passive retrofit measures did not affect the NG demand, which covers domestic hot water production, the trend of this term will therefore be neglected further on. The analysis of the results compares the implementation of individual retrofit measures (windows replacement (WINDOWS) and thermal insulation on exterior walls (WALLS)) to the renovation of the entire building envelope (EPBD) for the different neighbourhoods. The baseline ED is equal to 75.4 $\frac{kWh}{y \cdot m^2}$, while the EL to 42.3 $\frac{kWh}{y \cdot m^2}$. As shown in figure 1, Alfredo Bensaúde shows lowest demand, with an average $ED = 57.3\frac{kWh}{y \cdot m^2}$ $(EL = 33.3\frac{kWh}{y \cdot m^2})$, while Casalinho da Ajuda shows the highest, with an $ED = 101.0\frac{kWh}{y \cdot m^2}$ $(EL = 56.9\frac{kWh}{y \cdot m^2})$. The end-use energy demand of the oldest buildings (Standard 2) is on average 93.4 $\frac{kWh}{y \cdot m^2}$ (EL = 54.5 $\frac{kWh}{y \cdot m^2}$), while that of the most modern ones (Standard 5) is 71.0 $\frac{kWh}{y \cdot m^2}$ (EL = 36.7 $\frac{kWh}{y \cdot m^2}$).

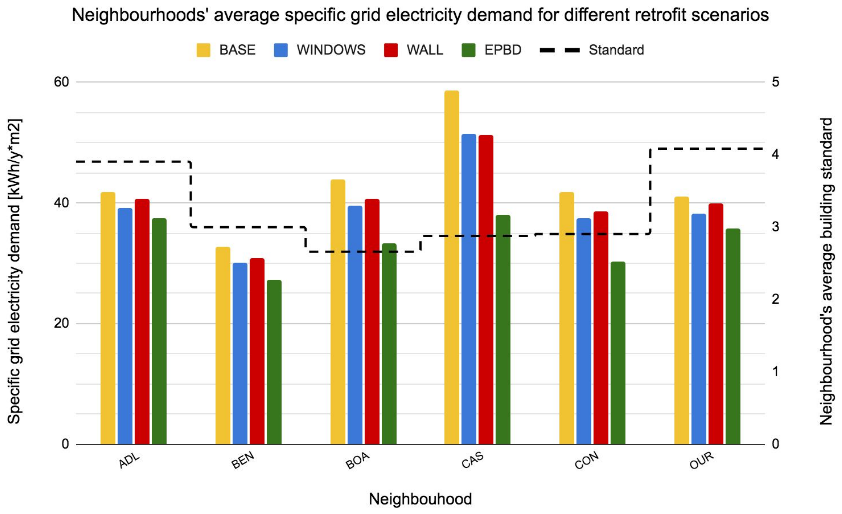

Figure 1: Average specific electricity demand (EL) and average construction standard (black line) at the current situation (yellow) and after the implementation of the retrofit measures WINDOWS (blue), WALL (red) and EPBD (green)

Figure 3 shows the electricity consumption pattern for the baseline (yellow) and the three retrofit scenarios (blue, red and green), while specifying to which standard (grey) those EL values refer. The EPBD retrofit would reduce the current inequality of energy performance within the different neighbourhoods. The average ED savings are 4.4% for Windows retrofit, 3.0% for Wall and 10.0% for EPBD; while the EL savings increase to 7.1%, 4.8% and 16.2% respectively. The highest savings are reached by 55 buildings (16%) of standard 2 and 3 in three neighbourhoods (Boavista, Condado and Casalinho da Ajuda), which show EL savings of more than 40% for EPBD (ED savings >20%) and than 10% for Windows and Wall.

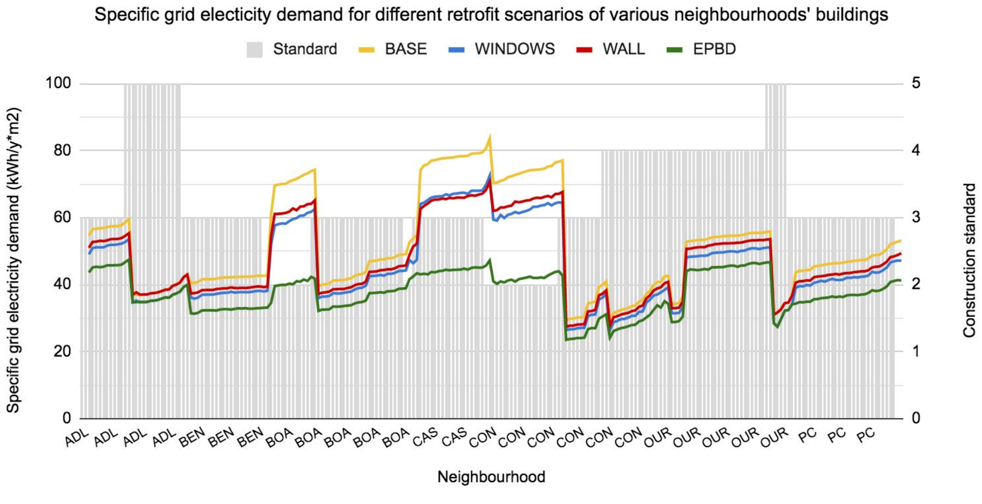

Figure 3: Distribution of the specific grid electricity demand (EL) at the current situation (yellow) and after the the retrofit activities WINDOWS (blue), WALL (red) and EPBD (green); the buildings are organised in ascending order of standard (grey)

3.2 Thermal comfort

All retrofit scenarios reduce the hours of thermal discomfort related to cold occurrences for each neighbourhood. The EPBD retrofit is the one contributing the most to improve comfort conditions, often leading above the threshold of 80% of hours in comfort. The only neighbourhood damaged by the intervention is Alta de Lisboa, due to the overheating effect caused by the additional insulation.

3.3 Economic analysis

3.3.1 Social tariffs vs regular tariffs

On average, the annual monetary savings obtained with social tariffs range between 20€ to 30€ per household, which is not enough to cover for the retrofit cost of around 2,000€ to 5,000€ per household. When using regular tariffs, the average savings slightly increase to 30-60€ per household, still not enough to cover for most renovations. These results confirm how classic economics might be ineffectual when dealing with the renovation of public housing, due to low energy consumption of low-income households.

3.3.2 NHS savings accounting

This chapter outlines the different results obtained applying to the economic analysis the two methodologies used to account for NHS savings (cost-effective vs. pragmatic). Table 3 compares the average renovation cost with the respective NHS savings derived by each retrofit scenario, calculated using both the cost-effective and the pragmatic methodology.

Table 3: Comparison of the average retrofit cost and annual NHS savings per household, calculated using the cost-effective and the pragmatic methods, with the share of buildings proving a feasible retrofit (NPV>0) with a discount rate equal to 3%

Retrofit scenario	**Average retrofit cost**	**Cost-effective NHS savings**	**Pragmatic NHS savings**	**Buildings with NPV > 0€**
WINDOWS	2,440€	156€/y	29€/y	16%
WALL	2,260€	135€/y	25€/y	8%
EPBD	5,430€	661€/y	124€/y	43%

With the first method, the NHS savings are from 4 to 10 times higher than the bill savings obtained with regular tariffs. With the pragmatic method, the NHS savings would exceed the bill savings only in the EPBD scenario. This makes the EPBD retrofit the most reasonable, with 43% of the buildings proving a viable renovation. Figure 5 and figure 6 show that the average building health expenses (yellow) increase with the age of the building. Using the cost-effective method, the yearly NHS expenses generally exceed the renovation costs of Wall (red) and Windows (blue) retrofits. For older buildings, the yearly NHS expenses almost double the EPBD retrofit costs (106,000€/y vs. 62,000€) and the NHS savings for the EPBD retrofit (32,000€/y) even surpass Windows and Wall retrofit costs (27,000€). Four out of ten buildings present a ROI of less than 35 years for the EPBD scenario, more than half of less than 3 years. For the Windows and Wall scenarios, most of the feasible interventions present ROIs lower than 2 years.

Those households in the best (*HRQLC*=0€) and worst conditions (*HRQLC*=19,620€) can never cover the investment with NHS savings. This "all-or-nothing" condition is caused by the disproportionate magnitude of *HRQLC* as compared with the retrofit costs (Figure 5) and by the binary nature *CI* and *EnI*. If a retrofit surpasses one of the thresholds (CI>80% or EnI<1), the households living in that building are attributed much lower NHS expenses, but if no threshold is reached the households would pay the same.

Using the cost-effective method, the hypothetical renovation of all buildings in a neighbourhood show very favourable ROIs of less than 10 years for at least one of the scenarios, u. The EPBD renovation of the entire Alfredo Bensaúde could even be repaid in 1.8 years. Using the pragmatic method, just four EPBD renovations would be feasible. Three neighbourhoods (Casalinho da Ajuda, Condado & Padre Cruz) show ROIs between 22 and 25 years, while the renovation of Alfredo Bensaúde could be repaid in 9 years. Retrofitting some buildings in the other neighbourhoods would still be feasible, indeed 22% of buildings in Boavista would present positive NPVs as compared to 25% for the cost-effective method.

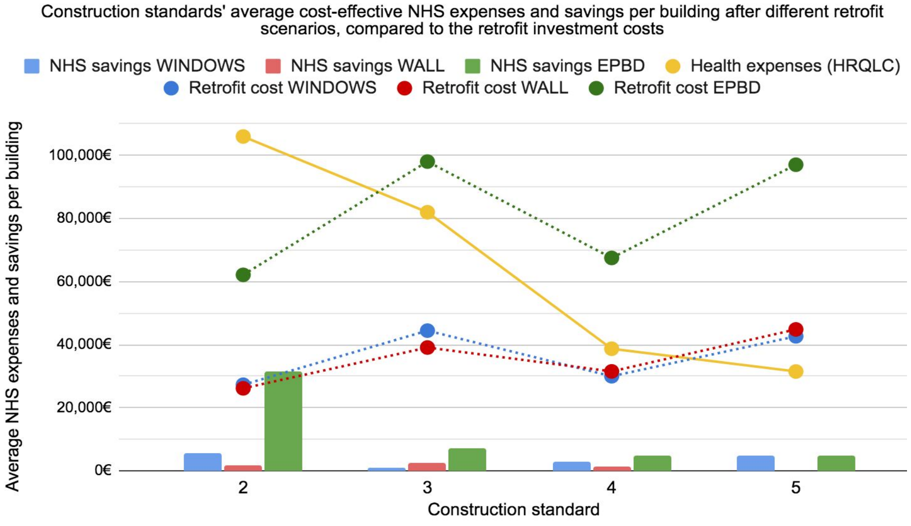

Figure 5: Construction standards' average building cost-effective NHS expenses (*HRQLC* - yellow line) and savings (columns) compared to the average renovation costs (dotted lines) derived from the Wall (red), Windows (blue) and EPBD (green) retrofits

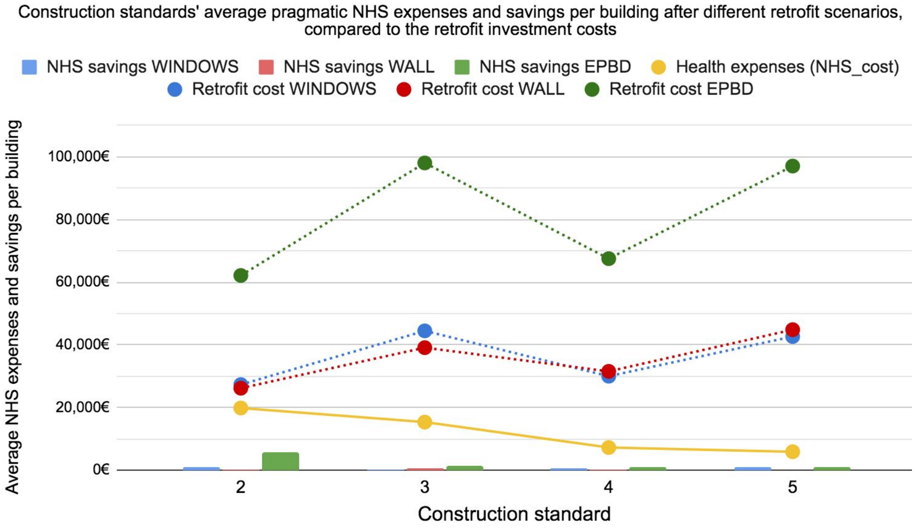

Figure 6: Construction standards' average building pragmatic NHS expenses (yellow line) and savings (columns) compared to the average renovation costs (dotted lines) derived from the Wall (red), Windows (blue) and EPBD (green) retrofits

4. Conclusions

Public health or fuel poverty are not always the primary concerns of energy efficiency retrofitting policies. This dimension is often neglected when determining the economic feasibility of building retrofits, which may result in exclusion of vulnerable groups (less affluent and fuel poors) from subsidy schemes and degradation of the already inefficient public housing stock. By enhancing comfort conditions, passive retrofits have the potential to tackle fuel poverty with positive effects on individuals' health and social life, while contributing to the reduction of energy consumption and CO_2 emissions.

This paper develops a similar approach to *ELPRE* adjusted to the urban scale, using 5 archetypes to identify the energy performance of Lisbon public housing stock. Focusing on a vulnerable fraction of the population, the economic implications of domestic thermal discomfort on public healthcare were examined in detail. The NHS savings related to public housing retrofit of the entire envelope resulted in 124€ per household each year, a value which is more than double than the national estimate given by *ELPRE*, which is sensible considering the precarious living conditions of the case study population.

The NHS savings derived from the renovation of the entire envelope make the investment feasible for 43% of the buildings; this renovation is recommended over replacement of singular components (windows and walls). When accounting for NHS savings, the retrofits would be especially viable for the neighbourhoods with the poorest population (Alfredo Bensaúde) or the oldest buildings (Condado, Casalinho da Ajuda).

Other methodologies have been developed to quantify the monetary benefits, in terms of NHS savings, of improving the thermal comfort of households through passive retrofit. These studies rely on the collection of a considerable amount of data on the buildings' thermal properties and the living conditions of their inhabitants, thus limiting the scale of the case study to a few households. For the first time a similar procedure is applied to the Portuguese context, managing to include a large sample of buildings with few inputs required. A bottom-up archetype approach enabled the analysis of 1,800 buildings located in seven social neighbourhoods of Lisbon. The results of the analysis at a neighbourhood level provide useful insights into the effects of passive retrofit actions on fuel poverty. This work proposes a more pragmatic way of accounting for NHS savings adjusted to the average per capita expenses on health in Portugal.

When discussing energy efficiency policies, public authorities should take into account the non-monetary benefits of housing renovations, especially regarding NHS relief. This work introduces the need for monetising these hidden benefits derived by retrofitting and including them into the investment sheets. This might open investment opportunities that do not exist for Portuguese vulnerable population, which generally encounters a small margin of savings in the utility bills due to its low energy consumption. The results of this work allow local authorities to redesign public policies, tackling at once climate change and social inequality. This strategy requires intersectional policy efforts in the environmental and health sectors, as free energy efficiency measures for people affected by a chronic respiratory disease.

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