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Influence Of Building Management On Optimality Definition In Residential Buildings Retrofitting

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ABSTRACT

Energy efficient retrofit strategies should not only enhance the energy performance of the building in a cost effective way, but also improve, or at least, not compromise the indoor thermal comfort during the all year, even when system is off. Even if the indoor thermal comfort is commonly not included among the objectives of the optimization process, a well-known problem of highly insulated buildings is that, if not correctly managed, they can undergo to important overheating issues. On the other hand, it is also true that, under discomfort conditions, occupants tend to react, making adjustments (operating the windows and/or the shading devices), to improve their thermal comfort sensation. In this paper, the influence of the occupants' adaptation on the definition of the optimal solutions for building retrofits has been investigated considering a set of reference building modules, representative of the Italian building stock and located in two typical Italian climates. In a first stage, the optimization of retrofits has been carried out evaluating the nominal performance, without considering the building management operated by the occupants as adaptation measure to uncomfortable conditions. In a second stage, the performance of the optimal solutions has been recalculated including some user-operated management actions and the differences between nominal and adapted performance assessed. This allows evaluating the efficacy of an appropriate management of the building by the occupants, through windows and shading operation, and its impact on nominal estimated performance. Finally, the optimization has been repeated including the adaptive management actions to investigate the possibility that some of the retrofit configurations neglected in the first optimization could reveal better performance than the selected ones.

1. INTRODUCTION

The enhancement of the existing buildings' performance requires the choice among a wide selection of energy efficiency measures. The rational approach, by means of a cost-optimization process, is able to find the configurations representing the best trade-off between energy and economic performance. Although the cost-optimal analysis represents a multi-objective optimization tool, useful to guide the investment in building renovation, the occupants' comfort is not usually included in the analysis. However, since any retrofit strategy should not only enhance the energy performance of the building in a cost effective way, but also improve, or at least, not deteriorate the indoor thermal comfort during the all year, optimization should be extended to comfort aspects. Moreover, as highlighted in recent works (Mlakar and Stryncar 2011, McLeord et al. 2013, Penna et al. 2015), one of the well-known problems in highly insulated buildings, including renovated ones, is that, if not correctly managed, they can undergo overheating issues, hampering the indoor environment livability. Not only this could raise complains about the quality of the renovation, but also induce occupants' reaction, making adjustments (operating the windows and/or the shading devices) in order to improve their conditions, and possibly compromising the building energy performance. Indeed, occupants are not passive actors but tends to adapt themselves to changing conditions in their environment and "to react in ways which tends to restore their comfort" (Nicol and Humphreys, 2002), which could lead, in case of building renovation, to unexpectedly high energy needs. Some authors have described this kind of outcomes under the name of rebound effect (Herring, 2006). According to Hirst et al. (1985) occupants tend for instance to increase the indoor setpoint in winter to feel more comfortable in new buildings. This was also evidenced by other studies as summarized in a review by Sorrell et al (2009).

In this paper, the influence of the occupants' behavior on the definition and on the actual performance of the optimal retrofit solutions has been investigated for a set of reference buildings, representative of different construction periods and windows orientations, located in two typical Italian climates, Milano and Messina, characteristic of respectively heating and cooling dominated climatic regions. A wide selection of energy efficiency measures has been evaluated, using a genetic algorithm for the multi-objective optimization to select the configurations assessed through a dynamic simulation code. The search of the best combination of measures has been conducted optimizing energy efficiency, global costs and the indoor thermal comfort at once. In the first stage, the optimization has been carried out evaluating only the nominal performance of the building, assuming a standard occupation profile and use of the building, such as in the typical asset rating procedure foreseen for energy labelling. In a second stage, the performance of the optimal solutions has been evaluated again, this time including some user-operated building adaptation management actions, through windows and shading operation in relation to the indoor and outdoor conditions. This allows assessing the impact of these interactions, not only on the comfort conditions, but also on the actual performance of the building. Finally, the optimization has been repeated including the adaptive management actions to investigate the possibility that some of the retrofit configurations neglected in the first optimization could reveal better performance than the selected ones.

2. CASE STUDY

In this study, a set of simplified building modules have been analyzed, originated from a shoebox-like configuration, ideally representative of the top of a multistorey building (penthouse typology, S/V=0.63 and infiltration rate set to 0.13 ACH), with a floor area of 100 m^2, an internal height of 3 m and a window to floor ratio equal to 14.4%. The modules' heating system is a standard boiler (efficiency, η= 89%) coupled with radiators and on-off control system. The set of buildings has been defined from the above model by the variation of:

a) Envelope thermal transmittance, to analyze two of the most diffuse Italian building structure, a typical building structure dated back before the first energy legislation (Italian parliament, 1976) (REF 1) and one between the first and the second one (Italian parliament, 1991) (REF 2);
b) Windows orientation, assuming two options, South and East;
c) Climate, considering two localities representative of the Italian territory, Milano (HDD_{20} = 2404 K d), as a heating dominated climate, and Messina (HDD_{20} = 707 K d), as a cooling dominated one.

Table 1 summarizes the values variations and the characteristics of the buildings' set. More detailed information about the building modules can be found in Penna et al. (2015).

Table 1: Variation of the reference building module

Variation	Values	
Construction period	REF 1 (before 1979) REF 2 (1979-1991)	U_{opaque}=1.03 W m^{-2} K^{-1} $U_{glazing}$=5.7 W m^{-2} K^{-1} U_{opaque}=0.49 W m^{-2} K^{-1} $U_{glazing}$=3.2 W m^{-2} K^{-1}
Windows orientation	Southern Eastern	
Climatic context	Milano Messina	HDD_{20} = 2404 K d - Cfa, Köppen Classification HDD_{20} = 707 K d - Csa, Köppen Classification

2.1 Energy Efficiency Measures (EEMs)

To improve the energy performance of the buildings set, the following Energy Efficiency Measures (EEMs) have been considered:

i) Walls external insulation with a thickness from 1 to 20 cm, in 1 cm steps;
ii) Roof external insulation with a thickness from 1 to 20 cm, in 1 cm steps;
iii) Replacement of glazing systems with the ones reported in Table 2. Also the windows' frames are replaced with an improved aluminum frames with thermal break (U_{frame}=1.2 W m^{-2} K^{-1});

iv) Substitution of the heat generator with modulating or condensing boilers with a climatic control system;
v) Installation of a mechanical ventilation system with heat recovery.

Some of the listed EEMs bring some energy performance improvements without any additional costs. In particular:

- The linear thermal transmittances of thermal bridges are reduced according to different insulation thickness and glazing types;
- The air tightness of the building is assumed to be improved in the case of substitution of the windows by the half of the starting value;
- Since the substitution of the radiators is not planned, the nominal capacity of the emission system does not change, although the boiler is substituted. This means that a climatic control of the radiator supply temperature, enables lowering this temperature under the design value, further increasing the boiler effectiveness.

Table 2: Technical specifications of the Energy Efficiency Measures considered in the analysis

Thermal characteristics of External Insulation: Polystyrene EPS		
Thermal conductivity λ (W m^{-1} K^{-1})	0.04	
Specific heat c (J kg^{-1} K^{-1})	1470	
Density ρ (kg m^{-3})	40	
Thermal characteristics of Glazing system		
	U (W m^{-2} K^{-1})	**SHGC**
DH – Double, high SHGC (4/9/4, krypton, low-e)	1.140	0.608
DL – Double, low SHGC (6/16/6, krypton, low-e)	1.099	0.352
TH – Triple, high SHGC (6/12/6/12/6 krypton, low-e)	0.613	0.575
TL – Triple, low SHGC (6/14/4/14/6 argon, low-e)	0.602	0.343
Nominal Efficiency of the Heating system		
Standard (STD)	89 %	
Modulating (MD)	96 %	
Condensing (CD)	101 %	
Technical characteristics of the Mechanical Ventilation System		
Ventilation Rate (m^3 h^{-1})	150.0	
Power (W)	59.7	

2.2 Building Energy Simulation Models

To analyze the impact of the building management on the definition of optimal solutions, in terms of energy, costs and comfort, two simulations or models have been implemented in TRNSYS (Solar Energy Laboratory, 2012a). The simulation time step of has been set to 10 minutes, in order to catch a detailed behavior of the building. The first one, called Nominal Model (NM), assumes standard utilization profiles, consistently with what is usually assumed in an asset rating for building energy labelling. No specific reactions to the indoor conditions are considered from the occupants. The second one, the Adaptive Model (AM), includes some rough user-operated management actions, such as those related to blinds and windows opening. This model can be assimilated to a tailored rating approach, because it tries to take into account the real operation of the building. In particular, based on the thermal sensations of the occupants, those actions that could reasonably prevent or minimize indoor thermal discomfort, have been considered. First a comfort range has been defined, in terms of a lower and a higher operative temperature bounds (CEN, 2007a). These are constant in the heating season, when the minimum indoor air temperature is maintained by the heating system, and vary with the running mean outside air temperature during summer, since no cooling system is considered. In particular, the comfort bounds consider a normal level of expectation (Category II) and an activity level ranging from 1 to 1.3 met. During the heating season, from 15th October to 15th April in Milan and from 1st December to 31st March in Messina according to the D.P.R. 74/2013 (Italian Parliament, 2013), the lower and upper bounds are 20 °C and 25 °C, respectively. During the rest of the year, they are related to the external running mean temperature, Θ_{rm}, according to the following equations:

$$\Theta_{o,limit,upper} = 0.33\Theta_{rm} + 18.8 + 3 \tag{1a}$$

$$\Theta_{o,limit,lower} = 0.33\Theta_{rm} + 18.8 - 3 \tag{1b}$$

The running mean temperature, is calculated as an exponentially weighted running mean of the daily outdoor mean air temperature, Θ_{ed}, for the seven days immediately before the analyzed one:

$$\Theta_{rm} = (1-\alpha)\,(\Theta_{ed-1} + \alpha\ \Theta_{ed-2} + \alpha^2\,\Theta_{ed-3} + \ldots + \alpha^6\,\Theta_{ed-7}) \qquad (2)$$

According to this approach, discomfort occurs when the indoor operative temperature comes out of the comfort range, and specifically, providing cold sensation for values lower than the lower bound, or hot for temperatures exceeding the upper bound.

2.2.1 Nominal Model (NM): As weather data files, the national Test Reference Years (TRY) of Milan and Messina (Comitato Termotecnico Italiano) is used. Trnsys Multi-zone building subroutine, Type 56 (Solar Energy Laboratory, 2012b), with Type 869 (Haller at al. 2011a, Haller et al. 2011b) model the building and the heating system respectively. A thermostat is set to switch on the boiler when the indoor air temperature is lower than 20°C, and switch it off, when it overcomes 22°C. When replacing the boiler, the water supply temperature is assumed to be regulated in relation to the outside one. Internal gains, half radiative and half convective, are modelled according to the Italian technical specification UNI/TS 11300 (UNI, 2008). The air change rate, is set to 0.5 ACH during the occupancy time. If the mechanical ventilation is considered, heat recovery is used to pre-heat the outdoor inlet air in winter, while in summer mechanical ventilation is operated to avoid the indoor overheating. Specifically, if the indoor operative temperature overcomes the upper bound of the comfort range and the outdoor temperature can cool down the indoor one, the mechanical ventilation system turns on, bypassing the heat recovery. When the building is occupied, if the outdoor conditions are worse than inside (too cold or too hot), the mechanical ventilation is operated with a fixed airflow rate of 0.5 ACH and to pre-condition the inlet air.

2.2.2 Adaptive Model (AM): Adaptive Model tries to simulate a more realistic operation of the building by the occupants, to prevent indoor overheating and restore thermal comfort. Thus some control actions to operate the shutters and the windows opening, have been added to the NM. Those control actions are inspired by common-sense reactions to discomfort conditions. Since people tend to operate actively on the building according to their thermal perception, in order to prevent discomfort conditions (Nicol and Humphreys, 2002, Mahdavi 2011), it is reasonable to assume they react differently in summer and winter conditions. Then, a “summer adaptation” period when occupants tends to actively react to discomfort conditions, has been defined according to the EN 15251 (CEN, 2007a). The start of the summer adaptation period is set when outdoor running mean temperature exceed the 10 °C, which corresponds to an indoor comfort operative temperature of 25 °C. Considering the TRYs, this period is 28th April – 14th October for Milan and 3rd April – 30th November for Messina. During this period, the occupants are presumed to be more incline to adapt, operating actively shading devices and increasing the ventilation rate by opening the windows. The applied shading factor is assumed 0.8 and two shadings controls are considered: when the building is not occupied, the shades are closed, while during the occupied time, they are closed only when the beam solar radiation incident on the window exceeds 150 W m^{-2}. The control strategy for windows opening has been set according to thermal sensation of the occupants. During all the year, when the building is occupied and the occupants feel hot (operative temperature is higher than the higher comfort bound), if the outside temperature can improve the indoor comfort (outside temperature is lower than operative temperature), the windows are considered to be opened. The ventilation rate, due to windows’ opening, has been modelled according to EN 15242 (CEN, 2008), which considers wind speed, temperature difference between inside and outside and windows opening angle. Two opening angles have been set according to the season. During the winter, the windows are considered partially opened, with an angle of 5°, while during the summer they are considered completely opened, i.e. with an opening angle of 90°. Windows are then closed when the operative temperature decrease below the lower comfort bound.

3. MULTI-OBJECTIVE OPTIMIZATION

The best combinations of retrofit strategies have been defined taking into account different aspects, namely energy savings, global costs and occupants wellbeing. For this purpose, a multi-objective approach has been used to minimize simultaneously those three target functions expressed by the Energy Performance for Heating (EPH), the Net Present Value of the total cost (NPV) and the Weighed Discomfort Time (WDT). Section 3.1 reports a description of these three objective functions. The solutions identified by this approach are the so-called Pareto front, which represents the best trade-off among different competitive targets. Considering that the optimization problem with three objective functions has three dimensions, the result of the optimization is a “Pareto surface”. In our case, the solutions laying on the Pareto surface are those with a lower EPH than the initial one, which for a given EPH, minimize the WDT at any given NPV.

3.1 Objective functions

3.1.1 Energy Performance for Heating (EP_H): EP_H represents the primary energy for heating per heated floor area to maintain the set temperature conditions during a year (CEN 2007b). This indicator takes into account natural gas consumed by boiler, and electricity, due to pumps or mechanical ventilation system.

3.1.2 Net Present Value (NPV): NPV is the actualized cash flow, generated by a new construction or a retrofit action considering the building lifespan of 30 years. According to the comparative framework methodology proposed by EU 244/2012 (European Commission, 2012), the following costs have been taken into account:

- the initial Investment Cost (IC) for the retrofits. The costs of different EEMs are reported on Table 3 and are define according to regional price list.
- the annual running costs, composed of the annual Energy Cost (EC) for heating and the Maintenance Cost (MC) for restoring building components. Energy costs and energy prices rising are reported in Table 4;
- the replacement cost (RC), for the periodic substitution of building/system elements;
- the residual value (RV) for the pieces of equipment with longer lifespan according to EN 15459 (CEN, 2007c).

Table 3: Investment costs for the Energy Efficiency Measures

Energy Efficiency Measures	**Costs**
Insulation of Vertical wall (* thickness (cm))	IC_{VW} = 1.6 x* + 38.53 EUR m^{-2}
Insulation of Horizontal wall (* thickness (cm))	IC_{HW} = 1.88 x* + 8.19 EUR m^{-2}
DH – Double glazing, high SHGC	IC_{DH} = 404.33 EUR m^{-2}
DL – Double glazing, low SHGC	IC_{DL} = 439.06 EUR m^{-2}
TH – Triple glazing, high SHGC	IC_{TH} = 477.65 EUR m^{-2}
TL – Triple glazing, low SHGC	IC_{TL} = 454.49 EUR m^{-2}
Standard (STD)	IC_{STD}=1000 EUR
Modulating (MD)	IC_{MDL}=1500 EUR
Condensing (CD)	IC_{MDL}=2000 EUR
Mechanical Ventilation System	IC_{MV} = 6000 EUR

Table 4: Parameters for the economic analysis

Parameters for the economic analysis			
Fuel Cost $^{(1)}$	0.85 EUR S m^{-3}	Electricity Cost $^{(1)}$	0.25 EUR kWh$_{el}^{-1}$
Lower Heating Value $^{(2)}$	32.724 MJ S m^{-3}	Annual increase of electricity price $^{(3)}$	1.71 %
Annual increase of fuel price $^{(3)}$	2.8 %		
VAT	10 %	Real Interest Rate	3 %
$^{(1)}$ Autorità per l´Energia Elettrica e il Gas, 2011, *Relazione annuale sullo stato dei servizi e sull'attività svolta,* Milan, Italy $^{(2)}$ *Energetico* Ministry of Economic Development, 2011, *Bilancio Nazionale 2010,* Rome. $^{(3)}$ EU Enery Trends to 2030, update 2009. European Union 2010.			

3.1.3 Weighted Discomfort Time (WDT): WDT, through degree-hours criterion (CEN, 2007a), indicates how much and for how long the operative temperature lies outside of the comfort range. To calculate WDT, the occupied hours during which the operative temperature exceeds the comfort bounds are weighted by the deviation *wf* from the range (Equations 3 and 4).

$$WDT=\sum wf \cdot \tau \,(K\,h) \tag{3}$$

$$wf= \Theta_o - \Theta_{o,limit} \quad (K) \text{ when } \Theta_o < \Theta_{o,limit,lower} \text{ or } \Theta_o > \Theta_{o,limit,upper} \tag{4}$$

3.2 Genetic Algorithm

The algorithm used to perform the optimization is the Non-dominated Sorting Genetic Algorithm, NSGA (Deb K. *et* *al*. 2002). The set parameters for the Genetic Algorithm (GA) are a fraction of 0.5 of tournament selection, 0.8 of arithmetic crossover and a mutation rate of 0.1. The initial population is composed by 128 individuals, defined through the Sobol's Method, a quasi-random number generator. This method defines random points uniformly distributed on the problem's space, having the advantages of improving the outcomes of the genetic algorithm by giving a good individuals' collection as initial population (Saltelli et al., 2004).

4. RESULTS AND DISCUSSION

To evaluate the impact of the building management on the definition of the optimal solutions, the analysis has been split in three different steps. A first optimization has been run using the Nominal Model, evaluating the nominal performance of the building without considering any human adaptive reaction to the indoor conditions. Secondly, the performance of the optimal solutions found in the first optimization, has been assessed using the Adaptive Model. By including adaptation management actions, it has been possible to evaluate how building management affects the performance of the selected optimal solution, highlighting the performance gap between asset and tailored rating of refurbished buildings. Finally, a second optimization run, using the Adaptive Model, has allowed investigating the possibility that some of the retrofit configurations neglected in the first optimization could reveal better performance than the selected ones, if considering the adaptation management since the optimization phase.

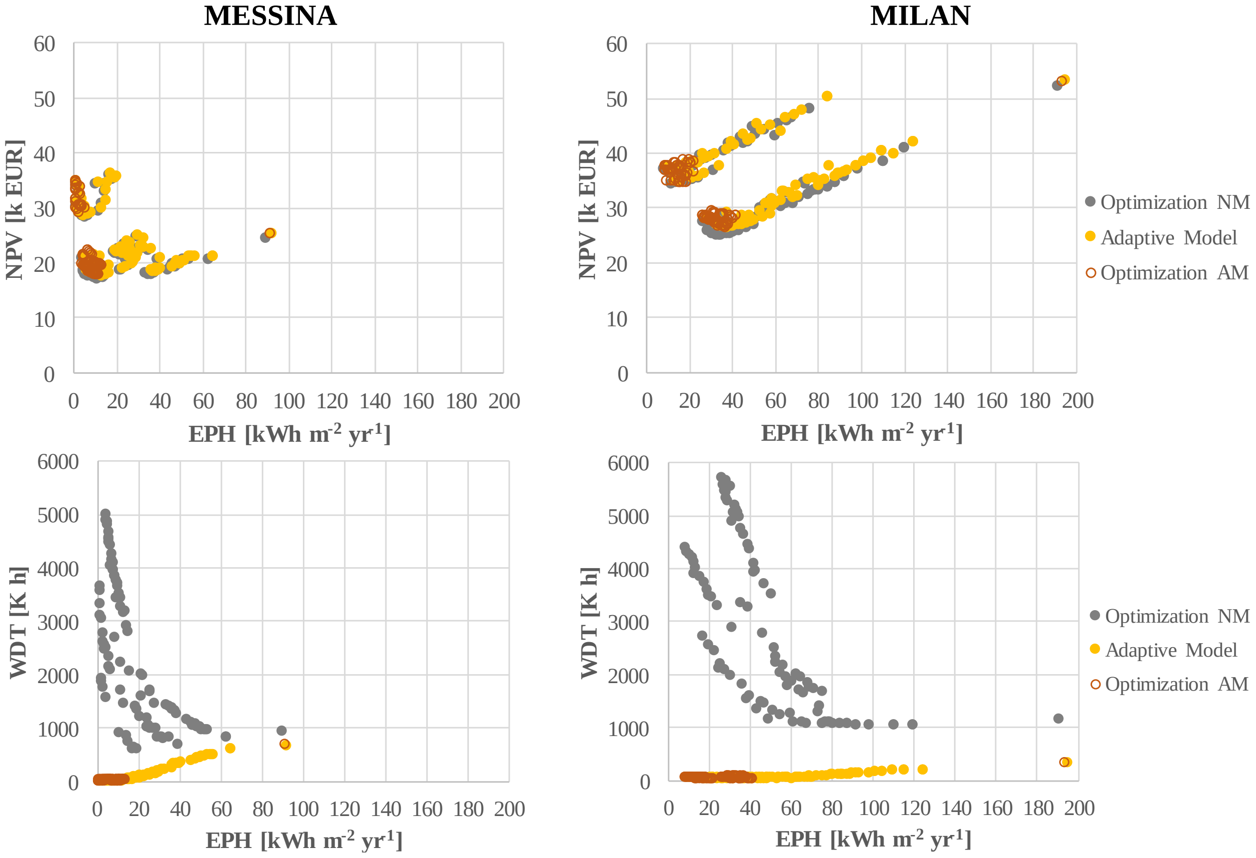

Figure 1: Pareto surfaces solutions of the case studies REF 1, windows east exposed. The graphs on the left refer to Messina, the ones on the right to Milan.

4.1 Comparison of the Pareto front solutions simulated with NM and AM

Figure 1 reports the results of the three different evaluation steps for the case studies REF 1 (building built before 1976) with windows East oriented, located in Messina and in Milan. The first two graphs report the relationship between energy and economic performances (EP_H – NPV), the second two show the relationship between energy and comfort performances (EP_H – WDT). The grey dots are the Pareto optimal solutions identified by the GA using the NM, the yellow ones are the same Pareto solutions simulated with the AM and the orange circles represents the results of the second optimization run with the AM. By comparing the grey and yellow dots is visible how considering the user-operated control actions affect the energy, cost and comfort performance.

One first finding concerns the increase of energy and costs of the Pareto frontier solutions when user adaptive management is included. This trend is clearer in Figure 2, where regression lines show the entity of the differences in energy and economic performance of the two models. In particular, the energy needs of the building increases by about 5% in Messina and 10% in Milan with user interactions. Consequently, the NPV increases by 1.5% in Messina and about 4% in Milan. Similar trends are visible in the other cases and not represented. Generally, two trends are highlighted by the results: the first one related to the building characteristics, such as construction periods and windows orientations, the second one related to the location of the building, in a heating and cooling dominated climatic region. The first trend is related to overheating: the lower are the heating needs, such as for (REF 2) and windows South oriented, the larger is the overheating issue. As a consequence, the more a case is affected by overheating, the more is the differences in energy and costs performance. This is due to the control actions modelled into the AM, and in particular with the windows' opening. When the user feels hot, windows opening increases the ventilation rate. Particularly when this occurs in winter, as it happens more frequently for the most efficient solutions, the indoor air temperature decreases and the heating system starts, increasing the building energy consumptions, and consequently the energy costs. The second trend is related to the location of the building: in Milan the differences in energy performance and costs are larger between the two models, if compared to the ones located in Messina. At the first sight, this could be seem in contrast with the previous statement, in fact, Milan presents higher heating needs. However, since in Milan, during the heating season, the outdoor temperature is considerably lower, when the indoor conditions are characterized by overheating, increasing the ventilation rate cools down more rapidly the indoor air temperature, worsening more consistently the building energy performance.

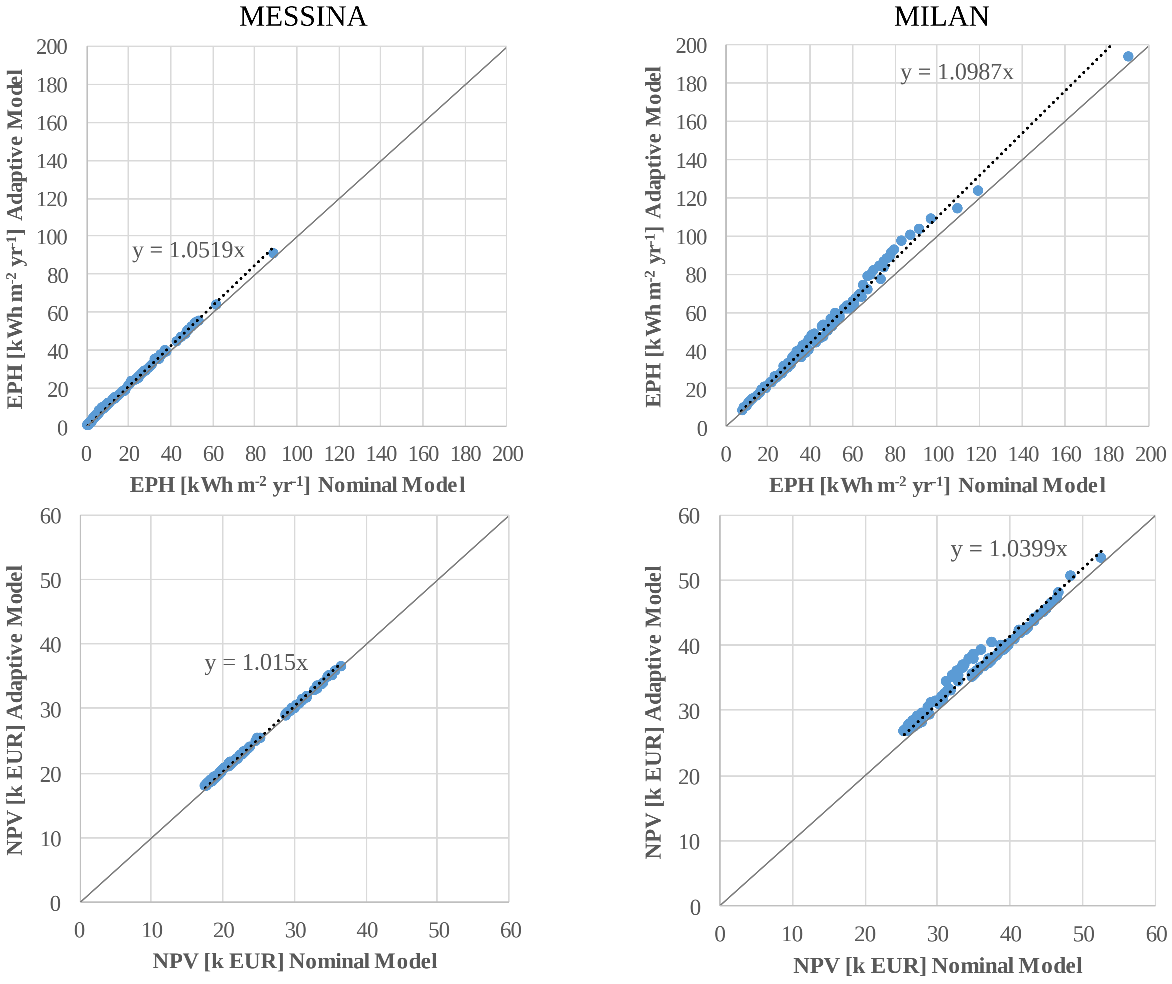

Figure 2: Regression analysis between the energy and economic performance of Nominal and Adaptive Models.

A further aspect underlined by the results is related to the comfort performance. The NM shows how improving the building energy performance leads to deteriorating the indoor thermal comfort. In particular, increasing the external insulation thickness increases the indoor thermal discomfort. In fact, as already highlighted by Penna et al. (2015), in highly insulated buildings a small energy input raises significantly the internal temperature and if the extra heat is not dissipated, the indoor livability can be hampered. According to the NM, the higher is the nominal building energy efficiency improvement, the higher is the indoor discomfort. However, adaptive reactions reveal capable not only to address this problem, but even to improve the situation particularly for the best energy performing configurations. The highest discomfort is for the base case, where no retrofits are considered. For this case, introducing the building management reduces the overheating risk, but not the discomfort caused by low indoor operative temperature. In fact, in poorly insulated building, even if the air temperature reaches the set-point of the heating system, the operative temperature can exit the comfort range because of the low mean radiant temperature.

4.2 Comparison of the Pareto front solutions identified with the two optimizations

A second optimization has been run using the AM to investigate the possibility that some of the retrofit configurations, neglected in the first optimization, could reveal better performance than the selected ones (orange circles in Figure 1). The graphs show that, if the user-operated control actions are considered since the optimization phase, the EEMs with EPH higher than the cost optimal ones are not selected by the algorithm. This means that the overheating problem, related to solutions with high energy efficiency, can be controlled more effectively by using the shading devices and by increasing the ventilation rate to dissipate the excess of heat when different configurations are selected. Solutions that in NM optimization were chosen, because of the better comfort despite of the high EPH, in the AM optimization are dominated and not included on the Pareto frontier. Conversely, solutions excluded when assessed according an asset rating approach are more easily managed and better performing also from an energy point of view.

Table 5: Combination of EEMs for the optimal solutions in terms of cost, energy and comfort evaluated with the Nominal and Adaptive Model for the set of reference buildings.

	REF 1								**REF 2**							
	EAST				**SOUTH**				**EAST**				**SOUTH**			
	ME (NM)	ME (AM)	MI (NM)	MI (AM)	ME (NM)	ME (AM)	MI (NM)	MI (AM)	ME (NM)	ME (AM)	MI (NM)	MI (AM)	ME (NM)	ME (AM)	MI (NM)	MI (AM)
COST OPTIMAL (CO)																
Wall	11	13	16	17	12	10	16	14	11	10	10	12	10	10	11	11
Roof	10	10	14	16	10	11	15	14	11	10	11	12	9	9	11	11
Win	DH	DH	DH	DH	0	0	DH	DH	0	0	0	DH	0	0	0	0
Boiler	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD
Vent	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD
EPH	10	11	34	36	23	25	22	29	24	27	56	40	14	16	43	54
NPV	18	18	25	27	15	15	22	24	15	16	24	26	12	12	20	23
WDT	3473	51	4995	85	877	392	4255	62	2123	188	2866	86	1361	193	2189	74
ENERGY OPTIMAL																
Wall	18	17	18	20	20	15	18	18	12	12	12	12	12	12	12	12
Roof	19	19	20	20	18	20	19	20	12	12	12	12	12	12	12	12
Win	TH	TH	TH	TH	TH	TL	TH	TL	TH	TH	TH	TH	TH	TH	TH	TH
Boiler	CD	STD	CD	MD	CD	MD	CD	CD	CD	STD	MD	CD	MD	MD	CD	CD
Vent	MVS	MVS	MVS	MVS	MVS	MVS	MVS	MVS	MVS	MVS	MVS	MVS	MVS	MVS	MVS	MVS
EPH	0.3	0.3	8	8	0.3	0.4	3	6	1	1	17	20	0	0	9	10
NPV	35	32	37	37	35	34	36	37	33	30	37	38	32	32	35	36
WDT	3675	29	4418	80	3166	21	3598	41	2908	39	3638	81	2307	26	2930	61
COMFORT OPTIMAL																
Wall	1	19	0	9	1	18	0	13	0	12	0	8	0	12	0	8
Roof	10	20	1	19	16	20	4	20	10	12	3	12	0	12	10	12
Win	TL	TL	DL	TL	0	TL	DL	TL	TL	TL	TL	TL	DL	TL	TL	TL
Boiler	CD	MD	STD	MD	STD	MD	STD	CD	MD	MD	MD	MD	MD	MD	MD	MD
Vent	MVS	STD	STD	MVS	MVS	STD	STD	STD	MVS	MVS	MVS	MVS	MVS	MVS	MVS	MVS
EPH	19	6	119	22	29	2	119	26	28	3	72	29	24	1	53	21
NPV	36	22	41	39	30	21	41	28	34	30	45	39	32	32	41	37
WDT	640	26	1061	50	423	18	1061	37	541	30	951	54	376	23	748	41

Table 5 reports the configuration of the Costs Optimal (CO), Energy Optimal (EO) and Comfort Optimal (CMFO) configuration defined by considering (AM) or not (NM) the user's management actions in the optimization process.
Generally, the CO solutions identified for the AM, presents higher insulation thickness than the NM original ones. This allows improving comfort conditions while limiting the drawbacks on the energy performance.
NM and AM EO solutions have almost the same configuration, sometimes differing for the heat generator. What is significantly different is the WDT, which with AM optimization not only improves with respect to NM, but is also better than the CO one.
As for the CMFO solution, for the AM optimization it is always way more insulated than the corresponding one with NM. If the NM selects, as CMFO, solutions with lower insulation thickness, by introducing some control actions to prevent the overheating risk, solutions with higher insulation and, consequently, with higher energy performance are also the most comfortable ones. The energy performance (EPH) is always better than for the CO, sometimes quite close to zero, and the NPV is almost always better than that of the EO, thus smoothing the path to the nearly zero energy building.

5. CONCLUSIONS

In this paper, the influence of the occupants' behavior on the definition and on the actual performance of the optimal retrofit solutions has been investigated for a set of reference buildings. The search for the best combination of measures has been conducted optimizing energy efficiency, global costs and the indoor thermal comfort at once. Firstly, the optimization has been carried out evaluating only the nominal performance of the building, assuming a standard occupation profile and use. This has highlighted how increasing the building energy performance leads to deteriorate the indoor thermal comfort, because of the overheating issue. Then the performance of the optimal solutions has been evaluated again, including some user-operated building adaptation actions to prevent overheating. In particular, including the adaptive management radically enhances the building comfort performance, reducing the overheating risk, but also increases energy consumptions and global costs.
Finally, the optimization has been repeated including the adaptive management actions showing that retrofit configurations neglected in the first optimization reveal better performance than the selected ones.
This paper highlights how high energy performance buildings, if not correctly managed, can presents really poor performance in terms of comfort. On the one hand, underestimating this issue can lead to improper estimation of the actual performance of the building, which is likely to be affected by the occupant's adaptive reactions. On the other hand, overheating and discomfort can be avoided or considerably reduced through an appropriate management of shadings and ventilation rates. Those strategies have to be considered when optimizing the combination of retrofit measures if the actual cost, energy and comfort optimal solutions have to be defined.
Finally, as a future development of this work, the evaluation of the potential of optimized building management strategies, also based on automated systems, to maintain adequate comfort condition while reducing the energy demand, seems worth investigating, either in combination with other energy efficiency measures, or on their own.

REFERENCES

CEN, 2007a. EN 15251, Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics. Bruxelles, Belgium

CEN, 2007b. EN 15217:2007. Energy Performance of Buildings. - Methods for ex- pressing energy performance and for heating certification of buildings. Bruxelles, Belgium

CEN, 2007c. EN 15459:2007, Energy Performance of Buildings—Economic Evaluation procedure for Energy Systems in Buildings. Bruxelles, Belgium

CEN, 2008. EN 15242:2008. Ventilation for buildings - Calculation methods for the determination of air flow rates in buildings including infiltration. Bruxelles, Belgium

Comitato Termotecnico Italiano, www.CTI2000.it

Deb, K., A. Pratap, and S. Agarwal. 2002. A fast and elitist multi- objectives genetic algorithm: NSGA-III. *IEE Transactions on Evolutionary Computation 6* (2):182–97.

European Commission (EC). 2012. Commission delegated regulation (EU) No. 244/2012 of 16, January. Brussels: European Commission

Haller M.Y., Paavilainen J., Konersmann L., Haberl R., Dröscher A., Frank E., 2011. A unified model for the simulation of oil, gas and biomass space heating boilers for energy estimating purposes. Part I: Model development, *J. Build. Perform. Simul. 4* (1): 1–18.

M.Y. Haller, J. Paavilainen, L. Konersmann, R. Haberl, A. Dröscher, E. Frank, 2011. A unified model for the simulation of oil, gas and biomass space heating boilers for energy estimating purposes. Part II: Parameterization and comparison with measurements, *J. Build. Perform. Simul. 4* (1): 19–36

Herring H., 2006. Energy efficiency, a critical view. *Energy 31* (1):10–20.

Hirst E., White D., Goeltz R., 1985. Indoor temperature changes in retrofit homes. *Energy 10*: 861–70.

Italian Parliament. 1976. Law 373 Norme per il contenimento del consumo energetico per usi termici negli edifici.

Italian Parliament. 1991. Law 10, Norme per l'attuazione del piano energetico nazionale in materia di uso nazionale dell'energia, di risparmio energetico e di sviluppo delle fonti rinnovabili di energia.

Italian Parliament, 2013, D.P.R. n.74/2013, Regolamento recante definizione dei criteri generali in materia di esercizio, conduzione, controllo, manutenzione e ispezione degli impianti termici per la climatizzazione invernale ad estiva degli edifici e per la preparazione dell'acqua calda per usi igienici sanitari

Mahdavi A., 2011. People in building performance simulation, in Hensen J.L.M. & Lamberts R., *Building performance simulation for design and operation*, Spon Press, New York, USA, p.56-83

McLeod R.S., Hopfe C.J., and Kwan A., 2013. An investigation into future performance and overheating risks in Passivhaus dwellings. *Building and Environment 70*:189–209.

Mlakar J., and Strancar J., 2011. Overheating in residential passive house: Solution strategies revealed and confirmed through data analysis and simulations. *Building and Environment 43*: 1443–51

Nicol J.F., Humphreys M.A. 2002. Adaptive thermal comfort and sustainable thermal standards for buildings. *Energy and Buildings 34*: 563-72

Penna, P., Prada, A., Cappelletti, F. and A. Gasparella. 2015. Multi-objectives optimization of Energy Efficiency Measures in existing buildings. *Energy and Buildings 95*: 57-69

Saltelli A., Tarantola S., Campolongo F., Ratto M., 2004. Sample generation, in*: Sensitivity Analysis in Practice. A Guide to Assessing Scientific Models*, John Wiley & Sons, Chichester, UK, pp. 193–204

Solar Energy Laboratory, 2012a, TRNSYS 17, TRNSYS. A transient system simulation program, 2012, http://sel.me.wisc.edu/trnsys

Solar Energy Laboratory, 2012b, TRNSYS 17, Multizone Building modeling with Type 56 and TRNBuild, Vol. 5, Madison, WI, USA

Sorrell S., Dimitropoulos J., Sommerville M., 2009. Empirical estimates of the direct rebound effect: a review. *Energy Policy 37*:1356–71.

UNI 2008, UNI/TS 11300-1, Energy performance of buildings – Part 1: Evaluation of energy need for space heating and cooling.