Enhancing the Energy and Non-Energy Performance of Existing Buildings: a Multi-Objective Approach

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ABSTRACT

A wide selection of energy efficiency measures (EEMs) are technically available to improve the energy performance of existing buildings, each of which can be applied to a different extent. The definition of the best combination of retrofit strategies is generally pursued through the balance of economic and energy targets. What this approach does not consider are some different performance aspects, although related to the same EEMs, and in particular the occupant well-being. In this framework, the definition of the best retrofit strategies should consider three objectives characterized by a competing nature: the energy savings, the economic advantage and the indoor thermal comfort. Government incentives play a crucial role in promoting retrofit projects. This financial subsidies should be addressed to incentive solutions not economically attractive but optimal in terms of energy savings and indoor thermal comfort. The aim of this work is to evaluate a large range of EEMs for different starting building modules. In particular it is investigated the entity of government subsidies required to improve the profitability of the optimal solutions in relation with different initial starting conditions. In order to define the optimal solutions, a multi-objectives optimization-based approached is implemented through an Evolutionary Algorithm coupled with the simulation code. Subject of the study is a set of building modules obtained by varying the initial characteristics of a reference residential module: windows orientation, compactness ratio and thermal characteristics of the envelope. Two different southern European climatic contexts are considered: Milano and Messina.

1. INTRODUCTION

The improvement of the energy performance of existing residential buildings is one of the most promising strategies to reduce the global energy demand. In Italy the thermal performance of buildings is particularly low because two-third of buildings were built before the adoption of any energy legislations (L. 373/1976). For this reason, refurbishment actions represent an enormous potential in energy saving. Because of the availability of a wide selection of Energy Efficiency Measures (EEMs) on the market, the evaluation of energy conservation opportunities in retrofit projects is not a simple task. Among all the possible EEMs the choice should be made considering the goals that have to be reached. In the last years the definition of the retrofit strategies has been pursued optimizing the balance of economic and energetic targets, probably because of the influence of the recent European Union legislation (European Commission, 2012) which has introduced the so-called "cost optimal approach". This method suggests the minimization of the net present value, accounting for both investment and operational costs along the lifespan of the renovated building. With this approach other performance aspects, such as occupants well-being, are neglected. In this case, the definition of best retrofit strategies should consider three objectives: the energy saving, the economic advantage and the indoor thermal comfort. Once focused the attention on the three objectives to achieve, it is fundamental not to limit the evaluation of EEMs to each single intervention "a variable at a time" or to a small set of options, thus giving no guarantee to find optimal solutions. To overcome this problem, optimization-based approaches have often been used to evaluate a large number of alternative options and to optimize objectives characterized by a competing nature. Several works (Asadi *et al.* 2012, Chantrelle *et al.* 2010, Griego *et al.* 2012, Hamdy *et al.* 2011) proved the results' reliability of optimization techniques in multi-objectives applications.

Besides the difficulties to consider a large number of possible alternatives and the achievement of different competing objectives, dealing with existing buildings is even more complicated than with the new ones. Firstly, designers have to face the technical complexity to work in an existing context and understanding the real opportunities associated to the building's refurbishment. Moreover, the renovation of existing buildings is often more expensive than building a new one. For this reason, government incentives are a key driver to promote and to sustain the employment of buildings energy retrofit. In literature (Amstalden *et al.* 2007, Gamtessa 2013, Higgins *et al*. 2014) the importance of the public subsidies in promoting investment in retrofitting has been already demonstrated. However, there is a lack of knowledge about where to address the incentives and how policies can make profitable the solutions that are not economically attractive, but optimal in terms of energy savings and indoor thermal comfort. Shorrock *et al.* (2005) pointed out this problem, proving how the benefits of certain interventions, such as the substitution of the glazing systems, are threatened by particularly long financial payback time. Also the climatic context (Degous et al. 2013) can influence the profitability of the introduction of EEMs.

In this work, the entity of the government subsides, required to improve the economic profitability of the optimal solutions, has been evaluated for different starting conditions. Subject of this study is a set of building modules obtained by introducing some variations to a reference residential module. The windows orientation, the compactness ratio and the thermal characteristics of the envelope are modified in order to study their relation with the optimal solutions and with the entity of public subsidies. Two different southern European climatic contexts are considered: Milano and Messina. The definition of optimal combinations of EEMs is pursued evaluating a wide range of retrofit options through an Evolutionary Algorithm coupled with the simulation code.

2. BASE CASES

The reference residential building module, subject of this analysis, is a low performance single storey-module with 100 m^2 of square floor and 3 m of internal height. Some characteristics (location, compactness ratio, windows orientation, opaque envelope thermal resistance) of this shoebox-like module have been changed, in order to consider different base cases to be optimized.

The module is located in Milano (HDD_{20}=2404 Kd, Climatic zone E in the Italian classification) and in Messina (HDD_{20}=707 Kd, Climatic zone B in the Italian classification), two representative climates of Northern and Southern Italy. Two building typologies have been analyzed: a semi-detached house (S/V =0.97) and a block of apartments. In this last the unit has been considered on the top floor (S/V = 0.63) and on an intermediate floor (S/V=0.3). Concerning the envelope thermal characteristics, two typical Italian cases have been taken into account. Two different insulation level have been assumed for the starting condition: in the first case (REF1) insulation properties are typical of an Italian building built before the introduction of any energy legislation (i.e. before the '70s), that means an opaque envelope resistance of 0.97 m^2 K W^{-1}, while in the second case (REF2) those of a building built in between the first energy legislation (1976) and the second one (1991), that means an opaque envelope resistance of 2.04 m^2 K W^{-1}. The window system is a single-pane glass (U_{gl} = 5.7 W m^{-2} K^{-1}) with standard timber frame (U_f = 3.2 W m^{-2} K^{-1}). The windows surface is 14.4 % of the floor area and it is South or East exposed. The two-dimensional thermal coupling coefficients for thermal bridges are calculated according to the technical standard EN ISO 10211 (CEN, 2008). The infiltration rate has been calculated according to the UNI EN 12207 (CEN, 1999) and the EN 15242 (CEN, 2007a). The reference air tightness n_{50} is 7 (.h^{-1}) and the associated infiltration rates for the different S/V ratios are 0.2 ACH for the semi-detached house, 0.13 ACH for top floor and 0.062 ACH for intermediate unit.

The heating system is a standard boiler coupled with radiators and on-off system regulation. The nominal heating power of the emission system is calculated for each reference case according to the UNI 12831 (CEN 2006), and then the power of the boiler was defined on the base of market availability.

3. ENERGY EFFICIENCY MEASURES (EEMs)

In order to improve the energy efficiency of the starting building, the following EEMs and levels have been considered:

i) external insulation of walls from a minimum of 1 cm up to 20 cm, in steps of 1 cm;
ii) external insulation of roof from a minimum of 1 cm up to 20 cm, in steps of 1 cm;
iii) external insulation of floor from a minimum of 1 cm up to 20 cm, in steps of 1 cm;
iv) substitution of the existent windows with higher thermal performance windows: four possible glazing types (double or triple plane with either high or low solar heat gain coefficients) and improved frames;
v) substitution of heating generator with modulating or condensing boiler;
vi) installation of a mechanical ventilation system with heat recovery to control the air exchange.

Extra energy performance improvements are introduced with some of the EEMs listed above, without any additional cost:

- the linear thermal transmittance of thermal bridges are reduced according to the different insulation thickness. Considering a progressive increase of 5 cm of insulation on the building elements, the linear thermal transmittances, related to the possible combinations of insulation thickness, are calculated by numerical method and a polynomial regression was used to calculate the variation of the thermal bridges effect.
- the air tightness of the building is assumed to be improved in the case of windows' substitution and the infiltration rates are considered the half of the original values.

Although the replacement of the boiler has been considered, the substitution of the radiators as emission systems has not been planned. The prices of the different EEMs have been determined according to the Regional Price List of Lazio, because it represents a good compromise between North and South Italy prices. Table 1 reports the technical characteristics of the EEMs and their associated costs.

Table 1: EEMs and associated Investment cost without VAT

Opaque Envelope: Insulation Layer			
Thermal characteristics of Polystyrene EPS			***Investment Cost (EUR m^{-2})***
Thermal conductivity λ (W m^{-1} K^{-1})	0.04		Vertical wall: IC_{VW} = 1.6 x* + 38.53 Horizontal wall: IC_{HW} = 1.88 x* + 8.19 * thickness (cm)
Specific heat c (J kg^{-1} K^{-1})	1470		
Density ρ (kg m^{-3})	40		
Transparent Envelope			
Thermal characteristics of Glazing system			***Investment Cost (EUR m^{-2})***
	U (W m^{-2} K^{-1})	**SHGC**	
DH – Double, high SHGC (4/9/4, krypton, low-e)	1.140	0.608	IC_{DH} = 404.33
DL – Double, low SHGC (6/16/6, krypton, low-e)	1.099	0.352	IC_{DL} = 439.06
TH – Triple, high SHGC (6/12/6/12/6 krypton, low-e)	0.613	0.575	IC_{TH} = 477.65
TL – Triple, low SHGC (6/14/4/14/6 argon, low-e)	0.602	0.343	IC_{TL} = 454.49
Aluminium Frame with thermal break	1.2	-	Included in glazing price
Heating System: Boiler			
Efficiency			***Investment Cost (EUR)***
Standard (STD)	89 %		IC_{STD}=1000 EUR
Modulating (MD)	96 %		IC_{MDL}=1500 EUR
Condensing (CD)	101 %		IC_{MDL}=2000 EUR
Mechanical ventilation system (MVS)			
Technical characteristics			***Investment Cost (EUR)***
Ventilation Rate (m^3 h^{-1})	150		IC_{MV} = 6000 EUR
Power (W)	59.7		

4. FIRST MULTI-OBJECTIVE OPTIMIZATION RUN

4.1 Multi-Objective Optimization

A multi-objectives optimization-based approach has been used to define retrofit strategies. The improvement of energy efficiency, the minimization of the total cost of the building over a 30-year lifespan and the maximization of the indoor thermal comfort are the objectives of this optimization process. These three targets correspond to three specific functions: the Weighed Discomfort Time (WDT), the Primary Energy for Heating (EPH), the Net Present Value of the total cost (NPV). The optimization process is performed through a Non-dominated Sorting Genetic Algorithm, NSGA (Deb K. *et al*. 2002), coupled with a dynamic simulation tool. The set parameters for the genetic algorithm are a fraction of 0.5 of tournament selection, a fraction of 0.8 of arithmetic crossover and a mutation rate of 0.1. The initial population is composed by 128 individuals and defined through the Sobol's Method, a quasi-random number generator. This method defines random points uniformly distributed on the problem's space: it has the advantages of reducing the random behavior of the genetic algorithm and giving a good individuals' collection as initial population. In the later stage the solutions that better meet the objectives functions are found, stored and used as parents for the following generation. Given the fact that the targets are opposing, optimal solutions are determined by Pareto dominance and are identified as the so-called Pareto Frontier. They represent the output of a competitive problem, when no alternative solutions exist that increase the fulfilment of an objective without hampering the attainment of another. With two objectives, the result is the so-called "Pareto-curve", and, as in this case, with three objectives the result is a "Pareto surface". In our case the solutions on the Pareto surface are those with a lower EPH than the initial one and for a given EPH those minimizing the WDT for a given NPV.

4.2 Objective Functions

The evaluation of the long term comfort performance of a building can be conducted by means of the Discomfort Weighted Time (WDT) index, as proposed by annex F of the technical standard EN 15251 (CEN, 2007b) through the Degree Hours Criteria. With this approach, the occupied hours during which the actual operative temperature lays outside the specified comfort range, are weighted by a weighting factor, which depends on the entity of the deviation from the range (Equation 1 and 2).

The comfort range of operative temperature has been defined on the base of a normal level of expectation (Category II) for an activity level of 1.2 met and a clothing index of 1 clo. During the heating season, which has been defined according to the Italian Legislation (D.P.R. n.74/2013) and based on the Italian Classification of Climatic zones, the lower and upper values for the operative temperature (20 °C to 25 °C) are fixed.

$$WDT=\sum wf \cdot time \ (K\,h) \tag{1}$$

$$wf= \Theta_o - \Theta_{o,limit} \quad (K) \text{ when } \Theta_o < \Theta_{o,limit,lower} \text{ or } \Theta_o > \Theta_{o,limit,upper} \tag{2}$$

During the rest of the year (when no system works), the comfort range has been calculated considering the adaptive comfort approach, according to annex A of the standard (CEN, 2007b), determining an acceptable operative temperature range (Equation 3a and 3b):

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

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

Those limits are based on the thermal experience of an individual defined with the exponentially weighted running mean of the daily outdoor mean air temperature, Θ_{ed}, calculated as a series of the seven days immediately before the analyzed one:

$$\Theta_{rm} =(1-\alpha)\ (\Theta_{ed-1} + \alpha\ \ \Theta_{ed-2} + \alpha^2\ \Theta_{ed-3} + \ldots + \alpha^6\ \Theta_{ed-7}) \tag{4}$$

The Primary Energy demand for heating (EPH) is calculated by means of the simulation tool TRNSYS. The national Test Reference Years of Milano and Messina (www.CTI2000.it) have been used to simulate the weather conditions.

The Multizone Building subroutine, Type 56, is used to define the building's characteristics. Type 869 (Haller, 2010), has been employed to model the different heating systems, since it is able to simulate the behavior of a modulating and condensing boiler. The operation of heating system is regulated by a thermostat that switches on the boiler, when the indoor air temperature (T_{air}) is lower than 20 °C, and switches it off, when T_{air} overcomes 22 °C. In combination with the replacement of the standard boiler with a more efficient one, the equipment of an outside sensor that regulates the water supply temperature in relation to the outside temperature has been considered.

The internal gains, half radiative and half convective, are modelled according to the occupancy schedule and to the values proposed by the Italian standard UNI 11300 (UNI, 2008), as reported in Table 2.

The ventilation rate has been fixed depending on the season, the occupancy schedule and the presence of a mechanical ventilation system. In winter, during the occupancy time, the air change rate is set to 0.5 ach. The same air change rate is assumed when a mechanical ventilation system is present, but in this case a heat recovery on the exhausted air is added. In summer, the ventilation rate is used as a passive strategy to avoid the overheating. In this case, in fact, when occupants feel warm (the operative temperature exceeds the upper limit of the comfort range) and the outside conditions can improve the internal comfort (the outside temperature is lower than the indoor temperature), the windows are open, and the air flow rate is calculated with the EN 15242 method (CEN, 2007a).

Table 2: Internal gains according to the occupancy schedule

	Schedule	Kitchen [W m^{-2}]	Bedrooms [W m^{-2}]		Total Gains [W]	
			Weekdays	Weekend	Weekdays	Weekend
Week days	7 - 17	8	1	2	450	500
	17 - 23	20	1	4	1050	1200
	23 - 7	2	6	6	400	400

Table 3: 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.

If the mechanical ventilation system is present, two different regimes are modelled: during unoccupied periods, if the operative indoor temperature overcomes the upper limit of the comfort range and the outdoor air temperature is lower than the indoor one, the mechanical ventilation system turns on, bypassing the heat recovery; during occupied periods, the opening of the windows is managed by the occupants, as previously explained, but if the outdoor conditions are worse than inside (too cold or too hot), the mechanical ventilation is operated with a fixed air flow rate of 0.5 ach and the heat recovery is operated in case of excessively cold conditions. The use of the shading devices is considered in the simulation building model by means of a shading factor of 0.8, and its operation is modelled to mimic the control action that users operate to prevent the summer overheating. The shading operation starts when outdoor running mean temperature exceed the 10 °C, which corresponds to an indoor operative temperature of 25 °C, considered as the "summer comfort condition" lower limit according to the standard EN 15251 (CEN 2007b). Exceeding this threshold, the occupants are presumed to operate actively in controlling the indoor air temperature. According to the national TRY of Milan and Messina, this period is set to: 28th April – 14th October for Milan and 3rd April – 30th November for Messina. In these periods two types of shading control are considered: during the unoccupied hours shading devices are deployed, while during the occupied time the shading systems are activated only when the beam solar radiation incident on the windows exceeds 150 W m^{-2}.
The economic evaluation of the possible EEMs has been conducted according to the comparative framework methodology of cost-optimal level, proposed by the EU 244/2012 (European Commission, 2012). The Net Present Value (NPV) of the possible combinations of retrofit solutions is calculated to define their associated economic benefits. This approach allows the analysis of different time series of cash flows related to each interventions. The NPV is evaluated for a lifespan of 30 years and it takes account of the initial Investment Cost (IC) for the retrofits; the Annual Energy Cost (EC) for energy supply and the Maintenance Cost (MC), for preserving and restoring the building and its elements; 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, 2009). To determine the EC the fuel and electricity price rising is also considered (Table 3).

4.3 Results of the first optimization

Figure 1 reports some of the results of the optimization process for different Climates and S/V ratios. The starting building configuration is indicated with a square. The graphs show the relationship between Primary Energy demand for Heating (EPH) and Net Present Value (NPV). The Weighted Discomfort Time (WDT) is represented in different colors: blue for the solutions with the lowest WDT, red for those with the highest values. The results of the first optimization show some clear trends:

i) in climates with predominant heating needs (Milan) and for larger S/V ratios, the economic efficiency of different ESMs is higher than in the other cases. This is due to the high running costs of the cases with unfavorable starting conditions, where introducing retrofit interventions can reduce significantly this cost item;
ii) decreasing S/V ratios makes the economic efficacy not always possible. This trend is emphasized in the hottest climate (Messina) for smaller S/V ratio and south oriented windows, with no solutions economically viable. That

is because the better the starting conditions are, the more difficult is to define economically advantageous solutions;

iii) increasing S/V ratios leads to a smaller number of solutions with EPH and WDT better than the cost-optimal ones, but with the possibility of meeting all the three objectives and reach an absolute optimum;

iv) the orientation of the windows influences considerably the EPH and the WDT. As it could be expected, windows South exposed lead to lower EPH and for these cases in hotter climate the optimal solutions are characterized by the introduction of a smaller level of EEMs. On the other hand, South orientation brings the problem of summer overheating, indeed these cases are characterized by higher WDT level;

v) the thermal characteristics of the opaque envelope influence the definition of the optimal solutions: the cases with better transmittance values (REF 2) are characterized by smaller insulation thickness addition, while, in Messina, the substitution of the window with a double glazing system is the only considered measure;

vi) the optimization in terms of internal comfort evidences the competing among the objectives; in fact, reducing the EPH of the buildings increases the WDT, probably due to the summer overheating;

vii) regarding the typology of EEMs, the thickness of the external insulation increases according to the heating needs and the external surface area, but it reduces considerably the achievement of high level of internal comfort. The factors that influence more the WDT are the SHGC of the glazing system and the introduction of the mechanical ventilation system: the best comfort level is achieved with low SHGC values and with the use of mechanical ventilation. On the other hand, both of the systems, because of the important investment costs, are not economically effective.

Once defined the optimal solutions for the different starting cases, the role played by the government subsidies, to promote solutions not economically attractive, but optimal in terms of energy savings and indoor thermal comfort, has been investigated.

4.4 Subsidies Definition

In Italy, the investments for energy retrofitting of residential buildings are currently funded with a 65 % incentive, which is going to decrease to 50 % next year. Incentives are given as tax relief over a period of 10 years and just up to a total amount of 60 000 EUR for each residential unit or 100 000 EUR for common parts of multi-flat buildings. Only interventions that guarantee the fulfillment of energy requirements are funded.

The aim of this work is to test a rational methodology, to define the amount of incentive able to make the most efficiency solutions also economically viable. Considering just the optimal solutions on each Pareto front, we calculated the necessary incentive to lead the best performing solutions (according to energy and comfort aspects) to the economic profitability. The NPV of the cost optimal solution (hereafter called NPV_{opt}) is taken as a reference for the economical profitability analysis. In this way it is possible to identify all the Pareto solutions with better EPH and WDT compared to the cost-optimal one. Among these solutions we chose those with the highest NPV (hereafter called NPV_{ref}) than the optimal one. The Net Present Value of the total incentive needed is then:

$$\Delta NPV = (NPV_{ref} - NPV_{opt}) \quad (5)$$

The single annual rates (AR) are calculated for a period of 10 years with a discount rate (dr) of 3 % by dividing the total incentive by the discount factor for identical annual payments (DF) as follows:

$$AR = \Delta NPV/DF \quad (6)$$

$$DF=((1+dr)^{10} -1)/(dr*(dr+1)^{10}) \quad (7)$$

Finally the total incentive (TI) is provided as a percentage of the Investment Cost (IC):

$$TI = 10AR / IC \% \quad (8)$$

In table 4 the total incentives calculated as IC percentages have been averaged between East and South.

Table 4: Total incentive percentages (TI) calculated as average of the two orientations

S/V ratio	REF1 - MILAN		REF2 - MILAN		REF1 - MESSINA		IC percentage REF2 - MESSINA	
	IC [kEUR]	IC percentage	IC [kEUR]	IC percentage	IC [kEUR]	IC percentage	IC [kEUR]	IC percentage
0.97	27.240	**53 %**	24.683	**57 %**	30.673	**63 %**	26.224	**79 %**
0.63	22.892	**64 %**	21.845	**74 %**	30.124	**83 %**	25.355	**96 %**
0.3	21.221	**82 %**	19.092	**96 %**	25.704	**108 %**	23.177	**118 %**

It can be seen that the average absolute incentive needed is higher for cases with higher S/V, while considered as percentage of investment cost, buildings with lower S/V ratio should be funded for a larger percentage of their investment cost. It should be underlined that the method gives as result the application of the same percentage on the initial investment cost for all the interventions, with the same S/V ratio, though not attaining energy requisites, and this percentage is the maximum possible for the same REF case. In Messina the incentive needed should be extremely high.

REF 1 (EPH-NPV) SOUTH

MILANO (0.3 – 0.63 – 0.97) **MESSINA (0.3 – 0.63 – 0.97)**

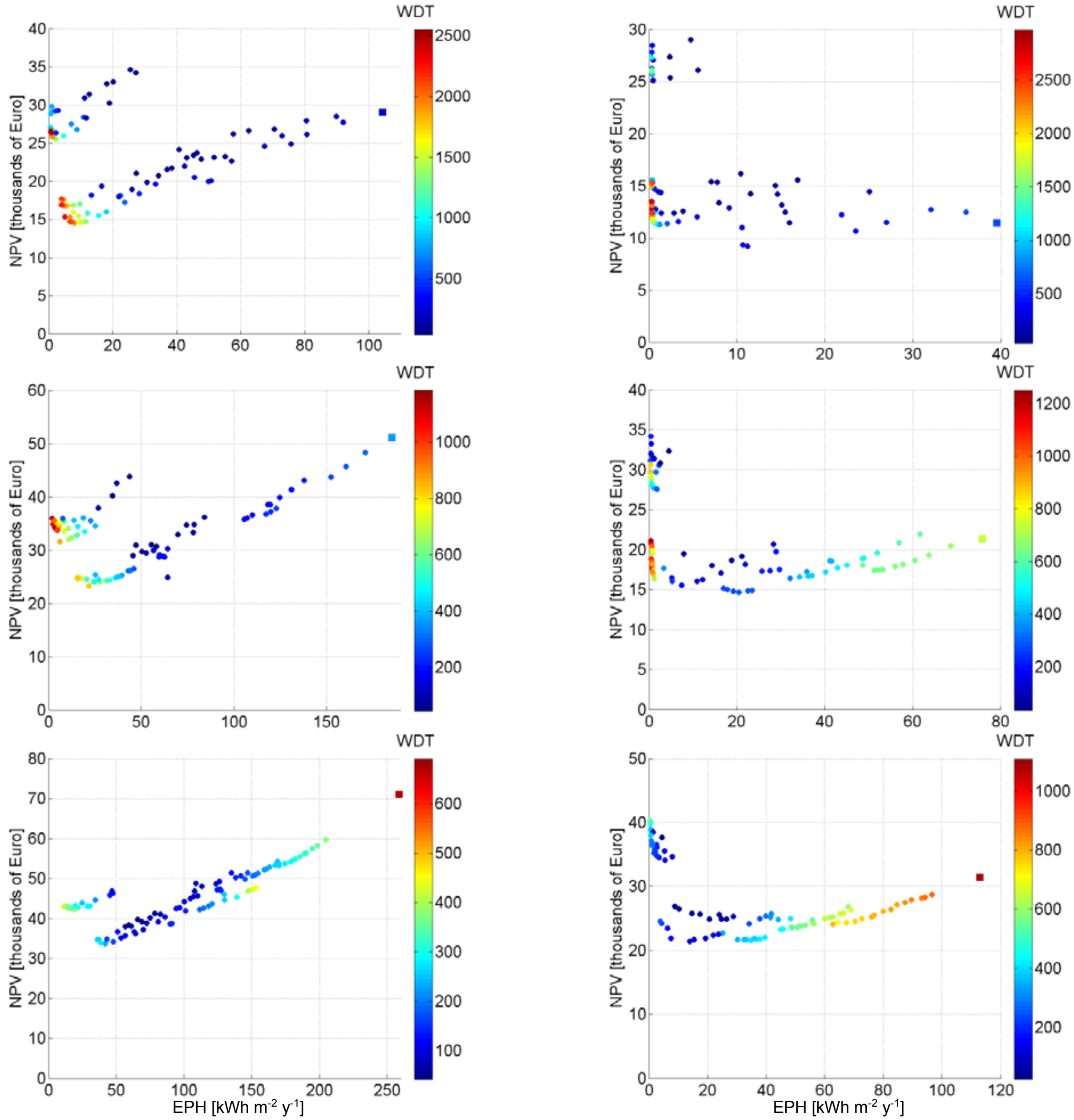

Figure 1: Results for the first optimization (without incentives) for the different cities and S/V ratios of the Pareto surface for the cases REF 1 with windows South oriented. The colors on the right represents the WDT in [K h]

5. SECOND MULTI-OBJECTIVE OPTIMIZATION

In order to verify how the incentives can influence and change the definition of the optimal solutions, a second optimization has been run, in which the single annual rates, calculated for a period of 10 years, are added to the cash flow in the calculation of the NPV. Table 5 and Figure 2 report the results of the second optimization for the REF 1 cases located in Milan. These cases have been chosen to perform this second optimization, because they represent the situations in which the EEMs can bring more benefits in terms of energy savings. The results show that:

i) the optimal solutions and the NPV values of the Pareto solutions change considerably, but the two Pareto surfaces (without and with incentives) are not significantly different in terms of EEMs;
ii) the introduction of the incentives into the economic analysis leads to cost-optimal solutions with higher energy performance, but with worse indoor thermal comfort, such as the substitution of glazing system with triple glazing instead of double for the cases with 0.3 ratio, and higher insulation thickness in the other cases;
iii) the best solutions, in terms of comfort, are the ones with low SHGC windows and with the mechanical ventilation system, but the incentives are not able to transform these ones in cost-optimal solutions;
iv) the NPV of the cases with incentives is always lower compared with the optimal solution without incentives. This means that through incentives the economic profitability of all the solutions, even of the ones with better thermal comfort, has been improved.

Table 5: List of retrofit measures applied to the optimal solutions for Messina (ME) and Milano without (MI-WO) or with incentives (MI-WI), case REF 1. EPH is expressed in (kWh/m^2/ y); NPV in (kEUR); WDT in (K h).

	S/V 0.3						**S/V 0.63**						**S/V 0.97**					
	EAST			**SOUTH**			**EAST**			**SOUTH**			**EAST**			**SOUTH**		
	ME	MI-WO	MI-WI	ME	MI-WO	MI-WI	ME	MI-WO	MI-WI	ME	MI-WO	MI-WI	ME	MI-WO	MI-WI	ME	MI-WO	MI-WI
COST-OPTIMAL																		
Wall	9	19	18	17	15	15	14	15	17	17	17	19	14	15	18	12	17	18
Roof							10	13	18	10	19	19	11	12	19	9	14	18
Floor													12	13	18	10	15	17
Win	DH	DH	TH	0	DH	DH	DH	DH	DH	0	DH	DH	DH	DH	TH	DH	DH	DH
Boiler	STD	STD	MD	STD	STD	STD	STD	MD	CD	STD	STD	MD	STD	CD	CD	STD	MD	MD
Vent	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD
EPH	2	17	10	11	8	8	9	33	26	20	22	16	23	54	43	14	42	37
NPV	12	17	8	9	14	14	18	27	17	15	23	14	25	37	25	21	34	24
WDT	358	1067	1142	343	1864	1864	104	337	437	294	851	901	51	118	171	107	240	313
v) COMFORT-OPTIMAL																		
Wall	4	2	2	3	2	2	11	4	3	8	3	3	17	15	11	15	16	17
Roof							19	17	19	11	18	18	19	19	19	19	17	18
Floor													18	10	9	15	9	10
Win	TL	TL	TL	TL	TL	TL	DL	DL	DL	TL	TL	TL	DL	DL	DL	DL	DL	DL
Boiler	MD	STD	STD	MD	STD	MD	MD	MD	MD	MD	MD	MD	MD	CD	CD	MD	MD	MD
Vent	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD
EPH	10	53	53	7	43	38	9	71	57	8	47	62	15	66	64	10	59	56
NPV	16	26	19	15	23	15	22	35	24	20	31	25	29	41	30	27	38	29
WDT	34	40	40	41	40	40	32	51	49	36	46	46	24	44	44	26	43	43
vi) ENERGY-OPTIMAL																		
Wall	7	16	16	15	17	20	20	18	20	15	18	19	17	19	19	18	17	18
Roof							17	20	20	17	20	20	20	19	20	20	19	19
Floor													19	19	19	19	19	19
Win	TL	TH	TH	TH	TL	TL	TL	TH	TH	TL	TH	TH	TH	TH	TH	TH	TH	TH
Boiler	STD	STD	STD	STD	STD	STD	CD	CD	CD	STD	CD	CD	CD	CD	CD	CD	CD	CD
Vent	MVS	MVS	MVS	STD	MVS	MVS	MVS	MVS	MVS	MVS	MVS	MVS	MVS	MVS	MVS	MVS	MVS	MVS
EPH	0.3	0.5	0.5	0.3	0.5	0.5	0.3	5.9	5	0.3	2.1	1.8	1.1	23	23	0.4	12	11
NPV	26	27	14	14	27	13	35	37	22	31	36	21	40	47	31	40	43	30
WDT	135	1286	1286	2779	974	1109	114	619	658	282	1172	1212	128	274	280	536	427	442

From the results of this second optimization is possible to come to the conclusions that incentives may overcome the upfront costs of some retrofit solutions at the expenses of the indoor thermal comfort. In fact, especially in the cases where the problem of summer overheating is higher (smaller S/V ratio and South orientation), the incentives increase the WDT. This could push the users to introduce cooling system to control the indoor environmental conditions during the summer periods, worsening the energy performance of the building. The financial policies should not be given indiscriminately to every kind of retrofit actions; on the contrary they should promote solutions able to improve the thermal comfort aspects, cutting down the barriers due to the higher investment costs.

MILAN REF 1 (EPH-NPV)

EAST (0.3 – 0.63 – 0.97) **SOUTH (0.3 – 0.63 – 0.97)**

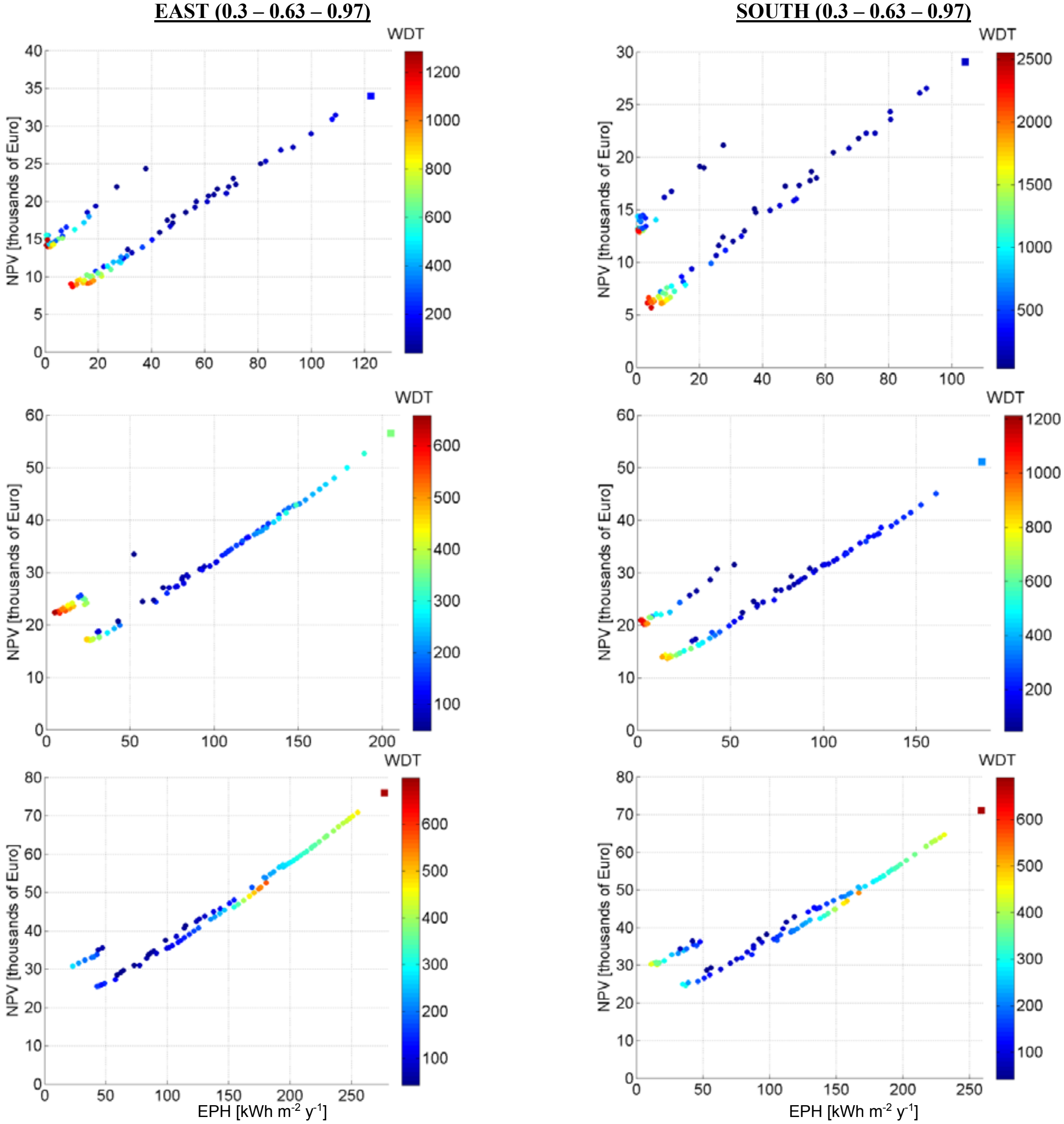

Figure 2: Results of the second optimization for Milan, reported according to the windows orientation and S/V ratio. The colored scale on the right of each plot represents the WDT expressed in [K h].

6. CONCLUSIONS

During the retrofit phase of a building it is important to choose solutions that optimize different aspects. The improvement of energy efficiency, the minimization of the total cost of the building during a 30-year lifespan and the maximization of the indoor thermal comfort constitutes the objectives of the optimization process of this work. A Genetic Algorithm coupled with a simulation tools have been used to investigate the most promising strategies for a set of different residential building modules, differing each other for the initial characteristics and for the climate context in which are located. The crucial role that incentives can play in promoting solutions not economically profitable, but optimal under the energy and the indoor comfort point of views, is demonstrated. Subsidizing equally the retrofit measures increases the economic profitability of the refurbishment and promotes the introduction of higher level of EEMs, but it could worsen the indoor thermal comfort, especially in those cases where the problem of the summer overheating is higher (smaller S/V ratio and South orientation). The financial subsidies should then address the choices in retrofitting, incentivizing solutions with higher thermal comfort that are not usually selected as optimal ones because of their higher investment costs. Further development of this research will be the testing of incentives related to specific EEMs, in order to verify their effectiveness.

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