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Assessment of the impact of a centralized heating system equipped with programmable thermostatic valves on building energy demand

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Abstract

The aim of the work presented in this paper concerns the assessment of actual energy savings achieved adopting a common tool of building thermal automation systems such as thermostatic valves. The idea comes from the study of the European Standard CEN EN15232 "Energy performance of buildings - Impact of Automation, Controls and Building Management" which highlights how the inclusion in buildings of automation systems leads to a reduction of energy consumption for the whole building. Starting from here, the actual advantages for the single user in adopting programmable thermostatic valves was evaluated taking into account the possible differences in heating energy demands due to an on/off timetable customization. The case study is a reference building sited in three different locations in Italy with two different values of envelope insulation. By means of Trnsys17 tool the reference building was divided into six thermal zones each one modelling an apartment. The possibility to customize the on/off timetable, through the use of programmable thermostatic valves, may introduce thermal dispersions. As a matter of facts when a user switch off his heating terminals his apartment tends to be a heat sink for the adjacent ones. The purpose of this study is to evaluate if the switching inhomogeneity due to the customization may constitute sensible energy penalties to other users. The results of this study may provide a contribution to the definition of the correct management policies of the terminals customization in order to optimize the use of the building automation systems.

Keywords: Trnsys; Building automation; Thermostatic valves; Energy savings.

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1. Introduction

On average, in Europe, a person spends about 90% of his time inside buildings. Residential and tertiary sectors are always treated as one big whole whose energy consumption is growing steadily and whose potential energy savings is largely studied between researchers [1-4]. The typical services provided in a building, such as space heating and cooling, lighting and appliances, nowadays are increasingly complemented by new types of consumption represented by telecommunications networks, data storage services and growing general level of home entertainment. The residential buildings, representing more than half of the whole national housing stock, have an important weight in the energy consumption of buildings and a negative impact on the air quality of large urban centers [5]. The Italian building stock can be defined as "old" and very inefficient, since most of the buildings date back to an era in which there was a high level of welfare and the management costs didn't constitute a great problem. Modern buildings from the last twenty years, built in compliance with energy regulations, usually have consumption for heating between 80 and 100 kWh/m^2 per year, while a typical old building, requires about 120 kWh/m^2 per year; more severe cases then, with massive type envelope and with extremely energy-intensive and inefficient plant, can reach values of more than 300 kWh/m^2 per year. Regarding the typology of construction, the condos in Italy represent nearly 70% of the homes of Italians and technological plant solutions provided for these compact housing groups are far from being aimed at containing consumption [6].

In this context the Decree 4 July 2014 n. 102, "Implementation of Directive 2012/27/EU on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU, and repealing Directives 2004/8/EC and 2006/32/EC" [7], establishes a framework of measures for promoting and improving building energy efficiency. The ultimate goal is the achieving of the national indicative energy savings target, which means to reduce, by 2020, 20 million of TEP, counted from 2010. Among the measures contained in the Decree, regarding the condo properties, it was scheduled as mandatory the installation of individual thermoregulation and heat accounting systems, from 31 December 2016. More specifically, among the solutions proposed, they recommended the adoption of building automation systems [8] such as individual temperature control and heat metering systems for measuring heat consumption of each radiator installed inside each apartment [9-10].

This study aims at evaluating the effects of the adoption of an energy efficiency measure such as programmable thermostatic valves, focusing on the actual obtained energy savings [11]. These effects are studied taking into account of the results of energy demands of single apartments and of whole building, by means of a BES software as Trnsys 17, a powerful tool used to perform several kind of dynamic energy simulations [12]. The effective energy advantages obtained by the users are evaluated assuming different on/off customization scenarios and comparing the simulation results with those obtained in case of maximum number of power-on hours allowed by current law.

Nomenclature

CLV	Current Law Value
WPV	Worse Performance Value
ISED	Ideal specific energy demand for space heating
S_P0	Ground floor apartment, south side
N_P0	Ground floor apartment, north side
S_P1	First floor apartment, south side
N_P1	First floor apartment, north side
S_P2	Second floor apartment, south side
N_P2	Second floor apartment, north side
C1	Customization 1 (the schedule chosen by user 1)
C2	Customization 2 (the schedule chosen by user 2)
U	Thermal transmittance
g	Solar factor
α	Solar absorbance
ε	Thermal emissivity

2. Methodology

The study was carried out considering a three floors building model for residential use with six apartments, two for each floor. The orientation of the building is such that the apartments have basically south or north facing and this is the reason why each apartment acronym is characterized by a number that represents the floor and a letter that point out the orientation. This virtual building was considered sited in three different towns of Italy, Milan, Palermo and Rome, with two different values of envelope thermal insulation [8]. For what concerns the on-off schedule customization of programmable thermostatic valves, only two kinds of users have been considered.

2.1. Building model

The building model is simple: it is composed by six apartments each with usable floor of 81 m^2 and interfloor height of 3 m. The glazed surface on each external wall is about 25%. For the sake of clarity, in Fig. 1 are shown both the 3D model (a) of the building, with its orientation, both the names given to each heated zone.

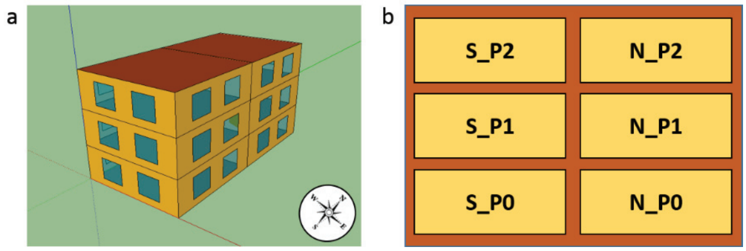

Fig. 1. (a) 3D building model overview; (b) view of acronyms used to name apartments.

The elements that constitute the envelope change according to the climate zone of the city where is sited the building. In fact, their thermophysical features are strictly related to climate conditions. Since two sets of simulations have been carried out, as a function of two values of building envelope thermal insulation, in the Table 1 are reported these values in the CLV case, when the law limits of thermal transmittance are respected.

Table 1. Opaque and glazed elements thermophysical features, CLV case.

Town	Type	U *($W/m^2 K$)*	α	ε	g
Milan	Wall	0.298	0.6	0.9	-
	Ground floor	0.310	0.6	0.9	-
	Roof	0.260	0.6	0.9	-
	Window	1.9	-	-	0.70
Palermo	Wall	0.449	0.6	0.9	-
	Ground floor	0.481	0.6	0.9	-
	Roof	0.339	0.6	0.9	-
	Window	3.2	-	-	0.7
Rome	Wall	0.359	0.6	0.9	-
	Ground floor	0.362	0.6	0.9	-
	Roof	0.278	0.6	0.9	-
	Window	2.1	-	-	0.7

In the WPV case, when the building envelope has worse performances, the thermophysical values shown in Table 2 are adopted for the envelope elements, for all the cities considered.

Table 2. Opaque and glazed elements thermophysical features, WPV case.

Type	U *(W/m² K)*	α	ε	g
Wall	0.659	0.6	0.9	-
Ground floor	0.609	0.6	0.9	-
Roof	0.502	0.6	0.9	-
Interior partition	2.84	0.6	0.9	-
Window	5.74	-	-	0.87

Since Trnsys needs to know the entity of heat sources present inside each zone, internal gains, set for each apartments, have been taken as following:

- 3 x person seated at rest, for a total gain (sensible and latent) of 300 W;
- 2 x 140 W PC with monitor, for a total gain of 280 W;
- 5 W/m^2 for artificial lighting, 10% convective part, for a total gain of 405 W;

All these gains are scheduled to be active between 8.00 and 18.00, except in those days, such as in the weekend for C2, when apartments are empty.

2.2. Simulations scheme

As previously mentioned, the logic followed to perform the simulations has taken into account the occurrence of two different customizations, C1 and C2. In fact, the main purpose of this paper is the evaluation of actual energy savings occurring with different on-off schedules between apartments users, even in case of a retrofit intervention on the building envelope. In Fig. 2, 3 and 4 you can see the on-off schedules chosen by two virtual users (C1 and C2), for each cities considered. As is shown below, the user corresponding to the second customization, C2, is not present during the weekend, while the C1 user, decided to set the same on-off schedules both for weekdays both for the weekend. It is clear that, since the maximum number of power-on hours allowed by the current laws, depends on the climate zone, we have three C1 and C2 users (Milan, Palermo and Rome).

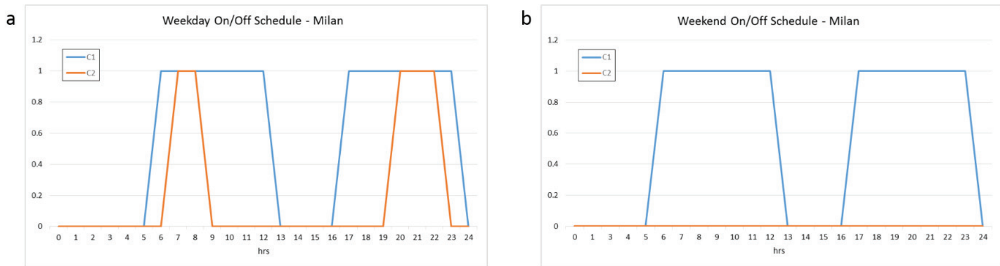

Fig. 2. (a) weekday schedule for Milan; (b) weekend schedule for Milan;

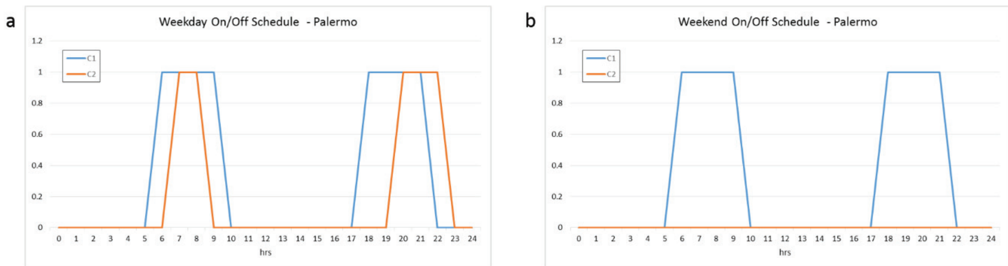

Fig. 3. (a) weekday schedule for Palermo; (b) weekend schedule for Palermo;

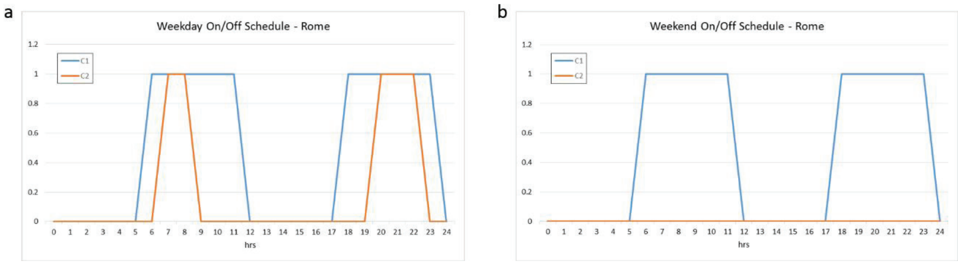

Fig. 4. (a) weekday schedule for Rome; (b) weekend schedule for Rome;

In order to have the same effects on energy demands, even though there are three different climates, and then three different C1 customizations, C2 schedules, have the same pattern. In this way, the energy demands are independent from the daily time slots and their effects depends only on the way they deal with the C1 customization.

The reference simulation (SIM 1) is the one customized with C1 schedule, that is when all the users power on the terminals for the maximum number of hours allowed by the laws. The simulations named SIM 2, SIM 3 and SIM 4, provide a user who customize differently from the others. Since we wanted to know which were the effects of a different customization in function of the apartment where it occurred, we changed, for each simulation, the apartment of the C2 customization. The last simulation, named SIM 5, provides three apartments customized with C2 schedule while the other ones are customized C1. In Fig. 5 are shown the patterns of simulations carried out.

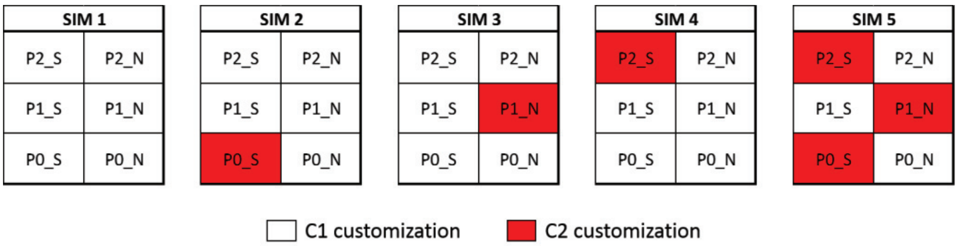

Fig. 5. The simulations carried out with the corresponding pattern of customization.

3. Results

The results will be presented starting from the WPV case (“old” building) to the CLV case. For every case, corresponding to an envelope thermal insulation value, the results regarding the three considered cities are shown. In the following tables, annual specific energy demands for space heating are shown, highlighting in red the values of the energy requirements related to those apartments customized differently from the other zones. The last column on the right is the whole building ISED. It must be pointed out that the first line in each table represents the results of the SIM 1 simulation which has been considered the reference simulation (with homogeneous customization).

3.1. WPV case

By analyzing Table 6, from SIM 2 to SIM 5 case, it is clear that a reduction of the operating time of the terminals means a 70% reduction of energy consumption, for those corresponding zones, if compared to the reference customization for all the users (SIM 1). Watching at the values from SIM 2 to SIM 4, the increasing of energy demands for the zones adjacent to the apartments customized C2, are between 0.5% and 13%. When three zones on six are customized C2, SIM 5, energy demands for the adjacent zones can grow by 30%.

Table 6. Simulations results for Milan.

	Specific energy demands *(kWh/m² · year)*						
SIM code	P0_S	P0_N	P1_S	P1_N	P2_S	P2_N	TOT
SIM 1	109.2	119.3	111.1	121.3	121.5	129.9	118.7
SIM 2	34.8	124.0	123.6	122.9	124.3	130.4	110.0
SIM 3	110.9	132.5	115.3	35.6	123.2	143.0	110.1
SIM 4	112.4	119.9	125.3	123.1	38.1	135.3	109.0
SIM 5	36.3	138.5	143.3	36.7	39.5	149.5	90.6

By observing the results for Palermo in Table 7, from SIM 2 to SIM 5 case, it occurs a 60% reduction of energy consumption, for zones customized C2. Watching at the values from SIM 2 to SIM 4, the increasing of energy demands for the zones adjacent to the apartments customized C2, are between 0.53% and 6.5%. When three zones on six are customized C2 (SIM 5), the increase in energy needs, for the adjacent zones, can grow by around 15%.

Table 7. Simulations results for Palermo.

	Specific energy demands *(kWh/m² · year)*						
SIM code	P0_S	P0_N	P1_S	P1_N	P2_S	P2_N	TOT
SIM 1	14.0	19.1	13.8	18.6	16.0	20.3	17.0
SIM 2	5.9	19.5	14.5	18.8	16.2	20.3	15.9
SIM 3	14.2	20.2	14.1	7.7	16.2	21.3	15.6
SIM 4	14.3	19.2	14.7	18.8	6.6	20.7	15.7
SIM 5	6.1	20.7	15.9	7.8	6.8	21.8	13.2

In Rome, in WPV case, a reduction of the operating time of the terminals, means a reduction of energy needs, for those corresponding zones, between 46 % and 54%, compared to the reference simulation SIM 1.

Table 8. Simulations results for Rome.

	Specific energy demands *(kWh/m² · year)*						
SIM code	P0_S	P0_N	P1_S	P1_N	P2_S	P2_N	TOT
SIM 1	34.2	40.6	36.0	42.2	37.3	42.6	38.8
SIM 2	18.3	41.2	37.1	42.4	37.8	42.8	36.6
SIM 3	34.5	42.0	36.7	21.6	37.6	44.0	36.1
SIM 4	34.6	40.7	37.2	42.5	20.1	43.4	36.4
SIM 5	17.2	64.2	57.0	19.2	19.0	68.5	40.9

The unusual fact is that SIM 5 returns global values even higher than all other simulations. In this case the disadvantages due to the increase of energy demands of adjacent zones customized C1 (SIM 5), are more important than the advantages due to the reduction of the energy needs of the single apartments customized C2, even if compared with the reference simulation (SIM 1).

3.2. CLV case

As previously said, in the CLV case the envelope thermal insulation value is set as required by the current laws. With this sensitivity analysis we would to modeling a typical retrofit strategy used to improve the envelope performance. Observing the values of IED for each zone in Table 3, from SIM 2 to SIM 5 case, it is clear that a reduction of the operating time of the terminals, means a sensible reduction (-60 % / -70%), for those corresponding zones, of energy needs, if compared to the reference customization for all the users (SIM 1).

Table 3. Simulations results for Milan.

Specific energy demands *(kWh/m² · year)*							
SIM code	P0_S	P0_N	P1_S	P1_N	P2_S	P2_N	TOT
SIM 1	47.9	56.9	47.6	56.3	55.2	62.1	54.3
SIM 2	17.8	60.0	55.3	57.4	57.2	62.5	51.7
SIM 3	49.2	65.4	50.2	18.6	56.4	70.4	51.7
SIM 4	50.3	57.4	56.6	57.7	20.0	65.7	51.3
SIM 5	19.1	69.7	68.4	19.4	21.2	75.2	45.5

For those zones adjacent to the apartment with C2 customization, it is possible to notice that energy demands increase, even up to values higher than 40%. The trend of specific energy demands for whole building decreases but the advantage due to the reduction of energy demands related to zones with C2 customization doesn't seem to have the same global effects. By observing the values of IED in Table 4, the reduction of energy needs is around 20%.

Table 4. Simulations results for Palermo.

Specific energy demands *(kWh/m² · year)*							
SIM code	P0_S	P0_N	P1_S	P1_N	P2_S	P2_N	TOT
SIM 1	6.1	10.3	6.1	9.5	7.6	10.2	8.3
SIM 2	4.8	10.4	6.2	9.5	7.6	10.2	8.1
SIM 3	6.1	10.5	6.1	7.5	7.6	10.4	8.1
SIM 4	6.1	10.3	6.2	9.5	6.0	10.3	8.1
SIM 5	4.9	10.6	6.4	7.6	6.0	10.5	7.7

Anyway, SIM 5 returns global values lower than the others, for Milan and Palermo. It is not the same by observing Table 5, where are shown the results of Rome. In this case the disadvantage due to the increase of energy demands of adjacent zones customized C1 (SIM 5), provides a higher total energy need for the whole building, if compared with SIM 2, SIM 3 and SIM 4.

In the city of Rome, a reduction of the operating time of the terminals means a reduction of energy needs, for those corresponding zones, between 53% and 63%, compared to the reference simulation SIM 1.

Table 5. Simulations results for Rome.

Specific energy demands *(kWh/m² · year)*							
SIM code	P0_S	P0_N	P1_S	P1_N	P2_S	P2_N	TOT
SIM 1	18.0	26.5	17.9	25.8	21.6	28.9	23.1
SIM 2	8.3	21.1	16.7	21.5	17.7	22.2	17.9
SIM 3	15.3	21.8	16.5	11.0	17.6	23.1	17.6
SIM 4	15.4	20.8	16.8	21.5	9.6	22.6	17.8
SIM 5	7.7	31.1	24.2	9.4	8.9	33.7	19.2

4. Conclusions

In this paper, the effects of different customizations in the on-off scheduling of programmable thermostatic valves have been evaluated. In particular, two kinds of customizations have been adopted: the first take into account the maximum number of power-on hours permitted by current laws, C1, in each climate zone; the second, C2, is a customization of a user who is used to spend less time at home. Two values of building envelope thermal insulation have been set, thus modeling two kinds of building: an "old" building and a retrofitted one. This choice is linked to the fact that the usual intervention adopted to minimize the heat dispersion through the building envelope is the thermal coat. The analysis carried out in this last case underline the necessity to improve the thermal resistance of interior walls. The simulations have been carried out for three italian cities: Milan, Palermo and Rome. By changing the apartment where C2 customization occurs, the corresponding energy balances have been obtained, observing a sensible expected reduction for the zones customized C2, while the zones adjacent to C2, provide an increasing in energy demands. Moreover, a simulation with three on six apartments customized C2 has been carried out, providing global energy savings for the whole building in the case of Milan and Palermo, while for Rome it occurred an increasing of 1% of energy needs. The results obtained might help to develop a logic for optimizing the customization of the thermostatic valves in order to reach the best configuration, in terms of energy savings, both for users both for the whole building. In addition, the study underline that different customizations may introduce the necessity to improve the insulation values of inter-apartment partition to make the effect of these customization an advantage both for a single user bot for the whole building.

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