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Effect of occupant behavior and control systems on the reduction of energy needs of residential buildings

Giovanni Semprini[a]*, Davide Barbieri[b], Alessandro Gober[b], Francesca Zandi[b]

[a]DIN University of Bologna, Via Risprgimento 2, Bologna 40136, Italy
[b]Energetic Consultants, Bologna, Italy

Abstract

Adoption of energy metering systems in apartments with centralized heating plant will lead to greater awareness of the users on energy consumptions. Moreover control systems allow to manage internal temperature according to kind of occupation of the apartment.
Starting from the energy consumption of a case study, an apartment block in Bologna, this paper shows the results, based on dynamic simulation, of reduction of energy needs resulting from retrofitting on the building envelope and the effects of thermoregulation systems. Different setting of the internal temperature in adjacent apartments can lead to a variation of energy consumption up to 30%.

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Keywords: building energy needs; occupant behaviour; control systems; dynamic energy simulation; thermostatic radiator valves

1. Introduction

The buildings dated back to the Italian economic boom of 60's and 70's are the biggest part of the national heritage building. In general they have an envelope with very poor thermal insulation and a central heating system with high energy consumption, sometimes due to the lack of a proper control system, obsolete components and a not balance pipe network. This group of buildings is one of the first target to be addressed to reduce primary energy consumption and CO_2 emission, through building envelope renovation and improving the plant system with more efficiency component and use of renewable sources.

* Corresponding author. Tel.: +39-051-2093286; fax: +39-051-2093296.
E-mail address: giovanni.semprini@unibo.it

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Many authors analyze solutions for energy retrofit of existing buildings: from systematic methodology for appropriate retrofitting [1], to the analysis of different solutions in traditional buildings related to the envelope and the heating plant systems [2], to more advanced retrofit approaches to nearly zero energy building also related to socio-oriented urban environments [3].

Despite many technical solutions for energy retrofitting of the whole building-plant system are now consolidated, high payback time of economic investments are the main cause of the slowdown of the interventions on the existing buildings, especially for those with central heating systems. For those buildings high energy consumption are sometimes due to lack of thermal control systems, in particular for apartments with different thermal loads due to different solar exposition or internal loads. In this case a simple solution, also required by national regulation, is to provide each heating terminal unit (radiator or convector) of thermostatic valve in order to control the indoor temperature.

Furthermore recent national laws [4], according to the European Directive 2012/27/EU [5] about energy efficiency, makes it mandatory the installation of appropriate thermal energy accounting systems for all existing buildings with central heating plant within December 31st 2016. This could become a strong incentive for occupants to control internal temperature for energy saving.

The paper aims to analyze the effect on energy saving with the use of local control system with thermostatic valves installed on each radiator and to show how different temperature set by users inside the apartments can lead to unwanted heat flows between adjacent flats.

2. Case study

The case study presented in this paper is a residential multi-floor building, built in 60's, located in the northern suburbs of the city of Bologna. It's a 8 floor building and it's divided into 64 apartment.

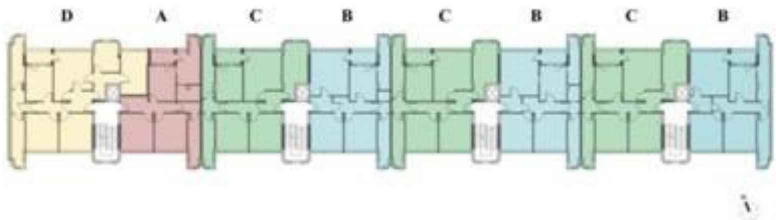


Fig. 1. Plan of a floor type

In the actual situation there are three different types of opaque walls: bearing structure of reinforce concrete, internal and external masonry walls, and precast concrete panels on the facades characterized by ribbon windows. Windows are made by aluminium frame with thermal break and simple double glazing. Tables 1-2 report thermal characteristics values for all building envelope structure types, both for actual situation and the adopted retrofitting solution.

The specific annual mean energy consumption of the whole building in the actual situation only for heating (based on measurement of delivered thermal energy supplied by a district heating system) is about 190 kWh/m^2 year, with values of 110-130 kWh/m^2 year for internal flats and 220-250 kWh/m^2 year for external flats (1st and 8th floors). Although the shape of the building is quite compact, high energy consumption depend not only to low thermal performances of building structures, but also to low efficiency of plant: the mean global efficiency including district heating and local distribution and control system is evaluated equal to 68%. Measurements inside some apartments, also confirmed by energy simulation on the whole building, give an internal mean temperature of about 22.5°C, sometimes with large difference of temperature (3-4°C) between flats and inside the same flat, that demonstrate high energy dispersion.

A typical energy retrofitting for the envelope, require an increase of the thermal insulation, like an external thermal coat and replacement of windows. For the building under study, a thermal insulation layer of 12cm of rock wool added to the external walls and the replacement of windows by a low emission one was supposed.

Table 1. Opaque surfaces technical data.

Opaque Surface	Actual situation		Retrofitting solution	
	d [m]	U [W/m²K]	d [m]	U [W/m²K]
Wall 01 (brick structure)	0,36	1,09	0,48	0,231
Wall 02 (brick structure)	0,32	1,12	0,36	0,258
Wall 03 (concrete structure)	0,32	2,84	0,44	0,266
Floor	0,28	1,71	0,32	0,281
Roof	0,27	1,55	0,39	0,254

Table 2. Windows technical data

Window	Actual situation			Retrofitting solution		
	d [mm]	Gas gap	U_w [W/m²K]	d [mm]	Gas gap	U_w [W/m²K]
Double glazing	3-13-3	air	2,058	6-16-6	argon	1,2

Although retrofitting solutions on the envelope are to be recommended, usually the first intervention on existing buildings is to improve the energy efficiency of terminal units and of control systems inside each rooms introducing thermostatic valves (TRV) mounted on each radiators (or convector), which realize a local thermal control system.

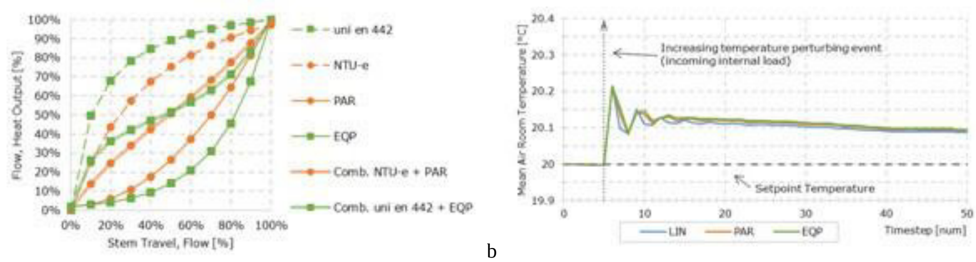
The study of energy performances of the building and the energy consumption of each apartment with different situations was performed with EnergyPlus software [6-7]. The period of simulation is the whole winter period from 15 October to 15 April.

3. Thermostatic valve and temperature control system

Two different approaches were compared, which lead to different performance assessments: first one using the standard energy performances of product (EN 442 [9]) dealing with radiators and convectors as plant terminal units, rather than algorithm that models them as a generic counter-flow heat exchangers (NTU approach).

In EnergyPlus many control types are pre-defined, but nothing with the TRVs properties as intended. However, by using the Energy Management System (EMS), is possible to introduce almost any control system combining into algorithms the sensors, actuators, and every own defined parameters through a basic and simplified programming language (EnergyPlus Runtime Language – Erl) for which the same calculation engine serves also as a parser.

In this paper we looked for a linear relationship between the process variable (room air temperature) and the parent variable (heat output from terminal unit) under the hypothesis of a linear behavior of the thermal problem (i.e. fixed room air temperature value by means of a variation of the thermal power delivered by a terminal unit) [8].



a b

Fig. 2. (a)Terminal and valve characteristic curves combinations to obtain linear output; (b) Room air temperature trend following a perturbing event with different curve types for the actuator

As shown in Fig.2, the output terminal unit as implemented into EnergyPlus with baseboard objects is better matched by a valve parabolic characteristic curve. This type of curve applied to the actuator shows up a more accurate process variable control.

Thermostatic radiator valves with a proportional band equal to 2°C installation brings to better comfort conditions in all the rooms because they take advantage of both endogenous and exogenous thermal gains, varying in time and space into the apartment.

4. Results

A first analysis is related to the effect on introducing thermostatic valves and setting the same value of internal temperature for each apartment. Calculation are performed with a common set point of 20°, even if in practical cases a higher temperature (21°C) can be held for comfort conditions. A reduction of the primary energy consumption of about 25-30% was estimated.

In order to analyze the effect of different internal temperature set point and to evaluate the variations in energy consumption between adjacent apartment, dynamic simulation was performed on a group of nine neighboring apartments, as indicated in Fig.3. The name of every apartments has been assigned as a letter, which indicates the typology, followed by a number, which indicates the floor. Six of these apartments (type A and C) have got only north-south exposition and the others three (type D) have also west exposition.

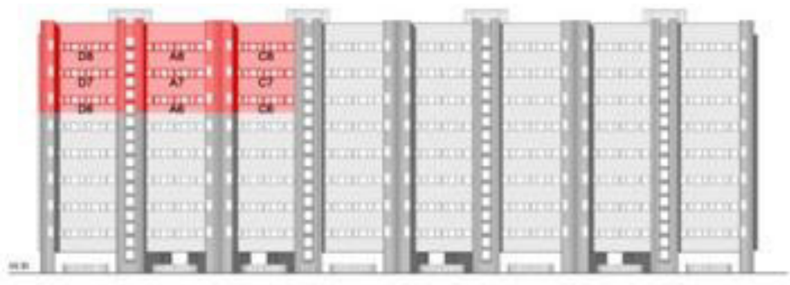


Fig. 3. Block of nine apartments simulated

The following results compare the actual situation, the building retrofitting solution and the internal set-point options, evaluated with a climatic data of the reference year of Bologna (G. De Giorgio collection). Results are intended as the delivered energy to terminal units.

A global retrofitting solution on the envelope give a general reduction of energy consumption of about 50% in every apartment.

Other analysis was carried out to study how a different inner temperature can affect the energy consumption of the neighboring apartments. Calculations are performed for the existing building with actual structures (case 1), for retrofitted external envelope (case 2) and in case with internal and external insulation (hypothesis of new building with internal structures, separating each apartments, having a thermal transmittance of 0.8 W/m^2K). For each case a variation of the internal temperature condition of apartment A7 is considered and the variation of energy consumption of adjacent apartments are evaluated. The internal temperature set-up (Tset) are as follow:

- Tset= 20°C in every apartment
- Tset= 18°C in A7 and Tset= 20°C in others adjacent apartment
- No heating in A7 and Tset= 20°C in others adjacent apartment

4.1. Case 1

In Fig. 4 the energy consumptions of the apartments A8, C7, D7, A7, A6 are shown and in Table 3 the increase compared with the situation in which A7 is at 20°C. The increase depend mainly on the area of the boundary surfaces with apartments A7: from a minimum of 2% to a maximum of 28% for the apartment A6 (which is below A7 when the latter is not heated). Only the apartment D7 presents a really little increase due to the fact that the common surface with apartment A7 is only 12m^2. Conversely, the apartment A7 presents high reduction in energy consumption (45%) maintaining only 2°C below.

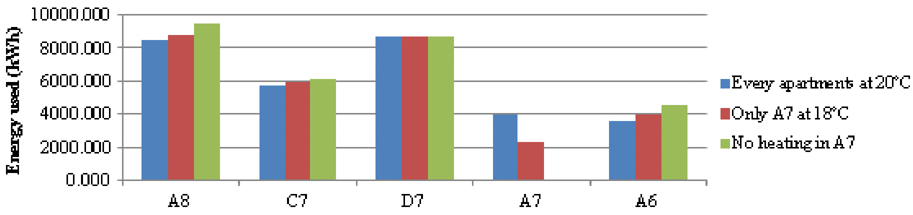


Fig. 4. Energy consumption of apartments A8, C7, D7, A7, A6

Table 3. Increase of energy consumption

	A8	A6	C7	D7
A7 indoor air temp 18°C	4,3%	10,0%	2,1%	0,16%
A7 not heated	11,4%	28,1%	5,7%	0,4%

4.2. Case 2

In this second while case absolute values of the energy consumption are in general lower than case 1, the percentage differences are more evident (increase of 35% for apartment A6)i

Table 4. Percentage of energy consumption

	A8	A6	C7	D7
A7 indoor air temperature 18°C	11,9%	16,3%	4,7%	0,5%
A7 not heated	24,0%	34,9%	9,7%	0,9%

4.3. Case 3

In this case every walls (internal and external) and floors have high thermal insulation performances. The heat fluxes between A7 and adjacent apartments are reduced and their increment on energy consumption are lower and sometimes negligible. Better results can be achieved with an higher thermal insulation of internal structures.

Table 5. Percentage of consumption

	A8	A6	C7	D7
A7 indoor air temperature 18°C	5,3%	8,0%	2,8%	0,24%
A7 not heated	15,5%	24,1%	8,4%	0,8%

5. Conclusion

The introduction of local control system in existing building, like thermostatic radiator valves acting on each room, allows not only to obtain better comfort conditions but also a general reduction in heating energy consumptions. Anyway this control system combined with local energy metering systems, brings the user to a more conscious behavior, sometimes leading it to maintain indoor thermal condition lower than usual with the purpose of spending less. Also different ways of occupancy can lead to variable internal set point during day or week.

Analysis for the case study showed that a different internal set point cause a variation of energy consumption of adjacent apartments. For existing multi-floor buildings with poor insulation, a reduction of 2°C in an internal apartment lead it to a reduction of effective energy consumption until 45% , while adjacent apartments suffer an increase of up to 30% .

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