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COMFORT AND PERCEIVED AIR QUALITY IN REFURBISHED SOCIAL HOUSES WITH MECHANICAL VENTIALTION SYSTEM: THE IMPACT OF OCCUPANTS BEHAVIOUR

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Abstract

The ever-growing demand for a better indoor air quality in residential buildings is increasing the number of whole-house ventilation system installations in new constructions and renovation. In Italy, for residential sector, the national code does not prescribe the use of mechanical ventilation (MV) systems, so their installation is left to the choice of house owners.

Two three-storey social housing apartment blocks in Northern Italy were studied. To reduce energy consumption, building envelopes as well as heating systems were refurbished. The thermal insulation was increased and the existing gas heater units were replaced with more efficient radiant ceiling systems. The refurbishment measures were the same for both constructions beside the MV system, which was installed in only one building.

Indoor temperature and relative humidity were monitored for several apartments during the heating season. The occupants were surveyed to investigate their thermal comfort and perceived air quality. The occupants were interviewed to better understand their responses, and to know how they operate the heating system and the mechanical ventilation system (when present).

Survey results show that there are no differences in terms of thermal comfort and perceived air quality between the occupants of the buildings with and without MV systems. The findings may be related to occupants' behaviour.

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Keywords: Occupants behaviour, refurbishment, thermal comfort, IEQ, mechanical ventilation

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1. Introduction

Buildings currently account for 40% of energy consumption and 36% of CO_2 emissions in the EU. About 35% of the EU's buildings are over 50 years old [1]. Residential energy consumption represents a significant part of the total energy use, in Italy it accounts for 17% of the annual total energy use [2]. By improving the energy efficiency of buildings, total EU energy consumption could be reduced by 5% to 6% and CO_2 emissions be lowered by about 5% [1].

Within the residential sector, the low-income housing segment is of particular interest for its social implications. More energy efficient homes for low-income people not only means reduced energy consumption and CO_2 emissions, but it also means lower energy bills for the part of the society more vulnerable to living costs.

Occupants' behaviour has the same impact as energy efficient technologies and passive solutions (i.e. improved building envelope) on household energy use [3]. Furthermore, occupants of low-income house may be more sensible to economic aspects, and this may reflects in the way they control the indoor environment (like open windows and thermostat setpoints). This is supported by the studies of Milne and Bordman [4], Soebarto and Bennets [5] and Nahmens et al. [6].

In this work we studied two three-storey social housing apartment blocks in Northern Italy. The buildings have been refurbished in order to reduce energy consumptions and increase indoor environmental quality. The thermal insulation of the buildings' envelope was increased and the existing gas heater units were replaced with more efficient radiant ceiling systems. The refurbishment measures were the same for both constructions beside the MV system, which was installed in only one building. Indoor temperature and relative humidity were monitored for several apartments during the heating season. The residents were surveyed to investigate their thermal comfort and perceived air quality. The survey also included some questions to better understand how they operate the heating system and the mechanical ventilation system (when present).

2. Building, HVAC system and control description

Two council housing buildings located in Northern Italy were studied. The two buildings are adjacent, with the same orientation and similar layout. Both edifices have three floors (four including the basement), with two apartments per floor, for a total of six units each; the basement is divided in six storages plus the space for the district heating substation.

Similar buildings are common in North and center of Italy, and are representative of a significant portion of the entire Italian building stock. The site is located within the "Middle Climatic Zone" (from 2100 to 3000 heating degree days), which is the most representative of the Italian climate [7].

Plants of the buildings are reported in Figure 1: living room and bath were highlighted in the plants.

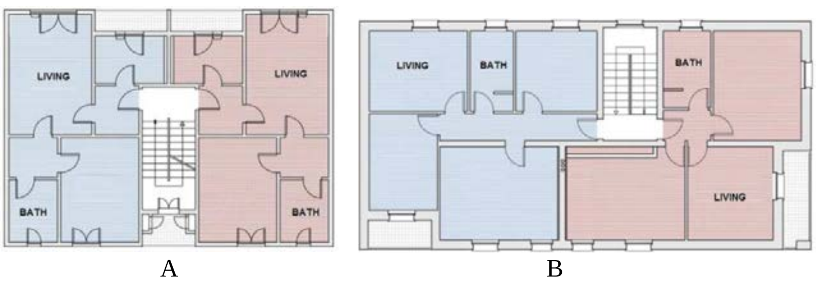


Figure 1. A) Building 1 and B) Building 2: plats.

The insulation of external walls of the buildings have been improved with the installation of 7.5 cm of expanded polystyrene. The single-pane windows were replaced with new double-pane windows (see Table 1). The renovation started before the Energy Performance Building Directive (EPBD) application in Italy, for this reason the U-value is lower than prescribed by the legislation in force today. For acoustic reasons a layer of plasterboard was placed against both sides of the walls that divide different units at the same floor.

Table 1. Building characteristics before and after renovation

Building elements	Before renovation	After renovation
Perimeter wall	U = 1.9 W/(m^2K)	U = 0.5 W/(m^2K)
Windows	U = 5.0 W/(m^2K)	U = 3.0 W/(m^2K)

The existing centralized boiler systems were replaced with substations connected to near district heating. The heat is provided by a cogeneration power plants located at about 1 km of distance. The gas heater units were replaced with radiant ceiling heating systems, composed by plastic tubes placed between an insulation layer and a plasterboard layer. In every apartment the heating system is controlled by a thermostat placed in the living room.

Only the apartments of the Building 1 were equipped with MV systems. Because of space and cost constraints, single flow MV systems, without heat recovery, and hygro-adjustable inlets were chosen.

Single flow systems do not use ducts. The house is kept below pressure using fans placed at the exhaust vents (generally located in bathrooms or kitchens). The outside air, not conditioned, enters through openings located in the main rooms. Usually these types of system can be:

- Manually controlled. It guarantees a constant air flow regardless of outside and inside humidity conditions.
- Hygro-adjustable. The inlets self-adjust the opening section based on the indoor relative humidity. This type was used in this study.

No cooling system was installed.

3. Methods

Indoor air temperature and relative humidity were monitored for six apartments (three per building, one per floor) for three weeks, from February 23rd to March 15th. The sensors were placed into the living rooms.

Before during and after the monitoring period several on-site inspections were performed to check the operation of the MV systems. The occupants were surveyed two times before and after the monitoring period to collect information about their perceptions of several environmental parameters. For this work we reported the results about temperature satisfaction (TS), air quality satisfaction (AQS), satisfaction with the amount of light (LS), and sound privacy satisfaction (SPS). Five-point Likert scales with ‘neutral’ mid-point were used for the questions. The scale ranged from ‘very satisfy’ (+2) to very ‘dissatisfy’ (-2). In Table 2 the survey questions are reported. The occupants were interviewed at the end of the test period (exit survey) to further investigate their perception over the renovated environment and how they operate the new heating and ventilation systems (when present). A total of 25 subjects were surveyed, 13 for Building 1 and 12 for Building 2.

Table 2. Survey questions

Questions
How satisfied are you with the temperature in your apartment.
How satisfied are you with the air quality in your apartment.
How satisfied are you with the amount of light(natural and artificial) in your apartment.
How satisfied are you with the sound privacy in your apartment (ability to have conversations without your neighbors overhearing and vice versa).

After the renovation, before to start the monitoring process, several blower door tests were performed to evaluate building airtightness.

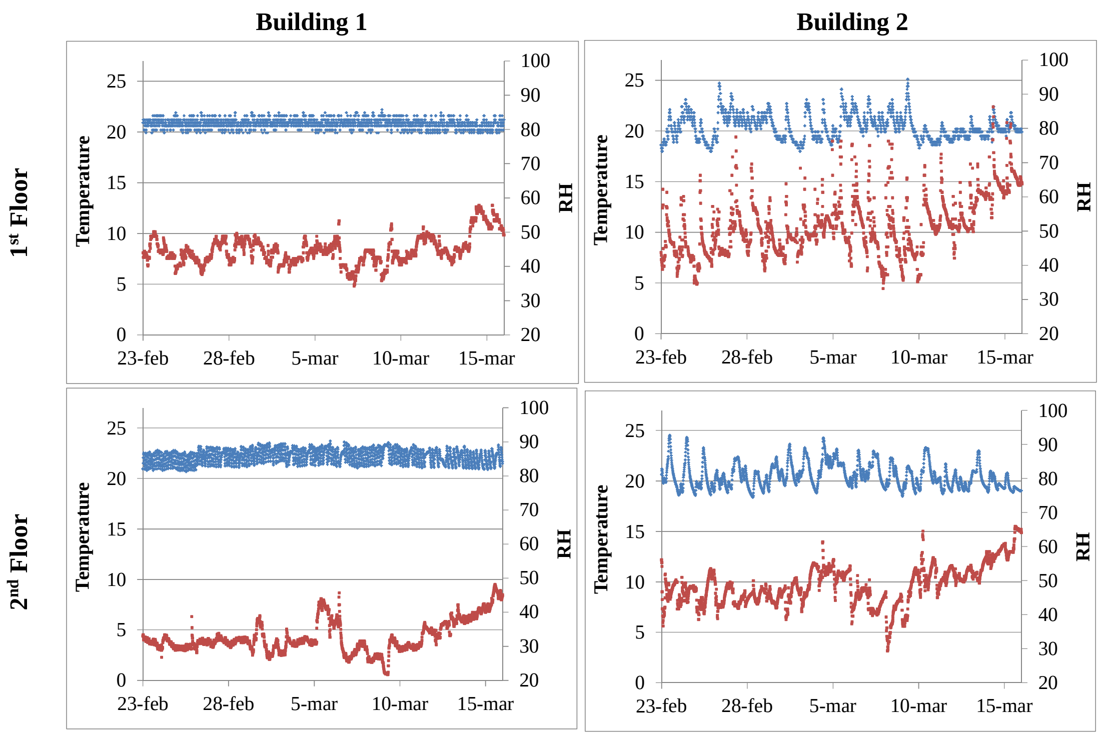
4. Results and discussion

To characterize the air leakage for every apartment several "Blower Door Tests" were performed in both buildings. Every apartment was tested with the method "A" in accordance with the UNI EN 13829 (the openings connected to the MV system were not sealed). In Table 3 the results of air change rate at 50 Pa (n_{50}) and air leakage coefficient (C_L) are reported for pressurization and depressurization conditions. As expected the openings for the ventilation in Building 1 impacts the envelope airtightness doubling the n_{50} values.

Table 3 Blower door results for Building 1and 2

	Building 1					Building 2				
	depressurisation		pressurization			depressurisation		pressurization		
	n_{50} [h^{-1}]	C_L [$m^3/(h\ Pa^n)$]	n_{50} [h^{-1}]	C_L [$m^3/(h\ Pa^n)$]	Mean value	n_{50} [h^{-1}]	C_L [$m^3/(h\ Pa^n)$]	n_{50} [h^{-1}]	C_L [$m^3/(h\ Pa^n)$]	Mean value
Floor 1	6.1	90	6.4	24	6.3	3.8	56	3.6	54	3.7
Floor 2	5.0	71	5.3	32	5.1	3.7	61	3.5	49	3.6
Floor 3	8.7	148	8.0	20	8.3	3.5	57	3.7	68	3.6

Indoor air temperature and relative humidity values, measured during three weeks, are reported in Figure 2 for the six monitored apartments. Air temperature trends are quite different between the two buildings. This is related to different thermostat setpoint schedules, decided by the users, more than to the presence of the MV systems. The relative humidity values are strongly related to the presence of the MV system. For the apartments in Building 1 the RH exceeds 50% only in one case, while for those in Building 2 sometimes RH reaches 80%.



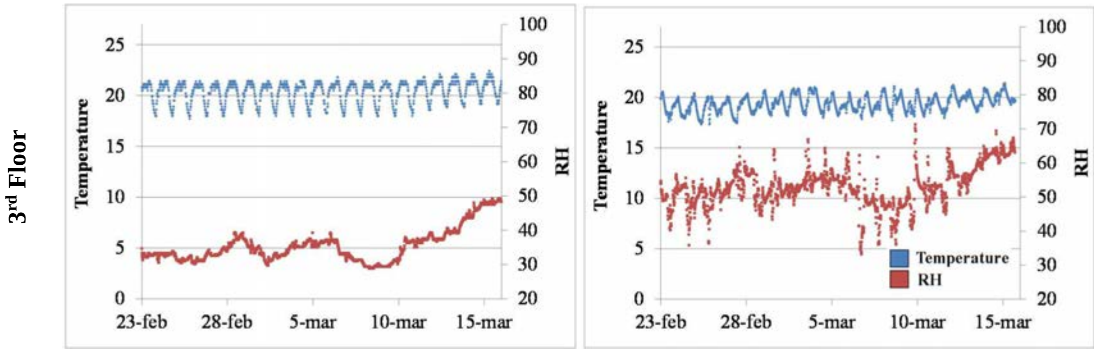


Figure 2 Air temperature and relative humidity for the monitored apartments.

Beside the users had direct control over the indoor temperature, they voted the temperature satisfaction (TS) neutral (Figure 3). The temperature setpoints chosen by the occupants appear to be a tradeoff between comfort and economic considerations, and the temperature selected seems to be just the minimum value considered not-unsatisfactory. There is no statistical difference between Building1 and 2 in terms of temperature satisfaction. Statistical analysis was performed with a non-parametric method called permutation test, using the software R [8].

The air quality satisfaction is slightly higher for Building 1 than for Building 2. Although the difference is statistically significant, it is minimal. There are two possible explanations for this:

- Occupants in Building 2 could open the windows to improve their perceived air quality, so they still had a good degree of control over the air change rate.
- During the inspections of Building 1 happened to find some ventilation openings sealed with cardboard and tape, or sometimes the MV system were turned off.

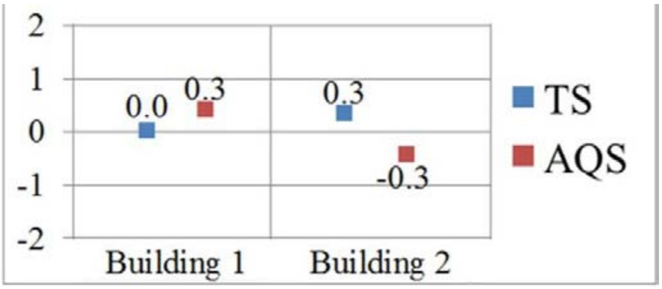


Figure 3. Survey results: average values

From the exit survey emerged that the reasons because the occupants sealed the vents were essentially two: improve comfort and reduce energy bills. The specific type of ventilation system used for the renovation, without heat recovery, let unconditioned cold air into the apartment causing draft sensations and increasing heating costs. The levels of CO_2 in one apartment of Building1 were measured from the 19th of December to the 16th of January (before the temperature and humidity monitoring period). The results are reported in Figure 4. The data shows that MV system was off until January 8th,data of one of the periodical on-site inspection. The occupants' behavior strongly affect the system operation, and in some cases annul the benefits of having a MV system.

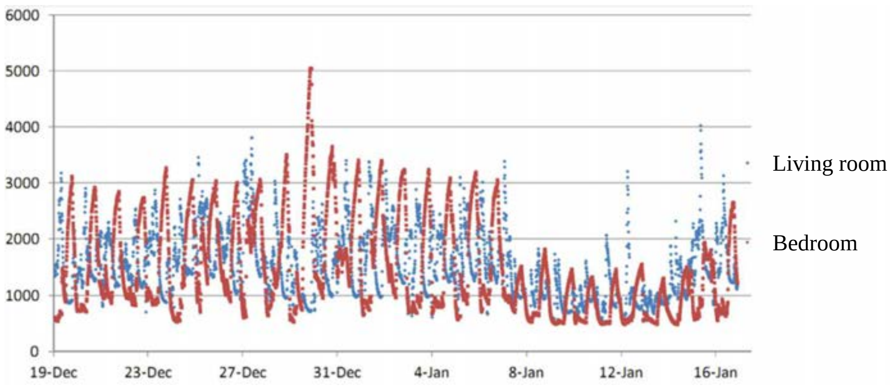


Figure 4 ppm of CO_2 measured in an apartment in Building 1.

5. Conclusion

- In social housing apartments the temperature setpoint seems to be strongly affected by economic considerations.
- Air quality acceptability is slightly higher in apartments equipped with MV systems.
- Economic aspects seem to prevail over IAQ benefits related to the use of MV systems.
- The ventilation systems installed in social housing apartments have to be carefully chosen. The occupants perceived the operation of single flow MV systems as an unwanted outdoor air infiltration. A solution that uses heat recovery may overcome comfort and energy cost issues.

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