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Influence of occupant behaviour lifestyle on an Italian social housing

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Abstract

The Post-Carbon City concept has a decisive effect on the building design, in terms of envelope and system technologies, and, especially, of interaction between the occupant and the building itself. Occupant behaviour lifestyle is one of the most significant driving factors of uncertainty in the prediction of building energy use and thus represents a fundamental aspect that is necessary to modelling. This study examines the difference between the energy consumptions assessed during design phase and the monitored ones for a social housing. Dynamic simulation was employed to demonstrate the impact of occupant behavior lifestyles and household composition on energy uses.

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Keywords: occupant behaviour lifestyle; household composition; energy consumptions; social housing

1. Introduction

During the last twenty/thirty years, energy demand is increased between 20% and 40% and in the next period this value will only raise [1]. The residential building sector is responsible for the major part of the energy consumed [2]. This problem is related to the fact that the large part of the existing building stock, especially in Italy, is inherited from the economic boom of 60's and 70's. These constructions usually present low thermal insulations, high transparent components U-values and old systems. To decrease energy demands one of the possible solutions is envelopes and systems retrofitting; in this way, there will be also an improvement of the economic value of the existing building park. In order to achieve the energy demands reduction goal, European and national laws are required. The European

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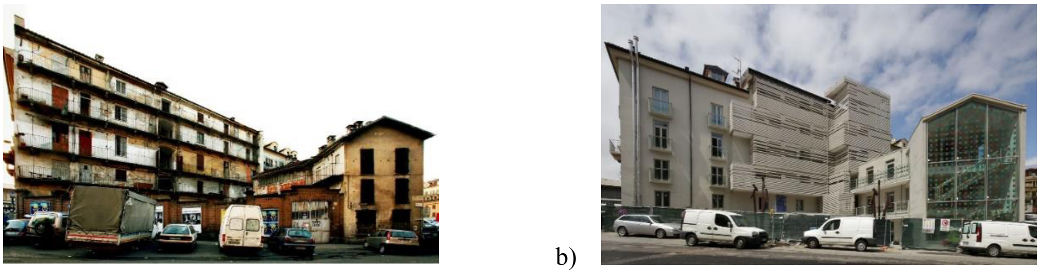
Commission wrote the "Roadmap for moving to a competitive low-carbon economy in 2050" with the aim to reduce greenhouse emission by 80% [3]. According to this roadmap, in a very limited period, the carbon-based society has to reduce carbon use, limiting the dependence from this material and think about a new sustainable way of development. In order to reach this target in the building sector, it is necessary that the cities, centre of economic and social activities, becomes the main characters of carbon reduction strategies. Through the new concepts of net-Zero Energy District and Post-Carbon City, the attention shifts from the building level to the district and the city ones [4]. The concept of Post-Carbon City should have a decisive effect on the building design, in terms of envelope technologies and system components, and, especially, in terms of sociological aspects referring to the interaction between the occupant and the building itself. Occupant behaviour lifestyle is one of the most significant driving factors of uncertainty in the prediction of building energy use and thus represents a fundamental aspect that is necessary to analyse; it should be considered already during the design phase. Extended literature studies [5-8] focus the attention to the influence of the users on the final energy uses, but no models exist that could be a reference of different occupant behaviour lifestyles, especially for nZEBs. Up to now, the focus is only on the implementation of the buildings features. Indeed, while predictive studies concerning energy performance investigated mainly nZEB models that addressed the optimization of the building/system features themselves, there is urgent need of reference models related to human behavioural issues. Nowadays, to reduce the energy consumptions only improving building energy performances and using renewable sources is not enough anymore; it is important not only planning low-energy buildings but also understanding and predicting the role of the users. A deeper knowledge on occupants' lifestyles influencing factors could lead to a more accurate buildings energy performance predictions. Moreover, a persuasive communication with the building occupants in the operational phase could lead to a minor gap between the predicted and real energy consumptions; it is fundamental trying to understand how to modify the habits of the occupants in order to achieve a more conscious energy use.

This paper describes the case of the Porta Palazzo Temporary Residence in Turin (Northern Italy) and, in particular, the difference between the energy consumptions assessed during design phase with a dynamic simulation software and the higher monitored building uses. Higher energy consumptions cause more expensive bills that have to be paid by building manager; due to this fact the manager, who subsidized the renovation of the existing building, has to pay more than what has been expected, losing a lot of money. In this specific case study, users are not motivated in energy savings, because they only pay the rent and not the energy bills. In detail, dynamic simulation was employed to demonstrate the potential impact of occupant behavior lifestyles and different household compositions on the final energy uses. Three different classes of occupant lifestyle (low/average/high consumer) were evaluated and two extreme household compositions (old couple, who spend most of their time at home, and young couple, who spend most of their time outside). The data obtained were compared with the real energy consumptions in order to demonstrate how a deeper knowledge of occupants' lifestyles could lead to more accurate energy assessment during design phase. Moreover, the occupants should be more aware of how their lifestyle effects the energy consumptions and they should be willing on modifying it. At the same time, the obtained results could suggest to the building manager how to achieve energy and economic savings influencing occupants' behaviour through guidelines and persuasive communication.

2. The case study

The Housing Program of *Compagnia di San Paolo* supports social housing projects since 2006 and one of them is the Porta Palazzo Temporary Residence (Fig. 1) [9], the case study analysed in this paper and located in the centre of Turin (North Italy), in Porta Palazzo neighbourhood, near the historic city centre. The main goal of the company is to help who can not be placed in the current real estate market because of economic and social problems. This population group, that represents the called "grey zone", include all those persons who are not poor but, at the same time, not rich enough to afford a monthly mortgage or rent at the current prices. The location chosen is not casual; it is a neighbourhood where we can find people from different country, so one other goal is to integrate Italian and foreign persons. One of the main characteristics of this residence is the permanence in the apartments limited to maximum eighteen months; temporary dwellings could offer, for subjects in a situation of housing vulnerability, a transitory solution. The short-lived staying of the users, the low rent cost, the common spaces and services are the main features of the building. The fabricate was built in the first twenty years of the XIX century, and already modified in 1825 because of the urbanistic renovation of the square; also, the entire neighbourhood in the last ten years [10] was under renovation. Turin Municipality, the owner of the Temporary Residence, agreed to lease free of charge to the *Compagnia di San Paolo* for thirty years. The renovation project, started in September 2011 and ended in July 2013, consisted in an envelope and systems energy retrofit and in an internal spaces redesign, included the creation of residential spaces, some common spaces and one restaurant; *Fagnoni&Associati Architetti* won the competition.



a) b)

Fig. 1. The Temporary Residence before (a) and after (b) the renovation

The building is divided into two part. The main one is composed of five floors. The underground floor with storage and technical local hosts the info-point and the polyvalent area; the ground floor consists of five small shops. From the first to the last level, there are residential spaces. The other part of the structure, called *manichetta*, with less functional and aesthetical value, have three floors. On the ground floor, it can be found the restaurant and its kitchen, and the manager's office. On the first and second floor, there is another level of the same restaurant and two one-room residences.

Concerning the energy retrofit, for the external walls, roof, inferior and intermediate slabs, an improvement of the thermal insulation was realized in order to decrease the transmittance U-values. In addition, the transparent components were changed with high-performance ones. About the HVAC systems, a high performance natural gas condensing boiler, fan-coil units in commercial spaces and radiant floors for space heating in residences and polyvalent area were installed. For the domestic hot water (DHW) supply, nine solar thermal collectors were positioned on the roof of the *manichetta* building in order to cover the 60% of the production, according with regional regulations. There is also a photovoltaic system used only for supply the external lighting consumption; this last energy use is not considered in the study.

3. Methodology

Comparing the monitored consumptions of the Porta Palazzo Temporary Residence and the ones hypothesized during design phase with a dynamic simulation software, a huge discrepancy emerges. Indeed, the difference between the estimated energy consumptions and the monitored ones highlights higher real end uses: +50% for space heating, +19% for DHW and +16% for electricity uses (internal lighting and equipment). This problem is not related to the building features, but to the interaction between the occupants' attitude and the building itself; indeed, the energy simulation took into account only one specific occupant behaviour lifestyle extrapolated from the assumptions of national and international regulations and standards.

Specific analyses were developed in order to study the influence of the occupant behaviour lifestyle on the final energy uses of this case study. In particular, two different type of analyses were elaborated through DesignBuilder, a dynamic simulation software [11].

In the first one, the aim was to underline the relationship between the user energy-attitude and the final consumptions. Hence, three classes of different energy-related occupant behaviour lifestyle were identified; low consumer (LC), who represents everyone is pro-active in energy saving, average consumer (AV), the user represented by standards, and high consumer (HC), who does not care about potential savings. In order to study the differences between the three classes for each final energy use (space heating, DHW, lighting, equipment), some variables were modified in the simulations. The space heating temperature set-points refer to comfort categories described in

EN15251 [12]; the high consumer variables refer to comfort category I, while the average and low consumer variables refer respectively to categories II and III. In detail, the heating set-points and the operating hours were differentiate as follows:

- Low consumer: 18 °C from 5am to 11pm; 16 °C from 11pm to 5am;
- Average consumer: 20 °C from 5:30am to 8pm; 18 °C from 8pm to 5:30am;
- High consumer: 21 °C during the whole day.

In all configurations, the heating system is working from 15th October to 15th April, according to Italian regulations for Climatic Zone E (HDD = 2617), in which Turin is located [13]. The weather conditions of Turin used in the simulations were extrapolated from the Weather for Energy Calculation Database of climatic data (base on the Italian Climatic data collection IGDG) [14]. The outdoor air flow rate is constantly set to 0.3 ACH. The lighting and equipment power densities were fixed respectively to 3.88 W/m^2 and 5.89 W/m^2, according to ASHRAE Standard 90.1 indications for these specific end uses [15]. The average consumer schedules for lighting and equipment refer to those of residential reference buildings available on the DOE (Department of Energy) dataset [16]. In order to assess the high consumer and low consumer, the operational levels of these standard schedules were respectively increased or reduced by 10% according with some literature data [17]. The daily DHW demand was set equal to 60 l/person for the average consumer, to 40 l/person and to 80 l/person respectively for the low and high consumption profiles [18].

The second analyses focused the attention on the influence of the household composition on the energy consumptions. Two extreme cases were studied; the first one, represented by a young couple who spend most of their time outside the residence. An old couple, the other case identified, on the contrary, stays in their home most of the time. For this investigation, other two variables were changed: the crowding index and the occupancy schedule. In the first analysis, the crowding index was 0.04 person/m², as defined by Italian Standard UNI 10339 [19]; in the second one the values were substituted in 0.014 person/m² for both young and old couple, consistently to have two people in each residence of the building. For both young and old couple the three classes of consumer (low, average, high) were recreated.

4. Results and discussion

4.1. Occupant behaviour lifestyle results

Figure 2 reports the simulation outcomes showing for each occupant behaviour lifestyle the electricity and natural gas annual consumptions subdivided by end uses (lighting, equipment, space heating, DHW production), expressed in kWh/m² of conditioned area.

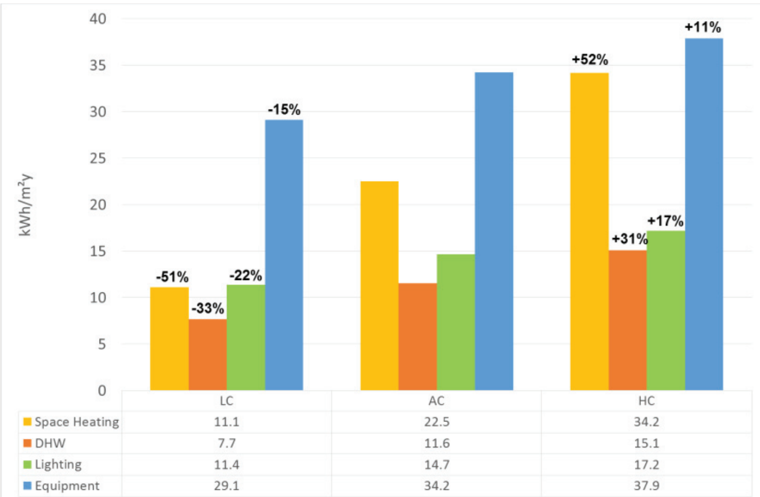


Fig. 2. Comparison between occupant behaviour lifestyles for natural gas and electricity consumptions, subdivided for end uses.

The percentages in the graph display the variations of the consumptions with respect to the average consumer. The results show significant difference of the building performance related to the various occupant behaviour lifestyles. For both low and high consumer the variation respect to the average consumer in terms of natural gas for space heating is about 50%, while the one for DHW production is about 30%. For lighting and equipment the differences, like before compared to the average user, are more contained; the simulations show a decrease of -22% and -15% and a raise of +17% and +11% for lighting and equipment.

The impact of the single variables on the total energy consumptions are presented as percentage variations of primary energy consumption of the low consumer and high consumer lifestyles compared to the average profile for the single energy-related behaviour patterns indicated by the vertical blue line (Figure 3). This analysis highlights that the most significant impact on the total energy use is given by the temperature set-points and operation-time variable for both the low consumer and the high consumer profile.

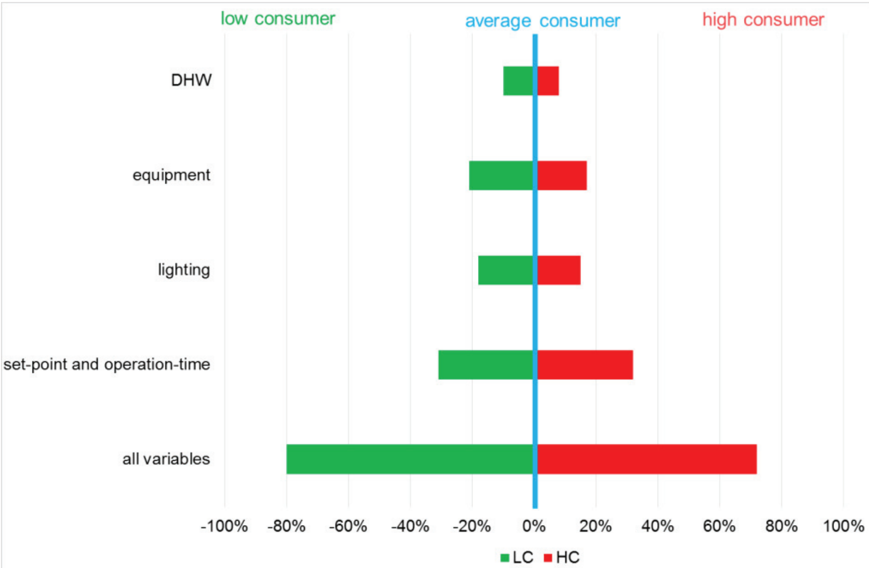
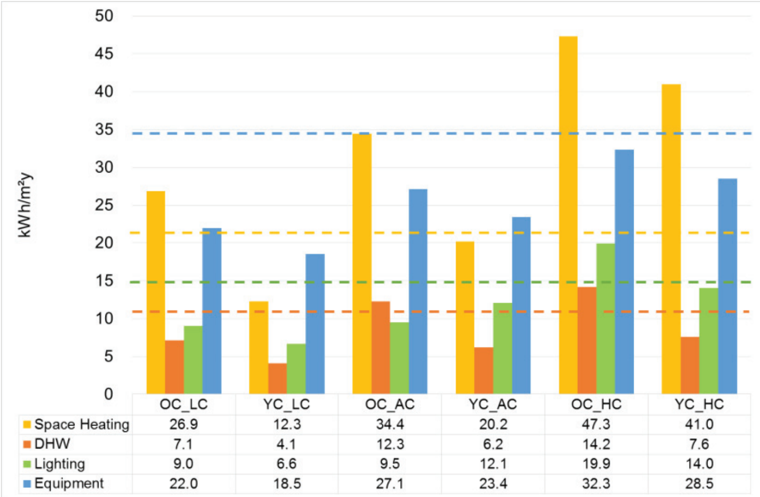


Fig. 3. Impact of single occupant-driven variables on the total energy use for type of occupant behaviour lifestyle.

This first analysis was carried out to demonstrate how simple changes, like modifying heating set-point and operating hours, could lead to energy savings and consequently to lower bills in the case of a user careful in energy use.

4.2. Household composition results

In this paragraph, the results obtained by the analysis of the effect of two different extreme household compositions on the energy performance of the building were analyzed. In Figure 4, the horizontal dashed lines represent the energy end uses for the average consumer analyzed before. It can be observed that, comparing the data with the average consumer scenario, natural gas consumptions for space heating and DHW increase for the old couple (OC) and decrease for the young one (YC), while the electricity consumption for lighting and equipment increase for both the couples. Moreover, the electricity and natural gas consumptions change significantly for the young (YC) and old (OC) couple associated to the various occupant behaviour lifestyles.



	OC_LC	YC_LC	OC_AC	YC_AC	OC_HC	YC_HC
Space Heating	26.9	12.3	34.4	20.2	47.3	41.0
DHW	7.1	4.1	12.3	6.2	14.2	7.6
Lighting	9.0	6.6	9.5	12.1	19.9	14.0
Equipment	22.0	18.5	27.1	23.4	32.3	28.5

Fig. 4. Comparison between household compositions for natural gas and electricity consumptions, subdivided for end uses.

Figure 5 shows the incidence of each single variable for these two types of household compositions on the total primary energy consumptions by defining the percentage of low and high consumer lifestyle compared to the average profile for each single energy-related behaviour patterns. For all scenarios, the most influencing occupant-driven variable on energy consumptions is constituted by the temperature set-point and operation-time.

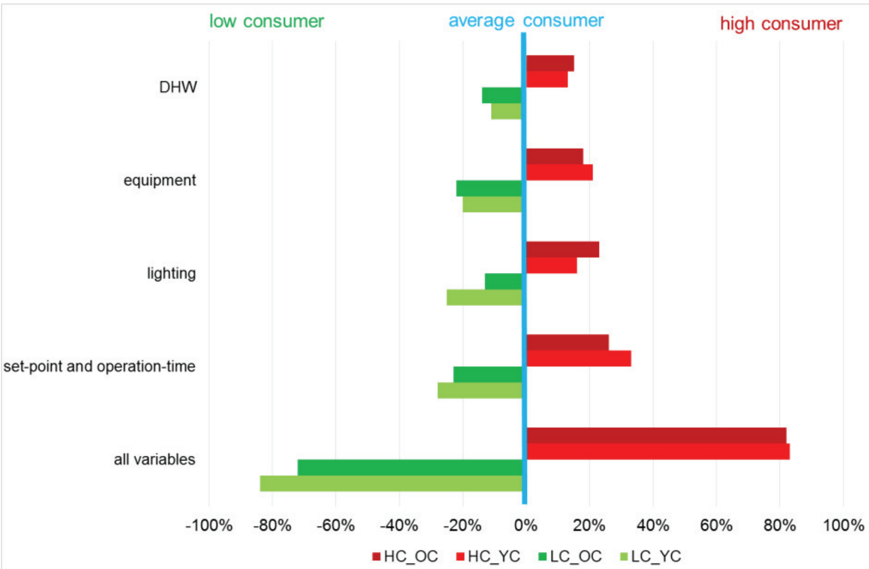


Fig. 5. Impact of single occupant-driven variables on the total energy use for type of household composition.

5. Conclusion

In this research, three different types of user energy-attitude lifestyle were studied considering the interaction between users and energy-related variables. Moreover, how the household compositions, associated with various behaviour lifestyles, influence the building energy performances was tested. The main goal of this research is to underline how the occupant behaviour lifestyle influences the real energy consumptions, especially in high performing buildings; respect to the average consumer the lower one could save the 24% in terms of primary energy and the higher one, on the other hand, consumes a plus of 20%.

For this case study, starting from the energy consumptions assessed during the design phase, is it possible to observe how the real energy demand, based on the results collected from whom is actually living the residence, is higher than the one that was expected. The main problem is that the influence of occupant behaviour lifestyle was not been foreseen because, nowadays, there are no models for the different occupants behaviour lifestyle to be use in design energy evaluations. Starting from these results it is obvious that already during the project phase it should be paid more attention to the human-related variables and it's urgent to define occupant lifestyles reference models.

Moreover, due to the results is noticeable how a building realized with high performing features is not enough to achieve the energy reduction if the users are not actively participating in the "savings process". At the same time is important to highlight how suggestions need to be addressed toward a more rational use of electrical devices by the inhabitants and the importance of the implementation and high-efficiency systems. It is fundamental to try to persuade the users to pay more attention to their influence on the energy end uses. They have to be more aware of their role in the building-energy balance and be more conscious about the use of the energy. In the specific case study, in which the manager pay the energy bill, it is important to focus the attention on the persuasive communication. Since the habitants do not have to pay the energy bills but only the rent, they are not sufficiently motivated to saving energy in order to limit the consumptions. In order to change this situation, the manager of the residence could give an "how to use the residence" guidebook where indicate advice that could help the users to change their energy-attitude.

It is important, in order to sensitize the inhabitants, get the message through that the internal comfort conditions could be achieved even if the indoor temperature is changed (from 21 °C to 18 °C). This is possible just modifying the clothing thermal insulation from 1 clo to 1.5 clo in order to achieve the perfect thermal neutrality coincident with comfort satisfaction. In this way, the PMV (Predicted Mean Vote) remains between -0.5 and +0.5. Just in order to not pass the limit of PPD (Predicted Percentage of Dissatisfied) of 10% the thermal insulation of clothing could decrease to 1.1 clo. Furthermore, nowadays numerous recent studies are focus on the correlation between the temperature and health benefits. An example is represented by analyses made by Stanford Medicine Centre for Sleep Sciences and Medicine [20] that show how sleep with an internal temperature between 16 °C and 18 °C is healthier. This consideration may be helpful to motivate higher consumer to limit energy consumptions. It is important to find solutions that can balance high-energy performance and high environmental satisfaction.

It should be aware that this study is not enough because is not possible think that all the users of a multifamily building behave in the same way. One of the limitations of this research is related to the fact that a high consumer could be at the same time a low or average consumer for some variables; in future analysis could be interesting to try to improve these studies combining different variables in order to analyses more realistic scenarios.

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