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PREDICTION OF USERS' BEHAVIOUR PATTERNS IMPACT ON ENERGY PERFORMANCE OF A SOCIAL HOUSING IN CREMONA, ITALY

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Abstract
Social housing is a crucial challenge of European cities, facing the pressing need to provide accommodation for an increasing and changing population with new family models. Functionality, adaptability and quality of living are fundamental topics in social housing. Economic constraints concur to shape the size of apartments and construction choices in the design phase. Further, energy efficiency is a key factor for long-term economic sustainability by reducing running cost in the operation phase. The availability of calibrated energy models is fundamental to perform effective energy management during building lifespan and the ability to investigate users' behaviour by means of physical-statistical models is fundamental to improve current design and operation practices.
The case study presented is a social housing located in Cremona, Italy, built by a Social Fund engaged in retrofit interventions on existing social housing and new construction. The variability of energy use, resulting from different occupancy, appliances, ventilation patterns and comfort settings has been investigated by means of simulations. Behavioural patterns are inherently dependent on age, number of components of the family, comfort preferences and activities (i.e. appliances and lighting use). Further, possible occupants' aggregations are constrained by size and flexibility of the architectural layout of residential units (e.g. number of users, change in ability due to ageing, etc.). The results are presented in a graphical way (i.e. energy demand vs outdoor temperature), enabling statistical correlation among energy demand and physical parameters assumed in different simulation scenarios, which can be used for model calibration in the operation phase (for energy management purposes). The results show the large variability of energy performance in different scenarios and the large difference with respect to standard assumptions, highlighting the benefits of parametric behavioural simulation to obtain realistic data for techno-economic assessments.

Keywords:
Social housing; behavioural pattern; energy performance; users' behaviour

1 INTRODUCTION

Social housing has a strategic role in the European residential sector. The European Committee for the promotion of the right to housing (CECODHAS) defines social housing as *housing solutions for those families whose needs cannot be met with market conditions and for whom assignation rules are established* [1].

In the European countries a variable percentage ranging from 30% to about 10% of the new construction is ascribed to social rented housing [2]. Refurbishment of social housing is a widely investigated field due to the large potential energy saving in the aging residential buildings stock in Europe [3,4]. Envelope redesign and renewable energy technologies are the main issues [5]

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because the construction period of the building stock ranges from 1920 and 1970 in most cases. Further, the new social housing is an experimental ground in which the Municipalities/Committee are interested in promoting energy efficiency [6,7] checking the evidence of cost-optimality criteria of the technological solutions adopted [8-11] and endorsing social upgrading. The new social housing design, as the case study used in this paper (Fig.1), is aligned with the best practices in energy efficiency [12].

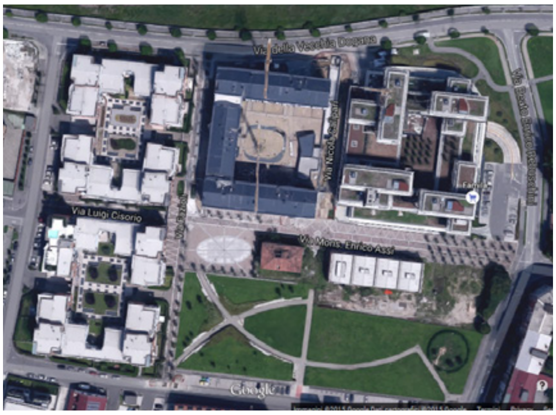

Fig. 1: Arial view of the social housing in Cremona, Italy.

Moreover, the performance gap that can be found in comparing the designed performance and the actual performance of the buildings is another interesting field. Probabilistic design and behavioural pattern analysis [13] can be employed to explore the uncertainty and variability of performance already in the design phase. The paper deals with occupants' behaviour variability in residential buildings and their influence on energy consumption. The new families, the new culture of living in the multi-ethnic society and the need of temporary housing solutions introduce new important topics to be considered in design optimization. The potential flexibility and re-configuration of the spaces during the building lifespan for the evolving families and the aging population (e.g. adaptation of spaces for disability) add additional complexity to the project. In order to provide meaningful techno-economic evaluations, parametric and probabilistic design techniques can be adopted [14,15].

2 CASE STUDY

2.1 Social Housing in Cremona

The case study described in the paper is a social housing settlement in Cremona (Italy) realized to achieve energy efficiency and flexibility for users. The settlement has a C shape with three main blocks with the major axis east-west and a block with the major axis south-north (Fig. 2).

Fig. 2: Layout of the Social Housing settlement in Cremona, Italy.

Fig. 3: View of the south façade of the building.

The south and west blocks have respectively six and five floors, while the north block has four floors (Fig.3,4).

Fig. 4: View of the east and north facades of the buildings in the courtyard.

2.2 Typical floor configuration

The apartments' sizes range from about 45 to 90 m^2 and the spaces can be used by different family groups, according to the standard prescribed by legislation. A typical floor with apartments of different sizes has been considered (Fig. 5) to analyse the impact of the variability of occupancy patterns on energy consumptions.

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Social housing has to be adaptable to changing users and aggregation of people, considering also possible scenarios in which a temporary accommodation takes place. The typical floor is composed of five apartments:

- n. 2 apartments are sized for families.
- n. 2 apartments can be used by couples or small families.
- n. 1 apartment is sized for a single user.

A percentage of about 20% of the apartments is considered as unoccupied due to change in occupants' range and temporary use (assumed as apartment used only during the weekend). The smallest apartment facing north can be considered as a temporary location for people in transition.

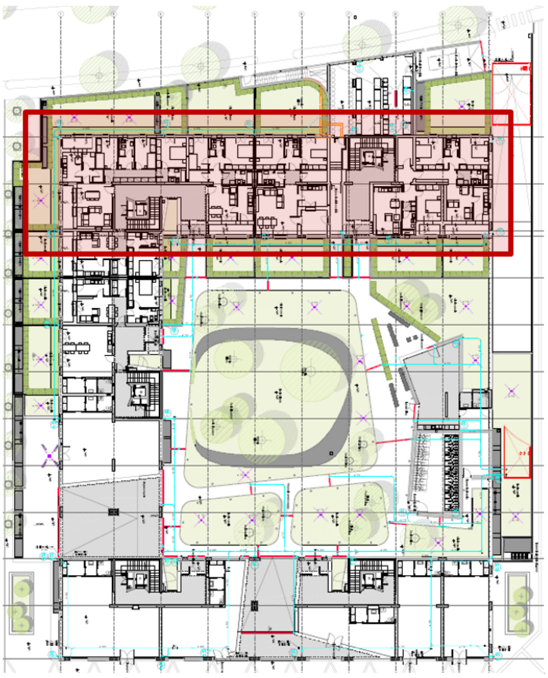


Fig.5: Detailed plan of the apartments and typical section of the floor (red).

In table 1 the sizes of the apartments, the location (South, North, West, East) and orientation of the windows (single, double, triple oriented), with the average possible number of users are listed. In the apartments, it could be possible to accommodate more users (e.g. +1) in a temporary use scenario; however, the analysis in this phase is oriented to model the different behaviour of typical families and couples. A denser and more intense use and space configuration will be examined in depth in further phases of the study and calibration of the models will be performed with measured energy consumption data.

In table 1 the users are defined as standard number (S.), related to the apartment area and people density for residential use (0.04 person/m^2) and assumed (A.) used to define a family (evolving over time).

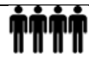
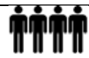
Name	*Size [m^2]*	*Side*	*Orient.*	*Users*	
				S.	*A.*
A1	86.9	E	S,E,N	3.48	
A2	83.9	W	S,N	3.36	
A3	53.7	SE	S	2.15	
A4	53.7	SW	S	2.15	
A5	46.1	N	N	1.84	

Table 1: Typical composition of apartments in the floor of a building block.

Nevertheless, the number of users is not sufficient to explore the variability of occupancy patterns; age and related behavioural components are key factors in energy consumption, as shown and discussed in section 3.

3 RESEARCH METHODOLOGY

The social housing case study has been used to simulate different configurations of the mixed use, evaluating the incidence of typical families' behaviour on the thermal energy consumption of the building. The data related to surface and users of the apartments have been combined, introducing the behavioural variability in simulation input data, as described in section 3.1. The calculation method to estimate the energy performance for single apartments and for the whole building is described in section 3.2, whereas the results are reported in section 4 and discussed in section 5.

3.1 Behavioural patterns

The social housing settlement in Cremona has been constructed following recent energy efficiency standards, with a high performance envelope. The variability of energy use, resulting from different occupancy, appliances, ventilation patterns and comfort settings, is dependent on age, number of components of the family, comfort preferences and activities (appliances and lighting use). The users listed in table 1 have different behaviours and impacts with respect to the standard values used for internal gains, ventilation rates and indoor set-point temperatures for residential buildings (i.e. 4 W/m^2 internal gains, 0.3 air changes per hour, 20/26°C winter and summer set points). Therefore, standard values have been adjusted with multipliers to introduce the behavioural variability due to age, family composition and temporary use (Fig. 4,5,6). The operating schedules used in simulation are defined for:

- Unoccupied apartment (randomly changing)
- Couple with sons (teenagers) (A1)
- Couple with kids (children) (A2)

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- Young couple (A3)
- Aged couple (A4)
- Single temporary use (A5)

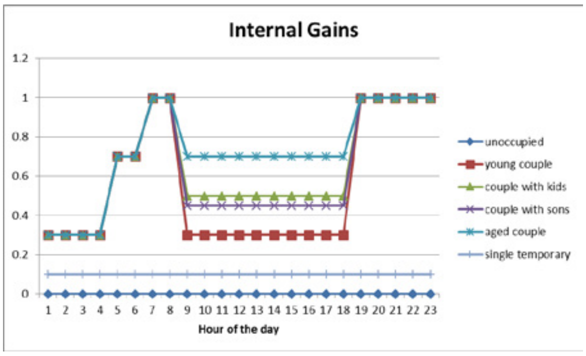

Fig. 4: Internal gains schedules.

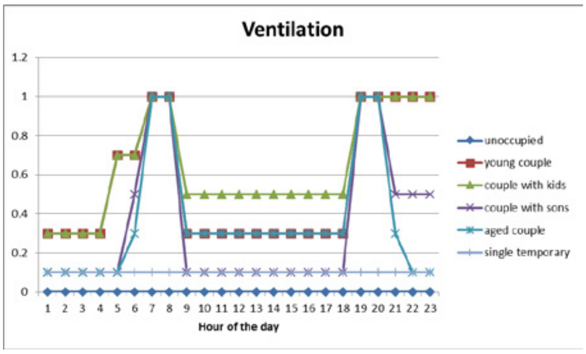

Fig. 5: Air change rate schedules.

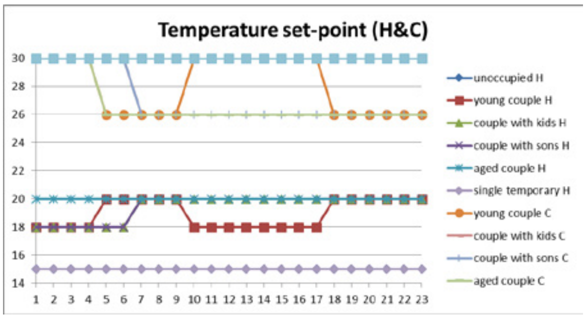

Fig. 6: Temperature set-point profiles.

3.2 Parametric energy simulation

The analysis of the behavioural pattern incidence has been carried out through parametric dynamic energy simulations [16]. The models have been simulated using variable occupancy profile patterns and related energy demand for appliances and lighting. First, the standard occupancy profile for residential buildings is applied to all the apartments. After that, it is compared to the variable patterns simulated parametrically. The mixed distribution has been further varied, changing the occupancy of the apartments, i.e. simulating a variability in tenants' presence in the building (occupied/unoccupied). Results are given as specific energy demand for heating and cooling to show the variability resulting from occupancy patterns. Results for the different apartments (A1-A5) are reported to check out the behavioural incidence, however the north facing single apartment has an unfavourable orientation affecting the energy performance.

4 RESULTS

The analysis shows the standard occupancy profile as daily energy demand for the building compared to custom behavioural occupancy profile during winter season (heating) and summer season (cooling). The standard profile for residential building considers a 24h occupancy with the people density reported in table 1 and data as described in section 3.1. The custom behavioural profile uses the data scheduled in fig.4-6 forecasting the full occupancy of all the apartments by the described families.

4.1 Standard profile vs custom profile

By comparing the heating demand (Fig.7) it is possible to verify how the standard profile underestimates the energy demand.

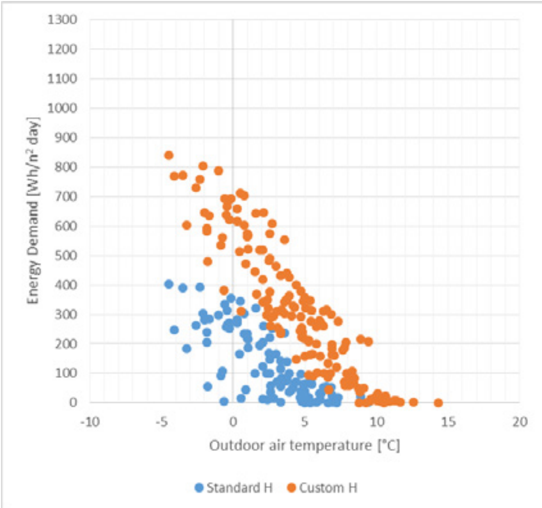

Fig. 7: Heating demand with standard occupancy profile and custom behavioural pattern.

Considering the cooling demand (Fig. 8) the standard profile shows a higher consumption with respect to custom profiles, due to variability of set-point temperature and occupancy.

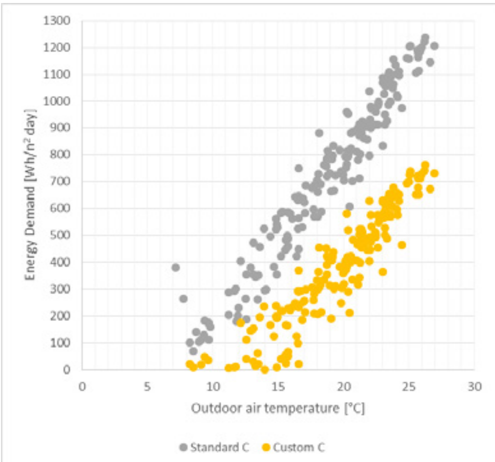

Fig. 8: Cooling demand with standard occupancy profile and custom behavioural pattern.

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The variability introduced by the families' use is shown in the following section.

4.2 Behavioural occupancy patterns

The behavioural patterns are constructed by interpreting the behaviour of groups of people considering the occupancy of the house's spaces, the use of equipment, the needs for ventilation and the variable set-point adopted during the day in winter and summer. The energy demand is not sharply divided for families, however, it is possible to recognize different distributions and trends: more people/more occupancy hours determine higher demand in winter (Fig. 9) while in summer more tolerance in changing temperature/ favourable exposition/less occupancy hours define reduced cooling demand (Fig. 10).

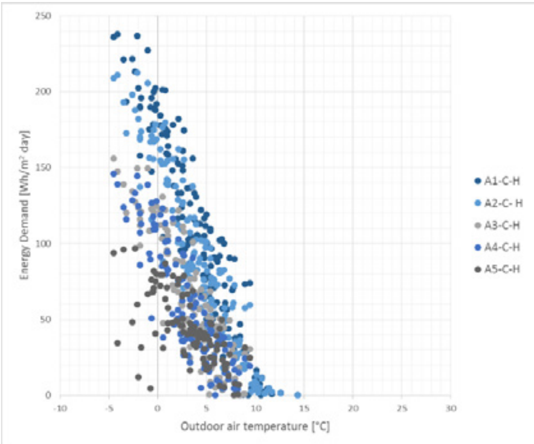

Fig. 9: Heating demand for behavioural patterns in the different apartments.

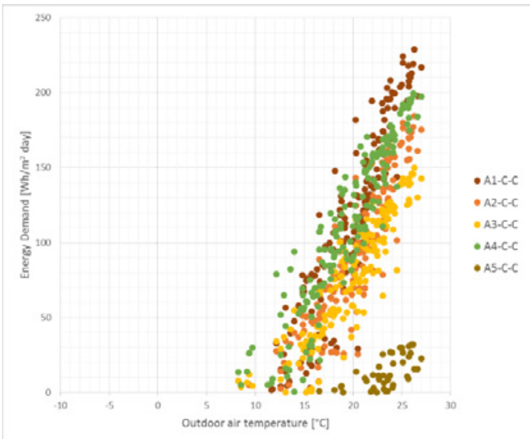

Fig. 10: Cooling demand for behavioural patterns in the different apartments.

5 DISCUSSION

5.1 Variability in occupancy

A specific issue is the occupancy of the apartments by tenants that varies significantly in time, affecting the energy demand of the building. For this reason, the analysis reported shows the variability of energy demand when an apartment is randomly considered empty (Fig. 11).

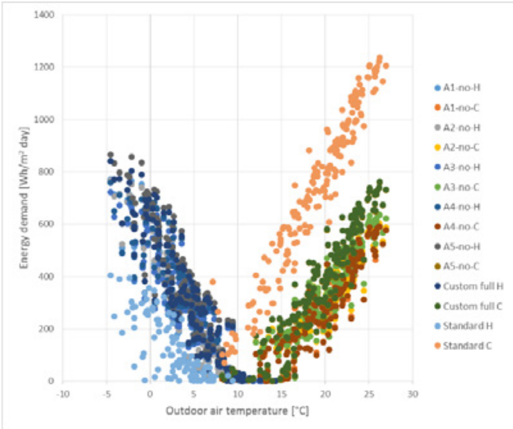

Fig. 11: Heating and demand with standard occupancy profiles and custom behavioural patterns.

The building is realized to comply with present energy efficiency legislation and its thermal energy demand (calculated in standard conditions) for winter is very low: 13.34 kWh/m^2 year. The energy demand, considering more realistic scenarios, results to be more than double, however, always no more than 51 kWh/m^2 year. In summer, the standard calculation largely overestimates the energy demand while in the realistic scenarios it is always lower than 63 kWh/m^2 year. The variability of occupancy (tenants) can lead to a maximum variation of 12% for heating and 27% for cooling for the custom (non-standard) simulation profiles considered (Fig. 12).

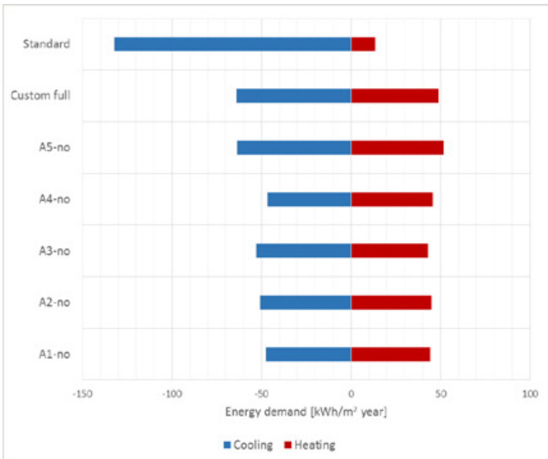

Fig. 12: Heating and cooling demand with standard occupancy profile and custom behavioural patterns and occupancy.

6 CONCLUSIONS

Behavioural occupancy patterns simulation is used to show the high variability in energy performance determined by end-users. The results highlight the limitation of simulations using standard profiles, without a parametric analysis. The variability in terms of energy performance is relevant and the difference encountered among

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parametric scenarios is up to 27% in the selected case studies. A much larger difference is the one encountered with respect to the standard profile which causes an overestimation of cooling and an underestimation of heating demand.

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