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Energy demand profiles assessment at district scale: A stochastic approach for a block of buildings demand profiles generation

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Abstract

A methodology, based on the concept of reference building models, was developed and applied in order to provide reliable demand profiles for a block of buildings. A block of buildings in Turin was taken as a case study. An engineering bottom-up approach was developed. A reference building was chosen and calibrated with metered data. Various simulation scenarios were developed and a parametric analysis was carried out. Seasonal heating profiles were generated for the reference building. The parametric analysis indicated the small dispersion of the heating profiles for the various scenarios. A database containing the building's heating profiles was created.

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Keywords: Energy demand profiles; Building model calibration; Typical days; Block of Buildings; District scale

1. Introduction

Approximately, half of the earth's population is living in cities and is going to increase due to a rise in population in developing countries. The main consumer of energy in urban areas is the building sector. In the European Union (EU) alone, the building sector consumes 40% of the total energy consumption [1]. As a part of the CINERGY Marie Curie ITN project funded by the 7th EU framework program, this paper develops a methodology in demand profiles generation at district scale. These demand profiles are used for decentralized energy storage systems sizing and analyzing at district level.

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In order to generate demand profiles at district scale, a building stock model was created. There are two modelling approaches of a building stock that can be found in the literature: bottom up and top-down models [2]. In order to predict the energy demand and assess the energy performance of a district, the bottom-up modelling approach is suitable because the analysis is carried out at a quite disaggregated level. The bottom-up approach is divided into statistical and engineering-based models. Statistical models are mainly data-driven models while engineering models are based on building physics calculations. There are three main techniques for creating an engineering bottom-up model: a) The brute force approach, is a full deterministic method where each building in a district is modelled and simulated individually. However, it requires a lot of power and time [3], b) The archetype approach includes the classification of the building stock according to its age and, geometrical and other parameters. The archetype demand is multiplied by the total number of buildings of the same class in order to obtain the overall energy demand of a district [4], c) Samples or representative buildings are used mainly for huge building stocks with a wide variety of building types. Representative buildings with actual building data assess large building stocks like cities and national stocks. This technique requires a large database of representative building models [5].

In the current paper, an engineering bottom-up approach for a block of buildings was developed. The method used a reference building model as a representative building. Parametric analysis of the reference model was carried out and seasonal heating profiles were generated for the reference building.

2. Methodology and example of application

The current investigation starts at a very disaggregated level and ends at the block of buildings scale. More specifically, the investigation starts from the individual building scale and after a parametric analysis and statistical interpretation, an average heating demand profile for all the buildings of the block of buildings is chosen. Also a methodology of the definition of monthly typical days of a given heating season was developed in order to have daily profiles which are suitable for investigating the thermal storage systems.

2.1. Case study

A block of buildings which is a typical form of the Italian urban design was selected. This kind of block of buildings is called “insula”. Insula is a block of residential buildings which dates back to ancient Rome. The insula investigated in this study is located in via Barrili 5, Turin, Italy (See Fig. 1 left). It is a rectangular block of buildings and consists of 12 buildings. All the buildings are multi-family residential buildings and most of them are connected to the district heating network of Turin. The buildings have similar construction and architectural parameters while there is a difference in the height and the number of floors. They were built under the same Italian regulations. The internal loads and the rest of the thermal parameters are similar to a particular building, which was chosen as a reference building because they are all residential buildings of Turin. In order to create heating demand profiles for the entire block of buildings, a reference building must be chosen as a representative building. The reference building is a real detailed white model where each room is an individual thermal zone. The reference building, which can be defined as an Example Reference Building [6], is a representative building construction of the Turin’s residential buildings. This building is connected to the district heating network of Turin with a heat exchanger of a nominal capacity of 150 kW. A satellite view of the block of buildings and the reference building model geometry are indicated in Fig. 1. The main geometrical parameters of the building are shown in Table 1.

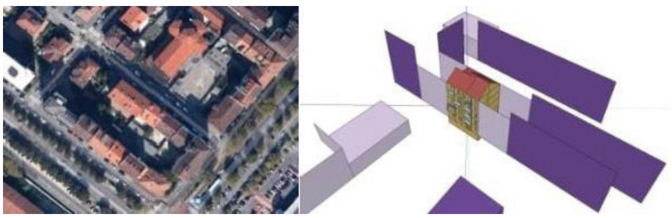

Fig. 1. Left: Stellite view of the "Insula"; Right: Reference building model in OpenStudio Plug-in.

Table 1. Reference building geometric data.

Construction age	Storeys	Total gross area (m^2)	Number of flats
1933	5	1000	12

2.2. Energy Modelling and Calibration

An initial version of the building model was developed by Monetti et al. [7] and according to Italian and international regulations and standards. The geometrical characteristics are based on the building's energy performance certificates and on-site inspections. The typical floor consists of two apartments and each apartment of five rooms. The walls are brick constructed with no thermal insulation. The buildings energy system consists of vertical columns and of cast-iron radiator units. The occupant's density, lighting and electrical equipment values of the base case model is 0.04 people/m^2, 3.88 W/m^2 and 5.38 W/m^2, respectively. The air infiltration rate is 0.3 ACH [7].

In order to evaluate the reliability of the reference building model, a calibration approach was developed. The reference building model was simulated in EnergyPlus v.7.0.0 [8] using the weather data file for the heating season 2011-2012. The seasonal heating profile was calibrated with the real metered data of a period of the heating season 2011-2012. The simulated profile had an hourly time step, while the metered data of the building substation of the district heating network had a time step between 4-6 minutes (sometimes more than 10 minutes and some of the data were missing). In order to compare the real data with simulated data, both of them need to have the same time step.

The time steps of the real data were modified in order to obtain an hourly profile. This was achieved by calculating the average hourly value of the real data. With the same time step, a comparison of the simulated and the real demand profiles was carried out. However, the peak of the simulation was underestimated in comparison with the real data peak. This is due to the water content of the heating loop. In the morning, the real system needs more heating energy to heat up the water which is contented in the circulation system. The calculation of the heating energy that the water content needs to heat up was computed with the following heat capacity equation:

$$Q = m_c \cdot c_p \cdot \Delta T (\text{kWh}) \tag{1}$$

Where:

- m_c is the water content and according to the regional regulations was defined as 5 Litres per 1 kW installed power capacity. It was multiplied by the maximum heating capacity of the season in order to calculate the water mass flow rate of the system.
- c_p is the water specific heat and is 4.186 kJ/kg K.
- ΔT is the temperature difference between the temperature of the water when the heating system is off (always 20°C) and the temperature that the water is reaching every morning. This temperature varies from day to day and month to month as a function of the outdoor climate. In the calibration, this temperature was assumed as the average inlet water temperature of each month (T_{final}=avgT_{Oct}, avgT_{Nov}, .., avgT_{Apr}). The temperatures were estimated from the metered data of 2011-2012.

This amount of heating energy was added to the morning peak of each day and the building model calibrated with the real metered data. Fig. 2 indicates the calibration results for three days in a row in December.

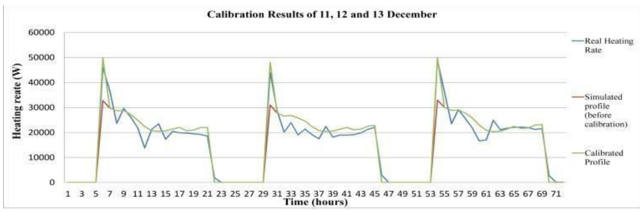

Fig. 2. Calibration results (month: December).

2.3. Parametric analysis

A parametric analysis was carried out. The parametric analysis in the reference building model resulted in a significant number of heating profiles. These profiles create a database of profiles which cover various scenarios of internal loads and other thermal parameters. From this database and with a random selection, profiles for the rest of the buildings of the block would be extracted in order to have the building heating profiles for the entire block of buildings. This methodology may be used in any block of buildings and districts with the same characteristics as this case study (similar geometrical, architectural and thermal properties of the buildings).

The reference building model was simulated in EnergyPlus [8]. The location of the simulation was Turin, Italy and was simulated under Turin's IWEC TMY weather file. More specifically, the parametric tool of EnergyPlus (Parametric:SetValueForRun and Parametric:RunControl) was applied and various parameters were used as inputs. The variables that were investigated through the parametric analysis were the relative position of the building (orientation), the internal loads such as occupant's density, lighting and electrical equipment loads and the infiltration rates.

The orientation scenarios covered the various relative positions of the buildings in the block. The orientation of the reference building was chosen as a base case scenario. The base case scenario (S1) is 0° and has North-East orientation. The rest of the orientation scenarios were created by adding 90° to the base case scenario and follow the real position and distribution of the buildings of the current block (see Table 2).

The infiltration rates have a distribution of ±20% in comparison with the base case infiltration rate. The internal loads have a distribution between -25% and +25% in comparison with the base case scenario. Empty apartments were also tested for approximately 25% of the building's area. These variables are some of the parameters that mostly affect the energy demand of the residential buildings. The internal loads and the infiltration rates are influenced by the occupant's behaviour. It is difficult to predict and control the human behaviour. The extensive variety and the unpredictable nature of the occupants' behaviour creates big differences and uncertainties in the energy building simulation. Therefore, in order to have representative profiles for various energy uses, the internal loads and infiltration rates were tested as parametric analysis variables. The geometrical building parameters were assumed to be the same for the buildings in the block.

The scenarios of the parametric analysis were a combination of the above variables. The parameters were simulated using a percentage distribution of floor area. The scenarios are indicated in Table 2.

Table 2. Variables of the parametric analysis.

Parameters	Variables			
Orientation (degrees)	S1: 0 (NE)	S2: 90 (SE)	S3: 180 (SW)	S4: 270 (NW)
Infiltration rate (ACH)	Low: 0.28	Typical: 0.35	High: 0.42	
	Light use	Typical use	Intensive use	Empty
Occupants density (people/m^2)	0.03	0.04	0.05	0.00
Lighting loads (W/m^2)	2.92	3.88	4.85	0.00
Electrical equip. (W/m^2)	4.035	5.38	6.725	0.00

A total number of 300 scenarios, 75 scenarios for each orientation, were created. The parametric analysis led to 300 seasonal heating rate profiles with an hourly time step for the reference building. These profiles were normalized by the conditioned area of the building. Thus, the profiles were expressed in kW/m^2. This normalization of the heating rate profiles was carried out in order to cover the variety of the area and the height of the buildings of the block.

The normalized profiles formed a database of heating demand profiles referring to various internal loads, infiltration rates and orientation scenarios. This database is suitable for an individual building energy assessment. In the next section, a district scale heating demand profiles generation was carried out using this database.

2.4. Block of buildings heating demand profiles generation

In this section a methodology for heating demand profiles generation for the block of buildings was developed. In comparison with the conventional archetypes method [4] which calculates and assesses the energy demand and consumption at a building stock under a simplified method, the current method generates seasonal profiles with hourly time step for the building stock of a block of buildings using the database that was created by the parametric analysis of the reference building model. According to the literature, the archetypes are simulated and then the energy consumption is multiplied by the number of the buildings at the building stock which is assessed [9].

In the current approach, for each building of the block of buildings, a normalized heating profile was extracted by the profiles database. The selection was carried out in a random way. This random approach was carried out to cover the uncertainty of the various occupants' behaviour and be a general approach that can be applied in any block of buildings beyond this case study. Also, the distribution of the occupants in a building or in a block of buildings is almost unpredictable, thus the random selection of the profiles with an iterative method gives a wide group of possible profiles for the individual building of the block and this method is suitable for general application.

The selection of the profiles for each building was carried out according to the following procedure:

- Selection for each building of the block of the appropriate orientation scenario according to the orientation of each building. The orientation definition was carried out by satellite maps.
- Then, a random selection of a heating profile between the 75 scenarios was carried out. This stage was carried out for each one of the 12 buildings of the block of buildings.
- Selection of the profiles for each building is an iterative procedure. The various scenarios of the iterations are following the above procedure. This is happening due to create a big group of profiles for each individual building and increase the probability to approach the real case of an urban block.
- For each one of the iterative scenario, the profiles of the buildings are summed in order to generate the total profile of the block. At the end a number of block of buildings profiles were created and the minimum, maximum and the average of these profiles were calculated.

The final result is a group of seasonal heating profiles with an hourly time step.

2.5. Definition and selection of typical monthly days

In order to have a synthetic picture of the thermal behaviour of the buildings, from the total seasonal profile of the block of buildings, 7 typical days were chosen. The typical days are extracted by the generated block of buildings profiles and are defined as a day whose average external air temperature (avgText) and average rate of the solar irradiance are closer to the corresponding mean monthly values. In practice the typical days, which were selected by the TMY, are real days for which these two quantities are closer to the mean values. The average temperature was selected as a primary variable. Results of such procedure are shown in Table 3.

Table 3. Monthly typical days parameters.

	October	November	December	January	February	March	April
Typical Day	24 Oct	09 Nov	08 Dec	09 Jan	09 Feb	25 Mar	04 Apr
Average Dry Bulb Temperature (C)	11.24	5.91	3.08	1.33	5.91	9.10	13.26
Average Global Horizontal Radiation (Wh/m^2)	69.96	78.29	40.83	53.04	78.29	118.58	79.58

2.6. Parametric analysis outcome and discussion of the total energy consumption

In this section, an example of parametric analysis is presented. Fig. 3 indicates the overall normalized seasonal heating consumption (kWh/m^2) for all the scenarios. The average consumption is 89.47 kWh/m^2. The maximum energy consumption for the 300 scenarios is 97.60 kWh/m^2 and the minimum is 80.40 kWh/m^2. The percentage difference between the two extreme scenarios is approximately 18%. The result indicated that the various scenarios have a small dispersion of seasonal heating consumption. Thus, the various scenarios may create a database of heating profiles based on the scenarios that were developed and be used for energy storage sizing and analysis.

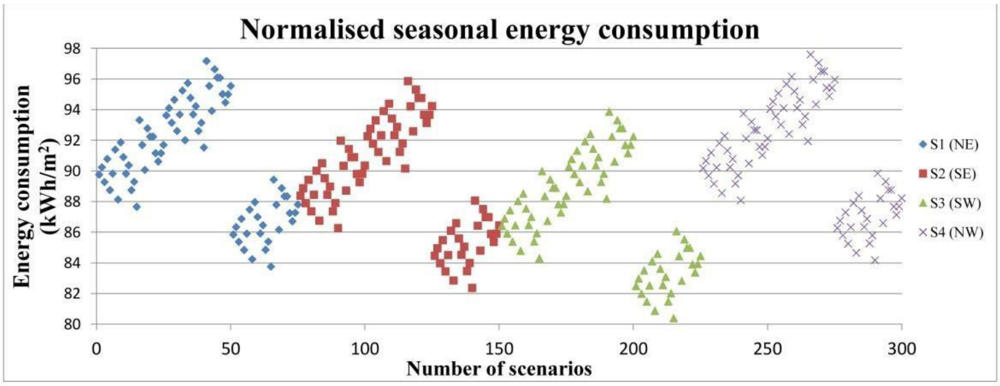

Fig. 3. Total seasonal energy consumption- anexample.

3. Conclusions

A methodology to generate a demand profile for a block of buildings was developed and partly applied to a case study as an example. This methodology includes the definition of a reference building as a representative building of the block and the parametric analysis of crucial variables in energy demand. The parametric analysis indicated that the dispersion between the various scenarios that were defined is small. After the parametric analysis, typical monthly days were selected in order to investigate decentralized energy storage systems at block of buildings and district scales.

A sensitivity assessment is going to be carried out in order to evaluate the reliability of the method. The investigation, sizing and analysis of thermal energy storage in the current block for the typical monthly days are also to be investigated.

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References

[1] De Rosa M, Bianco V, Scarpa F, Tagliafico LA. Heating and cooling building energy demand evaluation; a simplified model and a modified degree days approach. Appl Energ 2014; 128:217-229.
[2] Swan LG, Ugursal VI. Modeling of end-use energy consumption in the residential sector: A review of modeling techniques. Renew Sust Energ Rev 2009; 13:1819-1835.
[3] Pisello AL, Taylor JE, Xu X, Cotana F. Inter-building effect: Simulating the impact of a network of buildings on the accuracy of building energy performance predictions. Build Environ 2012; 58:37-45.
[4] Cheng V, Steemers K. Modelling domestic energy consumption at district scale: A tool to support national and local energy policies. Environ Modell Softw 2011; 26:1186-1198.
[5] Shimoda Y, Asahi T, Taniguchi A, Mizuno M. Evaluation of city-scale impact of residential energy conservation measures using the detailed end-use simulation model. Energy 2007; 32:1617-1633.
[6] Corgnati S, Fabrizio E, Filippi M, Monetti V. Reference buildings for cost optimal analysis: method of definition and application. Appl Energ 2013; 102:983-993.
[7] Monetti V, Fabrizio E, Filippi M. Influence of different temperature control patterns through TRV on district heating loads. Lect Notes Elect Eng 2014; 251-258.
[8] U.S. Department of Energy. EnergyPlus energy simulation software 2013 [cited 2015 Feb 10]. Available from: http://apps1.eere.energy.gov/buildings/energyplus/.
[9] Shorrock LD, Dunster JE. The physically-based model BREHOMES and its use in deriving scenarios for the energy use and carbon dioxide emissions of the UK housing stock. Energ Policy 1997; 25:1027-1037.