Calibration of a UMI Simulation Model for a Neighborhood in Bolzano, Italy

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Abstract

In recent decades, public authorities have focused their attention on the building sector, since it is responsible for a large share of the total energy consumption and, thus, should be involved in the development of sustainable energy policies. In this context, Urban Building Energy Models UBEM can play a significant role as they make it possible to study the behaviour of whole cities, as well as the potential of different building retrofitting strategies. In this contribution, the UBEM tool *umi* is used to study a neighbourhood in Bolzano, Italy, to contrast its capabilities and test the potential of a *k*-fold approach as preliminary calibration of the model, based on energy certificates and annual energy consumption data.

1. Introduction

The continuous growth of the world's population, combined with the phenomena of urbanization, will lead to an additional 2.5 billion people living in urban areas by 2050 (UN Department of Economic and Social Affairs, 2018). In this scenario, the building sector, which is already responsible for 40% of total energy consumption (European Parliament, 2010), will be crucial in ensuring sustainable development. Specifically, not only should new buildings be designed in a way that respects high efficiency criteria but also a thorough renovation of the existing building stock should be planned. To do so, it is necessary to: (1) identify those buildings responsible for the largest energy consumptions, and (2) define and optimize the impact of energy retrofitting programs.

Building Energy Models BEM, such as DOE-2 (Birdsall et al., 1990), TRNSYS (Klein, 1988) and EnergyPlus (U.S. Department of Energy, 2019), are widely employed to analyse the energy behaviour of single buildings. Furthermore, some studies in the literature have extended their range of application by evaluating the energy demand of groups of buildings (Huber and Nytsch-Geusen, 2012; Huang and Brodrick, 2000; Salom, 2002). However, the large amount of information needed as input and the required computational time make the BEM approach unsuitable for large scale applications.

As an alternative, urban scale simulations often rely on Urban Building Energy Models UBEM, which implement physical models of heat and mass flows in and around buildings to predict operational energy use, as well as indoor and outdoor environmental conditions (Reinhart and Davila, 2015). Examples of developed and validated UBEM software are CityBES (Chen et al., 2017), CitySim (Robinson et al., 2009), HUES (Bollinger and Dorer, 2016), SimStadt (Monsalvete et al., 2015), TEASER (Remmen et al., 2017), and the Urban Modeling Interface *umi* by MIT Sustainable Design Lab (Reinhart et al., 2013). Despite the variety of alternative models, a common issue faced by researchers is the availability of the whole set of required inputs and the need for model calibration.

In this work, *umi* was adopted to simulate the energy performance of a small neighbourhood served by a district heating network in the city of Bolzano, Italy, with the aim of discussing its capabilities and the impact of its modelling assumptions. After the preparation of the model, a *k*-fold cross calibration and validation procedure was run, using actual annual heating and domestic hot water energy demands as reference.

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2. Methodology

2.1 Case Study

A residential neighbourhood located in the western part of Bolzano, Italy, was chosen to develop the urban model. The area is composed of 95 residential buildings, built at the beginning of the 1990s and served by the local district heating network. Specifically, the space heating and domestic hot water (DHW) demands in the selected neighbourhood are supplied by 14 substations. Annual energy consumption is available for each substation for four years (2012, 2013, 2014, 2015). Since the substations serve different purposes (i.e. space heating demands, DHW demands, or both), for the sake of simplicity and consistency they were merged into 11 groups, each satisfying both heating and DHW demands for each cluster of the 95 buildings. Available annual space heating and DHW demands are distinguished for half of the buildings in the sample while for the remaining half, the DHW share of the global demand was considered for calibration.

2.2 Model Development

Building an urban energy model requires different steps, such as: model characterization, calibration and validation of the obtained results.

2.2.1 Geometry input data

As a first step, geometrical shape and height data for the buildings were collected. For this case study, the buildings' footprints were imported into Rhinoceros (McNeel, 2012) through a GIS file with the aid of the Grasshopper plug-in Meerkat (Lowe, 2015). To evaluate the heights of the buildings, the difference between a Digital Surface Model DSM and a Digital Terrain Model DTM were calculated for every building. Assuming a floor height equal to 3 m, the number of floors was first computed and then checked with Google Maps (Google, 2019). For those buildings characterized by a complex shape, different polysurfaces were prepared in order to obtain geometries representative of the case-study.

Since detailed data on the area of distribution of windows were not available, a glazing area per floor equal to 1/8 of the floor area was assumed, as prescribed by Italian law. To perform the glazing area calculation, floors were approximated as rectangular shapes, and a matrix with total floor areas and side lengths ranging from 1 to 60 m was prepared. All floor areas in the matrix were divided first by 8 and then by the number of externally exposed sides of each building, obtaining 4 different matrices. Finally, a division by each façade area (i.e. by 3 times the side length, as floor height was assumed to be 3 m) was performed. Using this process (shown in Fig. 1), it was possible to obtain the total glazing area for each side of every building, as well as the window to wall ratio, and these were used in the model.

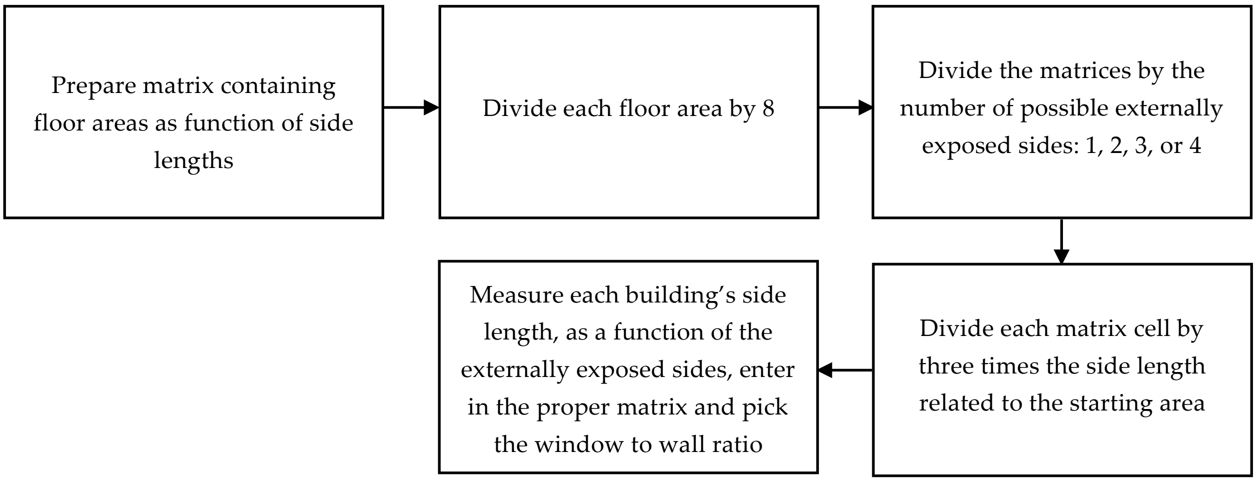

Fig. 1 – Window to wall ratio evaluation flowchart

After evaluating the window to wall ratio for every building, a model geometry inclusive of the surroundings, generated for shading purposes, was created, as shown in Fig. 2.

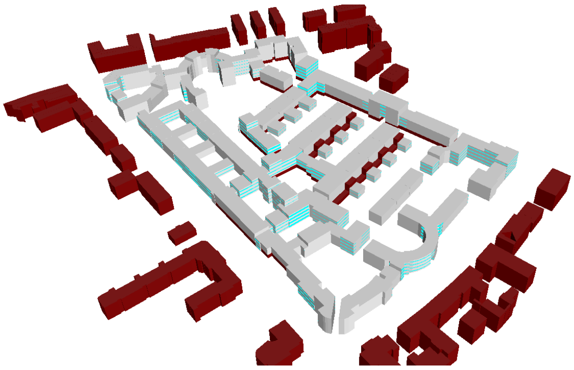

Fig. 2 – Model geometry and surroundings

2.2.2 Non-geometric properties

Non-geometric properties of the buildings in the sample, e.g. wall material layers, were obtained by consulting the 60 available energy certificates. Material properties and thermal transmittances of the different envelope components were used to generate 3 archetypes (Fig. 3). Buildings whose energy certificates were not available were assigned to Archetype 1, since they share similarities with this archetype when it comes to the period of construction and are mainly surrounded by buildings of this group.

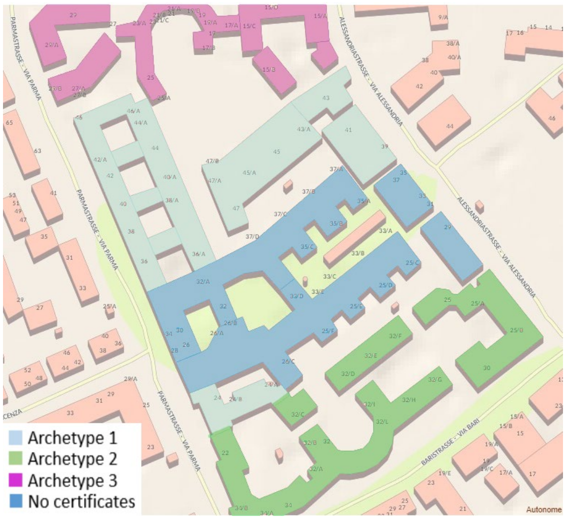

Fig. 3 – Definition of archetypes

Operation schedules and simulation parameters have been kept the same for each archetype and set according to Italian regulations and technical standards.

2.2.3 Sensitivity analysis

Once the model was created, a sensitivity analysis was carried out on schedule and simulation parameters. The weather conditions for 2012 were chosen as a test year and a variation of ±20 % was applied to the base values of ventilation rates and HVAC system efficiency, equal to 0.5 ACH and 0.87 respectively.

2.3 Model Calibration

2.3.1 Target energy consumption data

As mentioned above, actual annual energy consumptions are available for the 11 clusters of buildings from 2012 to 2015, although separate space heating and DHW demand data were provided for only half of the groups. From the available data, it was observed that the DHW share is typically between 25 % and 30 % of the total consumptions (Fig. 4).

2.3.2 Calibration and *k*-fold validation

The most significant variables resulting from the sensitivity analysis, as well as the DHW flow demand, were involved in a parametric calibration performed according to a *k*-fold cross validation approach. The *k*-fold cross validation is a statistical method which divides the available data into *k* segments (or folds), and performs *k* iterations of training and validation, each time selecting a different fold for validation and the remaining *k-1* folds for training.

In this case-study, the root mean square difference RMSD was adopted in order to compare the simulated annual results to the actual ones in the *k*-fold validation process. Specifically, for each group of buildings, the RMSD was computed over three years and the set of values with the lowest RMSD was checked for the fourth year, analyzing all possible combinations. The most frequent values for calibrated variables were selected for each group of buildings.

3. Results

Preliminary results were obtained from the sensitivity analysis using 2012 weather data to run the simulation. As regards the impact of ventilation rates and *HVAC* system efficiency, a -20 % variation causes, respectively, a reduction of 52 % and an increase of 135 % in heating demand. By comparison, a variation of +20 % leads to, respectively, an increase of 60 % and a reduction of 86 %. As a consequence, both variables were included in the calibration process, using the following ranges:

- between 0.82 and 0.87 with a 0.01 step for *HVAC* system efficiency;
- between 0.4 and 0.6 ACH with a 0.05 ACH step for the ventilation rate;
- between 0.001395 and 0.001845 $m^3\ m^{-2}\ h^{-1}$ with a step of 0.000035 $m^3\ m^{-2}\ h^{-1}$ for the water flow rate (i.e., a usage per capita between 55.8 l/person and 73.8 l/person per day).

The chosen combination for each group of buildings is reported in Table 1 and results for the year 2014 are found in Table 2. As can also be seen in Fig. 5, after the calibration the deviation from actual consumption is within 5 % in the majority of cases.

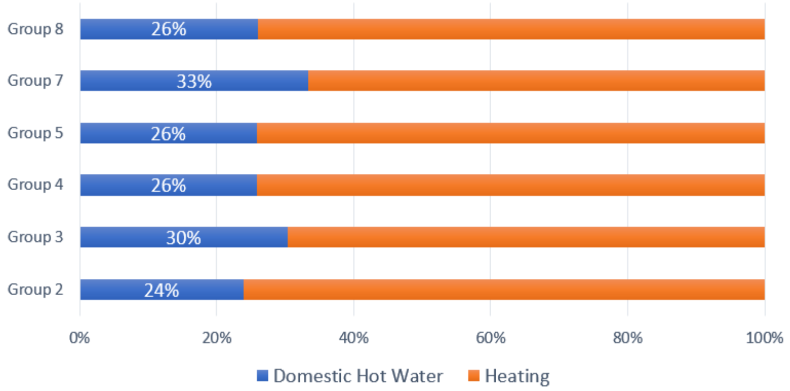

Fig. 4 – DHW share for group of buildings with subdivision

Table 1 – Chosen combinations after calibration results

Building group	*HVAC* efficiency	Ventilation rate [ACH]	Water consumption [$m^3\ m^{-2}\ h^{-1}$]	*DHW* share	Mean heating *RMSD* [%]	Mean *DHW* *RMSD* [%]
Group 1	0.83	0.55	0.001535	30 %	11.2	4.9
Group 2	0.82	0.60	0.001430	-	17.9	4.1
Group 3	0.84	0.50	0.001845	-	1.4	12.8
Group 4	0.84	0.55	0.001430	-	4.2	1.1
Group 5	0.84	0.55	0.001500	-	15.1	5.3
Group 6	0.83	0.60	0.001395	25 %	23.1	9.7
Group 7	0.85	0.55	0.001810	-	26.0	4.5
Group 8	0.83	0.60	0.001600	-	25.2	2.7
Group 9	0.83	0.60	0.001430	25 %	10.1	5.0
Group 10	0.87	0.55	0.001635	30 %	8.5	6.6
Group 11	0.85	0.40	0.001500	25 %	8.7	13.2

Table 2 Obtained results for 2014 and comparison with first simulation with base parameters

Building group	2014 heating demand [MWh]	2014 initial simulation [MWh]	2014 calibrated results [MWh]	*DHW* share	Initial simulation deviation	Calibrated simulation deviation
Group 1	292.3	264.3	288.0	30 %	-9.6 %	-1.4 %
Group 2	474.3	434.8	491.1	-	-8.3 %	3.5 %
Group 3	155.2	152.5	154.6	-	-1.7 %	-0.4 %
Group 4	129.6	121.6	124.7	-	-6.2 %	-3.8 %
Group 5	449.5	440.0	466.6	-	-2.1 %	3.8 %
Group 6	586.5	511.5	567.9	25 %	-12.8 %	-3.2 %
Group 7	820.6	819.9	855.9	-	-0.1 %	4.3 %
Group 8	294.4	260.5	293.6	-	-11.5 %	-0.3 %
Group 9	376.1	316.9	362.1	25 %	-15.7 %	-3.7 %
Group 10	349.8	334.0	341.4	30 %	-4.5 %	-2.4 %
Group 11	308.2	334.3	300.4	25 %	8.5 %	-2.5 %

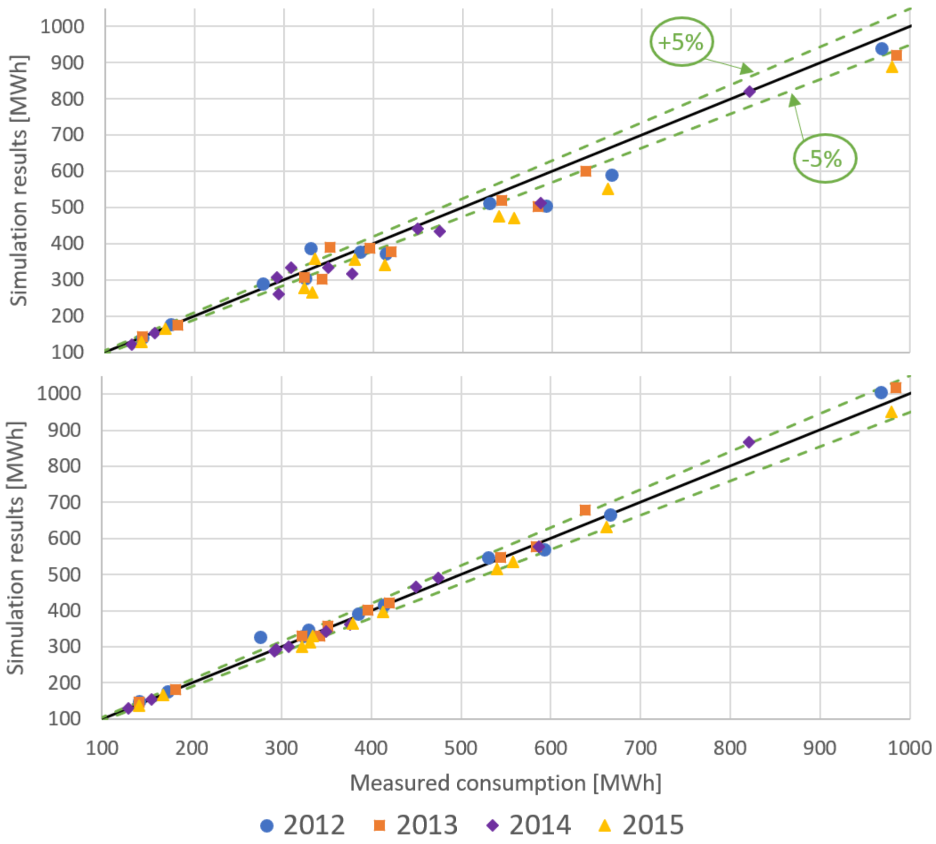

Fig. 5 – Heating demand results prior and after calibration

4. Discussion and Conclusion

In this work, the Urban Modeling Interface *umi* was used to develop and calibrate a model for a neighbourhood in Bolzano, referring to energy certificates and annual energy consumptions for space heating and domestic hot water. After creating the geometrical model and identifying the non-geometrical properties of the buildings, a sensitivity analysis and a calibration through the *k*-fold validation approach were performed. After calibration, it was shown that the *umi* model was able to provide representative results for space heating and domestic hot water demands for the considered case-study district. Moreover, the adopted *k*-fold approach demonstrated the effectiveness and potential for the calibration of urban models in these contexts; this can be seen in the presented case-study, in which the available data for model training and validation was limited and provided only on annual scale.

With a reliable model available, further developments can be now considered. These include comparisons with different approaches, and the assessment of the impact of several different conditions pertaining to the urban environment, as well as the non-energy performance of buildings in the district, such as occupant comfort. In particular, both energy and non-energy performances can be the object of further multi-objective optimization studies aimed at identifying the most effective energy efficiency measures based on indoor environmental quality, in addition to energy and cost efficiency.

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