Modeling hourly profile of space heating energy consumption for residential buildings

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Abstract – **The evaluation of energy consumption for space heating in urban environment is an interesting topic for the issues related to energy and pollution management. In the paper is presented the analysis of measured energy consumption for residential buildings located in the cities of Torino and Reggio Emilia (Italy). In the first analysis, space heating consumptions were correlated with climatic data. In the second analysis, the buildings have been grouped according to their energy signatures considering the observable characteristics (using a Geographical Information System, GIS) and the measured peak of energy request during the day. A correlation is shown between the hourly percentage peak of heat and the daily energy consumption for different outdoor temperatures; specifically, at the same temperature conditions, buildings with high peak of percentage hourly consumptions, show lower values of daily energy consumptions. This may be important to manage the district heating network for an optimization of the extension of the network, the heat storage stations localization or the gradual retrofit policy of buildings in the city.**

I. INTRODUCTION

The need to reduce energy consumption and greenhouse gas emissions (GHG) is a matter that is currently of great importance, especially in high-density urban context. In this work, the building sector, as responsible for about one-third of global greenhouse gas emissions, was analyzed and in particular the thermal energy-use of residential sector which is still one of the major contributor of GHG in cities. In Italy, to reduce energy consumption and GHG emissions, energy policies are focused on two prior actions: the improvement of energy efficiency and the exploitation of the available renewable energy sources. Also for building sector these actions can (also) improve energy accessibility, sustainability and affordability even in cities with high energy demand, high building density and low availability of renewable energy sources [1].

Energy consumption of building sector is influenced by several variables linked to the type of building, user behavior, climatic conditions such as outdoor air temperature and solar irradiation and, also, by the urban environment. For this reason, it is crucial to analyze in a better way the thermal energy-uses of different types of buildings with the aim to develop models helping energy policies to be more effective on the real buildings heritage.

Usually buildings energy models can be subdivided in three categories: top-down, bottom-up and hybrid models [2, 3]. Top-down models are developed for the evaluation of energy trends and to identify the different contributors in a territory (for energy plans from the national to the municipality scale) basing the analysis on aggregate consumption and socioeconomic data.

The bottom-up models are a more detailed approach used to understand the causes connected to different energy consumptions of each single contributor and to identify an average consumption of a typical building based on measurements in different years [3].

Finally, the hybrid models combine the above mentioned models with engineering ones to better describe energy consumptions taking into account other phenomena as, for example, the different urban environments [4].

A study conducted by Zhou et al. [6] has analyzed the relationship between offices energy consumption and the type of building envelopes in four areas of China. The results have shown that a linear regression model can be used to estimate the thermal energy-use of buildings located in different climatic areas with deviations under 15%. The independent variables used were the external air temperature, the thermal transmittance and the thermal inertia of building envelopes.

Another analysis proposed by Firku et al. [7] studied energy consumptions on a grid-connected and a stand-alone residential buildings in Texas to test energy consumption sensitivity to air temperature variations. It was noticed that energy consumption for heating and cooling is influenced by outside air temperature, but less in stand-alone building. Results show also that energy consumption depends also by other climatic variables, as solar irradiation and air humidity, and by the type of day and the time of the day.

Yao et al. [7] proposed a method for studying energy consumption of four different types of residential buildings located in Great Britain during the winter season. The energy consumption related variables were: climatic conditions, solar exposure, indoor air temperature, and type of envelope. In this study, the energy balance was calculated on an hourly period with a validation through the Esp-r software and a comparison of the results with national statistics.

In 2006, Huamani et al. [6] presented a study on energy consumption for space cooling in commercial buildings. The proposed method estimates the hourly cooling load considering as variables the outside air temperature and the solar irradiation. The results show that the method is detailed and accurate, with a deviation of about 13.2%. Also Cho et al. [5] studied energy consumption of commercial buildings but with daily, weekly and monthly measurements. They found that the influence of the period of measurements is highly significant.

As it can be noticed by the analyzed literature, the characteristics of buildings, as well as climatic, exposure and localization variables, significantly affect buildings thermal energy-use for space heating and cooling. The aim of this work is to identify simplified models to evaluate space heating energy consumption of buildings from monthly to hourly detail. These models will be useful to evaluate energy consumption of buildings at urban scale with few variables for smart energy policies, for example combining buildings emissions with traffic ones in the different periods of the year and in the different areas of a city. Moreover, with the hourly models for different buildings, heat distribution with district heating (DH) can be optimized considering also buildings that can still be connected to the DH network combining a technical and economic analysis [8]; also the possibility to insert storage systems to satisfy the morning heat peak and connect more users can be analyzed.

For this reason, in the first part of this work, a linear regression on space heating energy-use was defined with a monthly period. Also the energy signature was used to group buildings with different climate response on energy-use (on a weekly period). Then the hourly heat load profile was analyzed considering the morning peak as a function of the outdoor air temperatures, the type of building and the solar exposure.

Then, different energy consumption data have been collected with different purposes:

- monthly data for two different Italian cities Turin and Reggio Emilia (respectively with 79 and 405 buildings for the years 2014 and 2015) to evaluate:
  - how the main climatic variables (air temperature and solar irradiation) influence energy consumptions using a regression analysis [9];
- daily data for the city of Turin considering measurements on 55 users and two heating seasons (2012-2013 and 2013-2014) to:
  - classify the type of buildings with the energy signature, [10];
  - create a hourly load profile for space heating and a new classification of buildings;
  - analyze the hourly profile for different buildings and climate conditions.

All the analyses were performed using also the database on buildings information based on a Geographical Information System (GIS) to have more data about buildings characteristics and the description of population (with the Technical Maps given by the Municipalities of Turin and Reggio Emilia).

II. Case study

The study analyzes buildings connected to the DH network in the cities of Turin and Reggio Emilia, located in the area of the Po Valley, in Northern Italy. Both cities enjoy a temperate climate respectively with 2649 and 2515 HDD at 20 °C.

For the implementation of the monthly space heating energy consumption model, 79 buildings in the city of Turin and 405 buildings in the city of Reggio Emilia were analyzed for the years 2014 and 2015. The consumption data of both cities were provided by the DH company IREN, while climatic data (outdoor air temperature and solar irradiation) were provided by ARPA (Regional Agency for Environmental Protection) of Piedmont Region (weather station: via della Consolata [11]) and of Emilia Romagna Region (weather station: Reggio Emilia Urbana [12]). Furthermore, for the City of Turin the hourly data of 55 buildings were also provided with hourly time step for the heating season of 2012-2013 and 2013-2014. These buildings were divided by their use, residential and not residential, analyzing the heat load during the weekend. Found that the non residential users are offices, it was easy to find them since there as not heat consumption on Saturdays and Sundays. The final quantities of residential buildings were 45, while the non residential were 8, since two of them presented abnormal values of consumption. In order to generate the heat load and monthly space heating models as a function of the type of buildings and of the outside air temperature, the constructive characteristics of building (period of construction, surface to volume ratio, height of buildings, etc.), the database of the 2011 ISTAT census, urban factors as the buildings density, the aspect ratio, the solar exposure, the sky view factor (SVF, obtained through the use of Relief Visualization Toolbox [13]) and climatic data of the Politecnico di Torino weather station [14] were collected.

III. Methodology

The objectives of the models on space heating consumption proposed in this work will give the possibility to evaluate how the main variables on energy consumption can be used to describe yearly, monthly, daily or hourly energy-use in detail and how to improve energy planning with a spatial distribution.

In every model, energy-related variables can be distinguished in controlled and non-controlled ones. For energy planning, only few variables are available for all the buildings of a municipality or a territory; then, only a small part of those (few) variables are controllable but the energy-use depends also by the other not controllable variables. Anyway a good model can reach good results for energy planning using only the controllable variables.

Among the controllable variables can be considered the: building features (type of building, period of construction, surface to volume S/V ratio, heated volume, envelope characteristics), solar exposure (orientation, building density, aspect ratio H/W, sky view factor SVF, albedo of outdoor surfaces), type of users (population age, gender, level of education, percentage of foreigners) and environmental factors (outdoor air temperature, solar radiation, air relative humidity, urban heat island effect).

The main not controllable variables, however, are the: user behavior (settings of internal air temperature, duration of the heating period), level of energy efficiency of buildings due to retrofits improvement and the use of renewable technologies. However, the effect of uncontrolled variable usually can be estimate as a corrective factor typical of a building heritage [15]. Therefore, considering only the controllable variables, two models were defined using different methodologies for the analysis of energy consumptions. The first model was related to the definition of homogeneous groups of buildings and it was based on statistical methods such as multiple linear regression.

The model analysed the energy-related variables (building characteristics, as well as climatic variables and urban variables) in order to realize hourly thermal load profiles.

a) Linear regression model depending on outdoor air temperature and solar irradiation

The analysis carried out has a statistical approach using a linear regression. The equation considered in the calculations is as follows:

$$Y = \beta_0 + \beta_1 \cdot X_1 + \cdots + \beta_k \cdot X_k + e \qquad (1)$$

$$Y = \frac{kWh_{monthly} - kWh_{\min}}{kWh_{max} - kWh_{\min}} \qquad (2)$$

where: the dependent variable Y is the monthly variation of energy consumption, the independent variables X_1, ...X_k are the main climatic variables as the differences between indoor (20°C) and outdoor air temperatures and the monthly differences of solar irradiation; β_0 is the intercept, β_1 ... β_k are the partial regression coefficients and *e* is the statistical error.

The partial regression coefficients and the intercept have been determined reducing at minimum the sum of squared differences between the measured and calculated variation of energy consumptions [13].

The equation used in the model is therefore:

$$Y = \beta_0 + \beta_1(20 - T_m) + \beta_2(I_{max} - I_m) \qquad (3)$$

where: the coefficients β_1 and β_2 affect the weight of the differences in monthly air temperatures T_m and the monthly average daily solar irradiations I_m; the intercept β_0 represents the average fixed quote of monthly consumption variation.

b) Hourly heat load profile model based on the type of building and on the outdoor air temperature

Starting from space heating energy consumption measured on hourly time-step for 55 buildings, it was possible to subdivide buildings according to their energy-uses. Energy consumptions were collected for the heating seasons 2012-2013 and 2013-2014 and buildings were located in the central district of Turin and connected to the DH network.

To distinguish buildings with different energy consumptions, the space heating energy-use was reported as a function of the outdoor air temperature using the energy signature representation. In Figure 1, the weekly specific energy consumption for space heating is represented as a function of the average weekly air temperature. The data provided by the DH company concerned 55 buildings but considering only data covering both the two heating seasons and having a coefficient of determination R^2 higher than 0.8 with the energy signatures, the analysis was conducted only on 45 buildings for residential use. Among the 10 users left, 8 belongs to the non residential category and 2 were deleted since presented abnormal values of heat and energy consumption.

In Figure 1 the weekly specific energy-uses are reported for each building as a function of the weekly average air temperature. As it is possible to observe, there are many differences on space heating energy-use between buildings also considering the same outdoor air temperature. Considering the different energy consumptions, buildings were subdivided in groups characterized by different colors.

In Figure 2, the groups of buildings were also represented with the different slopes and intercepts of energy signatures (in Figure 1). In Figures 1 and 2, it is possible to observe, group 1 (pink) and group 2 (red) indicate buildings with higher thermal energy consumptions, while group 7 (grey), group 6 (fuchsia) and group 5 (yellow) represent buildings with lower energy consumptions.

In Figure 2 the differences by groups are also evidenced by the coefficients of the linear trend of energy signature (only energy signatures with a coefficient of determination R^2 higher than 0.8 have been represented).

For each building belonging to the groups, the building features (period of construction, S/V) and solar exposure (building orientation, SVF, height to distance H/W ratio, buildings density BD) were highlighted in Table I. In this table, the trend of variables can be observed because, as already mentioned, only the controlled ones (variables) have been taken into account. As an example, the period of construction has been considered but not the retrofit interventions that may have changed the energy consumption over the years; besides, in the energy signature, the outside air temperature is a controlled variable but (not) the inside air temperature and also the duration of the heating season are not controlled variable [15].

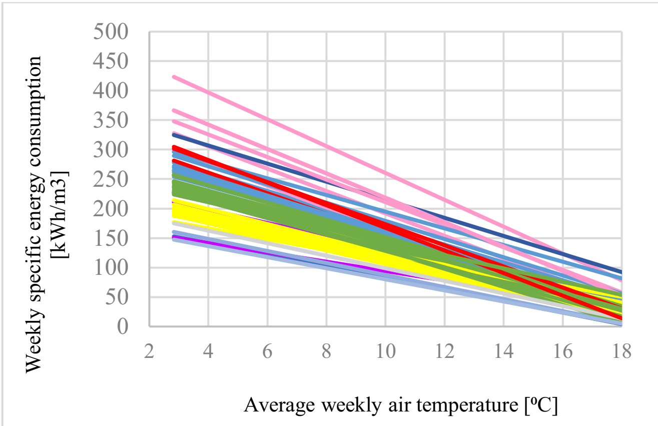


Figure 1- Energy signatures for 45 buildings in the central district of Turin.

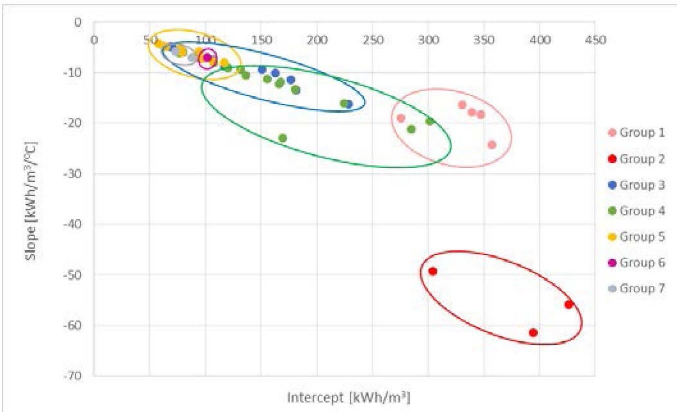


Figure 2 - Relationship between the slope and intercept of the specific energy-uses as function of outdoor air temperatures in Figure 1.

Table I. Building characteristics and solar exposure for the buildings classification 1 obtained through the energy signatures (Classification 1 in Figures 1 and 2). On the right a second classification based on the percentage of heat peak load in the morning (Classification 2).

Classification 1	Building	Period of construction	S/V [m2/m3]	Orientation	H/W	SVF_{ave}	BD [m^3/m^2]
1	10591	Up to1918	0.37	South East	0.71	75%	4.83
	10196	1946 - 1960	0.30	North East	0.79	78%	8.15
	10620	1946 - 1960	0.31	North East	0.76	80%	7.42
	10225	1971 - 1980	0.45	North West	0.47	94%	2.39
	11583	1971 - 1980	0.30	South West	0.71	81%	4.83
2	10682	1919 - 1945	0.26	North East	0.76	80%	6.97
	13194	1961 - 1970	0.30	North West	0.79	78%	6.95
3	10572	1919 - 1945	0.29	South West	0.77	76%	6.82
	10651	1919 - 1945	0.32	South East	0.78	77%	6.35
	10730	1919 - 1945	0.21	North East	0.76	69%	6.97
	10790	1919 - 1945	0.32	South East	0.71	73%	4.83
	10913	1919 - 1945	0.31	South East	0.76	80%	4.91
	10794	1946 - 1960	0.34	South West	0.75	77%	6.82
	10869	1946 - 1960	0.27	South East	0.75	81%	6.82
	10875	1946 - 1960	0.30	South East	0.75	80%	6.82
	10879	1946 - 1960	0.32	South East	0.78	78%	6.35
	10893	1961 - 1970	0.27	North East	0.76	76%	7.42
	10564	1971 - 1980	0.43	South West	0.75	64%	7.42
4	10230	1919 - 1945	0.35	South East	0.62	85%	4.51
	10433	1919 - 1945	0.32	South East	0.88	79%	5.97
	10449	1919 - 1945	0.30	South West	0.75	77%	6.63
	10718	1919 - 1945	0.21	North East	0.76	70%	6.97
	10795	1919 - 1945	0.40	South East	0.76	67%	6.97
	10798	1919 - 1945	0.28	South East	0.75	74%	6.63
	10975	1919 - 1945	0.31	South East	0.76	75%	4.91
	10241	1961 - 1970	0.25	South East	0.76	72%	7.42
	10357	1946 - 1960	0.29	South East	0.75	68%	6.82
	11617	1946 - 1960	0.37	South West	0.78	71%	7.31
	13108	1946 - 1960	0.28	South East	0.75	74%	6.82
	10876	1961 - 1970	0.32	North East	0.62	65%	6.00
	11436	1961 - 1970	0.30	South West	1.05	76%	10.11
	13172	1961 - 1970	0.26	South West	0.80	74%	8.08
5	10270	1919 - 1945	0.30	South East	0.80	70%	4.51
	10424	1919 - 1945	0.40	South East	0.82	66%	8.08
	10444	1919 - 1945	0.32	South East	0.78	67%	8.08
	10475	1919 - 1945	0.36	South East	0.71	77%	4.91
	11463	1919 - 1945	0.61	South East	0.62	73%	7.42
	10457	1946 - 1960	0.27	North East	0.76	74%	2.39
	10584	1946 - 1960	0.30	South East	0.75	74%	6.82
	10612	1946 - 1960	0.29	North East	0.75	70%	6.35
	10668	1946 - 1960	0.29	South East	0.76	66%	6.97
	10870	1961 - 1970	0.32	North East	0.76	70%	4.83
6	10422	1946 - 1960	0.40	South East	0.79	81%	8.15
7	10578	Before 1918	0.37	South East	0.71	78%	4.83
	11628	1961 - 1970	0.32	South East	0.61	85%	4.48

Classification 2	Classification 1	Building	Peak % value
1b	1	10591	9%
	4	10241	9%
	3	10564	8%
2b	2	13194	10%
	1	10196	10%
	1	10225	10%
	1	10620	10%
	4	13172	10%
	3	10794	10%
	3	10651	10%
	3	10730	10%
	3	10790	10%
	5	11463	10%
3b	4	13320	11%
	4	10449	11%
	4	10230	11%
	4	10718	11%
	3	10572	11%
	3	10879	11%
	3	10893	11%
	3	10869	11%
	7	12358	11%
4b	2	10682	12%
	1	11583	12%
	4	11436	12%
	4	10798	12%
	4	10876	12%
	3	10913	12%
	5	10270	12%
	5	10444	12%
	5	10612	12%
	5	10668	12%
5b	4	10357	14%
	4	10433	13%
	3	10875	13%
	5	10475	14%
	5	10457	14%
	5	10870	13%
	5	10584	13%
	6	10422	13%
6b	4	10975	15%
	5	10424	15%
	7	10578	15%
7b	4	11617	17%
	7	11628	17%

In Table I, it can be observed that the period of construction could be one of the variables influencing space heating energy consumption because buildings of different ages have various type of envelope, different thermal insulation level and different windows area; in the top part of Table I, there are mainly buildings with a period of construction 1971-1980 indicating buildings with light structures and more glazed surfaces that allow more dispersion to the outside. At the bottom of the table, in the last three groups, the 85 % of buildings were built before 1960, indicating buildings with massive envelopes and few glass surfaces. Another important factor is the solar exposure; buildings with higher consumption (top of the table) are predominantly North oriented (71% in the first two groups), while those with lower consumption are generally exposed to the South (South-East). Also the aspect ratio H/W is higher for the first groups with also higher buildings density BD and lower solar gains. From the Table I, some exceptions can be noticed. For example, the building 10591, belongs to group 1 with higher consumption but it was built before 1918; or building 11628 that belongs to group 7 with lower thermal consumption and it was built in 1961-1970. As already mentioned, anomalous energy consumptions could be influenced by not controlled variables.

For the evaluation of hourly thermal load profiles, measurements on two heating seasons were analysed (2012-2013 and 2013-2014). For these two heating seasons, two days with similar air temperatures have been chosen to check the daily loads of each building for every temperature (from cold to warm days); the choice of the days was also driven by the air temperature of the day before, as it influences the consumption required for space heating in the following day. At the top of the Table II, the cold days with higher temperature differences can be observed, while in the lower part can be found the warmer days with lower temperature difference.

The relative difference between the temperatures of the chosen days was also calculated and it can be seen that in all cases less than 8%. Once the hourly thermal load of each building has been reported for each outdoor air temperature, it has been observed that the values of the peak around 6 AM had different percentage values. Thus, it has been decided to make another classification of buildings according to the resulting percentage of heat load in the morning peak.

Table I also shows the subdivision of buildings based on the energy signature on the left (called Classification 1) and the one based on the morning peak of heat load on the right (Classification 2). High energy consumptions generally means low peak of heat load in the morning, because during the all day the building needs heat to maintain thermal comfort conditions inside the building; then the pink and red groups (1 and 2 for classification 1) are located at the top of the table also in the classification 2 (with low peak of heat load).; while the yellow, purple and grey groups are in the lower part also for classification 2 (with high peak of heat load).

There are, however, exceptions for users with higher or lower peak of heat load. For example, buildings 10241 and 13172 were in the central part of the table with classification 1 (group 4), while with the classification 2 they are in the groups with lower peak of heat load (groups 1b and 2b); this is due to the fact that the period of construction is 1961-1970, indicating a thin envelope with more glass surfaces. On the contrary, building 10975 which was also in the central part of the table (group 4), is one with higher heat peak, as it was built 1919-1945 with heavier envelope and a good solar exposition (South-East).

For each group of buildings, the hourly heat load was represented specifying also the daily energy consumption for every selected air temperature (see Table II). Finally, the average user was identified for each group of buildings, representing its relative hourly profile . As an example, the results of this analysis for group 4 is proposed in Figure 3 for an outside air temperature of -0.4 ºC. After a pick in the early morning, the heat load settles down to a constant value; this trend has been otbained averaging the hourly consumptions to reduce noise. In Table III, the the daily energy consumptions of the average user for all the groups of buildings and for all the selected air temperatures were reported. In Table III, it is possible to observe that group 1b is characterized by higher energy consumptions and group 7b by lower energy consumptions. As a function of daily air temperature, energy consumption varies but also the peak of heat load in the early morning. Finally, for each daily air temperature, also the average heat load profile was finally collected considering the different groups of buildings.

IV. RESULTS AND DISCUSSION

In this section, the results and the models obtained through the application of the methodology described above are reported. To test the models, a further application to the two different cities of Turin and Reggio Emilia is also presented.

TABLE II - SELECTED DAYS FOR ANALYSIS WITH THEIR RELATIVE AIR TEMPERATURE DIFFERENCES

N	Day	Data	Air temperature differences (20-T) [°C]	Day before air temperature differences (20-T) [°C]	Percentage deviation % of air temperature	Percentage deviation % of air temperature for the day before
1	Monday	11/02/2013	20.40	17.60	-	-
2	Tuesday	12/02/2013	18.30	20.40	0%	11%
	Thursday	20/01/2014	18.30	18.20		
3	Tuesday	08/01/2013	15.25	10.78	2%	47%
	Thursday	28/11/2013	15.58	15.89		
4	Monday	21/01/2013	14.64	17.60	1%	6%
	Friday	31/01/2014	14.80	18.67		
5	Thursday	06/12/2012	14.44	15.89	1%	10%
	Tuesday	17/12/2013	14.56	14.25		
6	Thursday	03/01/2013	13.87	14.88	1%	17%
	Saturday	28/12/2013	14.00	12.31		
7	Friday	15/03/2013	12.33	11.56	1%	14%
	Monday	06/01/2014	12.24	13.22		
8	Thursday	01/11/2012	11.57	13.00	0%	24%
	Sunday	23/02/2014	11.60	9.90		
9	Sunday	11/11/2012	9.56	10.55	2%	9%
	Tuesday	12/03/2013	9.73	9.63		
10	Thursday	11/04/2013	7.56	7.67	0%	9%
	Wednesday	06/11/2013	7.57	8.38		
11	Friday	27/10/2012	5.17	5.89	8%	4%
	Friday	19/10/2013	5.60	5.63		

a) Linear regression model depending on outdoor air temperature and solar irradiation

The multiple regression equation provides the possibility to study the relationship between monthly energy consumptions and the main average monthly climate variables: air temperature and solar irradiation. The partial regression coefficient and the intercept have been determined based on attitude to fit measured and calculated values on the two different cities: Turin and Reggio Emilia (Figure 4). In Table IV, the intercept β_0 and the partial regression coefficients β_1 and β_2 are presented. As it is possible to observe for both cities, the coefficient β_1 linked to the temperature gradient has the higher weight indicating that space heating consumption is most affected by the inside-outside air temperature differences. The coefficient β_1 is positive because energy consumption increases with the difference of temperatures, while the coefficient β_2 is negative because it refers to the exploitation of solar heat gains with maximum values in winter time. The higher relative deviation between calculated and measured energy consumptions for the city of Reggio Emilia is due to March and November 2015 particularly cold (see Figure 4).

b. Hourly heat load profiles of space heating consumption based on the type of building and the outdoor air temperature

In order to obtain a model of the hourly heat load profile as a function of the outdoor air temperature and of the group of buildings, the average heat load profile for each subgroup was finally collected in a single graph for each selected air temperature.

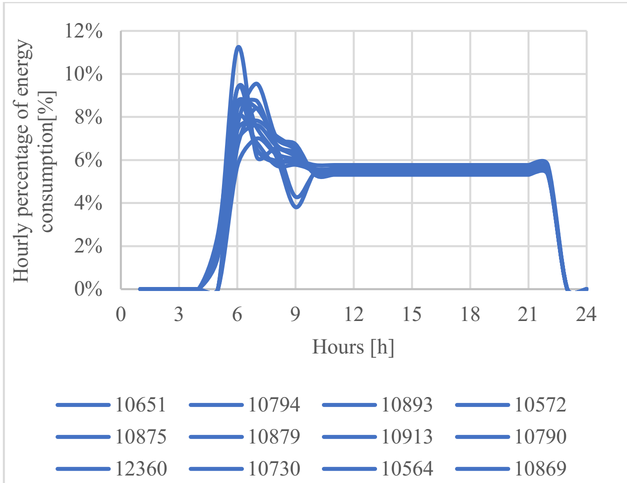
In Table V, the morning peak of heat load is reported for each group of buildings and air temperature. The percentage of the morning peak increases if the outside air temperature is higher; comparing Table V with Table III, higher heat load peaks are for lower energy consumption buildings (i.e. groups 5b, 6b and 7b).

TABLE III - DAILY SPACE HEATING CONSUMPTION OF EACH GROUP OF BUILDINGS AND FOR THE SELECTED AVERAGE DAILY AIR TEMPERATURES.

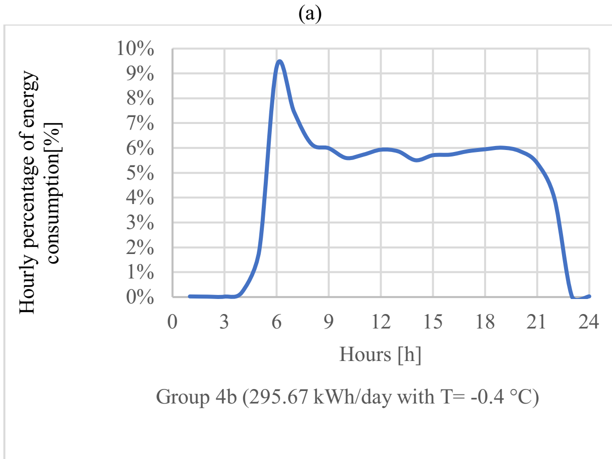
Daily air temperature [ºC]	Group 1b- Daily energy consumption	Group 2b- Daily energy consumption	Group 3b- Daily energy consumption	Group 4b- Daily energy consumption	Group 5b- Daily energy consumption	Group 6b- Daily energy consumption	Group 7b- Daily energy consumption
-0.40	363.21	327.77	298.55	295.67	267.88	265.77	264.50
1.70	337.42	298.58	286.33	278.72	260.08	245.67	241.89
4.58	262.34	243.17	234.76	224.68	208.33	196.58	190.86
5.28	319.29	274.18	264.81	256.77	237.83	222.02	222.91
5.50	232.82	222.45	204.62	200.64	182.24	174.83	169.03
6.07	231.25	217.84	202.01	194.59	179.96	164.58	160.05
7.72	210.82	210.99	189.99	182.53	162.34	161.59	144.50
8.41	179.11	177.65	152.74	140.36	131.04	127.89	124.08
10.36	171.77	161.59	143.11	136.24	125.52	116.95	119.56
12.44	132.33	129.26	116.73	107.46	95.68	94.30	84.24
14.62	130.73	120.19	95.25	88.46	87.94	79.81	78.79

TABLE IV. MULTIPLE REGRESSION ANALYSIS DATA WITH THE INTERCEPT β0 AND THE PARTIAL REGRESSION COEFFICIENTS β1 AND β2 FOR SPACE HEATING CONSUMPTIONS OF BUILDINGS OF TURIN AND REGGIO EMILIA WITH RELATIVE DEVIATION FROM THE MEASURED CONSUMPTION.

City	β_0	β_1	β_2	Relative deviation %
Turin	-0.30	0.10	-0.01	5
Reggio Emilia	-0.52	0.12	-0.03	14



(a)



(b)

Figure 3. (a) Daily heat load profile for the buildings of group 4b and for an air temperature of -0.4 ºC; (b) Average heat load profile with its average daily energy consumption with an outside air temperature of -0.4 ºC.

In Figure 5, can be observed that groups with higher thermal energy consumption show a lower morning peak value (and this tendency is repeated for all air temperatures). Moreover, after the morning heat peak, the trend became almost stable around 5-6% depending on outside air temperatures. This trend was obtained with the average of heat load variations to have simplyer curves, also with an intermittent use of the heating system.

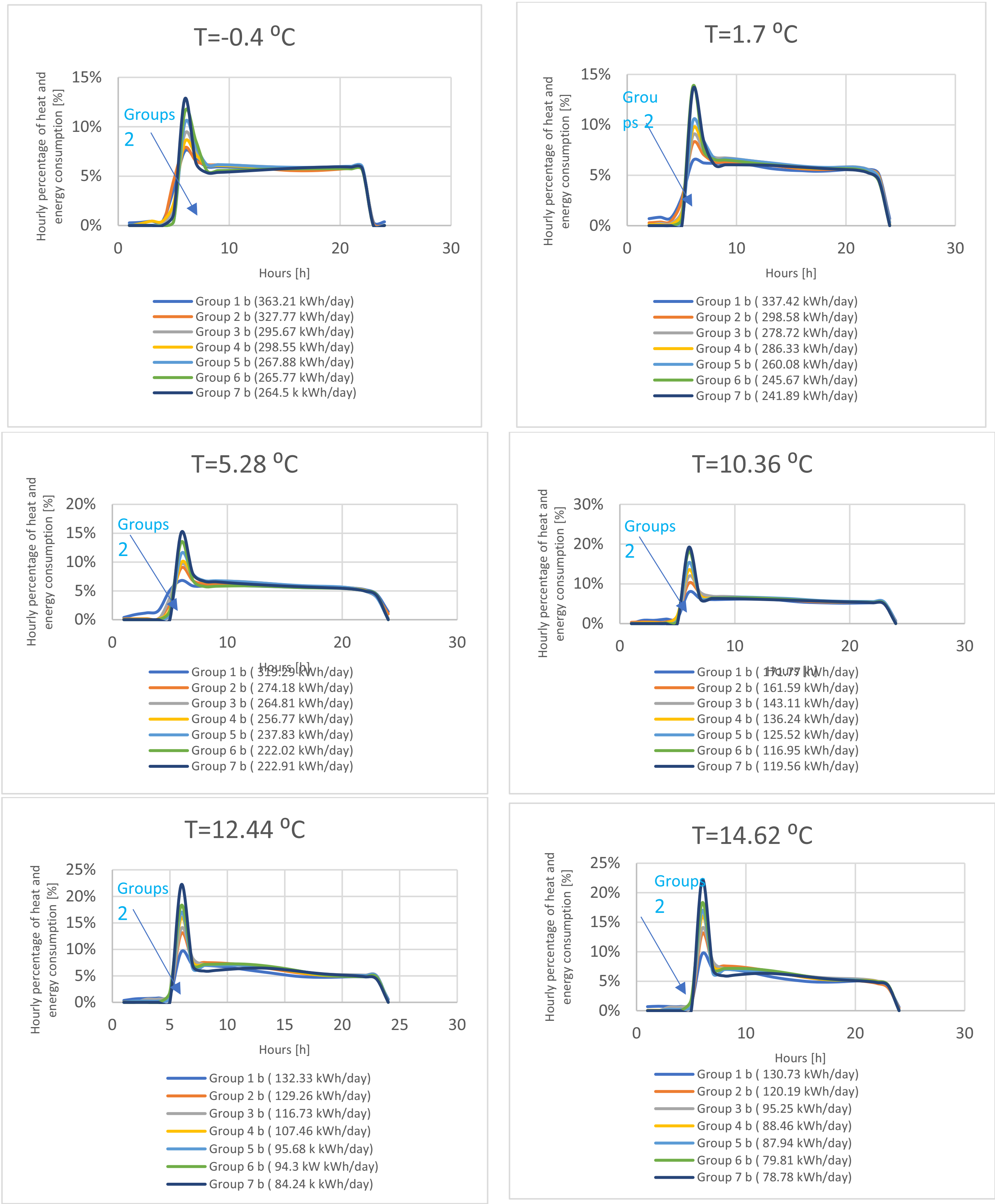


Figure 5. Daily heat load profile of buildings of each group and for all the selected outside air temperature from -0.4 to 14.62 ºC.

TABLE V - PERCENTAGE OF MORNING PEAK OF HEAT LOAD FOR THE DIFFERENT GROUP OF BUILDINGS AND FOR THE SELECTED AIR TEMPERATURES.

Daily air temperature [ºC]	Group 1b - Morning peak of heat load %	Group 2b - Morning peak of heat load %	Group 3b - Morning peak of heat load %	Group 4b - Morning peak of heat load %	Group 5b - Morning peak of heat load %	Group 6b - Morning peak of heat load %	Group 7b - Morning peak of heat load %
-0.40	8%	8%	9%	8%	10%	11%	13%
1.70	6%	8%	9%	10%	10%	14%	14%
4.58	7%	8%	10%	10%	11%	12%	15%
5.28	7%	9%	10%	10%	11%	13%	15%
5.50	7%	9%	10%	10%	12%	13%	15%
6.07	8%	9%	10%	11%	13%	16%	16%
7.72	10%	10%	10%	12%	13%	12%	15%
8.41	8%	10%	12%	14%	16%	18%	19%
10.36	8%	10%	12%	14%	15%	18%	19%
12.44	10%	13%	14%	16%	17%	18%	22%
14.62	10%	13%	14%	16%	17%	18%	22%

V. CONCLUSIONS

Space heating energy consumption of buildings is subjected to variations due to: the characteristics of the buildings, the climatic conditions and also by variables of the surrounding environment. In this work, simplyfied models to evaluate energy consumption at urban or territorial scale have been presented. In this vast areas, only few variables of buildings are known and usually energy-use data are collected at municipality scale. Then, there are many variables that are not controlled and they can influence the accuracy of the models.

The results of this work show that, once the characteristics of the buildings stock have been established, some of the controllable variables are sufficient to define:

- the monthly space heating energy-uses controlling the climatic variables, as the monthly average air temperature and daily solar irradiation;
- the heat load profiles for space heating at different climatic conditions.

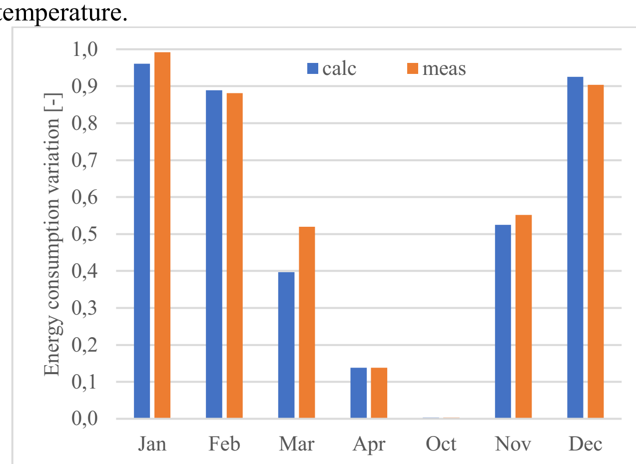
In the first part of this work, to evaluate only the climatic variables, a multiple regression analysis and the energy signature method were used. The first can be used to estimate energy consumption with different climatic conditions on a monthly period.

The second method, was useful to evaluate a model of buiding consumption for an average user at different outdoor air temperatures and the buildings were classified in order to evaluate how the different variables can influence energy consumptions.

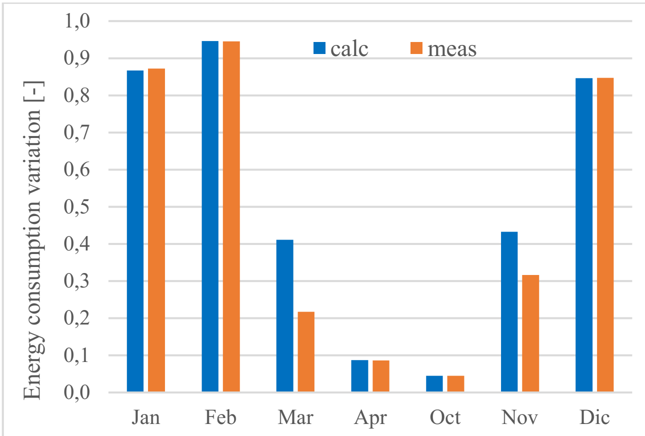
In the second part of this work, the hourly variations of energy consumptions were evaluated for 45 buildings in Turin for two heating seasons. The evaluation of the percentage peaks of heat load in the morning consented to create another buildings classification. Nevertheless, comparing the two classifications of buildings, it was possible to better analyse the energy-related constructive, climatic and urban features.

Generally, buildings with a lower daily consumption have a higher peak of the hourly heat load percentage and vice versa; the same trend can be observed for the same type of buidlings but changing the climatic conditions; with higher air temperatures, the hourly percentage of the peak of heat load is higher and vice versa.

Therefore, the daily heat load profile for the thermal energy-uses of different users can be obtained by a classification mainly based on the type of buidlng and on the outside air temperature.



(a) Turin



(b) Reggio Emilia

Figure 4. Representation of the monthly space heating consumptions variation (in blue the caculated and in orange the measurated values) for the cities of Turin (a) and Reggio Emilia (b).

Finally, these models will consent to achieve buildings energy consumptions from yealy data, to monthly, daily and hourly details. Many energy policies can be improved with this models for an optimization of the energy distribution network, which is based on the morning peak of heat load; they can be used also to evaluate how the different anthropic activities influence GHG emissions, for example considering the building space heating with the traffic flows in different hours and climatic conditions. Finally, using a GIS tool all these informations can be represented spatially distributed on a territory, allowing to adapt energy policies to the different built environments.

REFERENCES

[1] Mutani G., Todeschi V., Energy resilience in urban spaces, XXXVIII Conferenza Scientifica Annuale AISRE, September 20th, 2017, Cagliari, in press.

[2] Swan L.G., Ugursal V.I., Modeling of end-use energy consumption in the residential sector: A review of modeling techniques, 2008.

[3] Mutani G., Todeschi V., Space heating models at urban scale for buildings in the city of Turin (Italy), Energy Procedia, PII: S1876-6102(17)33400-8, DOI: 10.1016/j.egypro.2017.07.445.

[4] Carozza M., Mutani G., Coccolo S., Kämpf J.H., Introducing a hybrid energy-use model at the urban scale: the case study of Turin (IT), 3rd IBPSA-Conference, Bozen (IT), 2017, ISSN 2531-6702.

[5] Cho S., Kim T., Tae C., Effect of length of measurement period on accuracy of predicted annual heating energy consumption of buildings: Energy conversion and management, 2004.

[6] Zhou S., Zhu N., Multiple regression models for energy consumption of office buildings in different climates in China: Energy, 2013.

[7] Fikru M.G., Gautier L., The impact of weather variation on energy consumption in residential houses: Applied Energy, 2015.

[6] Yao R., Steemers K., A method of formulating energy load profile for domestic buildings in the UK, Energy and buildings, 2004.

[7] Huamani M.M., Orlando A.F., Methodology for generating thermal and electric load profiles for designing a cogeneration system, Energy and buildings, 2006.

[8] Guelpa E., Mutani G., Todeschi V., Verda V., A feasibility study on the potential expansion of the district heating network of Turin", Energy Procedia, Volume 122 (2017), CISBAT 2017 International Conference Future Buildings & Districts, Edited by Jean-Louis Scartezzini, Elesevier, ISSN 1876-6102,, Pages 847-852, DOI: 10.1016/j.egypro.2017.07.446

[9] Mutani G., Pastorelli M., De Bosio F., A model for the evaluation of thermal and electric energy consumptions in residential buildings: The case study in Torino (Italy), 4th International Conference on Renewable Energy Research and Applications ICRERA-2015, IEEE Conference Publications, pp: 1399 - 1404, DOI: 10.1109/ICRERA.2015.7418637.

[10] Delmastro C., Mutani G., Schranz L., Advantages of coupling a woody biomass cogeneration plant with a district heating network for a sustainable built environment: a case study in Luserna San Giovanni (To, Italy), Energy Procedia 78, 2015, 794–799, DOI 10.1016/j.egypro.2015.11.102.

[11] Weather data for: Consolata (Turin), available at: webgis.arpa.piemonte.it/webmeteo.

[12] Weather data for: Reggio nell'Emilia, available at: www.arpae.it/dettaglio_generale.asp?id=2615&idlivello=1521.

[13] Li W., Putra S. Y., Yang P.P., The Development of GIS Analytical Tools for Sky View Factor - GIS Analysis for the Climatic Evaluation of 3D Urban Geometry, Department of Architecture, School of Design and Environment, National University of Singapore; available at: http://clamsitel.pbworks.com/w/file/fetch/45645330/OK%20%20%20%20li.pdf.

[14] Weather data for: Politecnico di Torino, available at: https://www.swas.polito.it/intra/w4e_living_lab/operatore/esterno/meteo_mese.asp.

[15] Torabi Moghadam S., Mutani G., Lombardi P., GIS-Based Energy Consumption Model at the Urban Scale for the Building Stock, 9th International Conference Improving Energy Efficiency in Commercial Buildings and Smart Communities (IEECB&SC'16), ISBN 978-92-79-59779-4, ISSN 1831-9424, DOI:10.2790/290244, Frankfurt, March 2016, pp.56-63.