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Assessing Buildings Hourly Energy Needs for Urban Energy Planning in Southern European Context

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Abstract

For decreasing the fossil fuels consumption and reducing air pollution at urban level, current policies encourage a transition to distributed energy generation (DG) and support initiatives towards district heating and cooling networks (DES - district energy systems), promoting the integration of renewable energy sources (RES). Based on these approaches, the assessment of the energy demand fluctuations of the building stock is preliminary for energy planning at district scale, since systems' operation requires a complex balancing for maximizing the efficiency or minimizing the cost, combining the intermittent nature of RES (except biomasses) with non-RES and/or storage technology. Surveyed literature concerning recent studies aimed at optimizing district energy scenarios revealed that most of the assessment are limited to the seasonal and/or annual based buildings energy needs, while the ones that deal with a proper time scale (i.e. hourly based) refer to specific case studies, which are hardly replicable in other urban contexts. The purpose of the study presented in this paper was to provide reliable reference profiles of buildings thermal energy needs (for both space heating and cooling) with reference to the Italian context. Therefore, a set of building models, representative of typical solutions of different historical periods, was defined for both residential and diffuse tertiary (offices) use. Once elaborated accurate hourly internal loads curves, it was possible to provide, performing detailed simulations with TRNSYS model, profiles of energy need density, referred to cubic meter of building volume, for typical buildings placed in different climatic locations, covering the wide range of Italian context. Based on both the building typologies and the climatic variability considered, assumptions adopted for the study could be extended to other comparable context in southern Europe.

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Keywords: urban energy planning; typical building energy models; buildings hourly energy loads; thermal energy needs density profiles;

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1. Introduction

For decreasing the fossil fuels consumption and reducing air pollution at urban level, current policies encourage a transition to distributed energy generation (DG) and support initiatives towards district heating and cooling networks (DES - district energy systems), promoting the integration of renewable energy sources (RES).

Since systems' operation requires a complex balancing for maximizing the efficiency or minimizing the cost, combining the intermittent nature of RES (except biomasses) with non-RES and/or storage technology, the assessment of the energy demand fluctuations of the building stock is preliminary for energy planning at district scale.

The definition of the urban energy demand could be accomplished through different approaches, as highlighted in [2]-[4]. Several studies [7]-[10] were able to use real data, both from monitoring campaigns for specific case studies or measured consumptions from energy companies. However, accomplishing audits or monitoring campaigns is a time and economic consuming procedure, while official data on energy are not available for all contexts. Therefore, some studies regard the development of methodologies for load forecasting, which generally can be referred to the following main approaches [1]: the statistical ones, which require a huge amount of real data and survey the mathematical correlation among considered factors, and the physical ones, which are based on the detailed characterization of the buildings and on calculation of energy balances equations. For instance, Pedersen et al. [22], have estimated load profiles for heat and electricity for different building typologies, based on statistical analysis of measured consumptions, and elaborated a method for aggregation at urban level. Ziegler et al. [26], generalizing all heating load curves of considered building types by using density functions, have defined a heating density load curve for residential buildings. Other studies have focused on electricity loads [19][17][16] by accurately assessing the daily profiles related to equipment and artificial lighting use, or estimating the probability of activation and use of electric devices. Increasing number of studies use Artificial Neural Network for estimating the energy consumptions usually based on past data [11][11][12][20] [20][23]. For instance, Powell et al.[24], since monitored data of energy consumptions and climatic data from a University campus, have derived hourly loads for both thermal and electric uses. Oloffson et al. [21], since internal temperatures and energy consumptions, derived simplified equations based on outside and inside temperatures for defining hourly energy consumptions for the residential sector. Kato et al. [25] defined a Recurrent Neural Network for forecasting the thermal energy consumptions in non-steady state.

A complexity in deriving replicable methodologies for different contexts, rather than for specific case studies, emerges from the state of the art. Even if the need of dealing with the stochastic nature of energy loads has been highlighted in [5], the generalized application of statistical methods for estimation of load curves could be complex considering the huge amount of required real (statistical or monitored) data.

As previous studies have successfully shown [14][15][18], an alternative approach could be based on dynamic simulation of energy consumptions by representative building models and association of defined values to the considered building stock. Based on this approach, the present study has assessed profiles of hourly heating and cooling energy needs profiles of typical residential and office building models with reference to the Italian context.

2. Methodology

Buildings thermal energy needs are strictly related to the local climate, to the construction characteristics and to the usage patterns. In order to assess the energy behavior of different building solutions characterizing a large building stock, it can be useful to perform detailed simulation of reference building models.

For this purpose, typical building solutions were defined with respect to the most common ones of the Italian stock, which could also constitute a reference for similar contexts in Southern Europe.

The two most common categories of building use were considered in this phase of the study: the residential and the diffuse tertiary (office) ones. Starting from a usual parallelepiped shape, five different envelope solutions were defined to be representative of likely practices from the three main construction ages and, for considering the wide national climatic variability, seven climatic locations were selected.

In order to take into account the random orientation of the buildings in a generic stock, energy simulations of the resulting case studies were performed (by means of TRNSYS model [30]) by rotating the buildings based on the two axis (i.e. north-south and east-west) to cover the four main exposures and the average values of obtained thermal energy needs have been considered as overcomes.

2.1. Building models and thermal zones

The building models have a rectangular plan (dimensions are 20 m × 12 m), with five conditioned floors over an unconditioned basement (e.g. garage, cellars, technical rooms).

In order to properly assign the internal loads according to the different spaces use (see section 2.3), a schematic layout of the typical building floor was defined. In detail, the typical floor of the residential buildings is based on a greed of 15 square thermal zones (16 m^2 each), holds three different size flats (48, 80 and 96 m^2, respectively), corresponding to a total of 168 m^2 for both living-rooms and bedrooms, 24 m^2 for kitchens and 32 m^2 for bathrooms, and a 16 m^2 of unconditioned vertical distribution space (i.e. stair and lift). For the office buildings, the typical floor holds 8 conditioned square office rooms (25 m^2 each one), placed on the two main facades and with an unconditioned distribution space (40 m^2) in between.

Based on the thermal zones defined for the typical floor layouts, windows are considered on all façades in residential buildings and on the two main ones in the office buildings.

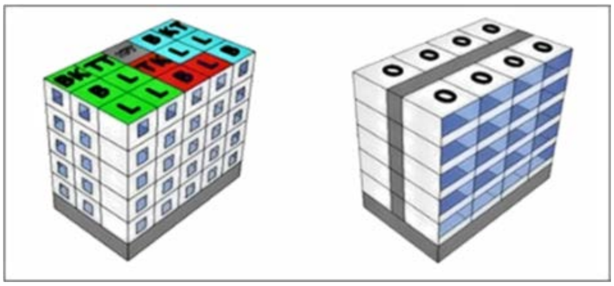


Fig. 1. Building models of residential (left) and office (right) buildings. Legend: B (bedroom); L (living room); K (kitchen); T (toilet); O (office).

2.2. Buildings construction and climatic locations

The building models construction was defined based on previous works of the authors [28]: for limiting the number of the considered variables, the internal structures remain always the same (based on the widely diffuse ones, hollow bricks walls and concrete and masonry slabs), while the horizontal envelope components (again simple concrete and masonry solutions) only change regarding the presence and thickness of a possible insulation layer, depending on the requirements of the considered construction period. Hence, the main variation regards the vertical building envelope, and involves a window percentage and a construction solution that are representative of likely practices from three main construction ages: newly built, 1960/80 and very old. Therefore, for every construction age, "conventional" vertical envelope solutions have been taken into account, with masonry external walls and a window surface equal to 1/8 of the floor area, which is a diffuse Italian praxis to provide natural ventilation and lighting, while alternative more glazed and lighter solutions have been considered for the office buildings of the contemporary and 1960/80 ages (Table 1, Table 2).

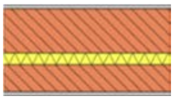
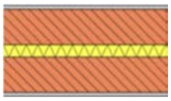
In order to take into account the wide national climatic variability the locations were selected, consistently with the Test Reference Year climatic files within TRNSYS database, according to both their heating degree-days, reported in [27], which represent the air temperature characteristics, and, since no official reference cooling degree-days are provided for the Italian cities, to their latitude for distinguishing, in first analysis, the amounts of solar radiation that influences the building performance in summer [28]. As a result, the seven different locations reported in Table 3 have been considered.

2.3. Internal heat loads and air change rate

The Italian technical standard UNI TS 11300-1 [31] defines the procedure to calculate the building heating and cooling needs but building use profiles enough detailed, disaggregated by type, are not provided. Alternatively, the Swiss Technical Worksheet SIA 2024 [6] was considered for this study.

The SIA 2024 provides the needed assumptions for building energy-use calculations, when no other sources (i.e., direct survey) are available. It also provides detailed occupancy and appliance use data expressed in terms of values (people per floor area, installation power density, etc.) and hourly schedules that modulate the occupancy as well as the loads of the installations, which do not operate at their nominal power all the time.

Table 1. Construction schemes and layers of the opaque part of the external walls for the different cases.

Scheme	**Layers**		**Thickness** [cm]	**U-value** [W/(m^2 K)]	**Heat Capacity** [kJ/(m^2 K)]
New Conventional					
in  ext	1	Gypsum plaster	1.5	0.33-0.47 MI/TS - PA	~260
	2	High density hollow bricks	17.0		
	3	Insulation (mineral wool)	7.0-3.5 MI/TS - PA		
	4	High density hollow bricks	8.0		
	5	Cement plaster	1.5		
New Glazed					
in  ext	1	Gypsum plaster	1.5	0.33-0.47 MI/TS - PA	~251
	2	Hollow bricks	12.0		
	3	Insulation (mineral wool)	8.5-5.0 MI/TS - PA		
	4	Hollow bricks	12.0		
	5	Cement plaster	1.5		
60/80 Conventional					
in  ext	1	Gypsum plaster	2.0	0.98	263
	2	Hollow bricks	12.0		
	3	Air	6.0		
	4	Hollow bricks	12.0		
	5	Cement plaster	2.0		
60/80 Sandwich Largely Glazed					
in  ext	1	Gypsum board	2.5	0.36	53
	2	Insulation (mineral wool)	10.0		
	3	Fiber cement board	1.5		
Old Conventional					
in  ext	1	Gypsum plaster	2.0	1.08-0.98 MI/PE-RM/PA	818-587 MI/PE-RM/PA
	2	Full Bricks (MI/PE) Tuff (RM/PA)	50.0		
	3	Cement plaster	2.0		

The usage patterns were derived by a huge amount of surveyed data, in order to cover most of the possible building types: a total of 44 building or even zone uses are summarized (i.e., hotels, offices, open-space offices, kitchen, living rooms, etc.). Therefore, also considering that the Swiss context is not much different from the Italian one, SIA 2024 was assumed as reference for the energy simulations, according to the methodology defined in [16].

Table 2. Office rooms: glazed surface characteristics for the different cases.

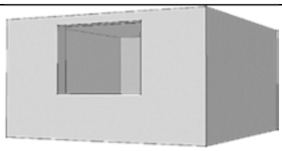
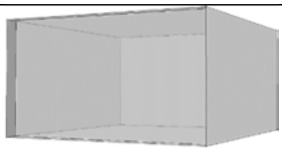
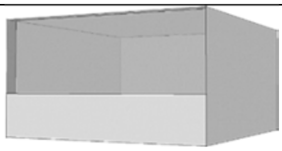
Solutions	Dimensions	Window U-value [W/(m^2 K)]	Solar heat gain coefficient (g)
New Conventional		1.77 - 2.81 MI/TS – PA	0.60 - 0.65 MI/TS – PA
60/80 Conventional		2.91	0.76
Old Conventional		2.73	
New Glazed		1.28 – 2.16 MI/TS – PA	0.39 - 0.41 MI/TS – PA
60/80 Sandwich Largely Glazed		2.91	0.76

Table 3. Heating degree-days (HDD) and latitudes of the selected locations.

	Bolzano	Milano	Trieste	Pescara	Roma	Napoli	Palermo
HDD	2791	2404	2102	1718	1415	1034	751
Latitude N	46.29	45.28	45.38	42.27	41.54	40.51	38.6

For homogeneously assigning the internal loads to the entire building models, the peak density values (in W/m^2 of floor surface), with related modulating schedules, for occupancy, equipment use and artificial lighting provided from SIA 2024 for different zone uses, have been weighted according to the zones of the layouts in section 2.1.

Similarly, the air change volumes and related modulating schedules, in addition to a constant rate of 0.2 h^{-1} considered due to infiltrations, have been assigned to the entire building models.

The detailed hourly values obtained are reported in the following figures.

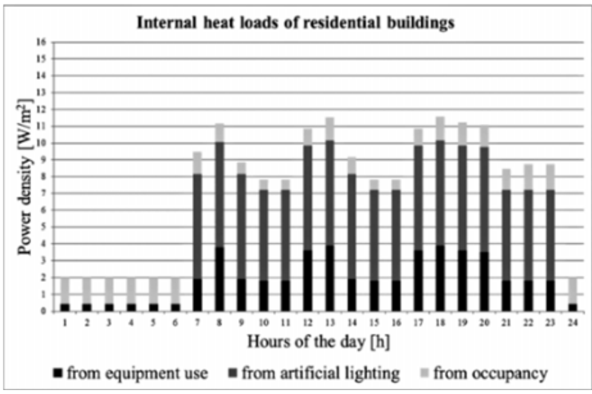


Fig. 2. Internal heat loads of residential buildings.

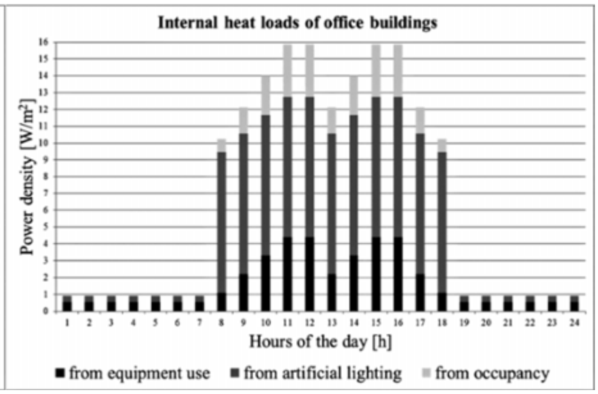


Fig. 3. Internal heat loads of office buildings.

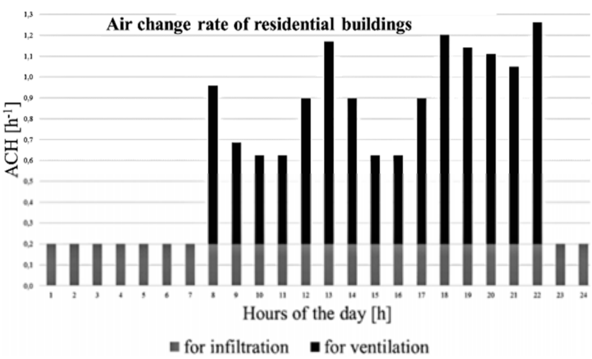


Fig. 4. Air change rate of residential buildings.

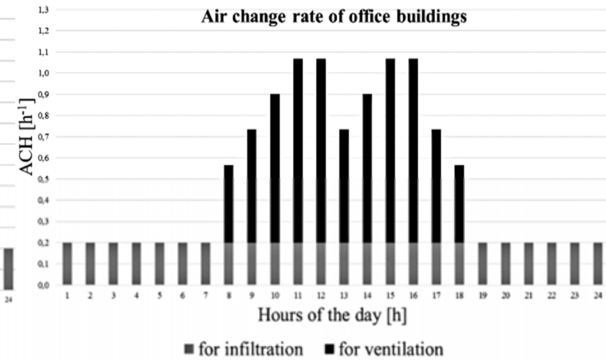


Fig. 5. Air change rate of office buildings.

2.4. Space heating and cooling settings

In Italy, the heating season length, and the limited number of hours per day in which the use of heating systems is allowed, is defined based on the HDDs according to [27], while any national rule doesn't concern the cooling systems use.

Table 4. Space heating season length and limited number of hours per day of the selected locations.

Location	Bolzano – Milano - Trieste	Pescara - Roma	Napoli	Palermo
Climate zone	E	D	C	B
Heating season	Oct15th - Apr 15th	Nov 1st - Apr 15th	Nov 15th - March 31st	Dec 1st- March 31st
Max. hours per day	14	12	10	8

For the office buildings, additionally, both heating and cooling needs have been evaluated, with reference to the usual tertiary system operations, only based on the period of occupancy. Regarding set-point temperatures (referred to 20°C for heating and 26°C for cooling, as usually), the following considerations have been assumed.

In common practice active systems are regulated according to air temperature sensors and the building simulation praxis refers to the same approach. However, the set-point regulation adopted for the building models of this study was performed according to operative temperature: thanks to this assumption, it is possible to properly take into account the performances of the different building envelopes in contributing to overall thermal comfort sensation, i.e. in providing suitable surface radiant temperatures. These last ones, in case of unfavourable resulting values, are often responsible of an overusing the air conditioning systems for correcting the indoor condition, air side, implying additional energy consumptions. Additionally, for the residential building models, variable operative temperature values were considered for assessing the thermal energy needs according to the adaptive comfort approach, which has a dynamic form depending on a transient parameter such as the external temperature of the considered period [29]. Adaptive comfort equations were developed, for different building uses and climatic contexts, on the assumption that the occupants are an active part of the enclosed environment: they can interact with the construction and can affect the building boundary conditions regardless of the presence of an air conditioning system, as usual in Italian residential sector. In these conditions, the real thermal needs strongly depend on the comfort mitigation strategies adopted by users, and the thermal expectations are strictly related to the outside mean climatic conditions (thermal experience). In particular, the equations adopted in [28] were assumed for this study.

3. Outcomes

As an example of the outcomes set, the hourly heating and cooling needs densities assessed for the residential building (conventional) and for the office building (largely glazed) of the construction period of 1960/80 (the one responsible of the largest amount of the Italian existing stock), are graphically reported with reference to the two extreme locations considered within Italian climate.

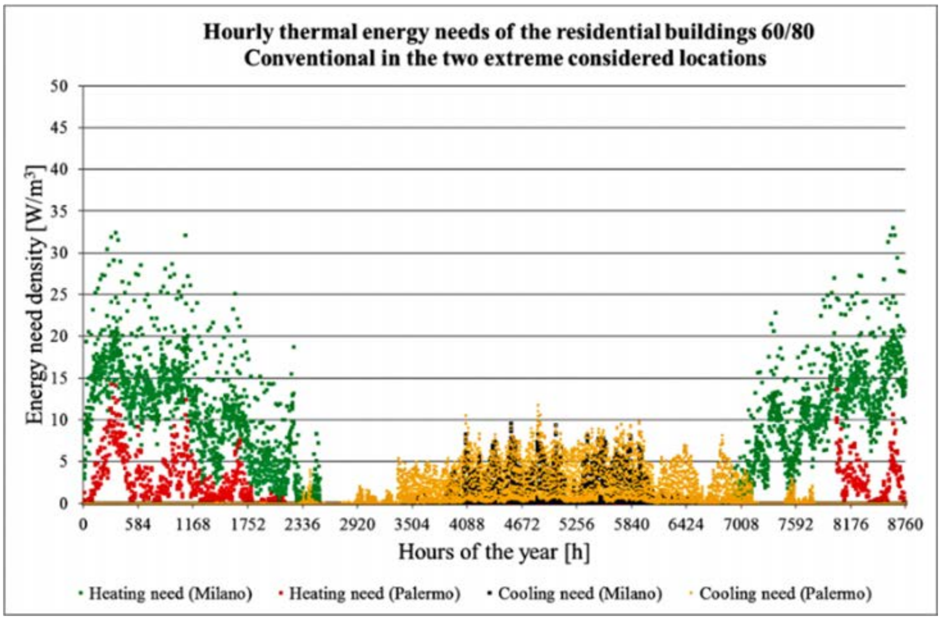


Fig. 6. Hourly thermal energy needs of the residential buildings 60/80 Conventional in the two extreme considered locations.

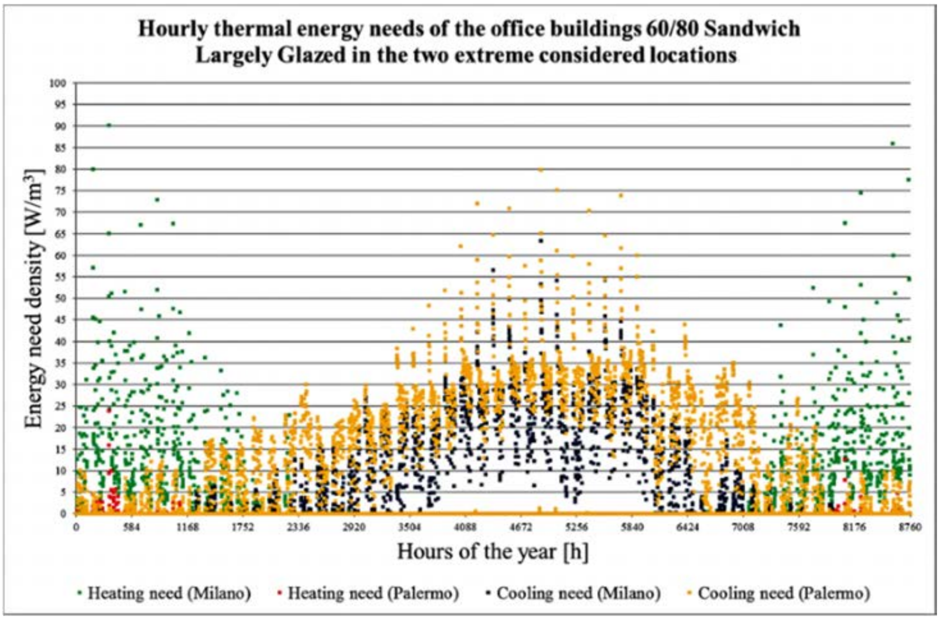


Fig. 7. Hourly thermal energy needs of the office buildings 60/80 Sandwich Largely Glazed in the two extreme considered locations.

The reported example of outcomes highlights the different magnitude of thermal needs densities due to the national climatic range for both residential and office buildings. Moreover, the differences in heating needs densities are relevant for both uses, conversely cooling needs densities reveal comparable peaks even if the resulting cooling period is significantly more extended in Southern Italy.

4. Conclusions

The study presented in this paper is preliminary for the assessment of the thermal energy demand fluctuations of building stocks, for optimizing the district energy systems' operation, toward the energy planning at urban scale based on the current policies. For this proposal, starting from a reference parallelepiped shape, a set of building energy models, representative of typical solutions of different construction ages, was defined for both residential and diffuse tertiary (office) use. Once elaborated hourly internal loads curves based on the accurate Swiss standard SIA2024, it was possible to provide, performing detailed simulations with TRNSYS model, thermal energy need profiles of the typical buildings placed in different climatic locations, covering the wide range of Italian context.

Resulting hourly density values, referred to cubic meter of building volume, can be taken into account for elaborating reference hourly profiles (e.g. pattern of the typical seasonal week) to be used for assessing the overall hourly energy needs of any built area in Italy, once the actual built volume of each building type of the considered building stock is known. Based on both the building typologies and the climatic variability considered, the main assumptions adopted for developing the study could be extended to other comparable context in southern Europe.

Further development will regard a sensitivity analysis of the buildings thermal energy needs profiles related to the building form factors (i.e. the surface-to-volume ratio, which defines the compactness) and to additional building features (e.g. shading devices, tilted roofs, etc.).

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