CLIMA 2016 - proceedings of the 12th REHVA World Congress

volume 6

Heiselberg, Per Kvols

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Heiselberg, P. K. (Ed.) (2016). *CLIMA 2016 - proceedings of the 12th REHVA World Congress: volume 6*. Aalborg: Department of Civil Engineering, Aalborg University.

Definition of Standardized Energy Profiles for Heating and Cooling of Buildings

*Borja Badenes[//1], Marco Belliardi[02], Adriana Bernardi[#3], Michele De Carli[*4], Maria Di Tuccio[#5], Giuseppe Emmi[*6], Antonio Galgaro[&7], Samantha Graci[*8], Luc Pockele[&9], Arianna Vivarelli[#10], Sebastian Pera[011], Javier F. Urchueguía[//12], Angelo Zarrella[*13]*

[//]*Energesis, Valencia, Spain*

[1]bbadenes@energesis.es

[12]javier@energesis.es

[0]*University of Applied Sciences of Southern Switzerland, Canobbio, Switzerland*

[2]marco.belliardi@supsi.ch

[11]sebastian.pera@supsi.ch

[#] *CNR-ISAC, Padova, Italy*

[3]a.bernardi@isac.crn.it

[5]mc.dituccio@isac.cnr.it

[10]a.vivarelli@isac.cnr.it

[*] *Department of Industrial Engineering, University of Padova, Italy*

[4]michele.decarli@unipd.it

[6]giuseppe.emmi@unipd.it

[8]samantha.graci@unipd.it

[13]angelo.zarrella@unipd.it

[&] *Department of Geosciences, University of Padova, Italy*

[7]Antonio.galgaro@unipd.it

[&]*Red, Padova, Italy*

[9]luc.pockele@red-srl.com

Abstract

For promoting the diffusion of GSHP (Ground Source Heat Pumps) a tool for sizing these systems will be carried out in the H2020 research project named "Cheap GSHPs". The paper presents the set up of a database with energy profile of a certain amount of buildings representative of the typology (single family houses, block of flats, office buildings) with different insulation levels and in different climatic conditions. Based on the weather analysis among European climatic files, twenty locations have been considered. For each location the overall energy and the mean hourly monthly energy profiles for heating and cooling (sensible and latent) have been calculated. Based on the results, the correlations with Degree Days (DD)

for heating and cooling have been found in order to generalize the results to have pre-calculated profiles for sizing GSHP.
Keywords - Weather conditions, Building Energy demand, Energy profiles for heating/cooling, GSHP

1. Introduction

The European Energy Efficiency Directive (2012/27/EU) demand to the Member States (MS) the activation of a suitable series of measures aimed to a more efficient use of energy in the various sectors of the economy. Targets provided to every MS are monitored in the period 2014-2020 in order to achieve the desired reduction of the total energy consumption by the means of a 20% of energy efficiency improvements [1]. According to the building sector it is known that in European Union (EU) it is responsible of about the 40% of the total final energy consumption, and of the 36% of the Europe global CO_2 emissions. During the last decade the European Commission released the first legislative instrument aimed to improve the energy performance of buildings: the "Energy Performance of Building Directive (EPBD) was introduced in the 2002 and updated in the 2010 [2, 3]. The way to reach the European objectives involves both the retrofit of the actual building stock, through a major renovation of the envelopes, both the diffusion of more efficient solutions for HVAC systems, capable of exploiting increased share of renewable energy.

One of the most interesting technologies is represented by shallow geothermal pumps. In sedimentary basins, the temperature is more or less constant near the surface, reflecting more or less the annual mean near-surface temperatures. In general, the temperature in the Earth's crust increases with depth. Down to depths of about 10'000 m, the average geothermal gradient is about 2-3 °C/100 m [4] resulting in temperatures around 100 °C at 3 km depth.

Geothermal heat pumps (GHPs), earth-coupled, ground-source, or water-source heat pumps, have been in use since the late 1940s. The biggest benefit of GHPs is that they use 25% to 50% less electricity than conventional heating or cooling systems. This translates into a GHP using one unit of electricity to move three units of heat from the earth. According to the Environmental Protection Agency (EPA), geothermal heat pumps can reduce energy consumption, and corresponding emissions, up to 44% compared with air-source heat pumps and up to 72% compared with electric resistance heating with standard air-conditioning equipment. [5]

Geothermal heat pumps are able to heat, cool, and, if so equipped, supply the house with hot water. Some models are available with two-speed compressors and variable fans for more comfort and energy savings. Relative to air-source heat pumps, they are quieter, last longer, need little maintenance, and do not depend on the temperature of the outside air.

The heating efficiency of ground-source and water-source heat pumps is indicated by their coefficient of performance (COP), which is the ratio of the heat provided to the energy input. Their cooling efficiency is indicated by the Energy Efficiency Ratio (EER), which is the ratio of the heat removed to the electricity input.

Shallow ground temperatures are relatively constant throughout trough Europe, so Ground Source Heat Pumps (GSHPs) can be effectively used almost anywhere. However, the specific geological, hydrological, and spatial characteristics of your land will help to determine the best type of ground loop for the evaluated site.

For promoting the diffusion of GSHP a tool for sizing these systems will be carried out in the H2020 research project named “Cheap GSHPs”. When dealing with GSHP it is required not only the energy demand of the building, but also the energy profiles. Moreover the cooling of the buildings as well has to be defined.

The paper presents the set up of a database with the energy profile of a certain amount of buildings representative of the residential typology of European building stock (single family houses, terraced house, block of flats) with different insulation levels and in different climatic conditions. At this time the database comprehend four residential buildings, three envelopes status, i.e. three level of insulation, and 20 cities spread over four climate zones. A set of 240 dynamic simulations have been realized, using of the commercial software TRNSYS®.

Climate conditions and energy demands have been analysed and correlate, by the means of a simple linear regression, to obtain a general model capable of predicting the energy needs of buildings according to different climatic conditions, on the basis of the climatic classification and on the number of the seasonal Degree Days, DD.

The database will be used both by non expert users, who want to know the size of the GSHP suitable for their application, and both by expert technicians that are interested in a first rough sizing of the GSHP in a very brief way. The database will be used in the calculation tool for sizing the GSHP which will be developed in the second step of the H2020 project.

2. Climate analysis

The “Cheap GSHPs” project focused on Europe geographical area. For this reason 20 locations have been selected in 14 Countries to represent the four climate classes more diffuse around Europe.

Köppen-Geiger climate classification is one of the most widely used climate classification systems. It was first published by climatologist Wladimir Köppen in 1884, with several later modifications by Köppen himself, notably in 1918 and 1936. Later, Rudolf Geiger collaborated with Köppen on changes to the classification system, which is thus referred to as the Köppen–Geiger climate classification system. More information about this topic can be found in another paper presented at this conference [6].

The European map of the Köppen-Geiger climate classification is presented in Figure 1. The locations considered in the paper are presented in Table 1, according to their geographical coordinated and the relative Köppen-Geiger Classification.

Figure 1. European map of Köppen-Geiger climate classification

Table 1. List of the locations considered in the paper. Geographical coordinates and Köppen-Geiger Climate Classification.

Location	Coordinates	Climate class	Location	Coordinates	Climate class
Madrid	40.4°N-3.7°W	Csa	Zurich	47.4°N-8.5°E	Cfb
Athens	38.0°N-23.7°E	Csa	Paris	48.9°N-2.4°W	Cfb
Cordoba	37.9°N-4.8°W	Csa	Berlin	52.5°N-13.4°E	Cfb
Palermo	38.1°N-13.4°E	Csa	London	51.5°N-0.1°W	Cfb
Lecce	40.4°N-18.2°E	Csa	Munich	48.1°N-11.6°E	Cfb
Venice	45.4°N-12.3°E	Cfa	Lodz	51.8°N-19.5°E	Cfb
Milan	45.5°N-9.2°E	Cfa	Debrecen	47.5°N-21.6°E	Dfb
Bologna	44.5°N-11.3°E	Cfa	Helsinki	60.2°N-24.9°E	Dfb
Dublin	53.3°N-6.3°W	Cfb	Minsk	53.9°N-27.5°E	Dfb
Bruxelles	50.9°N-4.4°E	Cfb	Kaunas	54.9°N-23.9°E	Dfb

3. **Building case studies**

The Cheap GHSPs project involves different type of buildings: single family houses, block of flats, office buildings and small commercial buildings. At the moment only residential buildings have been extensively analyzed. On the basis of statistical data and journals concerning the state of buildings around Europe [7-10], four building categories have been selected as representative samples of the European residential building stock. The case studies are presented in Table 2: they are four types of dwellings, two of them are single family houses the other two are apartment buildings.

Table 2. Case studies buildings. General informations.

	Building 1	**Building 2**	**Building 3**	**Building 4**
External view				
S/V ratio	0.84	0.9	0.39	0.46
Net area (m^2)	210	126	1330	681
% glazed area	14%	12%	25%	14%
No. storeys	2	4	6	6
No. dwellings	1	1	20	10
Urban structure	stand alone	contiguous	stand alone	stand alone

Each case study has been modelled with the dynamic code TRNSYS®. The envelopes have been detailed implemented according to the physical and thermal property of walls, roofs, floors and windows, using values typical of the age and the topology of the building. In order to find the optimum solution according to the opaque structures three levels of insulation have been considered during the analysis: no insulation, low level of insulation and good level of insulation. Polystyrene layers of 6 and 15 cm of thickness have been considered.

Regarding to windows, standard property have been chosen for each of the considered types. The property of glasses and frame were implemented on the bases of literature surveys. In general existing windows do not satisfy standard requirements, single glazing windows are still largely use and the average windows U-value around Europe is about 2.5 W/m^{2}K [11-13]. In the presented analysis the case studies without insulation and with low insulation level were equipped with a double glazed windows with an overall U-value of about 2.8 W/m^{2}K. The envelope well insulated was modeled with a double glazed windows with low emissivity gas, to guarantee an overall U-value equal to 1.4 W/m^2K. A 15% wood frame surface is considered in every building.

Considering the noticeable effect that occupancy have on the thermal energy demand [14-17] proper scheduling have been created in order to account internal gains due to people and lighting systems, according to standard ISO 7730 [18]. An average internal gain of 5 W/m^2 is considered, equally divided between the convective and radiant components. Air infiltrations and the effect of the natural ventilation on the heating and cooling energy demand have been evaluated as well, considering in the model an average value for the air infiltration rate of about 0.3 V/h, as suggested by Italian standard [19] and in agreement to some monitoring campaigns conducted on sample buildings in the past years [20].

4. **Correlation btween DD and enregy demand**

DD are essentially a simplified representation of outside air-temperature data. They are widely used in the energy industry for calculations relating to the effect of outside air temperature on building energy consumption.

Heating Degree Day (HDD) are a measure of how much (in degrees), and for how long (in days), outside air temperature was lower than a specific base temperature or balance point. They are often used for calculations relating to the energy consumption required to heat buildings.

Cooling Degree Days (CDD) are a measure of how much (in degrees), and for how long (in days), outside air temperature was higher than a specific base temperature. They are often used for calculations relating to the energy consumption required to cool buildings.

Weather normalization of energy consumption is one of the most common uses of DD. It enables a comparison of energy consumption from different periods or places with different weather conditions. Depending on the availability of outdoor temperature data, different methods can be used for calculating heating and cooling deegre days. The hourly or ideal method, produces the most accurate estimate, however it requires the availability of very detailed climate data, not always available for each location of interest. According to the ASHRAE daily mean temperature method, the daily degree days are the difference between the daily mean temperature T_d and the base temperature T_b. The calculations for daily Heating Degree Days (HDD_d) and Cooling Degree Days (CDD_d) are given by (1) and (2):

$$HDD_d = (T_b - T_d)^+ \qquad \text{if } T_d<14 \qquad (1)$$

$$CDD_d = (T_d - T_b)^+ \qquad \text{if } T_d>20 \qquad (2)$$

T_d is the average value calculated from the daily maximum and minimum temperatures.

Monthly Degree Days (DD_m) are calculated by summing up the daily Degree-Days (DD_d) in a month, and similarly yearly Degree Days (DDy), are calculated by summing up the monthly DD_m.

In degree-day theory the base temperature of a building is the outside temperature above which the building does not require heating. Different buildings have different base temperatures [21].

A common method of calculating an appropriate base temperature recommend to subtract the effect of the average internal heat gain from the building temperature, lowering the baseline temperature respect to the internal set point. This procedure introduces a sensible approximation, furthermore different buildings are generally heated to different temperatures, and average internal heat gain varies greatly from building to building.

Properly assess the baseline temperature is the key to reduce the approximation introduced by a correlation between DD and energy demand, however, it is not simple to generalize a suitable value to a series of buildings, even when they have common characteristics, same use, similar management of HVAC systems and similar internal loads

In the presented analysis there was the need to generalize as much as possible the calculus procedures. The baseline temperature (T_b) has been settled for heating and cooling conditions, equal to 18°C, and a threshold for the external temperature (T_t) was set equal to 14°C in HDD calculation and equal to 20°C for the CDD evaluation.

Considering that the buildings are managed under the same indoor set point temperatures and that the same conditions with regard to ventilation and internal gains are guaranteed, the variation of the baseline temperature for the case studies would mainly depend on the envelope features, as the heat capacity and the U-value. However the approximation introduced was found to be acceptable at this stage of the project.

DD for both heating and cooling conditions have been evaluated for each location, by the means of the weather database provided by Energy Plus Wheatear Data Source, only the data of Zurich are derived from the Meteonorm database. The weather data of the locations selected in this work result from the International Weather for Energy Calculations (IWEC), the result of the ASHRAE Research Project 1015. An exception are the Italian Climatic data, which are derived from the Italian Climatic data collection "Gianni De Giorgio" (IGDG). [22].

To obtain a generic set of correlation between DD and energy performance of buildings in Europe, for each one of the 20 locations a set of dynamic simulation were carried out to asset the heating and cooling energy demand of the 4 sample buildings and for each one of the 3 described envelope status. A total number of 240 dynamic simulations were performed. The simulation time was one year with a resolution time step of one hour.

Heating and cooling energy profiles have been analyzed on a monthly and on an annual basis in relation to the building type, the S/V ratio and the level of insulation of the envelope. The yearly energy demand per served unit area and the DD_y have been connected by means of a simple linear regression. In the following Figures this method will be referred as Correlation A.

A first attempt for the optimization of the correlations obtained was carried out evaluating the linear regression among locations of the same climate classification. In this way for each one of the Correlation A, 4 new correlations were obtained, one for each one of the Koppen Geiger climate classes involved in the analysis. In the following Figures this method will be referred as Correlation B.

Proper correlations have been searched both for heating and cooling conditions. According to cooling conditions sensible and latent loads were first evaluated separately, and then summed up to be correlated with CDD_y, achieving, this way, a better approximation respect to consider sensible loads alone. Figure 2 and Figure 3 present the correlations obtained, gathered on the basis of the building topology and on the insulation level.

5. **Conclusion**

Based on the results, the correlations with DD_y for heating and cooling energy demands have been found in order to have pre-calculated profiles for sizing GSHP systems. This way, based on the dimensions and on the type of building, the monthly average energy profiles can be derived based on the overall volume of the building, the level of insulation and the climatic condition.

The verification of the correlations obtained on the basis of a simple linear regression, leads to satisfactory results, with errors that in winter conditions are generally inferior to 10%. Locations of the Csa-class have the highest percentages errors, but they are characterized by limited energy requirements.

According to summer conditions, the accuracy of the correlations is generally worse. The lower the energy requirements are the greater the error introduced is, especially for locations of Dfb-class and Cfb-class. Some locations, characterized by particular climatic conditions, different from the typical climate profiles of their class, introduce the highest approximations: Dublin, Kaunas, Lodz and Zurich.

Possible improvements could be achieved in the future steps of the project by correlating the cooling energy needs not to base temperature CDD but to enthalpy based CDD, in order to better evaluate the effects of latent cooling loads [23]; or the accounting the effect of the solar radiation into the definitions of CDD [24].

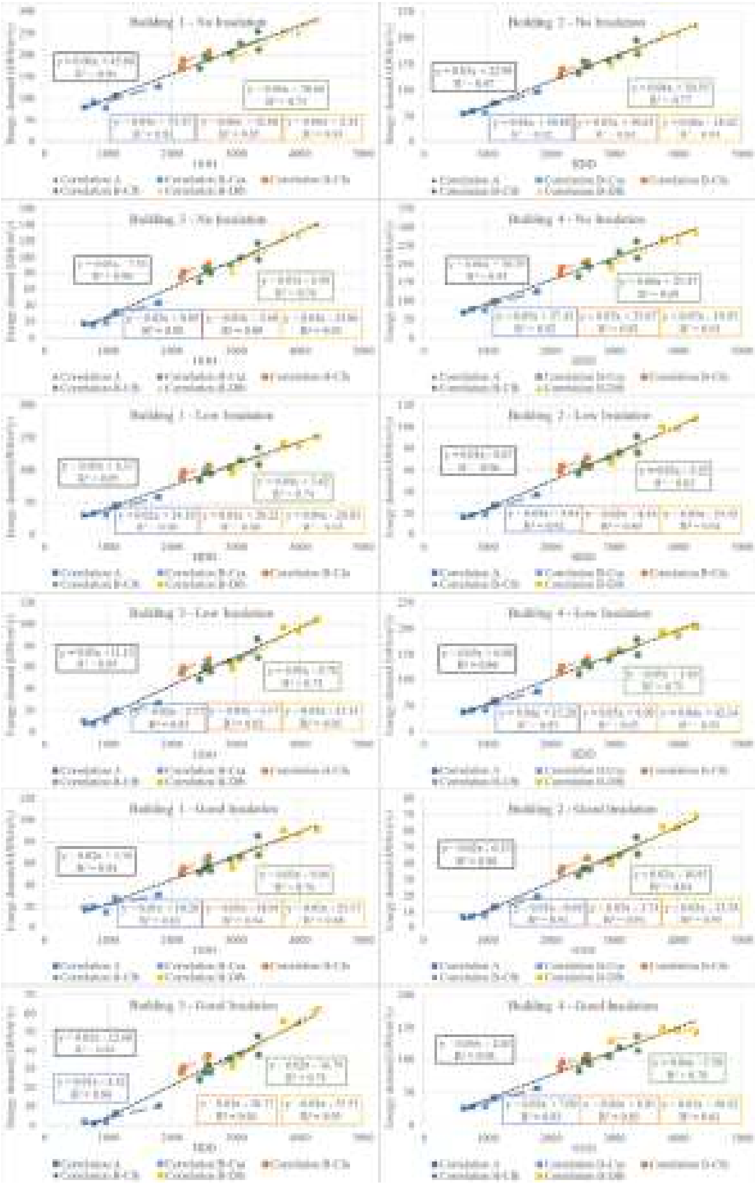

Figure 2: Simple linear regression between heating energy demand and HDD_y

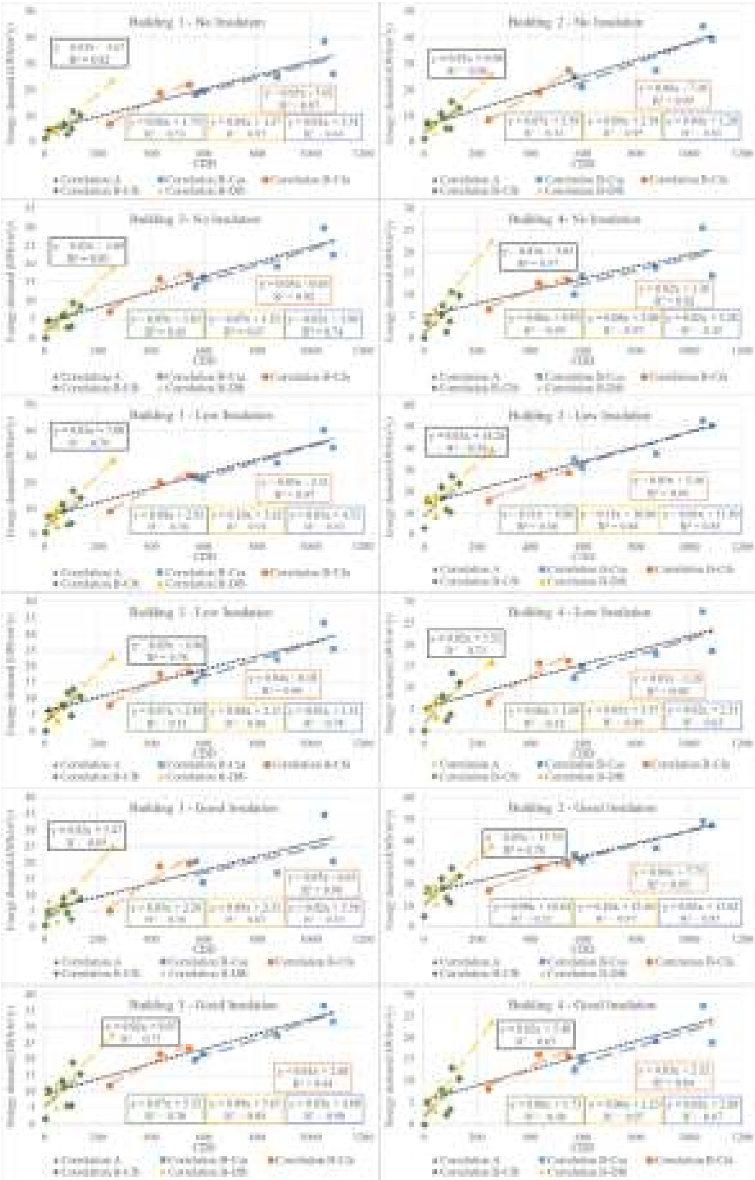

Figure 3. Simple linear regression between heating energy demand and CDD_y

Acknowledgment

This work has been carried out in the European Project Cheap-GSHPs. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 657982.

References

[1] European Union, "Energy efficiency Directive", Journal of the European Union (2012).
[2] Official Journal of the European Communities, Directive 2002/91/CE of the European Parliament and of the Council of 16 December 2002 on the energy performances of buildings, L1/65, 2003
[3] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performances of buildings (recast)
[4] F.Press, C.Siever, Earth: Fourth Edition, W. H. Freeman (1985), ISBN-10: 0716717433
[5] http://energy.gov/energysaver/geothermal-heat-pumps
[6] A data base for European climatic data for energy potentials and mapping. A. Bernardi,M. De Carli, M. Di Tuccio, G. Emmi, A. Galgaro, S. Graci, S. Pera, A. Vivarelli, A. Zarrella, Proceedings of Clima 2016.
[7] B.Atanasiu, C.Despret, M.Economidou, J.Maio, I.Nolter, O.Rapf, European building Under the Microscope, Building Performance Institute Europe (BPIE), 2011
[8] Towards nearly zero-energy buildings: The state of art national regulations in Europe, Energy, 57 (2013) 125-133
[9] T. Boermans, A. Hermelink, S. Schischar, J.Grozinger, M. Offermann, Principle for Nearly Zerp-energy Buildings, Ecofys Germany GmbH, Danish building Research Institute (Sbi), 2011
[10] Proceedings of the 7th International Conference on Energy Efficiency in Commercial Buildings IEECB'12, P. Bertoldi, G. Trenev, Joint Research Centre, 2013, pag 48
[11] C.Ahern, P.Griffiths, M. O'Flaherty, State of the Irish housing stock – modelling the heat losses of Ireland's existing detached rural housing stock & estimating the benefit of thermal retrofit measures on this stock, Energy Policy, 55 (2013) 139-151
[12]A. Kaklauskas, E. Zavadskas, S.Raslanas, R. Ginevicius, A. Komka, P.Malinaukas, Selection of low-e windows in retrofit of public buildings by applying multiple criteria method COPRAS: a Lituanian case, Energy and Building, 38 (2006) 454-462
[13] E. Zavadskas, S.Raslanas, A. Kaklauskas, The selection of effective retrofit scenarios for panel houses in urban neighbourhoods based on the expected energy savings and increase in market value: The Vilnius case. Energy and Buildings, 40 (2008) 573-587
[14] D. Aerts, J. Minnen, I. Glorieux, I. Woutersa, F. Descamps, Method for the identification and modelling of realistic domestic occupancy sequences for building energy demand simulations and peer comparison, Building and Environment, 75 (2014) 65-78
[15] Z. Yang, B.Becerik-Gerber, The coupled effects of personalized occupancy profile based HVAC schedules and room reassignment on building energy use, Energy and Building, 78 (2014) 113-122
[16] V. Motuzienea,T. Vilutiene, Modelling the Effect of the Domestic Occupancy Profiles on Predicted Energy Demand of the Energy Efficient House, Procedia Engineering, 57 (2013)
[17] I. Richardson, M. Thomson, D. Infield, A high-resolution domestic building occupancy model for energy demand simulations, Energy and Buildings, 40 (2008) 1560-1566
[18] UNI EN ISO 7730:2006, Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria
[19] UNI/TS 11300-1:2008, Determinazione del fabbisogno di energia termica dell'edificio per la climatizzazione estiva ed invernale, EC1:2010.
[20] G.Villi, C.Peretti, S.Graci, M. De Carli, Building leakage analysis and infiltration modelling for an Italian multi-family building, Journal of Building Performance Simulation, 6 (2013)
[21] http://www.degreedays.net

[22] https://energyplus.net/weather/sources
[23] Prediction of cooling energy use in builidngs using an enthalpy-based cooling degree days method in a hot and humid climate. M. Shin, S. Lok Do, energy and Buildings, 110 (2016) 5-70.
[24] Heating and cooling building energy demand evaluation; a semplified model and a modified degree days approach. M. de Rosa, V. Bianco, F. Scarpa, L. A. Tagliafico, Applied energy, 128 (2014) 217-229.