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A Simplified Calculation Method to Evaluate Heating and Cooling Loads of Buildings

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Abstract

Space heating and cooling energy need of a building can be evaluated through three kinds of methods: the quasi-steady state method, the simple hourly method and detailed dynamic simulation methods. In this work the calculation procedure of the simple hourly method has been implemented in MATLAB and then tested on a very simple building. The results obtained in terms of monthly heating and cooling net energy demand have been compared with those coming from a detailed dynamic simulation software, TRNSYS. Furthermore, the possibility of using a simplified set of climatic data is explored. The aim is investigating the use of dynamic simulation tools when the climatic conditions are not known in detail. This could be useful for locations with inadequate climatic database (especially in growing countries), as well as to predict the heating and cooling demand of a building from weather forecast. Then the simplified weather conditions have been applied to the simplified dynamic calculation method. With the purpose of checking the accuracy of the resulting simplified method for energy demand calculation, four locations (Stockholm, London, Rome and Ouagadougou) have been considered for the simulations.

Keywords – EN ISO 13790; simple hourly method; simplified weather data

1. Research Context

The EN ISO 13790:2008 *Energy performance of buildings - Calculation of energy use for space heating and cooling* [1] describes the procedures to be followed for the evaluation of space heating and cooling energy need. Three methods are provided: a fully prescribed monthly or seasonal quasi-steady state method, a fully prescribed simple hourly dynamic method and calculation procedures for detailed dynamic simulation methods. While in quasi-steady state methods the energy balance is evaluated over a long time period using gain and loss utilization factors to take dynamic effects into account, in dynamic methods the energy balance is evaluated over time steps of an hour or less, considering the heat stored in and released from the mass of the building.

As can be seen in various studies [2,3,4], the results obtained using the monthly method in terms of annual demand for heating and cooling are usually less accurate than those of the simple hourly method. The main problem related to the monthly method is that the general procedure given by EN ISO 13790 should be carefully investigated and adapted to the peculiarities of the climate of the place where the building is located. In particular the standard provides default values of the coefficient $a_{C,0}$ and $\tau_{C,0}$ (1.0 and 15.0 h respectively for residential buildings) to evaluate the gain/loss utilization factor, but it recommends to define specific values to be used by each country after the adoption of the standard. The correlation suggested by the standard to calculate a_C has demonstrated to be, with regards to South-Europe climate and building typologies, not suited to accurately describe the thermal behaviour of buildings, especially during summer period. The same happens for North-European countries.

In the simple hourly method the building is modelled as a resistive-capacitive system (5R1C) to be solved using the set of equations provided by the standard. The heating or cooling load, which corresponds to the amount of energy to be supplied or removed to reach the minimum or the maximum set-point temperature respectively, is calculated at each hourly time step. As stated by the standard, the results taken on an hourly base are not validated: an approach on a daily or monthly base is more appropriate to test the accuracy of this method.

In the study [5] the use of the 5R1C method has been compared with 5 detailed simulation tools. The validation tests carried out for a single room according to the EN ISO 15265 standard shows that this method is well suited to calculate both heating and cooling energy need and can therefore be used in warm, moderate and cold European climates. Although more simple than other tools, the author says that it provides results with the same level of accuracy.

The authors of the report [6] considered a flat of a multi-storey building located in Istanbul as case study. The results given by the simple hourly method applied to this non-complex building are similar to those found with EnergyPlus for all of the 5 examined building typologies with different thermal capacity.

In [2,3] a real building was considered and parametric studies were carried out considering different European climates, internal heat gain schedules, glazing areas, external wall constructions, ventilation schedules, building orientations, heating and cooling set-point strategies. A comparison was made between the results of the monthly and simple hourly methods and those obtained using two dynamic simulation tools, EnergyPlus and ESP-r, showing that the simple hourly method gives results that in most cases are closer to those of the detailed simulation software. The smallest differences were noticed for continuous heating in heavyweight building constructions and for buildings with low internal heat gains and/or high ventilation rates.

In the paper [4] MATLAB Simulink was used to implement the simple hourly method, applied to a detached house and 10 Polish locations. The results were compared to those obtained with the monthly method and EnergyPlus detailed simulations. The MATLAB model showed better accuracy than the monthly quasi-steady state method.

The 5R1C method has also been improved considering ventilation at a controlled supply temperature instead of at external air temperature, leading to the 6R1C method [7,8].

The R-C method takes as input hourly climatic data like the Test Reference Year (TRY) or the Typical Meteorological Year (TMY). The importance of climatic data in building energy consumption calculation has in fact quickly brought to the creation of meteorological database all around the world. Climatic parameters like dry bulb temperature, direct and diffuse solar radiation, relative humidity and atmospheric pressure have been hourly collected for many decades. The TRY and the TMY, developed from these data, have been validated by the EN ISO 15927-4:2005 *Hygrothermal performance of buildings - Calculation and presentation of climatic data - Part 4: Hourly data for assessing the annual energy use for heating and cooling* [9]. The TRY has been developed in 1976 by the National Climate Data Center in the USA [10]: years between 1948 and 1975 with too high or low mean temperatures were progressively removed until the selection of the most representative year. The development of the TMY [11,12] is based on a different procedure: for each month of the year of the last 2 decades, a typical month is selected using statistical methods. To avoid abrupt changes between the end of a month and the beginning of the next one, some of the variables must be smoothed.

The TRY and the TMY are typically used in detailed simulation software like TRNSYS and EnergyPlus. By the years they have been updated with new climatic data, but in the context of building energy simulation the accuracy of TRY is still lower than that of the TMY [13,14]. The EN ISO 15927-4:2005 has also introduced a new Test Reference Year (TRY_{en}), more significant for configurations highly sensitive to climate variability [15]. In the previous decades some weather generators have been created to provide more and more accurate weather data, like the RUNEOLE in 1999 [16] and the UKCP09 in 2009 [17].

The goal of the present work is to investigate a new tool which is based on few inputs and on a simplified method to evaluate heating and cooling loads, as well as on simple weather conditions.

2. Steps of Work

In the first part of this work the calculation procedure of the simple hourly method provided by EN ISO 13790 has been implemented in

MATLAB and then tested according to EN ISO 15265 [18], which specifies the general criteria and procedure to be followed for the validation of dynamic methods used to calculate the energy needs for heating and cooling of a room in a building. The case study presented in the standard has been considered and the results obtained in terms of annual energy need for heating and cooling have been compared to those provided by the standard as reference values. In this way the accuracy of the MATLAB model has been checked, along with its compliance with the standard.

Then a simplified method to generate weather data has been defined. A simple building has been considered as test case and four locations with different type of climate have been chosen: Stockholm (Sweden), London (England), Rome (Italy) and Ouagadougou (Burkina Faso).

The simplified dynamic calculation method and the simplified weather conditions have been tested and the results obtained in terms of annual heating and cooling net energy demand have been compared with those obtained using a detailed simulation software, TRNSYS, and TMY climatic data. With the purpose of checking the accuracy of the simplified methods for energy demand calculation, the set of simulations listed in Table 1 has been carried out for each of the considered locations.

Table 1: Considered cases

Case	Calculation method	Weather data
A	TRNSYS simulation	TMY
B	TRNSYS simulation	Simplified
C	R-C model	TMY
D	R-C model	Simplified

The comparison between cases C and A allows to estimate the accuracy of the simplified R-C model of the building against a detailed calculation model. The comparison between cases D and C gives the accuracy of the simplified weather generation model when applied to the simplified R-C model of the building. Finally the comparison between cases D and A gives the overall accuracy when applying the simplified method of the building and of the weather generated model against a fully detailed method with real weather conditions. According to the standard. three levels of accuracy have been defined for the comparisons:

- level A: $rQ_H \leq 5\%$ and $rQ_C \leq 5\%$;
- level B: $rQ_H \leq 10\%$ and $rQ_C \leq 10\%$;
- level C: $rQ_H \leq 15\%$ and $rQ_C \leq 15\%$.

rQ_H and rQ_C are the absolute values of the relative differences in annual heating and cooling net energy demand (Q_H and Q_C respectively, which added together gives Q_{tot}) between the considered case and the reference one:

$$rQ_H = | Q_H - Q_{H,ref} | / Q_{tot,ref} \quad (1)$$

$$rQ_C = | Q_C - Q_{C,ref} | / Q_{tot,ref} \quad (2)$$

3. The Simplified Weather

The method which has been developed in this work consists in creating, for each month of the year, the normalized temperature and solar radiation profiles of a typical day.

Considering the daily maximum θ_{max} and minimum θ_{min} air temperatures, the temperature θ_h at the hour h can be written as

$$\theta_h = \theta_{max} - p_{\theta,h} (\theta_{max} - \theta_{min}) \tag{3}$$

where $p_{\theta,h}$ is a coefficient hourly defined from 0 to 1. Its value is 0 for the highest temperature of the day, 1 for the lowest. The temperature profile of the typical day can be obtained from the 24 coefficients of the n days of the month, calculating the mean value for each hour.

A similar procedure can be followed for the global solar radiation I:

$$I_h = I_{max} - p_{I,h} I_{max} \tag{4}$$

where the value of the coefficient $p_{I,h}$ is 0 for the maximum solar radiation, 1 when there is no solar radiation.

In this way two tables of 288 values (24 hours, 12 months) can be obtained for the air temperature and the solar radiation of a location. The table of the normalized temperature monthly mean profiles allow to calculate the temperature profile of each day of the year, simply knowing the maximum and minimum temperature of the day. In a similar way the solar radiation profile of a day of the year can be obtained, calculating the daily maximum radiation which depends on the latitude of the location and its altitude.

4. Case Study

A really simplified building has been considered in this work. It is a zone of 9 x 9 m, 2.8 m height, without adjacent conditioned/unconditioned spaces. A window of 3.15 m^2 (U-value = 1.4 $Wm^{-2}K^{-1}$, g-factor = 0.589) has been considered in each of the external walls. The stratigraphy of the structures and the thermophysical properties of the materials are listed in Table 2, where the thermal capacity C_k is calculated considering only the first 10 cm from the inside, as prescribed by the simple hourly method.

A solar absorptance equal to 0.3 has been considered for the walls, 0.75 for the roof. As stated by EN ISO 13790, the ventilation air flow rate is equal to 0.7 $m^3h^{-1}m^2$ and the internal gains are equal to 6 Wm^{-2}. The set point temperature for heating and cooling is 20°C and 26°C respectively, with continuous operation all the days of the week.

Table 2: Thermophysical properties of opaque elements (from external to internal)

Material	d [m]	λ [W/mK]	ρ [kg/m^3]	c [kJ/kgK]	U-value [W/m^{2}K]	C_k [J/m^{2}K]
External walls						
Plaster	0.015	1.40	2000	1.00	0.339	180000
Insulation	0.100	0.04	40	0.80		
Bricks	0.240	0.89	1800	1.00		
Roof						
Insulation	0.160	0.04	40	0.80	0.233	192000
Concrete	0.240	2.10	2400	0.80		
Floor						
Insulation	0.080	0.04	40	0.80	0.313	128032
Concrete	0.240	2.10	2400	0.80		
Silence	0.040	0.22	80	1.44		
Stone	0.060	1.40	2000	1.00		
Floor	0.005	0.07	800	1.00		

5. Results and Discussion

In Fig. 1 the monthly energy need (both for heating and cooling) obtained using the two calculation methods and weather data are represented for the 4 considered cities.

As can be seen in Table 3, using the R-C method instead of a detailed calculation method (case C vs case A) leads to a relative difference of 10.0%, 5.8%, 8.7% and 6.8% for Stockholm, London, Rome and Ouagadougou respectively. Using also the simplified weather data instead of TMY ones (case D vs case A) gives a difference of 10.2%, 4.1%, 8.0% and 7.3% for Stockholm, London, Rome and Ouagadougou respectively.

In Fig. 2 the relative difference between the monthly energy need of the considered case and the monthly energy need of the reference case is represented on the vertical axis. On the horizontal axis is the monthly energy need of the reference case (case A or case C, depending on the comparison). As can be seen, the monthly difference between the considered cases is always lower than 15%, except for the months with a small energy need.

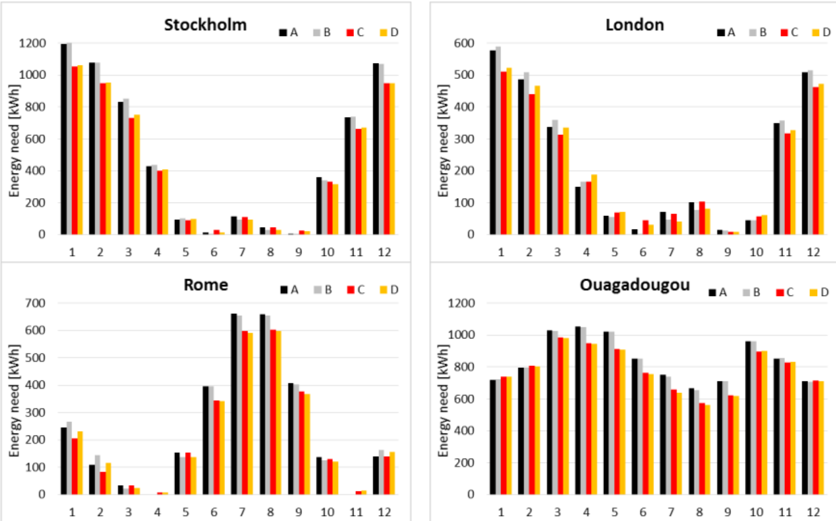

Fig. 1: Comparison of the monthly results given by the different calculation methods

Table 3: Comparison of the annual results given by the different calculation methods

City	Comparison	rQ_H	rQ_C	rQ_{tot}	Accuracy level
Stockholm	B-A	0.4%	0.8%	0.5%	A
	C-A	10.2%	0.2%	10.0%	C
	D-C	0.7%	0.9%	0.2%	A
	D-A	9.5%	0.6%	10.2%	B
London	B-A	3.1%	2.4%	0.7%	A
	C-A	6.5%	0.7%	5.8%	B
	D-C	4.2%	2.4%	1.9%	A
	D-A	2.5%	1.6%	4.1%	A
Rome	B-A	2.3%	1.6%	0.7%	A
	C-A	1.8%	6.9%	8.7%	B
	D-C	2.5%	1.7%	0.8%	A
	D-A	0.5%	8.4%	8.0%	B
Ouagadougou	B-A	-	0.4%	0.4%	A
	C-A	-	6.8%	6.8%	B
	D-C	-	0.5%	0.5%	A
	D-A	-	7.3%	7.3%	B

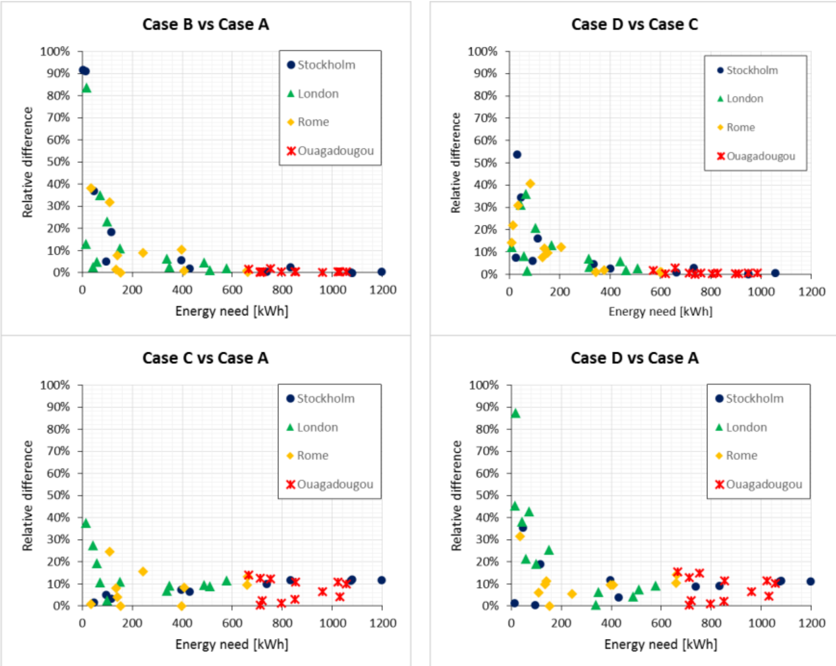

Fig. 2: Relative difference in monthly energy need and reference monthly energy need

6. Conclusions

In this research activity the use of a simplified method which reproduces the weather data of a typical day in each month has been investigated to understand if it is suitable to evaluate the monthly heating and cooling demand of a building. On a monthly basis the results obtained coupling these weather data with a simplified dynamic calculation method (5R1C model) are similar to those coming from detailed calculation methods and detailed weather data.

The procedure to generate the simplified set of climatic data should be explored further. For locations with inadequate climatic database (typically growing countries) this would allow to use dynamic simulation tools to evaluate the monthly heating and cooling energy need of a building.

It would be also interesting to analyze the possibility of using the simple hourly method with simplified weather data to predict the next day heating or cooling demand of a building starting from weather forecast (minimum temperature, maximum temperature, sunny/cloudy).

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