THE INFLUENCE OF INSIDE TEMPERATURE ON MONTHLY THERMAL OR REFRIGERATING LOADS FOR A HOUSE IN ROMANIA

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Abstract. The purpose of the present paper is to emphasize the influence of desired interior air temperature in a house on its thermal behaviour, and the corresponding cooling and heating loads. The ground floor of the house includes: a living room, a bedroom, a kitchen, a bathroom, the stairs room, all connected to a central hall. At the first floor there are two bedrooms, a bathroom, the stairs room and the main hall. Thermal gains or losses of the house partitions (walls, windows, ceilings, floors, etc.) are computed based on heat transfer laws and available norms, taking into account thermal inertia of exterior walls and accordingly the thermal transfer delay between interior and exterior of the house. The inside air temperature is set to different values inside comfort zone, in order to compare the savings or losses in required energy. The results are presented for full day simulations along the year, comparing each room's loads with respect to its orientation. The results are useful in designing thermal units, for optimal operation, corresponding to minimum yearly heating and cooling energy consumption and maximum comfort with respect to ambient monthly conditions.
Keywords: Seasonal thermal or refrigerating loads; inside air temperature; optimal operation; minimum heating and cooling energy consumption.

1. INTRODUCTION

Lately, efforts are made to reduce the pollution and global warming. Among the energy consumers, one of the main factors is represented by households. In this context, there have been many studies concentrated on ways to lower the consumption in residential buildings.

Luminosu et al. [1] calculated the monthly heat load required to heat a two stories house when a temperature of 20 °C is desired inside. Moreover, the particular case of using two solar hot water systems was analyzed. The first system is composed of heat-pipe collectors summing a total collecting surface of 25 m^2, and is designated to space heating. The second system, designed for domestic hot water has a collecting area of 5.63 m^2. The results revealed that the average value of the annual energy consumption is 79 GJ/year, and the two solar systems are able to provide 43.48 % of the space heating required energy and 62.75 % of the thermal energy required for domestic hot water, respectively. Balan [2] presented an interactive software application intended to calculate the space heating load of single-family houses. The algorithm was implemented in PHP programing language and was tested on a four members family house with a surface of 131.75 m^2. The influence of different constructive parameters on the heating load has been studied. Yoon et al. [3] studied the impact of interior and exterior blinds on a building energy load during summer or winter periods. The effect of the blind reflectance on the load has been modeled with EnergyPlus. The recommendations were to use windows with low Solar Heat Gain Coefficient and exterior blinds with low reflectance. Kazanci and Olesen [4] analyzed the thermal energy consumption and indoor environment of a one-story, single family house located in Denmark. Experimental measurements were conducted during an entire year, in different set conditions. The authors proposed the following solutions for a reduced energy consumption and optimum indoor environment: decreased glazing area, increased thermal mass, installation of solar shading, adjustment of the orientation of the house, and natural ventilation. A comparison between two cultural Heritage buildings located in Albania was performed by Resuli and Dervishi [5]. Computational simulation was used to evaluate possible energy consumption reduction scenarios. The results showed that the thermal performance of the buildings could be improved by replacement or rehabilitation of certain construction elements. A study on the consumption patterns of three most common types of households - apartment buildings, row-/terraced houses, and detached houses — was conducted by Heinonen and Junnila [6]. Also, a comparison between urban and rural living with regard to consumption was presented. The principal discovery was that occupation rate among others is an important factor to be accounted for in the estimation of the energy consumption. Therefore, one cannot rely only on the theoretical characteristics of a building to calculate the energy required. Bacher et al. [7] proposed a model to determine the space heating load of single-family houses located in Sønderborg, Denmark. Experimental measurements on sixteen houses have been used. The model output was represented by hourly heat load for each house. Finally, a model able to provide accurate result for all studied houses has been obtained. A review of different models found in the literature designated to calculate a buildings energy requirement has been conducted by Zhao and Magoulès [8].

All the above studies focused on possibilities of reducing houses energy consumption. The studies either proposed new building designs which enable lower energy requirements, or they targeted already existing buildings and analyzed ways to improve them.

In this paper we continue two previous studies [9,10] and analyze what the impact is of interior temperature of a house on its cooling or heating load. The particular case of a common single-family house design located in Romania has been considered. The present study shows results from simulations of different representative values of the interior air temperature and of different days covering an entire year. The selected interior air temperature values were chosen according to the corresponding thermal comfort interval. One important utility of the present study is that it serves as a practical reference for researchers in the domain to rely on in the designing process.

The paper is organized as follows. The house description is presented in Section 2. The mathematical model used for simulations is revealed in section 3. Results are discussed in Section 4 followed by the Conclusions section 5, at the end of the paper.

2. STUDIED HOUSE SPECIFICATIONS

The analysis was conducted for a two-story building inhabited by a family of four (two adults and two children). A side view of the house oriented S-W is presented in Figure 1.

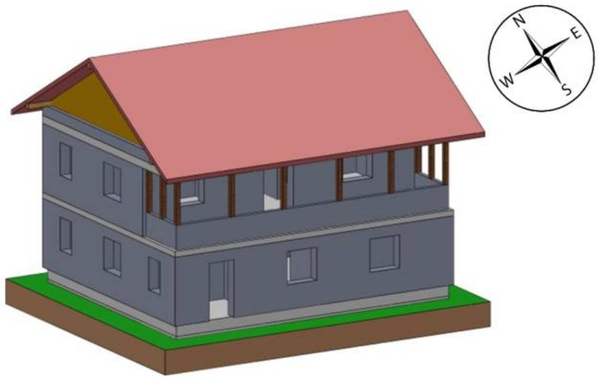

Fig. 1. House side view.

The total living surface of the house is 104.47 m^2. Ground floor structure (Figure 2) is based on a traditional architecture characterized by a central corridor functioning as a distribution room, neighboring the living rooms (bedroom and living room) and utility rooms (hall, kitchen, bathroom and staircase).

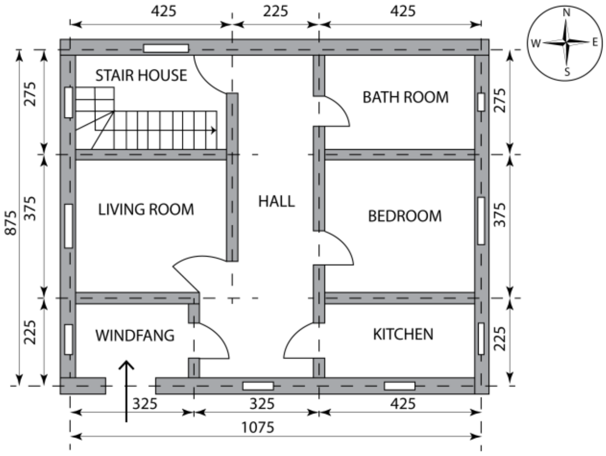

Fig. 2. House plan - ground floor.

Figure 2 shows a schematic detail of the ground floor, including all rooms dimensions and arrangement. It also holds information regarding the house orientation with respect to cardinal points. The total habitable area is 73.65 m^2. The entire ground floor is built on a concrete base of 52 cm height (3 stages).

First floor (Figure 3) preserves the conformation of the ground floor: central hallway provides access to two bedrooms, bathroom and terrace that stretches on the entire length of the house. Similar to Figure 2, Figure 3 reveals a schematic detail of the first floor, including all rooms dimensions and arrangement. The total habitable area is 59.05 m^2 and the total habitable area of the house is 137.70 m^2.

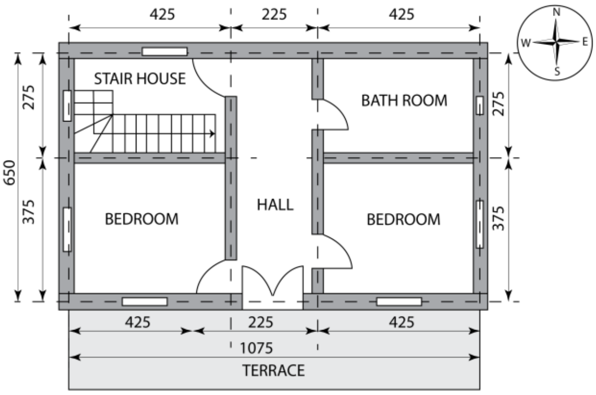

Fig. 3. House plan – first floor.

The house walls are made of autoclaved cellular concrete 25 cm thick plastered on both sides. Thermal insulation of the walls is made of 10 cm polystyrene applied on the external surface. Also, 5 cm polystyrene covers concrete elements, according to current norms.

The floor built at ground level has the following structure on the vertical, starting with the upper most layer to the lower one: wood flooring, leveling screed, styrofoam insulation, concrete, gravel filling, earth. Exterior windows consist of PVC frames profile with 5 internal cavities and EPDM gaskets. They are standard double glazed windows totaling a 24 mm thickness. The exterior door is made of an outer metal frame, insulated with polyurethane foam on the inside, covered on the outside with 14 mm thick wooden panel and on the inside with 7 mm pale. All interior doors are made of solid wood.

3. COOLING AND HEATING LOAD

3.1. Setup model

For the house presented in section 2, cooling or heating load, depending on the season, has been calculated in different conditions. For this a mathematical model has been implemented in MATLAB. The input ambient temperature values considered here were effectively measured values, averaged over four years, in Timisoara (45.7489° N, 21.2087° E), Romania, within a research project [9]. Solar radiation intensity has been calculated according to clear sky Hottel and Woertz model [12, 13]. The study included various interior air temperatures, from 20 °C to 26 °C. The calculations were made for a single-family consumption profile characteristic to a working day. The consumption patterns included thermal emissions from the family members and lightening systems, which obviously varied from one season to another. The profile was different depending on the season: between January and April and between October and December the winter profile has been considered; the summer profile corresponded to the interval from May until September.

3.2. Equations

MATLAB programming language has been used to perform the simulations [14]. The mathematical model is identical to the one described in Ref. [15], so only the main equations will be presented here. The calculations are in agreement with current norms [16 -18].

Heat fluxes through both outer elements (exterior walls, windows, exterior doors) and inner house elements (inner walls, doors, floors and ceilings) are taken into account by applying equation (1):

$$\dot{Q}_E = \dot{Q}_{PE} + \dot{Q}_{FE} + \dot{Q}_l \ \text{[W]} \qquad (1)$$

Also, in equation (1) thermal inertia of the elements is considered.

3.2.1. Heat flux through walls

Heat fluxes considered for a wall are as follows: convection between the wall and the ambient, convection between the wall and inner air, and conduction through the wall. Taking into account the thermal inertia of the wall employs a phase shift between the heat transfer calculation time, outside air temperature calculation time and wall temperature, respectively:

$$\dot{Q}_{PE} = k \cdot A\left(t_{ES_m} - t_i\right) + \alpha_i \cdot A\left(t_{ES} - t_{ES_m}\right) \cdot \eta \quad [W]$$
(2)

3.2.2. Heat flux through outer windows

The second term in equation (1), heat flux through windows, is calculated with the following expression [14]:

$$\dot{Q}_{FE} = \dot{Q}_{sun} + \dot{Q}_{thermal} \ [W] \qquad (3)$$

3.2.3. Heat flux through inner elements

The next formula was used to calculate the heat flux trough inner elements (walls, doors and ground floor ceiling), the last term of equation (1):

$$\dot{Q}_l = k_R \cdot A_R(t_R - t_i)\ [W] \quad (4)$$

where the subscript R refers to inner walls of a room, and the temperature difference $t_R - t_i$ takes values depending on the orientation of the next wall, as specified in Table 1.

Table 1. *Dependence of t_R-t_i on next wall orientation*

$t_R - t_i$ *value*	next wall orientation
2	N-V, N or N-E
3	E
4	S-E or S-V
5	V

3.2.4. Cooling or heating load

In order to maintain a certain constant temperature, T_i, inside the house, depending on the season, it is necessary to either evacuate the heat gains using a cooling system or supply for heat losses with a heating system. To design these systems and determine their load one must calculate the cooling or heating load, respectively.

The house total energy requirement, $\dot{Q}_{req}$, was calculated with equation (5):

$$\dot{Q}_{req} = \dot{Q}_E + \dot{Q}_H + \dot{Q}_W + \dot{Q}_{LS}\ [W] \quad (5)$$

All the terms in the above expression have been calculated according to the mathematical model described in [15].

4. RESULTS AND DISCUSSION

Simulations results consisted in the variation of the required heating or cooling load during the entire year, in order to maintain a constant temperature between 20 °C and 26 °C inside the house. The variation has been calculated for each month of the year. In all cases the maximum cooling load is higher compared to the maximum heating load. Figure 4 shows the results obtained for 20 °C, 24 °C and 26 °C. Negative values mean heating loads and positive values mean cooling loads. The data is representative for two months: February, which is characterized by highest required heating load values, and August, for which maximum cooling load values were obtained. As expected, for the lower inner air temperature of 20 °C, higher cooling loads and lower heating loads are required compared to the case with 24 and 26 °C, respectively.

Table 2 presents the maximum heating and cooling loads for 20, 24 and 26 °C. The required cooling load for the entire year ranges between 0 and approximately 4700 W (to keep 20 °C in the house), and between 0 and approximately 4300 W (to keep 26 °C in the house), respectively. Regarding the heating load, it takes values from 0 to approximately 1300 W (to keep 20 °C in the house) and from 0 to approximately 2200 (to keep 26 °C in the house), respectively.

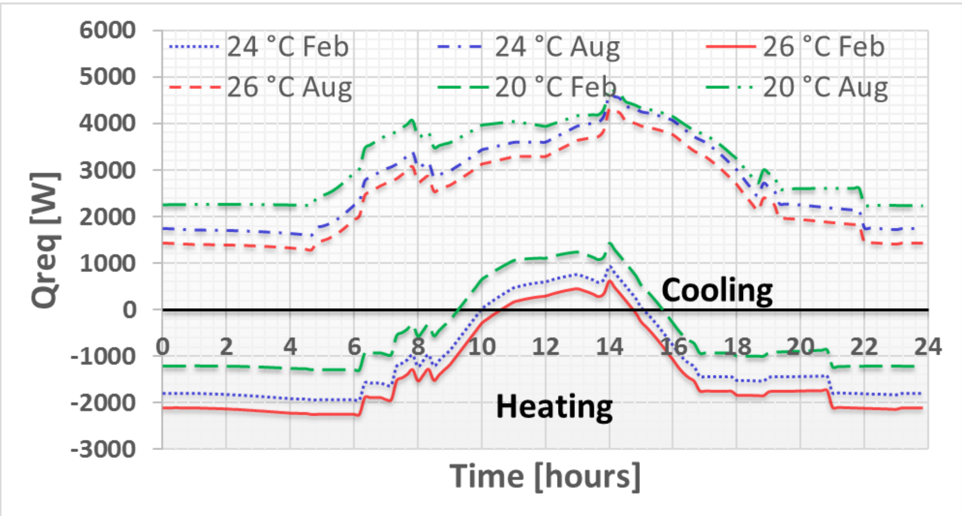

Fig. 4. Required cooling and heating load to maintain 20, 24 or 26 °C inside the house all along the year

Figure 5 presents the variation of the total energy necessary to maintain a temperature of 20, 24 and 26 °C respectively, inside the house. Monthly values are given for twelve months. The highest value required for the monthly cooling load is approximately 2373 kWh/month when the desired temperature is 20 °C, approximately 1910 kWh/month in the case of 24 °C, and approximately 1678 kWh/month for an inner temperature of 26 °C.

In all three cases the maximum value for the cooling load was obtained in August. The maximum heating load was obtained in February with the following values: approximately 500 kWh/month (20 °C), approximately 800 kWh/month (24 °C), and approximately 1000 kWh/month (26 °C), respectively.

Table 2. *Daily maximum heating and cooling loads*

	Maximum daily heating load [W]	Maximum daily cooling load [W]	Maximum daily heating load [W]	Maximum daily cooling load [W]	Maximum daily heating load [W]	Maximum daily cooling load [W]
	ti = 20 °C		ti = 24 °C		ti = 26 °C	
January	1097.8	0	1764.0	0	2074.6	0
February	1281.1	0	1935.2	0	2245.8	0
March	409.0	0	978.2	0	1288.8	0
April	0.0	3733.4	28.6	3260.5	339.2	2943.6
May	0.0	4003.5	0.0	4123.2	0.0	3806.2
June	0.0	3740.6	0.0	3384.9	0.0	3068.0
July	0.0	4410.5	0.0	4392.4	0.0	4075.4
August	0.0	4739.4	0.0	4624.0	0.0	4307.1
September	0.0	4503.4	0.0	4662.4	0.0	4345.4
October	0.0	4283.8	0.0	4442.4	0.0	4125.4
November	264.6	0	681.4	0	992.0	0
December	407.0	0	937.5	0	1248.1	0

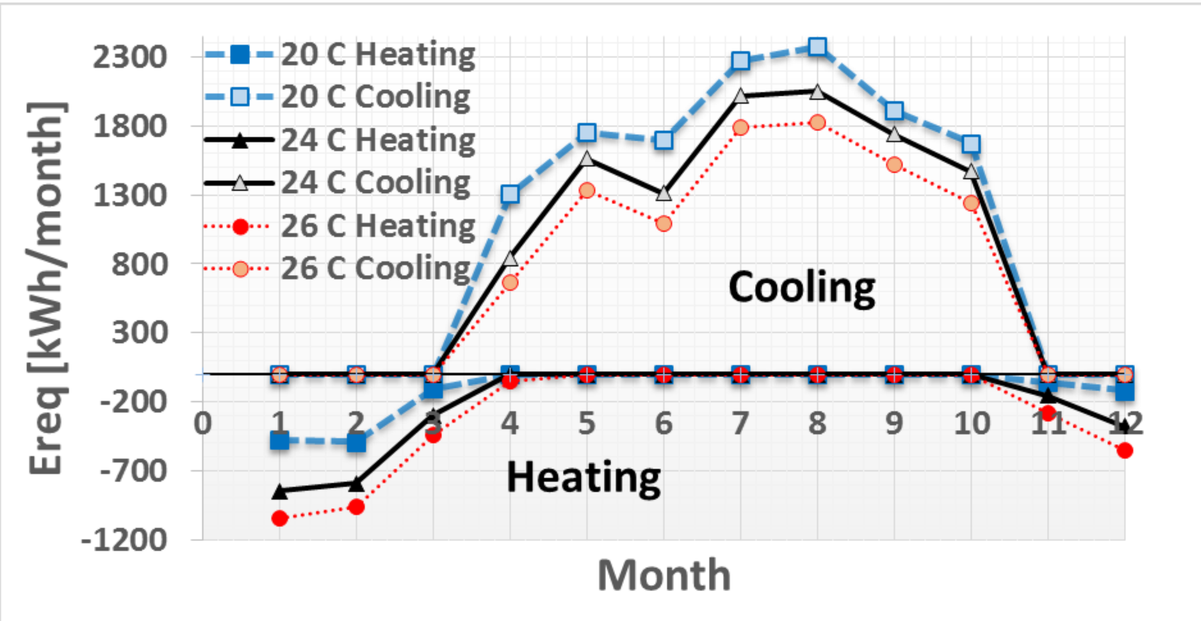

Fig. 5. Required cooling and heating monthly energy consumption to maintain 26°C inside the house all along the year

The yearly required energy consumption in order to maintain 20 °C inside the house is 15846 kWh/year, corresponding to 57 GJ/year.

In order to choose a cooling system, one must evaluate which is the maximum possible load it should cover. For this particular analysis, the highest required cooling load value has been obtained in all studied cases for the month August, with a maximum of 4800 W needed to maintain a temperature of 20 °C inside the house. As a conclusion, a system with a cooling power of approximately 5 kW would cover the studied house needs.

5. CONCLUSIONS

An analysis has been conducted to see how is the desired air temperature inside a house influencing the required heating or cooling load. The particular case of a single-family house was studied. A mathematical model implemented in MATLAB was used for simulations. The environmental conditions were considered those characteristic to Romania.

From the obtained results, the main conclusions are as follows.

1. August month dictates the highest cooling energy consumption in the summer and February dictates the highest heating energy consumption in the winter.
2. In order to maintain 20 °C inside the house in August, 2373 kWh/month are required. The consumption decreases to 1910 kWh/month for 24 °C and even more, to 1678 kWh/month, when the desired temperature is 26 °C.
3. In order to maintain 20 °C inside the house in February, 500 kWh/month are required. The consumption increases to approximately 800 kWh/month for 24 °C and even more, to 1000 kWh/month, when the desired temperature is 26 °C.
4. The building construction elements have an important effect on the total energy consumption.
5. The studied house would need a 5 kW cooling system, to cover the required cooling load all along the year.

The present study is intended as a reference for researchers in the house design process.

ACKNOWLEDGMENTS

This work was supported by a grant of the Romanian National Authority for Scientific Research and Innovation, CNCS – UEFISCDI, project number PN-II-RU-TE-2014-4-0846.

NOMENCLATURE

$\dot{Q}_{PE}$ - outer walls heat flux (thermal inertia is considered), [W]

$\dot{Q}_{FE}$ - outer windows heat flux (without thermal inertia), [W]

$\dot{Q}_{I}$ - inner elements heat flux, [W]

k - global heat transfer coefficient, [W/(m^2·K)]

α_i – inner convection heat transfer coefficient, [W/(m^2·K)]

A - wall surface, [m^2]

t_i - inside air temperature, [°C]

t_{ES} - outer air temperature in sunny areas, [°C]

t_{ES_m} - mean outer air temperature in sunny areas, [°C]

η - damping coefficient for temperature oscillations, [-]

$\dot{Q}_{E}$ - outer heat flux through walls and windows, [W]

$\dot{Q}_{H}$ - heat flux due to family members, [W]

$\dot{Q}_{W}$ - heat flux due to moisture sources, [W]

$\dot{Q}_{LS}$ - heat flux due to lightening, [W]

$\dot{Q}_{sun}$ - direct and diffuse solar radiation, [W]

$\dot{Q}_{thermal}$ - due to temperature differences between exterior and interior, [W]

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