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The Influence of the Outside Temperature on the Design of a Heating System

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Abstract

Human thermal comfort is dependent on both personal factors (clothes that we wear, physical activity) and environmental factors (temperature, air humidity, airflow – wind – and radiation).
The difference between the outside and inside air temperature of a building is the primary cause of heat loss in the winter months. In addition, the wind, humidity levels, and radiation sources are the greatest sources of heat loss during the winter. Heat loss of a building depends on the size of its border walls and on the factors of heat leakage boundary walls (through various building elements such as walls, roof, ceiling, floor, etc.).
In this paper, thermal comfort is explained using a model of a private house in Pristina, Kosovo i.e. thermal analysis is based on two methods: specific heat consumption q_A (W/m^2) and heated space q_V (W/m^3), and also based on the Unified Construction Code of Kosovo with the Excel program ThermoCalc. Thermal analysis is conducted for the Model Private House (MPH) for the heating season of 3240 hours, t_i=20 °C average design temperature within the room, and t_e=-18 °C outside design temperature.
The results of the thermal performance for heat consumption are presented using tables and diagrams.

Keywords:	Outside temperature; Influence; Thermal comfort; Design; Heat consumption

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1. Introduction

Thermal comfort and energy efficiency have gained the attention of numerous researchers around the globe [1]. Thermal comfort and assessment of indoor environmental quality depend on personal and environmental factors. Personal factors include clothes and level of physical activity, while environmental factors include air temperature, airflow (wind), air humidity, and radiation. The human body's physiological and psychological responses to the environment are dynamic and integrate various physical phenomena that interact with space [2]. ASHRAE 55 standard explains thermal comfort as a state of mind which expresses satisfaction with the thermal environment [3]. It is believed that in a real environment, people do not only passively accept the thermal stimuli, but also positively interact with the environment through the 'human-environment' feedback cycle [4].

The difference between the outside and inside air temperature of a building is the primary cause of heat loss in the winter. Heat loss of a building depends on the size of its border walls and on the factors of heat leakage boundary walls (through various building elements such as walls, roof, ceiling, floor, etc.). The wind, humidity levels, and radiation sources are the greatest sources of heat loss during the winter.

Indoor thermal comfort assessment is based on heat balance calculation and also on non-physical factors [5]. Thermal comfort, external air with meteorological parameters, and thermal characteristics of the building are the most influential factors for consumption of heating energy [6]. Some studies show the existence of strong relationships between thermal comfort and occupant's behaviour, considering indoor thermal environment [7, 8].

A facility's or building's heating, ventilating, and air conditioning system (HVAC) can maintain and enhance the desired conditions inside that particular facility.

Refrigeration is frequently added to HVAC systems - (HVAC&R). HVAC&R systems are used for both cooling and heating of various facilities [9].

The important factors that determine the energy consumption of HVAC systems are [9]:

- design, layout, and operation of the building that affects the external environment impacts on internal temperatures and humidity;
- required indoor temperature and air quality;
- heat generated internally by lighting, equipment, and people;
- design and efficiency of the HVAC plant, which delivers heating, cooling, and moisture control when is desirable in the building;
- operating times of the HVAC equipment and functionality of the controls that limits operation to exactly when the system is necessary.

'Outside' air – or external air is defined by various meteorological parameters or factors. Meteorological parameters change on daily basis and their change significantly depends on the characteristics of the observed locations, such as latitude, altitude, and terrain configuration (sheltered, close to bodies of water, etc.). Additionally, meteorological parameters that define outside air are outside temperature, humidity, wind speed, solar radiation and also clouds, cloud height, air pressure, and precipitation. In the heating technique (of all climatic and meteorological parameters) outside temperature is considered to be the most accurate parameter for analysis, while wind speed, humidity and the influence of solar radiation are considered parameters that are calculated using correction factors.

The meteorological observations are measured based on the daily mean temperature, daily maximal and minimal temperature, monthly mean, mid-year, and annual maximum and minimum temperatures. The daily mean temperature is calculated as the arithmetic mean value out of high temperature measured every hour during 24 hours. Considering that this particular method of collection and energy efficiency of heating and air conditioning is relatively complicated, the average daily value is usually calculated on the basis of the temperature measured in the 7, 14 and 21 hours, according to the following formula [10, 11]:

$$t_m = (t_7 + t_{14} + 2 \cdot t_{21}) / 4 \quad (1)$$

The average monthly temperature is calculated based on the average daily temperatures:

$$t_{m,m} = \sum_{i=1}^{n} t_{m,i} / n \text{, n - number of days in a month} \quad (2)$$

The average annual temperature is calculated based on the average monthly temperature:

$$t_{m,y} = \sum_{i=1}^{12} t_{m,m,i} / 12 \quad (3)$$

The annual heating temperatures determine the length of the heating period, or the number of working days of the heating system. Outside air temperature correlates with the length of the heating period affects the annual energy use for heating (size heating boilers, fuel consumption, pipelines, operating costs, etc.).

The main objective of this paper is analysing the influence of the outside air temperature on the thermal performance of the Model Private House (MPH).

2. Thermal performance and transfer of heat

2.1. Thermal performance

The thermal performance of a building or facility is the process of modelling the energy transmission concerning a building and its surroundings. For a conditioned building, it estimates the heating and cooling load and hence, the sizing and selection of HVAC equipment can be correctly made [9, 12]. On the other hand, for a non-conditioned building, it measures or calculates the variation of the building's inside temperature during a specific period and assists on estimating the interval of uncomfortable periods. The above analysis allows us to evaluate the quality of the design of an object/building, while simultaneously assisting us at developing enhanced designs for creating energy-efficient facilities that contain appropriate indoor conditions. However, clients are usually interested to know how much energy will they spent and how much can they save. Knowing the relative performance of buildings will enable architects to choose the best alternative. Hence, in order to design a functional passive solar building, it is necessary to know methods of estimating the performance of the buildings.

Numerous heat exchange practices occur in-between a building (object) and the external environment. As presented in Figure 1, heat streams by passing through different parts of the building such as floor, ceiling, roof, walls, etc. Heat exchange also occurs from different surfaces by convection and radiation [12].

Additionally, while solar radiation enters through transparent windows inside a building, surfaces inside the building concurrently absorb the radiation. Another factor that adds extra heat inside a space is the human presence and their activities such as the use of equipment, light, etc.

The way the human body reacts to its environment is shown in Figure 2. In the process of metabolism, the body generates heat from chemical reactions which are used to do work and the rest is released into the environment as the body maintains a stable temperature. The exchange of heat between the body and the environment around it occurs through conduction, radiation, evaporation, and convection. When the body loses heat, it becomes colder. When the body gains heat, it becomes hot and begins to perspire. The dynamics of air movement affects how much the body perspires and thus, the level of comfort.

The following factors dictate the thermal performance of a building and how efficiently it retains heat [8]:

- Design variables (geometrical dimensions of building components, i.e., roof and windows, walls, shading devices, orientation, etc.);
- Material properties (density, transmissivity, thermal conductivity, specific heat, etc.);
- Weather data (ambient temperature, solar radiation, humidity, wind speed, etc.); and
- A building's usage data (internal gains from tenants living inside, lighting and equipment, air exchanges, etc.).

The following is a block diagram depicting the factors which influence the heat balance in a building, Figure 3. Several analytical tools can be used to measure the affect that such factors have on the performance of a building (EnergyPlus, TRNSYS, Termis, BaseCalc, Therm Version 1.0, etc.) [13]. In order to estimate the performance of a building, the steady state, dynamic,

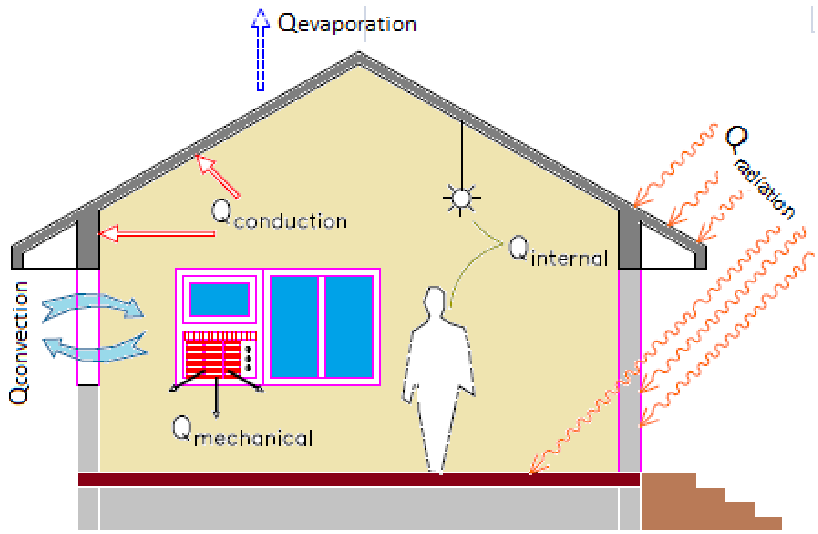

Figure 1. Heat exchange processes

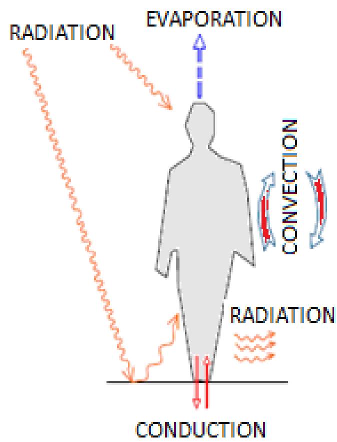

Figure 2. Heat exchange processes a human body

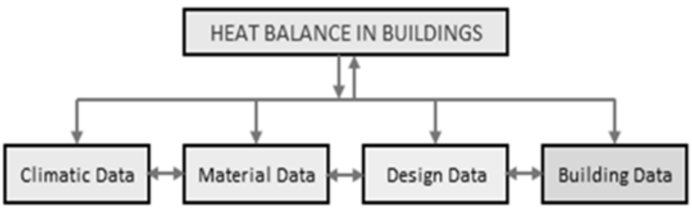

Figure 3. Thermal cycle for heat balance simulation flow paths of a building

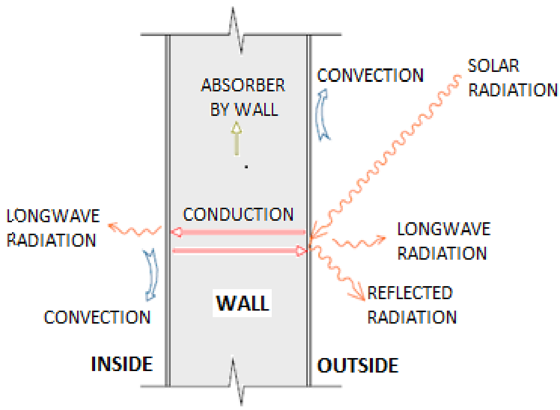

Figure 4. Heat transfer processes occurring in a wall [7]

and correlation methods are used. Some techniques are rather simple and provide data monthly or annually on temperature and average load. Others are more complex requiring more detailed information.

A good way to understand the effect heat conduction, convection and radiation have on a building, imagine a wall which has one surface exposed to solar radiation and the other surface facing another building (Figure 4). In addition, heat can be exchanged between the different elements of a building as well (for example walls, windows, roofs, etc.). These processes can have an effect on the temperature within a building resulting in a change in the comfort which the inhabitants experience.

Understanding the inherent nature of heat exchange and solar radiation reveals how a building interacts with the external environment.

3. Simplified method for performance estimation

Heat transfer (heat is energy) is the process of transition of heat from the hot to the cold body. Heat, therefore, passes from one physical body to another, from the warmer to the colder, the faster the higher the temperature difference between the two bodies. There are three modes of heat transfer [10]:

- Conduction (heat conduction);
- Convection (heat flow); and
- The radiation (heat radiation).

3.1. Conduction

The formula for calculating the rate of heat conduction (Q_{cond}) in between any component of a building (roof, wall, etc.) under a fixed state is as follows [12]:

$$Q_{cond} = A \cdot U \cdot \Delta T \,(W) \tag{4}$$

where:

A = Surface area (m^2),

U = Thermal transmittance (W/ m^2 K),

ΔT = Temperature difference between inside and outside air (K).

U is given by:

$$U = \frac{1}{R_T} \tag{5}$$

where R_T (m^{2}K/W) is the total thermal resistance and given by

$$R_T = \frac{1}{h_i} + (\sum_{j=1}^{n} L_j / k_j) + \frac{1}{h_0} \tag{6}$$

where:

h_i and h_o Respectively, are the inside and outside heat transfer coefficients;

L_j The thickness of the j-th layer and k_j is the thermal conductivity of its material.

Equation for calculating the rate of heat conduction (4) is resolved for each exterior constituent component or part of a building (roof, wall, door, window, etc.) and then the gained results are compiled. Moreover, the formula for expressing the heat flow rate through envelope by conduction is the sum of the area and the U-value products of all the elements of the building multiplied by the temperature difference [12].

$$Q_c = \sum_{i}^{N_c} A_i \cdot U_i \cdot \Delta T_i \tag{7}$$

where:

I = Building element, and

N_c = Number of components.

3.2. Ventilation

Because of the ventilation of air between the indoors and outdoors of a building, the heat flow rate is contingent on the rate of air exchange:

$$Q_v = \rho \cdot \dot{V}_r \cdot c \cdot \Delta T = \rho \cdot c \cdot \frac{N \cdot V}{3600} \cdot \Delta T \tag{8}$$

where:

ρ = Density of air (kg/ m^3),

$\dot{V}_r$ = Ventilation rate (m^3/ s),

c = Specific heat of air (J/ kgK),

ΔT = Temperature difference ($T_o - T_i$) (K),

N = Number of air changes per hour and V = volume of the room or space (m^3).

3.3. Solar heat gain

The solar heat gain that passes through transparent elements is as follows:

$$Q_s = \alpha_s \sum_{i=1}^{M} A_i \cdot S_{gi} \cdot \tau_i \tag{9}$$

where:

α_s = Mean absorptivity of the space,

A_i = Area of the i^{th} transparent element (m^2),

S_{gi} = Daily average value of solar radiation (including the effect of shading) on the i^{th} transparent element (W/m^2),

τ_i = Transmissivity of the i^{th} transparent element, and

M = Number of transparent elements.

3.4. Internal gain

The heat flow rate, due to internal heat gain and occupation, is given by the equation:

$$Q_i = \text{(No. of people x heat output rate)} + \text{Rated wattage of lamps} + \text{Appliance load} \quad (10)$$

3.5. Equipment gain

If a mechanical equipment both for cooling or heating is used, the heat flow rate of the equipment needs to be added to the heat gain of the building.

4. The influence of the outside temperature on the model of a heating system

The thermal analysis will be done on the Model Private House MPH: A_{mph}= 183.6 m^2, V_{mph}=550.8 m^3, Orientation: West (Figure 5).

Annual change in temperature determines the length of the heating period or the number of working days of the heating system. Outside air temperature is correlated with the length of the heating period affects the annual energy use for heating, and thus the fuel consumption (operating costs). The limits are determined by the heating period that average daily temperature at which to start or stop the heating. The temperature limits of heat are related to the comfort of people and amount to 12 degrees Celsius. Accordingly, the heating period of a place includes the number of days with the daily mean temperature lower than the temperature of the heating border. The heating season begins in Pristina on October 15^{th} and ends on April 15^{th}, 180 days = 3240 hours, but there may be variations depending on the flow of external air temperature [14].

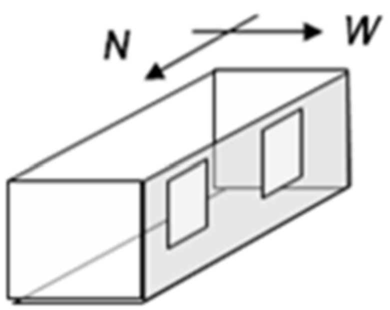

Figure 5. Design model MPH Pristina, t_o=-18^{0}C

The thermal analysis will be done based on two methods:

1. Specific heat consumption q_A (W/m^2) and heated space q_V (W/m^3), and
2. Based on the Excel program ThermoCalc.

Influential and necessary parameters to be analyzed are:

a. An average air temperature during the heating,

b. The temperature of the external air.

The analysis will be conducted for Pristina MPH model using climatic conditions and the air temperature for the period 2006 -2015. Moreover, maximum and minimum temperatures for January 2015, season 2015/16, and for the period 2006-2015 are graphically presented.

Results of the daily mean temperature, Figure 6, obtained in this way are very well coinciding with the arithmetic mean hourly values, according to equation (1) – Figure 7 and 8.

Outside design temperature can be determined according to the criteria Capljina [11]:

$$t_{o10} = 0.4 \cdot t_{av10} + 0.6 \cdot t_{\min 10} = -15.30\ °C \quad (11)$$

where:

t_{av10} = -5.70 ^oC – Average monthly temperature of the coldest month in the last 10 years,

t_{min10} = -21.70 ^oC – The minimum monthly temperature in the last 10 years [15].

4.1. Analysis on the basis of specific heat consumption per q_A and q_V

The method for estimating the heat consumption per square meter or heat consumption per cubic meter of heated space is not the most accurate treatment, but in any case, can be used in particular in the case of the previous considerations and conceptual designs. In practice, as well as in literature, we can find different information about the specific heat consumption q_A (W/m^2) or space q_V (W/m^3) in ranges [10, 11]:

– q_A= 70 to 170 (W/m^2) or q_V = 30 to 70 (W/m^3).

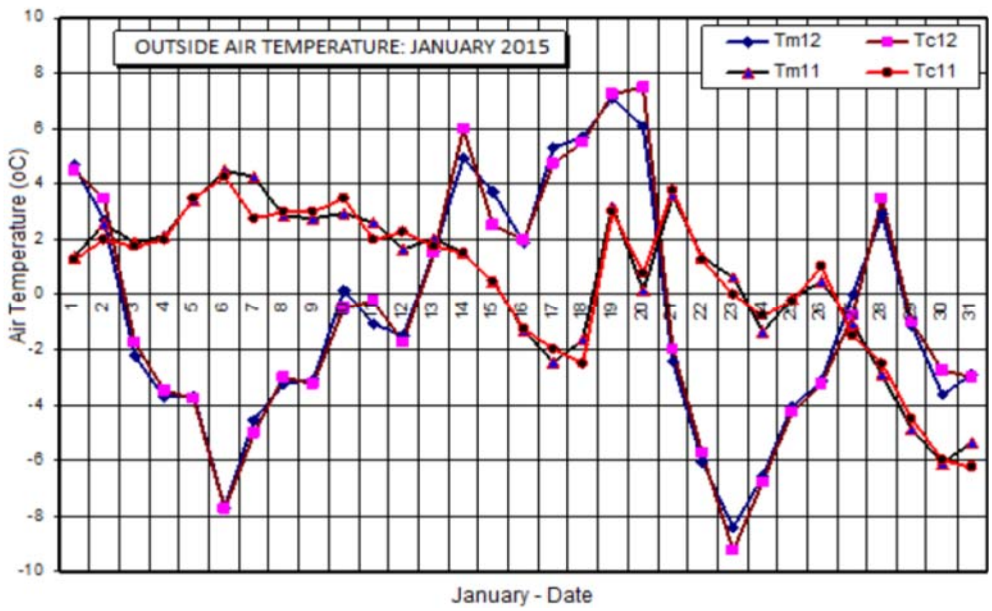

Figure 6. Daily outside temperature in Pristina, January 2015 [13]

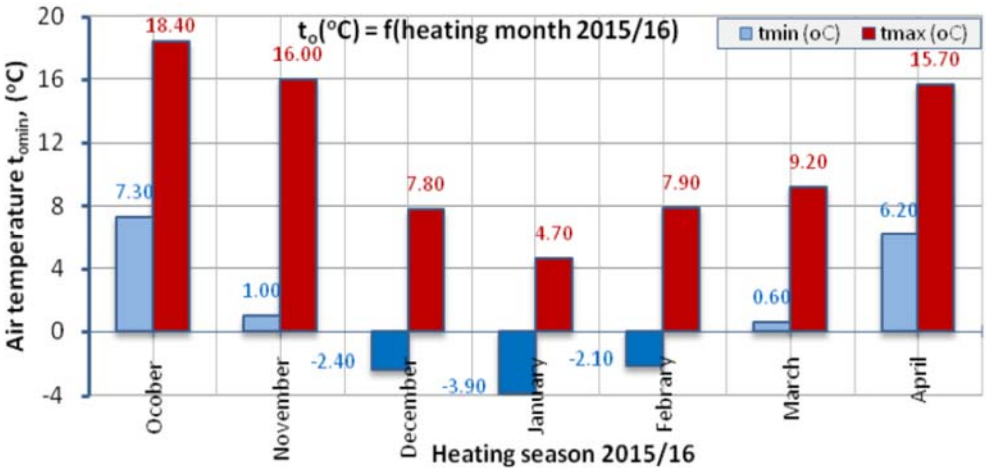

Figure 7. High and low air temperature during heating season in Pristina, 2015/16 [15]

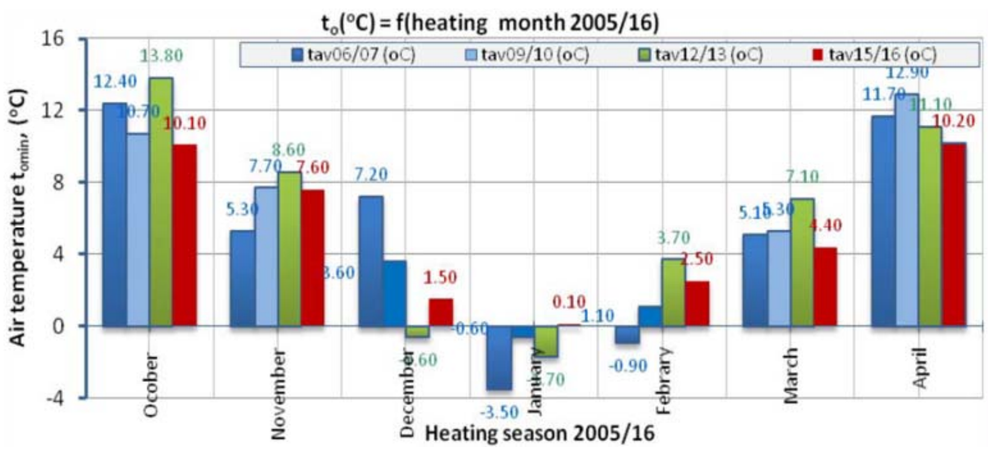

Figure 8. Average air temperature during the heating season in Pristina, 2006/15 [15]

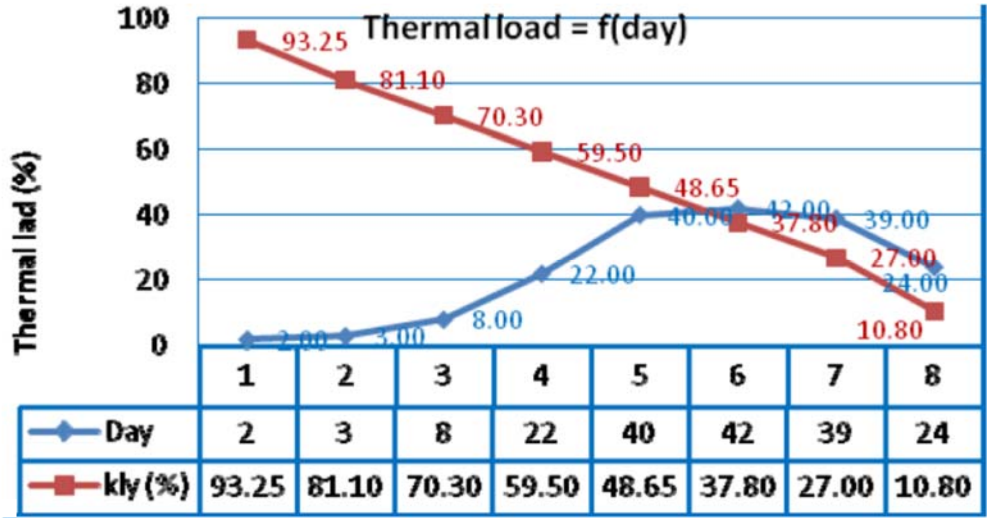

Figure 9. Relative length of the temperature interval during the heating season

4.1.1. The results obtained on the footing thermal analysis model

Specific heat for the above model MPH can be calculated as follows:

$$q_0 = w \cdot (t_i - t_e) = 41.8 \text{ (W/m}^3\text{)} \quad (12)$$

where:

w = 1.1 (W/m^{3}K – The average transmission heat losses;

t_i = 20 °C – Average design temperature within the room; and

t_e = -18 °C – Outside design temperature for heating season, Pristina, Kosovo [13].

The heat consumption can be calculated using the following form:

$$Q_k = \sum q_i V_i = 20953 \text{ (W)} \quad (13)$$

where:

Σq_i = 41,8 (W/m^3) - Specific mean heat for space heating, and

ΣV_i = 550.8 m^3 - Total volume of the heating consumption for the model.

The obtained value of heat consumption will increase by ventilation losses and losses for heat transmission and reduce with solar and internal gains of heat energy so that the total required heating sources is:

$$Q_t = Q_k + Q_v + Q_{tr} - Q_{sol} - Q_{ig} = 24683 \text{ (W)} \quad (14)$$

4.1.2. Thermal performance of the model and heat consumption

For the calculation of annual heat consumption, Qty (kWh), it is necessary to determine the ratio of the average load of the heating season. This ratio can be calculated with the following formula:

$$k_{pr} = \frac{w \Delta t_m}{q_0} 100\% = 39.21\% \quad (15)$$

where: Δt_m= 14,9 ^{0}C – the daily mean temperature, calculated as the difference between the external and the internal temperature in the room and observed for a number of years (for Pristina it is: 20 to 5.77 = 14.9 ^{0}C).

From Figure 9 we obtain that the average load during the heating season is k_{ly} = 41.4% and the average air temperature in the heating period is t_{om} = 4.27 ^{o}C.

The average heat load during the heating period is:

$$Q_{tm} = Q_t \cdot k_{ly} = 24683/1000 \cdot 41.40/100 = 10.22\, kW \quad (16)$$

The annual heat consumption can be determined from the following expression:

$$Q_{ty} = Q_{mt} \cdot t_{HS} = 10.22 \cdot 3240 = 33112.80\, kWh \quad (17)$$

where: t_{HS} = 180 days x 18 hours = 3240 h – time of heating season.

Average specific heat consumption:

$$q_{Aty} = \frac{Q_{ty}}{A_{mph}} = 33112.80 / 183.6 = 180.35 \ kWh / m^2 year \quad (18)$$

$$q_{Vaty} = \frac{Q_{ty}}{V_{mph}} = 33112.80 / 550.8 = 60.12 \ kWh / m^3 year \quad (19)$$

4.2. Analysis based on the Excel program ThermoCalc

The analysis of the influence of air temperature on heating, for the model of private house (MPH), is based on Unified Construction Code of the Republic of Kosovo, Part 3 - Buildings Chapter II - The Energy Saving Thermal and Thermal Protection according to EN832:2000 and EN832/AC:2004 relating to EN 13789:2000. This Technical Regulation Code regulates technical requirements for thermal energy saving and thermal protection. Requirements relating to new building projects, and projects for reconstruction and adaptation of existing buildings with an internal heating temperature above 12 °C.

Figures 10–14 provide a detailed data from analysis based on the Excel program ThermoCalc [16].

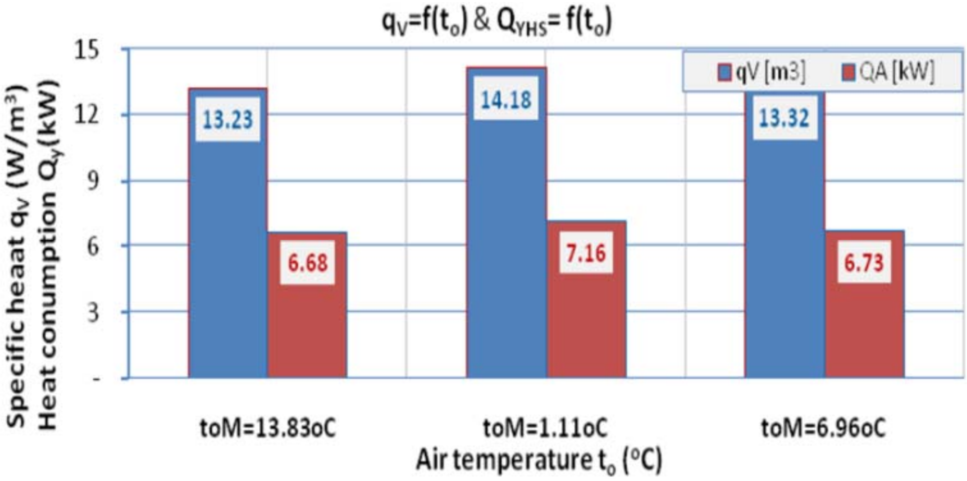

Figure 10. The influence of the air temperature (t_{omax} °C, t_{omin} °C, t_{oav} °C) in the specific heat consumption q_V=f(t_o); yearly heat consumption Q_{YHV}=f(t_o) 2015/16

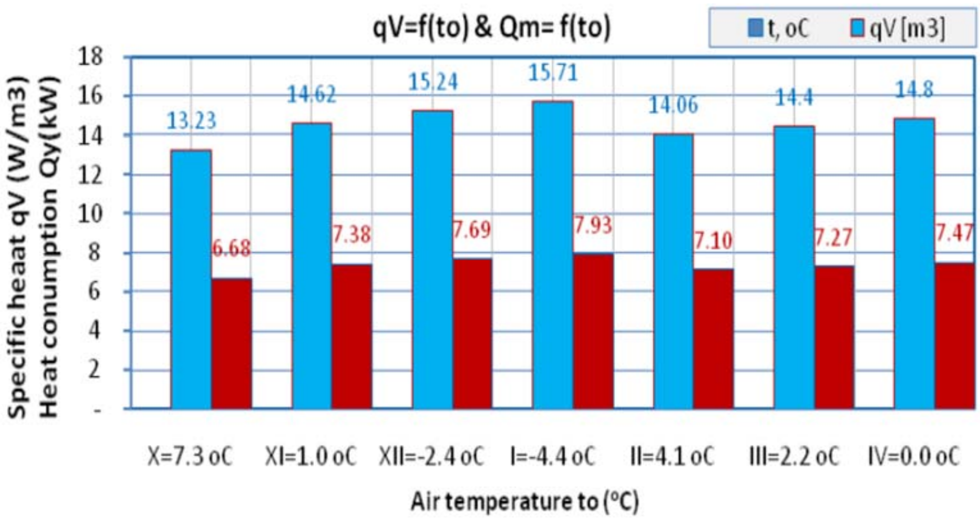

Figure 11. The influence of the air temperature (t_{omax} °C, t_{omin} °, t_{oav} °C) in the specific heat consumption q_V=f(t_o) and in the monthly heat consumption Q_{YHV}=f(t_o) from October2015 to April 2016

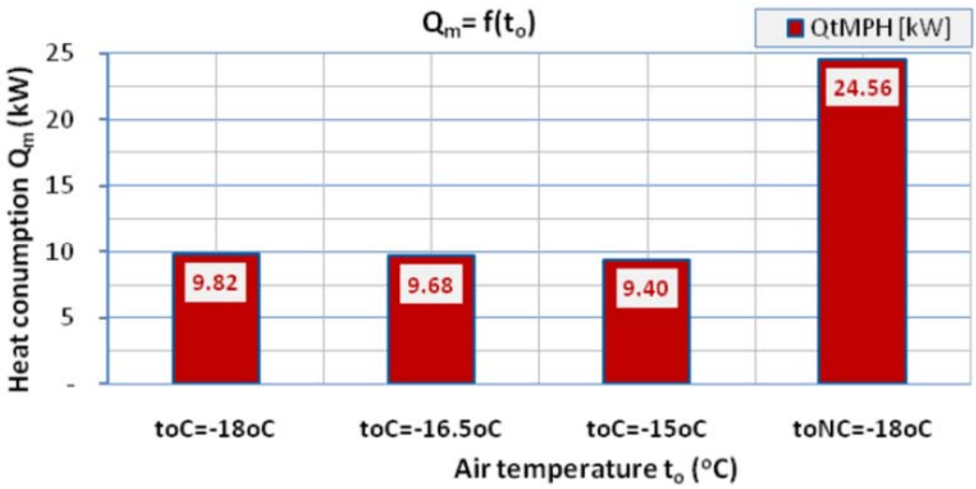

Figure 12. The influence of the air temperature in the heat consumption when the MPH model is designed based on Unified Construction Code (t_{oC}) and not based on Unified Construction Code (t_{oNC})

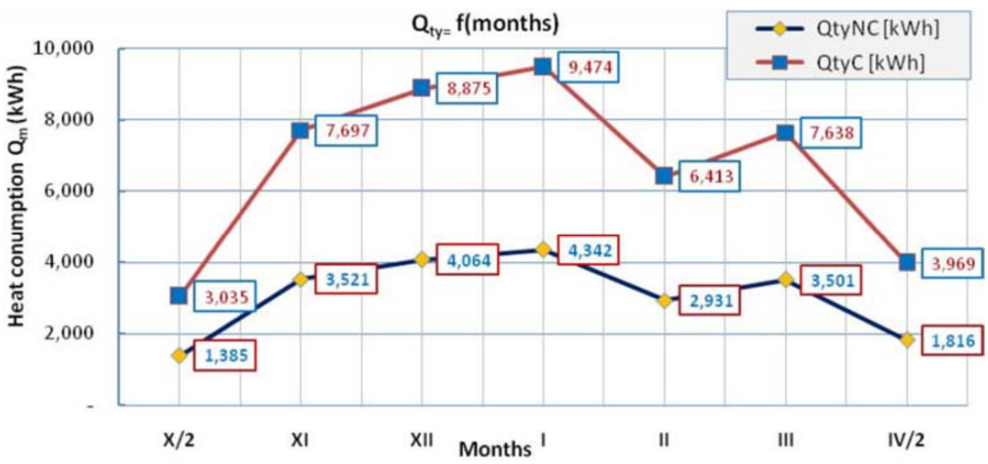

Figure 13. Heat consumption when the MPH model is designed based on Unified Construction Code (Q_{tyC}) and not based on Unified Construction Code (Q_{tyNC})

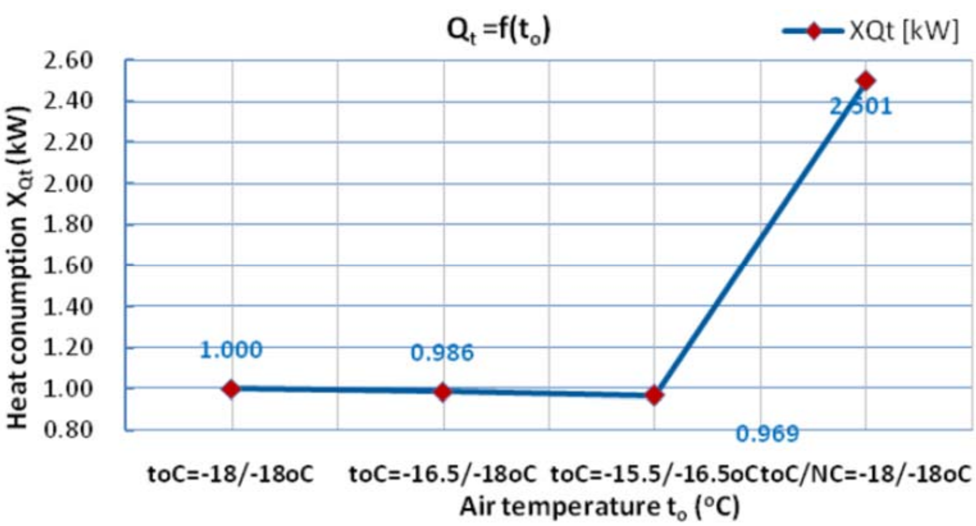

Figure 14. The influence of the outside temperature on the saving heating consumption

5. Conclusions and recommendations

Termokos, the district heating company in Pristina, is a local public utility company that operates the district heating system in Pristina. The heating system serves about 12,000 apartments, flats (634,086 m^2), stores, offices (43,056 m^2), schoolhouses (128,561 m^2) and public buildings (182,610 m^2), in total 988,313 m^2 [17].

More than half of the collective buildings of Pristina were constructed in the period 1950 to 1985, which is reflected in the relatively high specific heat consumption of these buildings. The current level of heat consumption in Pristina is estimated to be about 219 kWh/m^2 year, compared to 80–150 kWh/m^2 year in Western Europe, which indicates that there is a significant opportunity for Energy Efficiency – EE improvements [18].

In this paper, part 4. The influence of the outside temperature on the model of a heating system, Model Private House (MPH): A_{mph}= 183.6 m^2, V_{mph}=550.8 m^3, based on two simple methods:

- First method: Specific heat consumption q_A (W/m^2) and heated space q_V (W/m^3);
- Second method: Excel program ThermoCalc;

Results gained after using the above methods are:

- The specific heat consumption is q_{ty} = 178.88 kWh/m^2year (First method);
- The specific heat consumption is q_{tyEE} = 88.74 kWh/m^2year (Second method).

The relationship between annual consumption of specific heat consumption $x_q=q_{ty}/q_{tyEE}$=2.01 tells us how much heat loss for the current heating system used for flats, apartments, shops, offices, schoolhouses in Pristina.

The available evidence, x_q=2.01, shows that the building sector of Pristina provides significant opportunities for realizing energy savings. Since space heating accounts for the major share of energy consumption in buildings, most energy saving potential is associated with thermal insulation, basement, windows, roof, heat loss reduction, and the introduction of efficient boilers [18].

Based on Figure 10, we can comprehend the influence or the impact of outside air temperature in the specific heat consumption q_V (W/m^3) and of heat consumption Q (kW) during the heating season based on the maximum, minimum and average temperature (t_{omax} °C, t_{omin} °, t_{oav} °C) for the heating season of 2015/2016.

Moreover, if we analyse Figure 11 we can see the influence of the outside air temperature in the specific heat consumption $q_V=f(t_o)$ and of monthly heat consumption $Q_{YHV}=f(t_o)$ based on the maximum, minimum and average temperature (t_{omax} °C, t_{omin} °C, t_{oav} °C) from October 2015 to April 2016.

Based on the analysis of Figure 10 and 11, the opportunity for applying modular systems of two boilers can be considered as a choice for big cities. The first boiler can be used for covering the average heat load, based on the results gained after calculating the average outside air temperature t_{oav} (°C); the second boiler can be used for covering the peak heat load, t_{omin} (°C). Hence, this would result in the increase of the efficiency of the boilers. Moreover, we can plan the amount of burning fuels used for heating in the next season taking into consideration the monthly and yearly consumption of the energy for heating.

Furthermore, Figure 12 and Figure 13 implies that the influence of the air temperature in the heat consumption when MPH model is designed is based on Unified Construction Code and not based on Unified Construction Code (t_{oNC}). As a result, we can conclude that the outside air temperature influences the heating energy consumption. In Figure 12 we can see the ratio of heat consumption $x_{oC}=Q_{toNC}/Q_{tC}$=24.56/11.73=2.09 for the object that is not designed based on the Unified Construction Code (objects designed during 1950/85), and those who are based on the Unified Construction Code.

Figure 14 represents the influence of the air temperature on the saving heating consumption when MPH model is designed is based on Unified Construction Code $Q_{tC}=f(t_o)$.

In Figure 14 we can see the ratio of heat consumption is $X_{Qto}=Q_{toC-18}/Q_{toC-16}$=0.986 and $X_{Qto}=Q_{toC-16}/Q_{toC-16}$=0.969 i.e. saving heat consumption is 1.50% for adjusted outside temperature for +1.5°C.

Based on the results gained from Figures 7, 8, 13 and especially from Figure 12 we can analyse the impact of outdoor design temperature for heating consumption. The analysis is based on the calculation of energy consumption for outdoor temperatures t_{out}=-18/-16.5/-15°C. The gained results shows that for buildings constructed under the influence of the Unified Construction Code the outdoor temperature influence is very small, $Y_1=Q_{tC-18}/Q_{tC-16.5}$=1.40%; $Y_2=Q_{tC-16.5}/Q_{tC-15}$=1.70%k; $Y_3=Q_{tNC-18}/Q_{tC-18}$=150.10% compared to facilities that are built without Unified Construction Code.

Lastly, based on the above results we can conclude that the outdoor design temperature for the Republic of Kosovo needs to be adjusted on the basis of the new criteria, in order to build new facilities according to the Unified Construction Code.

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