TEMPERATURE CORRECTION FACTOR SIMULATION OVER THE HEATING PERIOD

by

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New Regulations on energy efficiency in buildings in the Republic of Serbia legislate values for the temperature correction factor used to calculate the heat flux to the outdoor environment through construction elements of a certain type. The temperature correction factor is used to correct errors caused by calculation of heat losses based on the design outdoor and indoor temperature difference of building elements adjacent to unheated spaces which are in direct contact with the ground or external environment. Since the temperature correction factor directly influences the calculation of total heat losses and total annual energy demand, it is recommended that the temperature correction factor be determined on the basis of measured values of outdoor and indoor air temperature, or, on the basis of the values obtained by the simulation. This paper presents the results of measurements in the High School of Design, Textile and Management in Belgrade in order to assess energy efficiency and the energy performance of buildings. Data obtained on the basis of measurements, such as indoor and outdoor temperatures, are used for the calculation of the heat transfer coefficient for the building envelope elements as well as to calculate a temperature correction factor for the unheated attic space of the building. This paper also offers a dynamic simulation of the multi-zones building in the TRNSYS environment. The aim was to compare temperature correction factor values obtained from measured temperature values, with those calculated from standard, taken from the Regulation table and produced by simulation.

Key words: *temperature correction factor, unheated space, TRNSYS*

Introduction

In line with growing energy needs and increasingly severe expert warnings about fossil fuel energy potential reduction, the professional community has exerted great effort to identify large energy consumers, assess the scale of their consumption and find ways of reducing it.

Buildings currently account for 40% of energy use in most countries, putting them among the largest end-use sectors. The International Energy Agency (IEA) has identified the building sector as one of the most cost-effective sectors for reducing energy consumption.

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Energy needs reduction by improving the energy performance of buildings also leads to a reduction in the concentration of CO_2 in the atmosphere, which is no less important than energy savings in the building sector [1].

The EU Directive on the energy performance of buildings was first adopted in 2002 with the intention of improving building energy efficiency, reducing carbon emissions and reducing the impact of climate change. This Directive adopted a four-pronged approach to improving the energy performance of buildings: to establish a calculation methodology, to set minimum energy performance requirements, to issue energy performance certificates and to inspect boilers and air-conditioning. In 2010, the Council of the European Union and European Parliament adopted a recast of the Energy Performance of Buildings Directive in order to strengthen its performance requirements and clarify and streamline some of the provisions from the 2002 version of the Directive [2, 3]. In 2012, an Energy Efficiency Directive was adopted to establish a set of binding measures to help the EU reach its 20% energy efficiency target by 2020. Under the Directive, all EU countries are required to use energy more efficiently at all stages of the energy chain from production to final consumption [4]. The Energy Performance of Buildings Directive and the Energy Efficiency Directive are the two main pieces of legislation aimed at reducing the energy consumption of buildings.

In Serbia, the housing stock is very old and characterized by very poor thermal envelope characteristics. Consequently, one of the most important goals of government in recent years has been to increase the energy efficiency of buildings. In order to get into step with European Union regulations, Serbia has adopted rules and introduced the obligation of building certification. The rules are defined in the Building Energy Efficiency Regulation (*Off. Gazette of RS*, No. 61/11) [5] and the Regulations on Conditions, Content and Manner of issuing certificates for buildings´ energy performance (*Off. Gazette of RS*, No. 61/11) [6] which define the limits for the heat transfer coefficients of thermal envelope elements, specific transmission losses and the annual consumption of final energy for new and old buildings. These regulations also establish the methodology for determining the energy performance of buildings based on recommendations from several EU standards.

The heat balance of a building includes all sources and sinks of energy inside the building, as well as all energy flows through its envelope. This envelope encloses the volume, which is kept around a set temperature for all weather conditions by the use of heating energy. Heat energy demand mainly depends on transmission losses, which flow through the building envelope from inside to outside depending on envelope thermal characteristics and indoor and outdoor temperatures.

It is necessary to consider the situation when an individual component of the thermal envelope is not in direct contact with the environment. Such components are in contact with so-called “unheated space” in which the air temperature differs from the temperature of the outside air. This difference is usually unknown.

There are a number of different ways to determine the temperature difference between heated and unheated space, necessary to calculate transmission heat losses. According to the adopted methodology, this problem is eliminated by the introduction of a temperature correction coefficient F_x, which is given in tables for all the thermal elements of the building envelope [5]. This paper considers the temperature correction coefficient F_x for the unheated attic of a building, comparing four different values: measured, calculated from standard, taken from the regulation tables [5] and simulated.

This paper takes, as its case study, a building constructed in 1917 which has not undergone any significant reconstruction apart from in certain small sections. The building was not a typical representative of a housing stock for a certain period. In order to increase the energy efficiency of the building and plan for necessary subsequent renovation, measurements were taken to act as a basis for the analysis and for the calculation of energy losses. The motivation was to show that in specific buildings, such as this one, there are differences in heating energy demand calculations according to standards or regulations and real energy need that are not negligible. In such cases, it is necessary to perform measurements, which will accurately determine the losses of the envelope and the amount of heat required for heating.

Methodologies to determine the temperature correction coefficient for thermal losses towards unheated space

Buildings, as energy systems, can be treated as single zones or be partitioned into several zones. The energy balance consists of the energy for heat balance at the building level and the energy balance at the system level. The energy for heat balance at the building level is the energy needs for heating and cooling the building and the quantity of energy required for this is calculated according to the heat balance for each zone.

The heat balance at the building zone level includes: transmission heat transfer between conditioned space and the external environment, ventilation heat transfer (by natural ventilation or by mechanical ventilation system), transmission and ventilation heat transfer between adjacent zones, internal heat gains, solar heat gains, storage of heat in the mass of the building, energy needs for heating and energy needs for cooling.

To calculate the energy losses of any building, it is necessary to determine the total transmission coefficient of the building itself. The total transmission coefficient H_T (WK-1) consists of several parts and it is calculated according to the following equation (1):

$$H_T = H_D + H_g + H_U + H_A \tag{1}$$

where H_D is the direct heat transfer coefficient between the heated or cooled space and the exterior through the building envelope, H_g – the steady-state ground heat transfer coefficient, H_U – the transmission heat transfer coefficient through unconditioned spaces, and H_A – the transmission heat transfer coefficient to adjacent buildings.

The H_U is the transmission heat transfer coefficient through unconditioned spaces and defines thermal losses between a conditioned space and the external environment with unconditioned spaces between them, which is the object of this paper.

There are several different ways to determine H_U, between a conditioned space and the external environments with unconditioned spaces between them and these can be calculated for a building energy audit according to eq. (2) [7]:

$$H_U = H_{iu} F_x \tag{2}$$

where H_{iu} [WK^{-1}] is the direct heat transfer coefficient between the conditioned space and the unconditioned space and F_x [–] is the temperature correction coefficient, used to correct the error resulting from use of a design outside temperature and internal temperature of unheated space rather than the real measured temperatures.

Perhaps the most precise way to determine the F_x coefficient is on the basis of the measured temperature values of the unheated area, adjacent heated space and the external environment. On the basis of the measured temperature values, the F_x temperature correction coefficient is calculated according to equation (3):

$$F_x = \frac{\theta_i - \theta_u}{\theta_i - \theta_e} \tag{3}$$

where θ_i [°C] is the air temperature in the heated space-internal, θ_u [°C] – the air temperature in the unheated area (attic), and θ_e [°C] – the external air temperature.

The second way for the determination of F_x is by use of standards [7-9]:

$$F_x = \frac{H_{ue}}{H_{iu} + H_{ue}} \tag{4}$$

where H_{iu} [WK^{-1}] is the direct heat transfer coefficient between the conditioned (internal) space and the unconditioned space and includes the transmission and ventilation heat transfers and H_{ue} [WK^{-1}] is the direct heat transfer coefficient between the unconditioned space and the external environment and includes transmission and ventilation heat transfers. The F_x coefficient is calculated assuming steady-state conditions. It results from a steady-state heat balance in the unconditioned space.

The third way to determine the F_x coefficient is to take the value from the table found in the Building Energy Efficiency Regulation [5]: here the F_x coefficient is 0.8 for every attic, regardless of roof construction.

To determine the impact of the calculated F_x coefficient on the energy performance of the building, a complete calculation must be performed to determine the total transmission loss of the building for all values of the coefficient F_x.

To calculate the total heat losses of the building, according to (1), it is necessary to calculate the losses through all elements of the building envelope:

– the direct heat transfer coefficient:

$$H_D = \sum_i A_i U_i + \sum_k l_k \Psi_k + \sum_j \chi_j \tag{5}$$

where A_i [m^2] is the area of element i of the building envelope, U_i [Wm^{-2}K^{-1}] – the thermal transmittance of element i of the building envelope, l_k [m] – the length of linear thermal bridge k, Ψ_k [Wm^{-1}K^{-1}] – the linear thermal transmittance of thermal bridge k, and χ_j [WK^{-1}] – the point thermal transmittance of point thermal bridge j.

The calculation of thermal transmittance U for inter-floor construction towards unheated attic space was made, according to standard ISO 9869 [10]:

$$U = \frac{\sum\limits_{j=1}^{n} q_j}{\sum\limits_{j=1}^{n} (\theta_{i,j} - \theta_{e,j})} \tag{6}$$

where q_j [Wm^{-2}] is heat flow density, $\theta_{i,j}$ [°C] – the air temperature inside the building, and $\theta_{e,j}$ [°C] – the temperature of external air in the vicinity of measuring surfaces.

– The steady-state ground heat transfer coefficient H_g is calculated according to ISO 13370 [11].

– Calculation of the transmission heat transfer coefficient through unconditioned spaces H_U is previously shown, according to eqs. (2)-(4).

Case study application

In this paper, the building analysed was the College of Textile Design, Technology and Management built in Belgrade in 1917. Apart from minor renovations in certain sections, the building has not been altered since it was erected, fig. 1. The building is non-residential and intended for education and culture. It consists of a basement, a ground floor, first floor and attic, under a complex roof construction. The orientation of the building is longitudinal eastwest with four free façades moderately exposed to the winds and with a useful surface area of 1259.1 [m^2].

Measurement description

Measurements were performed in the College building in order to assess the energy efficiency and energy performance of the building. Figure 2 shows a drawing of the front façade (west side) of the building.

Figure 1. College of Textile Design, Technology and Management

Measurements were carried out between March 2nd and September 28th 2015. Short-term measurements, lasting from 24 to 72 hours, were used for the calculation of thermal transmittance coefficients for the building envelope elements (glass and window frame, external wall of 35 cm thickness, external wall of 50 cm thickness, external wall of basement, inter-floor constructions towards unheated attic space and ground floor). Long-term measurements were performed using data loggers placed in the 16 rooms of the building in order to obtain the air temperature and relative humidity. A mini weather station was installed on the roof, to measure wind speed, total solar radiation, temperature and relative air humidity.

Figure 2. The front façade of the building (west side)

Figure 3 shows the plan of measuring points on the first floor of the building where measuring devices were placed. Tags 174H represent loggers for measuring air temperature and humidity in those rooms, which are located below the attic. These temperature values were used to determine the interior space temperature necessary for the temperature correction coefficient Fx calculation. Measurements required for the calculation of the thermal transmittance coefficients of the inter-floor construction were carried out in room No. 6.

The following measurements were made: fluxes through the inter-floor construction; air temperature and relative humidity in unheated space near the inter-floor construction; the ceiling surface temperature of the conditioned space; the air temperature in the vicinity of measuring surfaces and attic floor temperature.

Simulation description

The 3-D geometry model of the College building with zones, walls, windows and doors, roof, floor etc. was made in GoogleSketchUp software and is shown in fig. 4.

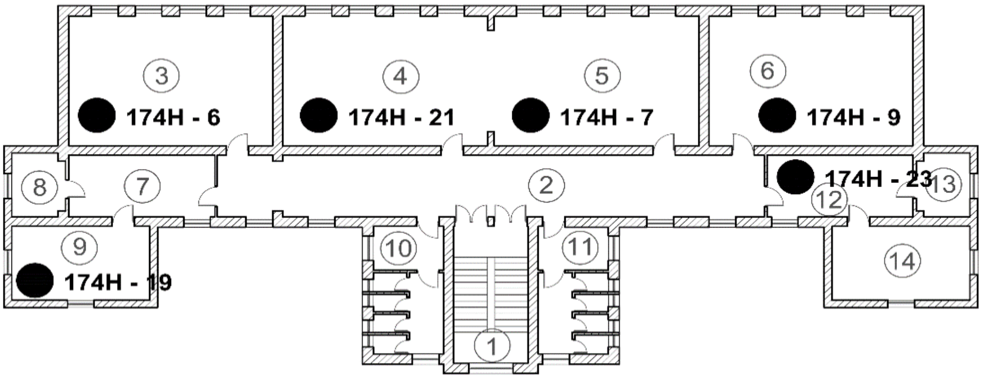

Figure 3. Plan of the first floor; *1 – stairs, 2 – corridor, 3 and 6 – classrooms, 4 and 5 – amphitheatre, 7 and 9 – office, 8 – pantry, 10 and 11 – toilets, 12 – reading room, and 13 and 14 – library*

The building geometry was taken as an input file for multizone Building modelling with Type 56 component and TRNBuild as its visual interface. This component models the thermal behaviour of a building divided into different thermal zones. In order to use this component, a separate pre-processing program must first be executed. The TRNBUILD program reads in and processes a file containing the building description and generates two files that will be used by the TYPE 56 component during a TRNSYS simulation (TRNSYS 17 version).

In order to analyse the selection of a more accurate temperature correction coefficient F_x for the calculation of thermal energy necessary to meet the facility's energy requirements, the dynamic simulation of the thermal behaviour of the whole facility was performed in TRNSYS Simulation Studio, fig.5. As shown in the schema in fig. 5, to acquire simulation results, four different Types (modules) of TRNSYS Simulation Studio are used: Weather Data (Type 15), Lights (Type 2), Building (Type 56), Irradiation and Simulation Results (Type 64). The building was modelled with four thermal zones, two of which are relevant to this discussion: the main building and the main roof which has a very complex structure. Two smaller zones are the small side roofs of buildings that are not physically connected to the large main

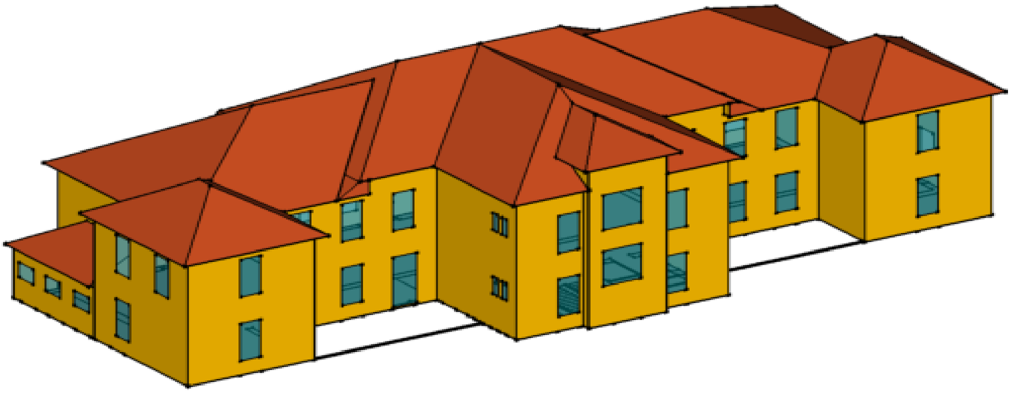

Figure 4. The 3-D model of the College of Textile Design, Technology and Management

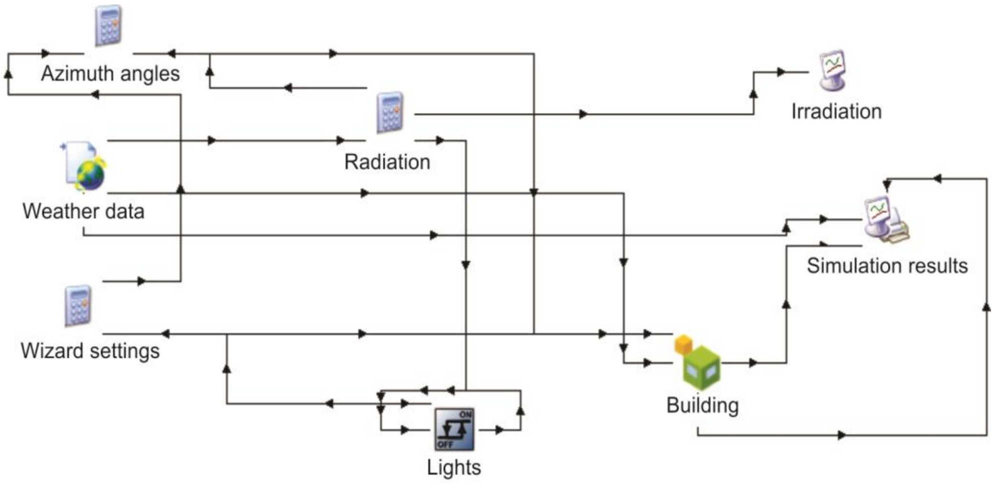

Figure 5. The TRNSYS simulation studio schema

roof. The building heating method is simplified for this purpose and set as a continuously heated building in the heating season, at a temperature equal to the mean measured temperature in the measurement period, $t = 21.1$ °C. The measured thermal transmittance values of the thermal building envelope (exterior walls, floors, windows, ceilings) are built into the model. The attic space has no heating and it is in the way of heat transfer from the ceiling of the heated space to the environment.

Results and analysis

Measurement results

Since the F_x coefficient is considered an important factor during the heating season, values measured over a period from the 12th-22nd March (11 days) have been taken into the calculation and comparison. Figure 6 shows measured values of external air temperature, unheated (attics) space temperature and the mean temperature of the internal heated space measured in several rooms on the first floor of the building. Measurements were carried out over the last month of the heating season and these diagrams show the difference between cold-days and transition periods.

The calculated value of the F_x coefficient for the 11-day period is shown in fig. 7. The diagram shows the difference between the external and the unheated space temperature. It is obvious that, if the external air temperature is higher than the temperature of the unheated area, the F_x coefficient exceeds 1 and increases with temperature difference. The average value of F_x coefficient for the entire measuring period is therefore slightly higher.

The structure of the inter-floor construction between the heated part of the building and the unheated attic was unknown and the heat transfer coefficient was determined from the measured value of inter-floor thermal transmittance. The surface areas of inter-floor and roof, were obtained from measurement and thermal transmittance of the roof was calculated, due to the lack of project documentation. The composition of the inter-floor construction towards the unheated attic was not known, so the heat transfer coefficient was determined from measurement: $U_{iu} = 0.87$ W/m^{2}K. The surface area of the inter-floor construction was 530.8 m^2 and amounted 21.5% of the total area of the building envelope. On

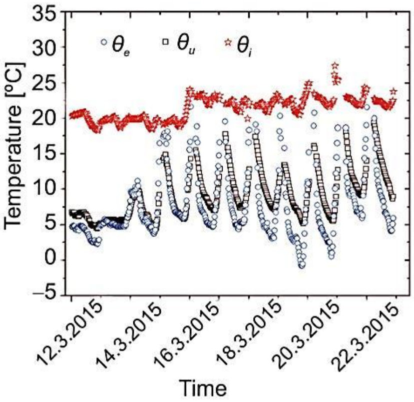

Figure 6. Measured temperatures over an 11-day period (θ_e – external air temperature, θ_u – unconditional space (attic) air temperature, θ_i – internal air temperature)

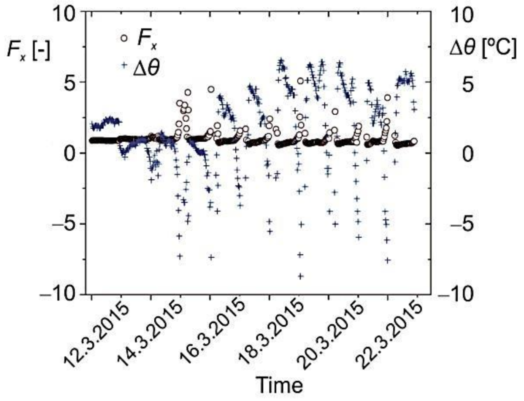

Figure 7. Coefficient F_x change and temperature difference between the outside air and the air temperature in the unheated area $\Delta\theta$ during the 11-day period

the basis of visual inspection, it was ascertained that the roof is constructed of plain tiles. The calculated heat transfer coefficient for the roof was U_{ue} = 5.14 Wm^{2}K and the total roof surface area was 777.6 m^2. The measured, calculated and F_x value from the regulation [12] are listed below in tab. 1.

Table 1. Temperature correction factor F_x and total building transmission losses H_T

	F_x [–]	H_T [WK^{-1}]
From standards recommendations	0.92	2211.6
From measured temperatures	0.97	2238.9
According to regulation	0.8	2160.4

To determine the impact of the calculated F_x coefficient on the energy performance of the building, a complete calculation of the total transmission losses of the building was made for each value of coefficient F_x. Table 1 shows the values obtained.

The results show a significant difference of H_T as a function of F_x. According to the 11 day measurements about 3.6% lower values were obtained compared to the regulation [5], and for the calculations [7-9], this difference is about 2.4%. The data obtained from measurement is much closer to the calculated results [7-9] than the tabular value [4]. If we take into account that F_x is only one of the coefficients used in the tables, the difference is not negligible. These results indicate that the coefficient F_x for inter-floor construction towards unheated space, much depends on the quality of roof construction and therefore, temperature correction coefficients F_x should be calculated according to the standards [7-9].

Simulation results

A thermal behaviour simulation for the building was carried out for the period within the heating season in December, January and February with selected simulation steps of 1 hour. For the presented roof construction, 6 different options were discussed depending on the thickness of the insulating material used, known commercially as URSA with a density ρ = 80 kgm^3

and thermal conductivity λ = 0.035 W/mK (Option 1 – Tiles, Option 2 – Tiles + Wooden board, Option 3 – Tiles + Ursa 2 cm, Option 4 – Tile + Ursa 5 cm, Option 5 – Tile + Ursa 14 cm, and Option 6 – Tile + Ursa 20 cm). Figures 8 and 9 graphically shows results of two extreme options, without insulation and with the highest insulation thickness, respectively. The outside temperature from the typical metrological year (TMY) Belgrade weather file, θ_e, the temperature inside the roof area, θ_u, and the temperature of the main building zone, θ_i, are presented. In fig 8, when the roof is not insulated (Option 1), outside temperature and the temperature in the roof area are only slightly different, while in fig. 9, where the roof is well insulated (Option 6), a significant temperature difference has appeared.

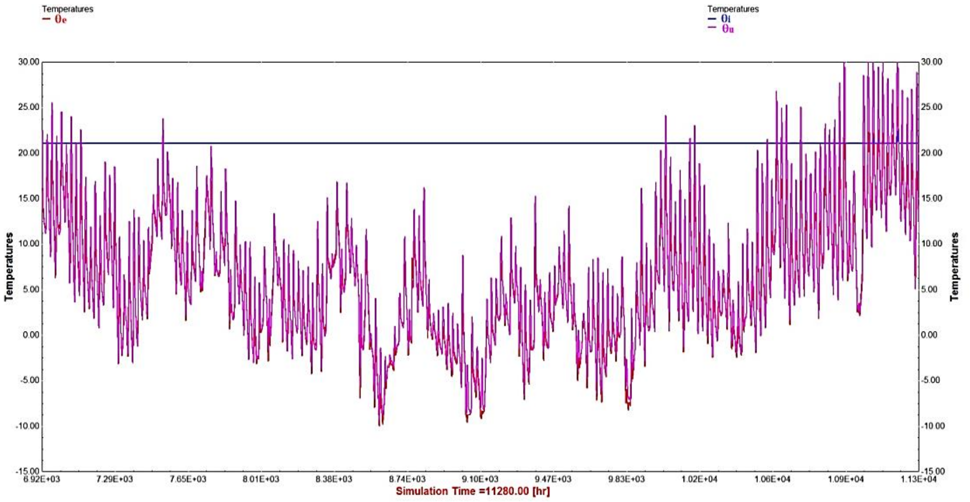

Figure 8. Zone temperatures (Option 1)

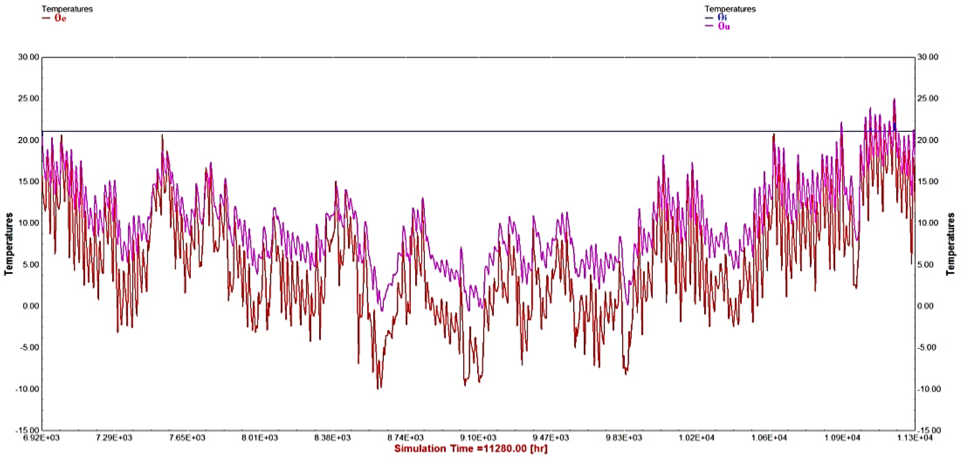

Figure 9. Zone temperatures (Option 6)

On the basis of eq. (2) and simulated temperature values, temperature correction factors F_x were calculated for all the considered options for each hour of simulation and then the mean values calculated for the observed period. The mean values of temperature correction factor and the corresponding standard deviation for different insulation thicknesses in the reporting period are shown in tab. 2.

Table 2 Temperature correction factor F_x by simulation

Options	1	2	3	4	5	6
Roof layers	Tile	Tile + Wooden board	Tile + Ursa 2 cm	Tile + Ursa 5 cm	Tile + Ursa 14 cm	Tile + Ursa 20 cm
U-value [$\mathrm{Wm^{-2}K^{-1}}$]	5.34	3.87	1.32	0.62	0.24	0.17
δ [m]	0.017	0.027	0.037	0.067	0.157	0.217
$\boldsymbol{F_x}$ [–]	0.94	0.91	0.83	0.78	0.73	0.73
Sd [–]	0.14	0.11	0.06	0.06	0.07	0.07

The results presented in tab. 2 show how temperature correction factor change depends on roof quality. When it is uninsulated, a roof consisting of only tiles with U-value equal to 5.34 $\mathrm{W/m^2K}$, the temperature correction factor is 0.94 which is very close to the value of $F_x = 1$ for external wall and flat roof directly exposed to the external environment [5]. With an increase in roof insulation thickness, *i. e.* reduction of thermal transmittance to 0.24 $\mathrm{W/m^2K}$, the temperature correction coefficient F_x reduces to the value of 0.73.

It is not possible to achieve the right steady state condition in measurements performed. Therefore, a steady state is assumed between two temperature measurements made in 10 minutes. The measurements were made in March, when in Belgrade there are more sunny days than in December, January, and February. It appears that the temperature of the outside air is higher than the air temperature in the attic, but it is a real state and affects the calculation of the heat losses of the building. In such a case, the value of the coefficient $F_x > 1$, and the mean value for the measured period of 11 days is 0.97, and the value according to the standard is 0.92. The simulation was done for the three months December, January, and February when this phenomenon is very rare and based on the obtained temperatures the value of the coefficient F_x is 0.94 for the non-insulated roof. These three values indicates that the worst selection of the temperature correction factor is 0.8, which is recommended by the Regulation and errors in calculation will be much lower if we use values obtained by measurements or according to the standard.

Conclusions

The calculation of total heat losses and total annual energy demand is directly influenced by the temperature correction factor used to correct errors caused by calculation of heat losses based on the difference between outdoor design temperature and indoor temperature of the building elements adjacent to the unheated spaces, rather than real temperature differences.

This paper considers the temperature correction coefficient F_x for the unheated attic of the College of Textile Design and Management in Belgrade comparing four different values: measured, calculated from standard, taken from the regulation table and dynamically simulated in TRNSYS Simulation Studio.

The results show that the temperature correction coefficient for very poor roof insulation has values very similar to those obtained in the three different ways: measured ($F_x = 0.97$), calculated from the standard ($F_x = 0.92$), and simulated ($F_x = 0.94$). A considerably lower value is achieved from the regulation table ($F_x = 0.8$).

The conducted analysis shows that for the building examined, the value of the temperature correction coefficient depends on roof insulation, which corresponds to the *U*-value of the roof. The temperature correction coefficient obtained by simulation for this building goes from 0.73 for a very well-insulated roof to 0.94 for the roof without insulation. This shows that the temperature correction coefficient depends on the *U*-value of the roof and cannot be used for any roof composition as a constant.

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