A study on the energy efficiency of different envelope materials and their influence of occupant's thermal comfort using dynamic simulation

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Abstract

This dissertation was written as a part of the MSc in Energy Building Design at the International Hellenic University. This study involves the simulation of an office building located in Thessaloniki. The aim of this study is to examine a variety of materials, which are integrated in the building envelope, so as to define what impact they have on thermal comfort and building's energy efficiency. There are two types of construction for the specific building (heavyweight and lightweight) and five types of glazing (clear, low-e summer, low-e winter, reflective, absorptive). Therefore, 10 different simulations were conducted for a 3-day time interval in April, August, October and December. The key parameters of all simulations were the temperature of floor surfaces (affected mean radiant temperature), predicted mean vote (PMV) values and thermostats (influenced heating & cooling energy needs). The simulation results of Energy Plus were assessed and transformed into qualitative results with the aid of ASHRAE Standard 55-2013 and European Standard EN15251.

I would like to thank my thesis supervisor Dr. Theodosiou Theodoros of the School of Science and Technology at International Hellenic University. Assist. Prof. Theodosiou was always available for every student that had questions or problems regarding the fulfillment of their thesis. He guided and enlightened me throughout the duration of my thesis mainly when I had to overcome any difficulties that came across and his advices on crucial points were always substantial. Finally, I am grateful for my parents and my girlfriend, with whose uninterrupted spiritual aid and boost during the whole period of this MSc programme I conclusively achieved to complete my MSc studies.

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Contents

1 Introduction

According to the existing global energy policy trends, there is a continuously rising vocation towards energy saving in all sectors as the worldwide mineral wealth shrinks and the available sources of energy as well. In the transport and industry sector new technologies have been developed so that less energy of every form is used for travelling and manufacturing of products. As far as the building sector is concerned, there is a constant tendency to the design and the construction of new energy efficient buildings as well as to the retrofit of existing buildings implementing energy saving measures. In this sector apart from the energy efficiency, which has been satisfied to some extent by the creation of new construction materials, thermal comfort plays also a significant role since buildings are occupied by people. This study will examine the influence of a variety of materials, used for construction of the building envelope, on thermal comfort and building energy efficiency.

2 Literature review

2.1 Energy efficiency

The energy efficiency of a building, except for the on-site energy generation with renewable energy sources, depends mainly on the energy consumption. Regarding the energy consumption, the *building sector* (residential, non-residential, construction industry) holds *36% of the global final energy use* and *39% of energy-related carbon dioxide (CO_2) emissions* according to Figure 1. This fact proves that the building sector is a big energy-consuming sector that needs attention and justifies the current tendency towards even more energy efficient buildings. In Figure 2, a rise of 6 exajoules (EJ) or a 5% increase in global buildings final energy use is recorded throughout the period 2010-2017. It is also remarkable that the buildings’ floor area increased by 17% during the same time interval.

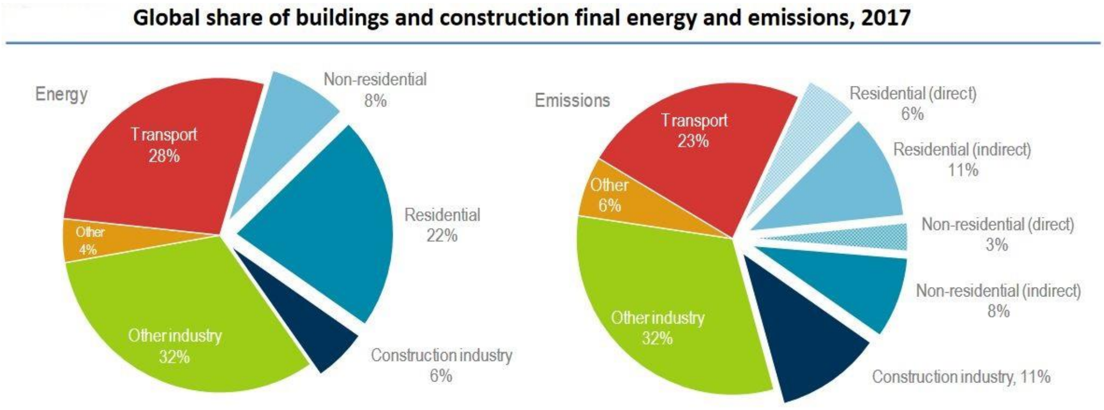

Figure 1: Global final energy use and CO_2 emissions by sector in 2017[1]

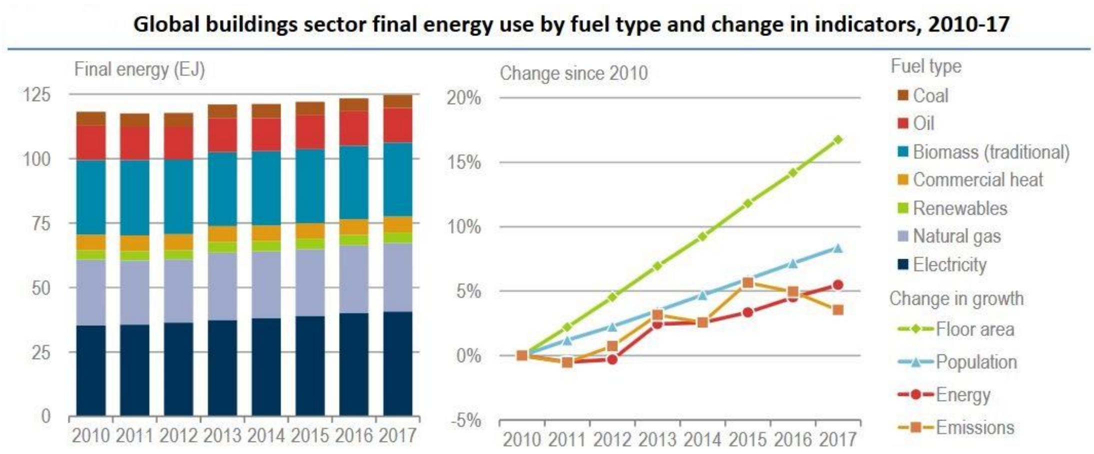

Figure 2: Global buildings final energy by fuel type and change in indicators in 2010-2017[1]

Moreover, the energy consumption of a building is determined by a variety of parameters related to the building, the environment and the occupants. In general terms, these are the building envelope and its losses to the environment, the heating, ventilation and air conditioning systems, the built environment and the climate and finally Indoor Environmental Quality (IEQ). IEQ is defined by 4 indices: Thermal comfort, Indoor Air Quality (IAQ), Visual comfort and Acoustical comfort [2]. The most significant one is thermal comfort which will be examined in the next paragraph.

2.2 Thermal comfort

Thermal comfort and building energy consumption are 2 parameters indissolubly connected to each other. Thermal comfort conditions are determined by the occupants or users of a building and dictate to a great extent the building energy needs and consumption for space heating, space cooling and ventilation. In the *residential sector* of U.S.

space *heating* and *cooling* account for the around *43% of the residential energy consumption* as shown in Figure 3. In the *commercial sector* of U.S., *space heating, space cooling and ventilation* hold *44% of the commercial energy use* (Figure 4).

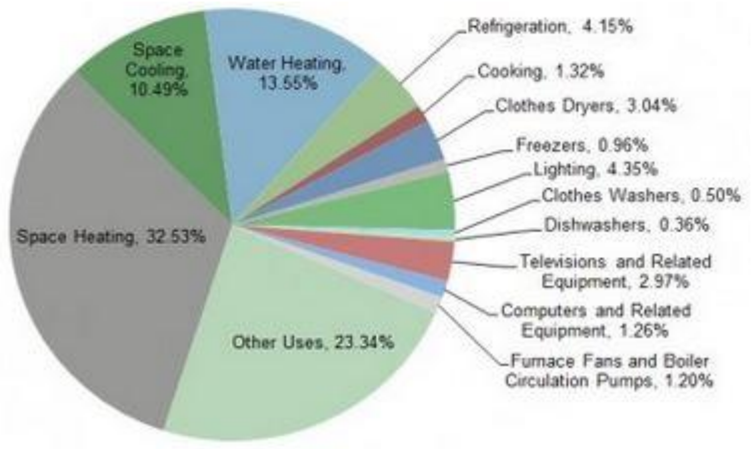

Figure 3: Average U.S. residential energy consumption by end-use in 2018[(3)]

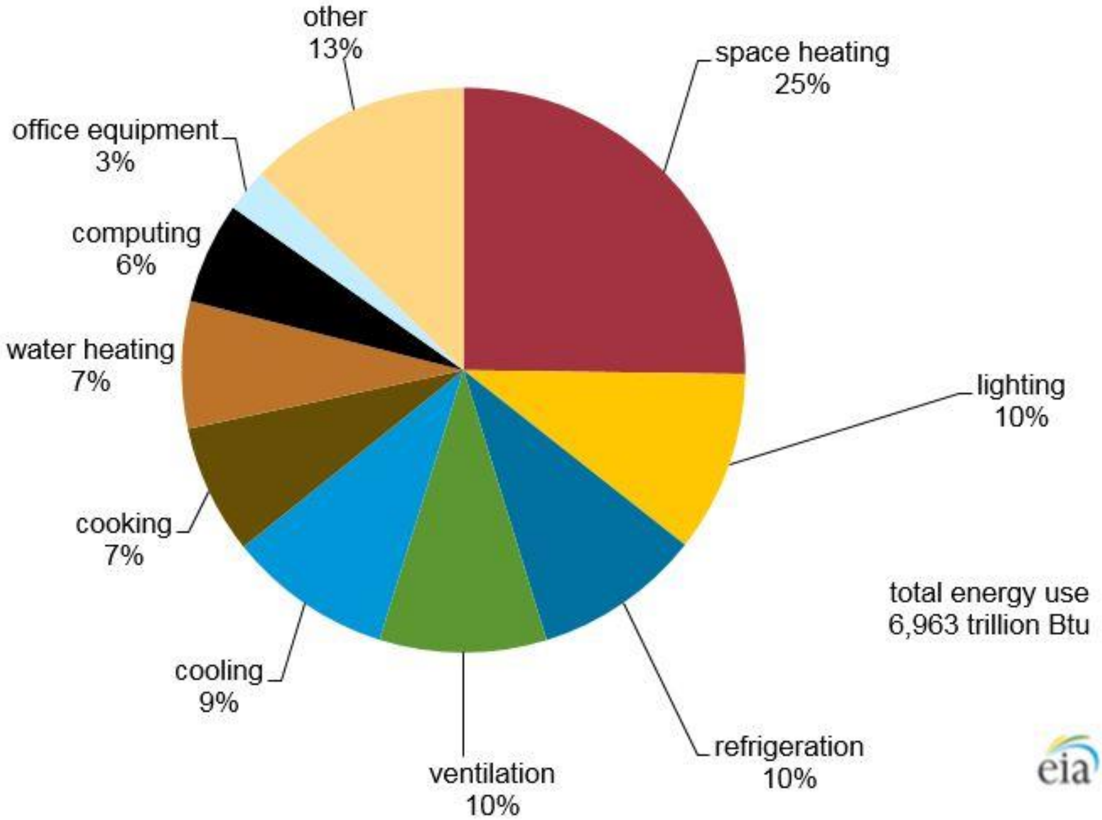

Figure 4: U.S. Commercial energy use in 2012[(4)]

According to American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) [5] *thermal comfort* is "the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation". In line with ASHRAE Standard 55, six *primary factors* in steady state define the conditions for acceptable thermal comfort: *1. Metabolic rate 2. Clothing Insulation 3. Air temperature 4. Radiant Temperature 5. Air speed 6. Humidity* [5]. The first two are attributes of the occupants of a building and the latter four are conditions of the thermal environment [5].

2.2.1 Mean radiant temperature (MRT)

The *mean radiant temperature* $\bar{t}_r$ (or MRT) is an important parameter in thermal calculations for the human body [6]. As defined in ASHRAE's Handbook [6], MRT is the uniform temperature of an imaginary enclosure in which radiant heat transfer from the human body equal the radiant heat transfer in the actual nonuniform enclosure. Measurements of globe temperature, air temperature and air velocity are combined in order to estimate the MRT [6]. The shape of the sensor is an important factor. As reported by ASHRAE [6], the spherical shape of the globe thermometer is a justifiable equivalent of a seated person (Figure 5) and an ellipsoid sensor is a better approximation of a human both upright and seated.

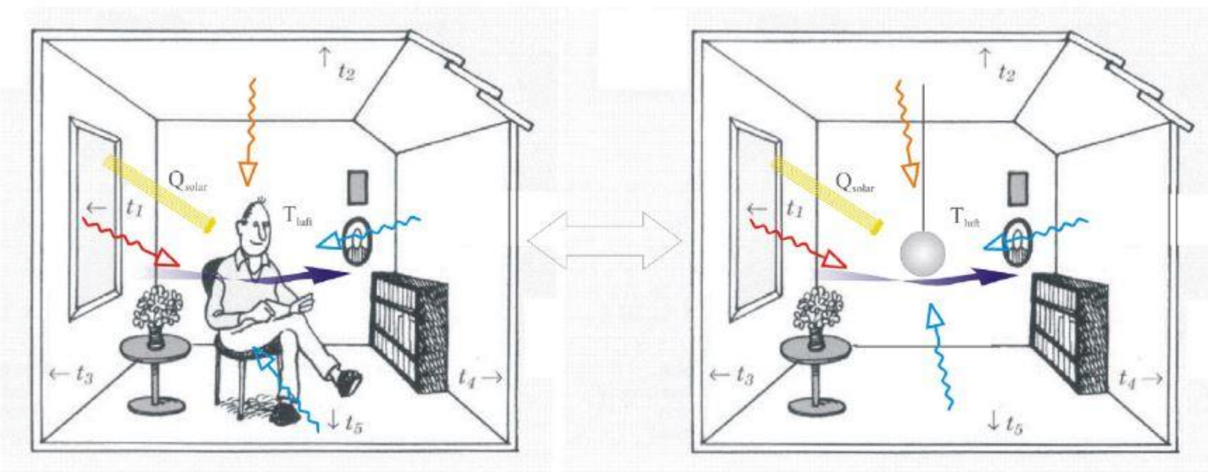

Figure 5: Modelling of human body as spherical sensor in the original environment(7)

In agreement with ASHRAE [6], *mean radiant temperature* can be calculated from the *measured temperature of surrounding wall and surfaces* and their positions with respect to the person (Figure 6) with the following equation:

$\bar{T}_r^{\,4} = T_1^4 \cdot F_{p-1} + T_2^4 \cdot F_{p-2} + \cdots + T_N^4 \cdot F_{p-N}$, where

$\bar{T}_r$ is the mean radiant temperature [K], T_N is the surface temperature of surface N [K] and F_{p-N} is the angle factor between a person and surface N

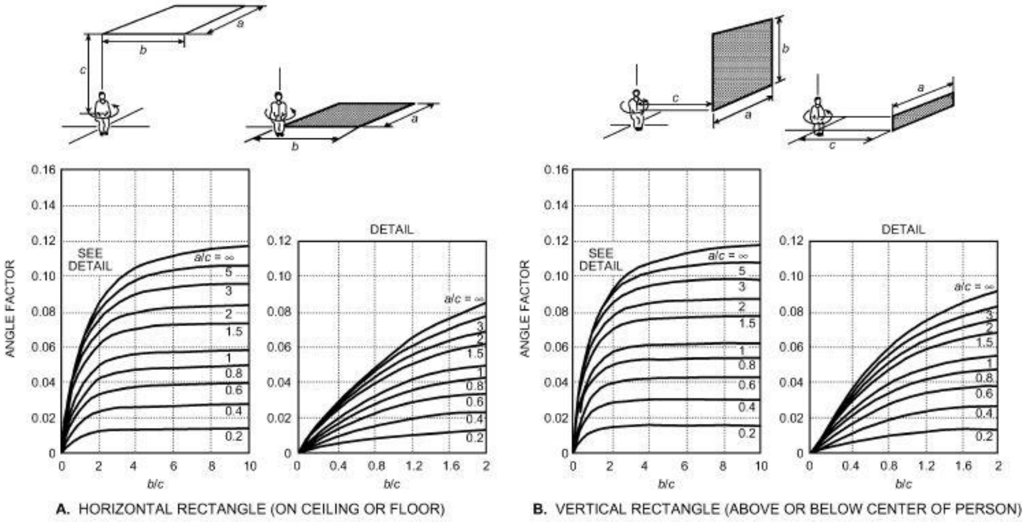

Figure 6: Mean value of angle factor between seated person and horizontal or vertical rectangle when person is rotated around vertical axis(6)

2.2.2 Operative temperature

Another significant parameter for thermal comfort is the *operative temperature t_o*. Conforming to ASHRAE standard's definition [5], it is the uniform temperature of an imaginary black enclosure and the air within it in which an occupant would exchange the same amount of heat by radiation plus convection as in the actual nonuniform environment. It is calculated [5] based on average air temperature and mean radiant temperature with the next equation:

$t_o = A \cdot t_a + (1 - A) \cdot \bar{t}_r$, where

t_a is the *average air temperature*

$\bar{t}_r$ is the mean radiant temperature

A is selected from the following Table 1 as a function of air speed:

Table 1(5)

Air speed (v_r)	< 0.2 m/s	0.2 to 0.6 m/s	0.6 to 1.0 m/s
A	0.5	0.6	0.7

2.2.3 Thermal comfort zone methods

a. Graphic comfort zone method

Pursuant to ASHRAE Standard 55 [5], this method can be used for determining acceptable thermal conditions in occupied spaces and is limited to typical occupants with *metabolic rates between 1.0 and 1.3 met* and *clothing insulation between 0.5 and 1.0 clo* (Figure 7). This method is also restricted to *maximum average air speed of 0.2 m/s* and *humidity ratio of 0.012 kg H_2O/ kg dry air*.

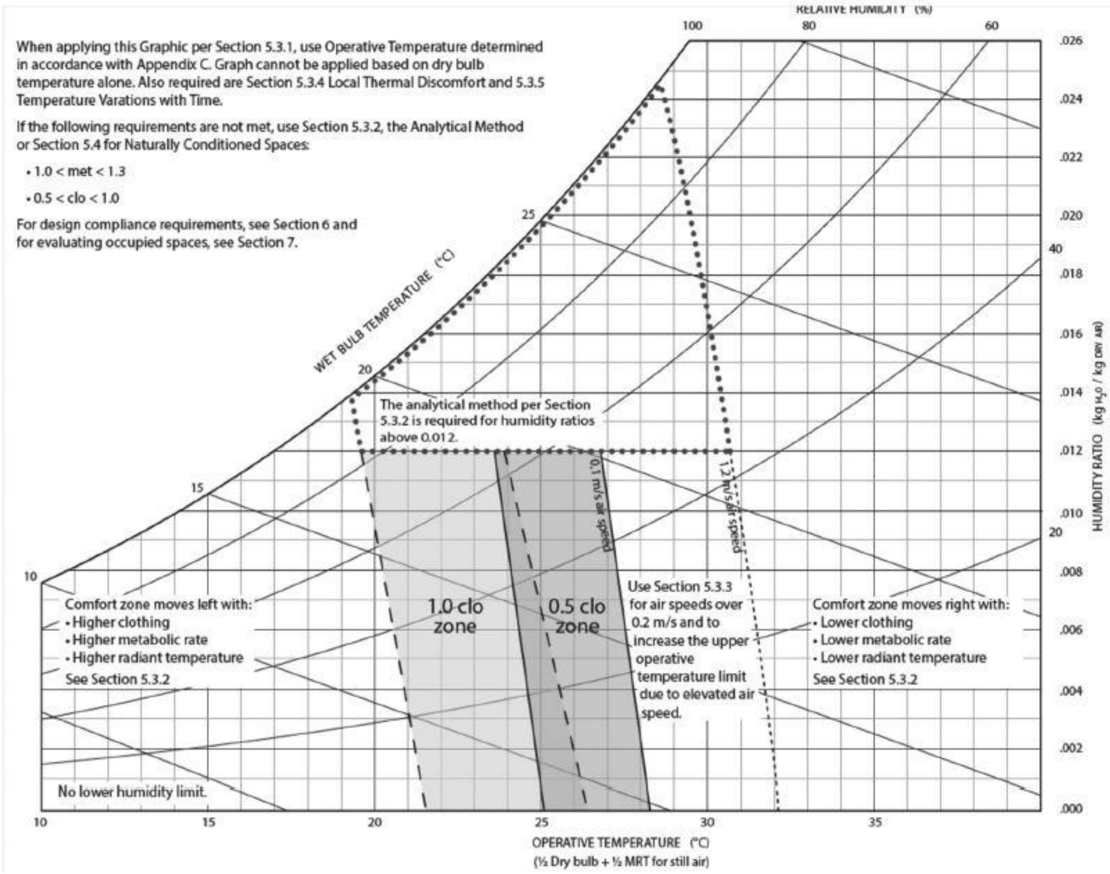

Figure 7: Acceptable range of operative temperature and humidity for spaces that meet the following criteria (1.0 < met < 1.3, 0.5 < clo < 1.0)[5]

b. Analytical comfort zone method (PMV-PPD model)

This method is applicable to spaces where occupants present metabolic rates between 1.0 and 2.0 met and clothing insulation below 1.5 clo [5]. ASHRAE created a thermal sensation scale for use in assessing people's thermal sensation. This scale is described in Table 2.

Table 2: ASHRAE thermal sensation scale[5]

-3	-2	-1	0	+1	+2	+3
Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot

The predicted mean vote (PMV) model uses heat balance principles to relate the thermal comfort factors to the average response of people on the above scale [5]. The predicted percentage dissatisfied (PPD) index is related to the PMV as defined in Figure 8. It has its basis on the assumption that people voting $\pm 2, \pm 3$ are dissatisfied and that PPD is symmetric around a neutral PMV.

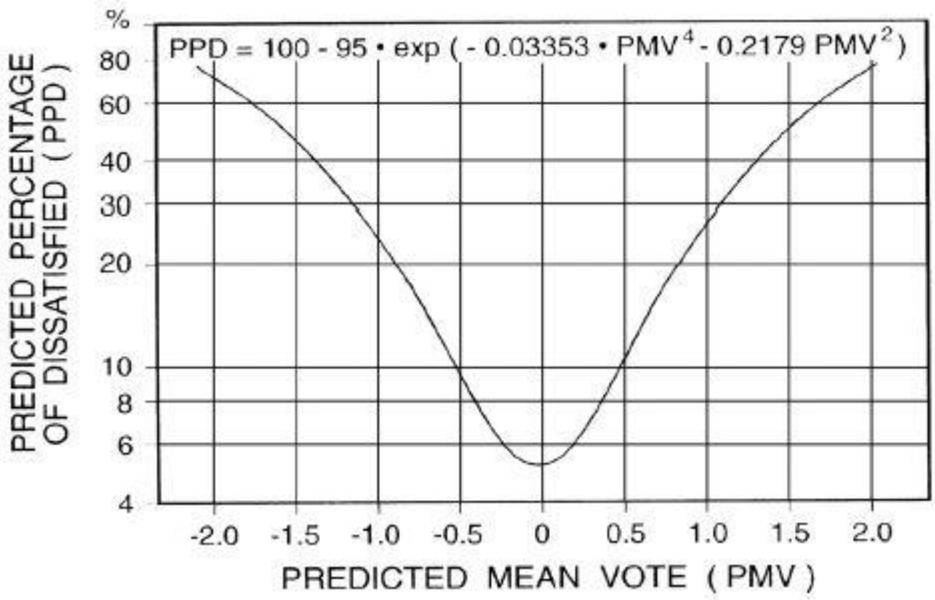

Figure 8: Predicted percentage dissatisfied (PPD) as a function of predicted mean vote (PMV)[5]

According to ASHRAE [5], *thermal comfort compliance* is achieved when PPD is lower than 10% or equivalently *PMV* is *between -0.5 and 0.5* (Figure 8). Based on the PMV-PPD model, standard *EN15251* sorts mechanically conditioned buildings into categories (Figure 9).

Category	Thermal state of the body as a whole	
	PPD %	Predicted Mean Vote
I	< 6	-0.2 < PMV < + 0.2
II	**< 10**	**-0.5 < PMV < + 0.5**
III	< 15	-0.7 < PMV < + 0.7
IV	> 15	PMV<-0.7; or +0,7<PMV

Figure 9: Recommended categories for design of mechanical heated and cooled buildings[8]

3 Building Data

3.1 Location

3.1.1 Climatic data

The examined building is an *office building* located in *Thessaloniki*, where the climate is a *local steppe* [9]. Figure 10 shows the maximum and minimum temperature of an average day for every month for Thessaloniki [10]. Hot days and cold nights (dashed red and blue lines) present the average of the hottest day and coldest night of each month of the last 30 years [10].

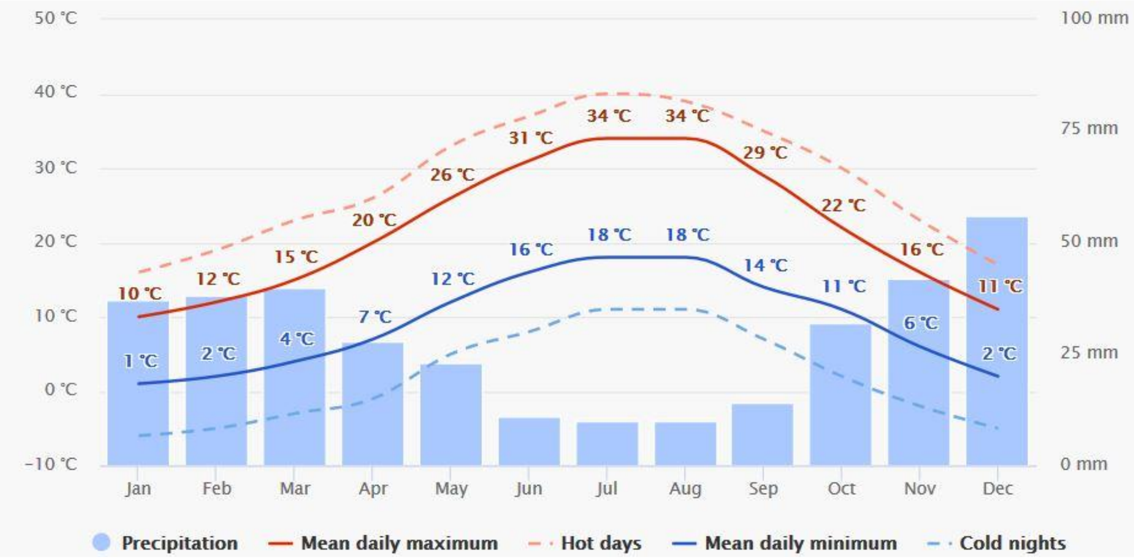

Figure 10: Average temperatures and precipitation in Thessaloniki[10]

As it is obvious from Figure 10, in Thessaloniki the highest average monthly temperatures are observed in June, July, and August and the lowest in December, January and February.

From Figure 11, it is remarkable that in Thessaloniki relative humidity above 70% is observed from October till March.

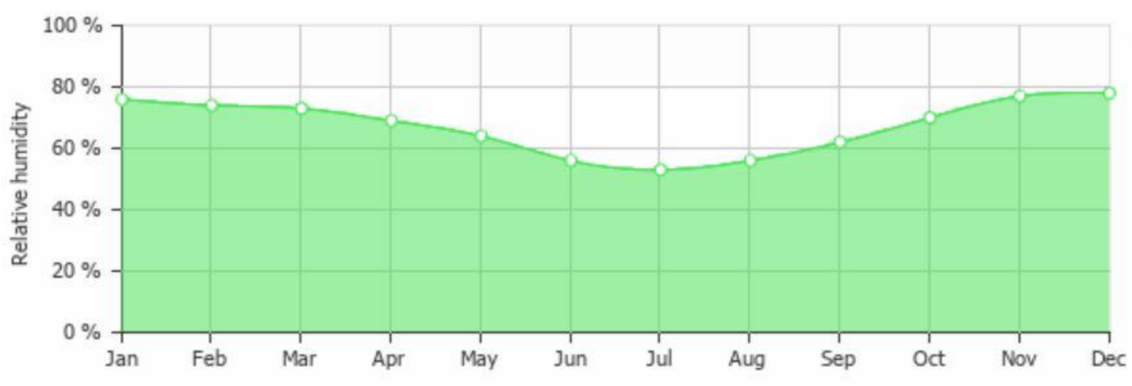

Figure 11: Mean monthly relative humidity in Thessaloniki(11)

3.1.2 Solar path

Solar path is the path sun follows in relation to any location. Solar path changes as date, time and location (latitude, longitude) change. Figure 12 depicts the solar path for every month for the location of Thessaloniki.

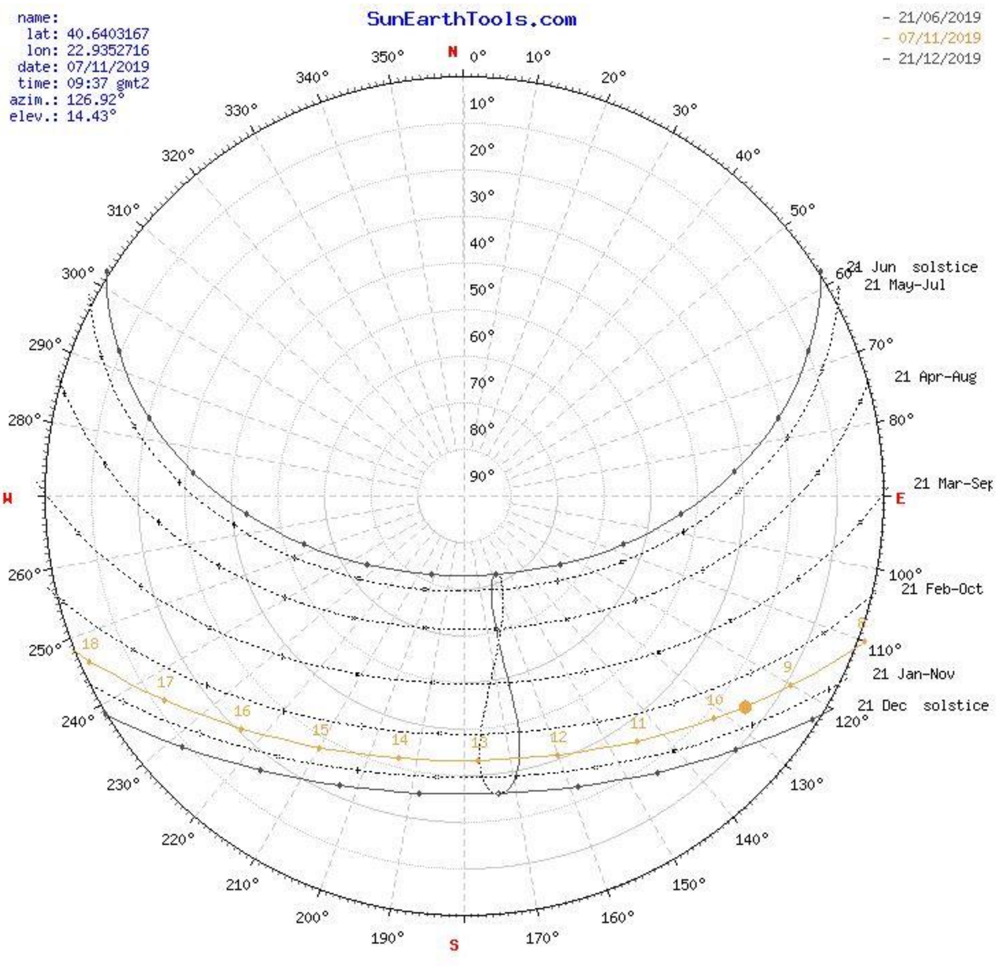

Figure 12: Solar path for the location of Thessaloniki(12)

3.2 Envelope

3.2.1 Material properties

In this subchapter, the main parameters of the building model are presented. Table 3, Table 4 and Figure 13 refer to the characteristics of all materials used for floor, roof, walls and windows.

Table 3: Material properties

Name	Plaster.ASv	XPS.07	Concrete.020	Brick.18	BitumenNot External	Mortar.01
Thickness [m]	0.02	0.07	0.2	0.18	0.014	0.01
Conductivity [W/m*K]	0.87	0.035	2.5	0.58	0.23	1.4
Density [kg/m^3]	1800	30	2400	1700	1100	2000
Specific heat [J/kg* K]	1100	1500	1000	1000	1000	1100

Table 4: Material properties

Name	Mortar.015	Garbilo.04	Garbilo.08	CerTiles	PlasterBoard.1.5 cm	Concrete.018	XPS.09
Thickness [m]	0.015	0.04	0.08	0.015	0.015	0.18	0.09
Conductivity [W/m*K]	1.4	0.81	0.81	1.84	0.25	2.5	0.035
Density [kg/m^3]	2000	1700	1700	2000	900	2400	30
Specific heat [J/kg* K]	1100	1000	1000	840	1100	1000	1500

Field	Units	Obj1	Obj2	Obj3	Obj4	Obj5	Obj6
Name		CLear_4mm	LowE_4_Ex	LowE_4_e0.05_Winter	LowE_4_e0.05_Summer	GREY 12MM	REF A CLEAR LO 6MM
Optical Data Type		SpectralAverage	SpectralAverage	SpectralAverage	SpectralAverage	SpectralAverage	SpectralAverage
Window Glass Spectral Data Set Name							
Thickness	m	0,004	0,004	0,004	0,004	0,012	0,004
Solar Transmittance at Normal Incidence		0,844688	0,714679	0,64153	0,64153	0,217	0,066
Front Side Solar Reflectance at Normal Incidence		0,07827056	0,1653401	0,292081	0,2602029	0,044	0,341
Back Side Solar Reflectance at Normal Incidence		0,07781072	0,135774	0,2602029	0,292081	0,044	0,493
Visible Transmittance at Normal Incidence		0,898778	0,886617	0,901361	0,901361	0,187	0,08
Front Side Visible Reflectance at Normal Incidence		0,084917	0,054971	0,049466	0,059394	0,045	0,41
Back Side Visible Reflectance at Normal Incidence		0,084805	0,064985	0,059394	0,049466	0,045	0,37
Infrared Transmittance at Normal Incidence		0	0	0	0	0	0
Front Side Infrared Hemispherical Emissivity		0,89	0,086218	0,050233	0,84	0,84	0,84
Back Side Infrared Hemispherical Emissivity		0,89	0,84	0,84	0,050233	0,84	0,4
Conductivity	W/m-K	1,1	1,1	1,1	1,1	0,9	0,9

Figure 13: Glazing properties

3.2.2 Structure

In all simulation cases roof and floor have a specific structure. The structure of walls and windows differs in each scenario. Regarding the material structure, all the descriptions of the following surfaces begin from the outside surface and end to the inside surface (Table 5).

Table 5: Surface structure

Surface	*Structure*
Roof	CerTiles–BitumenNot External–Mortar.01–XPS.09–Garbilo.08–Concrete.020–Plaster.ASv
Floor	CerTiles–Mortar.015–Garbilo.04–Concrete.020–XPS.09–Plaster.ASv
Heavyweight construction wall	Plaster.ASv–XPS.07–Plaster.ASv–Concrete.018–Plaster.ASv
Lightweight construction wall	Plaster.ASv–Brick.18–Plaster.ASv– XPS.07–Plasterboard.1.5cm
Clear glazing	Clear_4mm – Air 12mm – Clear_4mm
Low-e winter glazing	Clear_4mm – Air 12mm – LowE_4_e0.05_Winter
Low-e summer glazing	LowE_4_e0.05_Summer – Air 12mm – Clear_4mm
Reflective glazing	REF A CLEAR LO – Air 12mm – Clear_4mm
Absorptive glazing	GREY 12MM – Air 12mm – Clear_4mm

3.3 Operational schedules

For the examined office building two operating schedules are valid. As far as heating is concerned, the heating system is on during working hours (08:00 – 20:00) for the period 16 October – 15 April and the thermostat is set at 20 ^{o}C (mean air temperature). Therefore, when temperature drops below 20 ^{o}C, the heating system starts working. Regarding the cooling system, it is turned on during the same hours for the period 16 April – 15 October and the thermostat is set at 26 ^{o}C (mean air temperature). Consequently, if temperature is higher than 26 ^{o}C, then the cooling system starts working.

4 Methodology

The office building in the area of Thessaloniki, which is simulated in software Energy Plus, has a total floor surface of 81 m^2 (Figure 14). It has one east and one south window with area of 8.41 m^2 each. The rest side surface area is wall. The material properties of roof, floor, walls and windows are described in subchapter 3.2.2.

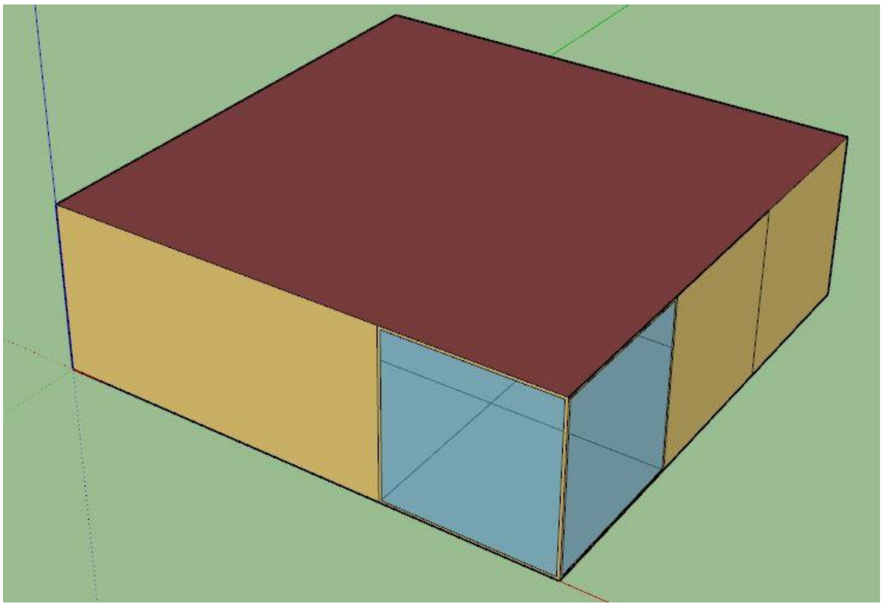

Figure 14: Office building in Thessaloniki – E+ model

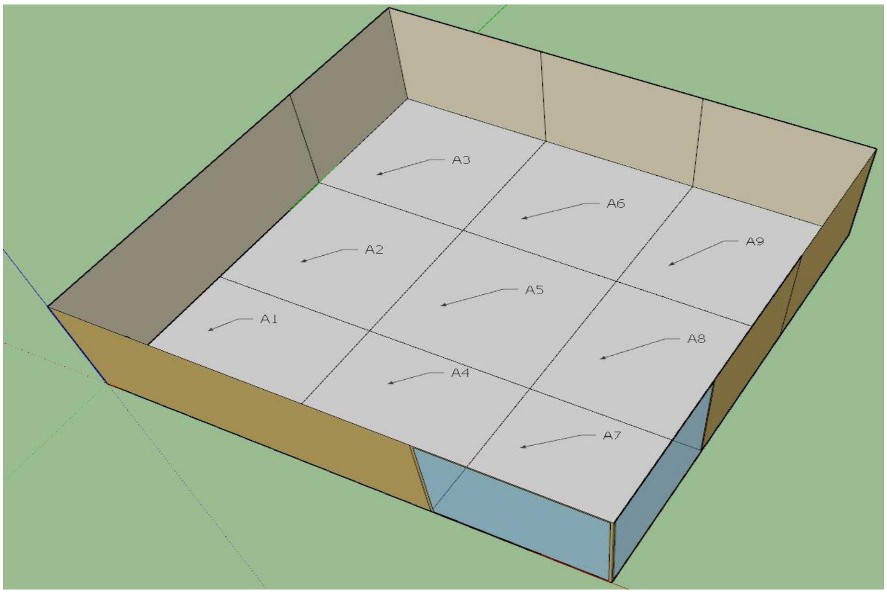

Figure 15: Floor surfaces A1 – A9

As stated in the chapter of Literature Review, thermal comfort depends inter alia on radiant temperature. Mean radiant temperature is calculated based on angle factors and the measured temperature of surrounding wall and surfaces. Therefore, temperature of floor surfaces A1-A9 (Figure 15), which hold 9 m^2 each, is one of the key parameters used for defining the thermal comfort of the office building. The final conclusions related to thermal comfort will be given by the PMV-PPD model, which is used for mechanically conditioned spaces, with the aid of the PMV variable and by European Standard EN15251. Finally, the annual heating and cooling energy needs of the building will be determined based on both air temperature and operative temperature in an attempt to integrate thermal comfort as a thermostat regulator.

5 Analysis

This chapter includes the simulation results of the building shows how the temperature and PMV values of surfaces A1-A9 vary as the type of construction, the time interval and the type of glazing change. The last subchapter presents the building energy needs for heating and cooling based on air and operative temperature.

In the following charts the range of Y-axis varies because comparisons and conclusions would otherwise be impossible.

5.1 Heavyweight construction

In this subchapter, the simulation results of the building with *heavyweight construction* are presented for each time interval and kind of glazing. Every case is compared to the *base case*, in which the building's glazings are *clear*.

5.1.1 Clear glazing (base case)

In the following charts the temperature and PMV values of surfaces A1-A9 and their variation in each time interval (April, August, October, December) are depicted.

In April (Figure 16) it is easily observed that surfaces *A7, A4, A8, A5* present the four *highest temperatures* in descending order, due to April's solar path (Figure 12) and the position of the glazings in the building envelope. As can be seen in Figure 16 the surface temperature fluctuates from 25.3 to 29.6 ^{o}C. Figure 17 shows that the PMV value varies from 0.6 to 1.27, which means that as far as the thermal environment is concerned the building belongs to categories III and IV according to the standard EN1521:2007.

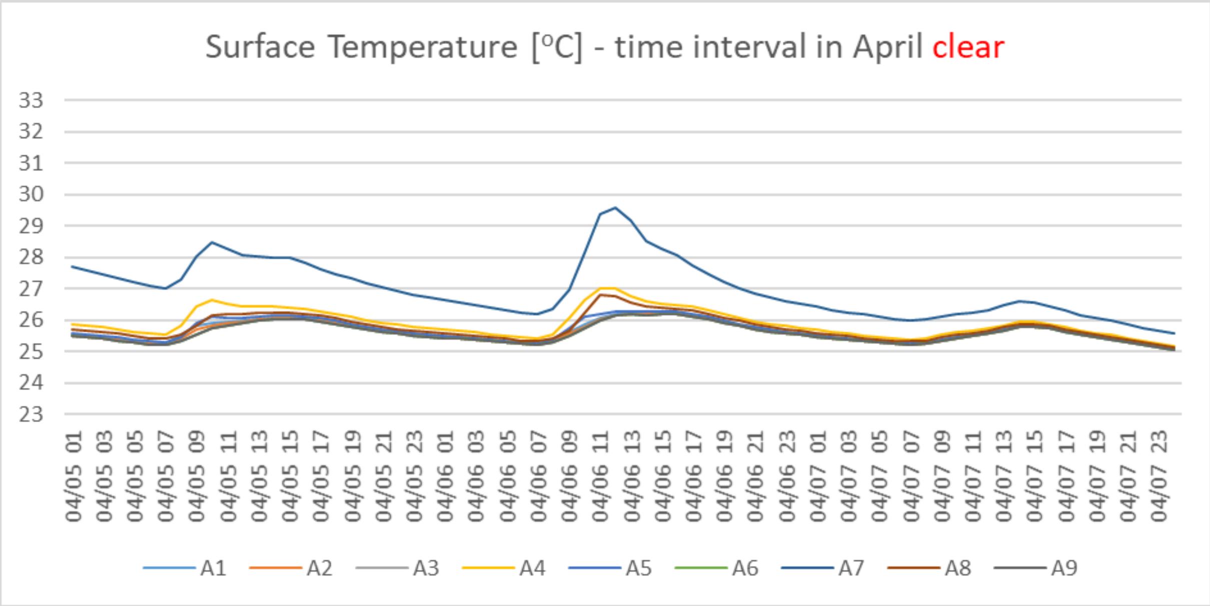

Figure 16: Surface Temperature [°C] – time interval in April – clear glazing

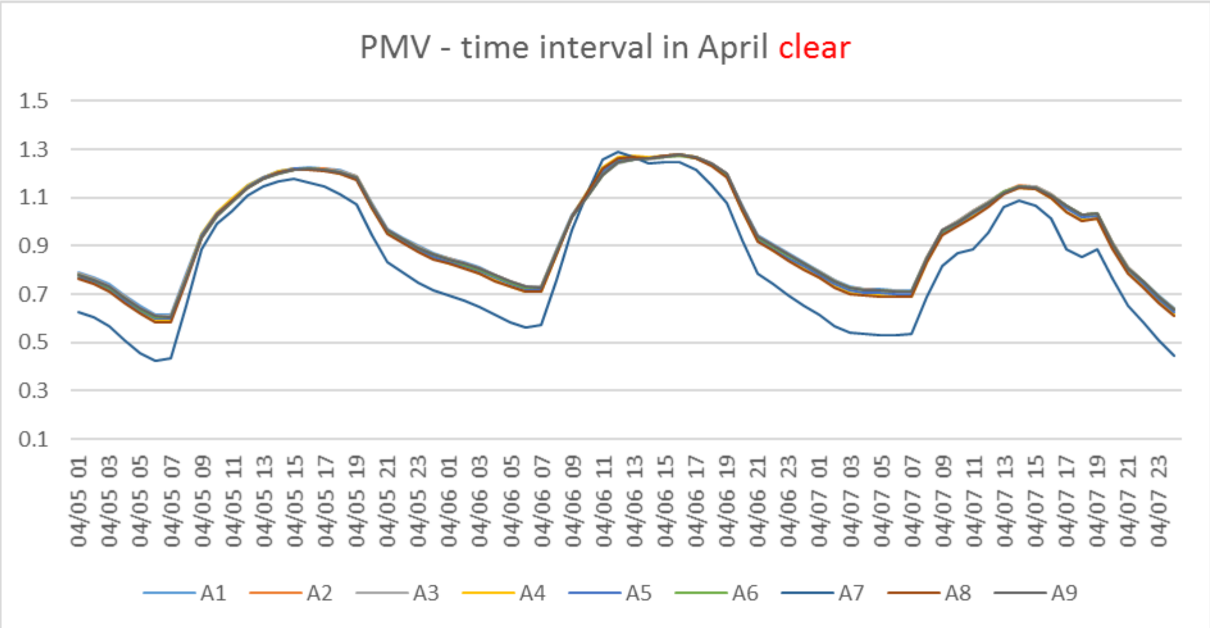

Figure 17: PMV – time interval in April – clear glazing

In August (Figure 18) surfaces *A7, A4, A8, A1* have the four *highest temperatures* in descending order. Apart from surface A1 the same happens in April (Figure 16), since the solar path is the same for April and August. In contrast to April, the surface temperature rises overall and has a range from 29.9 to 37.6 °C. PMV values for the same period (Figure 19) are higher than 0.75 concluding that the building is in category IV.

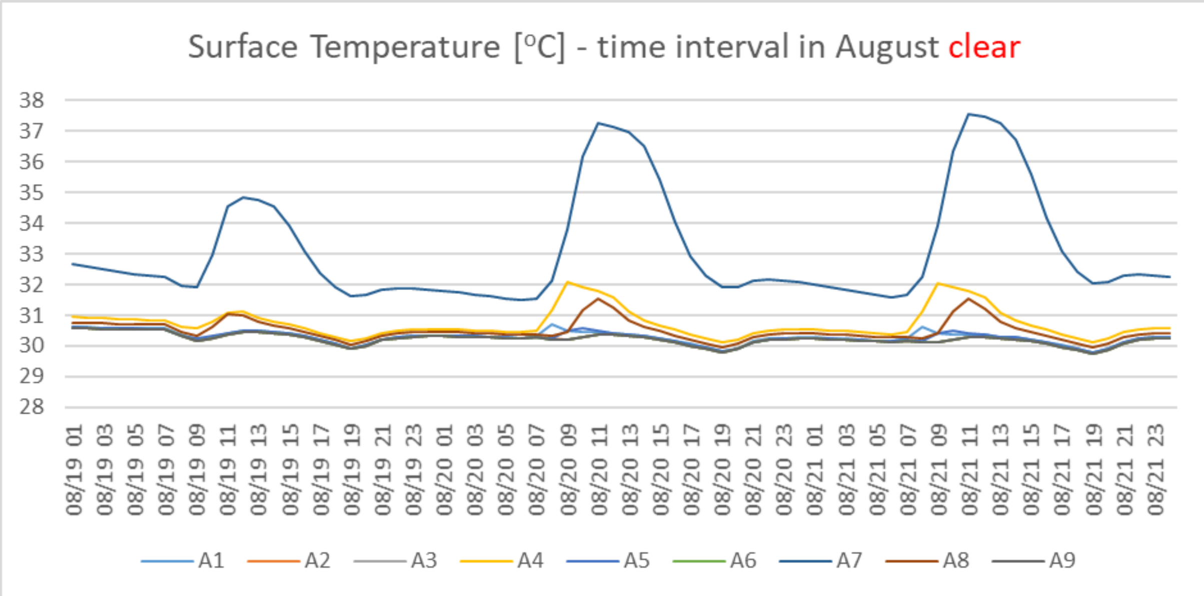

Figure 18: Surface Temperature [°C] – time interval in August – clear glazing

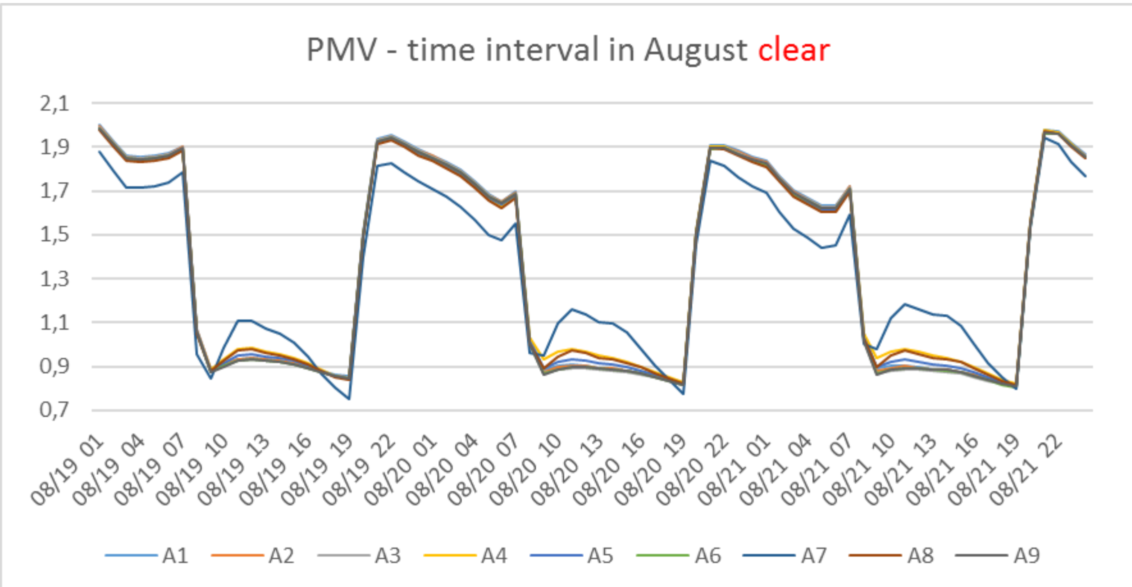

Figure 19: PMV – time interval in August – clear glazing

In October's time interval (Figure 20) surfaces *A7, A8, A5 and A4* hold the four highest temperatures. In this case, sun warms surface A4 less than A8 and A5 due to the fact that October's solar path is much smaller than April's. Throughout this period the surface temperature fluctuates in a wider range of 23.5 to 32.6 ºC. Respective PMV values (Figure 21) diversify from 0.46 to 1.63 deducing that the building can be in one of categories II, III and IV.

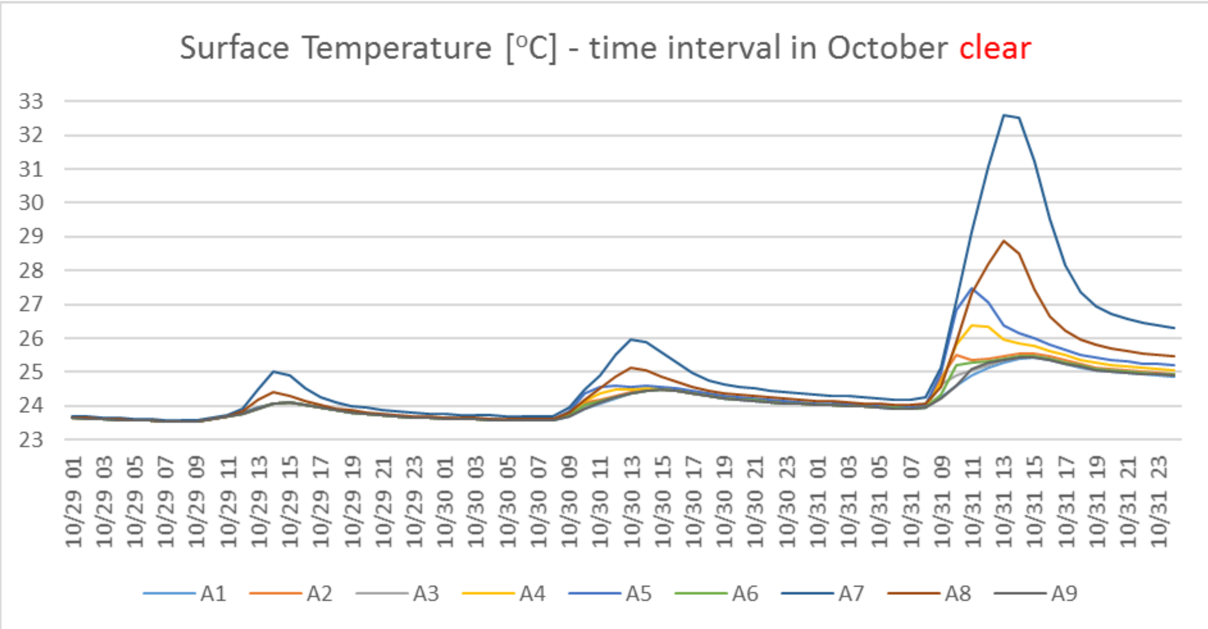

Figure 20: Surface Temperature [ºC] – time interval in October – clear glazing

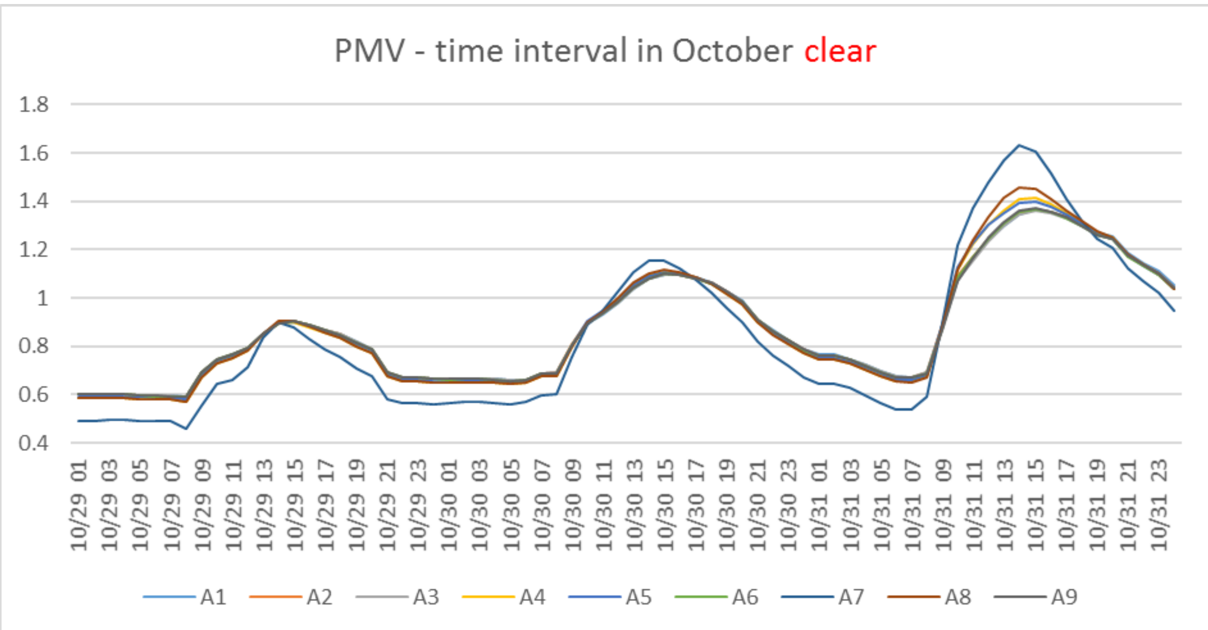

Figure 21: PMV – time interval in October – clear glazing

In addition to October, surfaces *A7, A8, A5 and A4* have the four *highest temperatures* in December (Figure 22). As can be seen in Figure 22 the surface temperature drops and ranges from 17.3 to 23 °C. In Figure 23 PMV presents a maximum value of -0.4 and a minimum value of -1.04 therefore classifying the building to categories II, III and IV.

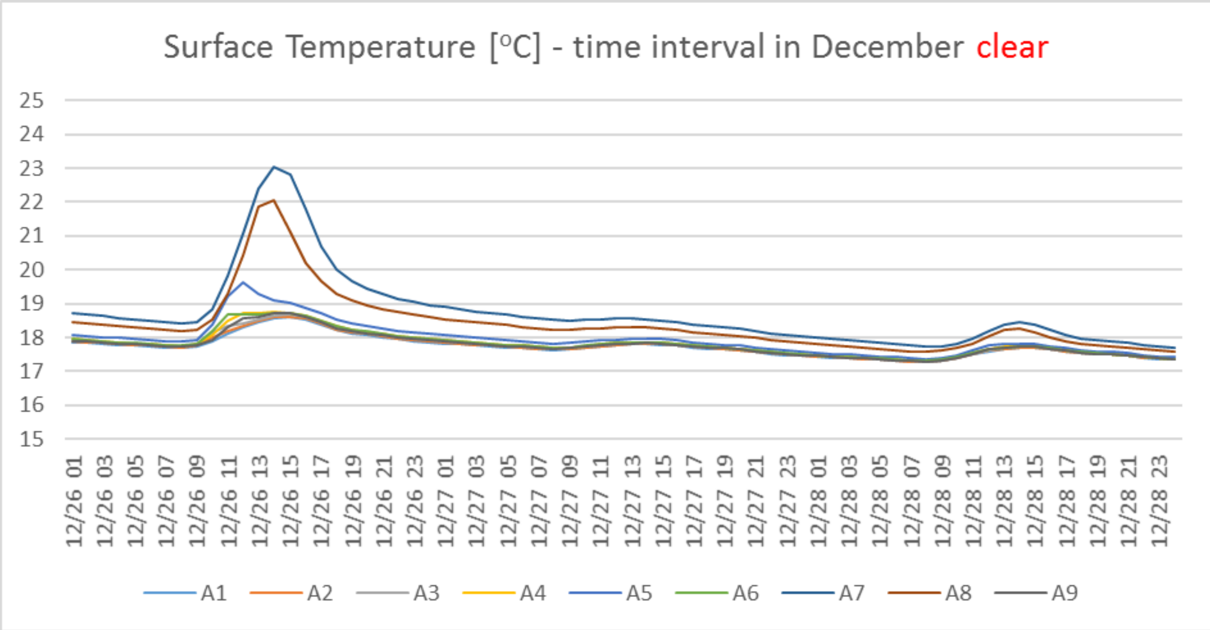

Figure 22: Surface Temperature [°C] – time interval in December – clear glazing

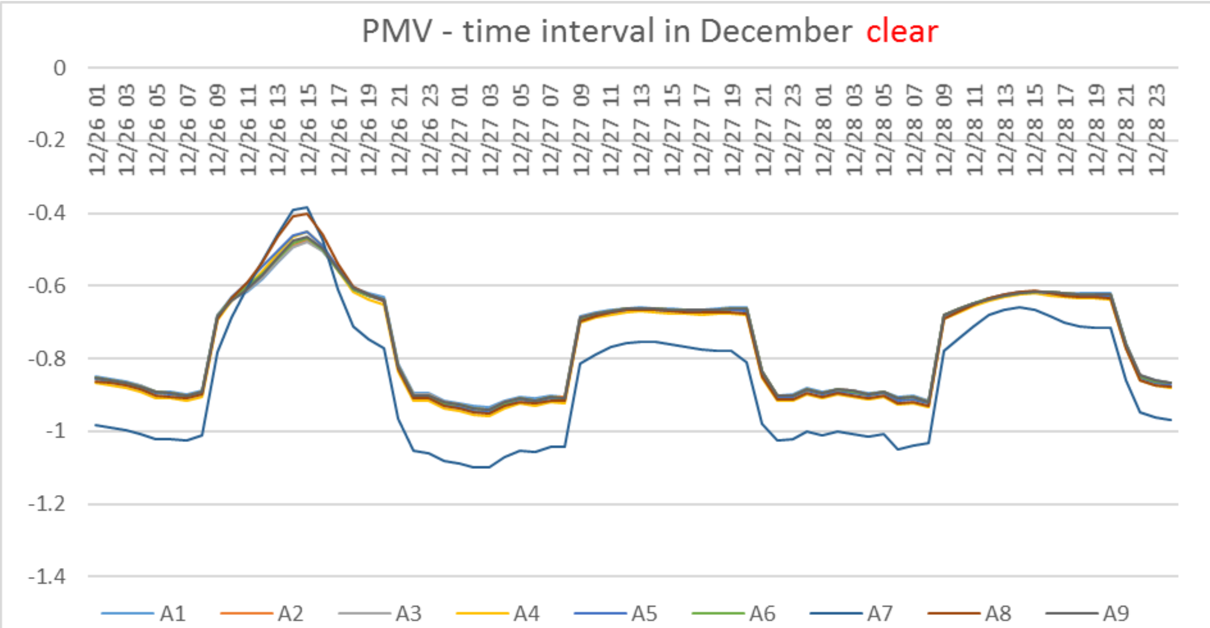

Figure 23: PMV – time interval in December – clear glazing

5.1.2 Time interval in April (05/04 – 07/04)

a. Surface temperature

As compared to the base case (clear glazing), both *low-e winter* and *low-e summer* glazing lower the surface temperature by *0.1 to 1.1 °C* (Figure 24) and by *0.3 to 1.3 °C* (Figure 25) respectively. For this period, the low-e winter glazing reduces less the temperature and it is more effective than low-e summer glazing, which allows less solar radiation into the building.

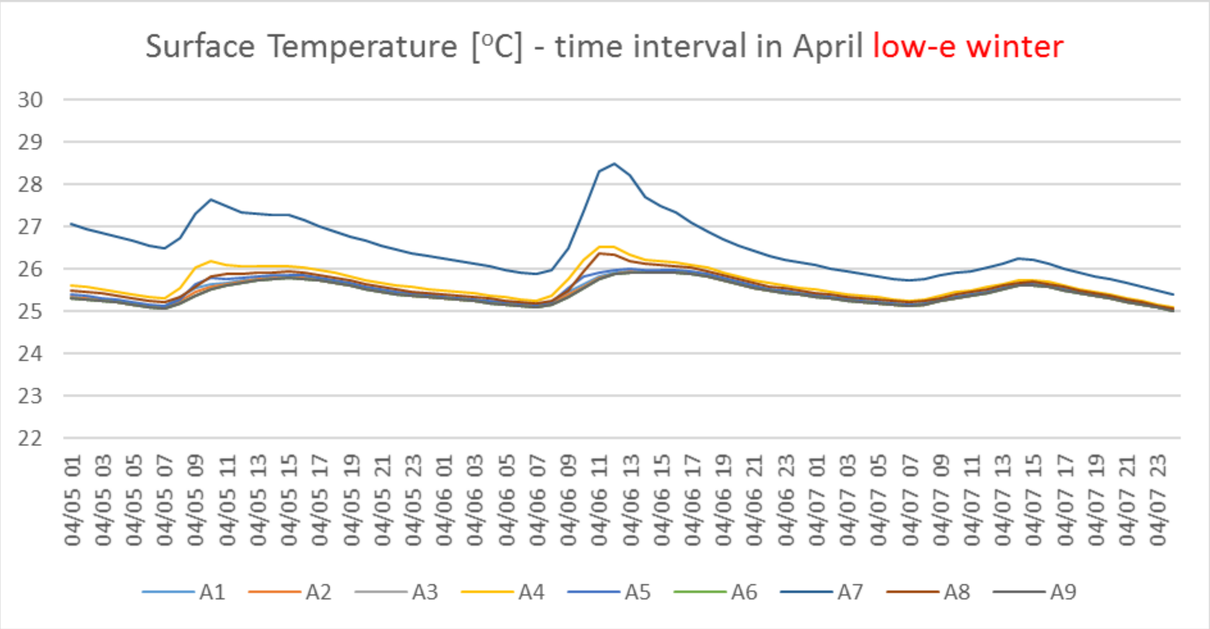

Figure 24: Surface Temperature [°C] – time interval in April – low-e winter glazing

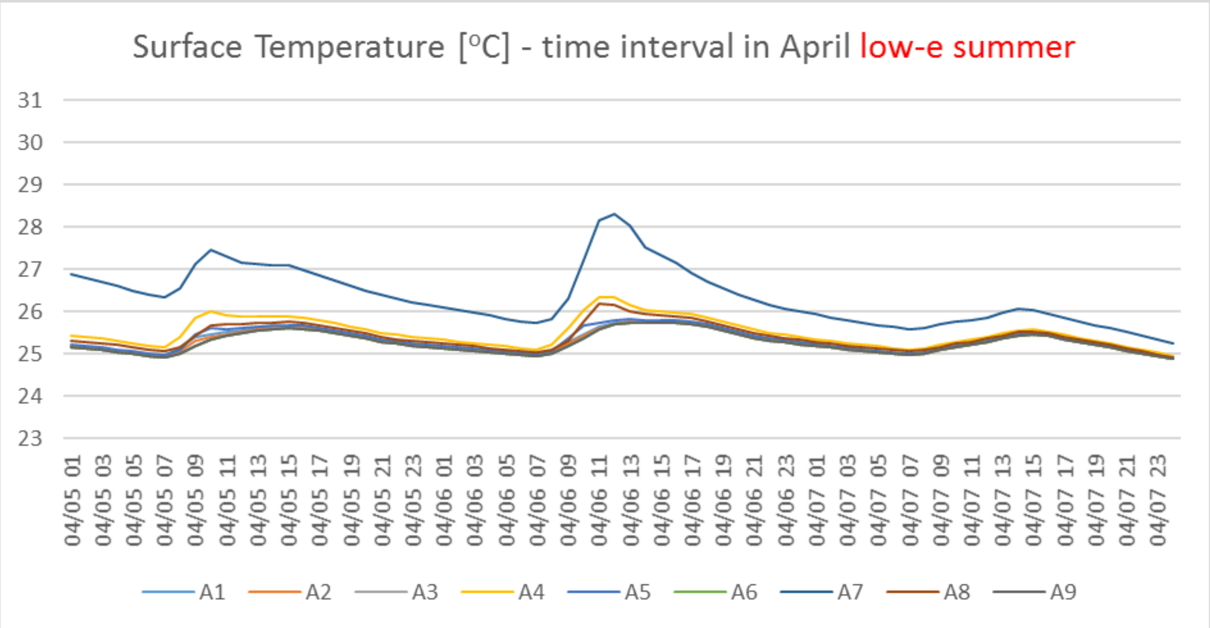

Figure 25: Surface Temperature [°C] – time interval in April – low-e summer glazing

As opposed to the other glazings, the *reflective* and *absorptive* ones decrease the surface temperature much more, specifically by *3.5 to 7.1 ^{o}C* (Figure 26) and by *2.5 to 5.5 ^{o}C* (Figure 27) respectively. In the case of the absorptive glazing, the surface temperature is higher than in the case of the reflective one, because its inner part absorbs more heat and thus warms the inside surfaces by convection. Furthermore, by using reflective glazing the surface temperature presents a slower rise in 2 of the 3 days in contrast with the base case.

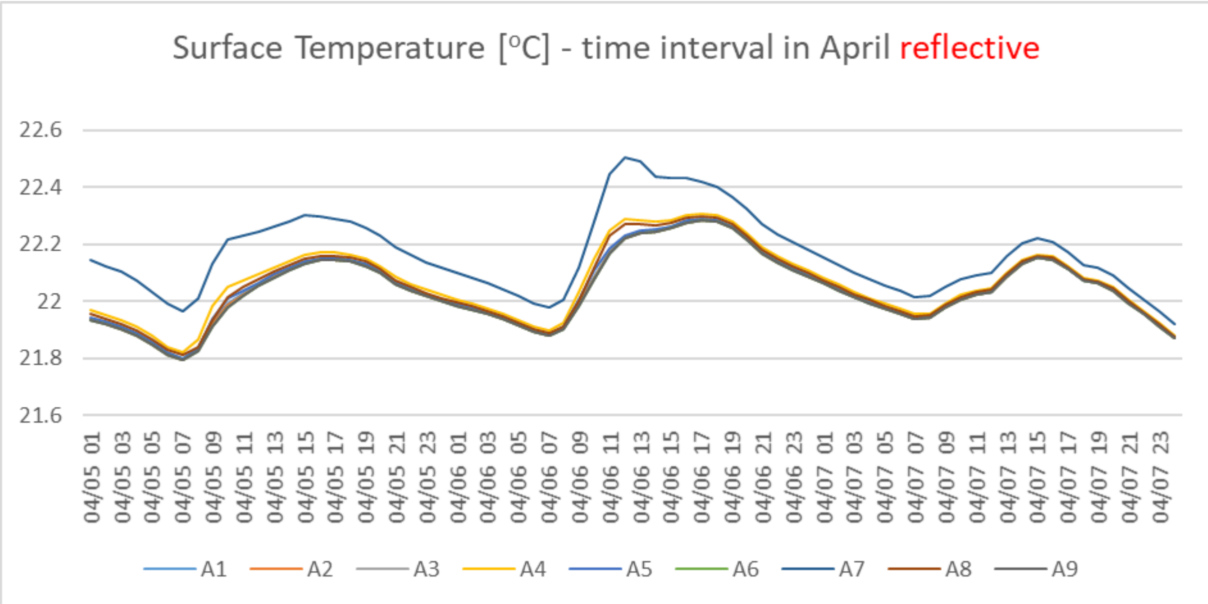

Figure 26: Surface Temperature [^{o}C] – time interval in April – reflective glazing

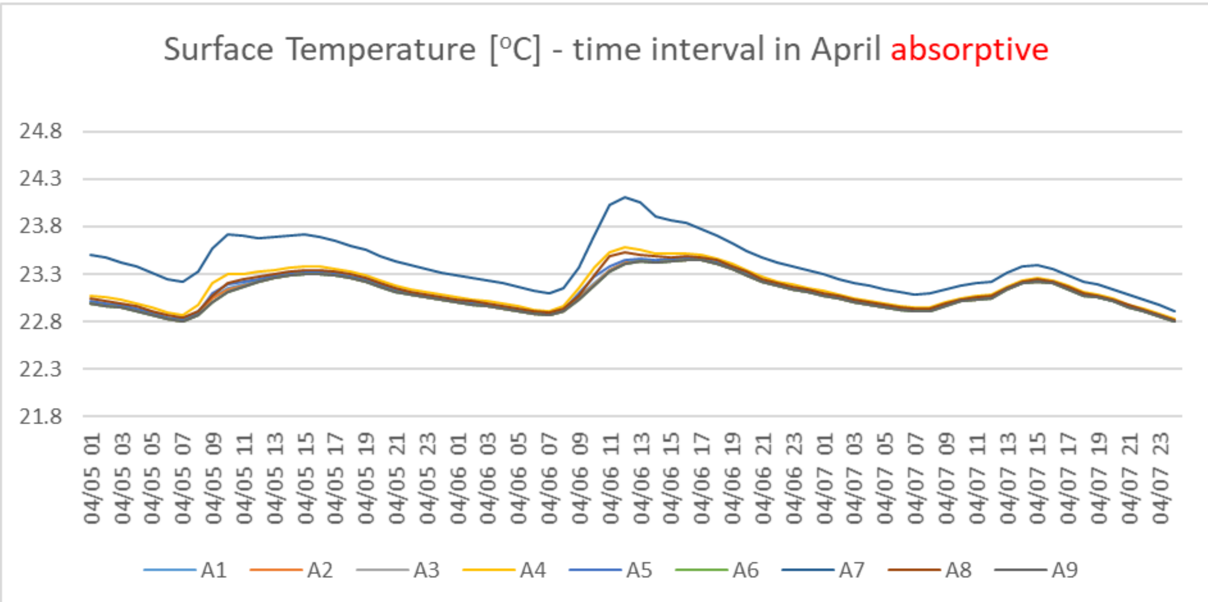

Figure 27: Surface Temperature [^{o}C] – time interval in April – absorptive glazing

b.PMV

In Figure 28 and Figure 29 it is shown that the use of low-e winter and low-e summer glazing has almost no effect on the PMV values and therefore the building remains in categories III and IV.

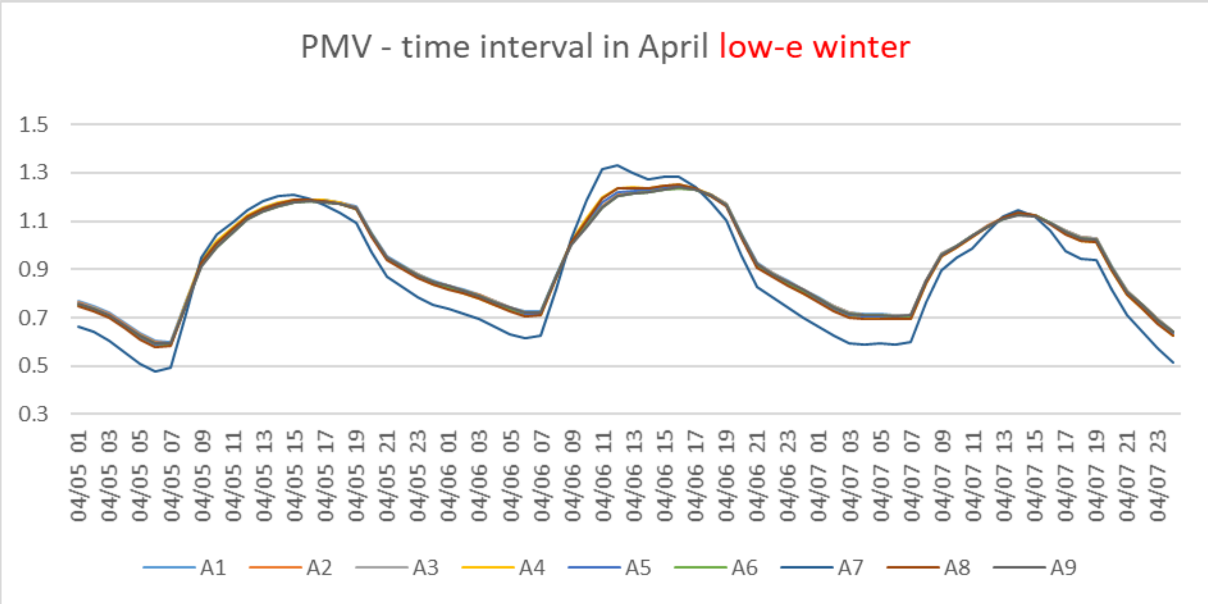

Figure 28: PMV – time interval in April – low-e winter glazing

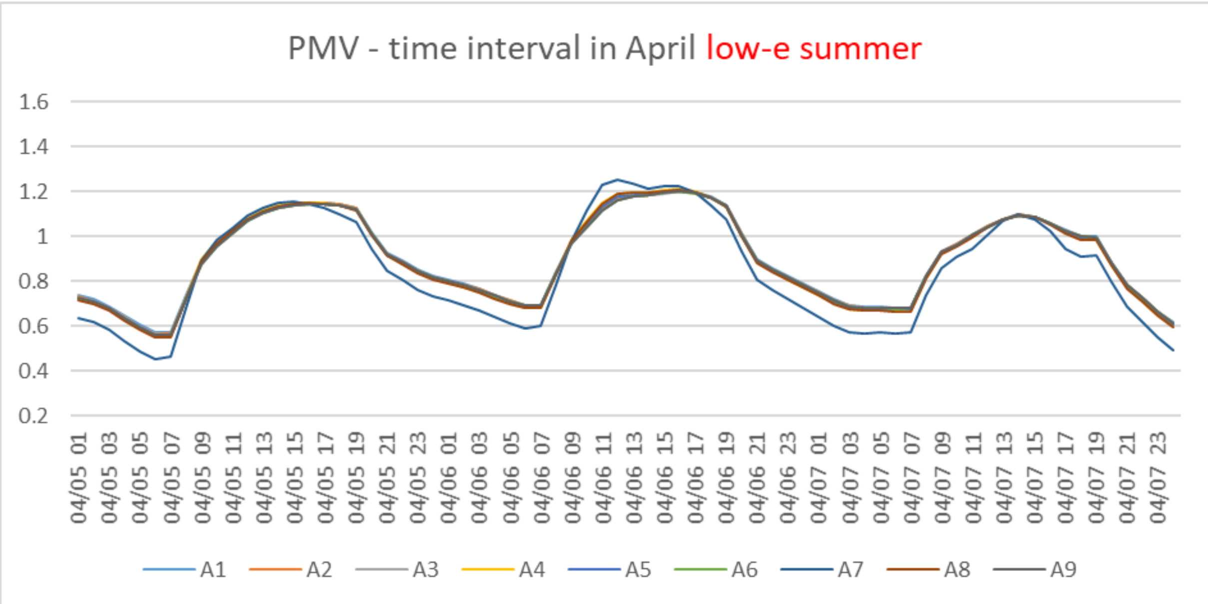

Figure 29: PMV – time interval in April – low-e summer glazing

Excluding surface A7, which is the most heated one, in the above 2 cases the building is limited to category IV.

From Figure 30 it can be deduced that by using the reflective glazing the PMV values drop and the building shifts to categories I, II and III. The PMV values present a smaller decrease in the case of absorptive glazing and the corresponding building belongs to categories II, III and IV (Figure 31).

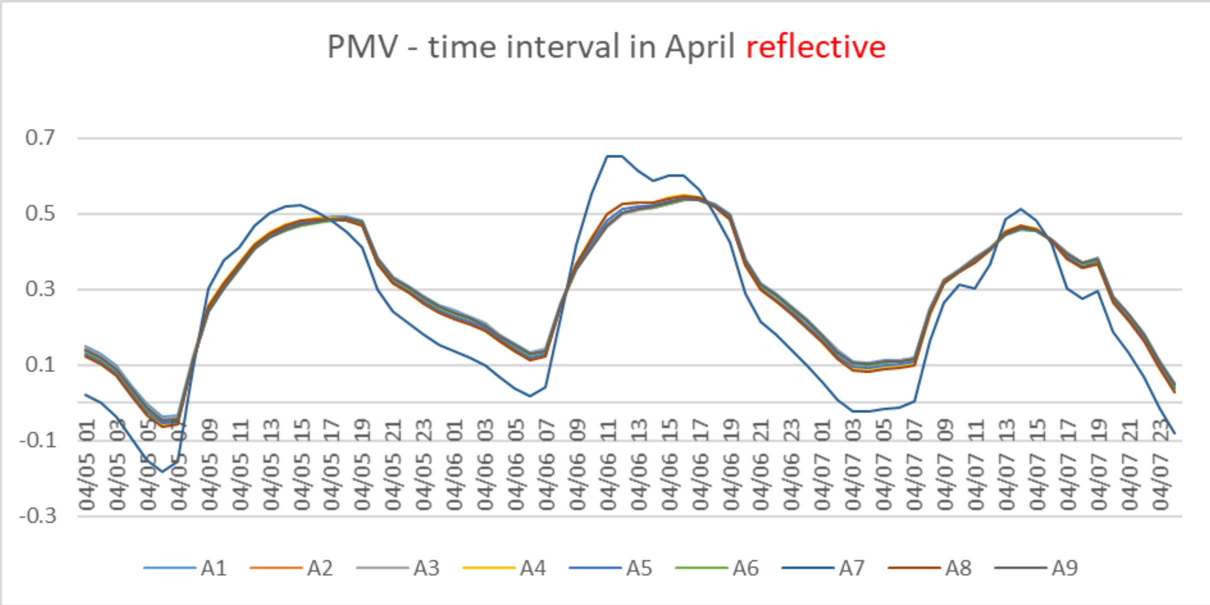

Figure 30: PMV – time interval in April – reflective glazing

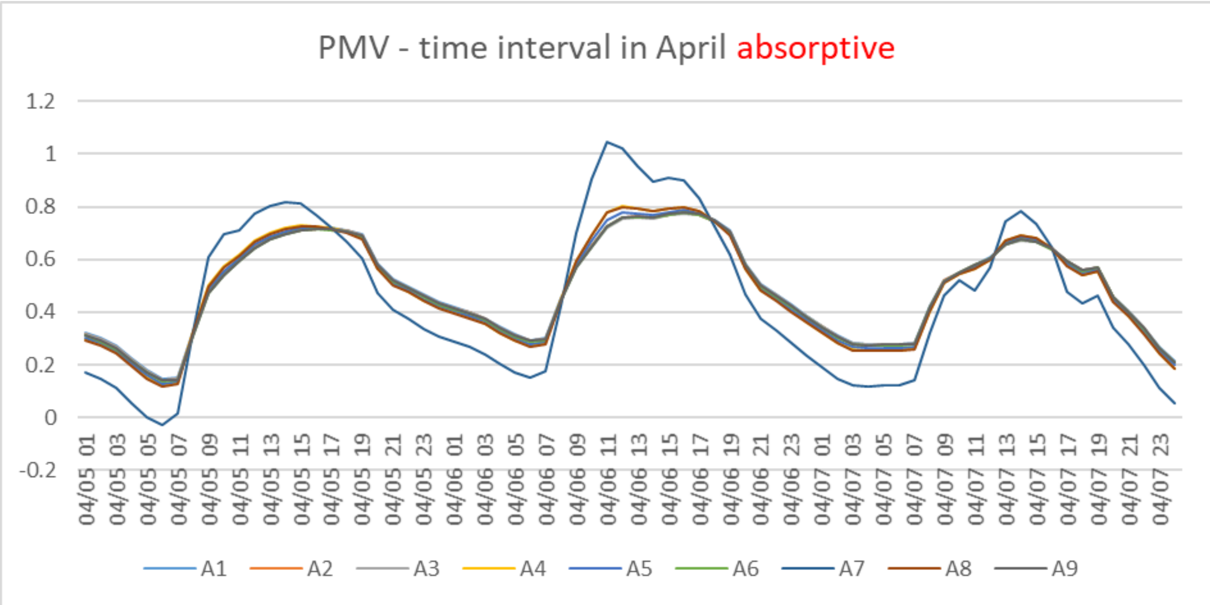

Figure 31: PMV – time interval in April – absorptive glazing

Exempting surface A7, with the use of reflective glazing the building belongs to categories II and III and the building with the absorptive one remains in categories II, III and IV.

5.1.3 Time interval in August (19/08 – 21/08)

a. Surface temperature

As opposed to the base case (clear glazing), the *low-e winter* and *low-e summer* glazing reduce the surface temperature by *0.4 to 2.2 °C* (Figure 32) and by *0.5 to 2.2 °C* (Figure 33) respectively. It is obvious that in the case of low-e summer glazing the temperature should have shrinked more and the glazing is not so effective.

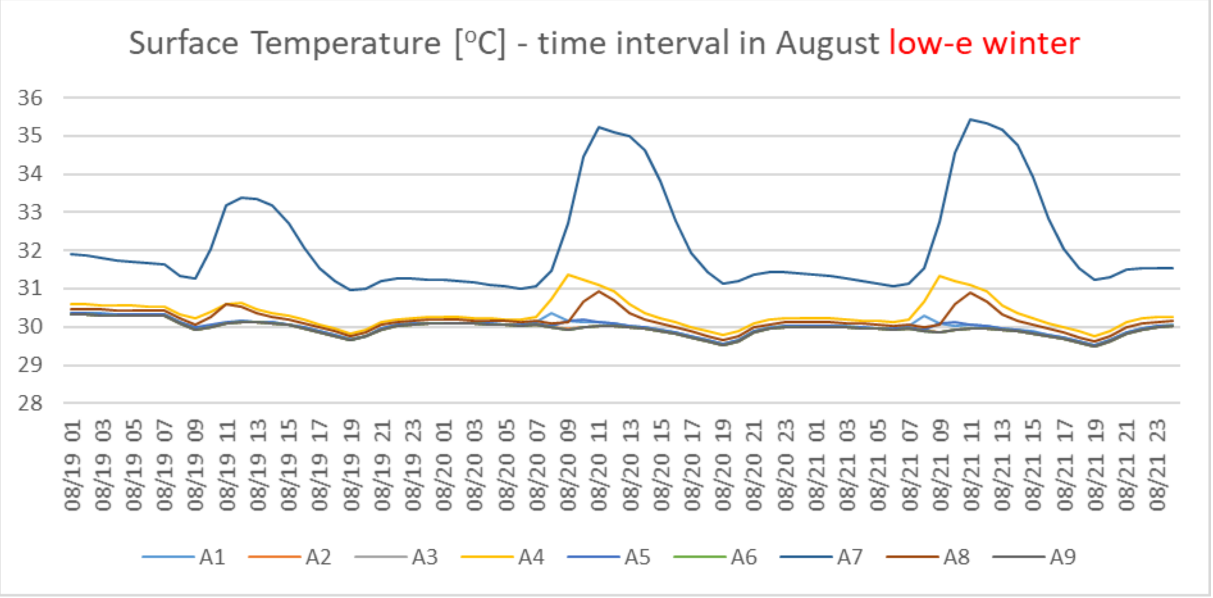

Figure 32: Surface Temperature [°C] – time interval in August – low-e winter glazing

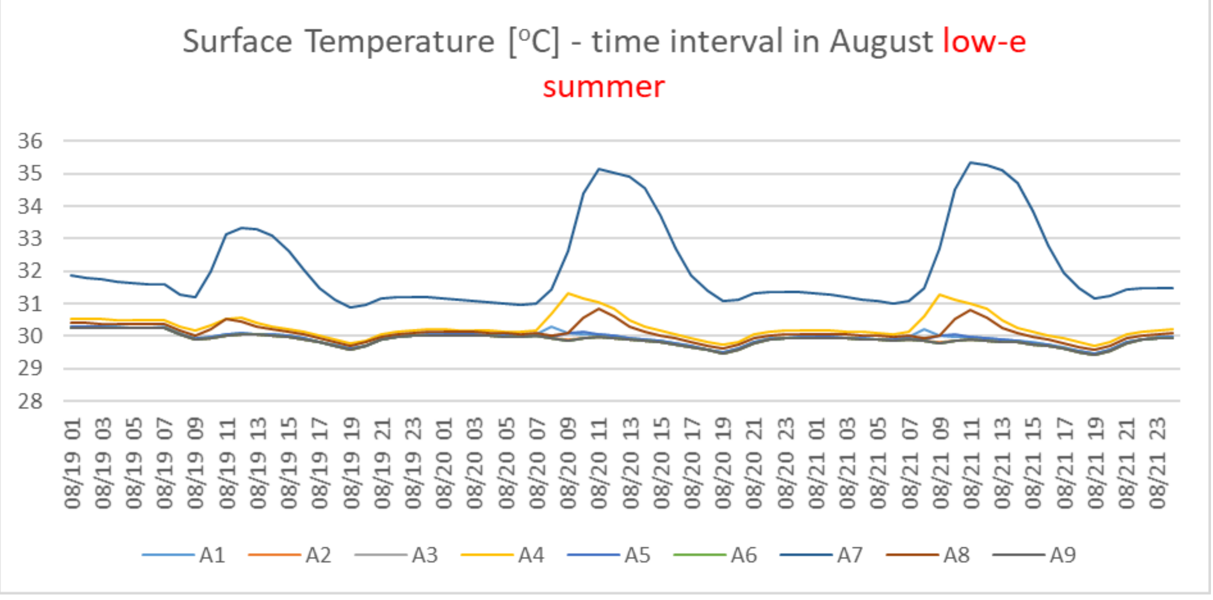

Figure 33: Surface Temperature [°C] – time interval in August – low-e summer glazing

On the contrary, the *reflective* and *absorptive* glazings decrease the surface temperature much more, specifically by *1.8 to 8.6 °C* (Figure 34) and by *1.3 to 7.2 °C* (Figure 35) respectively. In the case of the absorptive glazing, the surface temperature is higher than in the case of the reflective one, because its inner part absorbs more heat and thus warms the inside surfaces by convection. In contrast with the base case, in the case of reflective glazing the surface temperature rises with a time delay of 2 hours in 2 of the 3 days in contrast with the base case.

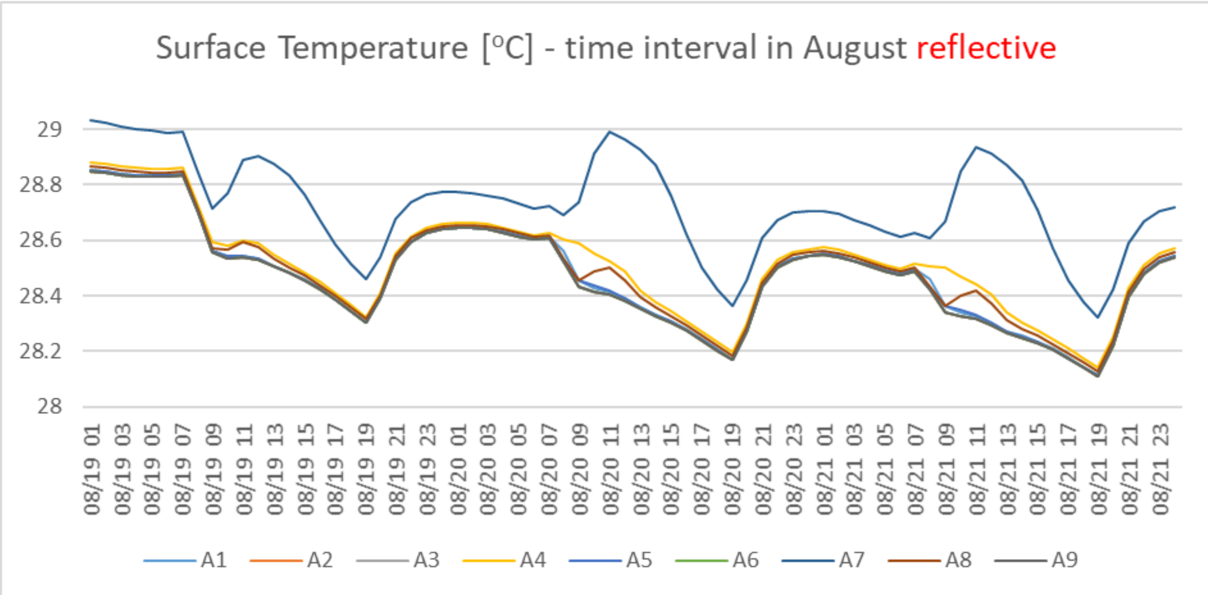

Figure 34: Surface Temperature [°C] – time interval in August – reflective glazing

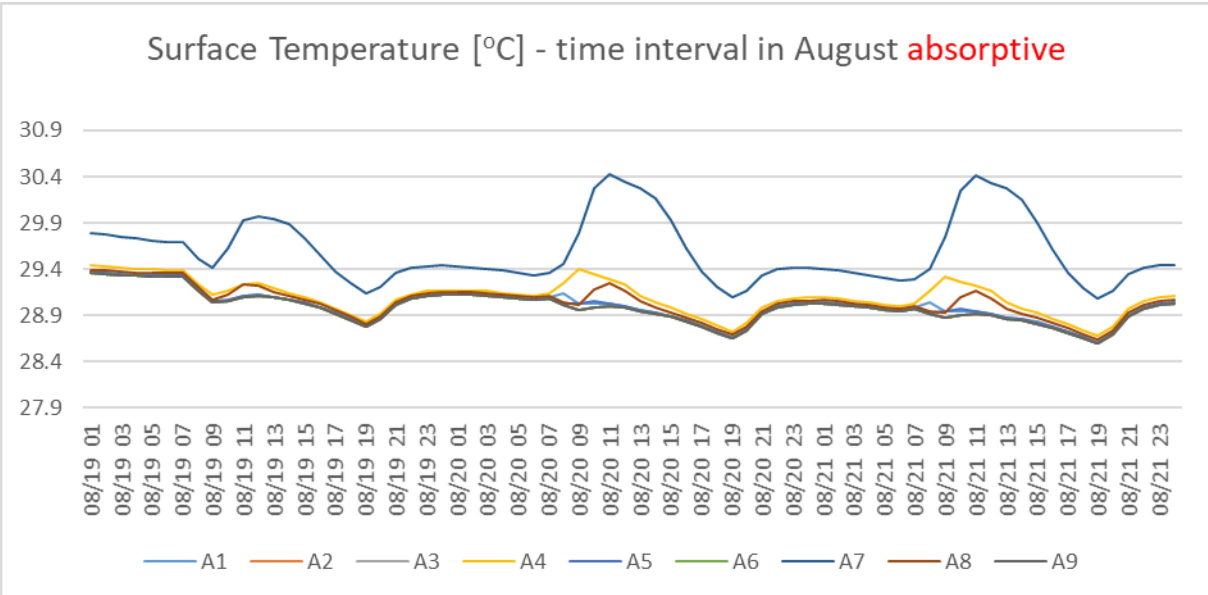

Figure 35: Surface Temperature [°C] – time interval in August – absorptive glazing

b.PMV

In Figure 36 and Figure 37, it is observed that using *low-e winter* and *low-e summer* glazing slightly changes the PMV values and therefore the building remains in category IV.

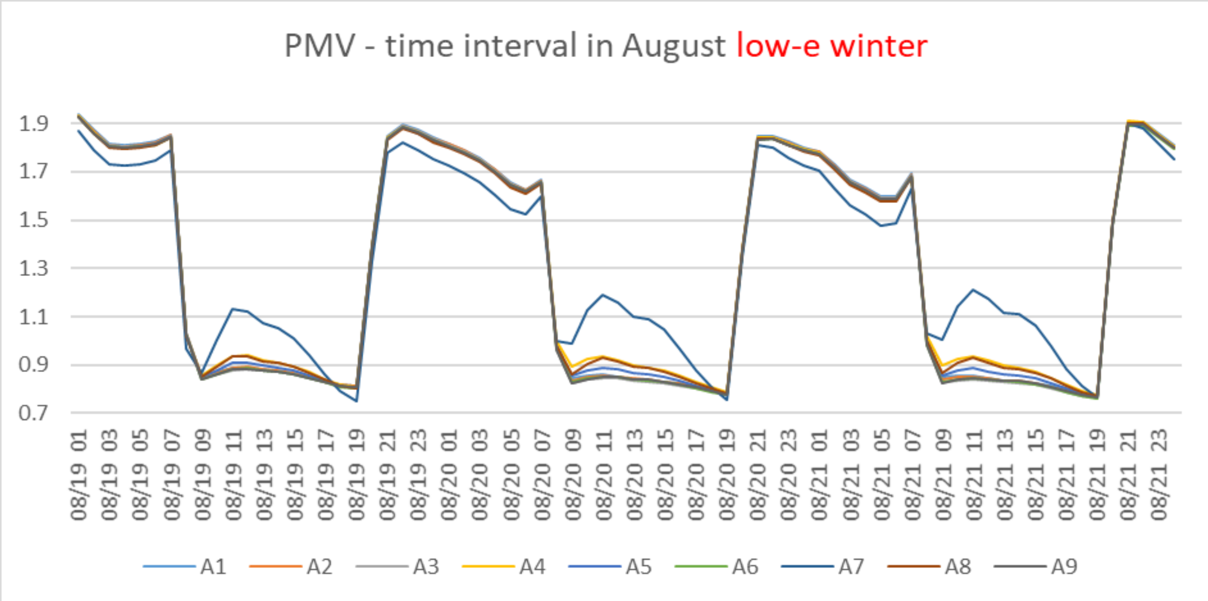

Figure 36: PMV – time interval in August – low-e winter glazing

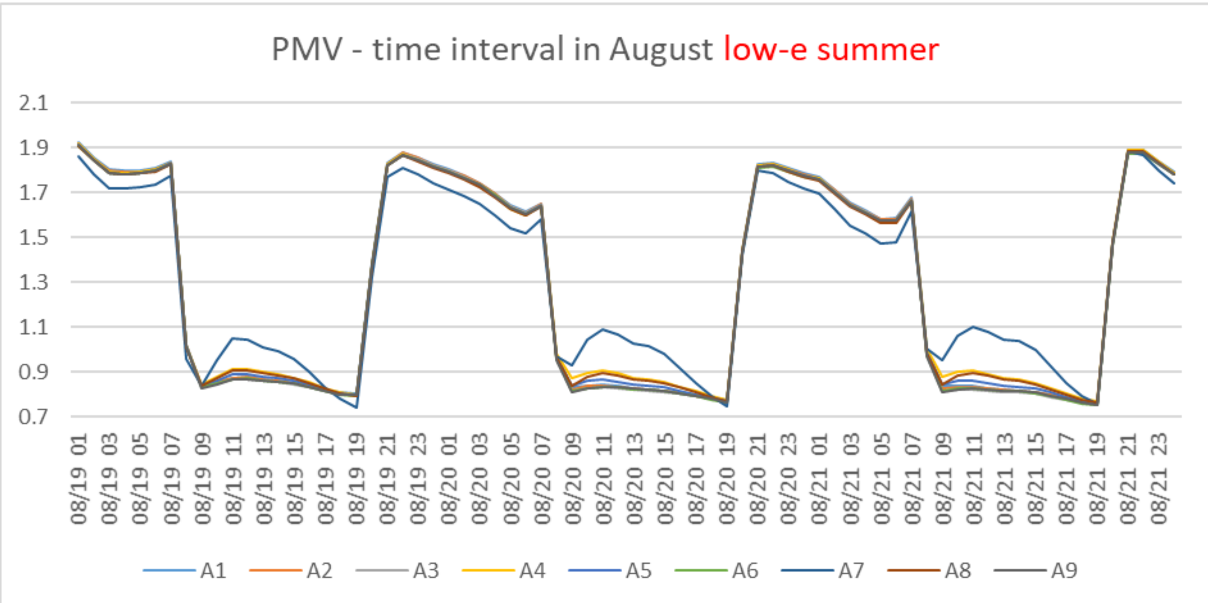

Figure 37: PMV – time interval in August – low-e summer glazing

By omitting surface A7 in August, the above 2 buildings remain in category IV.

From Figure 38 it can be concluded that with the help of reflective glazing the PMV values drop and the building belongs to categories III and IV. The PMV values present a smaller decrease in the case of absorptive glazing and the corresponding building is classified in categories III and IV (Figure 39).

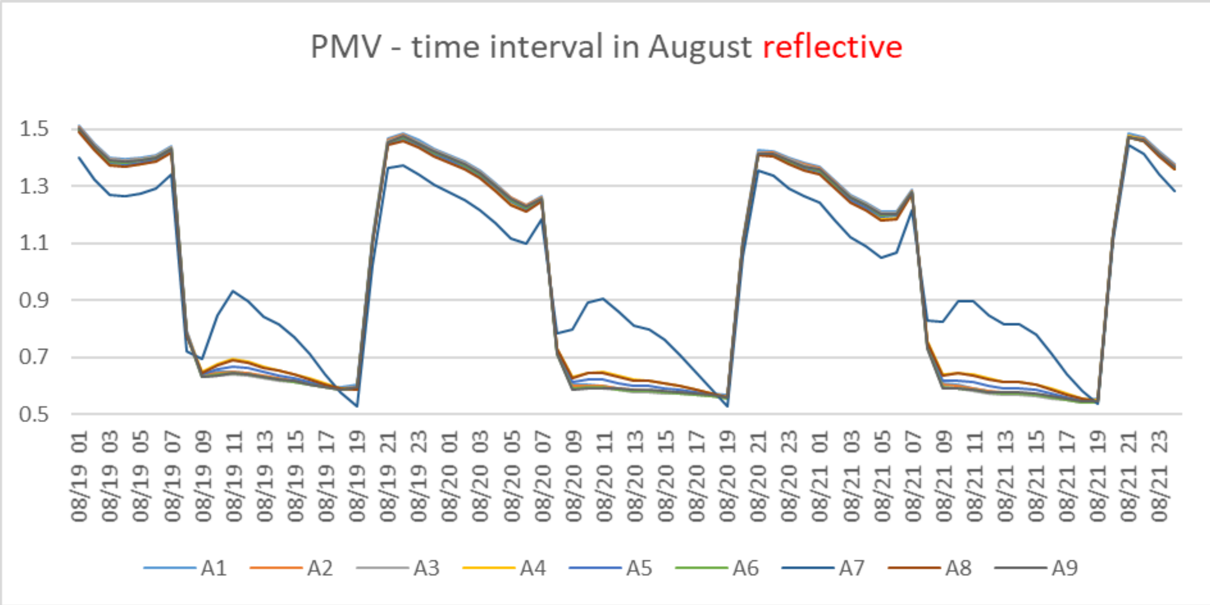

Figure 38: PMV – time interval in August – reflective glazing

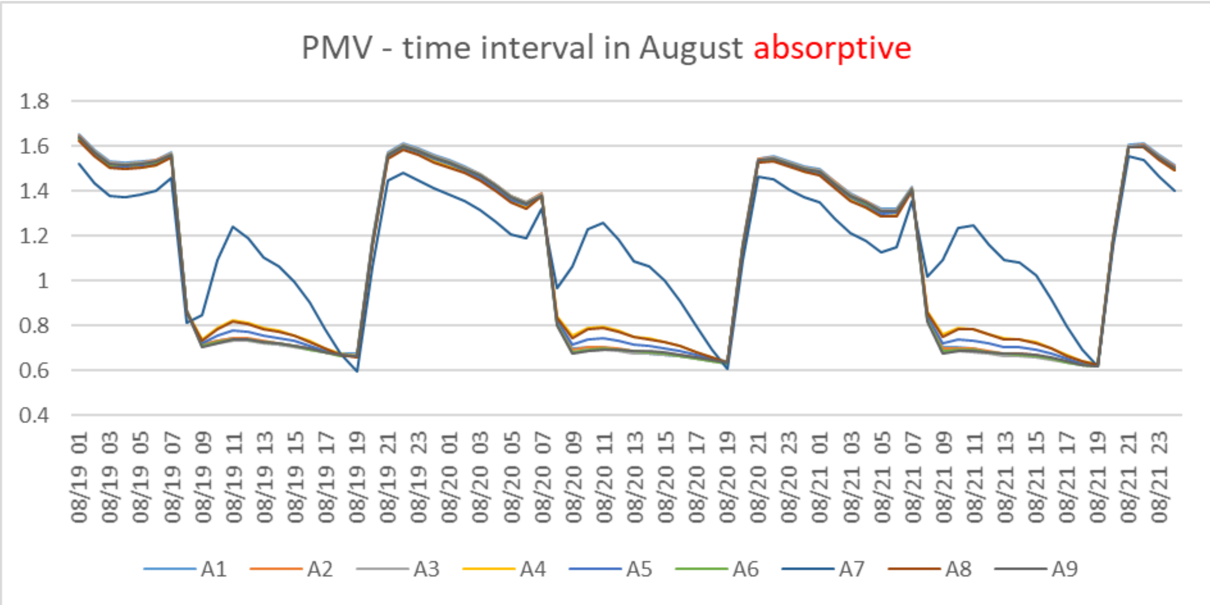

Figure 39 : PMV – time interval in August – absorptive glazing

Skipping surface A7, the reflective glazing restricts the building to category III and the absorptive one keeps it in categories III and IV.

5.1.4 Time interval in October (29/10 – 31/10)

a. Surface temperature

As compared to the base case (clear glazing), both *low-e winter* and *low-e summer* glazing lower the surface temperature by *up to 1.6 °C* (Figure 40) and by *up to 1.8 °C* (Figure 41) respectively. For this period, the low-e winter glazing reduces less the temperature and it is more effective than low-e summer glazing, which allows less solar radiation into the building.

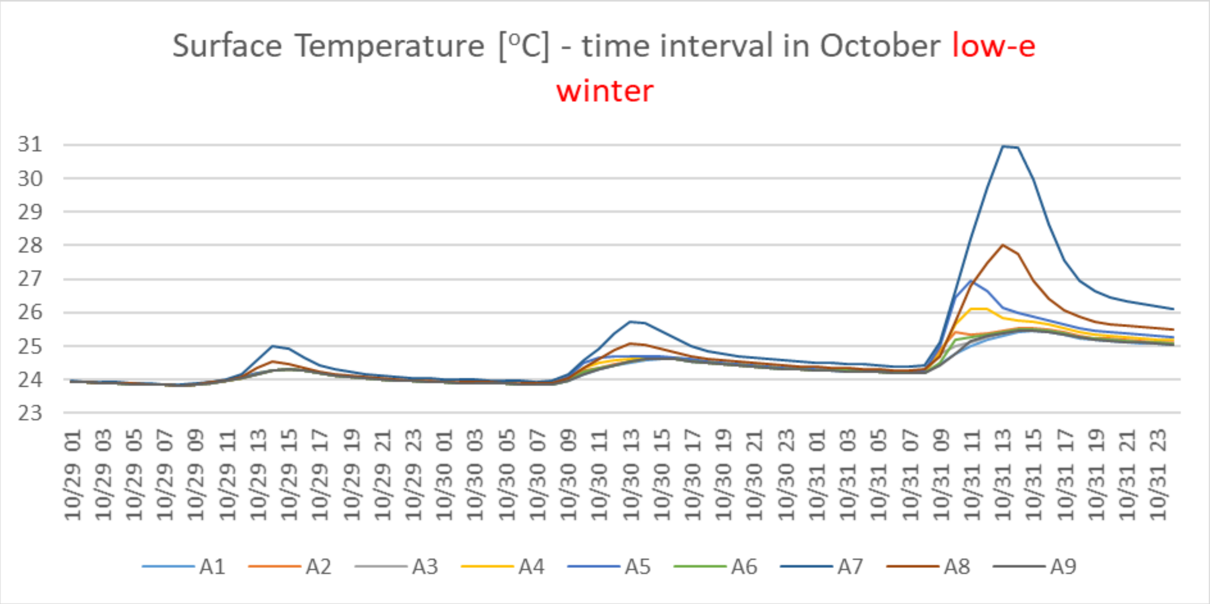

Figure 40: Surface Temperature [°C] – time interval in October – low-e winter glazing

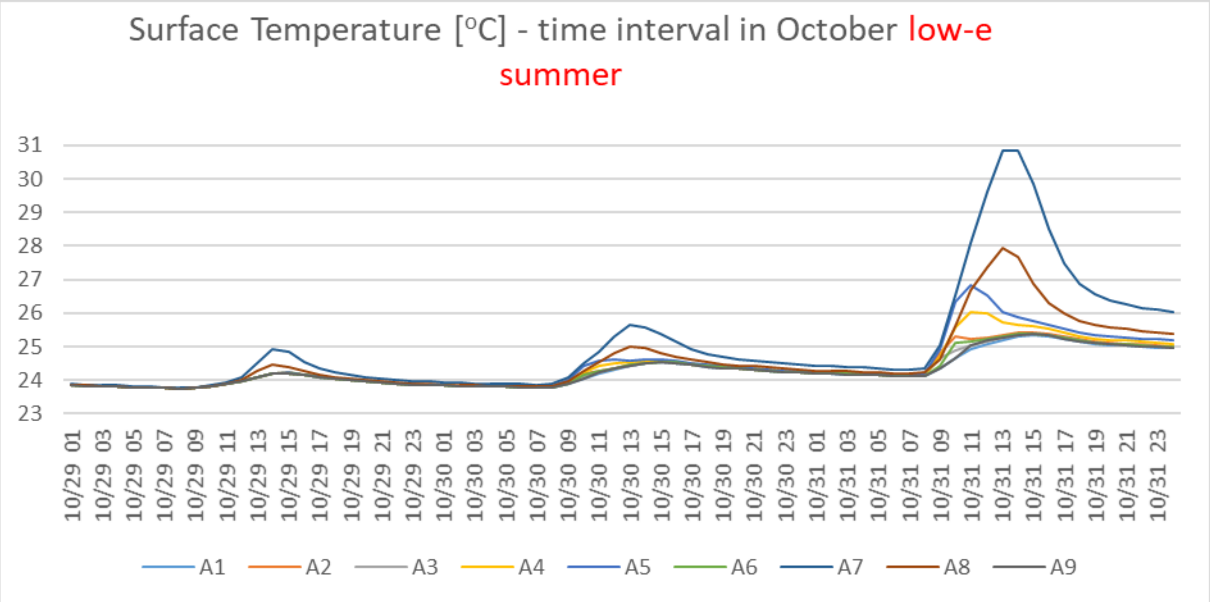

Figure 41: Surface Temperature [°C] – time interval in October – low-e summer glazing

On the other hand, the *reflective* and *absorptive* glazings decrease the surface temperature much more, specifically by *1.8 to 9.2 °C* (Figure 42) and by *1.3 to 7.3 °C* (Figure 43) respectively. In the case of the absorptive glazing, the surface temperature is higher than in the case of the reflective one, because its inner part absorbs more heat and thus warms the inside surfaces by convection.

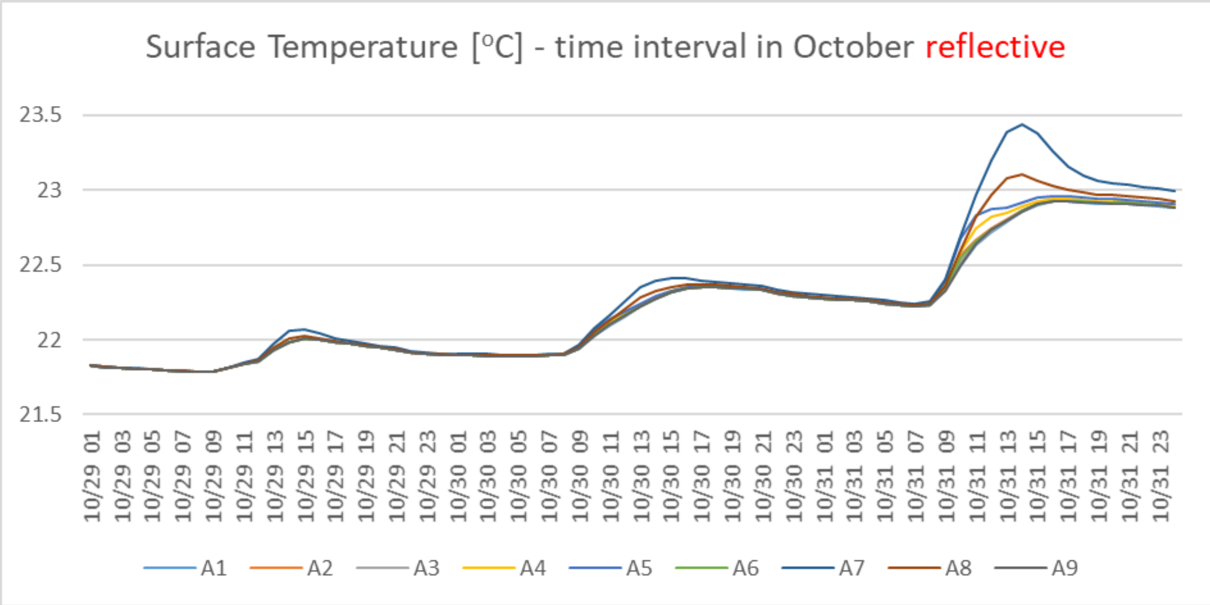

Figure 42: Surface Temperature [°C] – time interval in October – reflective glazing

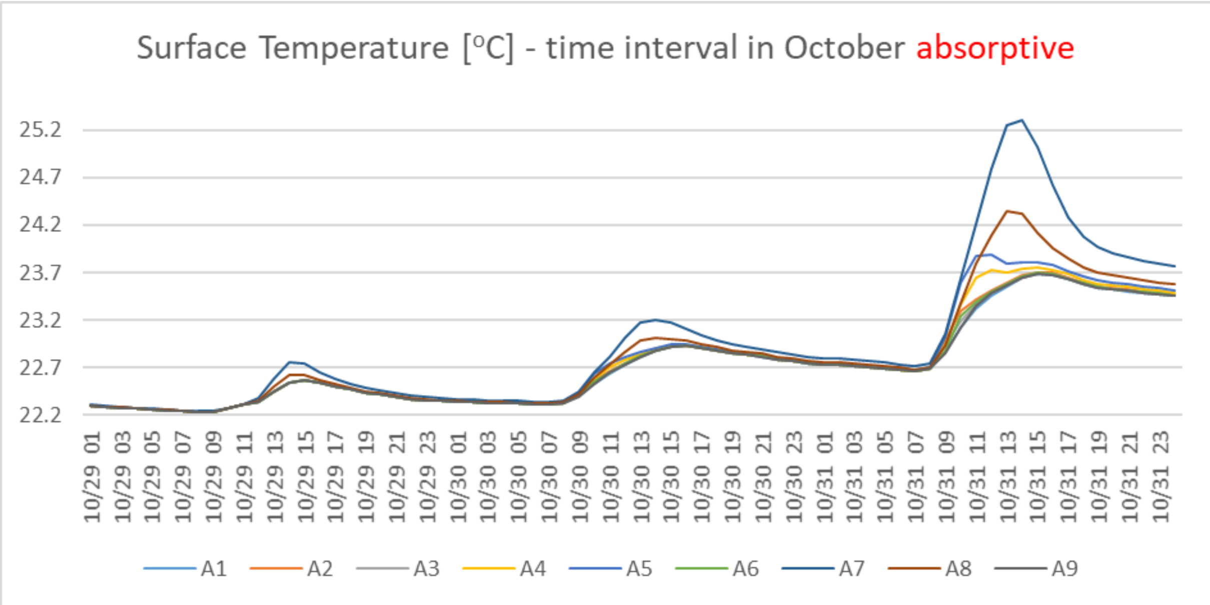

Figure 43: Surface Temperature [°C] – time interval in October – absorptive glazing

b.PMV

In Figure 44 and Figure 45, it is observed that using *low-e winter* and *low-e summer* glazing increases the PMV values and consequently the building does not belong to category II but to III and IV.

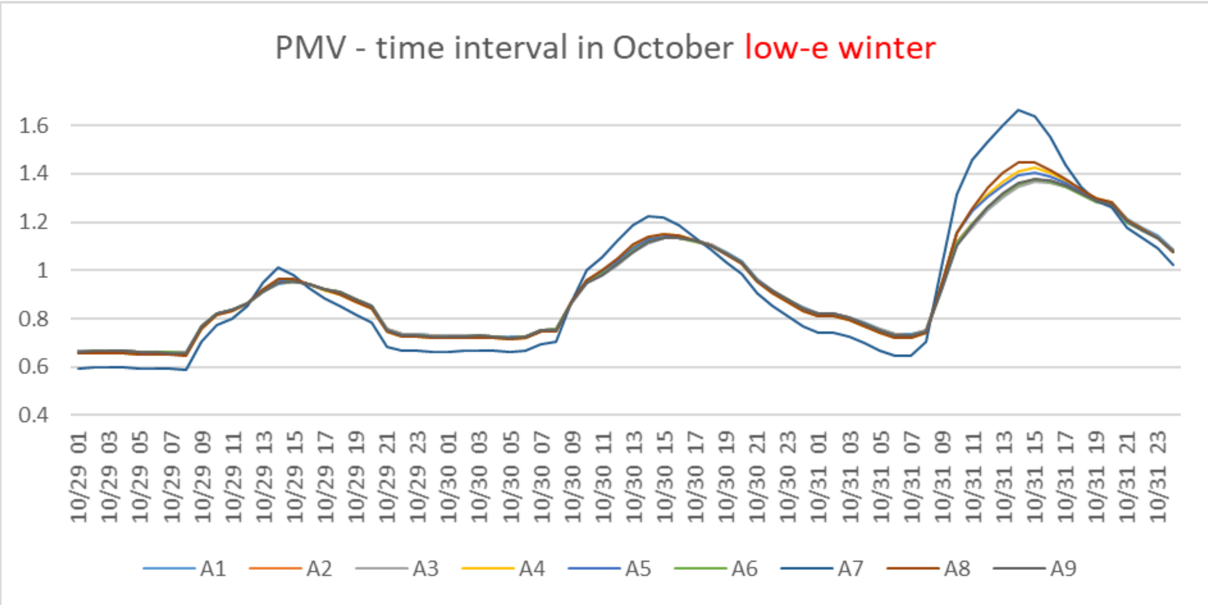

Figure 44: PMV – time interval in October – low-e winter glazing

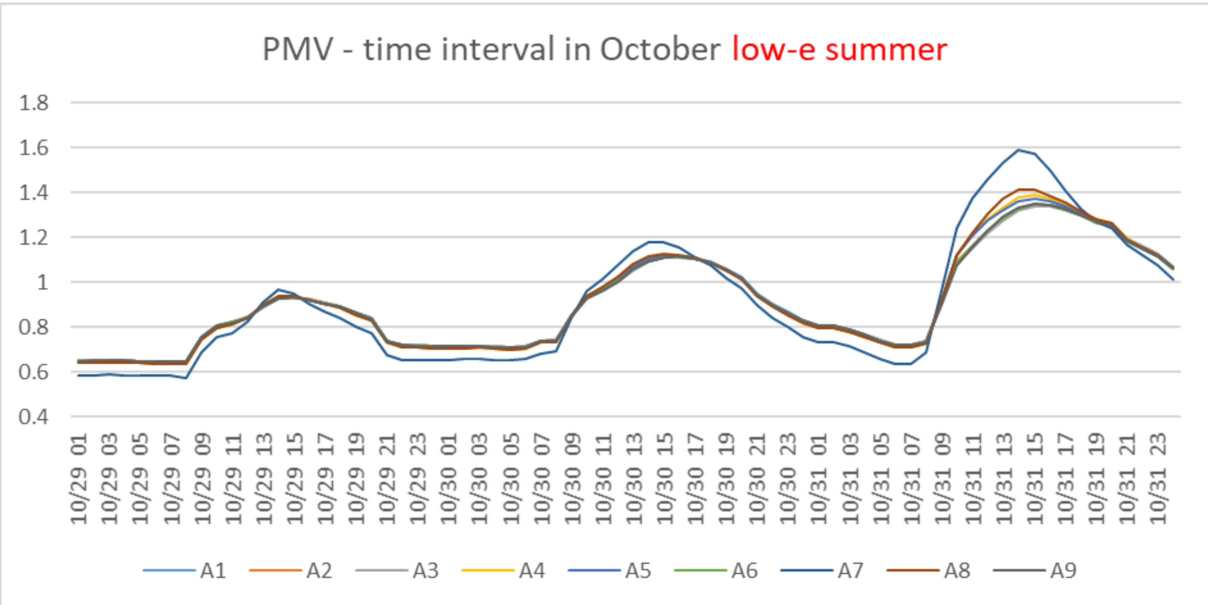

Figure 45: PMV – time interval in October – low-e summer glazing

Precluding surface A7, in these 2 cases the building is limited to category IV.

Figure 46 and Figure 47 show that the use of *reflective* and *absorptive* glazing decreases the PMV values, but the building remains in categories II, III and IV.

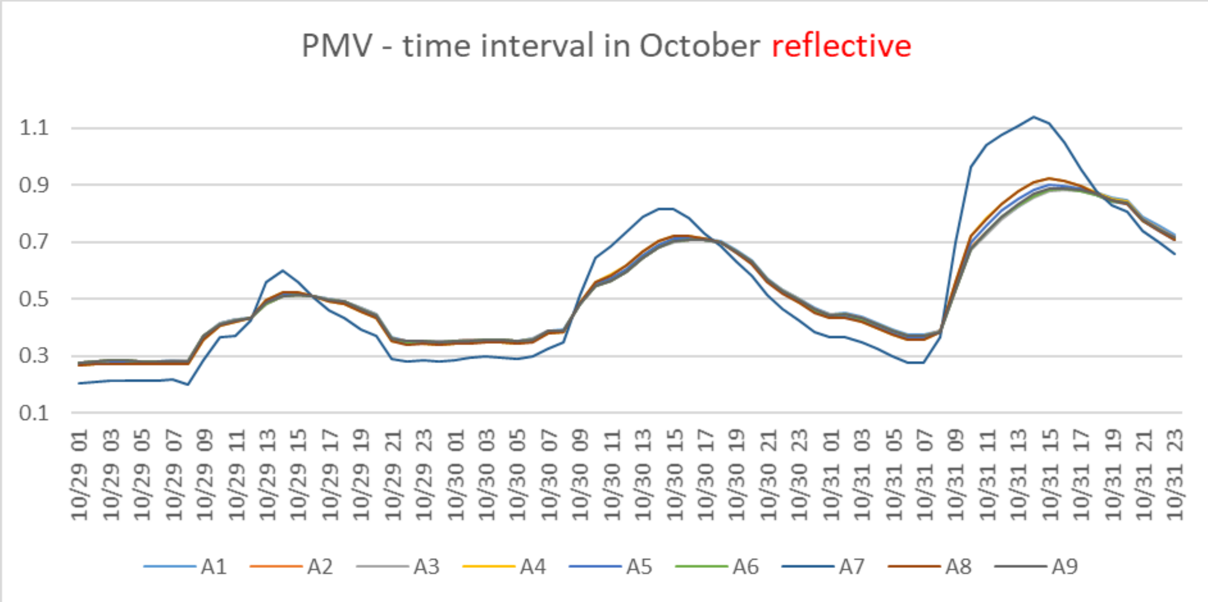

Figure 46: PMV – time interval in October – reflective glazing

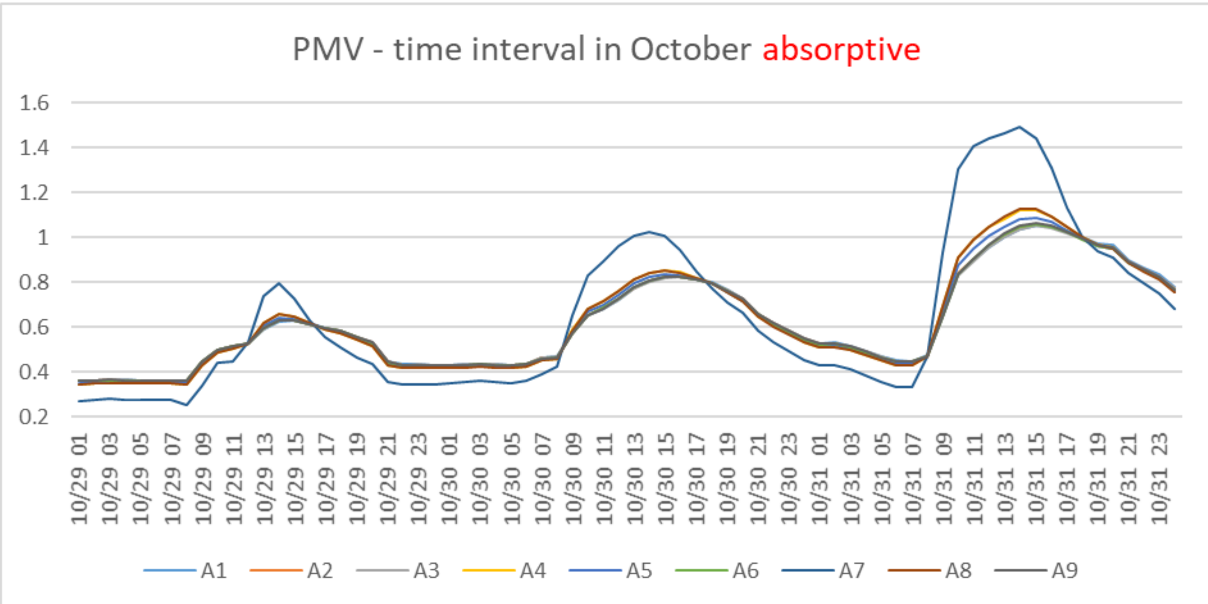

Figure 47: PMV – time interval in October – absorptive glazing

By excluding surface A7 the building with either reflective or absorptive glazing remains in categories II, III and IV.

5.1.5 Time interval in December (26/12 – 28/12)

a. Surface temperature

As compared to the base case, both *low-e winter* and *low-e summer* glazing lower the surface temperature by *up to 1 °C* (Figure 48, Figure 49). For this period, the low-e summer glazing should have reduced more the temperature than the low-e winter glazing since it allows less solar radiation into the building.

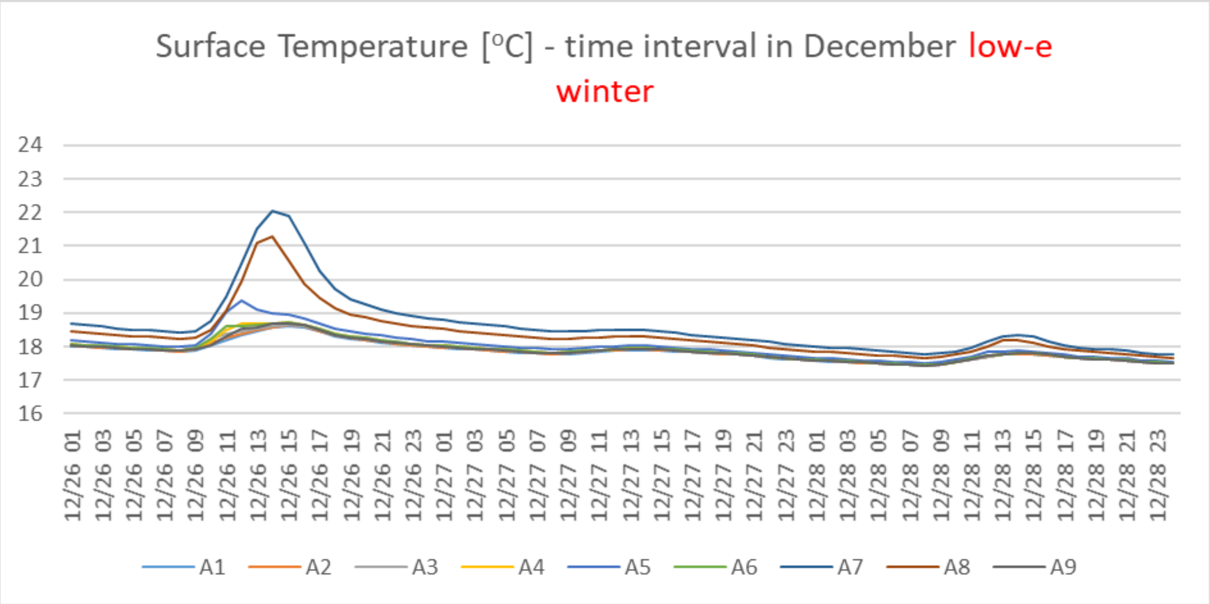

Figure 48: Surface Temperature [°C] – time interval in December – low-e winter glazing

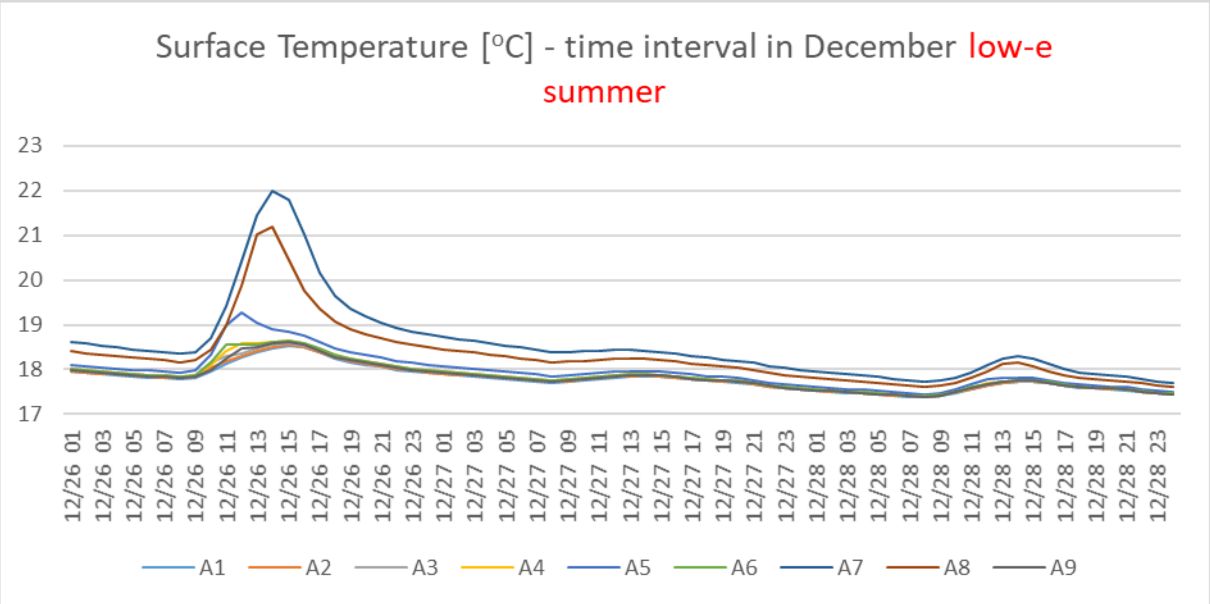

Figure 49: Surface Temperature [°C] – time interval in December – low-e summer glazing

As opposed to the other glazings, the *reflective* and *absorptive* ones decrease the surface temperature much more, specifically by *0.9 to 5.7 °C* (Figure 50) and by *0.7 to 4.7 °C* (Figure 51) respectively. In the case of the absorptive glazing, the surface temperature is higher than in the case of the reflective one, because its inner part absorbs more heat and thus warms the inside surfaces by convection.

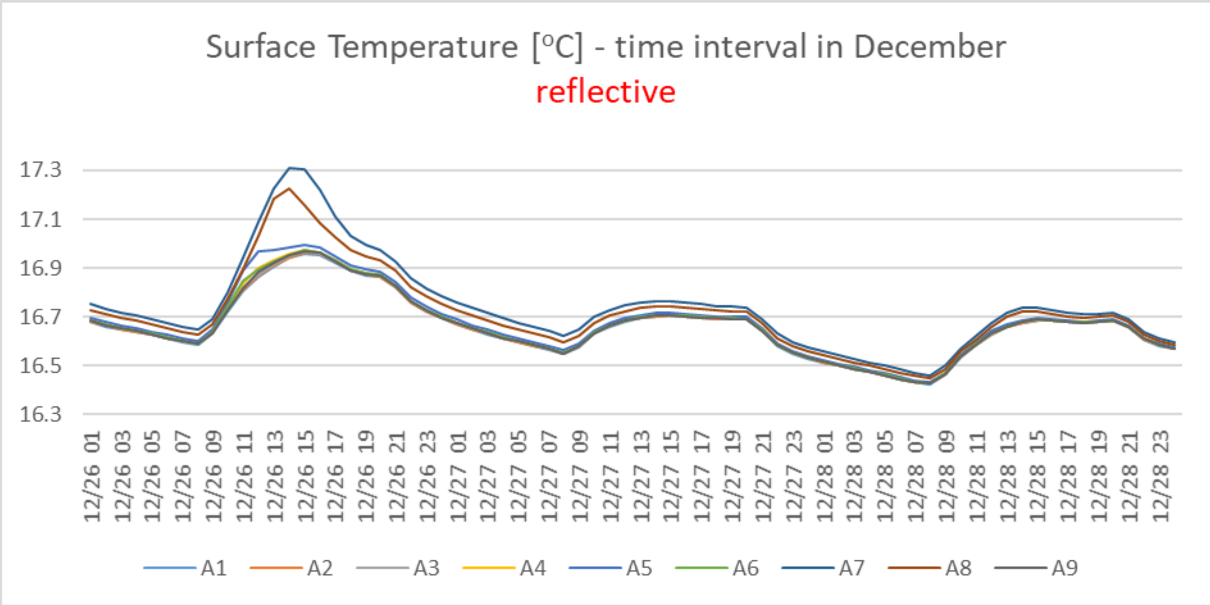

Figure 50: Surface Temperature [°C] – time interval in December – reflective glazing

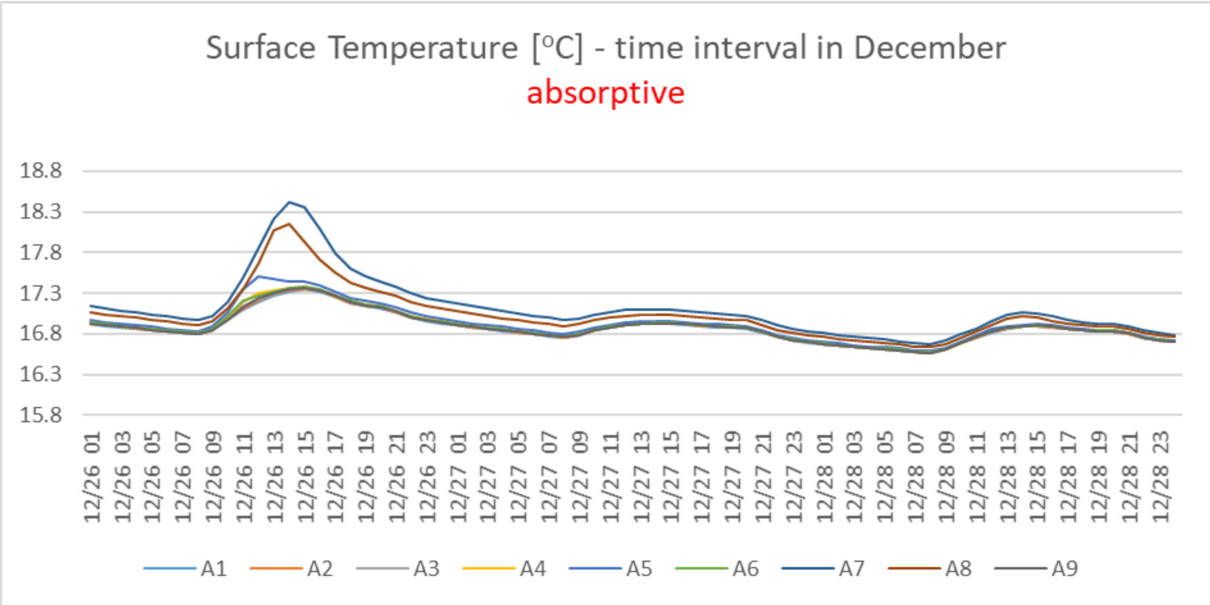

Figure 51: Surface Temperature [°C] – time interval in December – absorptive glazing

b.PMV

In Figure 52 and Figure 53, it is shown that the use of low-e winter and low-e summer glazing has almost no effect on the PMV values and therefore the building remains in categories II, III and IV.

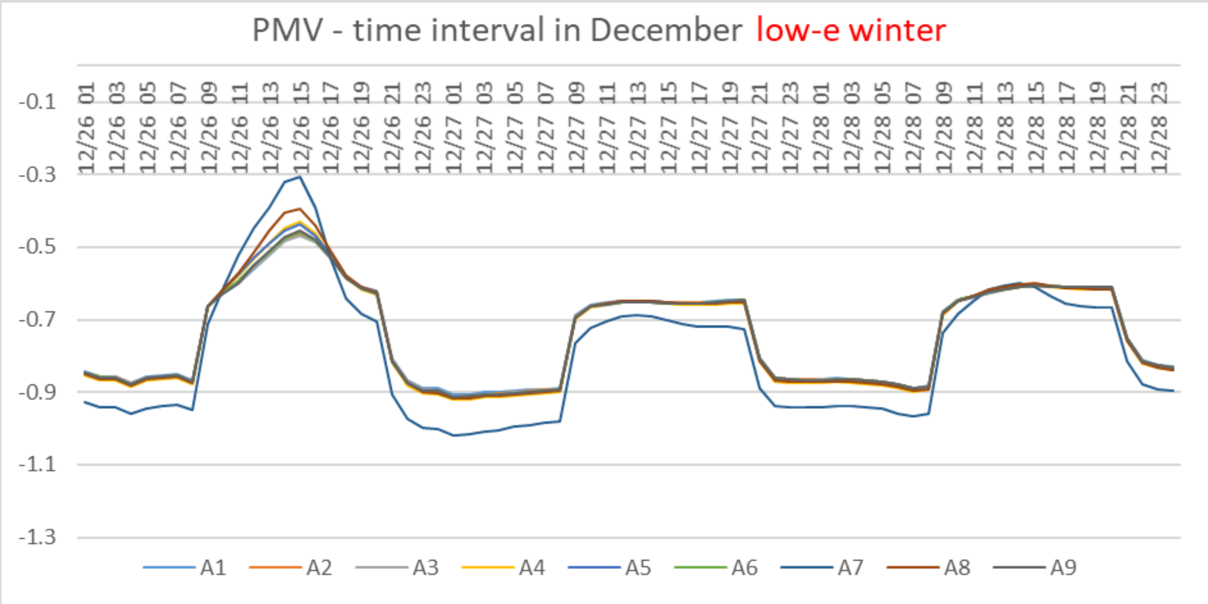

Figure 52: PMV – time interval in December – low-e winter glazing

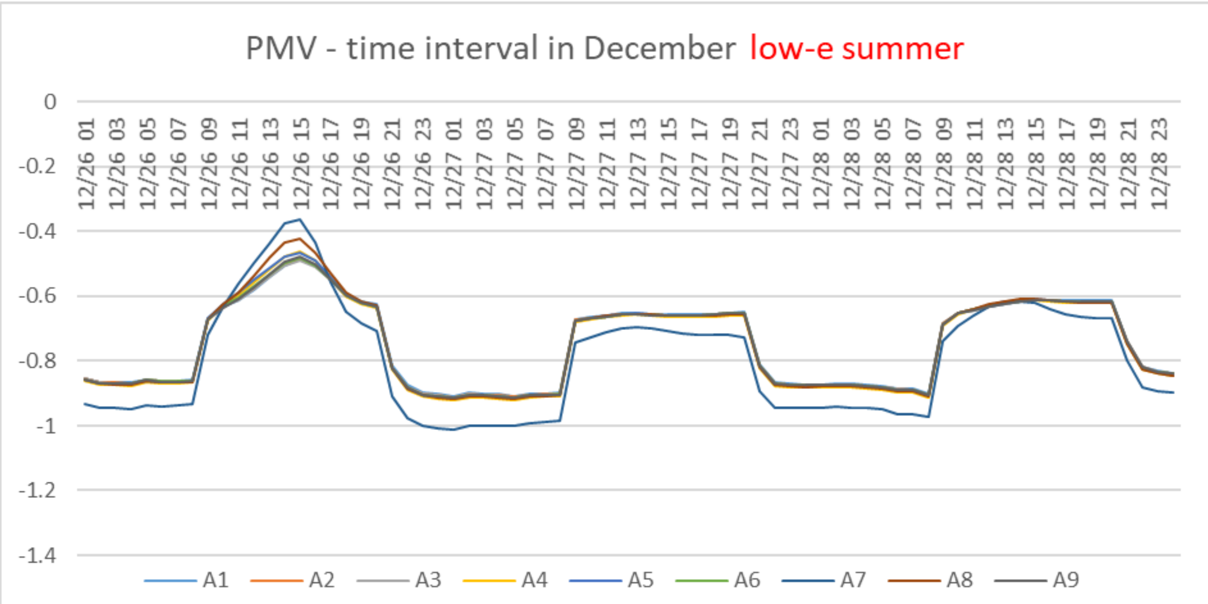

Figure 53: PMV – time interval in December – low-e summer glazing

The omission of surface A7 affects the above 2 buildings by restricting them to categories II and III.

From Figure 54 it can be deduced that the reflective glazing hardly alters the PMV values and the building doesn't belong to category II but to III and IV. The PMV values present a marginal decrease in the case of absorptive glazing and the corresponding building remains in categories II, III and IV (Figure 55).

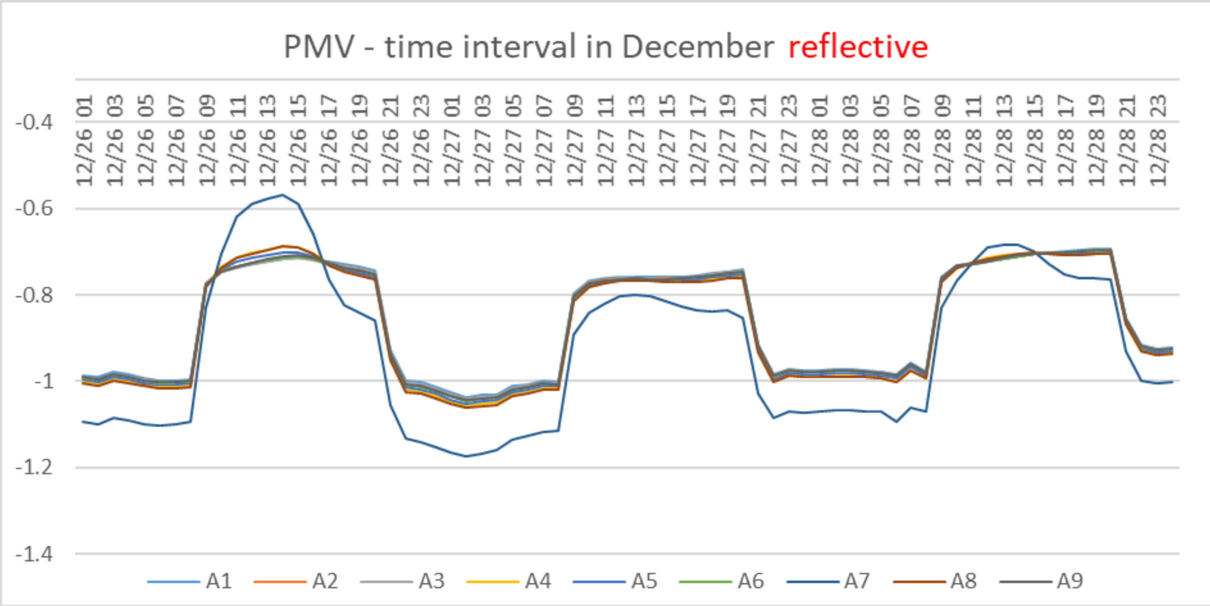

Figure 54: PMV – time interval in December – reflective glazing

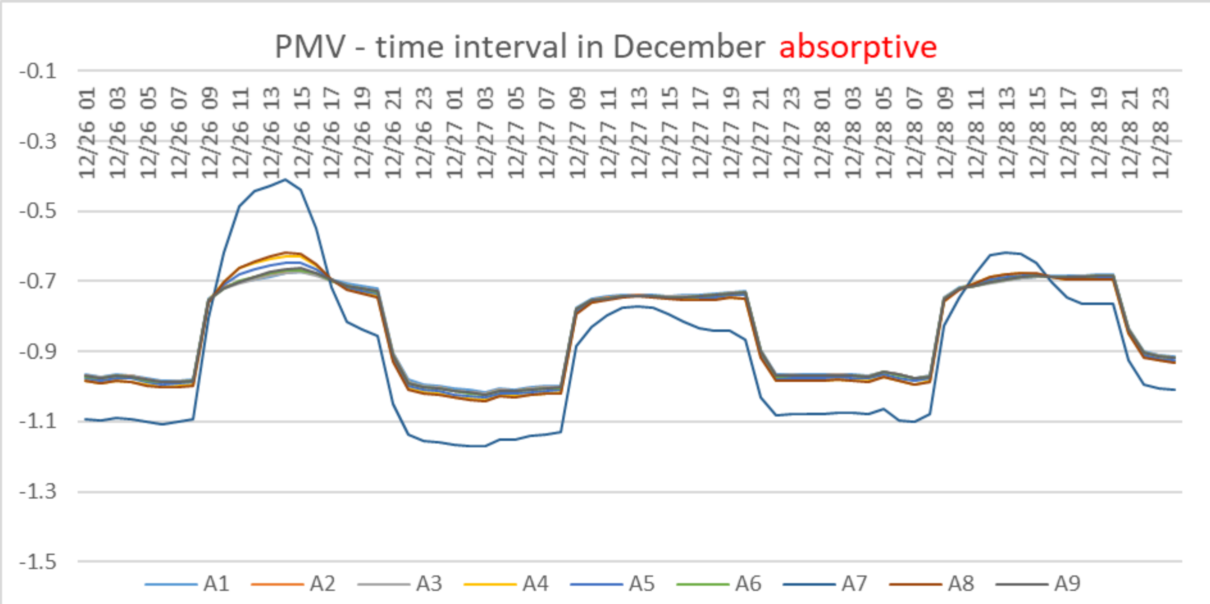

Figure 55: PMV – time interval in December – absorptive glazing

With the exclusion of surface A7, the building with reflective glazing doesn't change category and the building with absorptive glazing belongs to categories III and IV.

5.2 Lightweight construction

In this subchapter, the simulation results of the building with *lightweight construction* are presented for each time interval and kind of glazing. Every case is compared to the *base case*, in which the building's glazings are *clear*.

5.2.1 Clear glazing (base case)

In the following charts the temperature and PMV values of surfaces A1-A9 and their variation in each time interval (April, August, October, December) are depicted.

In Figure 56 it is observed that the surface temperature fluctuates from 25.9 to 30.3 ^{o}C and Figure 57 shows that the PMV value varies from 0.72 to 1.53, which means that as far as the thermal environment is concerned the building belongs to category IV according to the standard EN1521:2007.

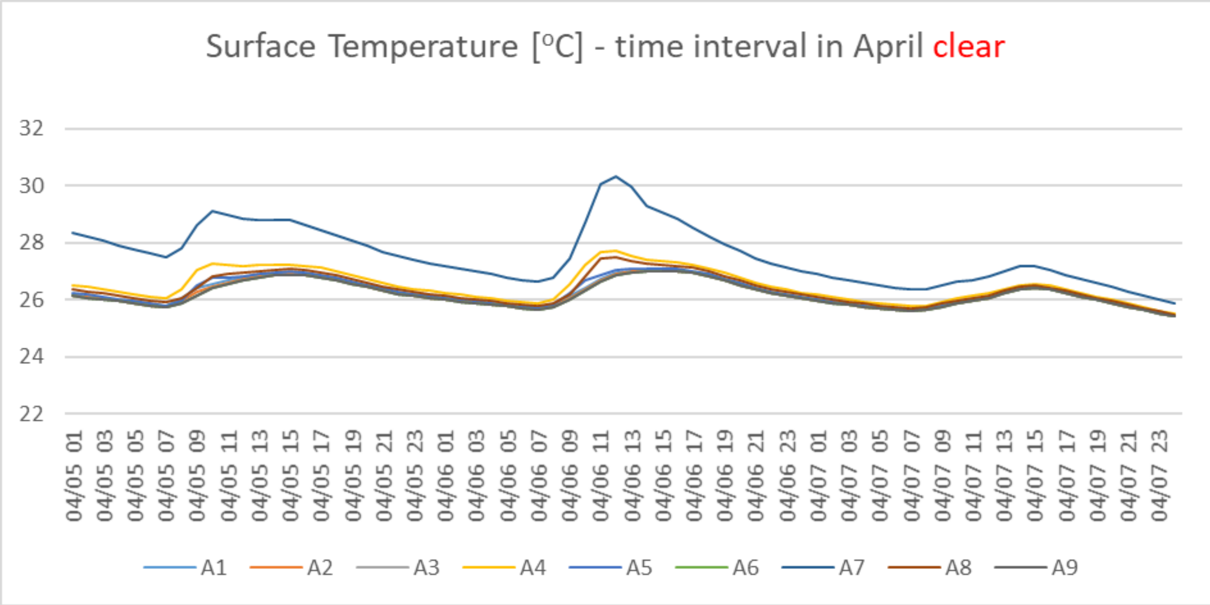

Figure 56: Surface Temperature [°C] – time interval in April – clear glazing

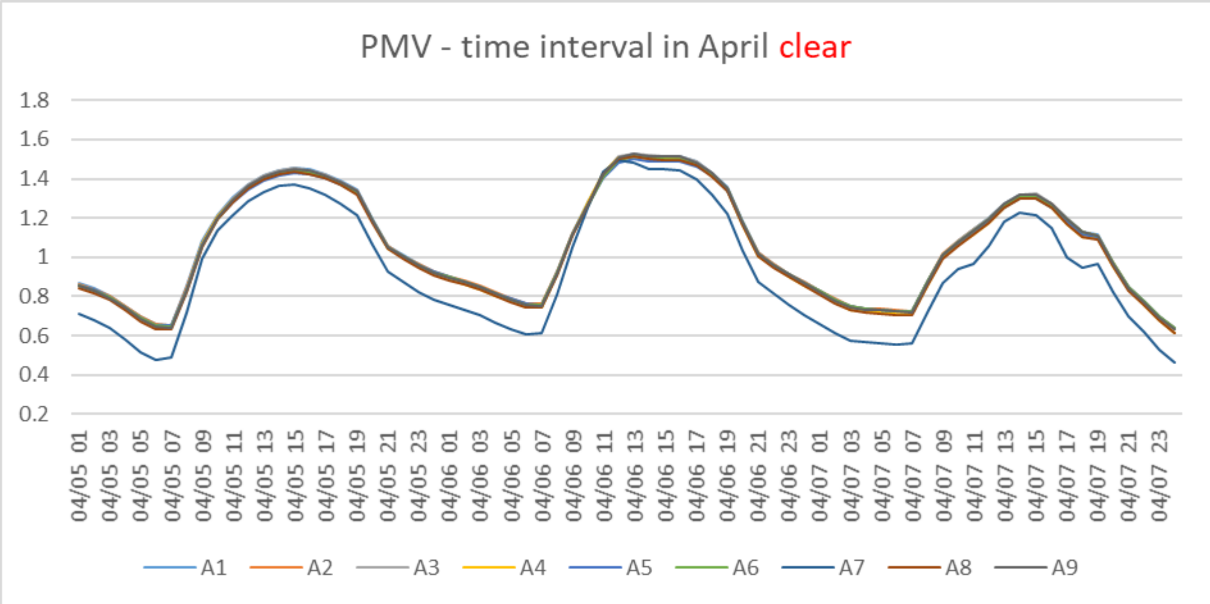

Figure 57: PMV – time interval in April – clear glazing

In August (Figure 58) surfaces *A7, A4, A8, A1* have the four *highest temperatures* in descending order. Apart from surface A1, the same happens in April (Figure 56), since the solar path is the same for April and August. In contrast to April, the surface temperature rises overall and has a range from 29.7 to 37.5 °C. PMV values for the same period (Figure 59) are higher than 0.72 concluding that the building is in category IV.

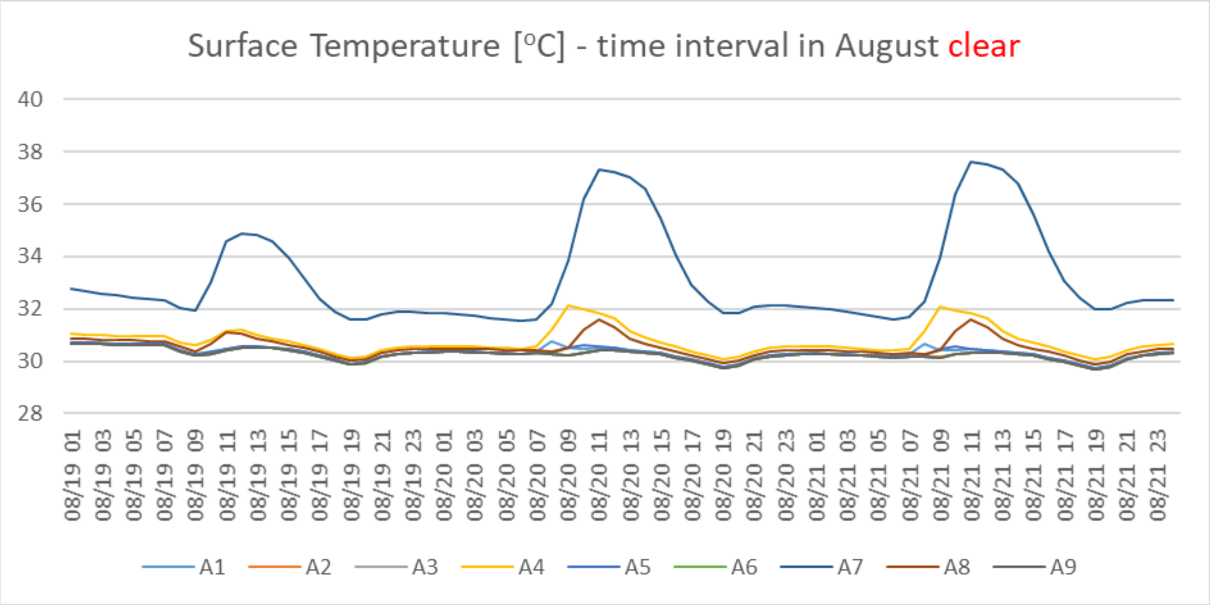

Figure 58: Surface Temperature [°C] – time interval in August – clear glazing

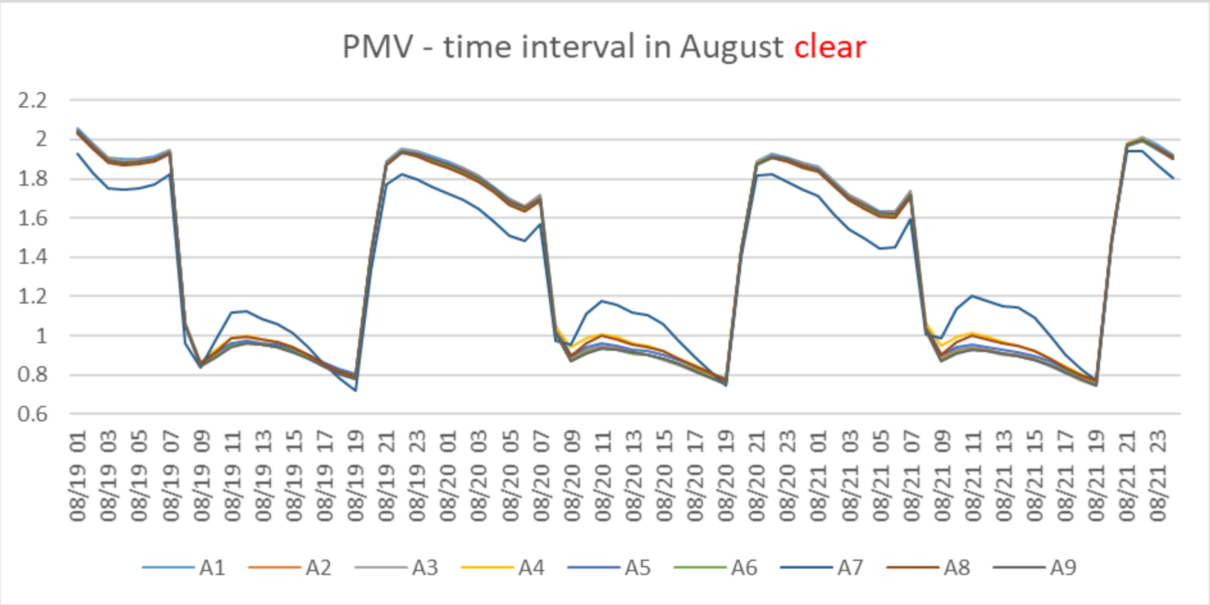

Figure 59: PMV – time interval in August – clear glazing

In October's time interval (Figure 60) surfaces *A7, A8, A5 and A4* hold the four highest temperatures. In this case, sun warms surface A4 less than A8 and A5 due to the fact that October's solar path is much smaller than April's. Throughout this period the surface temperature fluctuates in a wider range of 23 to 32.9 ºC. Respective PMV values (Figure 61) diversify from 0.36 to 1.82 deducing that the building can be in one of categories II, III and IV.

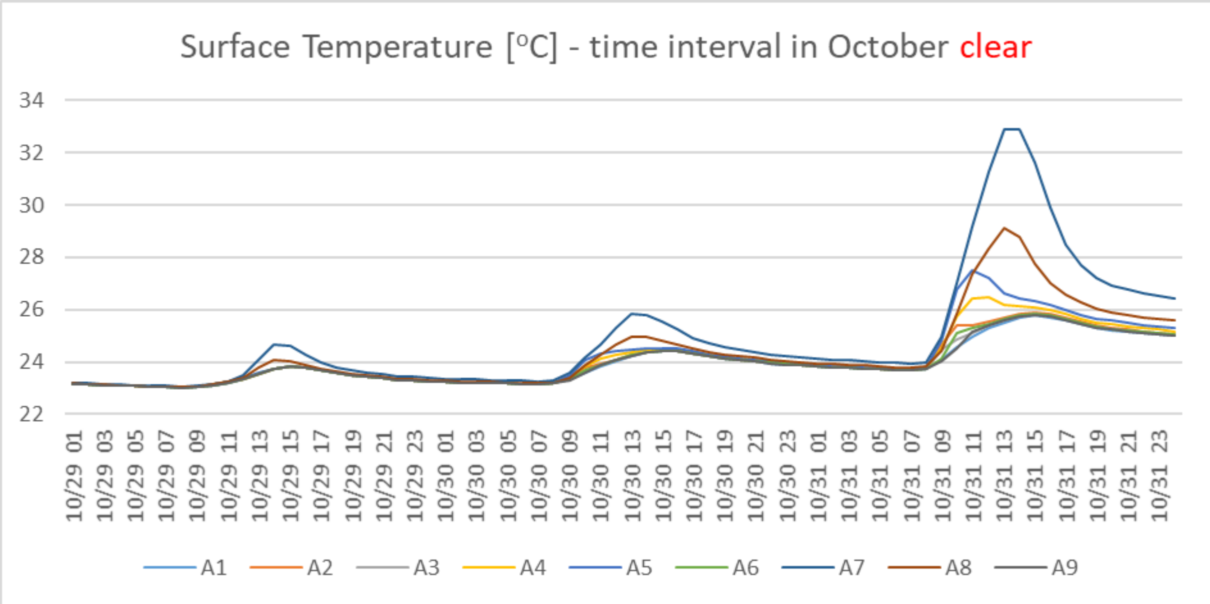

Figure 60: Surface Temperature [ºC] – time interval in October – clear glazing

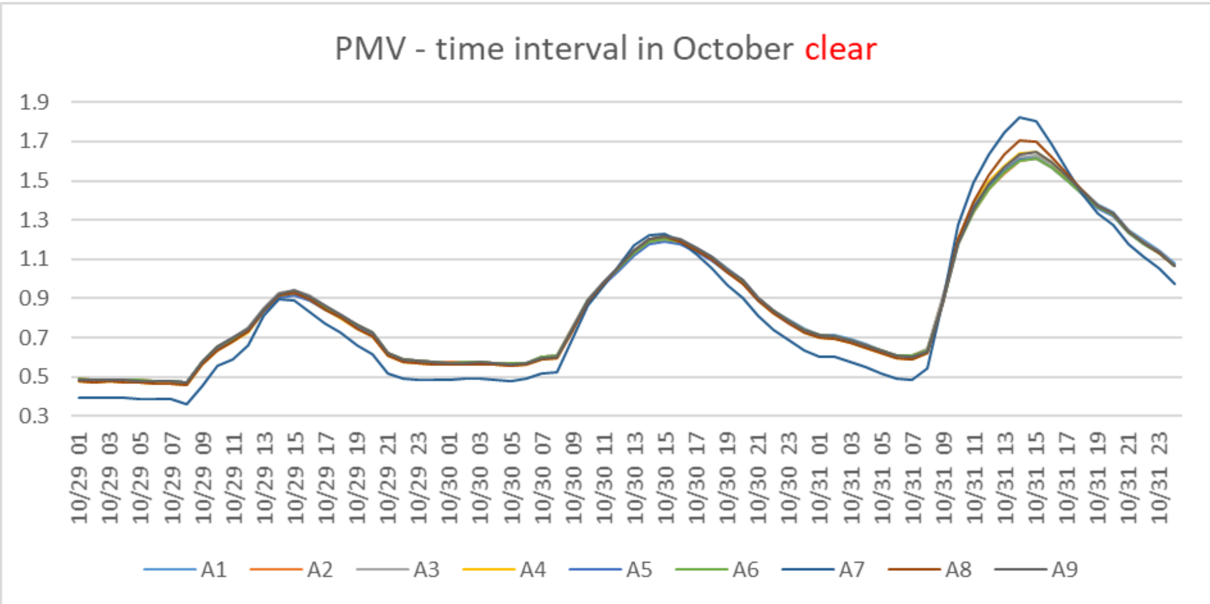

Figure 61: PMV – time interval in October – clear glazing

In addition to October, surfaces *A7, A8, A5 and A4* have the four *highest temperatures* in December (Figure 62). As can be seen in Figure 62 the surface temperature drops and ranges from 17.3 to 23.3 °C. In Figure 63 PMV presents a maximum value of -0.3 and a minimum value of -1.03, therefore classifying the building to categories II, III and IV.

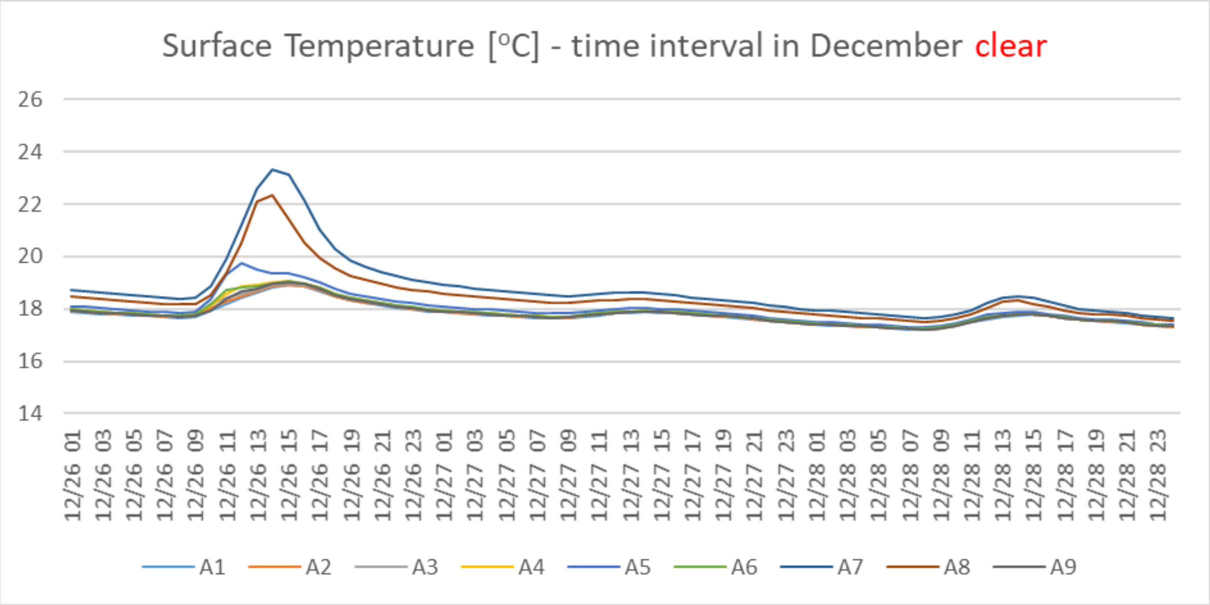

Figure 62: Surface Temperature [°C] – time interval in December– clear glazing

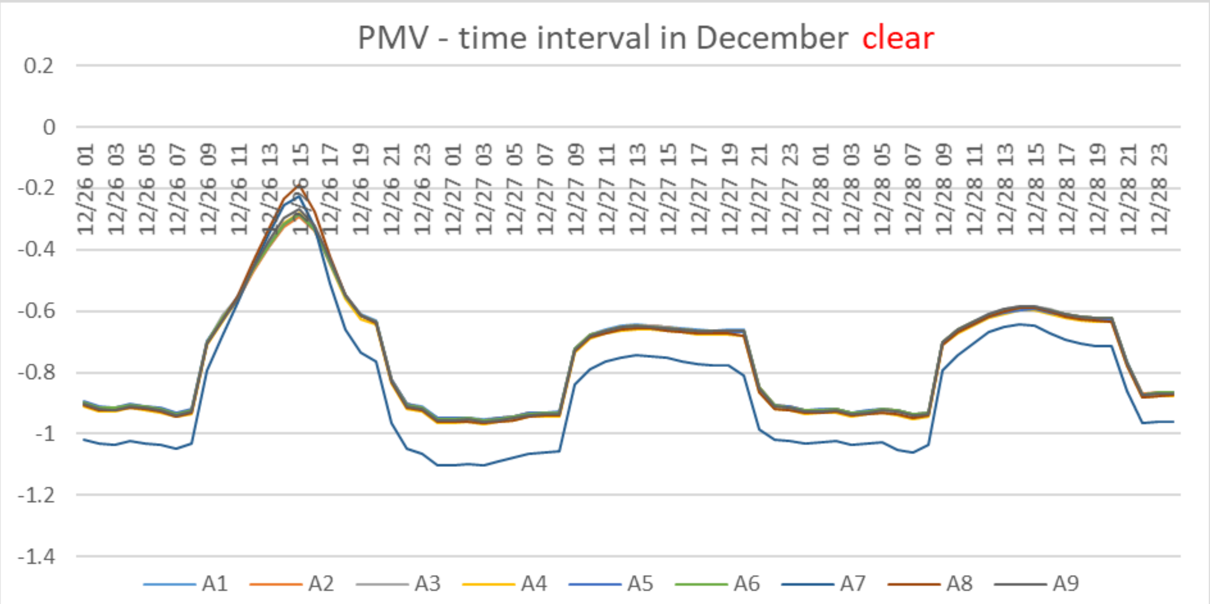

Figure 63: PMV – time interval in December – clear glazing

5.2.2 Time interval in April (05/04 – 07/04)

a. Surface temperature

As compared to the base case (clear glazing), both *low-e winter* and *low-e summer* glazing lower the surface temperature by *0.1 to 1.1 °C* (Figure 64) and by *0.3 to 1.3 °C* (Figure 65) respectively. For this period, the low-e winter glazing reduces less the temperature and it is more effective than low-e summer glazing, which allows less solar radiation into the building.

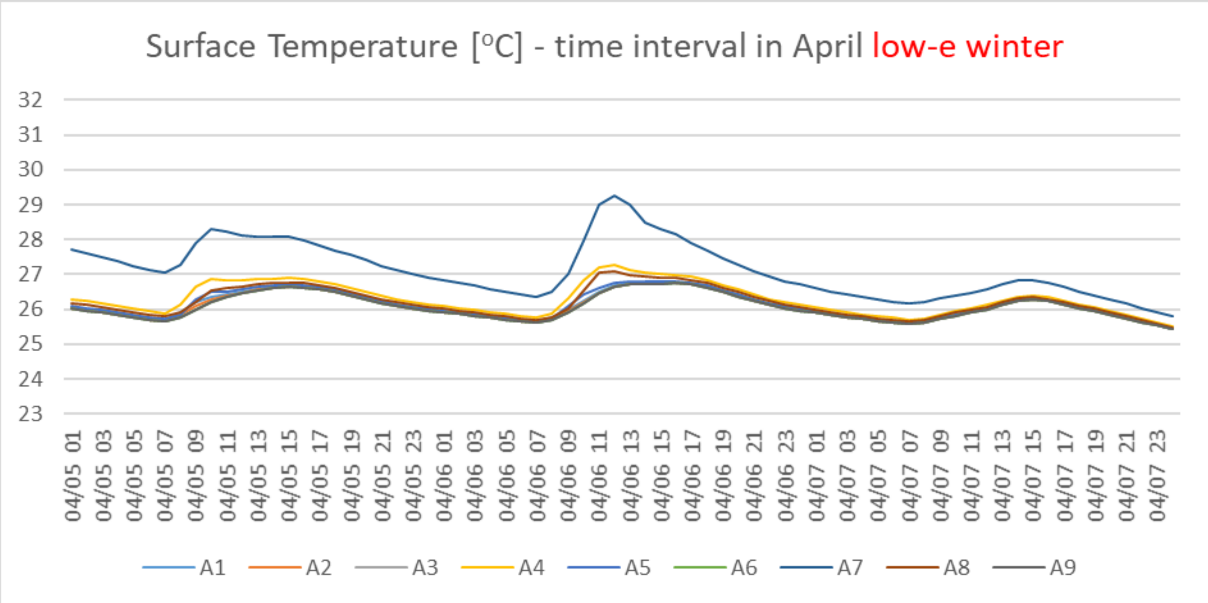

Figure 64: Surface Temperature [°C] – time interval in April – low-e winter glazing

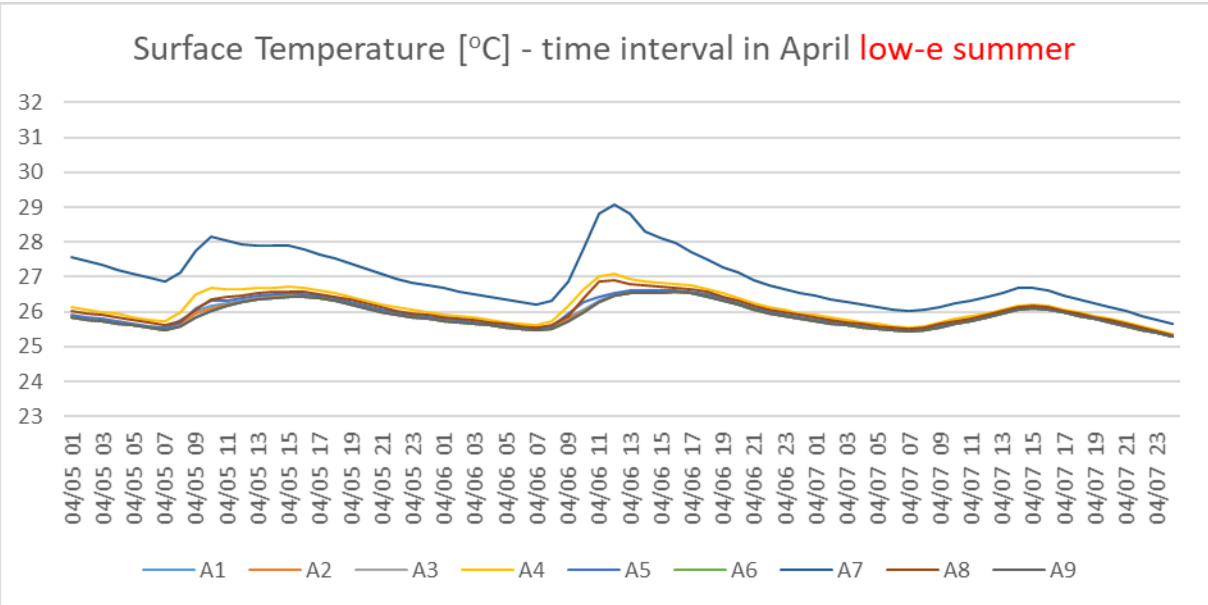

Figure 65: Surface Temperature [°C] – time interval in April – low-e summer glazing

As opposed to the other glazings, the *reflective* and *absorptive* ones decrease the surface temperature much more, specifically by *3.6 to 7.2 °C* (Figure 66) and by *2.5 to 5.6 °C* (Figure 67) respectively. In the case of the absorptive glazing, the surface temperature is higher than in the case of the reflective one, because its inner part absorbs more heat and thus warms the inside surfaces by convection. Furthermore, by using reflective glazing the surface temperature presents a slower rise in 2 of the 3 days in contrast with the base case.

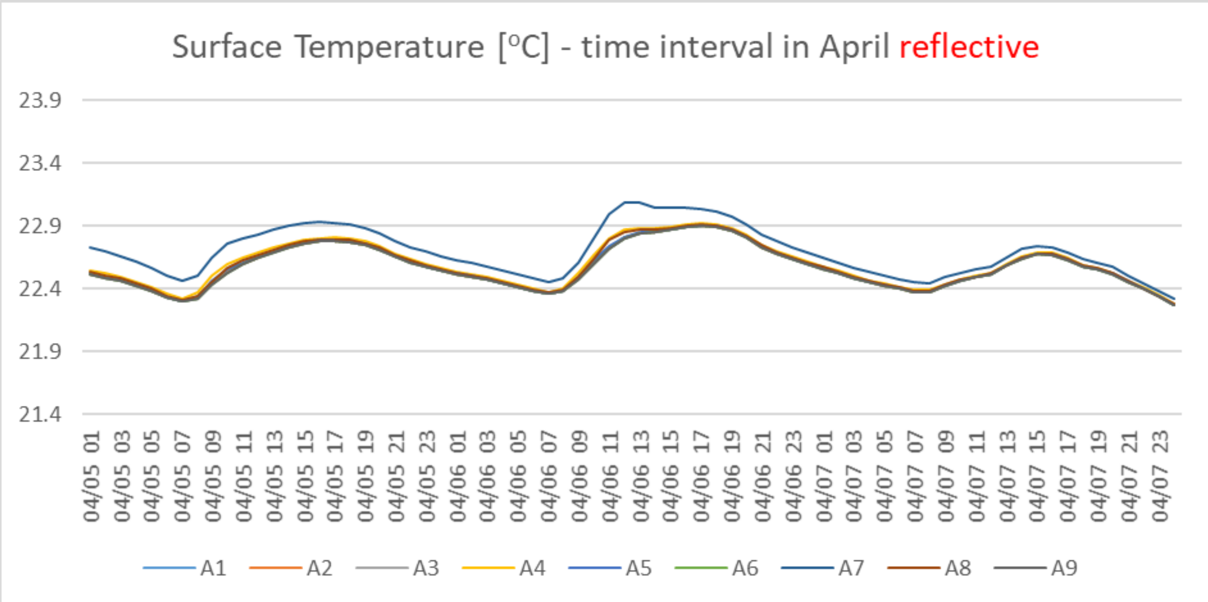

Figure 66: Surface Temperature [°C] – time interval in April – reflective glazing

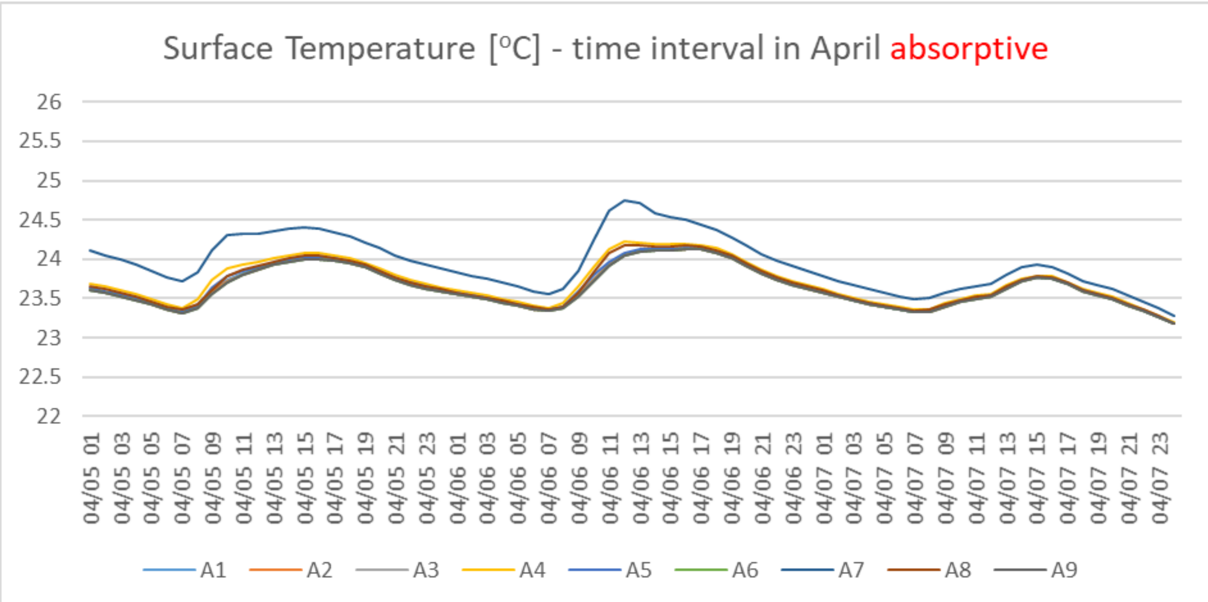

Figure 67: Surface Temperature [°C] – time interval in April – absorptive glazing

b.PMV

In Figure 68 and Figure 69, it is shown that the use of low-e winter and low-e summer glazing has almost no effect on the PMV values and therefore the building remains in category IV.

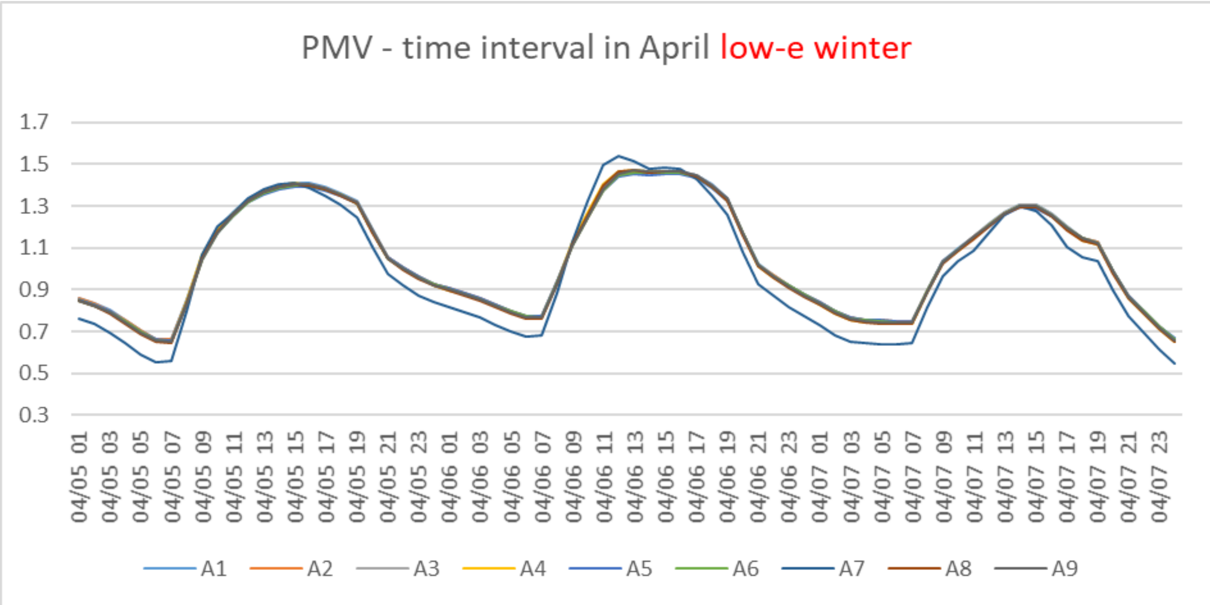

Figure 68: PMV – time interval in April – low-e winter glazing

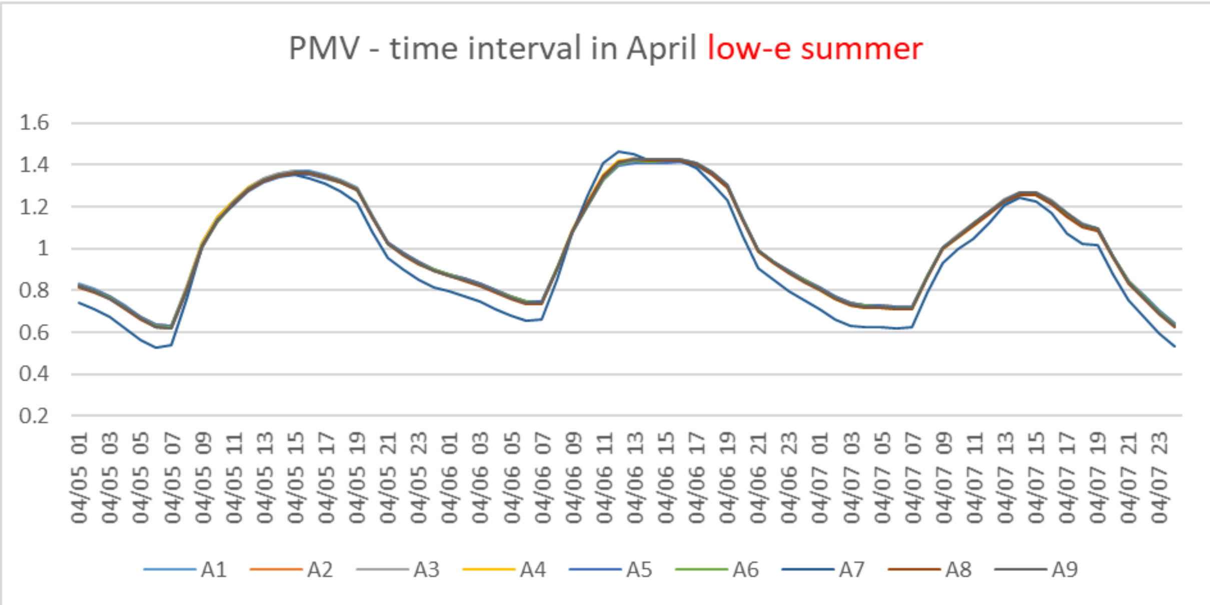

Figure 69: PMV – time interval in April – low-e summer glazing

By skipping surface A7, which is the most heated one, in the above 2 cases the building remains in category IV.

From Figure 70 it can be deduced that by using the reflective glazing the PMV values drop and the building shifts to categories I, II, III and IV. The PMV values present a smaller decrease in the case of absorptive glazing and the corresponding building belongs to categories II, III and IV (Figure 71).

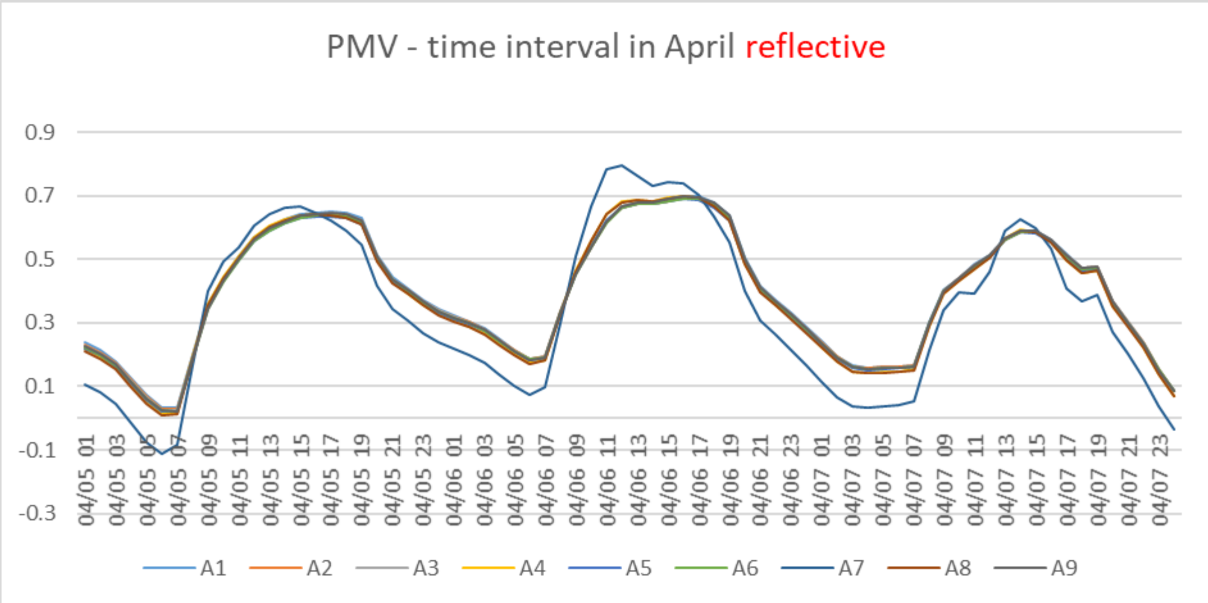

Figure 70: PMV – time interval in April – reflective glazing

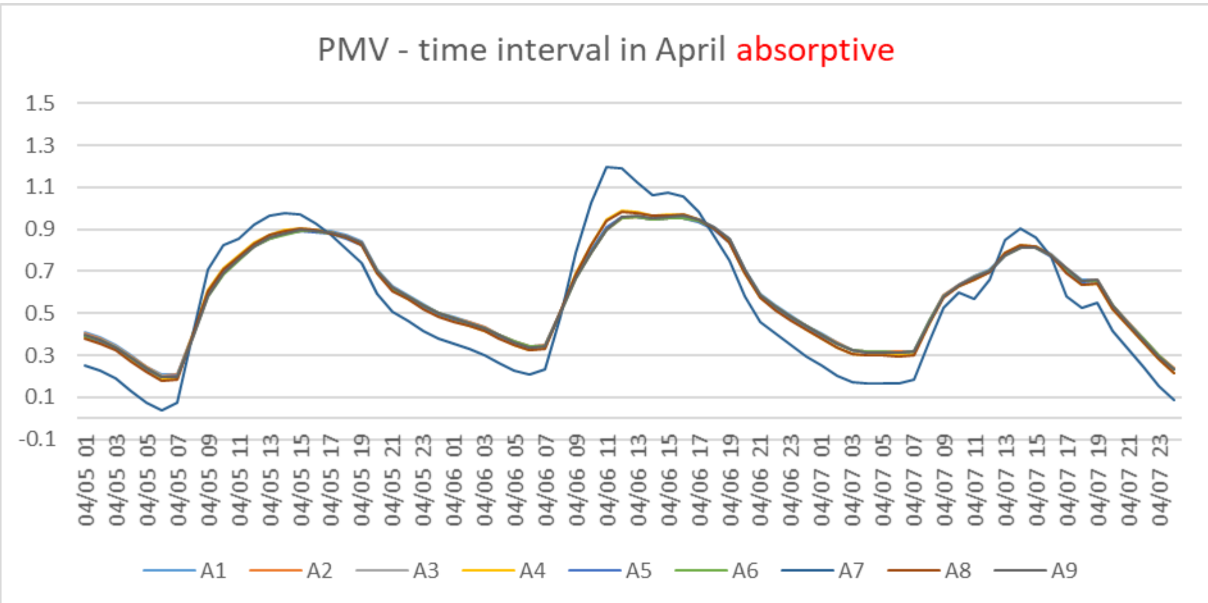

Figure 71: PMV – time interval in April – absorptive glazing

Exempting surface A7, which is the most heated one, the building with reflective glazing is classified to categories II and III. On the other hand, in the building with absorptive glazing remains in categories II, III and IV.

5.2.3 Time interval in August (19/08 – 21/08)

a. Surface temperature

As opposed to the base case (clear glazing), the *low-e winter* and *low-e summer* glazing reduce the surface temperature by *0.3 to 2 °C* (Figure 72) and by *0.3 to 2.1 °C* (Figure 73) respectively. It is obvious that the low-e summer glazing lowers the temperature more than the low-e winter and thus is effective.

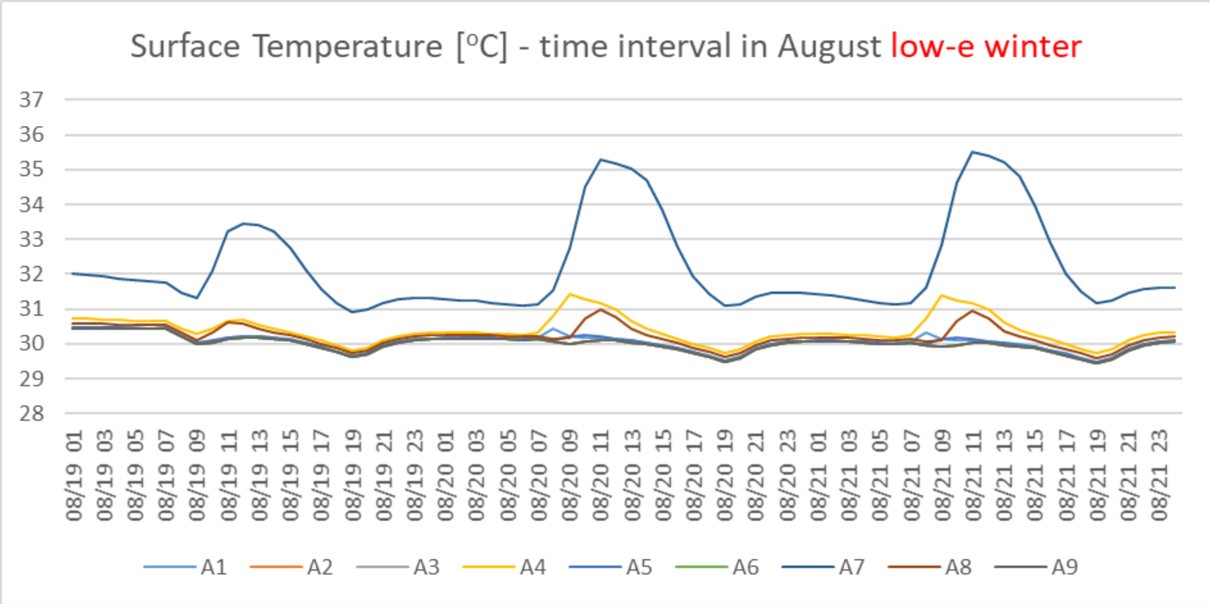

Figure 72: Surface Temperature [°C] – time interval in August – low-e winter glazing

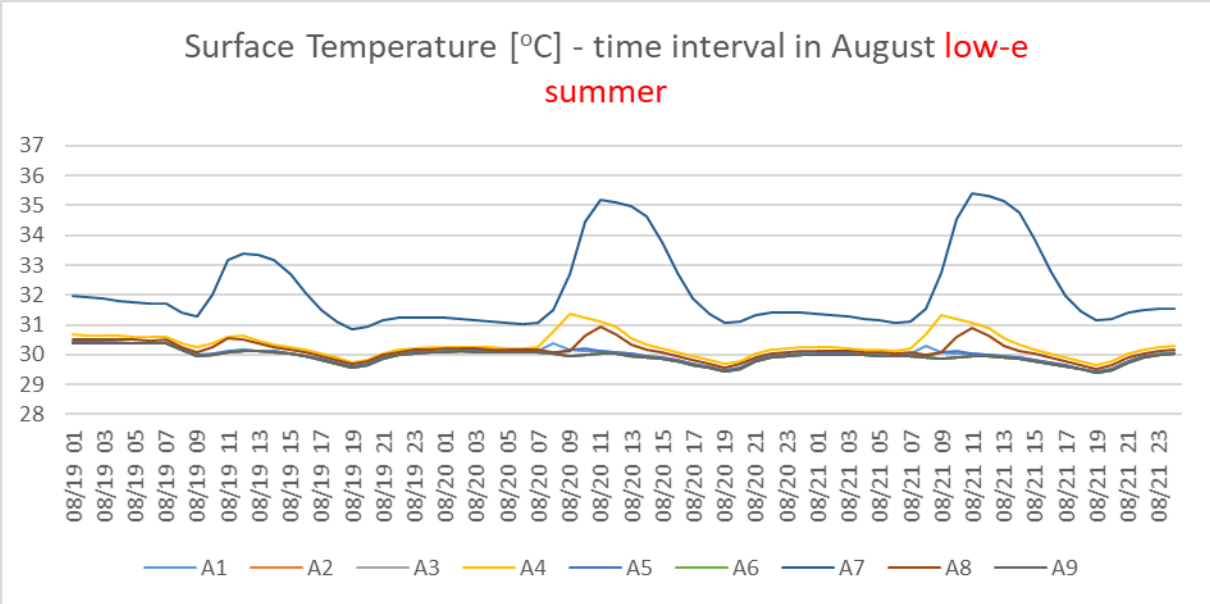

Figure 73: Surface Temperature [°C] – time interval in August – low-e summer glazing

On the contrary, the *reflective* and *absorptive* glazings decrease the surface temperature much more, specifically by *1.7 to 8.5 °C* (Figure 74) and by *1.1 to 7 °C* (Figure 75) respectively. In the case of the absorptive glazing, the surface temperature is higher than in the case of the reflective one, because its inner part absorbs more heat and thus warms the inside surfaces by convection.

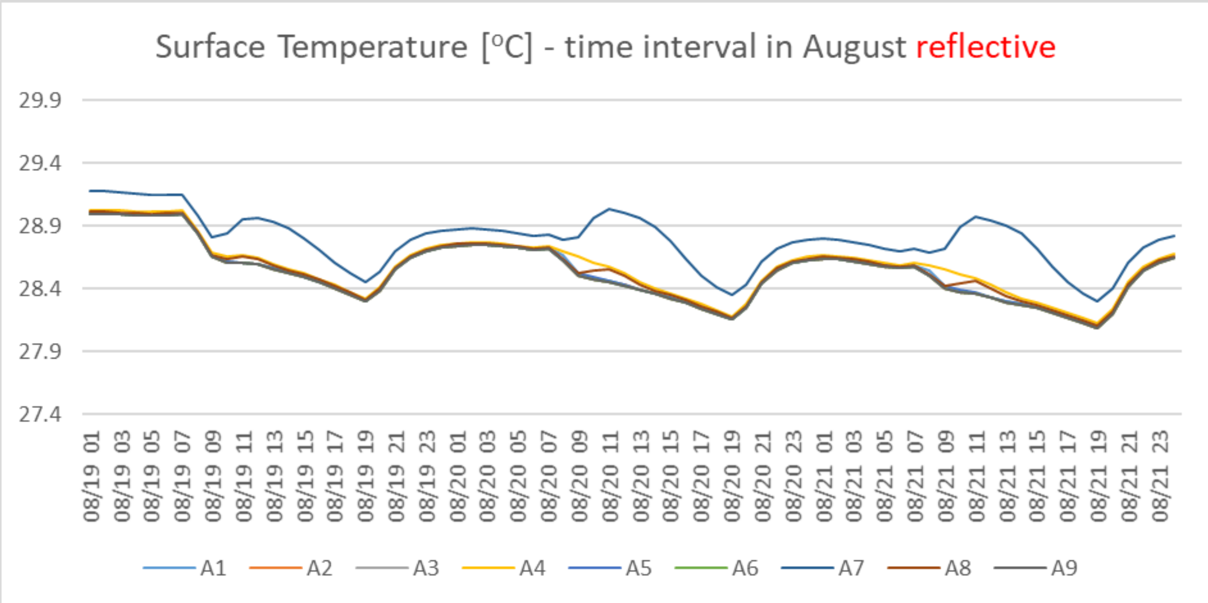

Figure 74: Surface Temperature [°C] – time interval in August – reflective glazing

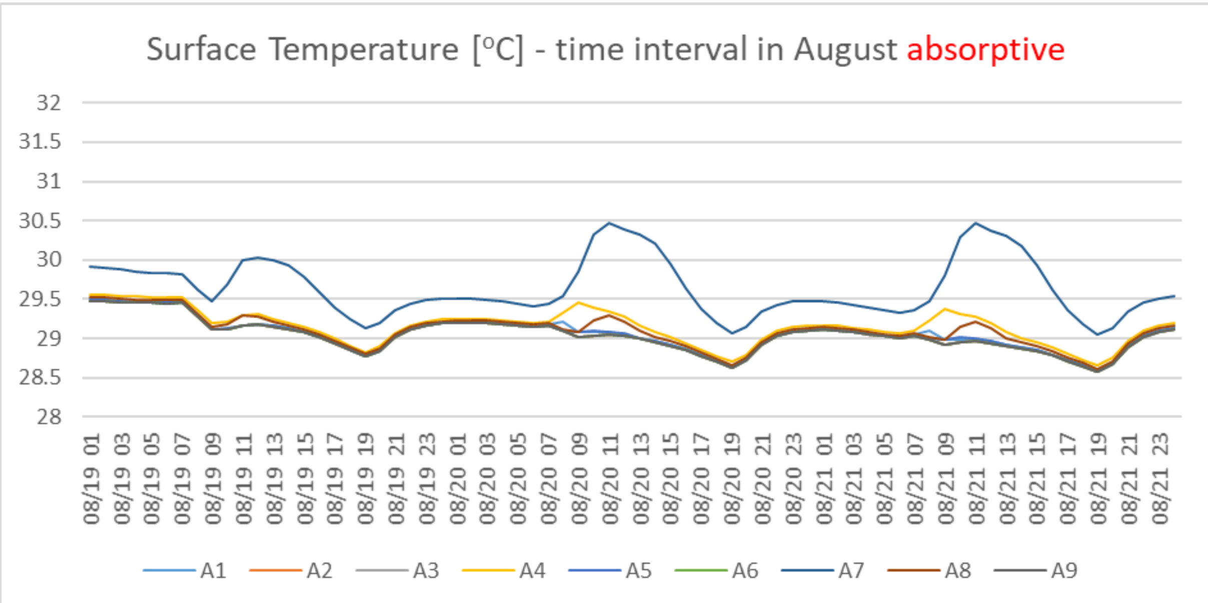

Figure 75: Surface Temperature [°C] – time interval in August – absorptive glazing

b.PMV

In Figure 76 and Figure 77, it is observed that using *low-e winter* and *low-e summer* glazing slightly alters the PMV values and therefore the building remains in category IV.

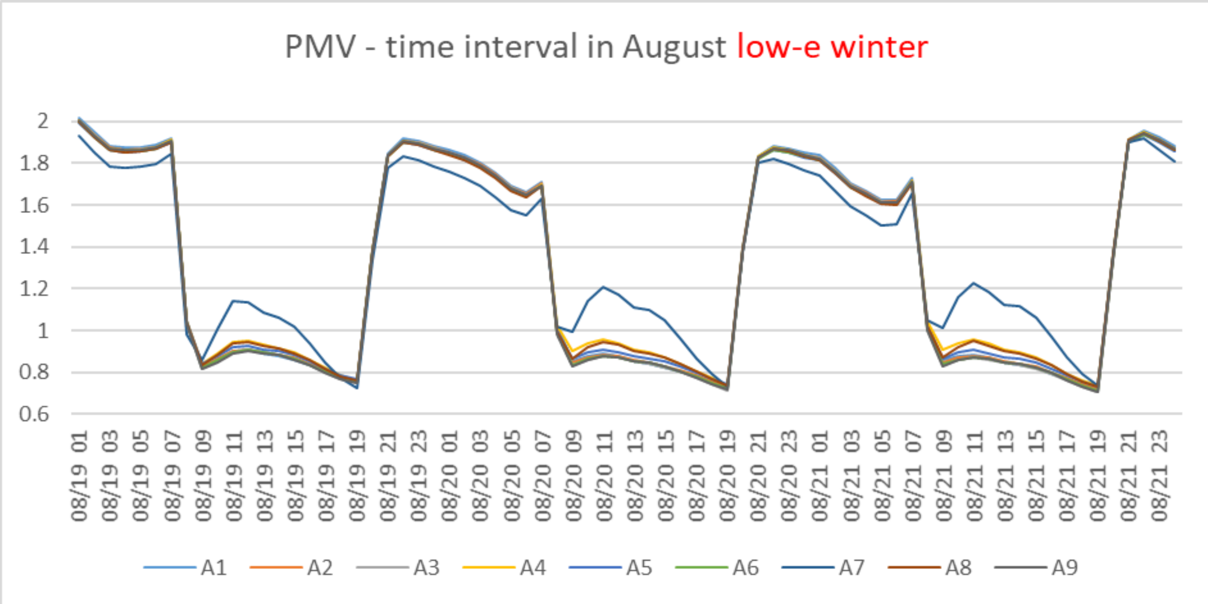

Figure 76: PMV – time interval in August – low-e winter glazing

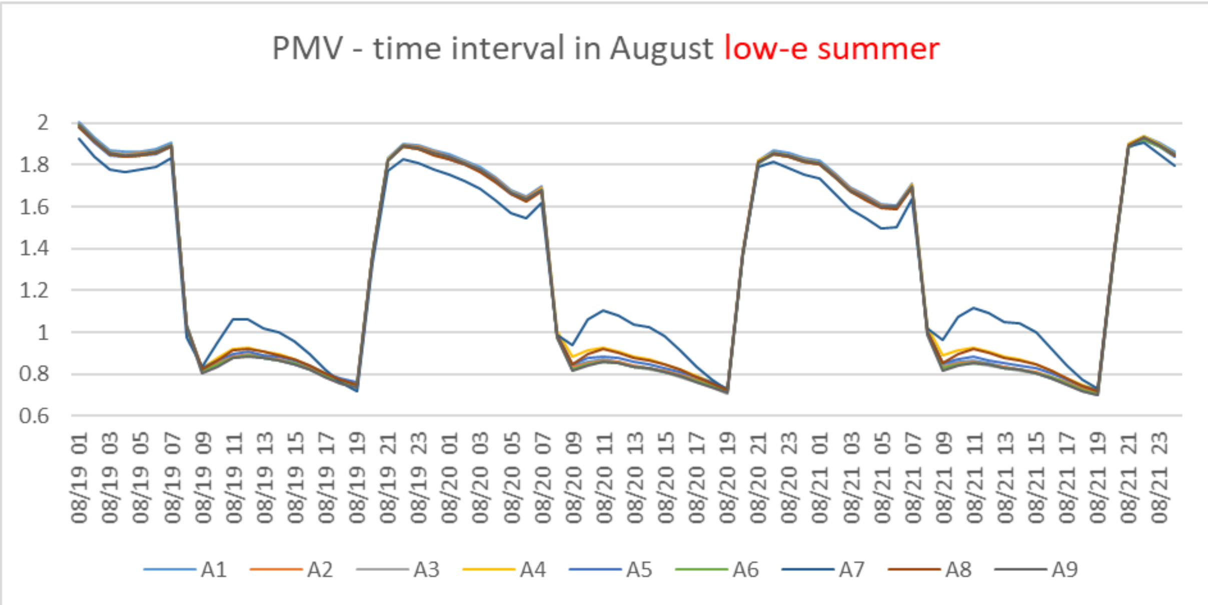

Figure 77: PMV – time interval in August – low-e summer glazing

The elimination of surface A7 doesn't affect the category to which the building belongs in both the above cases.

From Figure 78, it can be concluded that with the help of reflective glazing the PMV values drop and the building belongs to categories III and IV. The PMV values present a smaller decrease in the case of absorptive glazing and the corresponding building is classified in categories III and IV (Figure 79*)*.

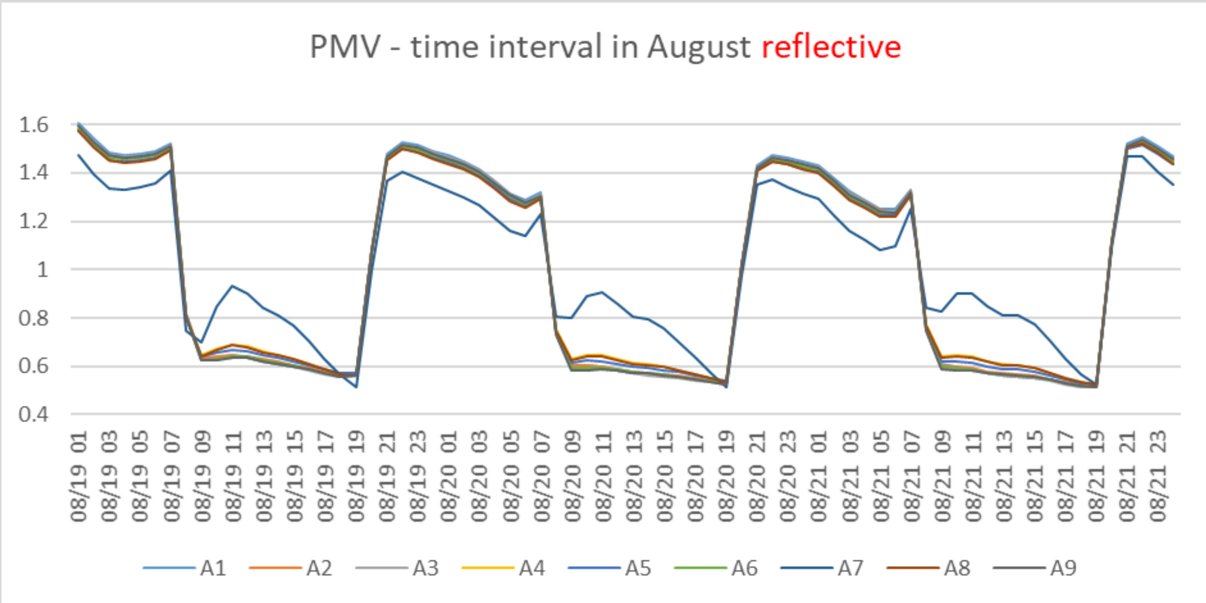

Figure 78: PMV – time interval in August – reflective glazing

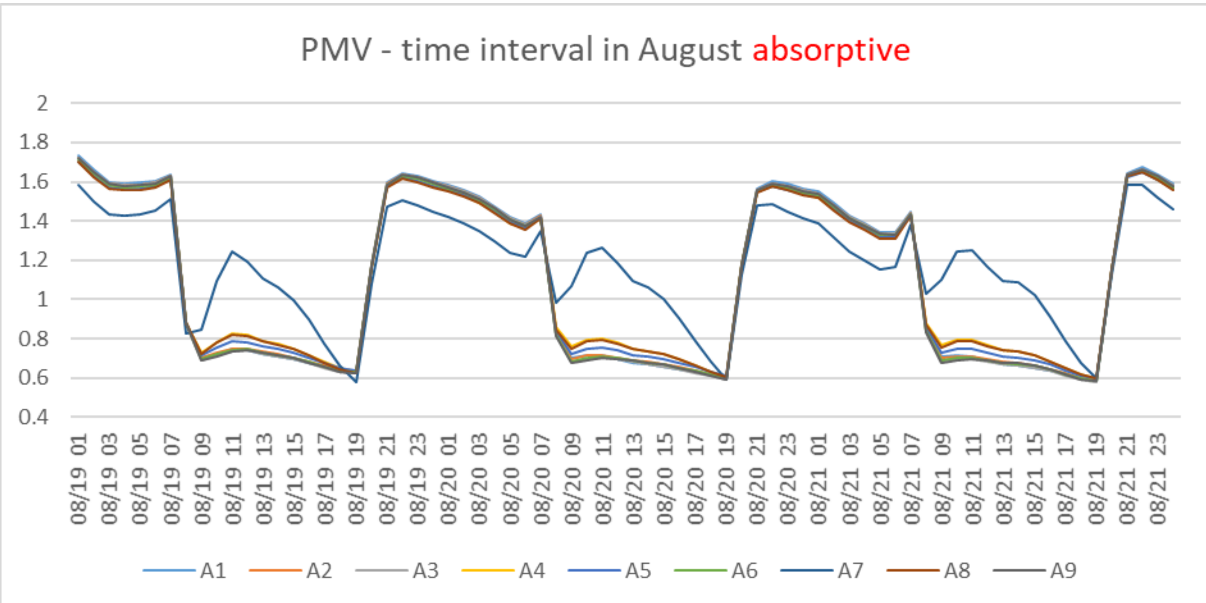

Figure 79: PMV – time interval in August – absorptive glazing

With the exclusion of surface A7, the building with the reflective glazing belongs only to category III and the one with the absorptive glazing remains in the same categories (III,IV).

5.2.4 Time interval in October (29/10 – 31/10)

a. Surface temperature

As compared to the base case (clear glazing), both *low-e winter* and *low-e summer* glazing lower the surface temperature by *up to 1.7 ^oC* (Figure 80) and by *up to 1.8 ^oC* (Figure 81) respectively. For this period, the low-e winter glazing reduces less the temperature and it is more effective than low-e summer glazing, which allows less solar radiation into the building.

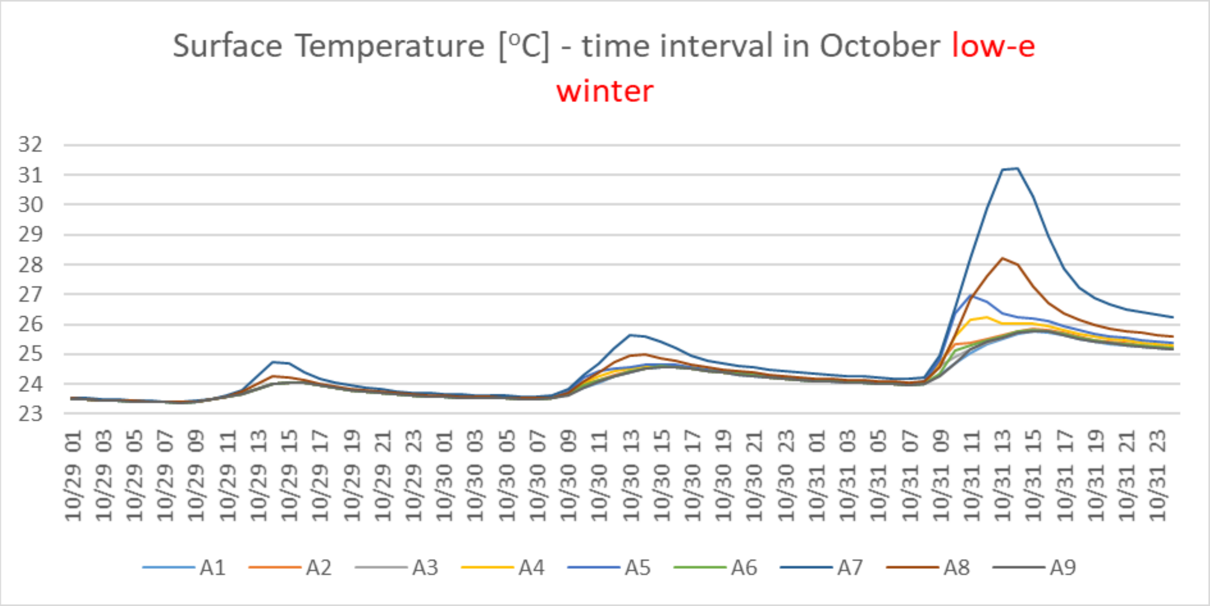

Figure 80: Surface Temperature [^{o}C] – time interval in October – low-e winter glazing

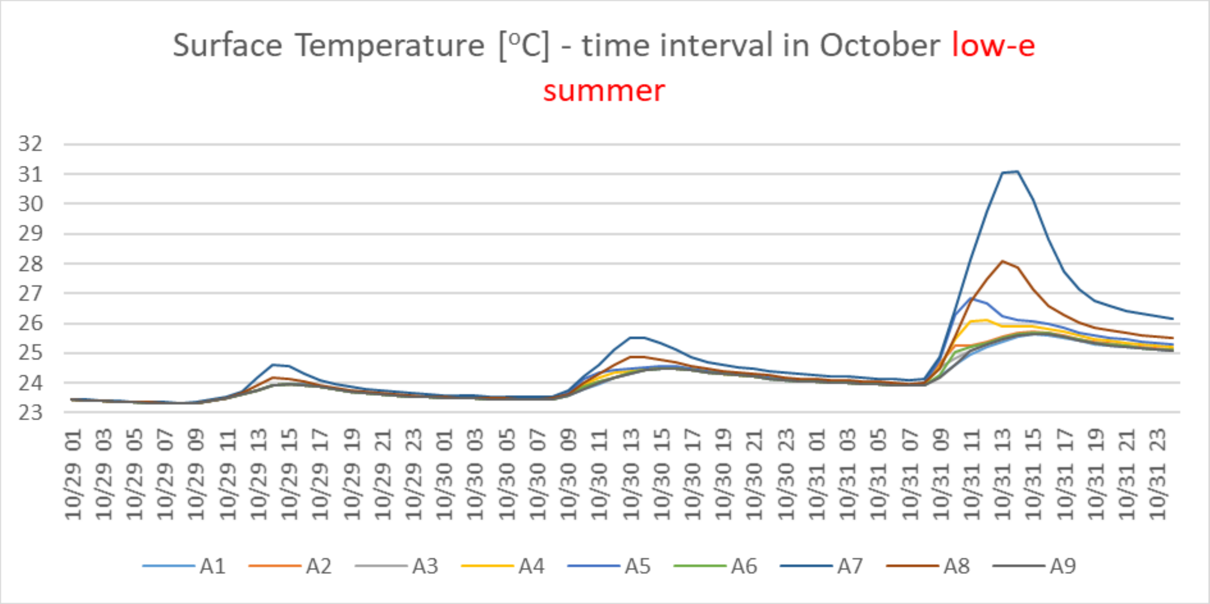

Figure 81: Surface Temperature [^{o}C] – time interval in October – low-e summer glazing

On the other hand, the *reflective* and *absorptive* glazings decrease the surface temperature much more, specifically by *1.5 to 9.3 °C* (Figure 82) and by *1.1 to 7.4 °C* (Figure 83) respectively. In the case of the absorptive glazing, the surface temperature is higher than in the case of the reflective one, because its inner part absorbs more heat and thus warms the inside surfaces by convection.

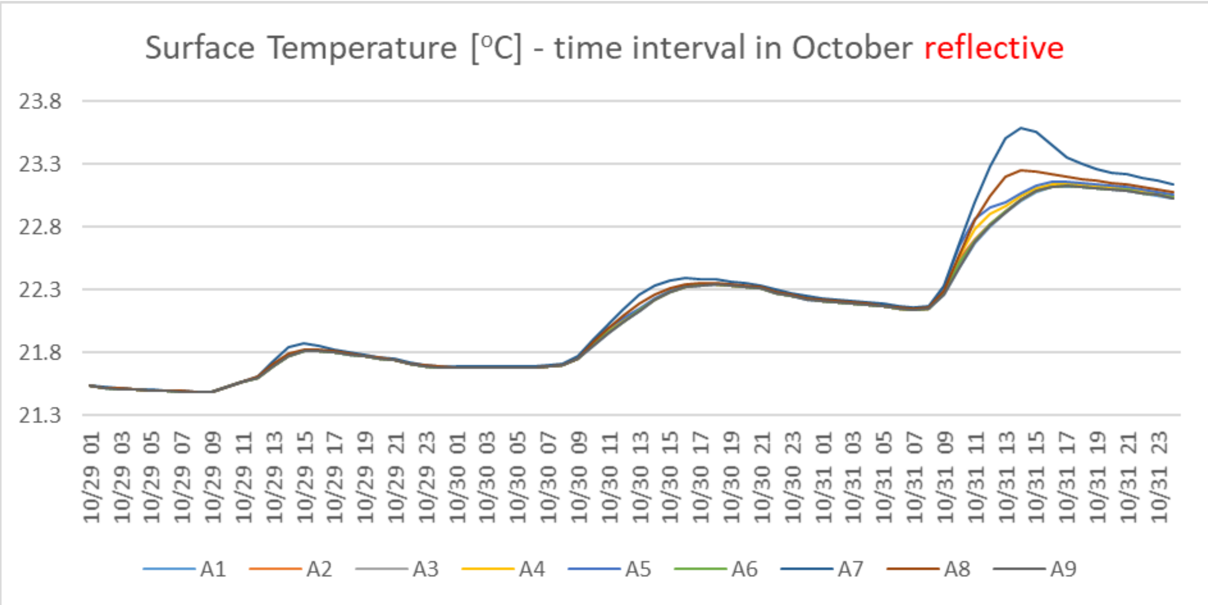

Figure 82: Surface Temperature [°C] – time interval in October – reflective glazing

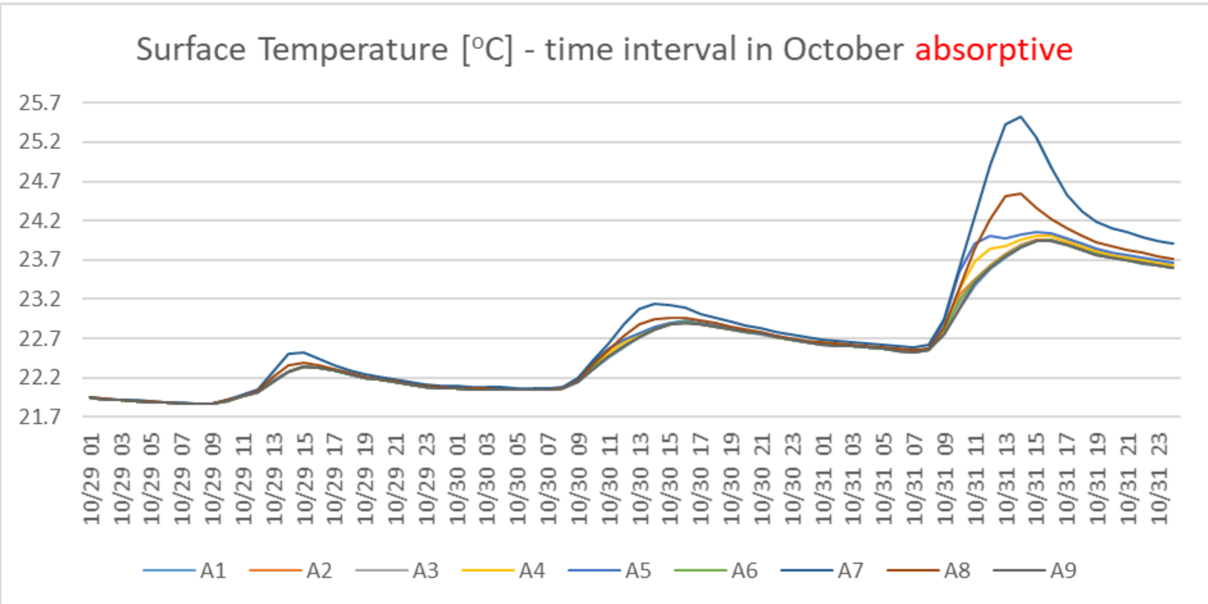

Figure 83: Surface Temperature [°C] – time interval in October – absorptive glazing

b.PMV

In Figure 84 and Figure 85, it is observed that using *low-e winter* and *low-e summer* glazing increases the PMV values. In the first case the building remains to categories II, III and IV and in the second one the building belongs to categories III and IV.

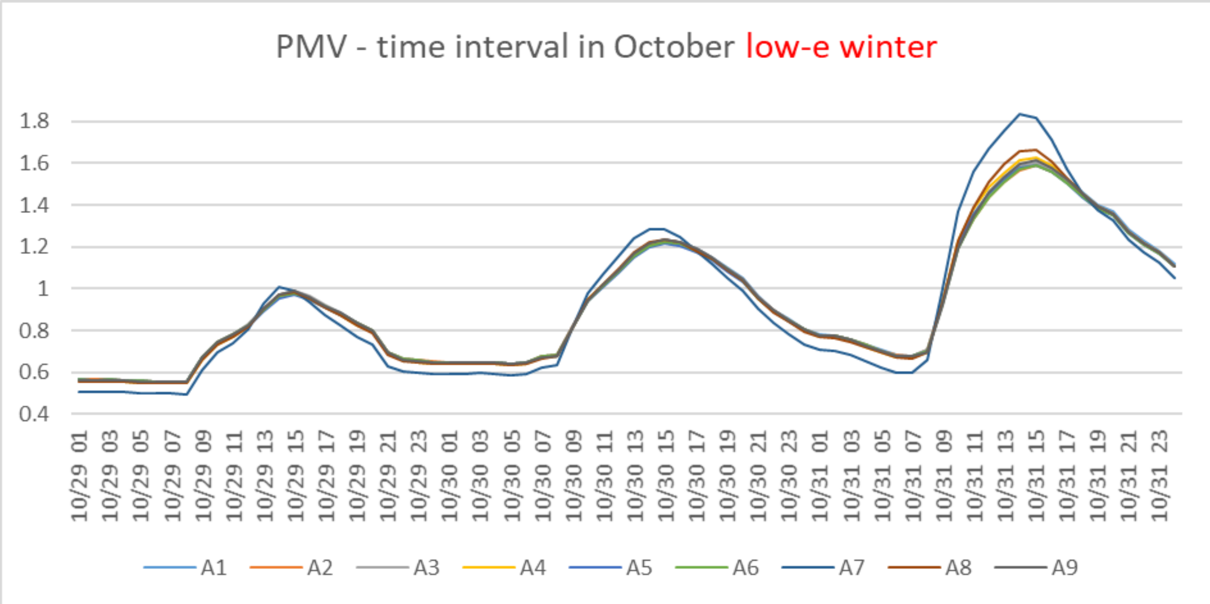

Figure 84: PMV – time interval in October – low-e winter glazing

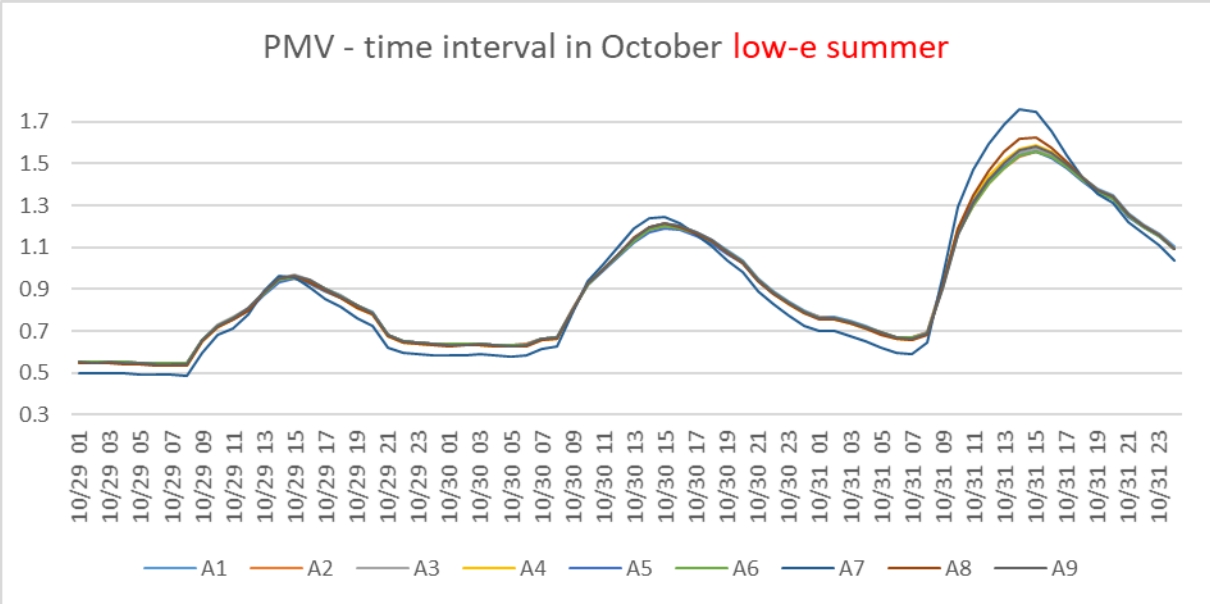

Figure 85: PMV – time interval in October – low-e summer glazing

Exempting the warmest surface A7, the buildings of the above 2 cases belong to categories III and IV.

Figure 86 and Figure 87 show that the use of *reflective* and *absorptive* glazing decreases the PMV values significantly but the building shifts to categories I, II, III and IV.

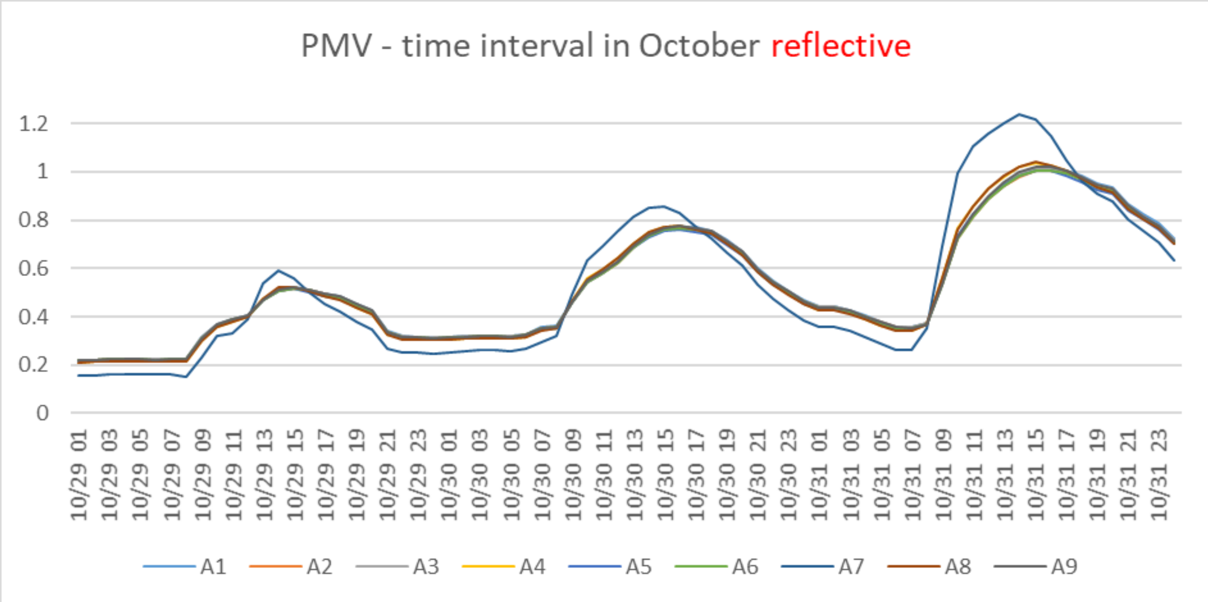

Figure 86: PMV – time interval in October – reflective glazing

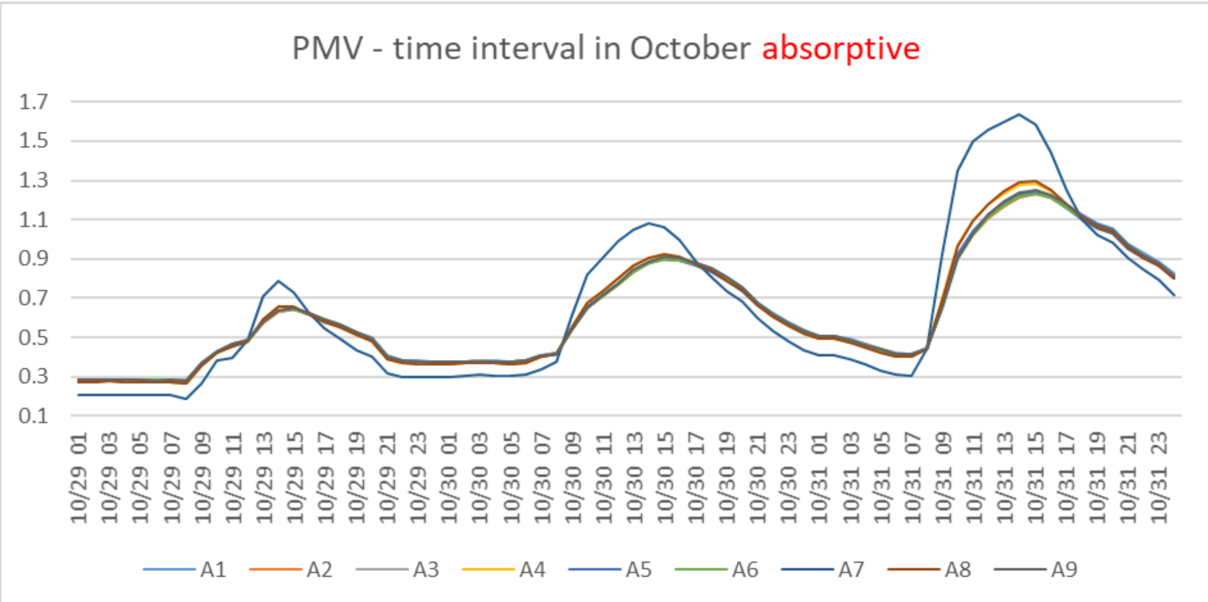

Figure 87: PMV – time interval in October – absorptive glazing

Skipping the most heated surface A7, both above types of building belong to categories II, III and IV.

5.2.5 Time interval in December (26/12 – 28/12)

a. Surface temperature

As compared to the base case, both *low-e winter* and *low-e summer* glazing lower the surface temperature by *up to 1 °C* (Figure 88) and *up to 1.1 °C* (Figure 89) respectively.

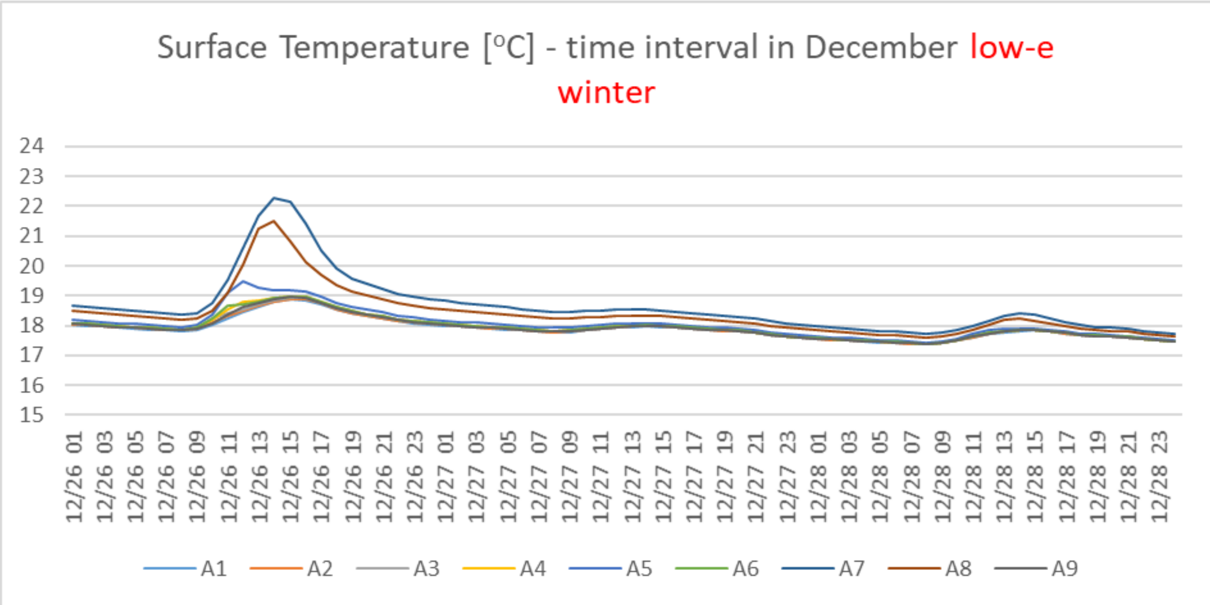

Figure 88: Surface Temperature [°C] – time interval in December – low-e winter glazing

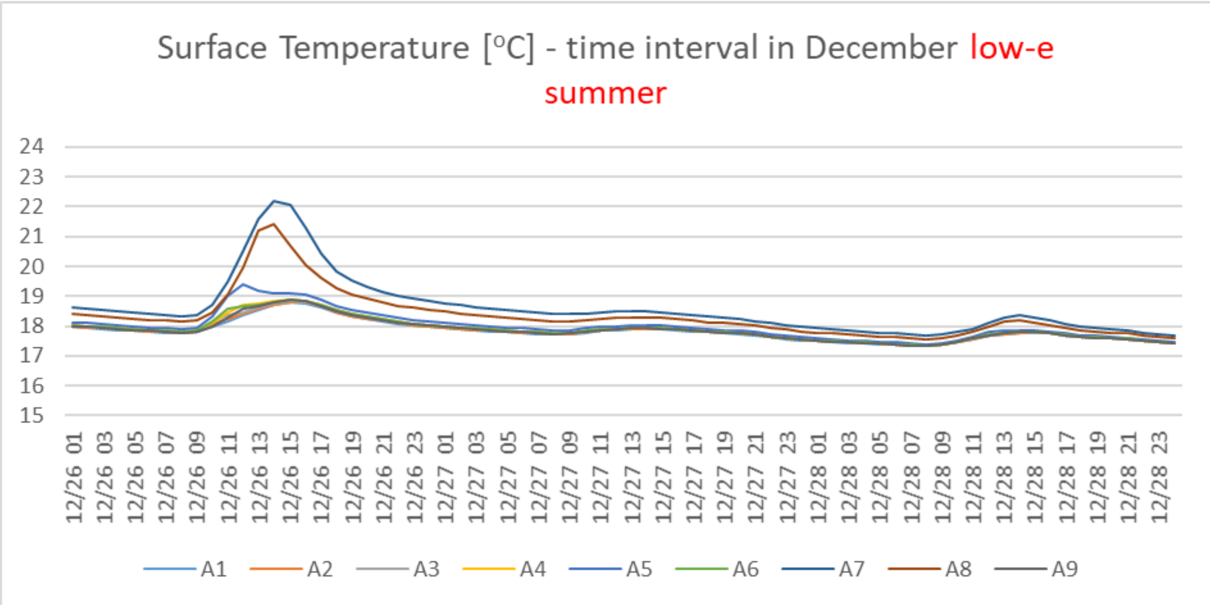

Figure 89: Surface Temperature [°C] – time interval in December – low-e summer glazing

As opposed to the other glazings, the *reflective* and *absorptive* ones decrease the surface temperature much more, specifically by *0.9 to 6.1 °C* (Figure 90) and by *0.7 to 4.8 °C* (Figure 91) respectively. In the case of the absorptive glazing, the surface temperature is higher than in the case of the reflective one, because its inner part absorbs more heat and thus warms the inside surfaces by convection.

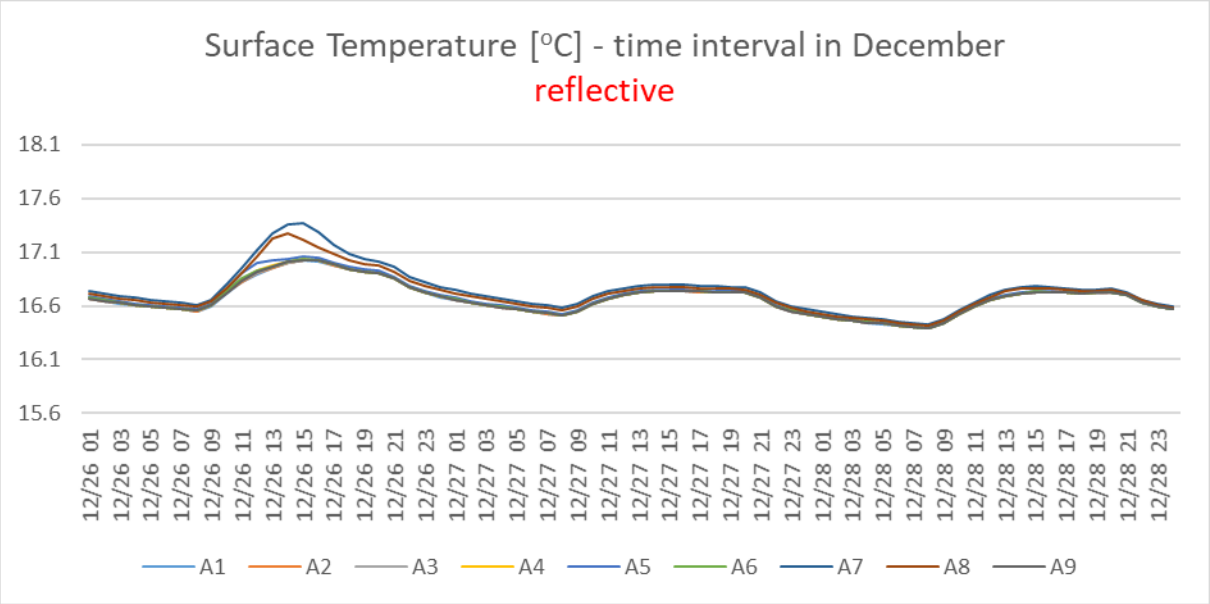

Figure 90: Surface Temperature [°C] – time interval in December – reflective glazing

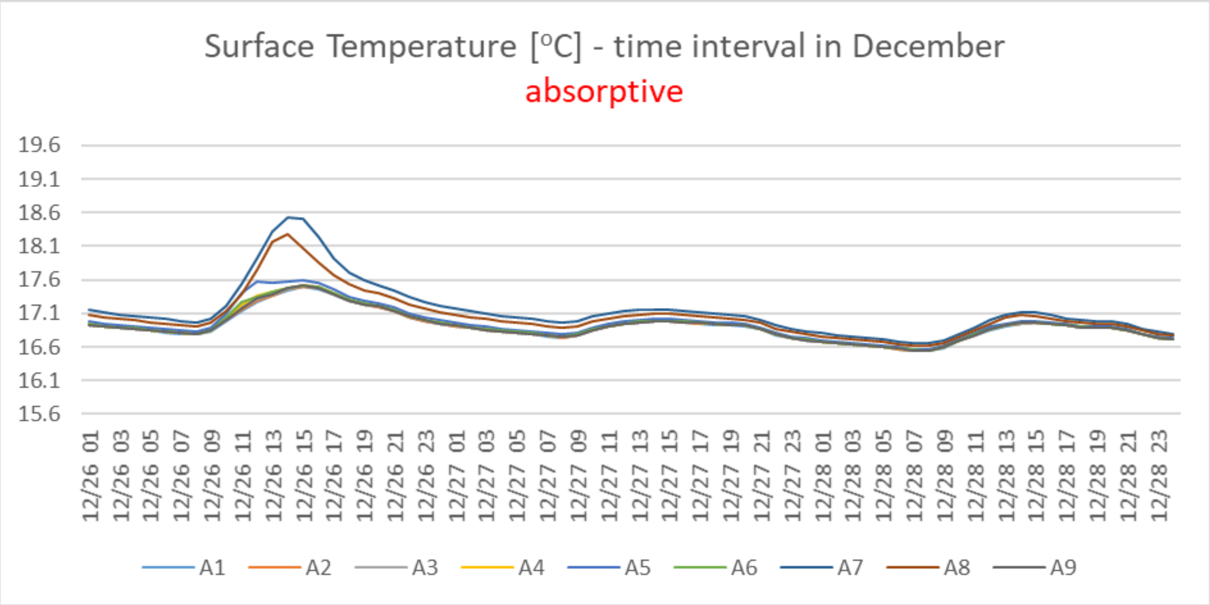

Figure 91: Surface Temperature [°C] – time interval in December – absorptive glazing

b.PMV

In Figure 92, it is shown that the use of low-e winter glazing has minor effect on the PMV values and therefore the building belongs to categories I, II, III and IV. In the case of low-e summer glazing (Figure 93), the PMV values slightly change and thus the building remains in categories II, III and IV.

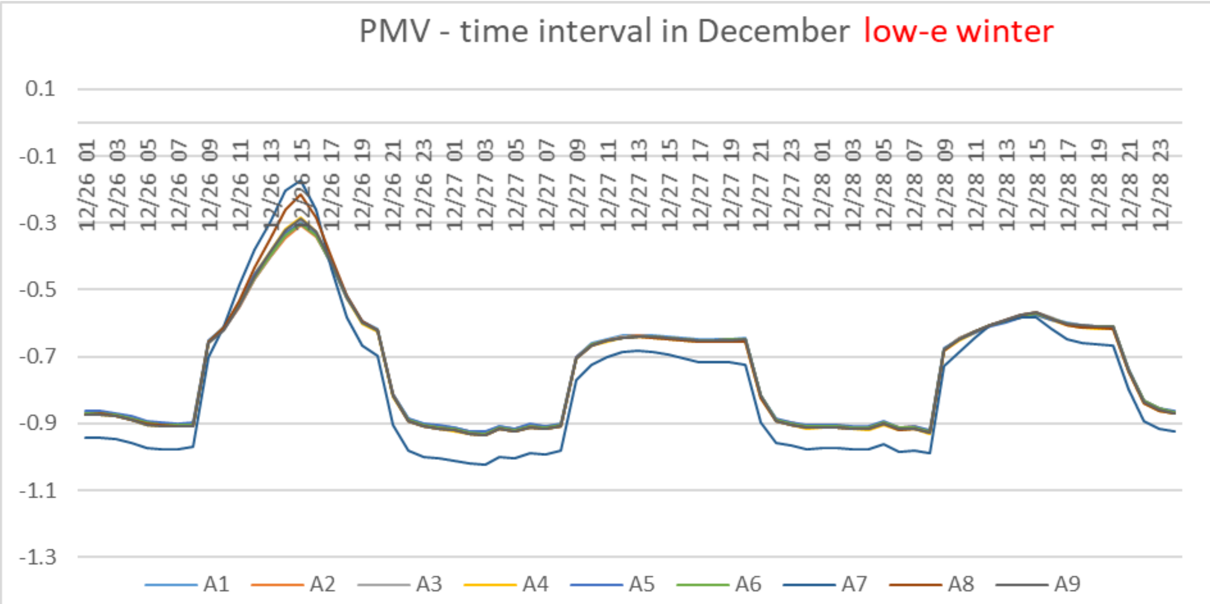

Figure 92: PMV – time interval in December – low-e winter glazing

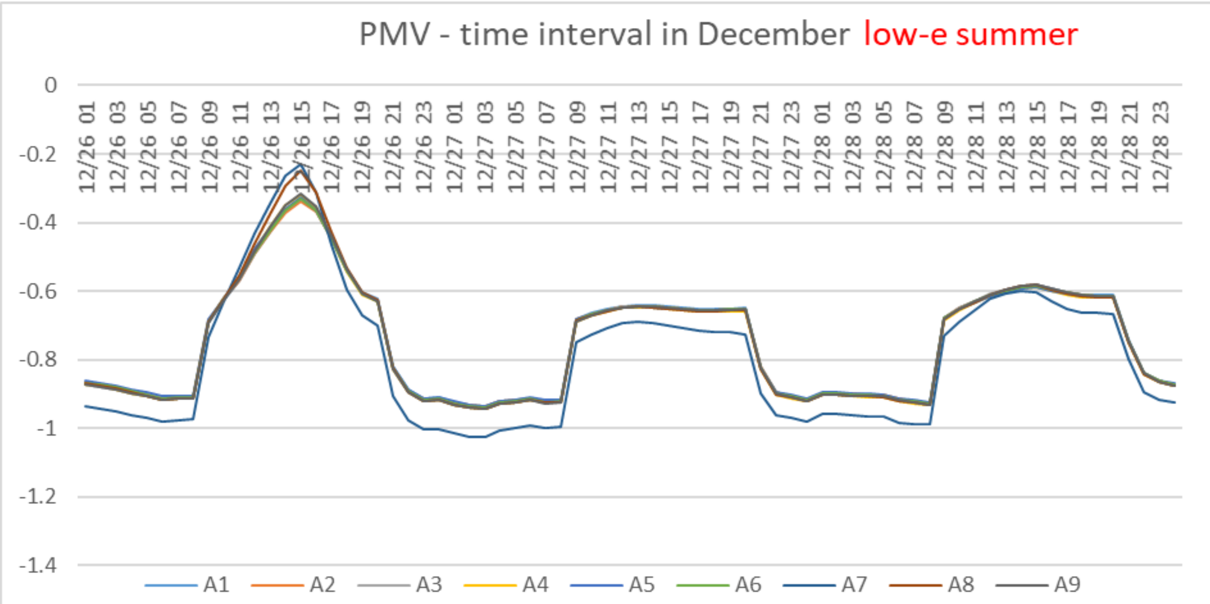

Figure 93: PMV – time interval in December – low-e summer glazing

By omitting surface A7, both the building with low-e winter glazing and the one with low-e summer glazing belong to categories II and III.

From Figure 94 it can be deduced that the reflective glazing hardly alters the PMV values and the building doesn't belong to category II but to III and IV. The PMV values present a marginal decrease in the case of absorptive glazing and the corresponding building remains to categories II, III and IV (Figure 95).

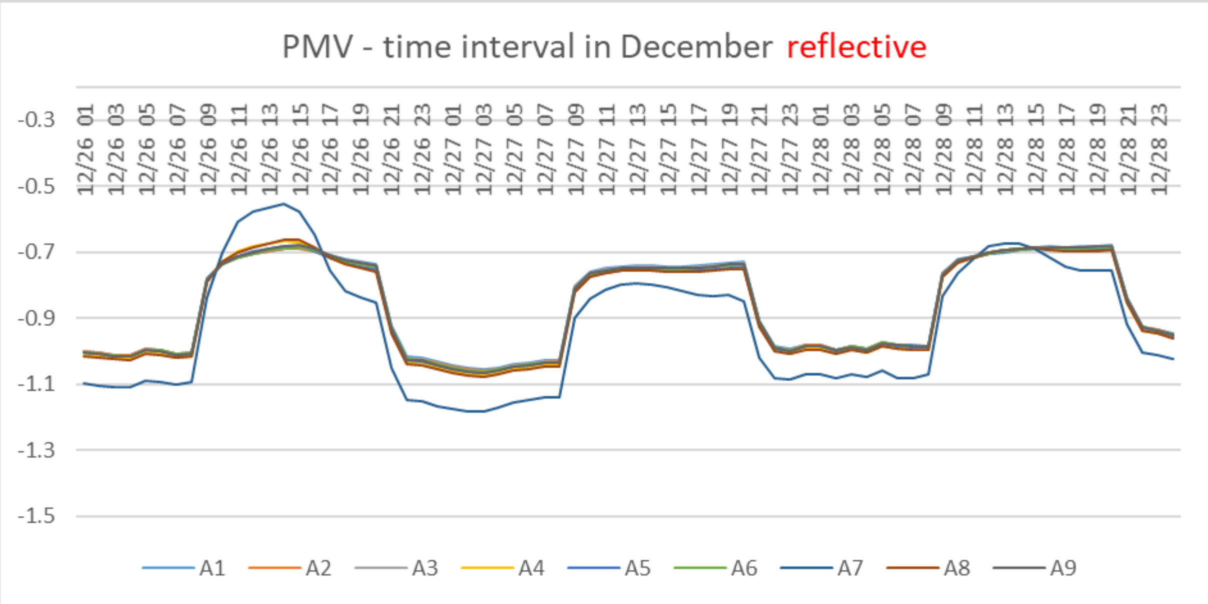

Figure 94: PMV – time interval in December – reflective glazing

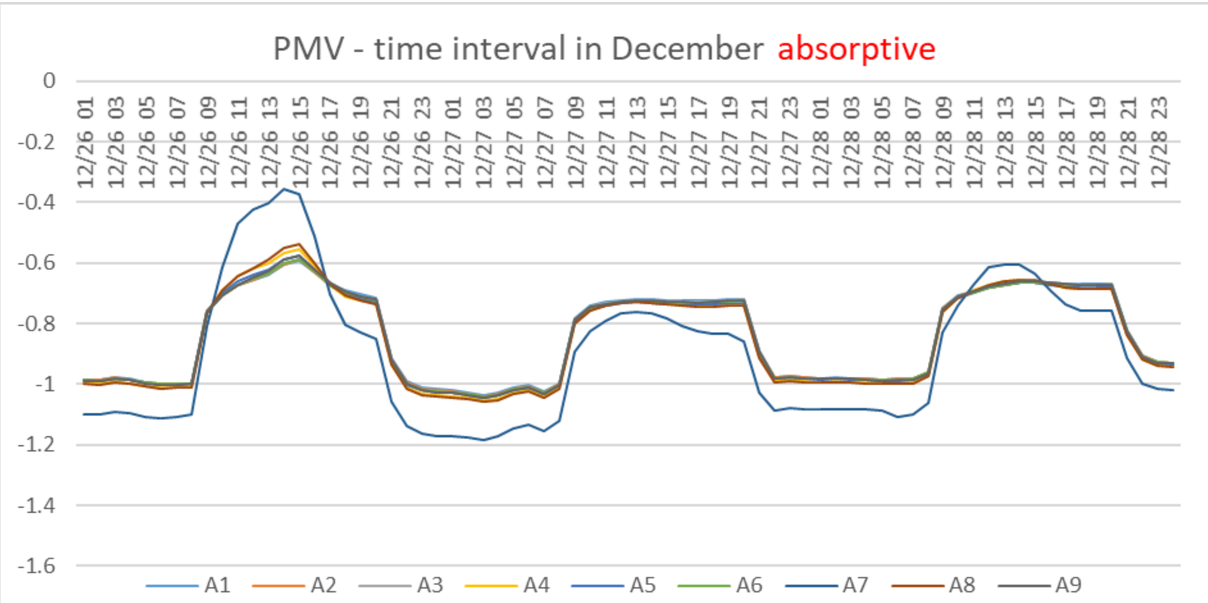

Figure 95: PMV – time interval in December – absorptive glazing

Eliminating surface A7 leads the above 2 buildings to categories III and IV.

5.3 Building energy needs

The building energy need for heating and cooling can also be calculated with the help of software “Energy Plus”. These calculations are conducted for every scenario based on both mean air and operative temperature, in an attempt to integrate thermal comfort as a thermostat regulator.

In Figure 96 it is obvious that the heating load for thermostat set to mean air temperature is much lower than that for thermostat set to operative temperature. This means that higher energy consumption is needed in order to achieve the requisite thermal comfort conditions (20 ^{o}C) during the heating period (16/10-15/4). During the same period Figure 98, Figure 99 and Figure 100 show that the temperature of surface A1 is much lower than mean radiant temperature. This explains the high values which PMV has (subchapters 5.2 & 5.3).

In Figure 97 it is remarkable that when thermostat is set to air temperature the cooling load is the same as when thermostat is set to operative temperature. As a consequence, the necessary thermal comfort conditions (26 ^{o}C) are almost achieved.

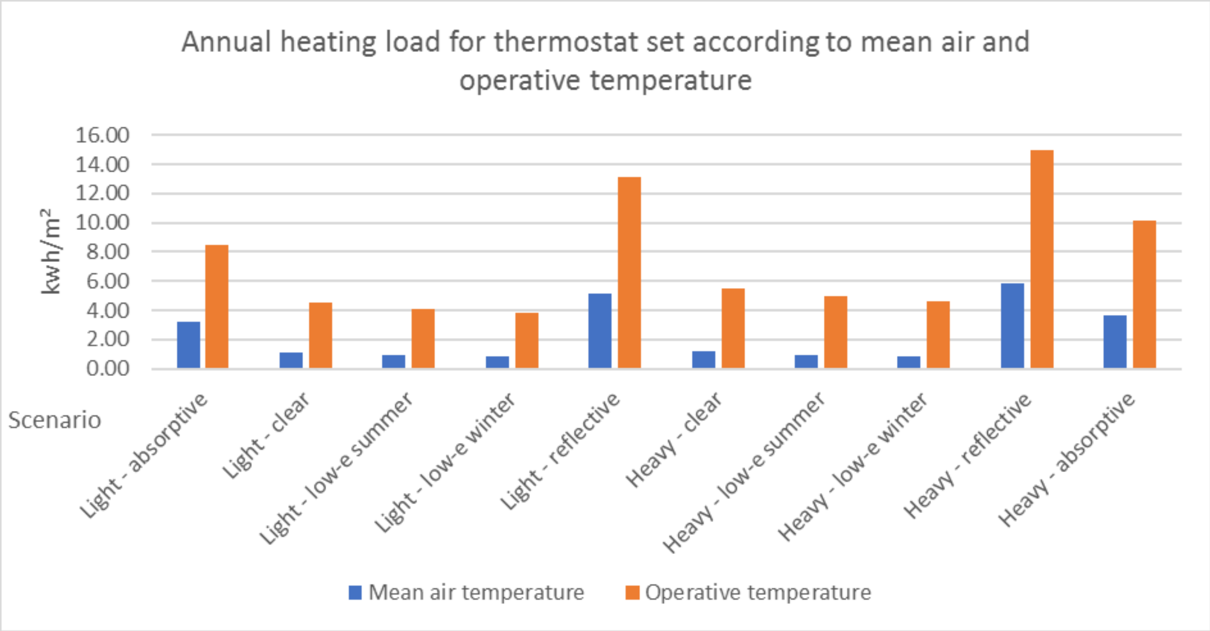

Figure 96: Annual heating load for thermostat set to mean air & operative temperature

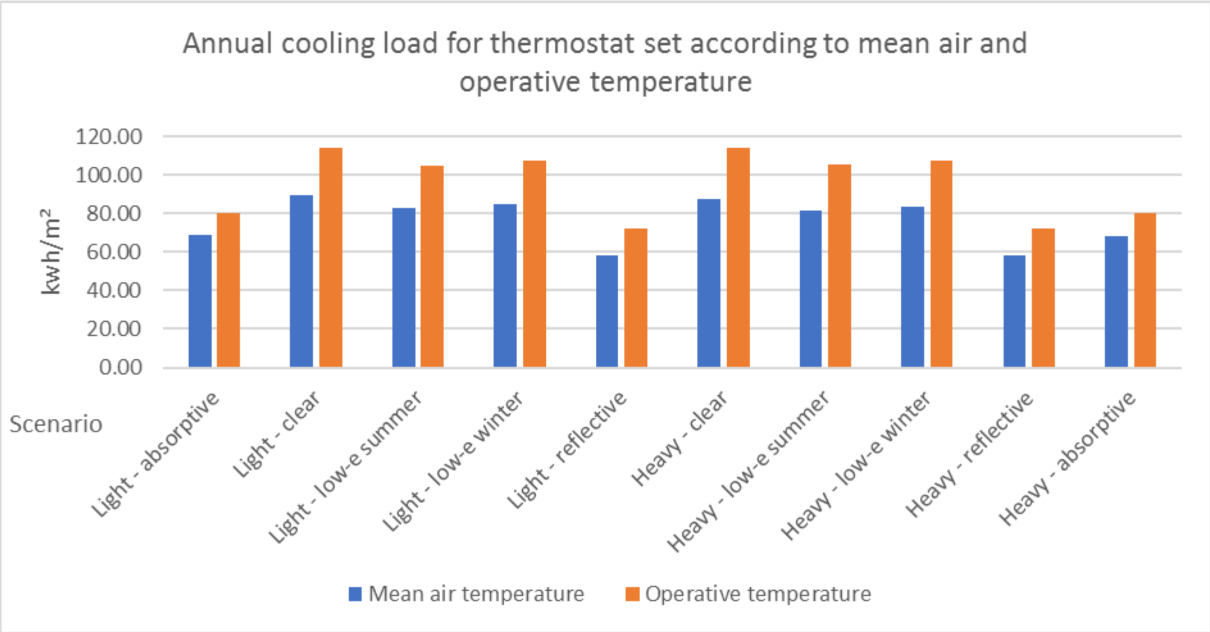

Figure 97: Annual cooling load for thermostat set to mean air & operative temperature

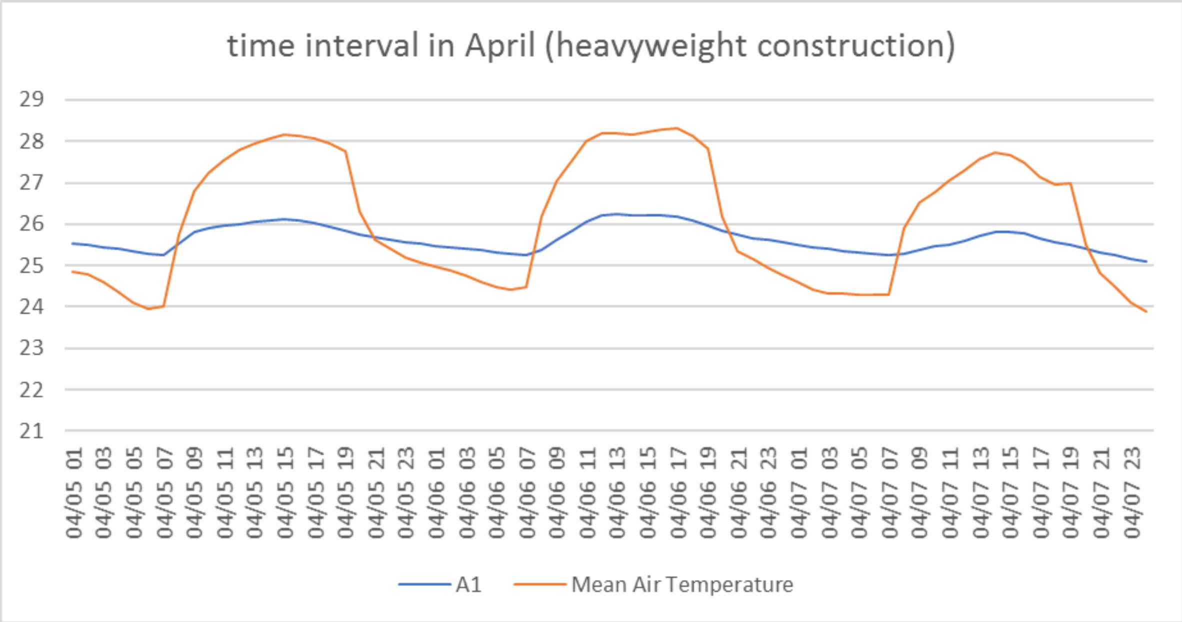

Figure 98: Temperature of surface A1 and MRT in April

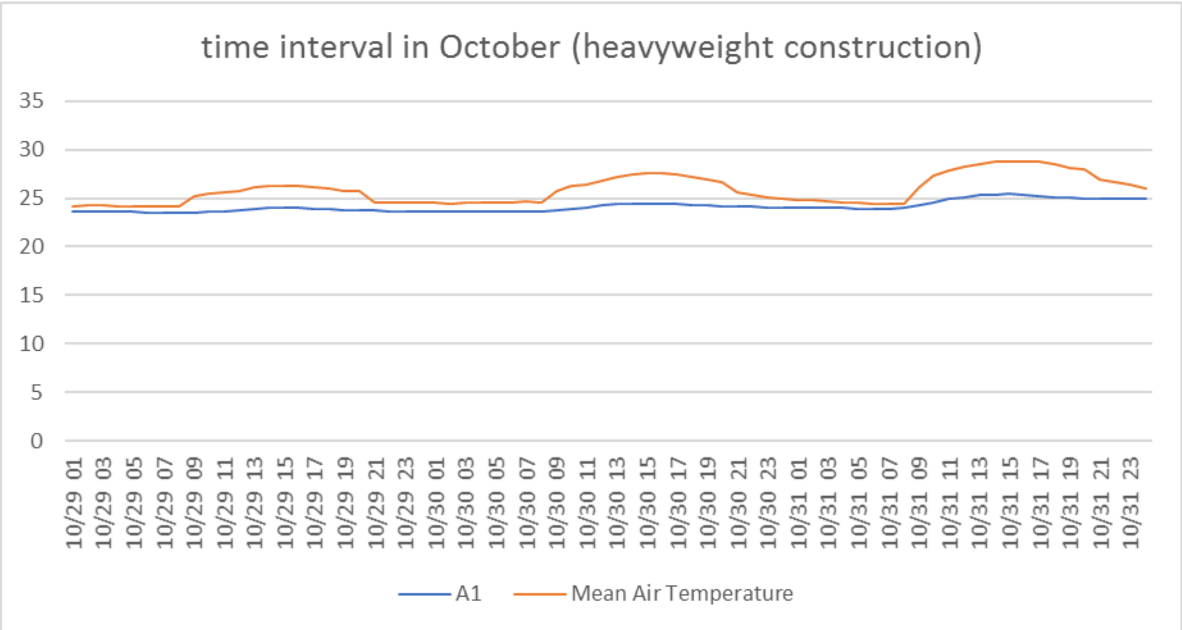

Figure 99: Temperature of surface A1 and MRT in October

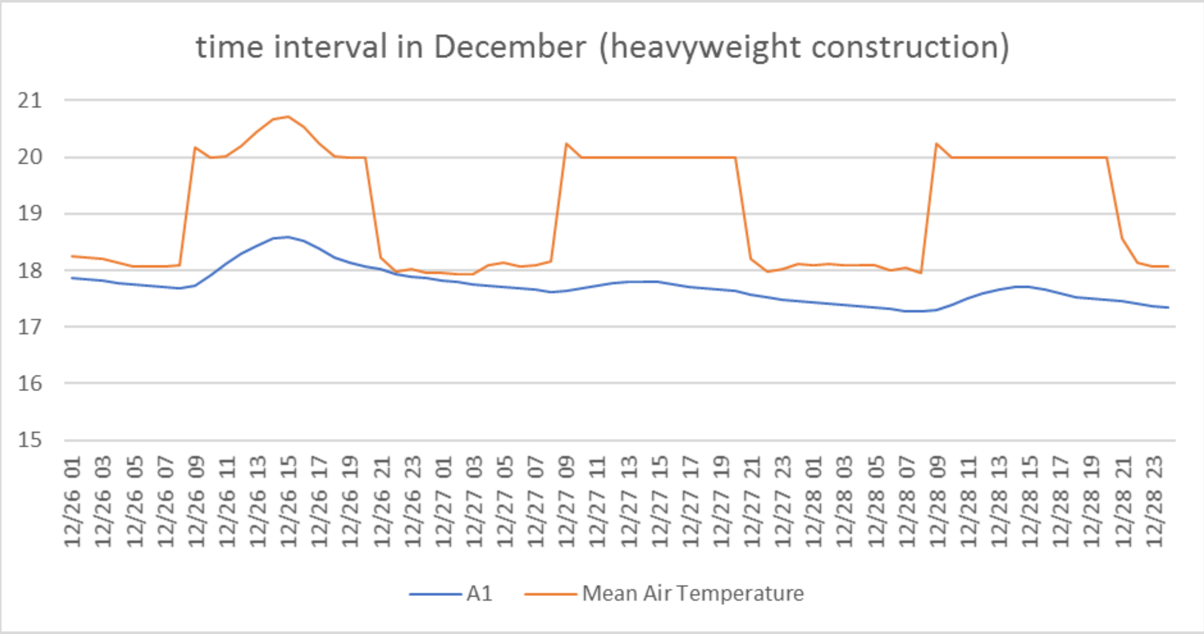

Figure 100: Temperature of surface A1 and MRT in December

6 Conclusions

6.1 Heavyweight construction

In the tables below (Table 6, Table 7, Table 8) the simulation results for the case of *heavyweight construction* are presented for each time interval and type of the glazing.

Table 6: Surface Temperature – Heavyweight construction

Surface Temperature (Heavyweight construction)								
Month	April		August		October		December	
Glazing	[C]	Diff.(-)	[C]	Diff.(-)	[C]	Diff.(-)	[C]	Diff.(-)
Clear	25.3-29.6	-	29.9-37.6	-	23.5-32.6	-	17.3-23.0	-
Low-e winter	25.2-28.5	0.1-1.1	29.5-35.4	0.4-2.2	23.8-31.0	0.0-1.6	17.5-22.0	0.0-1.0
Low-e summer	25.0-28.3	0.3-1.3	29.4-35.4	0.5-2.2	23.8-30.8	0.0-1.8	17.4-22.0	0.0-1.0
Reflective	21.8-22.5	3.5-7.1	28.1-29.0	1.8-8.6	21.7-23.4	1.8-9.2	16.4-17.3	0.9-5.7
Absorptive	22.8-24.1	2.5-5.5	28.6-30.4	1.3-7.2	22.2-25.3	1.3-7.3	16.6-18.3	0.7-4.7

Table 7: PMV – Building's category – Heavyweight construction

PMV - Building's category (Heavyweight construction)								
Month	April		August		October		December	
Glazing	PMV	Category	PMV	Category	PMV	Category	PMV	Category
Clear	0.60-1.27	III/IV	0.75-1.54	IV	0.46-1.63	II/III/IV	(-1.04)-(-0.40)	II/III/IV
Low-e winter	0.60-1.33	III/IV	0.75-1.48	IV	0.58-1.66	III/IV	(-0.95)-(-0.31)	II/III/IV
Low-e summer	0.60-1.26	III/IV	0.74-1.47	IV	0.57-1.59	III/IV	(-0.98)-(-0.36)	II/III/IV
Reflective	0.11-0.65	I/II/III	0.53-1.50	III/IV	0.21-1.13	II/III/IV	(-1.11)-(-0.56)	III/IV
Absorptive	0.40-1.02	II/III/IV	0.59-1.19	III / IV	0.25-1.45	II/III/IV	(-1.13)-(-0.41)	II/III/IV

Table 8: PMV – Building's category – Heavyweight construction (without surface A7)

PMV - Building's category (without surface A7) (Heavyweight construction)								
Month	April		August		October		December	
Glazing	PMV	Category	PMV	Category	PMV	Category	PMV	Category
Clear	0.93-1.26	IV	0.80-0.97	IV	0.57-1.63	III/IV	(-0.68)-(-0.40)	II/III
Low-e winter	0.90-1.23	IV	0.76-0.93	IV	0.75-1.44	IV	(-0.69)-(-0.39)	II/III
Low-e summer	0.83-1.19	IV	0.75-0.90	IV	0.75-1.40	IV	(-0.67)-(-0.36)	II/III
Reflective	0.24-0.53	II/III	0.55-0.69	III	0.37-0.90	II/III/IV	(-0.80)-(-0.69)	III/IV
Absorptive	0.47-0.80	II/III/IV	0.62-0.82	III / IV	0.44-1.12	II/III/IV	(-0.78)-(-0.62)	III/IV

Table 6 shows the temperature range of surfaces A1-A9 and its difference compared to the base case of building with clear glazings. Table 7 depicts the corresponding PMV range and building category based on PMV. In Table 8, the same information is demonstrated with precluding floor surface A7, which is the most heated one since sun warms it through the 2 glazings.

Regarding the heavyweight construction of the office building the following conclusions have been made:

- The *low-e summer* glazing could be more efficient during the time interval in August. It should have decreased the surface temperature in August more than the low-e winter glazing.
- The *low-e winter* glazing is not so effective in October's and December's time period. The surface temperature is nearly equal to the one in the case of low-e summer glazing.
- *Low-e summer and winter* glazings have similar performance: they slightly alter the PMV values in April, August and December and therefore the building remains in the same category as base case (clear glazing). In October they both increase PMV and change the building's category by 1 to 2 categories.
- The *reflective* glazing works outstandingly during all periods since it lowers the surface temperature by up to 9.2 ºC. This is justified by the fact that its outer part reflects huge part of the solar radiation. In April and August it delays the rise of surface temperature compared to the faster rise of base case.
- The *absorptive* glazing has similar but worse performance than the reflective one because its inner part absorbs more heat and thus warms the inside surfaces by convection.
- *Reflective and absorptive* glazings diminish PMV and change the building's category by 1 to 2 categories in April and by 1 category in August. In October they marginally change PMV values and thus building remains in the same category. In December only reflective glazing changes the building's category.
- With the exclusion of the warmest surface A7, in October and December both reflective and absorptive glazing change the building's category by 1 to 2 categories.

6.2 Lightweight construction

In the tables below (Table 9, Table 10, Table 11) the simulation results for the case of *lightweight construction* are presented for each time interval and type of the glazing.

Table 9: Surface Temperature – Lightweight construction

Surface Temperature (Lightweight construction)								
Month	April		August		October		December	
Glazing	[C]	Diff.(-)	[C]	Diff.(-)	[C]	Diff.(-)	[C]	Diff.(-)
Clear	25.9-30.3	-	29.7-37.5	-	23.0-32.9	-	17.3-23.3	-
Low-e winter	25.8-29.2	0.1-1.1	29.4-35.5	0.3-2.0	23.4-31.2	0.0-1.7	17.4-22.3	0.0-1.0
Low-e summer	25.6-29.0	0.3-1.3	29.4-35.4	0.3-2.1	23.3-31.1	0.0-1.8	17.3-22.2	0.0-1.1
Reflective	22.3-23.1	3.6-7.2	28.0-29.0	1.7-8.5	21.5-23.6	1.5-9.3	16.4-17.2	0.9-6.1
Absorptive	23.4-24.7	2.5-5.6	28.6-30.5	1.1-7.0	21.9-25.5	1.1-7.4	16.6-18.5	0.7-4.8

Table 10: PMV – Building's category – Lightweight construction

PMV - Building's category (Lightweight construction)								
Month	April		August		October		December	
Glazing	PMV	Category	PMV	Category	PMV	Category	PMV	Category
Clear	0.72-1.53	IV	0.72-1.48	IV	0.36-1.82	II/III/IV	(-1.03)-(-0.30)	II/III/IV
Low-e winter	0.82-1.54	IV	0.70-1.38	IV	0.49-1.81	II/III/IV	(-0.98)-(-0.17)	I/II/III/IV
Low-e summer	0.80-1.41	IV	0.70-1.37	IV	0.54-1.76	III/IV	(-0.99)-(-0.25)	II/III/IV
Reflective	0.19-0.80	I/II/III/IV	0.51-0.93	III/IV	0.15-1.24	I/II/III/IV	(-1.09)-(-0.55)	III/IV
Absorptive	0.37-1.20	II/III/IV	0.58-1.27	III/IV	0.18-1.64	I/II/III/IV	(-1.09)-(-0.36)	II/III/IV

Table 11: PMV – Building's category – Lightweight construction (without surface A7)

PMV - Building's category (without surface A7) (Lightweight construction)								
Month	April		August		October		December	
Glazing	PMV	Category	PMV	Category	PMV	Category	PMV	Category
Clear	0.82-1.53	IV	0.75-1.00	IV	0.58-1.70	III/IV	(-0.72)-(-0.20)	II/III/IV
Low-e winter	1.03-1.54	IV	0.70-0.95	IV	0.67-1.66	III/IV	(-0.70)-(-0.20)	II/III
Low-e summer	0.96-1.41	IV	0.70-0.92	IV	0.65-1.62	III/IV	(-0.70)-(-0.28)	II/III
Reflective	0.35-0.67	II/III	0.51-0.69	III	0.31-1.02	II/III/IV	(-0.80)-(-0.68)	III/IV
Absorptive	0.50-0.96	II/III/IV	0.58-0.82	III/IV	0.37-1.29	II/III/IV	(-0.75)-(-0.54)	III/IV

Table 9 presents the temperature range of surfaces A1-A9 and its difference compared to the base case of building with clear glazings. Table 10 demonstrates the corresponding PMV range and building category based on PMV. In Table 11, the same information is recorded with the exclusion of floor surface A7, which is the warmest one since sun heats it through the 2 windows.

Regarding the lightweight construction of the office building the next inferences have been made:

- The *low-e summer* glazing could be more efficient during the time interval in August. It should have shrinked the surface temperature in August much more than the low-e winter glazing.
- The *low-e winter* glazing is not so effective in October's and December's time period. The surface temperature is nearly equal to the one in the case of low-e summer glazing.
- *Low-e summer and winter* glazings have almost the same performance: they slightly alter the PMV values in April and August and thus the building doesn't change category. In October the low-e summer changes the building's category and in December low-e winter changes it.
- The *reflective* glazing works outstandingly during all periods since it lowers the surface temperature by up to 9.3 ^{o}C. This is justified by the fact that its outer part reflects huge part of the solar radiation. In August it delays the rise of surface temperature compared to the faster rise of base case.
- The *absorptive* glazing has similar but worse performance than the reflective one because its inner part absorbs more heat and thus warms the inside surfaces by convection.
- *Reflective and absorptive* glazings diminish PMV and change the building's category by 1 to 2 categories in April, by 1 category in August and by 1 to 3 categories in October. In December absorptive glazing marginally changes PMV values and thus building remains in the same category. In December reflective glazing changes the building's category by 1 category.
- With the omission of the most heated surface A7, in December low-e summer and absorptive glazing change the building's category by 1 to 2 categories.

6.3 Building energy needs

- The energy need for heating when thermostat is set to mean air temperature is smaller compared to the case when thermostat is set to operative temperature. More heating energy is necessary so as to fulfill the thermal comfort conditions during heating period (16/10-15/04).
- For the same period temperature surface (A1) is lower than MRT therefore this explains the high values of PMV index.
- For the cooling period (16/04-15/10) comparing the two settings of thermostat, air temperature and MRT, the thermal comfort is achieved.
- Finally, due to the restrictions that the program Energy plus has, namely air and mean radiant temperature cannot be calculated for every surface area A1-A9 separately, but only as average for the whole thermal zone of the building, further examination for the thermal comfort conditions cannot be conducted.

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