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Transient thermal response of opaque building envelope elements: EPFL campus case study

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Transient thermal response of opaque building envelope elements: EPFL campus case study

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Abstract. The building envelope acts as a shield against varying weather conditions and modulates thermal energy flow between outdoors and indoors. The choice of layers used in the assembly impacts the heat loss and gain through the wall structure and potentially can affect the comfort indoors. Thus, the building envelope plays an essential role in the thermal performance of the building. Optimizing the cladding design in the envelope has recently become increasingly important to reach sustainable development strategies for reducing greenhouse gas emissions by 2050. This paper aims to analyze several cladding types used on the EPFL campus in Lausanne and compare their impact on the energy performance of the building envelopes. The building assemblies constructed on the EPFL campus in different years vary in composition and thermo-physical properties of the layers used. The impact of these parameters on the thermal performance of the wall assembly is evaluated by comparing the variation of heat flux and temperature fluctuations within the wall structure. The results obtained highlight the importance of the building envelope layers and materials used in the wall structure. Due to the variations in the thermal inertia of different wall assemblies, a time shift of more than 3 hours in the transient response of the building envelope to the fluctuation of the outdoor weather conditions is observed.

1. Introduction

Residential and commercial buildings account for a large part of the energy use in the world. In particular, they are responsible for up to 50% of the energy use in Switzerland [1]. Designing an efficient wall assembly can have a substantial impact on reducing the energy use of the building. Different types of external cladding, acting as the external skin of the envelope, are used in the building structures that are exposed to the outdoor. The thermo-physical properties of the material used and the presence of an air cavity between the external façade and the internal wall core are among the characteristics that could vary in different cladding types. These differences will change the heat transfer mechanisms through the wall assembly and the sensitivity of the structure to the varying outdoor and indoor conditions. To address this issue, a number of wall structures within the EPFL campus with various external claddings are analyzed in the present paper. A numerical code is employed, and the thermal performance of different building envelopes is evaluated by comparing the temperature and heat flux distribution through the wall assemblies.

2. Methodology

2.1. Numerical modeling of the wall structure

The materials forming the layers of the building structures are analyzed to determine the parameters of each individual layer. To model the transient heat transfer mechanisms through the entire structure, a 2-D finite-difference method is considered. The temperature distributions in the layers used in the wall assembly are obtained using a nodal network at every time step. It should be noted that the numerical code has been validated using the experimental data in the literature [2]. The simulations are performed using the data of 8 hours in advance of the chosen day to ensure convergence of the simulations prior to the day of interest.

2.2. Case Study: EPFL Campus

Since its foundation in 1969, the Ecole Polytechnique Fédérale de Lausanne (EPFL) campus in Lausanne (Switzerland) has continuously grown, and new buildings have been added. The building assemblies constructed in different years vary in wall composition and the type of external cladding used. A comprehensive survey is performed to find various types of claddings used on the EPFL campus. The composition of each wall structure is identified, and the properties of different layers used in the building envelopes are specified. Among various wall assemblies presented on the campus, 4 of them are selected to simulate their thermal performance under real outdoor conditions. In Figure 1, clusters of buildings with similar building envelopes are highlighted on the EPFL campus map.

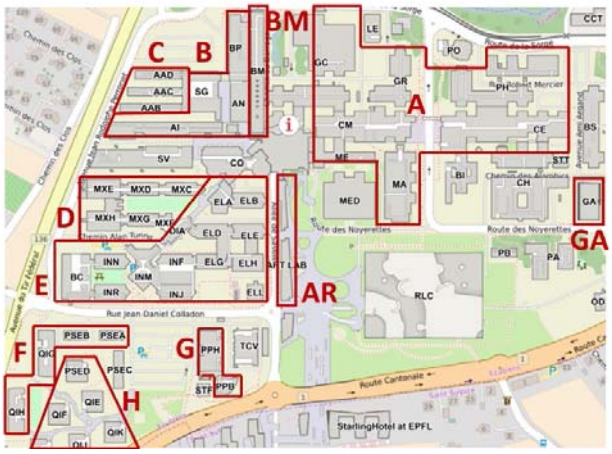

Figure 1. Map of EPFL campus and different clusters defined

2.2.1 *Selected building envelopes***.** The cross-section of different building envelopes studied are shown in Figure 2: **Cluster D** – Building MX (1990); **Cluster E** – Building ELL (1988); **Cluster G** – Building PPH**; Cluster GA1 -** kindergarten with a wooden panel external layer (2018); **Cluster GA2 -** kindergarten with a precast concrete panel external layer (2018). The thermo-physical properties of the materials used in each selection are listed in Table 1.

Table 1. Properties of the different materials [3]

No.	Material	Density [kg/m^3]	Thermal Conductivity [W/(m·K)]	Specific Heat Capacity [J/(kg·K)]	Emissivity [-]	Absorbance [-]
1	Silica Brick	1800	1.14	1000	0.8	0.4
2	Mineral wool	32	0.032	1030	0.8	-
3	Concrete	2400	2	1000	0.94	0.6
4	Reinforced Concrete	2500	2.4	1000	0.94	0.6
5	Precast Concrete	2400	2	1000	0.94	0.6
6	Ceramic Concrete	2100	1.5	1000	0.63	0.65
7	Wood	700	0.18	1600	0.82	0.5
8	Swisspor EPS	25	0.03	1380	0.05	-

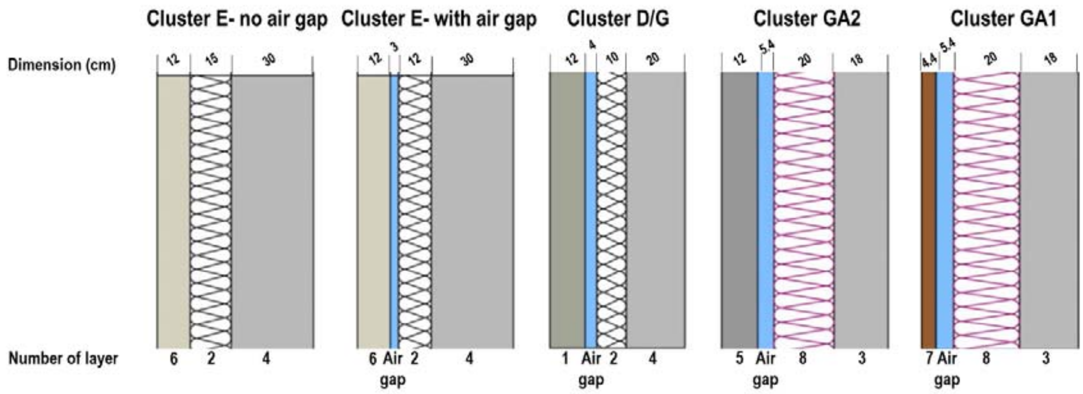

Figure 2. Structure of the wall assemblies studied (the material of each layer is given by a number referring to Table 1)

2.2.2 Weather Data. Figure 3 shows the weather data used for typical days in summer (August 13th) and winter (December 14th) of 2019 using recorded weather data on the EPFL campus [4]. The hottest day in summer 2019 (August 5th) is also considered to examine the impact of extreme conditions on the thermal performance of the building envelope in cluster GA2. The indoor temperature is set to 26°C in summer and 21°C in winter according to the SIA 2024:2015 [5]. It should be noted that the actual temperature indoors needs to be accounted for, and it is a function of the outdoor weather conditions. Considering the Swiss climate, this could likely result in a lower indoor temperature in summer. The horizontal solar radiations measured by the pyranometer are converted to the vertical direction to align with the façades [6].

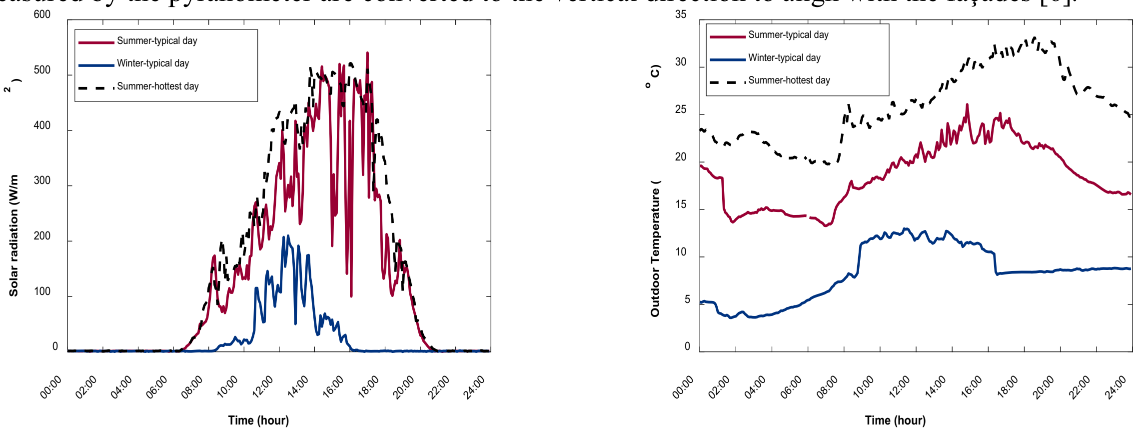

Figure 3. Vertical solar radiation (left) and Outdoor temperatures (right)

3. Results

3.1 Heat flux. The heat flux entering/leaving the interior space of the buildings depends on the temperature of the innermost layer and the indoor temperature. The heat flux passing through the wall assembly for different clusters is shown in Figure 4. Negative values indicate heat losses from the building, while positive ones indicate heat gains. As the values are always negative on typical days, it shows that the innermost layer is always at a lower temperature than the indoor air temperature. This can be explained by the fact that the outdoor air temperature, most of the time in the typical days, is lower than the indoor temperature. The heat losses are more pronounced in winter than in summer, which is due to the higher temperature difference between indoors and outdoors. As shown in the plots, cluster DG is more sensitive to the outdoor conditions compared to the other building structures and has higher variation in the heat flux passing through the wall core throughout the day. This can be attributed to the lower thickness of the insulation layer used in this assembly. By exposing the wall structure in cluster GA2 to the extreme summer conditions, the heat flux passing through the wall core becomes positive most of the time during the day, which is due to the higher outdoor temperature compared to the indoor temperature in this case. This behavior implies the considerable influence of the outdoor conditions on the thermal performance of the wall structure.

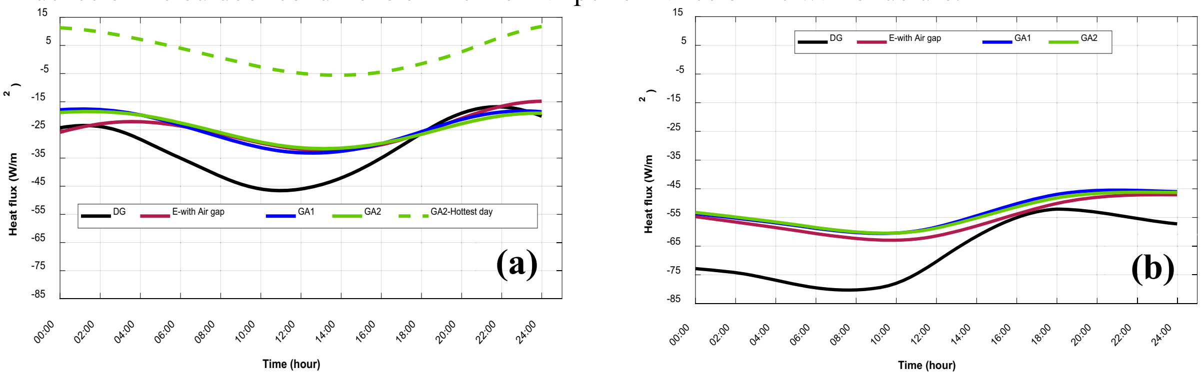

Figure 4. Heat flux passing through the building envelopes in the (a) Summer case and (b) Winter case

3.2 Heat flow in the cavity. As shown in Figure 2, the wall assemblies have a layer of the ventilated cavity that separates the external cladding from the wall core. The heat flow within the air-space plays an important role in its moisture removal and thermal performance [7,8]. The amount of heat flow in the cavity behind the external layer in each case is analyzed in this section. A model developed by [9] is used to determine the mass flow rate of the air in the cavity at each time step, that is a function of the temperature of the airflow at the top and bottom openings, the wind speed, and the local loss coefficients in the air gap. Thereafter, the heat flow carried by the airflow is determined using the mass flow in the cavity and its temperatures at the inlet and the outlet. According to Figure 5, the highest heat flow values are obtained for the wall structures GA1 (in summer) and GA2 (in winter) that have wider cavities compared to the other clusters. As it can be seen in Table 1, the thickness of the external cladding used in cluster GA1 is smaller than the other wall structures. Hence, the temperature gradient in the cladding in this cluster becomes lower, and the airflow in the cavity tends to get warmer for the same solar radiation exposure in summer. Moreover, the response to a temperature change in summer is quicker for the structure GA1 than for the other cases starting at 10:00 in the morning. The difference in the density and the specific heat capacity of the layers leads to variations in the overall thermal mass of the envelope. Therefore, due to the low thermal mass of the layers used in cluster GA1, its response to the temperature variation would tend to be faster and at a greater magnitude. In winter, cluster GA2 most of the time has the highest heat flow among the building structures. This is mainly due to the difference in the conductivity and solar absorptance of the external cladding used in various walls.

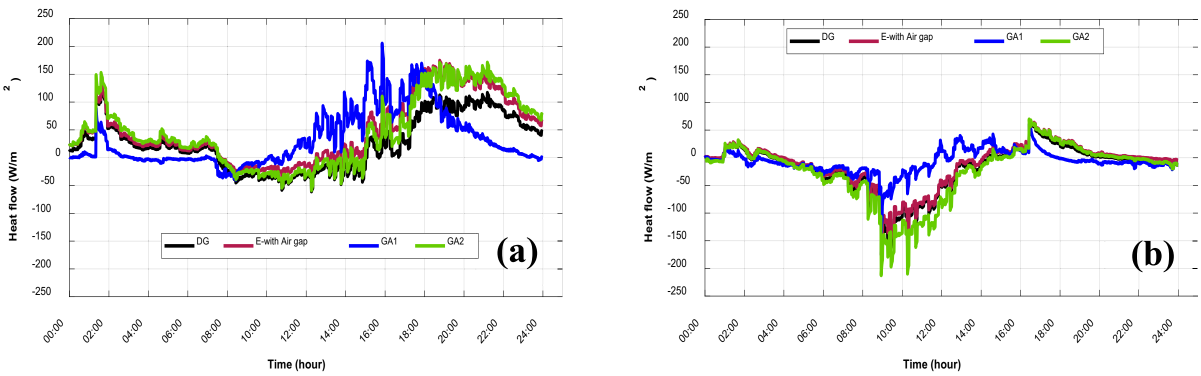

Figure 5. Heat low in the air cavity in the (a) Summer case and (b) Winter case

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3.3 Temperature distribution. The temperature distributions in the middle point on different surfaces through the wall layers are presented in Figure 6. The results show that the thickness of the insulation and the cavity play an important role in dissipating the temperature variation due to the varying outdoor conditions.

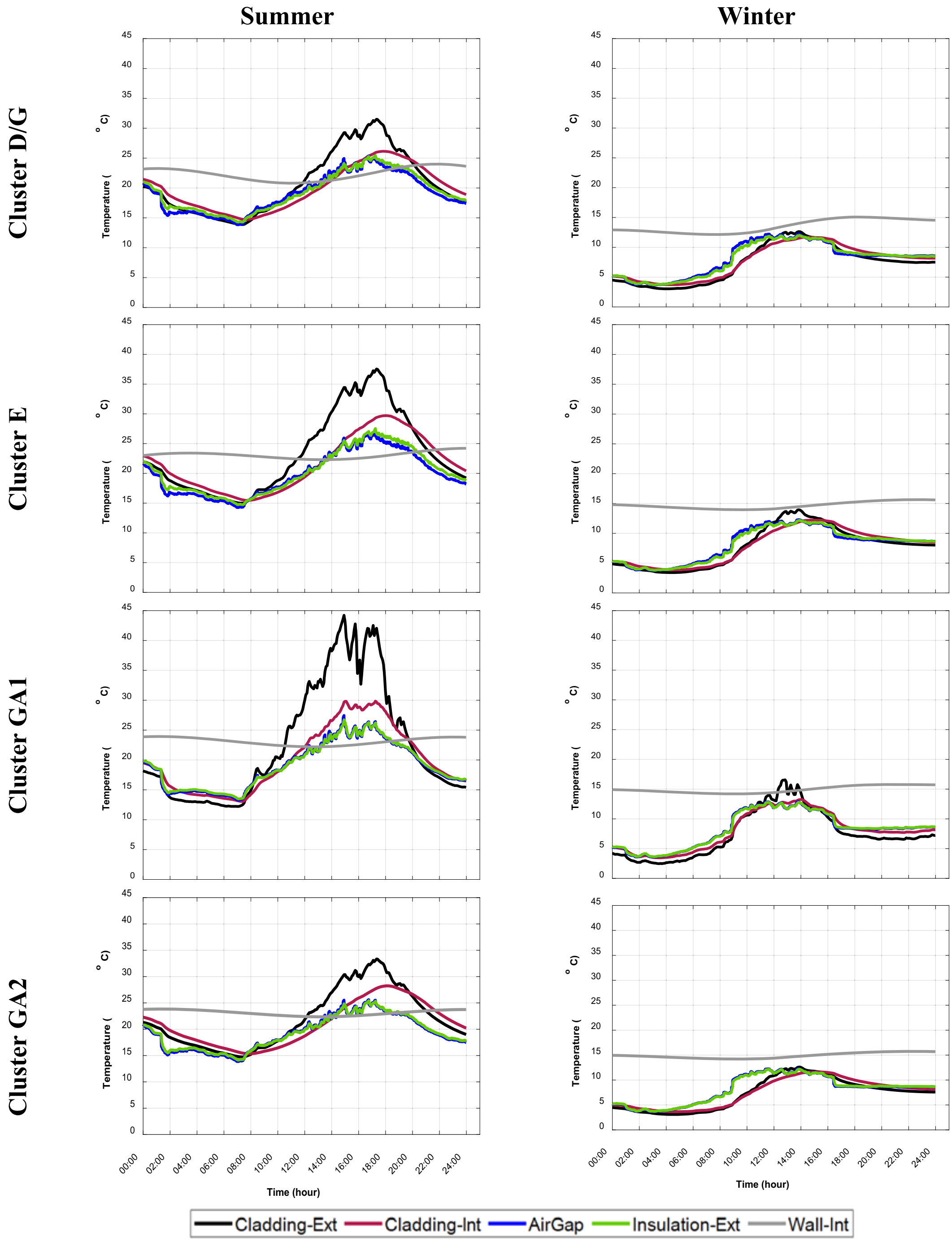

Figure 6. Temperature distribution on different surfaces of the wall assembly

Moreover, the change of temperature is more significant for the external layer than for the internal one. The difference in the thermal mass and conductivity of the external layers cause variations in the evolution of the temperatures of surfaces throughout the day. The highest temperature of the external cladding is observed for the cluster GA1, which confirms that the wooden cladding can easily absorb heat. However, as its conductivity is lower compared to the other claddings, the heat is not transferred through the layer as high as the materials with higher conductivity. In all graphs, a peak of surface temperature is observed in the afternoon, from 12:00 to 17:00, in summer. As it can be seen in Figure 6, since the maximum outdoor temperature usually occurs 2-3 hours after solar noon, the maximum temperature on the exterior surface of the cladding in summer occurs around 16:00-18:00. Conversely, the minimum temperature appears from around 3:00 to 7:00 in the early morning. The minimum outdoor temperature is usually before sunrise. It should be noted that the temperature distribution along the height of the external and internal layers was computed, and it was revealed that the temperatures could vary up to 2-3 °C.

3.4 Impact of the air cavity. Additional analysis is performed to examine the effect of the ventilated air cavity on the thermal performance of the wall structure. The air-space within the structure of cluster E is replaced with an insulation layer (Figure 2). The comparison showed that the presence of an air cavity helps to dissipate the heat flux in both cases. Therefore, it can have a positive impact in summer but a negative effect in winter. It has to be mentioned that the heat flux is usually positive in summer; however, the indoor temperature is always higher than the outdoor temperature in the typical days studied in this paper; therefore, the values are negative in most cases. Based on the results, the presence of an air gap could potentially decrease the heat gains in summer. Conversely, in winter, the dissipation of the heat flux will have a negative impact since it will lead to higher heat losses from the building. Finally, the temperatures of the layers in the wall assembly without the air gap are higher in both summer and winter, which consequently increased the thermal mass and the associated time lag.

4. Conclusions

This study aims to analyze and compare the thermal performances of selected wall assemblies on the EPFL campus by comparing the heat fluxes and temperature distribution through the structures using numerical simulations. It is shown that the properties of the materials and their thermal resistance have an impact on how the envelope dynamically reacts to the environment. In particular, the higher thickness of the insulation layer plays a key role in lowering the heat gains in summer and heat losses in winter. The high thermal mass materials in the wall core can facilitate a greater time lag of the heat flux passing through the assembly, which is beneficial from the energy-saving point of view due to the load shift. The choice of the external layer is another important factor. For the walls that are often exposed to the Sun, the materials with low solar absorption should be used to avoid high temperatures on the exterior surface of the cladding and reduce the heat propagation into the indoor space in summer. These results highlight the importance of considering the dynamic behavior of building envelopes and can be used as references for new buildings to come.

Acknowledgment

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