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An Experimental Evaluation of the Thermal Performance of Felt Type Vegetated Facade System

Elif Özer Yüksel[1] and Nil Türkeri[2]

[1] Department of Architecture, Faculty of Architecture, Gebze Technical University, Kocaeli, Turkey, e.yuksel@gtu.edu.tr

[2] Department of Architecture, Faculty of Architecture, İstanbul Technical University, Kocaeli, Turkey, sahal@itu.edu.tr

Abstract. *Vegetated facade systems (VFS) have been used as green building envelope systems in recent years. Using VFS for ecological strategies and evaluating thermal performance of these sytems are not a new concept. However, there is not any experimental study in literature which evaluates thermal performance of felt type VFS applied on an insulated existing building wall which is located in Csa climate during cooling and heating periods. Hence, an experimental study was conducted to measure thermal performance of felt type (type which used felt material as growing media) VFS in Kocaeli (under Csa climate). Test results indicate that in day time with high amount of solar radiation, felt type VFS decreased exterior surface temperatures of an insulated existing wall by maximum of 30°C. Also, interior surface temperatures of vegetated facade were lower than interior surface temperatures of reference facade with the maxiumum difference of 1.8°C. Although high differences between exterior surface temperatures of vegetated and reference walls were observed, there was no significant difference between interior surface temperatures of vegetated and reference walls. This is due to the fact that existing building exterior wall assembly includes 5 cm thickness expanded thermal insulation material which enchance thermal performance of brick wall. In addition, indoor air temperatures behind both facades were close to each other, and were not suitable according to ISO 7730 and ASHRAE 55 Standards comfort range for representative summer days with high ambient air temperatures. Nevertheless, indoor air temperatures behind vegetated facade were in the comfort range in the fall representative day which required cooling, while indoor air temperatures behind reference facade were not in the comfort range in summer representative day.*

Keywords: *Vegetated Facade System, Thermal Performance, Field Measurement, Surface Temperature, Sustainability.*

1 Introduction

Fourth Assessment Report of Intergovernmental Panel on Climate Change indicates that average temperature on earth has increased by 0.75 °C from the beginning of the 20th century until today (IPCC, n.d.). Additionally, it is predicted that average air temperature on earth will increase by 1.8-4°C at the end of 21th century (MCCAR, n.d.). Also it is claimed that annual average air temperature in Turkey will rise by 2.5-4°C in following years (Turkey's National Climate Change Adaptation Strategy, 2011). Urbanization causes reduction of huge amount of green areas and replaces them with buildings and surfaces with low albedo value (Cheng *et al*., 2010; Koyama *et al*., 2013; Wong *et al*., 2010). These changes cause a significant rise of urban temperature known as heat island effect, which is responsible for the increase of ambient air temperatures (Wong *et al*., 2010; Alexandri and Jones, 2008). Use of vegetated surfaces and vegetated facade systems plays an important role to reduce urban heat island effect (Koyama *et al*., 2013; Alexandri and Jones, 2008; Olivieri *et al*., 2014). Greenhouse effect plays also an important role in the increase of ambient air temperatures. Building sector is responsible of 40% of the CO_2 and other greenhouse gases emissions. With improvements in economic development, energy use in building sector has increased (Perez *et al*., 2017; Technology Roadmap, 2013). In order to decrease greenhouse gases emissions it is essential to use renewable energy sources instead of fossil fuels and/or reduce energy consumptions. Energy consumption caused by building sector can be reduced by several sustainable design strategies. One of them is covering walls with vegetation, that is called as vegetated facade systems (VFS). "Greeney” is a common term in literature, hovewer in the present study it is prefered to nomenclature these systems as “vegetated facade systems” because of the reason that main components of these system are vegetation and growing media. Literature review reveals that vegetated facades minimize heat gain through building facade, decrease surface temperature and increase energy efficiency of buildings (Perez *et al*., 2017; Safikhani *et al*., 2014; Raji *et al*., 2015; Konteleon and Eumorfopoulou, 2010; Haggag *et al*., 2014; Feng and Hewage, 2014; Perini *et al*., 2011). Studies in Köppen subgroup “Csa” (mild with no dry and hot summer climate) indicate that vegetated facade systems reduce the maximum exterior surface temperature of reference building surface up to 25°C in cooling period (Olivieri *et al*., 2014; Akbari *et al*., 1997). Aim of the present paper is to evaluate thermal performance of felt type VFS in Csa climate conditions during cooling period in summer and fall seasons. Also, by means of the results of the present study it is aimed to fill the gap in literature regarding data of thermal performance of VFS applied on insulated wall and lack of data for thermal performance of felt type VFS. Initially, design of vegetated facade, instrumental setup and measurement parameters are presented. Subsequently, solar radiation and surface temperature results are given and values of both vegetated and reference facades are comparatively assessed.

2 Materials and Methods

Thermal performance monitoring was conducted at a building located in Gebze Technical University, Gebze, Kocaeli. Gebze Technical University is located at 40°48'41"N, 29°21'19"E (GTU, 2017). Kocaeli is classified as “Csa” (mild with dry and hot summer climate) according to Köppen climate classification. Vegetated facade system and instruments were installed in the first week of September 2016. Trial tests were done during 5 months after installation of experimental setup. Monitoring including whole parameters are started on 04 February 2017.

2.1 Experimental Building

An existing office building located on Gebze Technical University Campus was chosen as experimental building, two facade surfaces of the building were determined to be used as vegetated and reference facades. Both facades are oriented to the south. They are exposed to solar radiation for the majority of the day (especially hours when solar radiation reaches high values) and there are no obstructions in front of the facades. Also, there is no opening in the respective south oriented walls, both facades are fully opaque and have same dimensions. Window to wall ratio (WWR) of east oriented exterior wall of room which south wall was fully vegetated is 20%, while WWR of east oriented exterior wall of room which south wall was non vegetated is 13%. Spaces behind both facades are office rooms which have approximately similar conditions. Both of them have the same heating and cooling systems, which is air conditioning. It operates between 08:00 and 17:00 during week days and doesn't operate during weekends. Existing wall system of the building is composed of the following components from inside to outside: 19 cm brick wall with 2 cm thickness interior plaster and 5 cm thickness expanded polystrene heat insulation material and 3 cm thickness exterior plaster. This wall system is considered to be reference wall system. Most widely used VFS in Turkey is "felt system" (Yüksel and Türkeri, 2016a). Additionally, there is no previous experimental study in literature in which the thermal performance of a felt type VFS under Csa climate region has been measured during neither cooling period nor heating period (Yüksel and Türkeri, 2016b; Yüksel and Türkeri, 2017). Therefore felt type was chosen as vegetated facade system. Also, "euonymus japonica" was selected due to its well adaptation to survive in temperate and mediterranean climates. The vegetated facade is composed of two main components: existing wall system and vegetated system. Vegetated system consists of following components from inside to outside: 40x40x2mm galvanized steel frame mounted on the wall, PVC panel of 1 cm thickness fixed on this frame, first and second layers of geotextile felt attached on it and vegetation layer embedded the felt pockets.

2.2 Instrumental Setup for Monitoring

An instrumental setup was designed and installed at the reference and vegetated facade systems to measure solar reflectance, surface and air temperatures (Figure 1a,b). Local meteorological data (air temperature and humidity, atmospheric pressure, wind direction and wind velocity) was measured by a weather station installed on the roof parapet of existing building (Figure 1c).

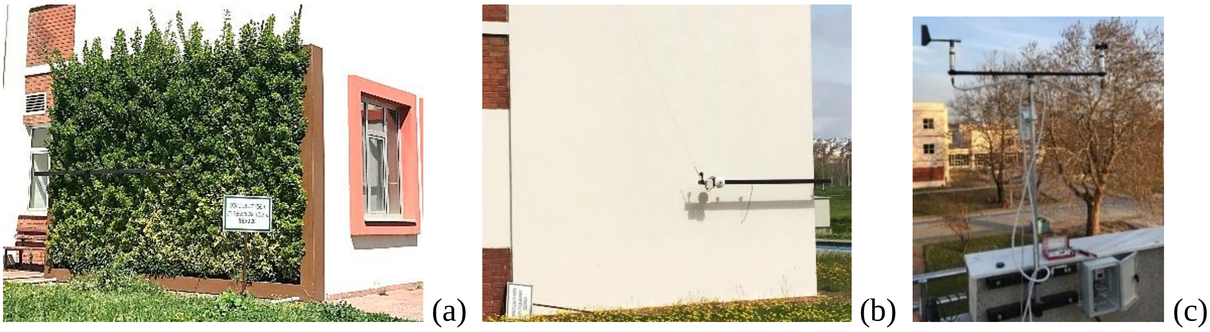

Figure 1. Image of VFS (left) and RFS (middle) and image of the weather station on the roof parapet (right).

Figure 2 designates sections of reference facade and vegetated facade test assemblies. Three pyranometers were used to measure solar radiation incident and solar reflectance. A pyranometer ("I" in Fig. 2b) was installed vertically in front of the vegetated facade to measure solar irradiance reflected from the vegetated facade. Two pyranometers were installed in front of the reference facade vertically and mounted back to back symmetrically. One of these pyranometers, ("D" in Fig. 2a) was used to measure solar radiation incident on reference and vegetated facades and the other ("E" in Fig. 2a) measures solar irradiance reflected from the reference facade. Only one pyranometer was decided to measure incident solar radiation since solar radiation values reaching each both facades are accepted as identical. Infrared non-contact thermometers were used to measure surface temperatures of exterior wall of reference facade ("F" in Fig. 2a), exterior wall of vegetated facade ("N" in Fig. 2b), back ("M" in Fig. 2b) and front ("L" in Fig. 2b) side of the PVC panel, second layer of felt ("K" in Fig. 2b). Contact thermometers were used to measure surface temperatures of interior walls of reference ("G" in Fig. 2a) and vegetated ("O" in Fig. 2b) facades. Also, indoor temperature and humidity sensors were placed 20 cm in front of the interior wall surface of the reference ("H" in Fig. 2a) and vegetated ("P" in Fig. 2b) facades in order the measure indoor air temperature of the rooms behind the vegetated and reference walls. Additionally, a temperature sensor ("J" in Fig. 2b) was placed inside the leaves to measure the air temperature among leaves (Yüksel and Türkeri, 2017).

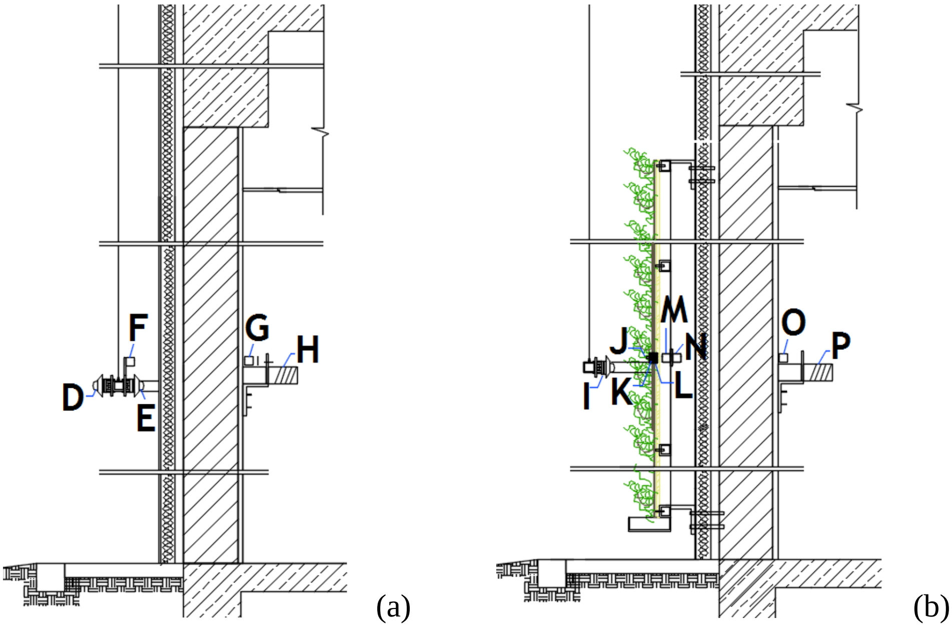

Figure 2. Section of reference facade (left) and vegetated facade (right) test assemblies.

Monitoring periods included months representing summer and fall seasons of the year 2017. Data regarding each parameter was recorded every 10 minutes during these periods. Nevertheless, user behaviours were found to be different in office rooms during weekdays behind vegetated and reference rooms. Hence, representative weekend days were selected for the summer and fall periods when high solar radiation was observed and exterior surface temperatures of reference facade reached maximum values.

3 Test Results

Exterior and interior surface temperatures and indoor air temperatures of vegetated and reference facades were compared with each other. Also, indoor air temperatures were evaluated according to comfort temperature range identified in ISO 7730 and ASHRAE 55 Standards. Additionally, solar reflectance ratio of reference facade and vegetated facades were compared with each other. Solar reflectance ratio were calculated according to ASTM E

1918:2006 (ASTM E1918:2006). For each representative day and for both facades, the ratio of reflected solar irradiance values to total solar irradiance values was calculated between 09:00-15:00. August 12, 2017 and September 24, 2017 were chosen as representative days for the summer and fall periods, respectively, because of the reason that high solar radiation values occured and exterior surface temperatures of reference facade reached maximum values in that hot days. Test results regarding that days such as microclimate values, solar reflectance values of reference and vegetated walls and maximum exterior surface temperatures of reference and vegetated facades are shown in Table 1.

Table 1. Microclimate, solar reflectance and maximum exterior surface temperature values observed on August 12, 2017 and September 24, 2017.

Ambient air temp. ranges	Relative humidity ranges	Max. solar radiation reaching to facades	Max. solar radiation reflecting from RFS	Max. solar radiation reflecting from VFS	Solar reflectance of RFS	Solar reflectance of VFS	Max. exterior surf. temp. of RFS	Max. exterior surf. temp. of VFS
22.4°C - 33.1°C	29% -93%	454W/m^2 (at 14:10)	364W/m^2	54W/m^2	0.88	0.12	53.2°C (at 14:40)	30°C (at 16:40)
13.1°C - 25.6°C	39% -93%	642W/m^2 (at 14:10)	448W/m^2	73W/m^2	0.80	0.10	53.3°C (at 15:00)	23.6°C (at 15:50)

Exterior surface temperatures of vegetated wall were extremely lower than exterior surface temperatures of reference wall for both periods during the day time (Figure 3 and Figure 4).

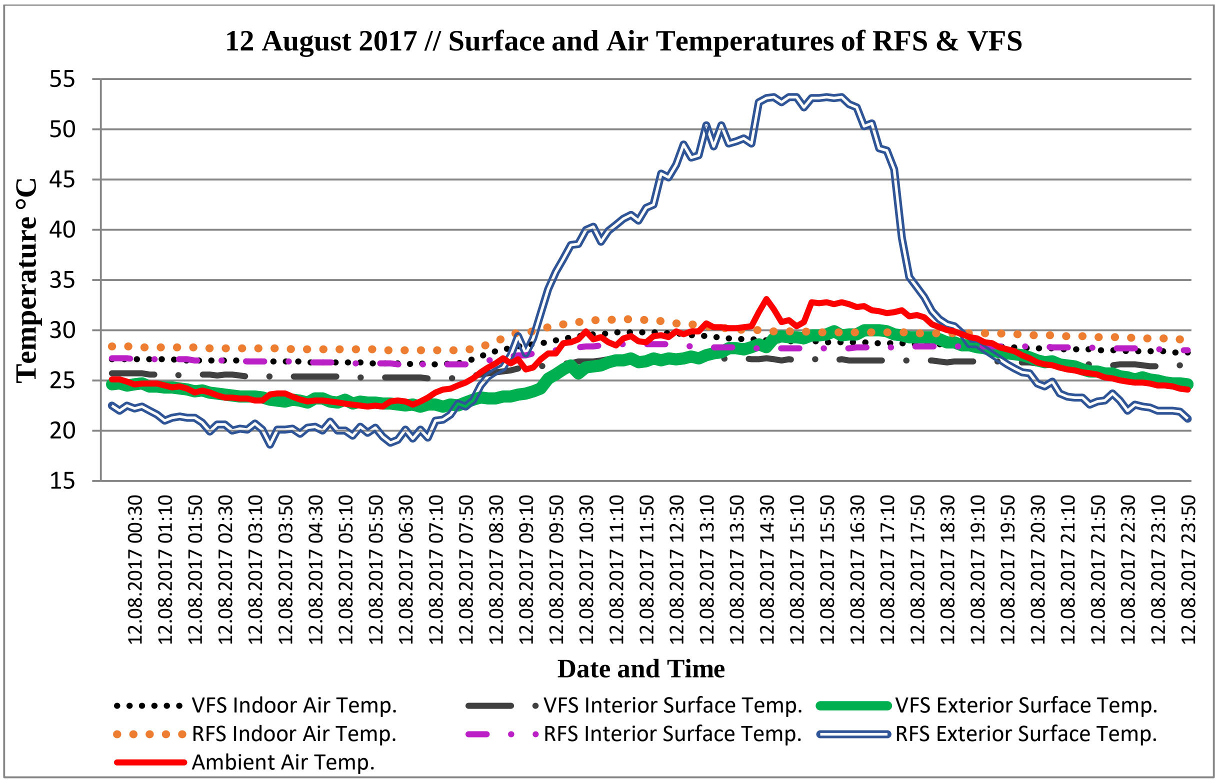

Figure 3. Exterior and interior surface and indoor air temperatures of RFS and VFS on August 12, 2017.

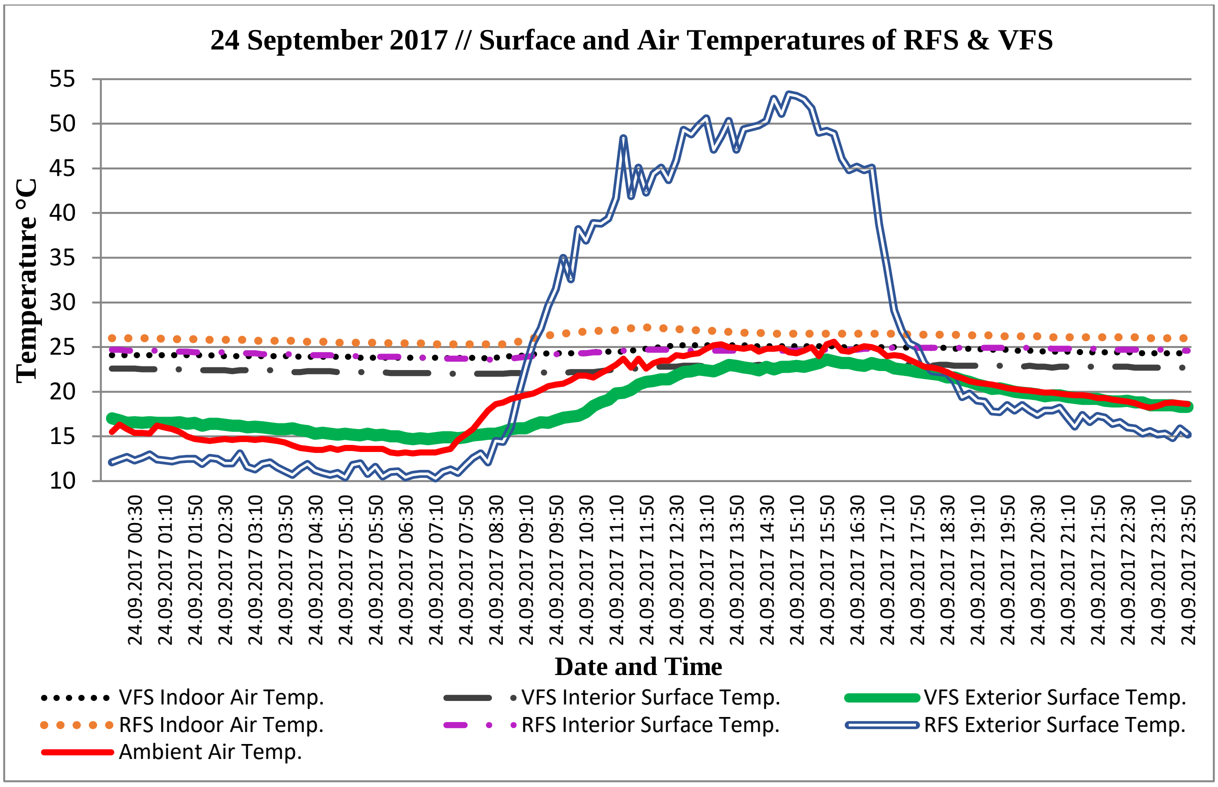

Figure 4. Exterior and interior surface and indoor air temperatures of RFS and VFS on September 24, 2017.

Differences between maximum exterior surface temperatures of reference and vegetated facades were 24°C and 30.5°C for representative days of summer and fall periods, respectively. Also, during the night time, exterior surface temperatures of vegetated wall are higher than exterior surface temperatures of reference walls for both periods. Interior surface temperatures of reference facade were also higher than interior surface temperatures of vegetated facade along the day time. Differences between maximum interior surface temperatures of reference and vegetated facades were 1.3°C and 1.8°C for representative days in summer and fall periods, respectively (Fig. 3 and Fig. 4). Additionally, Fig. 3 presents that on August 12, indoor air temperatures behind both facades were not in the range of 23-26°C which is recommended as a comfort range for cooling period in ISO 7730:2005 Standard and ASHRAE Standard 55-2010. Nevertheless, on September 24, max. indoor air temperature (25°C) behind vegetated facade is lower than upper limit value of 26°C, while maximum indoor air temperature (26.5°C) behind reference facade is higher than 26°C (Fig. 4).

4 Discussion

Although high differences between exterior surface temperatures of vegetated and reference walls were observed, there was no significant difference between interior surface temperatures of vegetated and reference walls. Also, there was no significant difference between indoor air temperatures behind vegetated and reference walls. The results regarding indoor air temperature differences between vegetated and reference facade showed similarities with the results of the study conducted under a different climate condition

(Cfa:humid subtropical climates) by Chen et al., (2013) which revealed that cooling effect of VFS on the indoor environment is relative small because of the high heat resistance of the wall. If the existing exterior wall was designed without any thermal insulation, it is obvious that the VFS would present greater passive cooling effect. In addition, indoor air temperatures behind both rooms were not suitable according to comfort temperature ranges indicated in standards for representative summer day. Nevertheless, indoor air temperatures behind VFS were in the comfort range in the fall representative day in day time which required cooling, while indoor air temperatures behind reference facade were not in the comfort range. Also, it can be claimed that indoor air temperatures of both rooms were not only affected by exterior surface temperatures of south oriented walls, but also by the surface temperatures of interior walls, ceeling, slab and east oriented exterior walls. Also, it can be assumed that vegetated room gained and lost more heat through windows due to higher WWR compared with reference room. It can be claimed that if east facades of both rooms had same WWR, vegetated room would show greater performance in terms of indoor air temperatures compared with reference room.

5 Conclusions

It can be concluded that felt type VFS decreases exterior surface temperatures of an insulated existing wall located in Csa climate. In addition, most remarkable results were observed in fall period, and in that period the differences between exterior surface temperatures of reference and vegetated facades reached to 30.5°C. These results suggest that VFS has a positive contribution on thermal performance of building wall during cooling period. In addition, solar reflectance of reference facade was 3-8 times higher than solar reflectance of VFS. Although solar reflectance of reference facade was higher than solar reflectance of VFS, exterior surface temperature of vegetated facade was significantly lower than exterior surface temperature of reference facade. That is because VFS transfers less energy to exterior wall of building even though VFS absorbs more solar radiation compared with reference facade system. Thus, it can be claimed that VFS uses most of energy reaching on its surface and so transfers less amount of energy to the exterior wall surface of building wall. Also, lower solar reflectance values of VFS indicate that these systems have positive impact on reducing urban heat island effect.

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ORCID

Elif Özer Yüksel: https://orcid.org/0000-0002-1041-8748
Nil Türkeri: https://orcid.org/0000-0003-4060-6528

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