A litterature review of experimental setups monitoring thermal performance of vegetated facade systems

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Abstract

The decline of green spaces through urbanization, the urban heat island effect resulting from the use of materials with low albedo value, and the greenhouse effect occurring as a result of the consumption of fossil fuels all lead to an increase in ambient air temperature. Use of roof, facade, and pavement materials with high albedo value and vegetated surfaces play an important role in reducing the urban heat island effect. It is essential to use renewable energy sources instead of fossil fuels and/or reduce energy consumption in order to decrease the greenhouse effect. There are various numerical and experimental studies in some countries of the world that investigate the contribution of vegetated facade systems (VFS) used as energy-efficient and sustainable systems to improve the thermal performance of the building envelope. However, in Turkey there has been no empirical study to measure and evaluate the thermal performance of VFSs. Therefore, a PhD thesis is being conducted at Istanbul Technical University to measure thermal performance of vegetated facade systems under Kocaeli climate (temperate humid) conditions. In the present study, a literature review investigating existing experimental setups has been conducted and experimental approaches are being complied, classified and tabulated. Hence, test assemblies, types of measured variables, sensors that have been used to measure different parameters, and location of the sensors within the assemblies have been determined. In addition, the resulting recommendations for further experimental studies have been put forward. The aim of the study is to explain and evaluate the existing experimental setups and, based on these and context-limitations of the thesis, put forward the details of experimental setup that will be used for the thesis.

Keywords

Vegetated Facade Systems (VFS), living walls, thermal performance, experimental setup, test assemblies

DOI 10.7480/jfde.2017.2.1742

1 INTRODUCTION

According to the Fourth Assessment Report of IPCC (Intergovernmental Panel on Climate Change), the average air temperature on earth has increased by 0.75°C since the beginning of the 20th century (IPCC, 2007; MCCAR). There are several adverse effects of air temperature increase on human health, such as respiratory problems, cardiovascular diseases, and infections [WHO, 2003; EPA]. Urban heat island effect and greenhouse effect are the main causes of ambient air temperature increase. In order to reduce heat island effect it is essential to use surface materials with high albedo value and vegetated surfaces (Nuruzzaman, 2015; Taha, 1997). It is also essential to use renewable energy sources instead of fossil fuels and/or to reduce energy consumption in order to decrease the greenhouse effect. In literature, there are various studies that outline the contribution of vegetated facade systems (VFS) on improving the thermal performance of building envelopes. However, in Turkey, no experimental study has yet measured and evaluated the thermal performance of VFSs. Therefore, a PhD thesis is being conducted at Istanbul Technical University to measure the thermal performance of vegetated facade systems under Kocaeli climate (temperate humid) conditions for which it is essential to determine the details of an experimental setup of vegetated and reference facades. The aim of this study is to propose the experimental setup that will be used for the thesis. Initially, classification of VFSs are presented. Subsequently, a literature review of existing experimental setups installed to measure thermal performance of VFS is put forward. Based on the results of the literature review, details of the experimental setup to be installed to measure the thermal performance of a felt type VFS are put in place. In the final part of the paper, plans and sections of the experimental setup of the vegetated and reference facades have been drawn, and which show types and location of sensors, parameters to be measured, and vegetated and reference facade assemblies.

2 DIFFERENT TYPES OF VEGETATED FACADE SYSTEMS

There are different classifications for VFSs. One classifies VFSs in two main categories, as green facades and as living walls (Fig. 1). The location of growing media plays an important role in this type of classification (Safikhani, Abdullah, Ossen, & Baharvand, 2014). In a green facade, climbing plants are rooted on the ground or in planter boxes that hold soil (Safikhani et al., 2014; Mir, 2011). Green facades can be divided into three categories: traditional, double skin, and perimeter flowerpots systems (Perez, Rincon, Vila, Gonzalez, & Cabeza, 2011; Perez, Coma, Martorell, & Cabeza, 2014). Additionally, green facades can be divided into two categories as direct and indirect systems (Manso & Gomes, 2015). Traditional (direct) green facades are systems in which climber plants use the facade material as a support and attach to the building wall directly (Perez et al., 2011; Manso & Gomes, 2015). Double skin (indirect) green facades include a supporting structure for climbing plants to grow vertically, thus creating a green curtain separated from the wall (Perez et al., 2011; Manso & Gomes, 2015). Perimeter flowerpots are the type of green facades where hanging shrubs are planted around the building (Perez et al., 2011; Perez et al., 2014). In living walls, shrubs or various plant species are grown in pre-vegetated or in-situ panels that are attached to a frame or to building wall directly (Safikhani et al., 2014; Mir, 2011). There two main types of living walls: the felt system and the panel system. The felt system is a type of VFS where plants are supported by a continuous geotextile felt (Perez et al., 2014). Panel systems are composed of panels made of plastic, metal, concrete etc. that are fixed to a structural wall or frame. These panels are perforated, and these perforations hold substrates and plants (Perez et al., 2011; Perez et al., 2014).

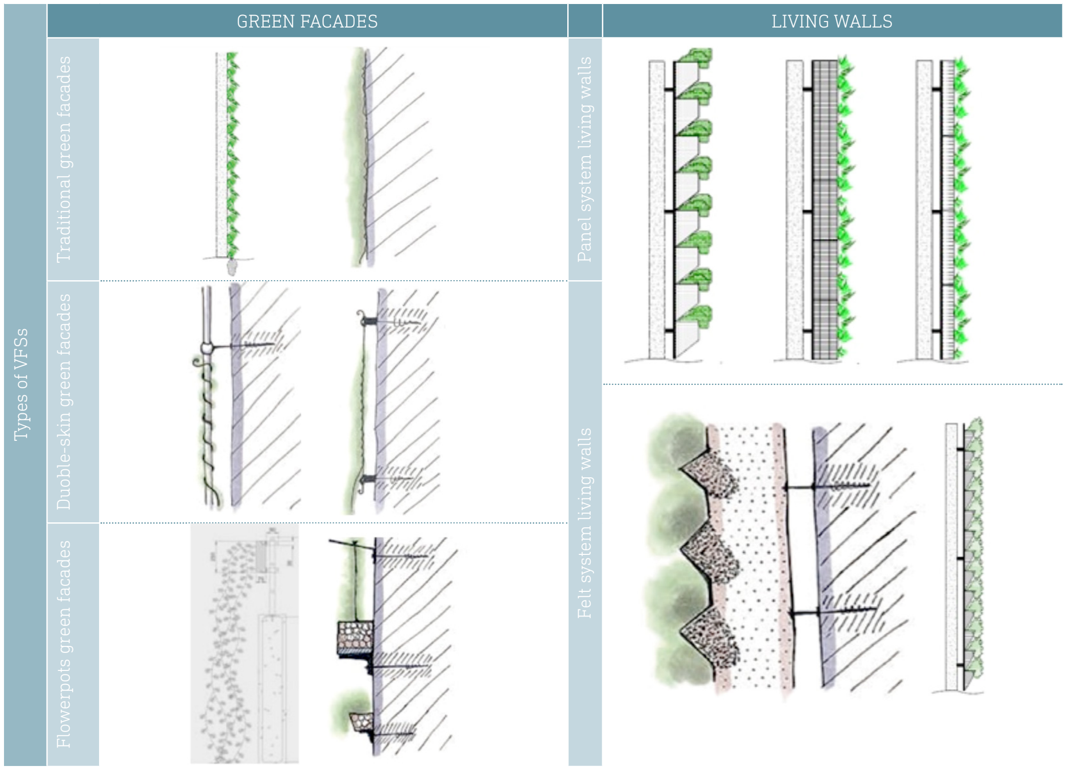


FIG. 1 Classification of VFSs (Mir, 2011; ÖkoKauf Wien)

3 LITERATURE REVIEW OF EXISTING EXPERIMENTAL SETUPS

By means of a literature review, 20 experimental studies evaluating the thermal performance of VFSs have been analyzed in terms of measured parameters, types and location of sensors, and assemblies of reference and vegetated wall setups. In this paper these studies are categorized according to Köppen climate classification as "Group A (tropical climates)", "Group B (dry and arid climates)","Group C (temperate climates)" and "Group D (continental climates)". Table 1 presents the location of the experimental setup, the type of VFS whose thermal performance has been measured, images of reference and vegetated facade assemblies, and measured parameters. To sum up results obtained from Table 1, many parameters are measured to show the thermal performance of a VFS, especially ambient air temperature, solar irradiance, and exterior, interior and substrate surface temperatures of the reference and vegetated facade. As seen in Table 1, exterior air temperature and exterior surface temperature of the vegetated and reference wall have been measured in all studies. The interior surface and air temperature of the vegetated and reference wall are measured in 10 studies. The thermal performance of felt type vegetated facade systems has also been measured in two studies. In one of these studies, conducted in Venice and Lonigo in Italy, by Mazzali, Peron, Romagnoni, Pulselli, and Bastianoni (2013), parameters such as ambient air temperature and humidity, wind velocity, surface temperature of the felt layer, back and front surface temperature of PVC panel, exterior and interior surface temperature of the vegetated and reference walls, and solar irradiance reaches to the facade are measured (Table 1). In another study conducted in Singapore by Wong et al.(2010), parameters such as ambient air temperature and humidity, wind velocity and direction, surface temperature of felt layer, and exterior surface temperature of the vegetated and reference walls are measured (Table 1).

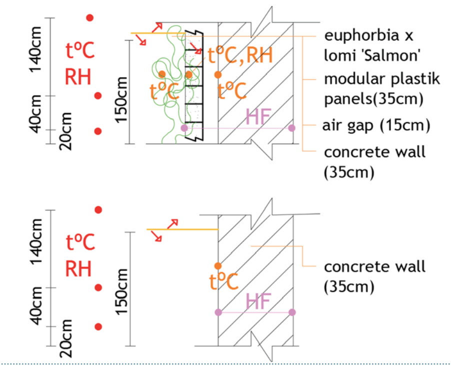
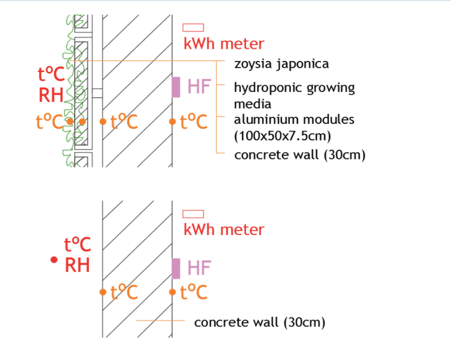
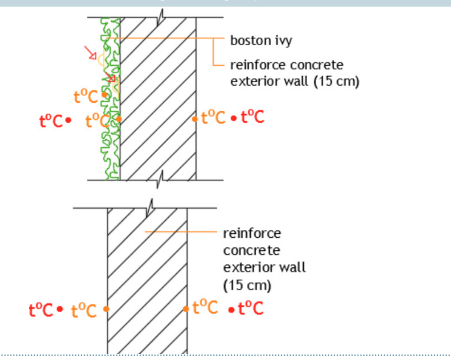
KÖPPEN GROUP LOCATION AUTHOR,YEAR		TYPES OF VFS / SCHEMATIC IMAGES OF WALL ASSEMBLIES/ LOCATION OF SENSORS	MAIN PARAMETERS
GROUP C: "Cwa" humid subtropical/ mild with dry winter and hot summer	Hong Kong, China Jim et all, 2011	**Panel System**  Plant species: euphorbia x lomi 'salmon'	• Ambient air temp., humidity and dew point temperature • Plant surface temperature • Soil surface temperature • Exterior surface temperature of ref. and veg. walls • Solar radiation reaching to and reflected from facade • Heat flux
GROUP C: "Cwa" humid subtropical/ mild with dry winter and hot summer	Hong Kong, China Cheng et all, 2010	**Panel System**  Plant species: zoysia japonica	• Ambient air temperature, humidity • Plant surface temperature, humidity • Substrate surface temperature • Exterior and interior surface temp. of ref. and veg. walls • Solar radiation reaching to and reflected from facade • Heat flux
GROUP C: "Cfa" humid subtropical / mild with no dry season, hot summer	Tokyo, Japan Hoyano, 1988	**Traditional (direct greening) System**  Plant species: parthenocissus tricuspidata	• Ambient air temperature • Air velocity among leafs • Plant surface temperature • Exterior and interior surface temp. of reference and vegetated walls • Indoor air temperature • Heat flux • Solar radiation reaching behind and front of leaves

TABLE 1 Details of existing experimental setups measuring thermal performance of VFS (Mazzali et al., 2013; Perini et al., 2011)

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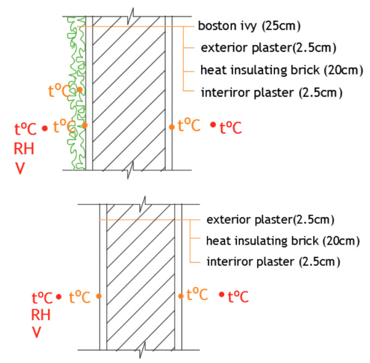
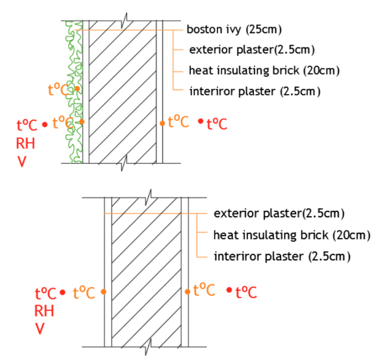
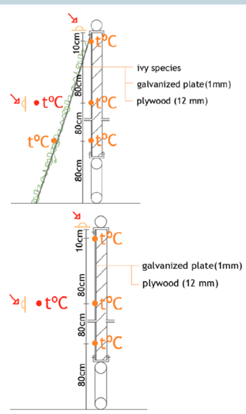
KÖPPEN GROUP LOCATION AUTHOR,YEAR		TYPES OF VFS / SCHEMATIC IMAGES OF WALL ASSEMBLIES/ LOCATION OF SENSORS	MAIN PARAMETERS
GROUP C: **"Cfa" humid subtropical** / mild with no dry season, hot summer	Thessaloniki, Greece Eumorfopolou,2009	Traditional (direct greening) System  Plant species: parthenocissus tricuspidata	• Ambient air temperature, humidity, wind velocity and direction • Exterior and interior surface temperature of reference and vegetated walls • Air temperature among leaves • Indoor air temperature and humidity • Solar radiation reaching facade
	Greece Konteleon et all, 2010		• Ambient air temperature, humidity, wind velocity and direction • Exterior and interior surface temperature of reference and vegetated walls • Air temp. among leaves • Indoor air temperature and humidity • Solar radiation reaching facade
	Nagoya, Japan Koyama et all., 2013	 Plant sp.: momordica, ipomoea, canavalia etc.	• Ambient air temperature • Exterior surface temperature of reference and vegetated walls • Solar radiation on vertical and horizontal surface • Leaf transpiration rate and solar transmittance, total number of leaves, leaf percentage coverage etc.

TABLE 1 Details of existing experimental setups measuring thermal performance of VFS (Mazzali et al., 2013; Perini et al., 2011

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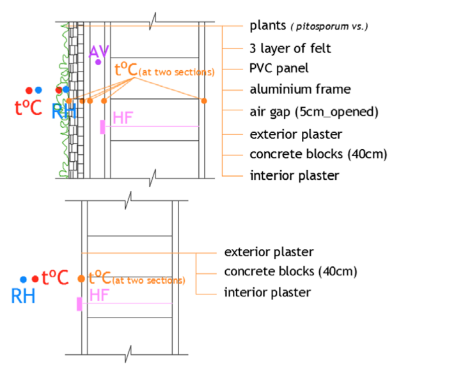
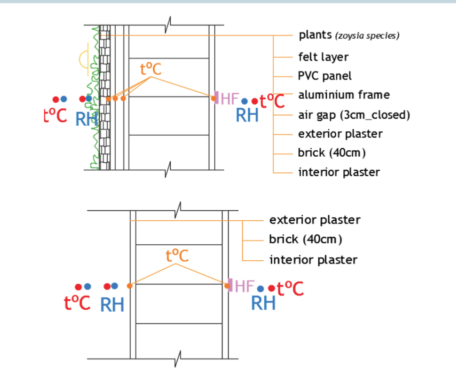
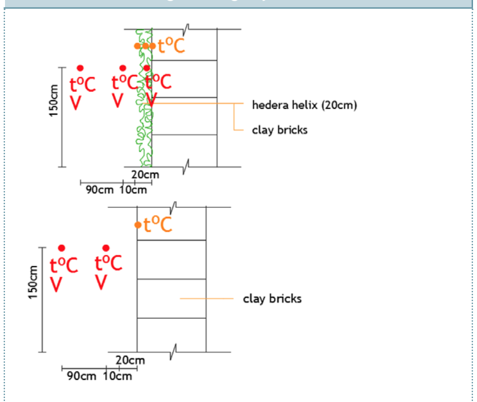
KÖPPEN GROUP LOCATION AUTHOR,YEAR		TYPES OF VFS / SCHEMATIC IMAGES OF WALL ASSEMBLIES/ LOCATION OF SENSORS	MAIN PARAMETERS
GROUP C: **"Cfa" humid subtropical** / mild with no dry season, hot summer	Lonigo, Italy, Mazzali et all., 2013	**Felt System**  Plant species: juniperus, sedum, geranium spp., etc.	• Ambient air temperature and relative humidity, air velocity • Substrate surface temperature • Panel surface temperature • Exterior and interior surface temperature of reference and vegetated walls • Heat flux • Solar radiation
	Venice, Italy Mazzali et all., 2013	**Felt System**  Plant species: zoysia japonica	• Ambient air temperature and relative humidity, air velocity • Panel surface temperature • Exterior and interior surface temperature of reference and vegetated walls • Indoor air temperature and humidity • Heat flux • Solar radiation
GROUP C: **"Cfb"** marine west coast / mild with no dry season, warm summer	Delft, Holland Perini et all., 2011	**Traditional (direct greening) System**  Plant species: hedera helix	• Ambient air temperature and relative humidity, air velocity of 1m and 10cm in front of the bare and green facade and in the middle of the plant layer • Air temperature and velocity among leaves • Surface temperature on inner and outer leaves • Exterior wall surface temperature

TABLE 1 Details of existing experimental setups measuring thermal performance of VFS (Mazzali et al., 2013; Perini et al., 2011)

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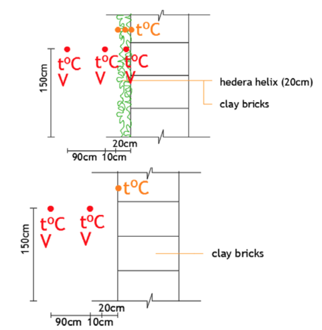
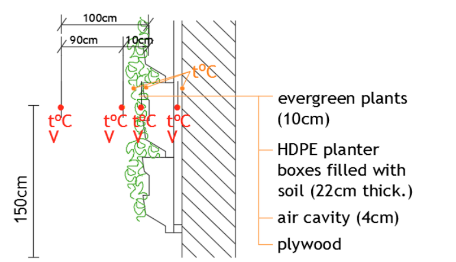
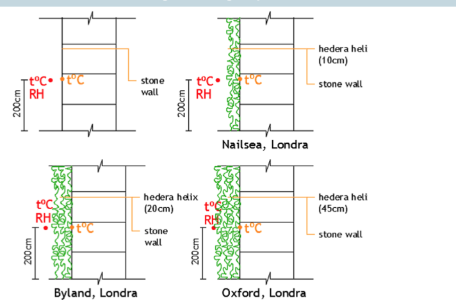
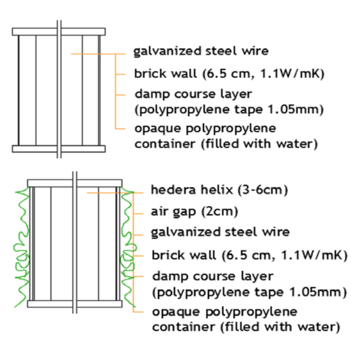
KÖPPEN GROUP LOCATION AUTHOR,YEAR		TYPES OF VFS / SCHEMATIC IMAGES OF WALL ASSEMBLIES/ LOCATION OF SENSORS	MAIN PARAMETERS
aGROUP C: **"Cfb"** marine west coast / mild with no dry season, warm summer	Rotterdam, Holland Perini et all., 2011	**Double Skin (indirect greening) System**  Plant species: hedera helix, vitis spp., clematis spp., jasmine spp., pyracanta spp.	• Ambient air temperature and relative humidity, air velocity of 1m and 10cm in front of the bare and vegetated facade, in the middle of the plant layer and air cavity • Surface temperature on inner and outer leaves • Exterior wall surface temperature
	Benthuizen, Holland Perini et all., 2011	**Panel System**  (no bare facade was available to compare) Plant species: no information	• Ambient air temp. and relative humidity, air velocity of 1m and 10cm in front of green facade, in the middle of the plant layer and air cavity • Surface temp. behind leaves placed in boxes • Exterior wall surface temp.
	London, England Sternberg et all., 2011	**Traditional (direct greening) System**  Plant species: hedera helix	• Ambient air temperature and relative humidity • Exterior wall surface temperatures
	Sheffield, London, Cameron et all., 2015	Double Skin (indirect greening) System  Plant species: hedera helix	• Ambient air temperature • Surface temperature of leaves • Exterior wall surface temperatures

TABLE 1 Details of existing experimental setups measuring thermal performance of VFS (Mazzali et al., 2013; Perini et al., 2011)

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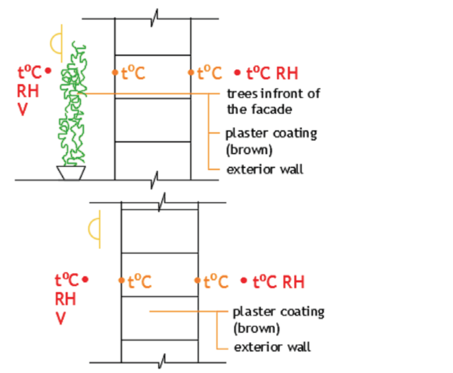
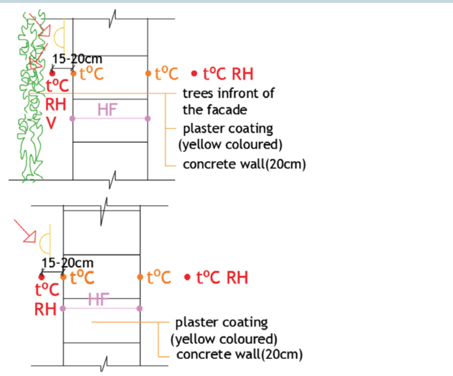
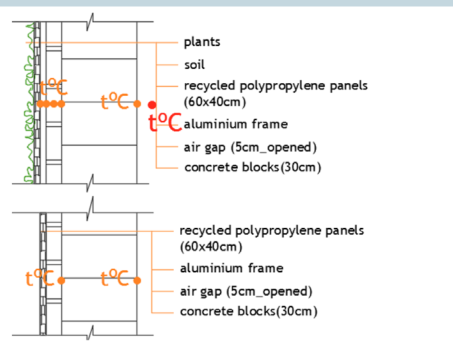
KÖPPEN GROUP LOCATION AUTHOR,YEAR		TYPES OF VFS / SCHEMATIC IMAGES OF WALL ASSEMBLIES/ LOCATION OF SENSORS	MAIN PARAMETERS
GROUP C: **"Csa"** Mediterranean / mild with no dry and hot summer	California, USA Akbari, 1997	Double Skin System/ planter pots in front of the facade  Plant species: no information	• Ambient air temperature and relative humidity, air velocity and direction • Ceiling and roof surface temperature • Exterior and interior surface temperature of walls • Indoor air temperature and humidity • Solar radiation
	Athens, Greece Papadakis et all, 2001	Double Skin System/ planter pots in front of the facade  Plant species: no information	• Ambient air temperature and relative humidity, air velocity • Exterior surface temperature of reference and vegetated walls • Solar radiation • Positive and negative heat flux
GROUP C: **"Csa"** Mediterranean / mild with no dry and hot summer	Pisa, Italy Mazzali et all., 2013	**Panel System**  Plant sp.: Zoysia spp. Cynodon spp., Dicondra vs.	• Surface temperature of soil • Surface temperatures of polypropylene panel • Exterior surface temperature of reference and vegetated walls • Indoor air temperature

TABLE 1 Details of existing experimental setups measuring thermal performance of VFS (Mazzali et al., 2013; Perini et al., 2011)

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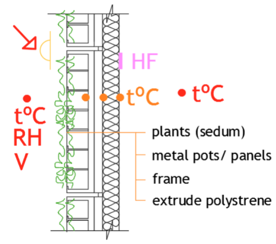
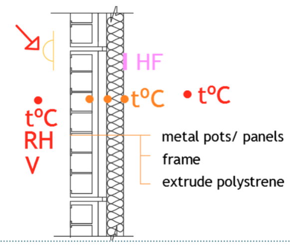
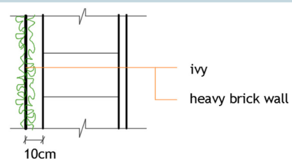
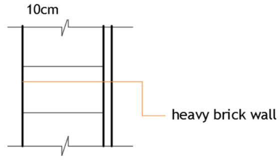
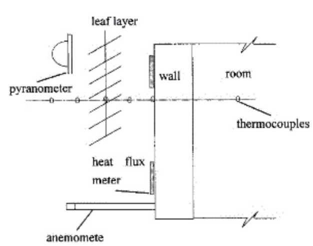
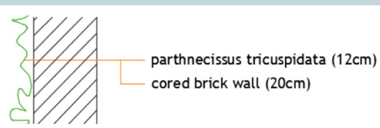
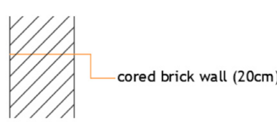
KÖPPEN GROUP LOCATION AUTHOR,YEAR		TYPES OF VFS / SCHEMATIC IMAGES OF WALL ASSEMBLIES/ LOCATION OF SENSORS	MAIN PARAMETERS
GROUP C: "Csa" Mediterranean / mild with no dry and hot summer	Madrid, Spain Olivieri et all., 2014	**Panel System**   Plant species: sedum sp.	• Ambient air temperature and relative humidity, air velocity • Surface temperature of panel • External and internal surface temperature of thermal insulation • Indoor air temperature • Heat flux
	Pekin, China Di, et all., 1999	**Traditional (direct greening) System**    Plant species: no information	• Exterior wall surface temperature • Leaf surface temperature • Ambient air temperature of 5cm in front of the facade and 5cm and 10cm in front of the leaves • Indoor air temperature • Wind velocity • Solar radiation • Heat flux
	Chicago, USA Susorova et all., 2013	**Traditional (direct greening) System**   Plant species: parthenecissus tricuspidata	• Ambient air temperature • Air velocity in front of the facade • Leaf surface temperature • Air temperature inside the leaf layer • Exterior and interior wall surface temperatures • Relative humidity • Solar radiation

TABLE 1 Details of existing experimental setups measuring thermal performance of VFS (Mazzali et al., 2013; Perini et al., 2011)

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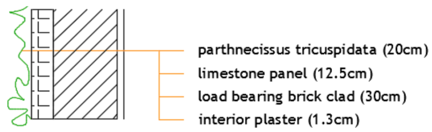
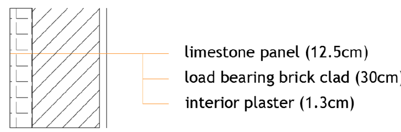
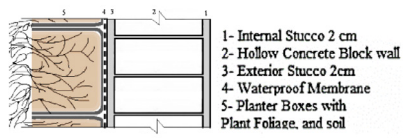
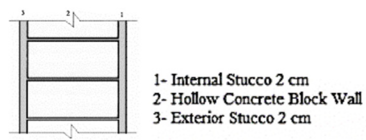
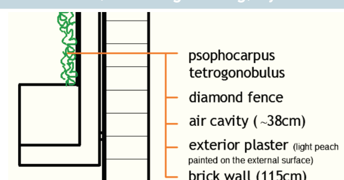
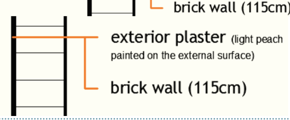
KÖPPEN GROUP LOCATION AUTHOR,YEAR		TYPES OF VFS / SCHEMATIC IMAGES OF WALL ASSEMBLIES/ LOCATION OF SENSORS	MAIN PARAMETERS
	Chicago, USA Susorova et all., 2014	Traditional (direct greening) System   Plant species: parthenecissus tricuspidata	• Ambient air temperature and relative humidity of 5cm in front of the ref. and veg. facades and air velocity of 15 cm in front of facades • Solar radiation on horizontal and vertical surface • Exterior and interior wall surface temperatures • Indoor air temperature and relative humidity • Heat flux
GROUP B: **"Bwh"** subtropicak desert/ low-latitude desert	Abu Dhabi, UAE Haggag vet all, 2014	**Panel System**   Plant species: no information	• Ambient air temperature of 1m in front of the facade • Exterior and interior wall surface temperatures • Indoor air temperature
GROUP A: **"Af"** tropical wet / no dry season	Penang, Malaysia Rahman et all., 2011	**Double Skin (indirect greening) System**   Plant species: Psophocarpus tetrogonobulus	• Ambient air temperature • Exterior and interior wall surface temperatures • Indoor air temperatures, humidity and air velocity • Solar radiation

TABLE 1 Details of existing experimental setups measuring thermal performance of VFS (Mazzali et al., 2013; Perini et al., 2011)

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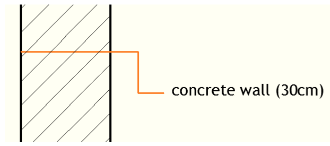
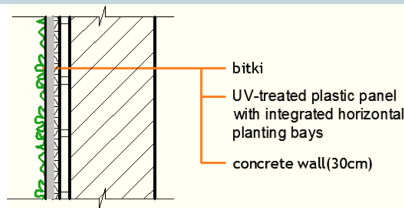
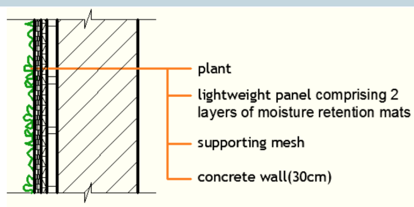
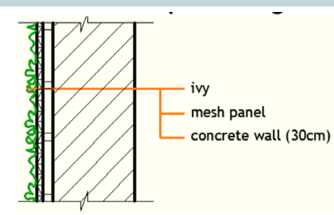
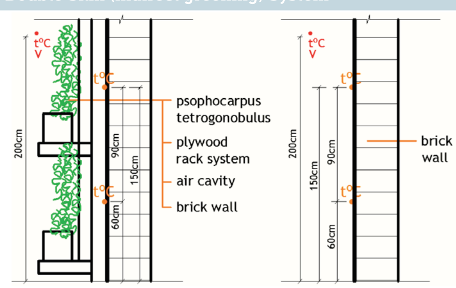
KÖPPEN GROUP LOCATION AUTHOR,YEAR	TYPES OF VFS / SCHEMATIC IMAGES OF WALL ASSEMBLIES/ LOCATION OF SENSORS	MAIN PARAMETERS
GROUP A: "Af" tropical wet / no dry season Singapore Wong et all., 2010	**Reference Wall**  *all of the samples are not shown in the table	• Ambient air temp. and relative humidity, air velocity, direction and rainfall • Ambient air temperature and humidity of 15,30,60 and 100cm in front of the vegetated and reference facades • Surface temperature of substrate • Exterior surface temperatures of reference and vegetated walls
	Panel System  	
	Felt System  	
	Double Skin (indirect greening) System  	
GROUP A: "Af" tropical wet / no dry season Penang, Malaysia Basher et all., 2016	**Double Skin (indirect greening) System**  Plant species: Psophocarpus tetrogonobulus	• Ambient air temperature • Air velocity • Exterior wall surface temperature

TABLE 1 Details of existing experimental setups measuring thermal performance of VFS (Mazzali et al., 2013; Perini et al., 2011)

According to the literature review, it can be claimed that **ambient air temperature** and **exterior surface temperature** of vegetated and reference walls have been measured in all studies.
The interior surface temperature of vegetated and reference walls and the indoor air temperature behind the vegetated and reference walls are measured in fewer studies. Furthermore, in some studies evaluating the thermal performance of a panel system, there is no data given about surface temperature measurements of growing media or substrate.

In order to obtain reliable results about the thermal performance of vegetated facade systems and heat transfer through the vegetated and reference walls, it is recommended that the following be measured: exterior air temperature and relative humidity; wind velocity and direction; solar radiation reaches to and reflected from the facade; exterior and interior surface temperatures of the wall; indoor air temperature and relative humidity; and the surface temperature of growing media (necessary for only felt and panel systems). Recommendations for further studies are given based on the different types of vegetated facade systems.

The measurement of various types of vegetated facade systems are required with regard to different parameters. It is recommended that, for further studies regarding thermal performance of **traditional green facade systems**, the following be measured: microclimate parameters (ambient air temperature, relative humidity, wind direction and velocity, air pressure); air temperature among leaves; exterior surface temperature of vegetated and reference walls, interior surface temperature of reference walls; indoor air temperature of room; and solar radiation reaches to and reflected from the vegetated and reference facade.

For **double-skin green facade systems**, it is necessary to measure additional parameters measure such as the air temperature of the air cavity between the wall and mesh/cable/rope, and the air velocity in the cavity.

It is also recommended that for further studies regarding thermal performance of **panel type living wall systems**, the following be measured: microclimate parameters (ambient air temperature, relative humidity, wind direction and velocity, air pressure); air temperature among leaves; exterior surface temperature of vegetated and reference walls; surface temperature of growing media (soil, mineral granules, coconut fibers, recycled fabric, aminoplast resin foam etc.); surface temperature of panel (plastic, metal, concrete etc.), interior surface temperature of reference walls; indoor air temperature of rooms; and solar radiation reaches to and reflected from the vegetated and reference facade.
Parameters such as microclimate parameters, air temperature among leaves, exterior surface temperature of vegetated and reference walls, surface temperature of felt layer (2 or 3 layers of felt/ finishing layer of felt), surface temperature of panel (polyvinylchloride panels), interior surface temperature of reference walls, and indoor air temperature of rooms, should all be measured in studies to evaluate the thermal performance of **felt type living wall systems**.

Based on the measured parameters that show the thermal performance of the felt type vegetated facade system in literature, parameters have been determined that are to be measured in the PhD thesis. Accordingly, ambient air temperature and humidity, wind velocity and direction, surface temperature of felt layer, back and front surface temperature of PVC panel, exterior and interior surface temperature of the vegetated and reference wall, interior air temperature behind the vegetated and reference facades, solar irradiance that reaches the facades, and solar irradiance reflected from the vegetated and reference facades are determined as parameters to be measured in the PhD thesis.

In addition, as a conclusion of the literature review, it can be claimed that there is, as yet, no detailed information about the location of sensors. According to results obtained from the literature review, the height of sensors/instruments or the distance of sensors from the ground are indicated only in 5 of the 20 studies, and 7 of the 24 different setups. In some studies, sensors used to measure the same parameters are located at different heights within experimental setups, thus different surface temperatures at different heights of the same setups have been shown. Additionally, the location of sensors differs according to design features of the experimental setups in the studies. It can be claimed that in most of the studies the distance of sensors from the ground level varies between 100cm and 200cm, while in a few studies the distance is less than 100cm. Thermal bridge area is an important key factor in determining the location of sensors. Considering the thermal effects of thermal bridge areas, measurement sensors should be placed at a minimum of 100cm above ground level, or away from any thermal bridge area. Based on these criteria and data obtained from literature review, the location of sensors to be placed on the proposed experimental setup for the thesis is determined in Section 4.

4 DETAILS OF EXPERIMENTAL SETUP TO BE INSTALLED TO MEASURE THE THERMAL PERFORMANCE OF VFS

In order to install the experimental setup for the PhD study it is essential to choose an existing building whose exterior wall will be vegetated and used as reference. The measurement parameters of vegetated and reference facades, location and types of sensors measuring these parameters, the area of vegetated facade system (dimensions, height, width of the VFS), and types of VFS and plant species must also be established. In previous studies it was decided that the thermal performance of a “felt type” vegetated facade system will be measured in the PhD study as it is the most widely used vegetated facade system in Turkey. Additionally, there is no previous experimental study in which the thermal performance of a "felt type" vegetated facade system under Csa climate region has been measured during a heating and cooling period in literature (Yüksel & Türkeri, 2016a; Yüksel & Türkeri, 2016b). The "felt type" of vegetated facade system has been chosen to be installed as the experimental setup, following results obtained from previous studies (Yüksel & Türkeri, 2016a; Yüksel & Türkeri, 2016b).

In the present paper, parameters and types of sensors that will be measured in the PhD thesis have been specified by means of the literature review, and having regard to existing experimental setups. In addition, the design criteria of the experimental setup have been explained in Table 2. The selected plant species is “euonymus japonica”, which is evergreen and suitable for local climate conditions and vertical vegetation. An existing building on which experimental setups will be installed has been selected according to various criteria. For example, there is a preference for vegetated and reference facades to be opaque, oriented to the south, and free from any obstructions in front of the facade. Additionally, two rooms in approximately the same conditions should be selected in order to compare the results reliably. Based on these criteria, an existing building located at Gebze Technical University Campus has been selected. Two rooms whose opaque exterior walls face south and are exposed to solar radiation for the majority of the day have been chosen. Dimensions and floor height, window to wall ratio, and air conditioning of these two rooms are similar, while interior and exterior wall materials, floor coverings, and ceiling materials of the two rooms are typical.

DESIGN CRITERIA OF THE EXPERIMENTAL SETUP			
1. SELECTION OF BUILDING AND BUILDING FACADE(S)	• oriented towards the south • no obstacles in front of the facade • heat insulated building walls • two similar rooms • completely opaque facade		
2. SELECTION OF VGS AND PLANT TYPE	felt type vegetated facade system "euonymus japonica" evergreen plant		
DETERMINATION of PARAMETERS & TYPE and LOCATION of SENSORS	**parameters**	**type of sensor**	**location of sensor**
	interior surface temperature of vegetated facade	Infrared non-contact temperature sensor	175 cm above the ground level
	interior surface temperature of reference facade	Infrared non-contact temperature sensor	175 cm above the ground level
	exterior surface temperature of vegetated facade	Infrared non-contact temperature sensor	175 cm above the ground level
	exterior surface temperature of reference facade	Infrared non-contact temperature sensor	175 cm above the ground level
	surface temperature of back and front side of PVC panel	Infrared non-contact temperature sensor	175 cm above the ground level
	surface temperature of 2.layer of felt	Infrared non-contact temperature sensor	175 cm above the ground level
	indoor temperature and humidity back of the vegetated and reference facade	indoor temp. and hum. sensors	175 cm above the ground level
	micro climate variables: ambient air temperature, humidity, wind direction and velocity	meteorological station	on the roofing parapet of existing building
	solar irradiation reflected from the vegetated facade	Pyranometer	180 cm above the ground level
	solar irradiation reflected from the reference facade	Pyranometer	180 cm above the ground level
	solar irradiance reaches to the veg. and ref. facade	Pyranometer	180 cm above the ground lev.

TABLE 2 Design criteria of experimental setup

In Figure 2, an image of existing building and exterior walls that will be vegetated and used as reference can be seen.

FIG. 2 Image of Gebze Technical University Chemical Engineering Building facade and proposed wall surfaces for experimental setup (left: proposed vegetated wall surface, right: proposed reference wall surface)

Existing building wall assembly, consisting of brick, external and internal plaster, and thermal insulation can be seen in Figure 3.

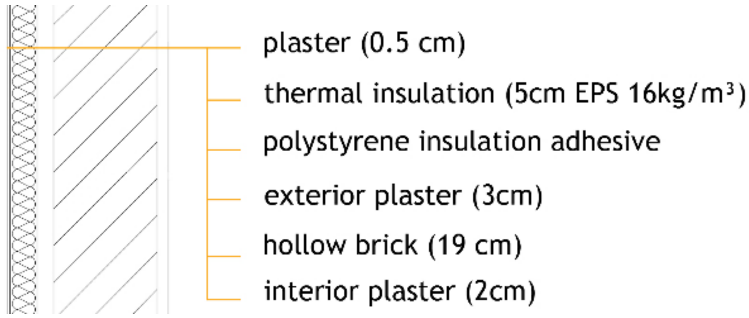


FIG. 3 Section of existing building wall assembly

Details of experimental setups such as measurement parameters, location and types of sensors used to measure these parameters, and assemblies of vegetated and reference facades can be seen in Fig. 4 and Fig. 5. As seen in Fig. 3, existing building exterior wall assemblies consist of 2cm thick interior plaster, 19cm thick hollow brick, 3cm thick exterior plaster and 5cm thick EPS (16kg/m3) thermal insulation. In addition to these layers, vegetated facade assemblies consist of 40x40mm galvanized steel box profiles, PVC panel, 2 layers of felt (1000gr/m2) and evergreen plants named as "eounymus japonica". Surface temperature sensors (OPTRIS, CS Micro Thermometer) will be mounted on different layers of the vegetated facade, such as the interior and exterior wall surfaces, the back and front side of the PVC panel, and on two layers of felt on the interior and the exterior surfaces of the reference wall. A Pyranometer (Deltaohm LP PYRA 02) will be mounted vertically in front of the vegetated facade in order to measure solar irradiance reflected from the vegetated surface. Two pyranometers will be also installed in front of the reference facade vertically. These pyranometers will be mounted back to back; one of them measures solar irradiation reflected from the reference facade while the other measures solar irradiance reaches to the reference and vegetated facades. Values of solar radiation reaching each both facades are accepted as identical. Additionally, indoor temperature and humidity sensors (GE HumiTrac) will be placed 20 cm in front of the interior wall surface of the vegetated and reference facades. A temperature sensor (Pt 1000) will also be placed inside the leaves to measure the air temperature among leaves. Additionally, it has been decided to place a meteorological station (Deltaohm HD 2003_3 axes ultrasonic anemometer) on the roof of the building in order to measure ambient air temperature, humidity, wind direction and velocity.

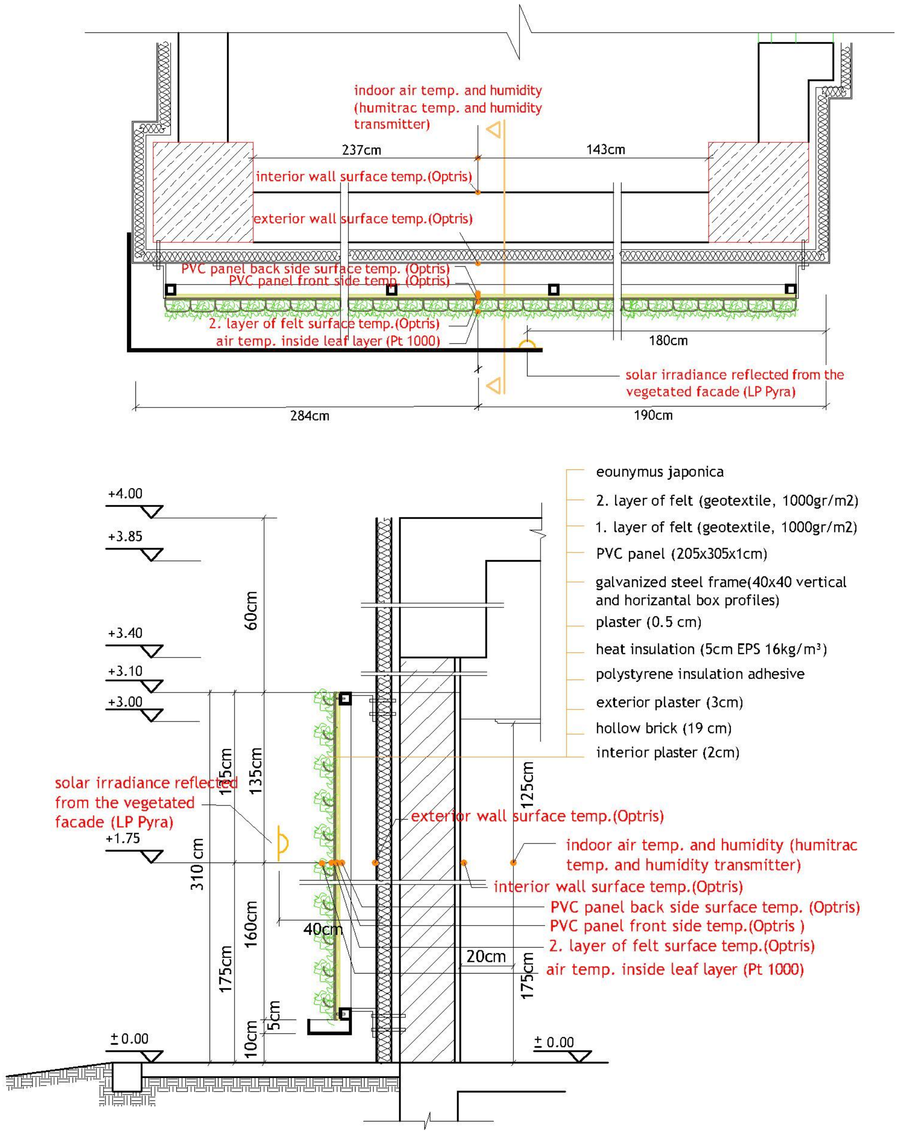


FIG. 4 Sections and plans of experimental setup of vegetated facade

5 CONCLUSION

Details of experimental setups to be installed as part of the PhD thesis have been determined according to the results obtained from the literature review. For the PhD thesis, the surface temperatures of various layers of the vegetated and reference facades, air temperatures among leaves, indoor air temperature and humidity level behind the vegetated and reference walls, and microclimate parameters must be measured in order to compare the thermal performance of the vegetated and reference facades. Solar radiation reaching and reflected from both facades will be measured in order to determine the reflectivity of the felt type vegetated facade system, which is planted with “euonymus japonica”. According to results of the measurements that will be taken over the period of one year, including a heating and cooling period, the thermal performance of felt type vegetated facade system conducted in Kocaeli (temperate humid climate) will be demonstrated.

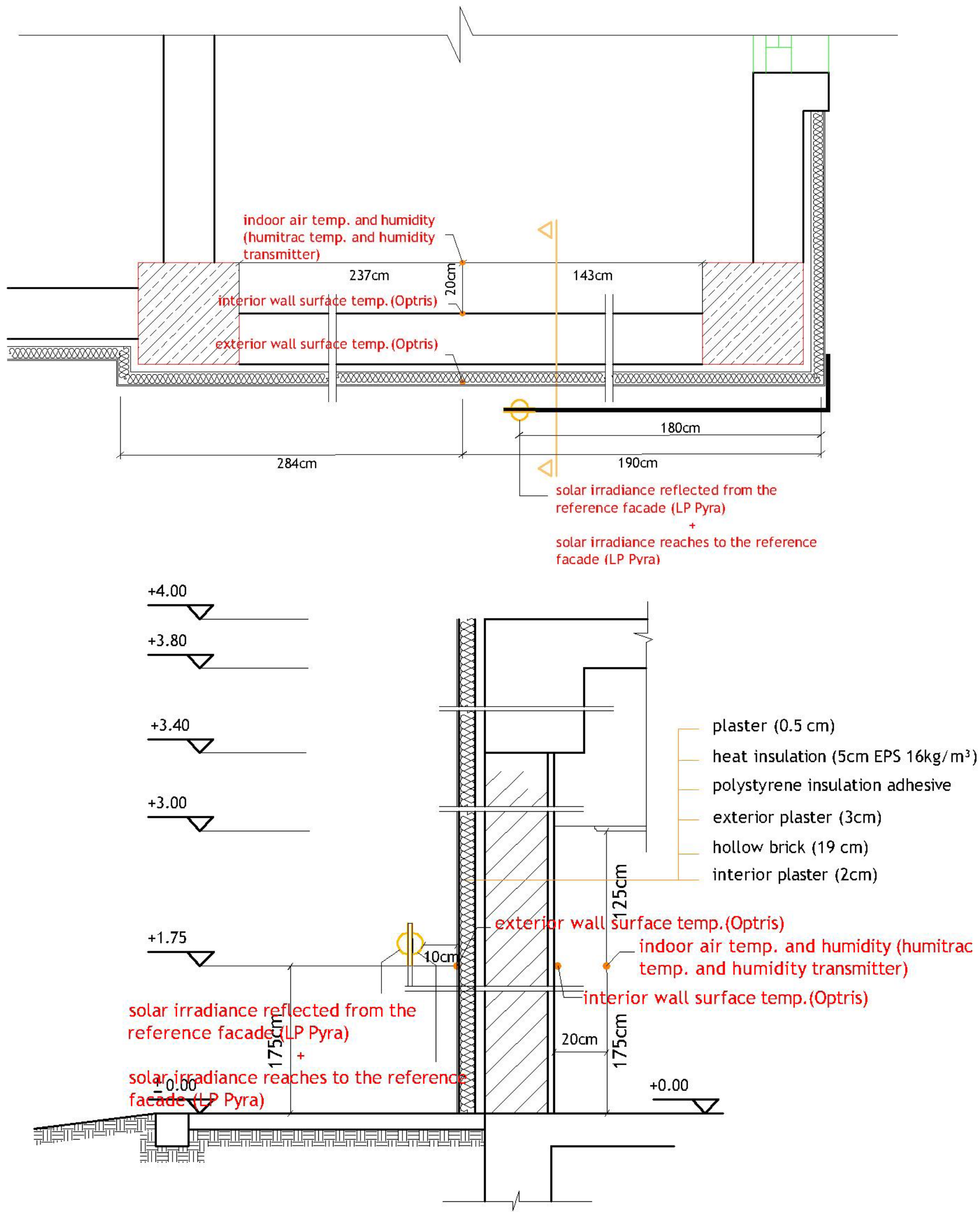


FIG. 5 Sections and plans of experimental setup of reference facade

As a result of the literature review, it can be claimed that in some studies there are missing parameters such as interior surface temperature, indoor air temperature, surface temperature of growing media (necessary only for living wall systems such as panel and felt systems) and air temperature among leaves. In order to obtain reliable results about the thermal performance of vegetated facade systems and heat transfer through the vegetated and reference walls, it is recommended that exterior air temperature and relative humidity, wind velocity and direction, solar radiation reaches to and reflected from the facade, exterior and interior surface temperatures of vegetated and reference walls, indoor air temperature and relative humidity, and surface temperature of growing media/substrate be measured.

In addition, there is no detailed information about the location and type of sensors in some studies. Consequently, for further studies it is recommended that the experimental setup be explained in more detail and that drawings including wall assemblies, measurement parameters, location and type of sensors of vegetated facade and reference facade be included as part of the study.

Acknowledgement

Authors gratefully acknowledge Istanbul Technical University (ITU) Scientific Research Department for funding the research project.

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