Manuscript Details

Manuscript number	ATE_2019_1095
Title	Predictive model of surface temperature difference between green façades and uncovered wall in Mediterranean climatic area
Article type	Research Paper

Abstract

Buildings vertical surfaces strongly condition microclimate inside the building. The improvement of the thermal behaviour of the building envelope in urban areas is a suitable solution to increase energy savings. Green façades are a promising passive cooling strategy for building envelopes. One parameter useful to evaluate the effectiveness of a green façade is the external surface temperature of the building. The reduction of the building surface temperature in the warm periods obtained with a green layer plays an important role for cooling energy saving. A multiple linear regression model simulating the difference of the surface temperature between a wall covered with vegetation and an uncovered wall was developed. The model was built using the experimental data measured in 2015. The data were recorded by sensors and data logger on three wall prototypes in scale facing south. The prototypes were realized in order to simulate a vertical closure for civil buildings commonly used in the Mediterranean area. The cooling thermal effect of two different climbing plants, Pandorea jasminoides variegated and Rhyncospermum jasminoides, was analysed and compared, through the evaluation of the external surface temperature of the protected vertical walls in comparison to a control uncovered wall. The model was used to simulate the behaviour of the green walls during summer 2016. The simulated data were compared with the measured data. Coefficients of determination (R2) higher than 0.96 were obtained. The results of the research showed that the model can simulate the thermal effects of green façade in a similar Mediterranean climate. Data measured and simulated showed that the vegetated walls recoded surface temperatures lower than the uncovered wall up to 7.69 °C in summertime.

Keywords	Multiple linear regression analysis; box plot data visualization; cooling effect; urban agriculture; building thermal performance; climatic data

Corresponding Author	Evelia Schettini
Corresponding Author's Institution	University of Bari
Order of Authors	Ileana Blanco, Evelia Schettini, Giuliano Vox
Suggested reviewers	Carla Balocco, José Luis Miralles i Garcia, Pietro Picuno

Submission Files Included in this PDF

File Name [File Type]

Blanco et al_Cover letter_Applied Thermal Engineering.doc [Cover Letter]

Blanco et al_Highlights.docx [Highlights]

Graphical_abstract.pptx [Graphical Abstract]

Blanco et al_Manuscript.docx [Manuscript File]

To the Editor of
Applied Thermal Engineering

Subject: Paper “Predictive model of surface temperature difference between green façades and uncovered wall in Mediterranean climatic area”
Authors I. Blanco, E. Schettini, G. Vox

Dear Editor,

I would like to submit the research paper entitled “Predictive model of surface temperature difference between green façades and uncovered wall in Mediterranean climatic area”, authors I. Blanco, E. Schettini, G. Vox for publication in Applied Thermal Engineering.

The paper compares the cooling thermal effects of two different climbing plants (*Pandorea jasminoides variegated* and *Rhyncospermum jasminoides*) used as green vertical passive systems on building walls in Mediterranean climate conditions. The climatic data of the experimental site were used to develop a statistical predictive model on the thermal performance of the façade. The statistical predictive model provides a tool to simulate the results of the application of green façades in a similar Mediterranean climate.

Best regards,

Evelia Schettini

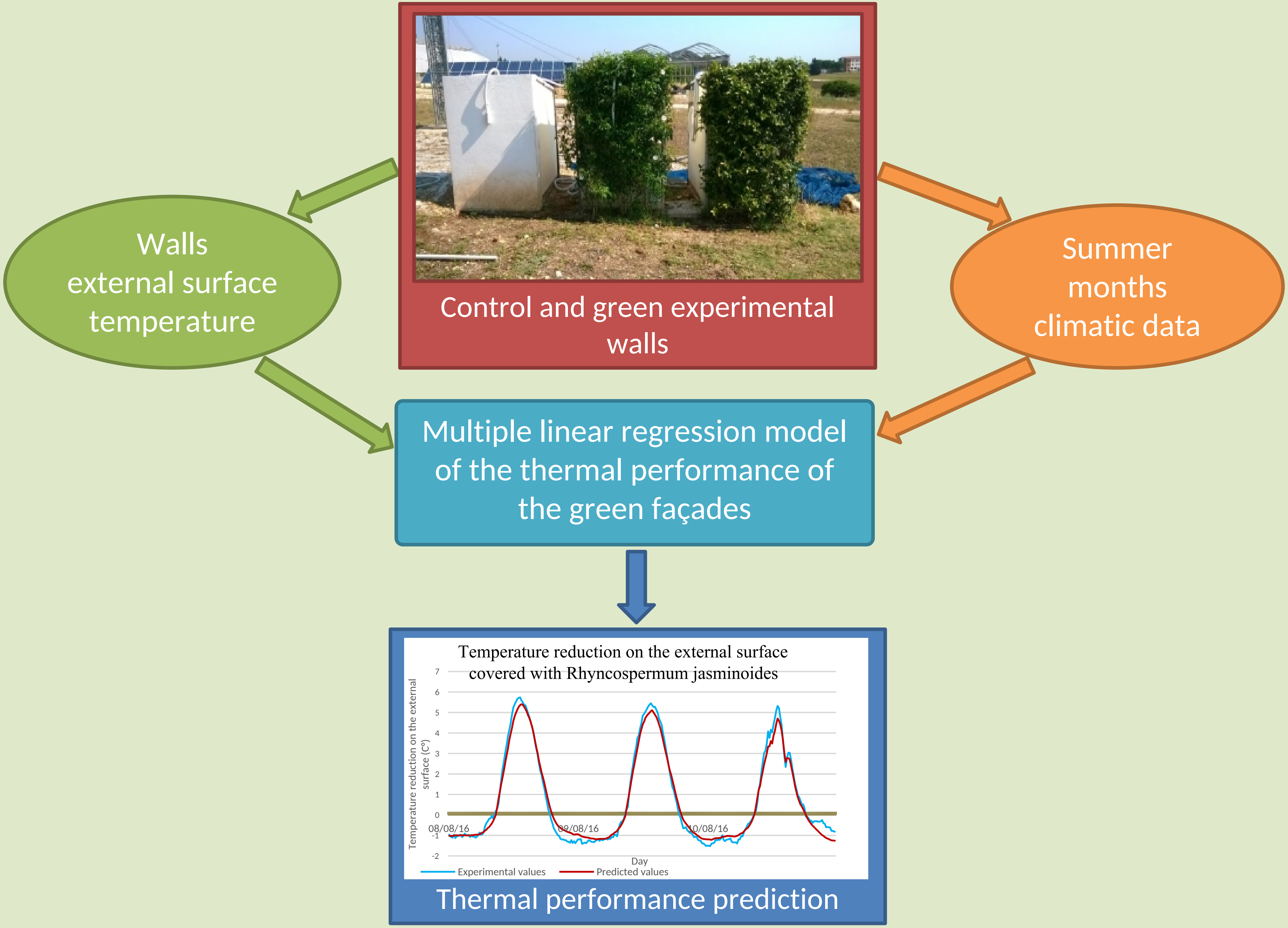
Bari, 19/02/2019

Corresponding author:

Evelia Schettini
Department of Agricultural and Environmental Science (DISAAT)
University of Bari
Via Amendola 165/a,70126 Bari, Italy
Tel +39 080 5443060: Fax: +39 080 5442977
e-mail: Evelia.schettini@uniba.it

Highlights:

- The green façade shows lower surface temperature than the control wall.
- A multiple linear regression is developed to simulate thermal behaviour.
- The regression is based on the climate conditions parameters.
- A prediction tool for the thermal benefits of the two green façades.



Walls external surface temperature
Control and green experimental walls
Summer months climatic data
Multiple linear regression model of the thermal performance of the green façades
Temperature reduction on the external surface covered with Rhyncospermum jasminoides
Temperature reduction on the external surface (C°)
7
6
5
4
3
2
1
0
-1
-2
08/08/16
09/08/16
10/08/16
Day
Experimental values
Predicted values
Thermal performance prediction

Predictive model of surface temperature difference between green façades and uncovered wall in Mediterranean climatic area

Ileana Blanco, Evelia Schettini*, Giuliano Vox

Department of Agricultural and Environmental Science DISAAT – University of Bari, Bari, Italy

* Corresponding author

E-mail addresses: ileana.blanco@uniba.it (I. Blanco), evelia.schettini@uniba.it (E. Schettini), giuliano.vox@uniba.it (G. Vox).

Abstract

Buildings vertical surfaces strongly condition microclimate inside the building. The improvement of the thermal behaviour of the building envelope in urban areas is a suitable solution to increase energy savings. Green façades are a promising passive cooling strategy for building envelopes. One parameter useful to evaluate the effectiveness of a green façade is the external surface temperature of the building. The reduction of the building surface temperature in the warm periods obtained with a green layer plays an important role for cooling energy saving.

A multiple linear regression model simulating the difference of the surface temperature between a wall covered with vegetation and an uncovered wall was developed. The model was built using the experimental data measured in 2015. The data were recorded by sensors and data logger on three wall prototypes in scale facing south. The prototypes were realized in order to simulate a vertical closure for civil buildings commonly used in the Mediterranean area. The cooling thermal effect of two different climbing plants, *Pandorea jasminoides variegated* and *Rhyncospermum jasminoides*, was analysed and compared, through the evaluation of the external surface temperature of the protected vertical walls in comparison to a control uncovered wall.

The model was used to simulate the behaviour of the green walls during summer 2016. The simulated data were compared with the measured data. Coefficients of determination (R^2) higher than 0.96 were obtained. The results of the research showed that the model can simulate the thermal effects of green façade in a similar Mediterranean climate.

Data measured and simulated showed that the vegetated walls recoded surface temperatures lower than the uncovered wall up to 7.69 °C in summertime.

Keywords: Multiple linear regression analysis; box plot data visualization; cooling effect; urban agriculture; building thermal performance; climatic data

1. INTRODUCTION

Nowadays the diffusion of the greening technology for more sustainable buildings is encouraged by the worldwide growing interest in urban green (Berardi et al., 2014; Fernandez-Caňero et al., 2013; Santamouris, 2012). Urban Green Infrastructures (UGIs) are sets of man-made elements whose performance is influenced by built environment, climate conditions of the area and used plants (Raji et al., 2015; Gagliano et al., 2015). Public and private green open spaces, planned and unplanned, such as remaining native vegetation, parks, gardens, street trees, sporting fields, golf courses, are classified as UGIs. Moreover, also engineered options such as greenery systems in a building as green roofs, green balconies, sky gardens, indoor sky gardens and vertical greening are UGIs (Norton et al., 2015; Raji et al., 2015; Cameron et al., 2014; Schettini et al., 2016; Schettini et al., 2018a).

The thermal effect of greenery systems on the microclimate of buildings is related to the climate conditions of the area, i.e. air temperature and relative humidity, solar radiation, wind velocity and direction. Besides, the vegetation type, plant position, plant height, coverage ratio, leaf area index (LAI), foliage (orientation, dimension, thickness and density), radiometric characteristics of the leaves (emissivity, reflectivity, absorptance and transmissivity), plant's biological processes (photosynthesis, respiration and transpiration), and the growing medium (thickness, water content and density, substrate thermal properties) affect the thermal behaviour of the vegetation. The building itself and the surrounding built environment influence the thermal behaviour of UGI. Building characteristics, such as roof and wall construction materials (Vox et al., 2016), dimension, wall orientation, insulation level, and building indoor usage, must be considered.

The presence of UGIs will provide environmental benefits at building and urban scale (Pérez et al., 2014; Raji et al., 2015). UGIs contribute to improve urban climate reducing urban air temperature, extreme air and wall temperature values and thermal excursions on the building surface (Norton et al., 2015; Tan et al., 2014; Vox et al., 2015; Blanco et al, 2017; Campiotti et al., 2013). Urban greening can supply several ecosystem services such as improving aesthetically the place to live and work, removing airborne pollutants and improving air quality, enhancing storm-water management and water run-off quality, providing sound insulation and noise absorption (Cameron et al., 2014; Kohler and Poll, 2010; Rowe, 2011; Fernandez-Caňero et al., 2013). UGIs improve the habitat for invertebrates, birds, weeds and plants promoting and increasing biodiversity. Moreover, UGIs mitigate the frequency and magnitude of the heat events due to urban heat island (Karlessi et al, 2011; Jaffal et al., 2012), reduce the ambient temperatures, improve human thermal comfort and decrease energy loads on building (Pérez et al., 2014; Cameron et al., 2014; Norton et al., 2015).

The application of greening systems to the building envelope allows the improvement of the thermal performance of the building. Improving envelope energy performance is a suitable solution to increase energy saving (Balocco and Petrone, 2017). Vertical surfaces of buildings constitute part of the building envelope that strongly condition the microclimate inside the building.

The systems that allow greening a building vertical surface are classified with different terms in literature: vertical greening systems (Perini et al., 2011; Oluwafeyikemi and Julie, 2015), vertical greenery systems (Wong et al., 2010; Azkorra et al., 2014; Pérez et al., 2017; Coma et al., 2017), green walls (Kontoleon and Eumorfopoulou, 2010; Su and Lin, 2015; Wong and Baldwin, 2016; Djedjig et al., 2017; Vox et al., 2018b), vertical greens (Perini et al., 2011), vertical gardens (Peck et al., 1999; Alexandri and Jones, 2008; Perini and Ottelé, 2014), bio shaders (Ip et al., 2010), vertical landscaping (Allan and Kim, 2016; Yu et al., 2016), green façades (Coma et al., 2014; Flores Larsen et al., 2015; Hoelscher et al., 2016; Blanco et al., 2018), living walls (Charoenkit and Yiemwattana, 2016; Safikhani and Baharvand, 2017). Such a wide classification often leads to a non-real interpretation of the results obtained considering the different greening systems.

Data of tests carried out in real conditions are generally collected in short time making the comparison of the greening system performance even more difficult. Several authors presented experimental data at real scale concerning short summer periods (Chen et al, 2013; Pérez et al., 2014; Susorova et al., 2014; Vox et al., 2017). The performance of the greenery systems in winter have been less investigated and it requires further investigations (Pérez et al., 2014; Coma et al., 2017; Schettini et al., 2018b).

Another problem for the understanding of the scientific results is that some studies reported the maximum temperature differences while other researchers reported the average temperature differences (Charoenkit and Yiemwattana, 2016). The parameter most commonly reported for assessing the thermal performance of green vertical systems is the wall external surface temperature of the building or prototype. Comparisons between surface temperature studies do not allow an adequate assessment of the thermal performance, due to differences in building construction characteristics (Hunter et al., 2014). However, the analysis of this parameter permits comparing the potential effects related to the change of one parameter, such as the plant species, the distance of the supporting structure from the building for the indirect green façades, the irrigation regimes, the climate conditions.

Olivieri et al (2014) have expressed the need to develop a performance predictive model of a vegetal façades based on the local weather conditions. Simulation models often were not validated with real data (Pérez et al., 2014; Raji et al., 2015; Hunter et al. 2014).

In this research, the system that allows greening a vertical surface is a green façade (Cuce, 2016; Riley, 2017; He et al., 2017; Convertino et al., 2019). It is characterized by climbing plants rooted in the ground. The plants climb on a structural support located at a small distance from the wall.

Aim of the paper is the development of a statistical predictive model of the thermal performance of the façade in summer (from June to August). The statistical predictive model is a tool to simulate the results of the application of green façades in a similar Mediterranean climate.

The thermal performance of the green façade in summertime, period characterised by the highest external air temperature values, was analysed through the evaluation of the external surface temperature of the covered vertical walls in comparison to the uncovered control wall. The multiple linear regression model was built based on the data gathered during summer 2015. The regression model was validated with the data collected during summer 2016.

2. MATERIALS AND METHODS

2.1. Experimental test

The test took place at the experimental centre of the University of Bari in Valenzano (Bari), Italy, having latitude 41° 05' N, longitude 16° 53' E, altitude 85 m asl. The area is characterized by warm temperate climate with calm, dry and hot summer and by a notably variation of solar radiation intensity with season; the winter months are much rainier than the summer months. The

Mediterranean climate of the area can be classified as Csa, according to the Kopper-Geiger climate classification (Kottek et al., 2006).

In order to simulate a vertical closure for civil buildings commonly used in the Mediterranean area, a vertical wall with perforated bricks joined with mortar was designed. Each brick had a thickness of 0.20 m, a height of 0.25 m and a length of 0.25 m. The masonry was characterized by a thermal conductivity (λ) equal to 0.282 W m^{-1} K^{-1} (following UNI EN 1745: 2012) and a specific heat capacity (C_p) equal to 840 J kg^{-1} K^{-1}. The thermal properties of the plaster, with a thickness of 0.02 m, were: λ equal to 0.55 W m^{-1} K^{-1} and C_p equal to 1000 J kg^{-1} K^{-1}. The wall was characterised by a density (*d*) equal to 695 kg m^{-3}, a solar absorption coefficient (α_s) equal to 42.1% and a long wave infrared emissivity coefficient (ε_{LWIR}) equal to 95.3%.

Three wall prototypes in scale, each having a width of 1.00 m and a height equal to 1.55 m, were made facing south. On the backside of each wall, a sealed insulation structure was realized with sheets of expanded polystyrene. Each sheet of expanded polystyrene had a thickness of 0.03 m, λ equal to 0.037 Wm^{-2} K^{-1}, C_p equal to 1404 J kg^{-1} K^{-1} and *d* equal to 15 kg m^{-3}. The presence of the insulating structure allowed evaluating only the thermal behaviour of the wall due to the plants and to the incident solar radiation. A blue shading net was placed onto the back structure to reduce the effect of the incident solar radiation.

The walls were located in a wide open space with no shadow on the vertical surfaces.

Two walls were covered with vigorous evergreen climbing plants, one with *Pandorea jasminoides* variegated, the second with *Rhyncospermum jasminoides.* The third wall, used as control, was kept uncovered. The plants were transplanted on 18 June 2014. An iron net was placed 0.15 m far from the wall in order to provide a support for the climbing plants (Figure 1).

Figure 1. The three walls at the experimental field of the University of Bari; the right one is greened with *Rhyncospermum jasminoides*, the central one with *Pandorea jasminoides variegated* and the left one is the control wall (uncovered).

The drip irrigation method was used for all the plants and fertilization with N, P and K was performed.

2.2. Data acquisition

The external air temperature and relative humidity, the wind speed and direction, the surface temperature of the wall on the external plaster exposed to the solar radiation, the solar radiation on a horizontal plane and the solar radiation incident on the vertical surface were measured during the test. The value of solar radiation on a horizontal plane is a reference radiation value useful for the comparison of different climatic zones. The solar radiation on the vertical wall represents the fraction of solar radiation incident on the south facing green façades.

The external air temperature was measured by a Hygroclip-S3 sensor (Rotronic, Zurich, Switzerland); it was adequately shielded from solar radiation. The temperature of the external plaster surfaces exposed to the solar radiation was measured using thermistors (Tecno.EL s.r.l. Formello, Rome, Italy). Both the solar radiation on a horizontal plane and the solar radiation normal to the wall were measured by means of pyranometers (model 8-48, Eppley Laboratory, Newport, RI, USA) in the wavelength range 0.3-3 mm. Wind speed and direction were measured by Young Wind Sentry anemometer (Young Company, Traverse City, MI, U.S.A).

The climatic parameters were measured with a frequency of 60 s, averaged every 15 min and recorded on a data logger (CR10X, Campbell, Logan, USA) throughout the experimental test.

Plant Leaf Surface Index (LAI) was measured with an AccuPAR PAR/LAI Ceptometer (model LP-80, Decagon Devices Inc., Pullman, WA, USA). LAI varies throughout the year from 2 to 4 for *Rhyncospermum jasminoides*, and from 1.5 to 3.5 for *Pandorea jasminoides variegated*. These values ranged from a minimum to a maximum because, despite the plants are evergreen, in winter they lose some leaves.

Analysis of variance (ANOVA) was carried out with the CoStat software (CoHort Software, Monterey, CA, USA).

2.3. Climate conditions of the experimental field during 2013-2015

A preliminary study of the climate parameters of the site was carried out. The study was realized in order to define the experimental conditions.

In the period from January 2013 to December 2015, the experimental field was characterized by values of the external air temperature ranging from -1.4°C to 41.4°C. The yearly cumulative solar radiation on a horizontal plane varied in the range 4891-5327 MJ m^{-2}. The monthly value of cumulative solar radiation on a horizontal plane ranged from 143 MJ m^{-2}, recorded in January 2014, to 802 MJ m^{-2}, recorded in July 2015. The annual cumulative solar radiation on the south facing vertical wall varied in the range 3515-3759 MJ m^{-2}; the monthly value ranged from 209 MJ m^{-2} (January 2014) to 397 MJ m^{-2} (September 2013).

2.4. Multiple linear regression analysis

Data can be statistically analysed and modelled by means of a statistical regression analysis. Regression analysis is a methodology to investigate the functional equation between a dependent variable or response and the variables that influence the response, known as independent or predictor or influence variables (Fumo and Biswas, 2015; Yildiz et al., 2017). In relation to the number of predictor variables, simple linear regression has only one predictor variable while multiple linear regression has more than one predictor variable. The univariate linear regression analysis models the connection among variables by fitting a linear equation to the data. The linear fitting of multiple linear regression analysis is attempted by keeping constant all but one of the predictor variables (Fumo and Biswas, 2015).

Regression models are influenced by number of input parameters, kind of data, time interval, forecasting temporal horizon (Yildiz et al., 2017).

In this paper the multiple linear regression technique is used to forecast and model time series. The response variable that is analysed is the difference of the external surface temperature between the control wall and the green façade. The response variable at time t is coded as y_t. The external climate conditions were used as predictors variables: external air temperature and relative humidity, horizontal and vertical solar radiation, wind velocity and direction.

The multiple linear autoregressive model used in this research is:

$$y_t = \beta_0 + \beta_1 y_{t-1} + \beta_2 x_{1,\,t} + \beta_3 x_{1,\,t-1} + \beta_4 x_{2,\,t} + \beta_5 x_{2,\,t-1} + \beta_6 x_{3,\,t} + \beta_7 x_{3,\,t-1} + \beta_8 x_{4,\,t} + \beta_9 x_{4,\,t-1} + \beta_{10} x_{5,\,t} + \beta_{11} x_{5,\,t-1} + \beta_{12} x_{6,\,t} + \beta_{13} x_{6,\,t-1} + \varepsilon_t \quad (1)$$

where: the response variable y_t is the difference between the external surface temperature of the control wall and of the green façade at time t; t = 1, …, n=8832, with a time sample of 900 s, extends from June to August 2015. The predictor variable y_{t-1} is the difference between the external surface temperature of the control wall and of the green façade at time $t-1$; $x_{j,t}$ and $x_{j,t-1}$ are the weather predictor variables at time t and at time $t-1$, respectively, with $j = 1, \dots, 6$. The value j=1 refers to the external air temperature, j=2 to the horizontal solar radiation, j=3 to the external air relative humidity, j=4 to the wind velocity, j=5 to the wind direction and j=6 to the vertical solar radiation. β_l, with $l = 0, \dots, 13$, are the regression parameters of the model; β_0 is the intercept. ε_t is the error standing for the difference between the predicted data and the observed data.

The objective of the regression model is to minimize the sum of squared errors by varying the coefficient β_l.

The Regression Tool in Excel's Data Analysis add-in was used to obtain the estimated regression parameters ($\hat{\beta}_l$) with the Least Squares Method.

The fitted values ($\hat{y}_t$) were obtained by using the $\hat{\beta}_l$ values in eq. (1). The error (ε_t) is the difference between the observed data (y_t) and the fitted data ($\hat{y}_t$):

$$y_t = \hat{y}_t + \varepsilon_t \quad (2)$$

The fitted values are obtained considering, for the predictor variables, one of the n observations.

Three parameters can be used to measure the quality of the fitting of the multiple linear regression model: the coefficient of determination (R^2), the adjusted coefficient of determination (R_{adj}^2) and the root-mean-square error (RMSE). In this research, these parameters for the model proposed are defined as:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2} \quad (3)$$

$$R_{adj}^2 = 1 - (1 - R^2)\frac{n-1}{n-p-1} \quad (4)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n-k}} \quad (5)$$

where n is the number of observations; *p,* equal to 13, is the total number of the variables; *k,* equal to 14, is the number of regression coefficients; y_i are the observed data, $\overline{y}$ is the mean value of y_i, $\sum_{i=1}^{n}(y_i - \hat{y}_i)^2$ is the sum of squared errors and $\sum_{i=1}^{n}(y_i - \overline{y})^2$ is the total sum of squares.

The R^2 is a measure of how much variation of the response variable is explained by every predictive variables dataset at time *t*. It represents the percentage of variability in the independent variable that is explained when considering as if all predictor variables in the model affect the response variable. A high value of the R^2 means that the predictors account for a great amount of variability in the independent variable. The coefficient of determination R^2 ranges between 0 and 1. When R^2 is close to 1 then most of the variation of the observed values can be explained by the model (Raziei and Pereira, 2013). Even with a high value of R^2, a more detailed analysis is needed to ensure that the model can be used to describe the observed data and to predict the response for another set of data different from the one used to generate the model (Fumo and Biswas, 2015).

The R_{adj}^2 indicates how well terms fit a curve or line, but it is adjusted for the number of terms in a model. The R_{adj}^2 gives the percentage of variability explained by only those predictor variables that really affect the response variable. Adding more useless variables to a model, the R_{adj}^2 will decrease. Adding more useful variables, the R_{adj}^2 will increase. The R_{adj}^2 will always be less than or equal to the R^2 for large datasets. R_{adj}^2 can be positive or negative.

The RMSE is a standard statistical metric that measures the scatter in the data around the model. It indicates how concentrated the data is around the line of best fit; it measures how accurately the model predicts the response. The RMSE is the most important criterion for fit if the main purpose of the model is prediction and for describing uncertainty. The smaller RSME the better is the model's performance (Raziei and Pereira, 2013). A small RMSE implies that the sample is accurate and precise.

Meteorological and surface temperature data recorded during summer 2015 at the experimental field were analysed and a multiple linear regression model was fitted on 2015 data. The model estimates the difference between the external surface temperature of the control wall and of the green façade. Then the model was used to predict the behaviour of the green façade during summer 2016. The validation of the model was done by comparing the data observed during summer 2016 and the data predicted with the model. The predicted data *($\hat{y}_{tp}$)* were obtained by eq. (1), using the predictor variables measured in 2016. The regression parameters where obtained with the data recorded in 2015.

3. RESULTS AND DISCUSSION

3.1. **The measured wall temperature**

The monthly values of the external surface temperature recorded on the uncovered control wall during 2016 are shown in Figure 2 by multiple box-plots (Nuzzo, 2016). The median ranged from 7°C to 26°C. Ignoring the outlier values, maximum values were recorded around 41°C and minimum values close to -1°C.

Concerning the warmest period in the summer 2016, from June to August, the external surface temperatures recorded on the control wall were characterized by a high variability and the median was in the range 22-26°C. The period from June to August recorded surface temperature peaks on the control wall over 38°C, neglecting the outlier values. The other warm months were characterised by maximum values of about 32-33°C. Thus, the mitigation of the wall surface temperature due to the presence of the plants was analysed for June, July and August when the cooling effect is expected to be more effective.

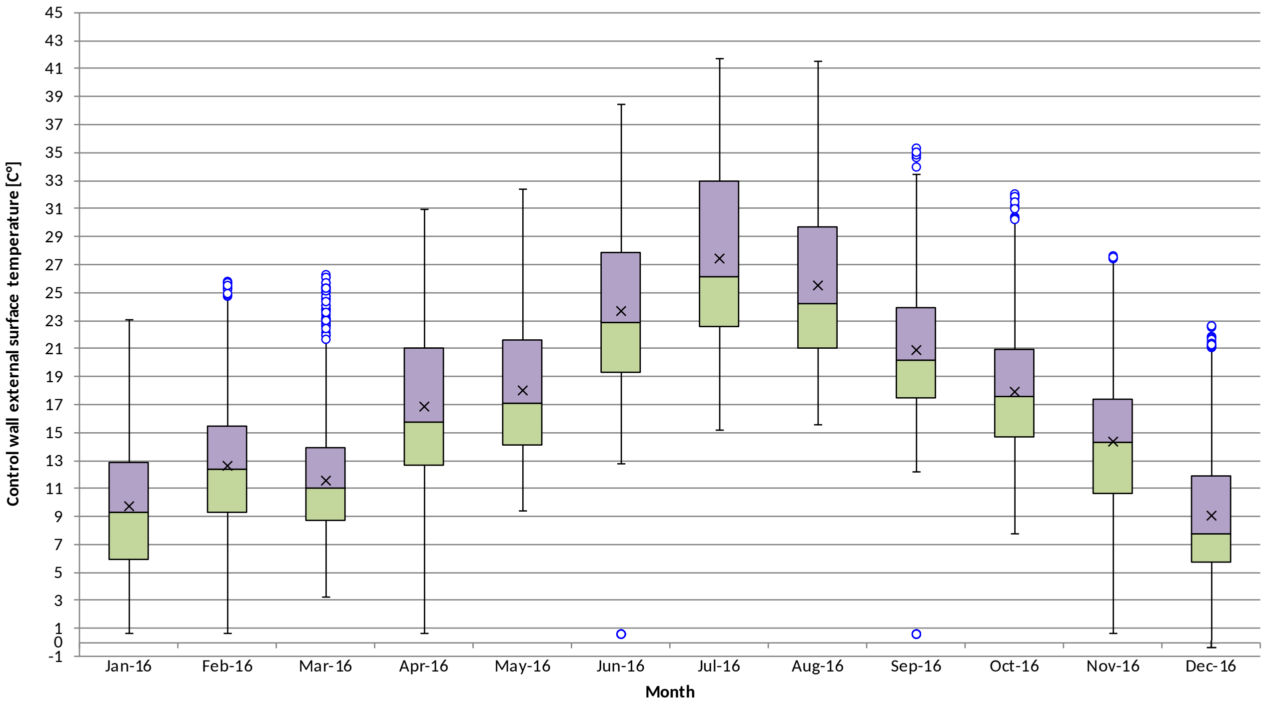


Figure 2: External surface temperature of the control wall during 2016.

A value of the horizontal solar radiation of 200 Wm^{-2} was found by Vox et al. (2018a) as a threshold value for arousing a cooling effect by the green façades on the wall external surfaces. A solar radiation threshold value emerged as necessary to incite notable cooling functions on the walls behind the green layers during daytime, with a direct dependence of the surface temperature on the solar radiation level. This result is in agreement with Jim (2015) that assessed a solar radiation minimum value of 300 Wm^{-2} for mobilizing effective transpiration cooling for indirect green façades forming a 10 cm air gap between wall and support mesh.

Table 1 shows the monthly average of the daily maximum difference between the surface temperature recorded on the control wall and the surface temperature recorded on the green walls in 2016. One-way ANOVA analysis at a 95% probability level were performed for each month of the analysed period in order to compare the average values. Duncan's test was applied with a significance level equal of 0.05. No significant difference was recorded between the two plants.

The ANOVA analysis showed that statistically significant differences were recorded between the green walls and the control wall for the monthly average of the daily variation of the wall external surface temperature (Table 1). It was calculated as the difference between the highest temperature and the lowest temperature registered each day during daytime, when solar radiation on a horizontal surface was higher than 200 W m^{-2}. In June and August no significant difference was reported between the two plants for the temperature variation. During July, that was the hottest month, *Rhyncospermum jasminoides* showed the lowest temperature variation (7.93 °C). This value was statistically different from the variation recorded both for the wall covered with *Pandorea jasminoides variegated* and for the control wall.

In August, the following maximum daytime temperature variation were recorded: 11.75°C for *Rhyncospermum jasminoides,* 13.42 °C for *Pandorea jasminoides variegated* and 18.40 °C for the control wall (Table 2). The variations were evaluated when solar radiation on a horizontal surface was higher than 200 W m^{-2}.

The average of the maximum reduction of the covered walls surface temperature versus the uncovered control wall showed no significant difference between the two plants (Table 1).

The highest maximum reduction value between the surface temperature measured on the control wall and on the green wall was recorded in August: 7.69°C for *Rhyncospermum jasminoides* and 7.67 °C for *Pandorea jasminoides variegated* (Table 2).

Table 1: Monthly average of the daily maximum difference value between the surface temperature recorded on the control wall and on the green walls; average daytime temperature variation with solar radiation on a horizontal surface higher than 200 W m^{-2}. Data recorded in 2016.

	Average of the maximum reduction of the covered walls surface temperature versus the control wall (°C)			Average variation of the wall external surface temperature during daytime; solar radiation on a horizontal surface ≥ 200 W m^{-2} (°C)		
	June	July	August	June	July	August
Rhyncospermum jasminoides	5.07^{a}	5.81^{a}	5.93^{a}	7.13^{b}	7.93^{c}	6.65^{b}
Pandorea jasminoides variegated	5.08^{a}	5.57^{a}	5.46^{a}	8.10^{b}	9.07^{b}	7.87^{b}
Control wall	-	-	-	12.44^{a}	14.08^{a}	12.94^{a}

$^{a-c}$Average values of the temperature in a column (i.e. for a specific month) with a different superscript letter statistically differ at $P < 0.05$ using Duncan’s test.

In one summer month with Thessaloniki’s climatic conditions, characterised by warm temperate humid climate, Eumorfopoulou and Kontoleon (2009) reported a temperature reduction of the maximum values in the exterior surface of a plant-covered east wall equal in average to 5.7 °C, varying from 1.9 °C to 8.3 °C. Pérez et al. (2014) reported a reduction from 1.7 °C to 13.0 °C of the external building surface temperature in warm temperate climate region in the case of a wall covered with traditional green façades during summertime. Susorova et al. (2014) reported an average decrease of the façade surface temperatures due to the presence of vegetation on the façade from 1.0 °C to 9.0 °C during summer on brick infills external surface.

Table 2: Maximum difference value between the surface temperature recorded on the control wall and the surface temperature recorded on the green walls; maximum daytime temperature variation considering solar radiation on a horizontal surface higher than 200 W m^{-2}. Data recorded in 2016.

	Maximum reduction of wall external surface temperature versus control wall (°C)			Maximum range of wall external surface temperature during daytime; solar radiation on a horizontal surface ≥ 200 W m^{-2} (°C)		
	June	July	August	June	July	August
Rhyncospermum jasminoides	6.48	7.02	7.69	10.87	10.41	11.75
Pandorea jasminoides variegated	6.58	6.73	7.67	12.32	11.96	13.42
Control wall				17.54	16.87	18.40

The daily thermal behaviour of the walls is shown in Figures 3-5. One typical sunny day for month was chosen. The external air temperature, the surface temperature of the external plaster of the three walls exposed to solar radiation, the temperature of the air gap between the vegetation and the wall, the solar radiation on a horizontal plane are shown.

The wall external surface temperature of the control wall rose in the morning in synch with the solar radiation values more than the temperature of the external side of the walls screened by the plants. During the daytime, with the solar radiation on a horizontal surface higher than 200 W m^{-2}, the external wall temperature of the control wall was always higher than the external wall temperature of the green façades. The presence of the vegetation layer mitigated the temperature of the external plaster of the walls. The maximum value of the wall surface temperature of the green façade was always recorded at least 1 hour late in comparison to the maximum value of the wall surface temperature of the control wall.

After sunset and at nighttime, the temperatures on the external wall of the green façades were higher than the temperatures on the control wall up to 2 °C. The green façades acted as thermal screens during night, but this behaviour is not desirable in summer.

The air-gap temperatures always followed the hourly evolution of the external ambient air temperature (Fig. 3-5). The air-gap temperatures often remained below the external ambient air temperature mainly for *Rhyncospermum jasminoides*. It is in agreement with the findings of Chen et al. (2013) and Pérez et al. (2011), which assessed the ability of the green façades to create a behind-green layer microclimate, characterized by lower air temperature than the external one during daytime in summer sunny days.

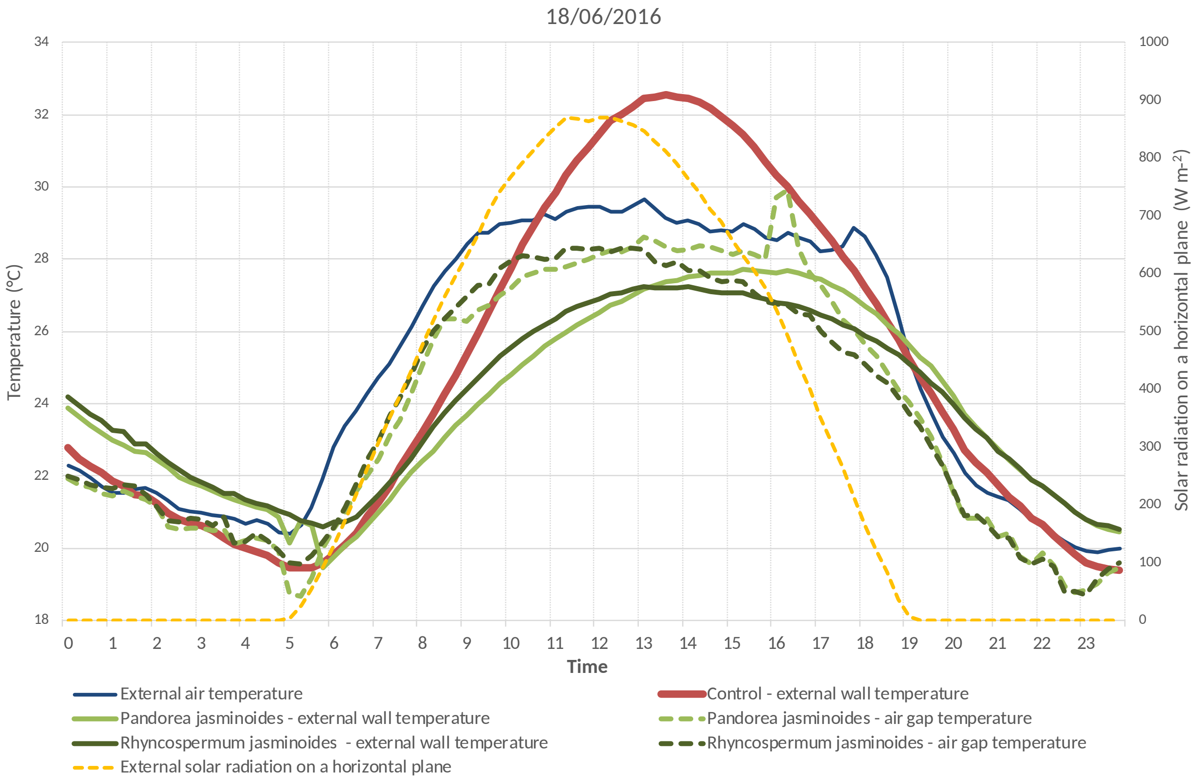


Figure 3: External air temperature, surface temperature of the external plaster of the three walls exposed to solar radiation, air gap temperature between the vegetation and the wall, solar radiation on a horizontal plane; 18/06/2016.

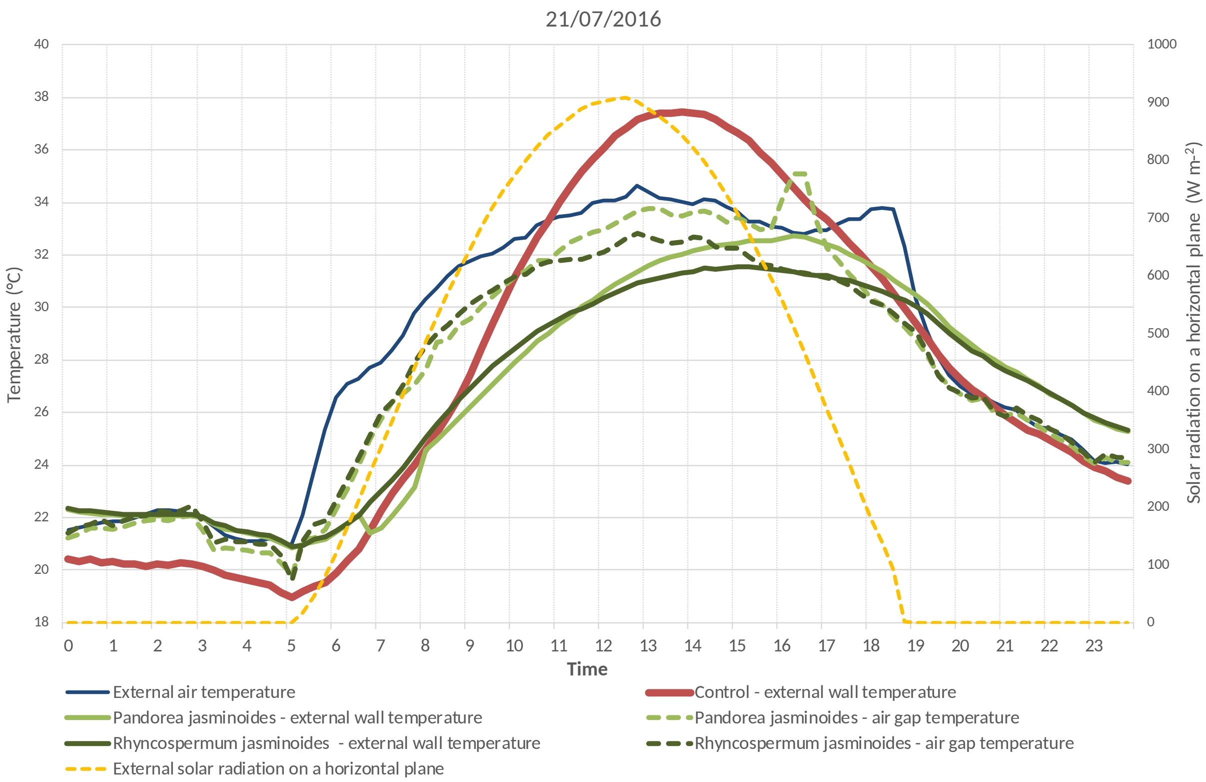


Figure 4: External air temperature, surface temperature of the external plaster of the three walls exposed to solar radiation, air gap temperature between the vegetation and the wall, solar radiation on a horizontal plane; 21/07/2016.

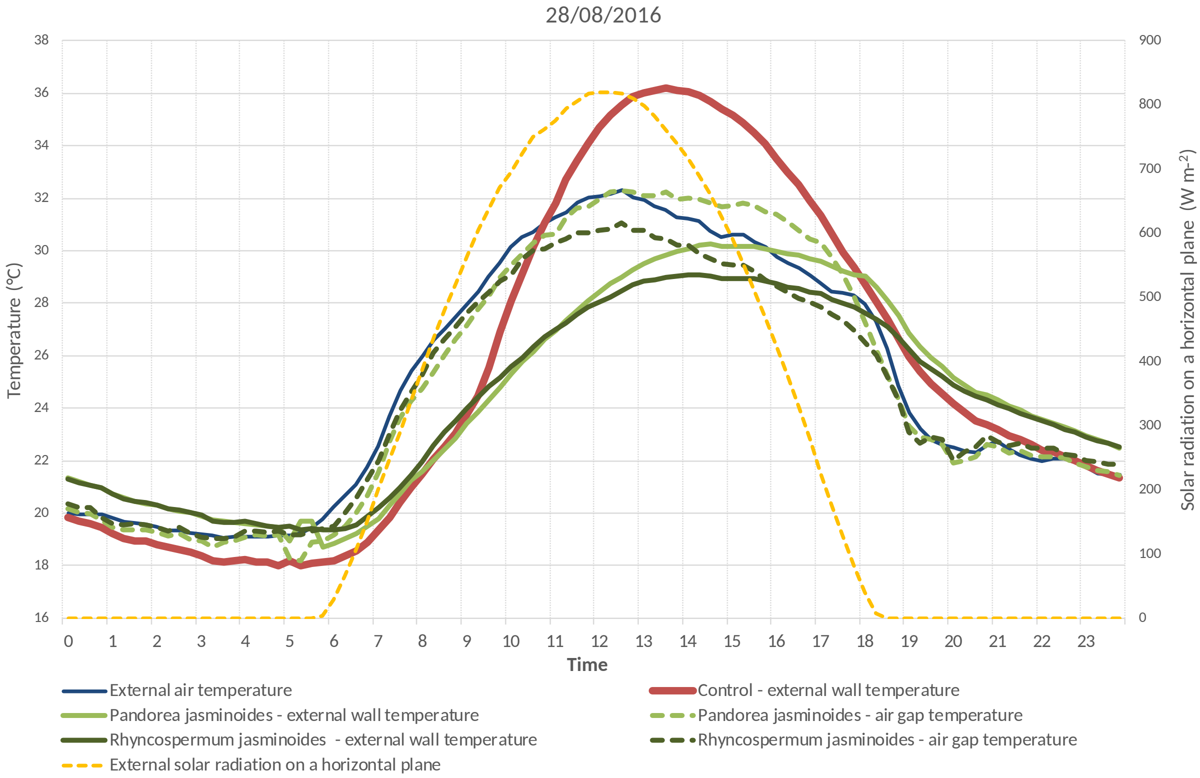


Figure 5: External air temperature, surface temperature of the external plaster of the three walls exposed to solar radiation, air gap temperature between the vegetation and the wall, solar radiation on a horizontal plane; 28/08/2016.

3.2. **Regression analysis results**

The regression model estimated the difference of temperature between the control wall without vegetation and the green wall at time t. It was built based on the data measured during summer 2015 at the experimental field.

Due to the great amount of heterogeneous data and to the variable thermal performance of the green walls through the different hours of the day, the observed data related to summer 2015 were grouped in 5 radiation slots. They were characterized by intervals of solar radiation on a horizontal surface (I_{hor}) as shown in Table 3. Figure 6 shows the distribution of the radiation slots in a typical summer day at the experimental site.

Table 3: Solar Radiation slots used in the regression model

		Solar Radiation on a horizontal surface
	$I_{hor\ 200}$	$I_{hor} < 200$ W m^{-2}
	$I_{hor\ 200\text{-}400}$	$200 \leq I_{hor} < 400$ W m^{-2}
	$I_{hor\ 400\text{-}600}$	$400 \leq I_{hor} < 600$ W m^{-2}
	$I_{hor\ 600\text{-}800}$	$600 \leq I_{hor} < 800$ W m^{-2}
	$I_{hor\ 800}$	$I_{hor} \geq 800$ W m^{-2}

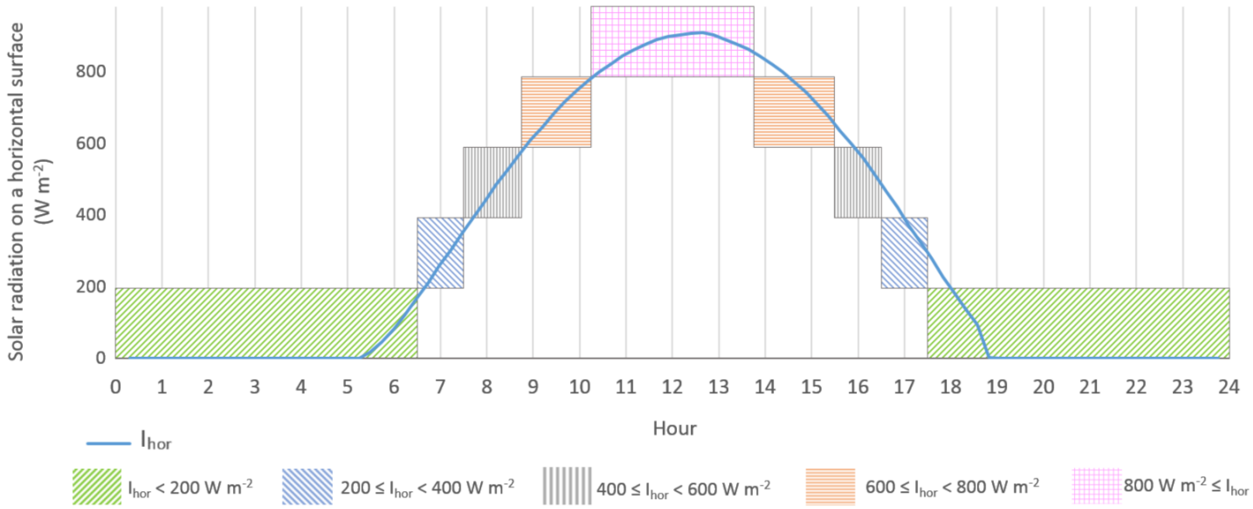


Figure 6: Daily distribution of the radiation slots.

A regression model for each green wall and for each I_{hor} was developed by using the data observed in the summer season 2015 (June-August 2015). 5 regressive models for each plant were developed, as shown in Tables 4-5. The models reproduce the thermal performance of the green façades in comparison with the control wall described in this research.

A regression coefficient β_j measures the partial effect of the predictor variable x_j on $\hat{y}_t$ holding the other predictor variables fixed. This interpretation is not valid, of course, for the intercept β_0. The value of the coefficients β_j is characterised by the unit of the measurement, thus these coefficients cannot be compared to each other. Therefore, the coefficients β_j cannot be assumed as indicators of the importance of the predictor variable in the explanation of the variability of the $\hat{y}_t$.

When a coefficient β_j is equal to 0, it means that the influence of the related predictor weather variable on the difference of temperature between the control wall without vegetation and the green wall is not significant.

The coefficients related the external air temperature predictor variable (β_2 and β_3) are significant for every I_{hor}: often β_2 is positive and high while β_3 is smaller in absolute value and negative. Therefore, the contribution of the predictor at time *t-1* often partially compensates for the contribution at the following time *t*. A positive and high value for β_2 means that the higher the temperature, the greater the difference of temperature between the control wall without vegetation and the green wall.

The coefficients that explain the dependency of the solar radiation variable are β_4 and β_5 (horizontal solar radiation) and β_{12} and β_{13} (vertical solar radiation); these coefficients can be positive or negative characterised by a low absolute value.

The dependency on the external air relative humidity variable is highlighted by the β_6 and β_7 coefficients. A positive low value for β_6 means that the higher the humidity, the greater the difference of temperature between the control wall without vegetation and the green wall.

The dependency on the wind velocity variable is highlighted by the β_8 and β_9 coefficients while on the wind direction by the β_{10} and β_{11} coefficients. As expected, the lowest dependence of the wind velocity variable results for I_{hor} < 200 Wm^{-2}, from sunset to sunrise when the wind has generally calmed down compared to other hours of the day.

Tables 4-5 also show the parameters of quality analysis. It can be noted that the coefficients R^2 and R_{adj}^2 are very high, with values higher than 0.95, for all the radiation slots and for both the green walls. R^2 and R_{adj}^2 show the goodness of the fit by the trained models. In this case, they have similar values due to the large datasets being used. The scattering around the model explained by RMSE is low.

A multiple regression model becomes more effective by adding a significant variable to it, while the addition of an unimportant variable can make the model worse. Thus, in order to analyse the importance of the individual regression coefficients, the Student t test was applied. The t-value represents the test statistic for the Student t test. The t-values test the hypothesis that the coefficient is different from 0. The coefficient with the highest t-value identifies the most important variable.

The t-values connected to the individual regression coefficients are presented in Tables 6-7. In both green façades the coefficients related to the variables external air temperature $x_{1,t}$ and vertical solar radiation $x_{12,t}$ show high t-values. Thus $x_{1,t}$ and $x_{12,t}$ confirm to be the parameters with the greatest influence on the dependent variable, in addition to y_{t-1}, as expected.

The predictive models described by Olivieri et al (2014) concern a green façade covered with sedum and a wall characterised by metal finish; they are characterized by values of R^2 varying between 0.63 and 0.87.

Table 4: Estimated regression coefficients and quality model parameters for the green wall covered with *Rhyncospermum jasminoides*, for the summer period 2015.

Estimated Regression coefficient		β_0	β_1	β_2	β_3	β_4	β_5	β_6	β_7	β_8	β_9	β_{10}	β_{11}	β_{12}	β_{13}			
Quality model parameters																**R^2**	**R_{adj}^2**	**RMSE**
Predictor variable to whom the regression coefficient is related			y_{t-1}	$x_{1,t}$	$x_{1,t-1}$	$x_{2,t}$	$x_{2,t-1}$	$x_{3,t}$	$x_{3,t-1}$	$x_{4,t}$	$x_{4,t-1}$	$x_{5,t}$	$x_{5,t-1}$	$x_{6,t}$	$x_{6,t-1}$			
Weather predictors variables				External Air Temperature	External Air Temperature	External solar radiation horizontal	External solar radiation horizontal	External Air relative Humidity	External Air relative Humidity	Wind Velocity	Wind Velocity	Wind Direction	Wind Direction	External solar radiation vertical	External solar radiation vertical			
Slot of solar radiation	$I_{hor\ 200}$	-0.2484	0.9297	0.0798	-0.0787	-0.0006	0	0.0045	-0.0035	0.0069	0	0.0001	0.0001	0.0041	-0.0019	0.99	0.99	0.06
	$I_{hor\ 200-400}$	0.0000	0.9291	0.1261	-0.1302	0	0	0	0	0.0428	-0.0440	0.0002	0	0	0	0.99	0.99	0.11
	$I_{hor\ 400-600}$	-0.5393	0.9288	0.0957	-0.0877	0.0004	-0.0003	0.0103	-0.0076	0	0	0	0	0.0009	0	1.00	1.00	0.11
	$I_{hor\ 600-800}$	-0.2462	0.9218	0.1280	-0.1247	0.0002	0	0.0019	0	-0.0361	0	-0.0003	0	0.0018	-0.0006	1.00	1.00	0.12
	$I_{hor\ 800}$	-0.3601	0.9223	0.1469	-0.1398	0.0002	0	0.0026	0	-0.0198	-0.0240	-0.0007	-0.0002	0.0019	-0.0005	0.99	0.99	0.12

Table 5: Estimated regression coefficients and quality model parameters for the green wall covered with *Pandorea jasminoides variegated*, for the summer period 2015.

Estimated Regression coefficient		β_0	β_1	β_2	β_3	β_4	β_5	β_6	β_7	β_8	β_9	β_{10}	β_{11}	β_{12}	β_{13}			
Quality model parameters																**R^2**	**R_{adj}^2**	**RMSE**
Predictor variable to whom the regression coefficient is related			y_{t-1}	$x_{1,t}$	$x_{1,t-1}$	$x_{2,t}$	$x_{2,t-1}$	$x_{3,t}$	$x_{3,t-1}$	$x_{4,t}$	$x_{4,t-1}$	$x_{5,t}$	$x_{5,t-1}$	$x_{6,t}$	$x_{6,t-1}$			
Weather predictors variables				External Air Temperature	External Air Temperature	External solar radiation horizontal	External solar radiation horizontal	External Air relative Humidity	External Air relative Humidity	Wind Velocity	Wind Velocity	Wind Direction	Wind Direction	External solar radiation vertical	External solar radiation vertical			
Slot of solar radiation	$I_{hor\ 200}$	-0.3915	0.9064	0.0972	-0.0914	0	0	0.0013	0	0.0062	0	0.0002	0	0.0031	-0.0030	0.95	0.95	0.14
	$I_{hor\ 200-400}$	-0.4110	0.8511	0.1233	-0.1119	-0.0004	0	0	0	0.0582	-0.0682	0	0	0.0040	-0.0021	0.96	0.96	0.20
	$I_{hor\ 400-600}$	-0.8940	0.8581	0.0225	0	0.0020	-0.0020	0.0034	0	-0.0305	0	0	0	-0.0021	0.0041	0.98	0.98	0.20
	$I_{hor\ 600-800}$	-0.3841	0.8777	0.1172	-0.1038	-0.0002	0	0	0	-0.0484	0	-0.0004	0	0.0029	-0.0006	0.99	0.99	0.15
	$I_{hor\ 800}$	-0.5010	0.8912	0.1496	-0.1360	-0.0002	0	0	0	-0.0516	0	-0.0006	0	0.0026	0	0.99	0.99	0.14

Table 6: *t*-values for the estimated regression coefficients for the green wall covered with *Rhyncospermum jasminoides*, for the summer period 2015.

t values															
Estimated Regression coefficient		β_0	β_1	β_2	β_3	β_4	β_5	β_6	β_7	β_8	β_9	β_{10}	β_{11}	β_{12}	β_{13}
Predictor variable to whom the regression coefficient is related			y_{t-1}	$x_{1,t}$	$x_{1,t-1}$	$x_{2,t}$	$x_{2,t-1}$	$x_{3,t}$	$x_{3,t-1}$	$x_{4,t}$	$x_{4,t-1}$	$x_{5,t}$	$x_{5,t-1}$	$x_{6,t}$	$x_{6,t-1}$
Slot of solar radiation	$I_{hor\ 200}$	-18.7532	452.2826	24.9633	-24.7520	-7.1618		7.6639	-5.8971	7.5257		2.6402	3.2594	15.3185	-10.4104
	$I_{hor\ 200\text{-}400}$		188.6119	11.3593	-11.5942					4.7248	-4.7095	2.6155			
	$I_{hor\ 400\text{-}600}$	-8.0228	309.3902	6.3024	-5.7320	4.9900	-4.5227	3.7734	-2.8566					9.9100	
	$I_{hor\ 600\text{-}800}$	-3.5560	349.6711	12.0055	-11.7481	4.6788		3.9699		-8.3222		-4.6222		15.5231	-5.1987
	$I_{hor\ 800}$	-4.8567	287.0584	13.4283	-12.7777	5.7365		5.2636		-2.6074	-3.2402	-8.1288	-2.7625	21.3396	-5.7590

Table 7: *t*-values for the estimated regression coefficients for the green wall covered with *Pandorea jasminoides variegated*, for the summer period 2015.

		t values													
Estimated Regression coefficient		β_0	β_1	β_2	β_3	β_4	β_5	β_6	β_7	β_8	β_9	β_{10}	β_{11}	β_{12}	β_{13}
Predictor variable to whom the regression coefficient is related			y_{t-1}	$x_{1,t}$	$x_{1,t-1}$	$x_{2,t}$	$x_{2,t-1}$	$x_{3,t}$	$x_{3,t-1}$	$x_{4,t}$	$x_{4,t-1}$	$x_{5,t}$	$x_{5,t-1}$	$x_{6,t}$	$x_{6,t-1}$
Slot of solar radiation	$I_{hor\ 200}$	-11.2070	183.4354	15.9750	-15.4290			8.1673		2.7744		3.8887		7.7124	-7.8066
	$I_{hor\ 200-400}$	-4.8556	76.6593	5.6440	-5.0289	-3.1565				3.4415	-3.9074			7.3328	-3.8128
	$I_{hor\ 400-600}$	-6.2462	103.9778	6.5624		6.5789	-7.0016	3.7466		-3.9686				-3.0516	5.5188
	$I_{hor\ 600-800}$	-7.8042	216.9989	8.9842	-7.9374	-4.2656				-9.3785		-4.5116		22.5625	-4.6244
	$I_{hor\ 800}$	-9.2642	225.4776	11.8691	-10.7676	-4.3664				-9.7011		-6.7293		33.5433	

3.3. **Use of the predictive model in the case study**

The predictive model was calibrated using the data recorded during summer 2015. The model was used to simulate the difference between the surface temperatures of the walls during summer 2016. External air temperature and relative humidity, solar radiation, wind velocity and direction were used as model input.

Figures 7-8 show the difference of the external surface temperature between the control wall and the green walls, comparing the simulated values and the values measured at the experimental field. The data concern 9-15 August 2016, a long period of clear sky.

As shown in Figure 7, the maximum difference between the external surface temperature of the control wall and of the green wall covered with *Pandorea jasminoides variegated* was 6.10 °C and 5.92 °C for the simulated values and the measured values, respectively. The highest negative difference between the external surface temperature of the control wall and of the green wall was -1.83 °C and -2.29 °C for the simulated values and the measured values, respectively.

Concerning the *Rhyncospermum jasminoides* (Figure 8), the maximum difference between the external surface temperature of the control wall and the green wall was 5.98 °C and 6.80 °C in the case of the simulated values and of the measured values, respectively. The highest negative difference between the external surface temperature of the control wall and of the green wall was -1.52 °C and -1.83 °C for the simulated values and the measured values, respectively.

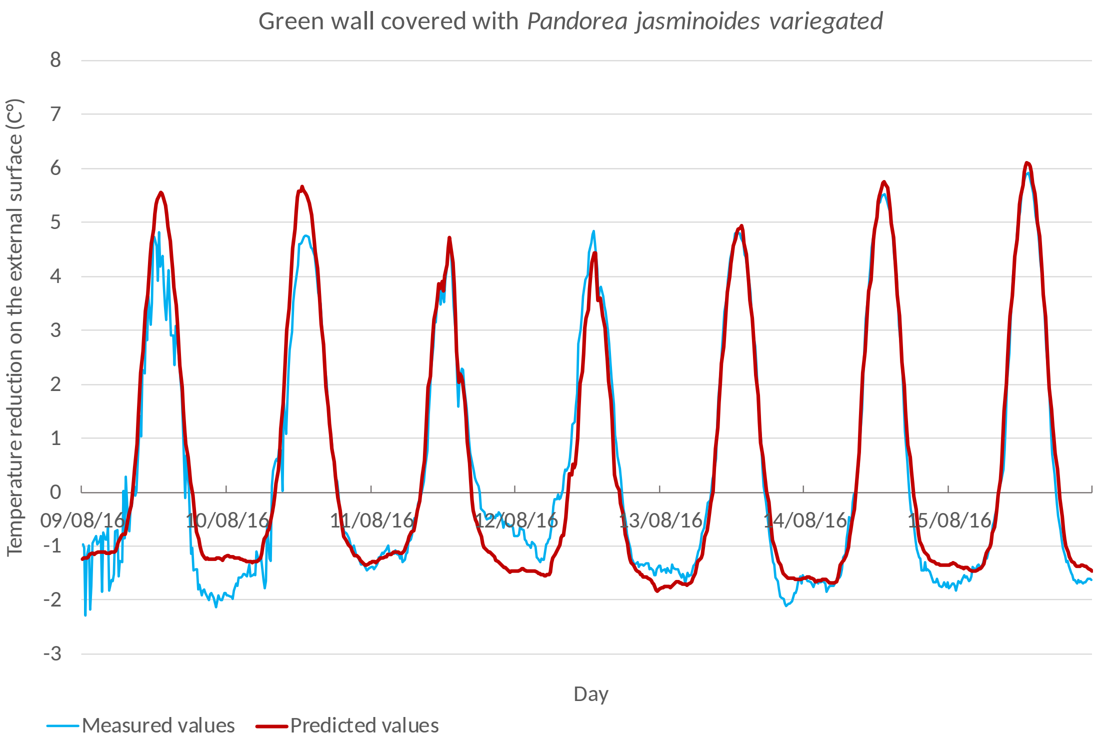


Figure 7: Difference of the external surface temperature between the control wall and the green wall covered with *Pandorea jasminoides variegated:* simulated data and measured data at the experimental field, 9-15/08/2016.

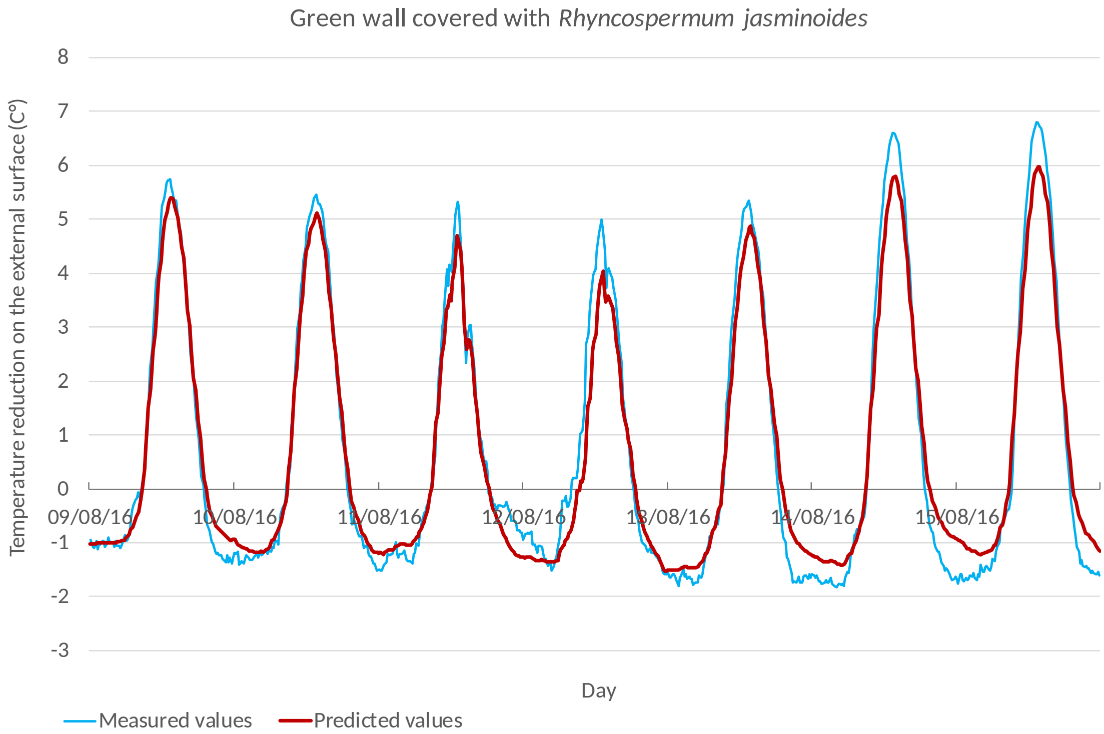


Figure 8: Difference of the external surface temperature between the control wall and the green wall covered with *Rhyncospermum jasminoides:* simulated data and measured data at the experimental field, 9-15/08/2016.

Figure 9 shows the correlation analyses for the simulated results and experimental results for the difference of the external surface temperature between the control wall and the green walls. Coefficients of determination (R^2) were 0.96 and 0.98 for the wall covered with *Pandorea jasminoides variegated* and the one covered with *Rhyncospermum jasminoides*, respectively. For both cases, determination coefficients show a good agreement between simulated results and experimental results because they are approaching 1.

The simulated and experimental differences of temperature deviate by maximum 1.95 °C, with an average difference between the numerical predictions and the experimental measurements of 0.07 °C and a standard deviation equal to 0.49 °C, for the wall covered with *Pandorea jasminoides variegated.* The simulated and experimental differences of temperature deviate by maximum 1.59 °C, with an average difference between the numerical predictions and the experimental measurements of -0.03 °C and a standard deviation equal to 0.46 °C, for the wall covered with *Rhyncospermum jasminoides.* The RMSE was 0.50 °C and 0.46 °C for the validation of the model regarding *Pandorea jasminoides variegated* and *Rhyncospermum jasminoides*, respectively. These values show the good agreement between the simulation results and the experimental measurements and are comparable with the results of the validation of the analytical models presented by Susorova et al. (2013), Djedjig at al. (2015), Scarpa et al. (2014), Dahanayake and Chow (2017), Suklje et al. (2019), He et al. (2017).

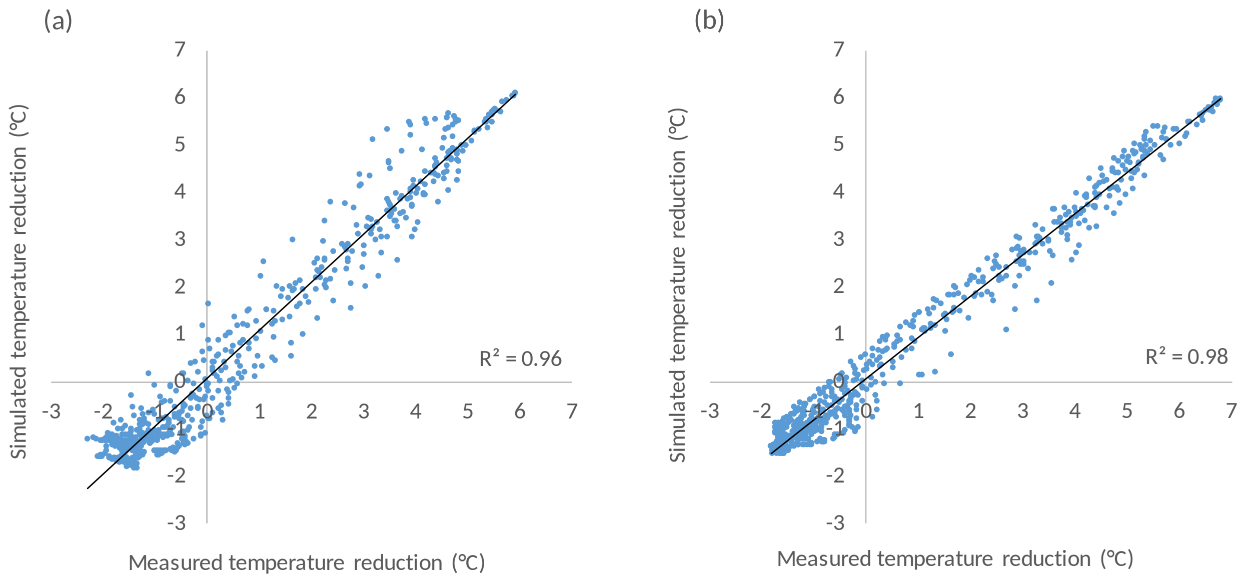


Figure 9: Comparison of simulated and experimental difference of the external surface temperature between the control wall and the wall covered with *Pandorea jasminoides variegated* (a) and *Rhyncospermum jasminoides* (b), 9-15/08/2016.

Susorova et al. (2013) studied the thermal effects of plants on heat fluxes through building external walls through a self-developed a mathematical model of a green façade. The model was experimentally validated taking into consideration a bare wall and a green façade with *P. tricuspidata*, south exposed, on a real building in Chicago, USA. The comparison of the measured and modelled exterior surface temperatures for the vegetated facades showed R^2 values equal to 0.96 on a sunny day and 0.86 on a cloudy day.

Djedjig at al. (2015) developed a green envelope model and integrated it into a building simulation software (TRNSYS). The results were validated through experimental comparisons during one summer month with an outdoor reduced scale building having a west-oriented green wall. The average difference between the numerical predictions and the experimental measurements of the green wall surface temperature during the month of august was 0.22 °C for the vegetated facade with a mean-root-square error of 1.42 °C.

Scarpa et al. (2014) developed a living wall mathematical model that was able to account for different features of living walls. The model validation was carried out through comparison with field measurements assessed during a summer and a winter week on two different kinds of living walls, one with closed air cavity and grass and the other one with open air cavity and a vertical garden. The maximum difference between the simulated and the field data of the external surface temperature of the living wall during the summer week was 1.0 °C. The RMSE for the living wall with the open air cavity was 1.1 and 0.4 during the summer and winter validation period, respectively. The RMSE was 0.5 during both the summer and winter validation period, for the living wall with the closed air cavity.

A self-developed mathematical model integrated into EnergyPlus building simulation program was used by Dahanayake and Chow (2017) for analysing the impact of living walls on building energy performance. The simulation results regarding the exterior surface temperature were validated against two experimental studies carried out on living walls in a summer month and in the period June-September respectively. The agreement of simulated results with experiment results was assessed by means of a correlation analysis showing R^2 values of 0.88 and 0.80 for each experimental study, respectively.

Suklje et al. (2019) proposed a modelling approach that considers the vertical greenery system as a homogeneous layer with apparent thermo-physical properties. The model was validated on the period July-August against the data that were generated for an indirect green façade in summer conditions by using a validated thermal response model, for vertical green systems, developed in a previous study (Suklje et al. 2016). It was shown that outer surface temperature of the building envelope differs by maximum ±1.1 °C, with standard deviation equal to 0.3 °C, from the calculated data.

He et al. (2017) investigated the thermal performance of living wall system by developing a coupled heat and moisture transfer model. Model output parameters were compared with field data, measured in a summer and a winter week, in order to validate the accuracy of the model. The analysis on the exterior surface temperature of living wall structure layer showed an RMSE of 0.15 °C both in summer and winter conditions.

4. CONCLUSION

Building design requires nowadays the use of energy performance simulation models. A predictive model for the estimation of the difference of temperature between an uncovered wall and vegetated walls was developed. External climate conditions were used as predictors and input of the model: external air temperature and relative humidity, horizontal and vertical solar radiation, wind velocity and direction. The data measured in the summer 2015 were used to build the model, data were grouped in 5 solar radiation slots in order to facilitate the interpretation of the predictive models. The developed overall model refers to green façades covered with *Pandorea jasminoides variegated* and *Rhyncospermum jasminoides*.

The model was validated by comparing the data of the surface temperatures measured in the summer 2016 with the data obtained by the model, using the climatic data of 2016 as model input. The validation showed good results with coefficients of determination (R^2) higher than 0.96. A maximum standard deviation equal to 0.49 °C between the numerical predictions and the measurements was recorded for the difference of temperature between the uncovered and the vegetated walls.

The research showed that the model can be used for the prediction of the thermal benefits of the green façades in the Mediterranean area during summer, by adopting a new dataset of weather conditions. The results indicate that in early design phases the statistical models can be a valid substitute of the energy simulation models for buildings characterized by constructive characteristics typical of this Mediterranean area.

ACKNOWLEDGEMENTS

The contribution to programming and conducting this research must be equally shared between the Authors.

The present work has been carried out under the “Piano triennale della Ricerca 2015-2017 nell’ambito del Sistema Elettrico Nazionale, Progetto D.1 ‘Tecnologie per costruire gli edifici del futuro’, Research activity: “Analisi di tecniche di raffrescamento sostenibili applicabili in edifici civili e in edifici serra”, Piano Annuale di Realizzazione (PAR) 2017", Accordo di Programma Ministero dello Sviluppo Economico – ENEA funded by the Italian Ministry of Economic Development.

References

Alexandri, E., Jones, P., 2008. Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates, Building and Environment, Volume 43, Issue 4, 480-493, ISSN 0360-1323, http://dx.doi.org/10.1016/j.buildenv.2006.10.055.

Allan, S.S.T., Kim H.I., 2016. A Study of Workflow for Simulations of Vertical Greenery Systems, Architecture Research, 6 (6), 142-153. doi: 10.5923/j.arch.20160606.02.

Azkorra, Z., Pérez, G., Coma, J., Cabeza, L.F., Bures, S., Álvaro, J.E., Erkoreka, A., Urrestarazu, M., 2014. Evaluation of green walls as a passive acoustic insulation system for buildings, Applied Acoustics, 89, 46-56.

Balocco, C., Petrone, G., 2017. Numerical Modelling for the Thermal Performance Assessment of a Semi-Opaque Façade with a Multilayer of Nano-Structured and Phase Change Materials, Buildings, 7, 90. https://doi.org/10.3390/buildings7040090

Berardi, U., Ghaffarianhoseini, A.H., Ghaffarian Hoseini, A., 2014. State-of-the-art analysis of the environmental benefits of green roofs. Applied Energy 115, 411-428. https://doi.org/10.1016/j.apenergy.2013.10.047

Blanco, I., Schettini, E., Scarascia Mugnozza, G., Vox, G., 2018. Thermal behaviour of green façades in summer. Journal of Agricultural Engineering, 49(3), 183-190. DOI: https://doi.org/10.4081/jae.2018.835.

Blanco, I., Schettini, E., Scarascia Mugnozza, G., Campiotti, C.A., Giagnacovo, G. Vox G., 2017. Vegetation as a passive system for enhancing building climate control. Acta Hortic. 1170, 555-562. DOI: 10.17660/ActaHortic.2017.1170.69.

Cameron, R.W.F., Taylor, J.E., Emmett, M.R., 2014. What's 'cool' in the world of green façades? How plant choice influences the cooling properties of green walls. Building and Environment 73, 198-207. https://doi.org/10.1016/j.buildenv.2013.12.005

Campiotti, C.A., Schettini, E., Alonzo, G., Viola, C., Bibbiani, C., Scarascia Mugnozza, G., Blanco, I., Vox, G., 2013. Building green covering for a sustainable use of energy. Journal of Agricultural Engineering 44, 253-256. doi:10.4081/jae.2013.s2.e50

Charoenkit, S., Yiemwattana, S., 2016. Living walls and their contribution to improved thermal comfort and carbon emission reduction: A review. Building and Environment, 105, 82-94, http://dx.doi.org/10.1016/j.buildenv.2016.05.031.

Chen, Q., Li, B., Liu, X., 2013. An experimental evaluation of the living wall system in hot and humid climate. Energy and Buildings 61, 298-307. https://doi.org/10.1016/j.enbuild.2013.02.030

Coma, J., Pérez, G., Solé, C., Castell, A., Cabeza, L. F., 2014. New Green Facades as Passive Systems for Energy Savings on Buildings, Energy Procedia, 57, 1851-1859, ISSN 1876-6102, http://dx.doi.org/10.1016/j.egypro.2014.10.049.

Coma, J., Pérez, G., de Gracia, A., Burés, S., Urrestarazu, M., Cabeza, L.F., 2017. Vertical greenery systems for energy savings in buildings: A comparative study between green walls and green facades, Building and Environment, 111, 228-237 DOI: 10.1016/j.buildenv.2016.11.014.

Convertino, F., Vox, G., Schettini, E., 2019. Heat transfer mechanisms in vertical green systems and energy balance equations. International Journal of Design & Nature and Ecodynamics, 14(1), 7-18. DOI: 10.2495/DNE-V14-N1-7-18

Cuce, E., 2016. Thermal regulation impact of green walls: An experimental and numerical investigation, Applied Energy, 194, 247-254, DOI: 10.1016/j.apenergy.2016.09.079.

Dahanayake, K.W.D.K.C., Chow, C.L., 2017. Studying the potential of energy saving through vertical greenery systems: using EnergyPlus simulation program, Energy and Buildings, 138, 2017, 47–59. https://doi.org/10.1016/j.enbuild.2016.12.002.

Djedjig, R., Ganaoui, M. El, Belarbi, R. and Bennacer, R., 2017. Thermal effects of an innovative green wall on building energy performance, Mechanics & Industry, 18(1), art. n. 104, DOI: http://dx.doi.org/10.1051/meca/2016015.

Djedjig, R., Bozonnet, E., Belarbi, R., 2015. Analysis of thermal effects of vegetated envelopes: Integration of a validated model in a building energy simulation program, Energy and Buildings, 86, 93-103.

Eumorfopoulou, E.A., Kontoleon, K.J., 2009. Experimental approach to the contribution of plant-covered walls to the thermal behaviour of building envelopes, Building and Environment 44 (5), 1024-1038. http://dx.doi.org/10.1016/j.buildenv.2008.07.004.

Fernandez-Cañero, R., Emilsson, T., Fernandez-Barba, C., Herrera Machuca, M.A., 2013. Green roof systems: A study of public attitudes and preferences in southern Spain. Journal of Environmental Management 128, 106-115. https://doi.org/10.1016/j.jenvman.2013.04.052

Flores Larsen, S., Filippín, C., Lesino, G., 2015. Modeling double skin green façades with traditional thermal simulation software, Solar Energy, Volume 121, Pages 56-67, ISSN 0038-092X, http://dx.doi.org/10.1016/j.solener.2015.08.033.

Fumo, N., Rafe Biswas, M.A., 2015. Regression analysis for prediction of residential energy consumption. Renewable and Sustainable Energy Reviews, 47, art. no. 4190, 332-343. DOI: 10.1016/j.rser.2015.03.035

Gagliano, A., Detommaso, M., Nocera, F., Evola G., 2015. A multi-criteria methodology for comparing the energy and environmental behavior of cool, green and traditional roofs. Build. Environ. 90, 71-81.

He, Y., Yu, H., Ozaki, A., Dong, N., Zheng, S., 2017. An investigation on the thermal and energy performance of living wall system in Shanghai area, Energy and Buildings 140, 324-335, DOI: 10.1016/j.enbuild.2016.12.083.

Hoelscher, M.-T., Nehls, T., Jänicke, B., Wessolek, G., 2016. Quantifying cooling effects of facade greening: Shading, transpiration and insulation, Energy and Buildings, 114, 283-290, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2015.06.047.

Hunter, A.M., Williams, N.S.G., Rayner, J.P., Aye, L., Hes, D., Livesley, S.J., 2014. Quantifying the thermal performance of green façades: A critical review. Ecological Engineering 63, 102-113.

Ip, K., M. Lam, A. Miller, 2010. Shading performance of a vertical deciduous climbing plant canopy, Building and Environment, 45 (1), 81-88

Jaffal, I., Ouldboukhitine, S. E., Belarbi, R., 2012. A comprehensive study of the impact of green roofs on building energy performance. Renewable Energy 43, 157-164.

Jim, C.Y., 2015. Thermal performance of climber greenwalls: Effects of solar irradiance and orientation, Applied Energy, 154, 631-643 http://dx.doi.org/10.1016/j.apenergy.2015.05.077.

Karlessi, T., Santamouris, M., Synnefa, A., Assimakopoulos, D., Didaskalopoulos, P., & Apostolakis, K., 2011. Development and testing of PCM doped cool colored coatings to mitigate urban heat Island and cool buildings. Building and Environment 46, 570-576.

Köhler, M., Poll, P. H., 2010. Long-term performance of selected old Berlin greenroofs in comparison to younger extensive greenroofs in Berlin. Ecological Engineering 36(5), 722-729.

Kontoleon, K. J., Eumorfopoulou, E.A., 2010. The effect of the orientation and proportion of a plant-covered wall layer on the thermal performance of a building zone. Building and Environment 45, 1287-1303.

Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F., 2006. World Map of the Köppen-Geiger climate classification updated. Meteorologische Zeitschrift 15 (3), 259-263. DOI: 10.1127/0941-2948/2006/0130

Norton, B. A., Coutts, A. M., Livesley, S. J., Harris, R. J., Hunter, A. M., Williams, N. S. G., 2015. Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. Landscape and Urban Planning 134, 127-138.

Nuzzo, R. L., 2016. The Box Plots Alternative for Visualizing Quantitative Data, PM&R, 8 (3), 268 – 272. DOI: https://doi.org/10.1016/j.pmrj.2016.02.001

Olivieri, F., Redondas, D., Olivieri, L., Neila, J., 2014. Experimental characterization and implementation of an integrated autoregressive model to predict the thermal performance of vegetal façades. Energy and Buildings, 72, 309-321, https://doi.org/10.1016/j.enbuild.2013.12.062.

Oluwafeyikemi, A., & Julie, G., 2015. Evaluating the impact of vertical greening systems on thermal comfort in low income residences in lagos, nigeria. Paper presented at the Procedia Engineering, 118, 420-433. doi:10.1016/j.proeng.2015.08.443

Peck, SW, Callaghan, C, Kuhn, ME, Bass, B. 1999. Greenbacks from green roofs: Forging a new industry in Canada. Status report on benefits, barriers and opportunities for green roof and vertical garden technology diffusion. Canada: Canada Mortgage and Housing Corporation.

Pérez, G., Coma, J., Sol, S., Cabeza, L.F., 2017. Green facade for energy savings in buildings: The influence of leaf area index and facade orientation on the shadow effect, Applied Energy, 187, 424-437.

Pérez, G., Coma, J., Martorell, I., Cabeza, L.F., 2014. Vertical Greenery Systems (VGS) for energy saving in buildings: A review. Renewable and Sustainable Energy Reviews 39, 139-165. https://doi.org/10.1016/j.rser.2014.07.055

Pérez, G., Rincón, L., Vila, A., González, J.M., Cabeza, L.F., 2011. Green vertical systems for buildings as passive systems for energy savings. Applied Energy 88(12), 4854-4859. https://doi.org/10.1016/j.apenergy.2011.06.032

Perini, K., Ottelé, M., 2014. Designing green façades and living wall systems for sustainable constructions, International Journal of Design and Nature and Ecodynamics, 9 (1), 31-46.

Perini, K., Ottelé, M., Fraaij, A.L.A., Haas, E.M., Raiteri, R., 2011. Vertical greening systems and the effect on air flow and temperature on the building envelope. Building and Environment 46(11), 2287-2294. https://doi.org/10.1016/j.buildenv.2011.05.009

Raji, B, Tenpierik, MJ, Van Den Dobbelsteen, A, 2015. The impact of greening systems on building energy performance: A literature review. Renewable and Sustainable Energy Reviews, 45, 610-623.

Raziei, T., Pereira, L.S., 2013. Estimation of ETo with Hargreaves-Samani and FAO-PM temperature methods for a wide range of climates in Iran, Agricultural Water Management, 121, 1-18. DOI: 10.1016/j.agwat.2012.12.019

Riley, B., 2017. The state of the art of living walls: Lessons learned, Building and Environment 114, 219-232, DOI: 10.1016/j.buildenv.2016.12.016.

Rowe, D. B., 2011. Green roofs as a means of pollution abatement. Environmental Pollution 159, 2100-2110.

Safikhani, T, Baharvand, M., 2017. Evaluating the effective distance between living walls and wall surfaces, Energy and Buildings, Volume 150, Pages 498-506, ISSN 0378-7788, http://dx.doi.org/10.1016/j.enbuild.2017.06.029

Santamouris, M., 2012. Cooling the cities – A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. Solar Energy 103, 682–703. https://doi.org/10.1016/j.solener.2012.07.003

Scarpa, M., Mazzali, U., Peron, F., 2014. Modeling the energy performance of living walls: validation against field measurements in temperate climate, Energy and Buildings, 79, 155–163. http://dx.doi.org/10.1016/j.enbuild.2014.04.014

Schettini, E., Campiotti, C.A., Blanco, I., Vox, G., 2018a. Green façades to enhance climate control inside buildings Acta Horticulturae, 1227, 77-84. DOI: 10.17660/ActaHortic.2018.1227.9

Schettini, E., Campiotti, C.A., Scarascia Mugnozza, G., Blanco, I., Vox, G., 2018b. Green walls for building microclimate control. Acta Horticulturae. 1215, 73-76. DOI: 10.17660/ActaHortic.2018.1215.13

Schettini, E., Blanco, I., Campiotti, C.A., Bibbiani, C., Fantozzi, F., Vox, G., 2016. Green control of microclimate in buildings. Agriculture and Agricultural Science Procedia 8, 576-582. DOI: 10.1016/j.aaspro.2016.02.078

Su, Y.-M., Lin, C.-H., 2015. Removal of indoor carbon dioxide and formaldehyde using green walls by bird nest fern, Horticulture Journal, 84 (1), 69-76. DOI: 10.2503/hortj.CH-114

Šuklje, T., Hamdy, M., Arkar, C., Hensen, J.L.M., Medved, S., 2019, An inverse modeling approach for the thermal response modeling of green façades, Applied Energy, 235, 1447-1456, https://doi.org/10.1016/j.apenergy.2018.11.066.

Šuklje, T., Medved, S., Arkar, C., 2016, On detailed thermal response modeling of vertical greenery systems as cooling measure for buildings and cities in summer conditions, Energy, 115 (1), 1055-1068, https://doi.org/10.1016/j.energy.2016.08.095.

Susorova, I., Azimi, P., Stephens, B., 2014. The effects of climbing vegetation on the local microclimate, thermal performance, and air infiltration of four building facade orientations. Building and Environment 76, 113-124. https://doi.org/10.1016/j.buildenv.2014.03.011

Susorova, I., Angulo, M., Bahrami, P., Stephens, B., 2013. A model of vegetated exterior facades for evaluation of wall thermal performance, Building and Environment, 67, 1-13. https://doi.org/10.1016/j.buildenv.2013.04.027.

Tan, C. L., Wong, N. H., Jusuf, S. K., 2014. Effects of vertical greenery on mean radiant temperature in the tropical urban environment. Landscape Urban Plan. 127, 52-64.

UNI EN 1745, 2012. Masonry and masonry products - Methods for determining thermal properties. UNI - Ente Nazionale Italiano di Unificazione - Italian Organization for Standardization; IT.

Vox, G., Blanco, I., Schettini, E., 2018a. Green façades to control wall surface temperature in buildings. Building and Environment, 129, 154-166. DOI: 10.1016/j.buildenv.2017.12.002

Vox, G., Scarascia Mugnozza, G., Blanco, I., Schettini, E., 2018b. Heat fluxes in Green Walls. Acta Horticulturae, 1215, 273-278. DOI: 10.17660/ActaHortic.2018.1215.49.

Vox, G., Blanco, I., Fuina, S., Campiotti, C.A., Scarascia Mugnozza, G., Schettini, E., 2017. Evaluation of wall surface temperatures in green facades. Proceedings of the Institution of Civil Engineers - Engineering Sustainability 170 (6), 334-344. DOI: 10.1680/jensu.16.00019

Vox, G., Maneta, A., Schettini, E., 2016. Evaluation of the radiometric properties of roofing materials for livestock buildings and their effect on the surface temperature. Biosystems Engineering 144, 26-37. DOI: 10.1016/j.biosystemseng.2016.01.016

Vox, G., Blanco, I., Campiotti, C.A., Giagnacovo, G., Schettini, E., 2015. Vertical green systems for buildings climate control. In Proceedings of the 43rd International Symposium - Actual Tasks on Agricultural Engineering. Sveučilište u Zagrebu, Agronomski fakultet, Zavod za mehanizaciju poljoprivrede, Opatija, Croatia, pp. 723-732.

Wong, I., Baldwin, A. N., 2016. Investigating the potential of applying vertical green walls to high-rise residential buildings for energy-saving in sub-tropical region, Building and Environment, 97, 34-39, ISSN 0360-1323, http://dx.doi.org/10.1016/j.buildenv.2015.11.028.

Wong, N.H., Kwang Tan, A.Y., Chen, Y., Sekar, K., Tan, P.Y., Chan, D., Chiang, K., Wong, N.C., 2010. Thermal evaluation of vertical greenery systems for building walls. Building and Environment 45(3), 663-672. https://doi.org/10.1016/j.buildenv.2009.08.005

Yildiz, B., Bilbao, J.I., Sproul, A.B., 2017. A review and analysis of regression and machine learning models on commercial building electricity load forecasting, Renewable and Sustainable Energy Reviews, 73, 1104-1122. DOI: 10.1016/j.rser.2017.02.023

Yu, L.J., De Vera, Santos A., Tan, K.W., Tawawneh, M.A., 2016. Water Absorbing Plantation Clay for Vertical Greenery System, MATEC Web of Conferences 60, 01002, DOI: 10.1051/matecconf/20166001002