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Abstract: Green façades can represent a sustainable solution for construction of new buildings and for retrofitting of existing buildings, in order to reduce the energy demands of the buildings' cooling systems, to mitigate the urban heat island and to improve the thermal energy performance of buildings. Green façades can allow the physical shading of the building and promote evapotranspiration in summer, and increase the thermal insulation in winter. An experimental test was carried out at the University of Bari (Italy) for two years. Three vertical walls, made with perforated bricks, were tested: two were covered with evergreen plants (Pandorea jasminoides variegated and Rhyncospermum jasminoides) while the third wall was kept uncovered and used as control. Several climatic parameters concerning the walls and the ambient conditions were collected during the experimental test. The daylight temperatures observed on the shielded walls during warm days were lower than the respective temperatures of the uncovered wall up to 9.0°C. The nighttime temperatures during the cold days for the vegetated walls were higher than the respective temperatures of the control wall up to 3.5°C. The results shown in the present research allow to fill the gap in literature concerning the lack of data for all the seasons of the year, in order to obtain a complete picture of the building thermal performance in the Mediterranean climate region.

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Bari, 4/09/2017

To the Editor of
Building and Environment

Subject: Paper “Green façades to control wall surface temperature in buildings”
Authors G. Vox, I. Blanco, E. Schettini

Dear Editor,
I would like to submit the research paper entitled “Green façades to control wall surface temperature in buildings”, authors G. Vox, I. Blanco, E. Schettini, for publication in Building and Environment.

The paper presents the results concerning two years of experimental test in the Mediterranean climate region, allowing to fill the gap in literature concerning the lack of data for all the seasons of the year. Moreover, the impact of climatic conditions on the thermal insulation performance of green façades was analyzed by considering different weather scenarios. Considerations on the thermal behavior of the green facades were carried out over the course of the day and over the varying of the seasons.

Best regards,

Evelia Schettini

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Highlights

- Thermal behavior of plant layer observed over the day and the seasons
- Two years of experimental data in Mediterranean climate region
- Thermal insulation of green façades in different weather scenarios
- Summer daylight temperatures of green facades up to 9.0°C lower than uncovered wall
- Winter nighttime temperatures of green facades up to 3.5°C higher than uncovered wall.

Green façades to control wall surface temperature in buildings

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Green façades to control wall surface temperature in buildings

ABSTRACT

Green façades can represent a sustainable solution for construction of new buildings and for retrofitting of existing buildings, in order to reduce the energy demands of the buildings' cooling systems, to mitigate the urban heat island and to improve the thermal energy performance of buildings. Green façades can allow the physical shading of the building and promote evapotranspiration in summer, and increase the thermal insulation in winter. An experimental test was carried out at the University of Bari (Italy) for two years. Three vertical walls, made with perforated bricks, were tested: two were covered with evergreen plants (*Pandorea jasminoides variegated* and *Rhyncospermum jasminoides*) while the third wall was kept uncovered and used as control. Several climatic parameters concerning the walls and the ambient conditions were collected during the experimental test. The daylight temperatures observed on the shielded walls during warm days were lower than the respective temperatures of the uncovered wall up to 9.0°C. The nighttime temperatures during the cold days for the vegetated walls were higher than the respective temperatures of the control wall up to 3.5°C. The results shown in the present research allow to fill the gap in literature concerning the lack of data for all the seasons of the year, in order to obtain a complete picture of the building thermal performance in the Mediterranean climate region.

Keywords: urban agriculture, green walls, air-conditioning, energy savings, microclimate, urban heat island

1. INTRODUCTION

In the last decades, unprecedented urban growth has occurred and in the near future most of the urbanization will take place in developing countries, with Africa and Asia providing 85% of the world's urban dwellers by 2030 (United Nations, 2016). Africans are expected to triple by the end of the century while Asian population is expected to reach over five billion people around the middle of the century. In 2014, 54% of the world's population lived in urban agglomerations than in rural areas while in 1950 only 30% of the world's population was urban (United Nations, 2016). It is projected that 70% of the world's population will be urban by 2050 (United Nations, 2016). When rural or natural regions are transformed into cities, changes to the landscape can lead to modifications in the weather patterns over that areas. Building surfaces and pavements are made mainly with non-reflective and water-resistant construction materials, consequently accumulating incident solar radiation during daytime and then releasing heat at night (Vox et al., 2016). Heat is trapped also because the decrease of green areas in cities induces a reduction of shades and radiation interception, together with the reduction of the infrared radiation emitted towards the atmosphere, the limitation of the circulation of air in urban canyons and the high production of waste heat from cooling systems, motorized vehicular traffic and industrial processes (Santamouris, 2012; Campiotti et al., 2013). So as a city grows, more heat is trapped with a consequential increase of the air temperature in downtown even up to 6°C higher in comparison to the surrounding suburban and rural areas (Santamouris, 2012; Kanechi, et al., 2014; Schettini et al., 2016; Vox et al., 2015). This phenomenon is known as the Urban Heat Island (UHI). UHI negatively influences outdoor comfort conditions as well as induces a more use of air conditioning systems with a raise of peak electricity demand. Nowadays, energy use in buildings accounts up to 36% of Europe’s CO_2 emissions (Cabeza et al., 2010).

The implementation of green infrastructures in cities is a sustainable solution useful to improve the energy efficiency of buildings (Perini et al., 2011; Wong et al., 2010; Berardi et al., 2014; Santamouris, 2012; Fernandez-Caňero et al., 2013; Kazemi and Mohorko, 2017; Cameron et al., 2014; Cheng et al., 2010; Perez et al., 2011). Green vertical systems can be used because the surface area of the building envelopes is generally left bare while surrounding areas at ground level are increasingly occupied by buildings and paved surfaces, and portions of the roofs are occupied by building services (Jim, 2015; He et al., 2017). Green vertical systems offer several benefits on the façade, as the extension of wall lifetime, the thermal insulation of the wall, and the reduction of solar absorbance. They also offer benefits on the building, as the reduction of heat load and of energy consumption, the improvement of the internal comfort due to a reduction of the surface temperature and the attenuation of temperature fluctuations. The enhancement of the acoustic comfort, the increasing of the property values, the implementation of spaces for recreation and amenity are other advantages. Vertical gardens protect the exterior finishes and masonry from ultra violet radiation, rain, extreme temperature fluctuations and presence of moisture even if they could damage the wall they are covering. Other benefits can be found at a larger scale: energy consumption reduction (decreasing cooling and heating loads); urban heat island effect decreasing; air pollution mitigation (enhancing urban air quality, reducing dust and heavy metal accumulation in air, filtering airborne particles); sound absorption (sound insulation and noise absorption); water management improving (enhancement of stormwater management, of water run-off quality, of urban hydrology, of the use of rainwater). Moreover, vertical planting contributes to improve health and well-being and to preserve urban biodiversity, acting as habitat for colonizing species such as spontaneous plant species, weeds, beetles, bees, ants, spiders and birds.

Green vertical systems are classified according to construction techniques and characteristics into green façades and living walls (Cuce, 2016; Riley, 2017; He et al., 2017). Green façades are characterized by climbing plants rooted in the ground or in pots at different heights of the façade; the plants climb on the building façade directly through morphological features (such as aerial roots, leaf tendrils and adhesion pads) or indirectly on a structural support (such as wire, mesh, trellis) located to a small distance to the wall. Living walls are classified as continuous or modular: the former is based on lightweight and permeable screens in which plants are inserted individually; the latter is composed of modular elements, such as trays, vessels, planter tiles and flexible bags, which include the growing media where plants can grow (Manso and Castro-Gomes, 2015). The modular elements are fixed to a wall or freestanding frame with artificial irrigation and fertigation system. The presence of a gap between the building wall and the greening system (generally from 3 cm to 15 cm) acts as a thermal buffer, improving its thermal insulation impact on building (Perez et al., 2014).

Several authors presented experimental data at real scale concerning short summer periods (Chen et al, 2013; Perez et al., 2014; Susorova et al., 2014; Vox et al., 2017), more studies are necessary to analyse the thermal performance of a building throughout the whole year. In summer the efficacy of greenery systems has been widely assessed while the performance of the greenery systems in winter requires further investigation for its climatic conditions dependence (Perez et al., 2014; Coma et al., 2017).

The aim of this paper is to analyse experimental data for a long period in the Mediterranean region. Two different climbing plants were tested as green façades at the University of Bari, South Italy. Several climatic parameters concerning the walls and the weather conditions were collected for estimating the variations of the surface temperature of the walls equipped with the greenery systems in comparison with the uncovered wall.

2. MATERIALS AND METHODS

From June 2014 to December 2016, an experimental research was carried out at the University of Bari in Valenzano (Bari, Italy) at latitude 41° 05' N, longitude 16° 53' E, altitude 85 m ASL. This area has a Mediterranean climate classified as Csa, according to the Kopper-Geiger climate classification (Kottek et al., 2006). It is characterized by warm temperate climate with dry and hot summer; the winter months are much rainier than the summer months and the average annual temperature is 16.1 °C.

Three walls were built facing south following the typical Mediterranean building solutions, i.e. perforated bricks joined with mortar. Each wall was characterized by a width of 1.00 m, a height of 1.55 m, and a thickness of 0.22 m. The bricks used (0.20 m x 0.25 m x 0.25 m) have a thermal conductivity λ (UNI EN 1745, 2012) equal to 0.282 W m^{-1} K^{-1}, a specific heat capacity C equal to 840 J kg^{-1} K^{-1}, and an average density of the masonry work (including plaster) equal to 695 kg m^{-3}. In order to insulate the walls and to evaluate the influence of the vegetation layer on the wall, a sealed structure was made on the backside of the wall with sheets of expanded polystyrene with a thickness of 30 mm and a thermal conductivity of 0.037 W m^{-2} K^{-1}. A shading net was positioned onto the structures in order to reduce the effect of the incident solar radiation on the sealed structure.

Pandorea jasminoides variegated and *Rhyncospermum jasminoides* were transplanted on June 18, 2014. A third wall was kept uncovered for control. As plant supporting structure, an iron net was placed at a distance of 15 cm from the wall. These plants were selected due to their ease to climb the wall and their well adaptation to the climatic conditions of the experimental area (Figure 1). The plants were irrigated with the drip system.

The external air temperature, 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 effective value of the solar radiation measured 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 a pyranometer (model 8-48, Eppley Laboratory, Newport, RI, USA) in the wavelength range 0.3-3 mm. Environmental conditions 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.

Statistical analyses were carried out with the CoStat software (CoHort Software, Monterey, CA, USA). Oneway analysis of variance (ANOVA) at a 95% probability level was carried out in order to compare mean temperature values; Duncan's test was applied with a significance level equal of 0.05.

3. RESULTS

The Mediterranean climate is characterized by calm, hot and dry summers and warm and wet winters and by a notably variation of solar radiation intensity with season. Both the solar radiation on a horizontal plane and the solar radiation on the vertical wall were measured.

In the period from January 2015 to December 2016, the experimental field was characterized by values of the external air temperature ranging from -0.3°C to 41.4°C in 2015 and from 0.7°C to 39.2°C in 2016. The yearly cumulative solar radiation on a horizontal plane was equal to 5282 MJ m^{-2} and 5129 MJ m^{-2} in 2015 and 2016, respectively. The monthly value of cumulative solar radiation ranged from 177 MJ m^{-2}, recorded in January 2016, to 802 MJ m^{-2}, recorded in July 2015. The annual cumulative solar radiation on the vertical wall was equal to 3752 MJ m^{-2} and 3575 MJ m^{-2} in 2015 and 2016, respectively. The monthly value of cumulative solar radiation on the vertical wall ranged from 232 MJ m^{-2} (June 2016) to 357 MJ m^{-2} (September 2015).

The impact of climatic conditions on the thermal insulation performance of green façades was analysed by considering different weather scenarios in summer and winter. One representative day of each weather scenario was selected and the results are presented and discussed. On sunny days the external solar radiation on horizontal plane and the external solar radiation on the vertical wall displayed a typical bell-shape. On cloudy days, the solar radiation curves were peak shape irregular curves characterised by peaks due to the presence of the sun and minimum points due to the presence of clouds in the sky.

3.1 Thermal performance in summer

The two summers were characterized by external air temperatures ranging from 15.7°C to 41.4°C, with an average value of 27.6°C, during 2015, and from 15.6°C to 39.2°C, with an average value of 25.4°C, during 2016. Therefore, both for a sunny day and for a cloudy day, “a hot day” (Figure 2), “a warm day” (Figure 3) and “a cool day” (Figure 4), characterized by temperature respectively over the average, on average and below the average were analysed.

In summer, daytime the maximum value of the wall surface temperature of the green façade was always recorded at least 1 hour late in sunny days and less than 1 hour late in cloudy days in comparison to the maximum value of the wall surface temperature of the control wall. It is due to the phase shift of the thermal wave due to the green façades highlighted in presence of the sun.

The day characterised by the highest maximum external air temperature, equal to 41.4°C, was chosen to analyse a hot summer sunny day during the experimental test period (Figure 2a). During hot sunny days, the differences between the curve of the surface temperatures of the two green façades on the external plaster exposed to the solar radiation and of the control wall without greening cladding were wide particularly in the hot hours of the day, as shown in Figure 2a, while a reduction of solar radiation intensity during afternoon promptly compressed these differences. During the daytime, 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, and the amount of vegetative cooling was kept within a range of 6-7 °C.

The maximum reduction of temperature between the control wall without greening and the covered ones was equal to 9.0 °C and was recorded on 31/08/2015 at 13.00 h for the wall protected with *Pandorea jasminoides variegated*.

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.

A hot summer partly cloudy day was shown in Figure 2b: the presence of clouds, with a reduction of solar radiation intensity, reduced the differences between the curve of the external wall surface temperatures of the two green façades and of the control wall. Throughout the hours from early evening to early morning, the external wall temperatures of the two green façades were higher of about 1-2°C than the external wall temperature of the control.

Figure 3a shown the external air temperature, the wall surface temperature of the three walls exposed to solar radiation, and the curves of the solar radiation both on a vertical wall facing south and on horizontal plane for a warm summer sunny day, characterised by the average external air temperature of the day (equal to 25.9°C) similar to the average mean value of 2016 (equal to 25.4°C). During the hot hours of the day, the vegetative cooling was kept up to maximum 6 °C while at nighttime the external wall temperatures of the green façades were higher than the temperature of the control wall up to 2 °C.

A warm summer cloudy day was shown in Figure 3b: the external wall temperatures of the two green façades closely followed the external wall temperature of the wall without plants. In the afternoon and at nighttime the external wall temperatures of the two green façades were higher than the external wall temperature of the control; the amount of vegetative warming was kept within a narrow range of 1-2 °C.

On a cool summer sunny day (Figure 4a), the external wall temperature of the control wall rose in the morning being synchronized with the solar radiation more than the external wall temperature of the wall covered with plants. During daytime the differences between the external wall temperatures were about 3-4 °C while a reduction in irradiance promptly reduced these differences.

A cool summer cloudy day was shown in Figure 4b: the external wall temperatures of the two green façades closely followed the external wall temperature of the wall without plants.

Both after a sunny or a cloudy day, the green façades acted as thermal screens during night with a higher external wall temperature of the two green façades; this behaviour in summer is not desirable.

3.2 Thermal performance in winter

The winter periods were characterized by temperatures ranging from -0.3°C to 20.9°C, with an average value of 9.6°C, during 2015 and from 1.7° C to 22.6° C, with an average value of 10.9°C, during 2016. Two different weather scenarios were analysed through “a particularly cold day” (Figure 5), “a cool day” (Figure 6) and “a warm day” (Figure 7), characterized by temperature respectively below the average, on average and over the average.

Regardless of the different weather conditions, in winter the vegetation layer increased the insulation performance of the green façades from sunset to early morning: the external wall temperature of the green façades was always higher, within a range of 1-

2 °C, in comparison to the external wall temperature of the control wall without greening cladding (Figures 5-7).

During a cold wave, the highest increase of temperature of the external covered surface in comparison with the control wall without greening was equal to 3.5°C and it was recorded on 06/01/2016 at 19.45 h for the *Pandorea jasminoides variegated*. The green façades act as a thermal screen with a vegetative warming. This behaviour is desirable in wintertime contributing to reduce the heating energy cost.

Winter sunny days were characterised during the daytime by an external wall temperature of the control wall higher of 3-4 °C on a cold day (Figure 5a), of 5-6 °C on a cool day (Figure 6a), of 4-5 °C on a warm day (Figure 7a), in comparison with the external wall temperature of the green façades.

Cloudy days were characterised by air temperature regimes connected with the feeble solar radiation environment: the diurnal temperature ranges have been reduced and small peaks were displayed as responses to the presence of solar radiation rays. During the daytime of winter cloudy days, the wall temperature curves cluster together as shown in Figure 5b, Figure 6b and Figure 7b.

3.3 Surface average temperatures

Surface temperature of the external plaster of the three walls exposed to solar radiation gathered during the experimental period from January 2015 to December 2016 fluctuated over the course of the day and over the varying of the seasons.

Table 1 shows the monthly average values of the maximum, minimum and mean daily external air temperature and surface temperature of the external plaster of the three walls exposed to solar radiation, and the monthly cumulative solar radiation on a horizontal plane and on the vertical wall.

The monthly average of the daily maximum surface temperatures recorded on the control wall were mainly statistically higher than the values recorded on the green façades during all the seasons (Table 1), demonstrating the cooling effect of this green technology during daytime. The cooling behaviour is desirable in warm period. The mitigation of the wall surface temperature due to the plants was observed throughout the year; no significant difference was pointed out between the two plants. The differences between the average values of the maximum daily temperatures recorded for the control and for the walls covered with the plants ranged between 0.3 °C and 5.7 °C for *Rhyncospermum jasminoides*, and between 0.9 °C and 5.1 °C for *Pandorea jasminoides variegated*, the higher differences being recorded from July to September each year (Table 1).

The monthly average of the daily minimum surface temperatures recorded on the wall not covered with plants were statistically often lower than the values recorded on the walls covered with climbing plants during all the seasons (Table 1), demonstrating the heating effect of this green technology during nighttime. The heating behaviour is desirable in cold period. No significant temperature difference was recorded between the surfaces covered with the two plants. The differences between the lowest mean temperatures recorded for the wall shielded with plants and the control ranged from 1.0 °C to 1.9 °C for *Rhyncospermum jasminoides*, and from 0.9 °C to 1.7 °C for *Pandorea jasminoides variegated* (Table 1). The minimum surface temperature of the external plaster protected with the two green walls closely followed the daily minimum external air temperature.

No significant differences were pointed for the monthly average daily surface temperatures recorded on the control wall and on the green façades during all the seasons (Table 1).

4. DISCUSSION

In this study, a long-term monitoring activity was carried out on two green façades and on a control wall in Mediterranean climatic conditions. The thermal behaviour of two different climbing plants, *Rhyncospermum jasminoides* and *Pandorea jasminoides variegated*, was observed over the course of the day and over the varying of the seasons. Environmental conditions and surface temperature of the external plaster of the three walls exposed to solar radiation were gathered throughout the two years of experimental test. The measures were collected with a frequency of 60 s, averaged every 15 min and recorded on a data logger. The data recorded allowed a reliable statistical analysis. Moreover, during two years of data gathering it was possible to consider different weather scenario to analyse the thermal behaviour of the green façades. No significant difference emerged in the behaviour of the two selected plant species. Similar analyses using data recorded during a short period of time, from few days to a month or to at least a season, can be unreliable.

The field test was carried out to overcome a lack of literature on experimental data on green façades for a long period (Bianco et al., 2016; Cuce et al., 2016; Coma et al. 2017; Perez et al., 2014; Charoenkit and Yiemwattana, 2016). Simulation models often were not validated with real data (Perez et al., 2014; Raji et al., 2015; Hunter et al. 2014).

In the present research the daylight temperatures observed on the south oriented green façades during warm days were lower than the respective temperatures of the uncovered wall up to 9.0 °C. The nighttime temperatures during the cold days for the vegetated walls were higher than the respective temperatures of the control wall up to 3.5°C. The application of the green layer significantly reduced wall surface temperatures during warm days; it also resulted advantageous during cold weather scenarios by retaining warmth around the building, thus reducing or delaying the demand for indoor heating. The heating effect behind green façades during the evening/night period of warm days requires further attention in relation to internal comfort at night.

Although the cooling influence of the green walls is well recognized, few authors reported experimental data under similar climatic conditions (Csa) in the Mediterranean region and no one considered two years of experimental data.

Coma et al. (2017) reported the results obtained on experimental houses-like cubicles with a green wall system tested in Catalonia, Spain, under the same Csa climatic conditions. In two short winter periods, the green wall registered the highest external wall temperature reductions, equal to 16.5 °C, on the south while in east and west the reductions were 4.5 °C and 6.5 °C, respectively (Coma et al., 2017).

Stenberg et al. (2011) under warm temperate climate conditions at Oxford (UK) found a wall temperature reduction of 9.15 °C generated by a 45 cm thick ivy cover on a south exposed wall.

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 the plant-covered east wall equal in average to 5.7 °C, varying from 1.9 °C to 8.3 °C.

Cameron et al. (2014) studied the thermoregulative performance of wall shrubs and climbing plants on brick walls in controlled environments. Test was carried out during 2010 from 1/9 to 17/12. Among all tested plants, *Hedera* and *Stachys* showed better cooling potential with wall temperature reductions of 7.3 °C and 7.6 °C in comparison with controls, respectively.

Perez et al. (2014) reported the following reduction of the external building surface temperature: from 1.7°C to 13°C in warm temperate climate region and from 7.9°C to 16°C in snow 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. A south façade of a building covered with plants was monitored for four days, from August 29 until September 1, 2012, at Illinois Institute of Technology, characterized by a hot humid continental climate.

Chen et al (2013) reported for a living wall system a reduction of the exterior wall temperature by a maximum of 20.8°C and of the interior wall by 7.7°C. comparing to the bare wall situation. The test was carried out from July to September 2012 in Wuhan (China), characterised by a hot and humid climate.

Wong et al. (2010) analysed the thermal performance of eight different vertical greenery systems installed in 2008 in Singapore, characterized by tropical rainforest climate. Maximum reductions of the wall surface temperature were of 11.58 °C and were observed in clear days during daytime hours of April on a living wall made of plant panels. The panels were embedded within stainless steel mesh panels inserted into fitting frames, on a vertical interface, using small plants.

Available literature reports the thermal behaviour of the green façades as vegetative cooling in summer daytime and the ability to act as a thermal screen with a vegetative warming in winter nighttime. However, some studies reported the maximum temperature differences while other researchers reported the average temperature differences (Charoenkit and Yiemwattana, 2016). Furthermore the magnitude of thermal performance strongly depends on the wall orientation, size, characteristics of the building on which the experimental wall is positioned, apart from plant species, substrate type and foliage layer thickness. This wide variation in data collection together with the short time of gathering makes the comparison of the green façades performance even more difficult.

5. CONCLUSION

The data recorded during the experimental test were useful to assess the temperature regime in green façades under different weather scenario of the seasons in the Mediterranean climate region. The long-term experimental test demonstrated that both species *Pandorea jasminoides variegated* and *Rhyncospermum jasminoides* are suitable for green walls. The results shown in the present research allow to fill the gap in literature concerning the lack of data for all the seasons of the year.

Façades covered with vegetation could be used in passive design where the plants reduce overall temperatures of the building. This strategy utilizes plants to increase energy efficiency by functioning as a natural shading system and reducing heat gain. Future research should be addressed to evaluate throughout the year if and to what extent the resulting decrease in the summer cooling load counterbalances the possible increase in the winter heating load.

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Figure Captions

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

Figure 2: External air temperature, surface temperature of the external plaster of the three walls exposed to solar radiation, solar radiation on the vertical wall facing south and on horizontal plane: (a) a hot summer sunny day, 17 September 2015; (b) a hot summer cloudy day, 15 August 2015.

Figure 3: External air temperature, surface temperature of the external plaster of the three walls exposed to solar radiation, solar radiation on the vertical wall facing south and on horizontal plane: (a) a warm summer sunny day, 3 August 2016; (b) a warm summer cloudy day, 16 August 2015.

Figure 4: External air temperature, surface temperature of the external plaster of the three walls exposed to solar radiation, solar radiation on the vertical wall facing south and on horizontal plane: (a) a cool summer sunny day, less warm than average, 6 September 2016; (b) a cool summer cloudy day, 16 July 2015.

Figure 5: External air temperature, surface temperature of the external plaster of the three walls exposed to solar radiation, solar radiation on the vertical wall facing south and on horizontal plane: (a) a cold winter sunny day, 1 January 2015; (b) a cold winter cloudy day, 18 January 2016.

Figure 6: External air temperature, surface temperature of the external plaster of the three walls exposed to solar radiation, solar radiation on the vertical wall facing south and on horizontal plane: (a) a cool winter sunny day, 27 January 2016; (b) a cool winter cloudy day, 13 March 2016.

Figure 7: External air temperature, surface temperature of the external plaster of the three walls exposed to solar radiation, solar radiation on the vertical wall facing south and on horizontal plane: (a) a warm winter sunny day, 2 February 2016; (b) a warm winter cloudy day, 5 February 2015.

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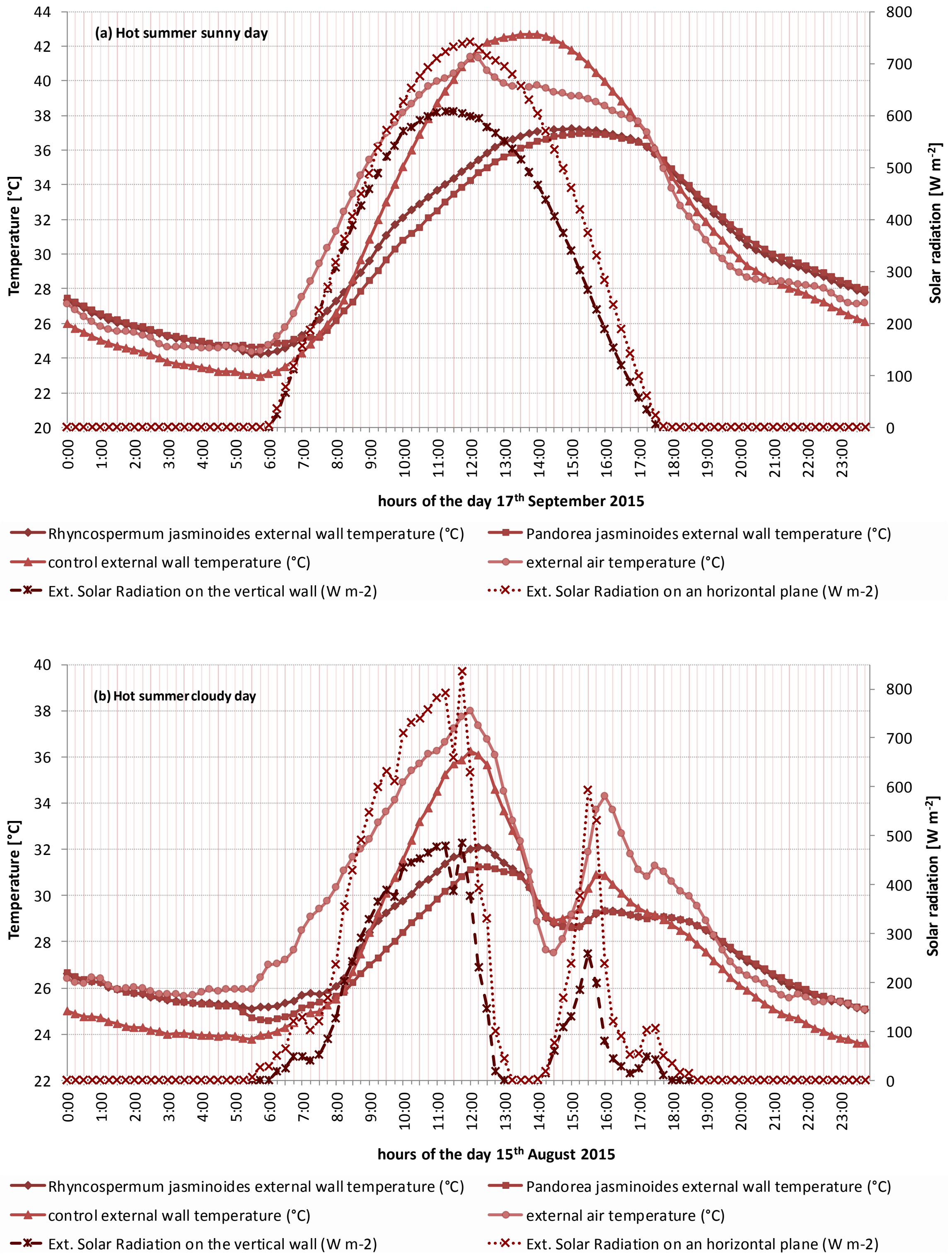

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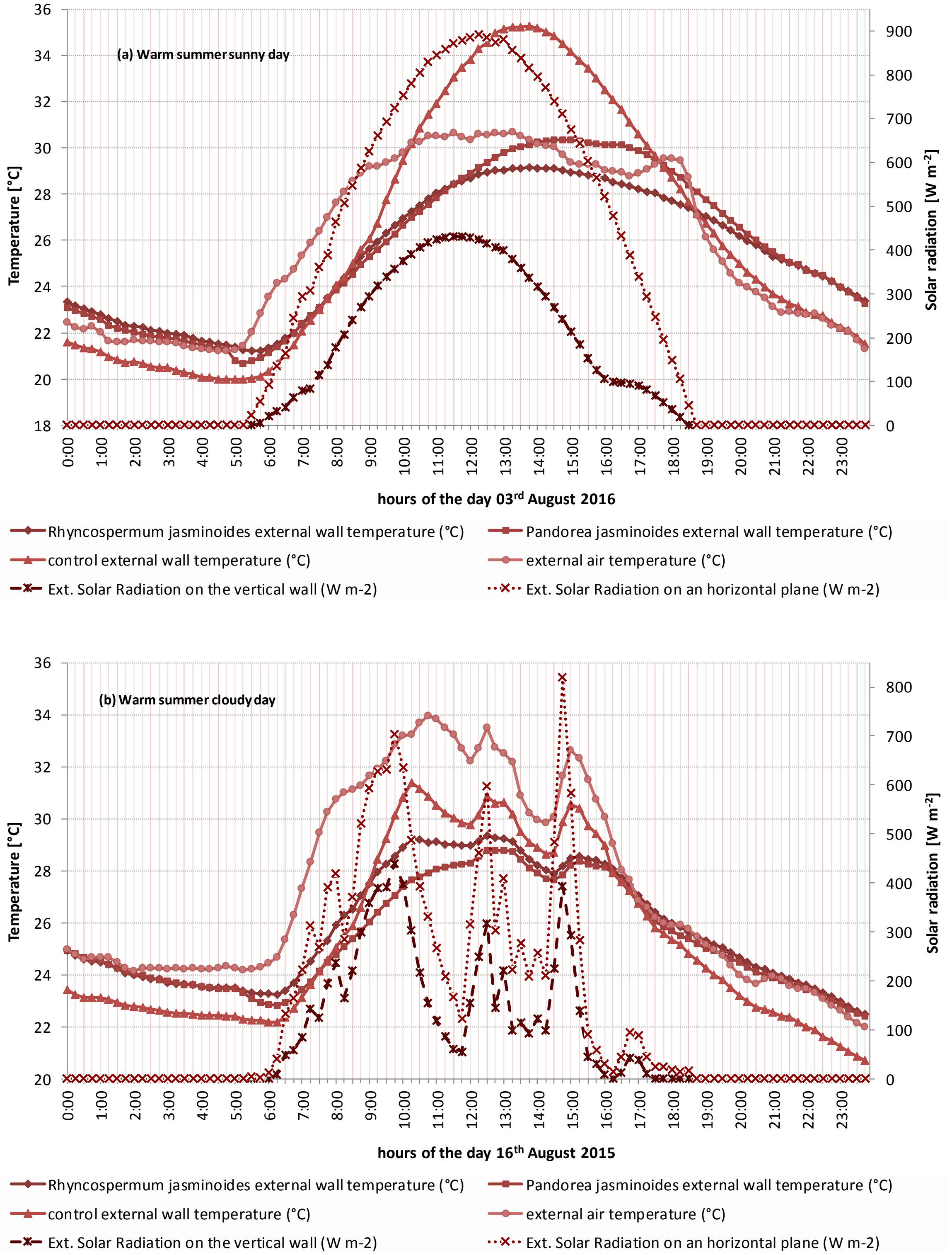

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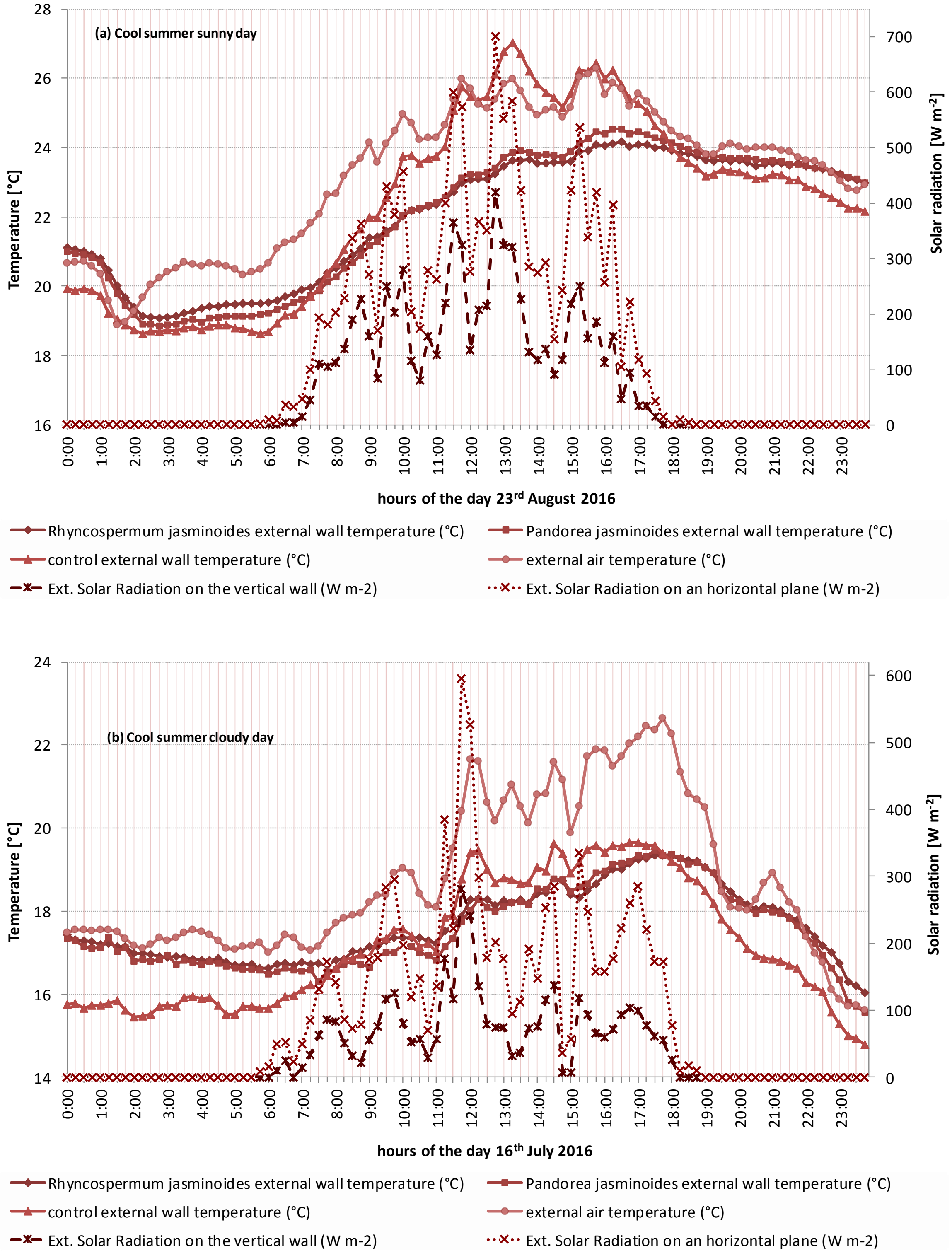

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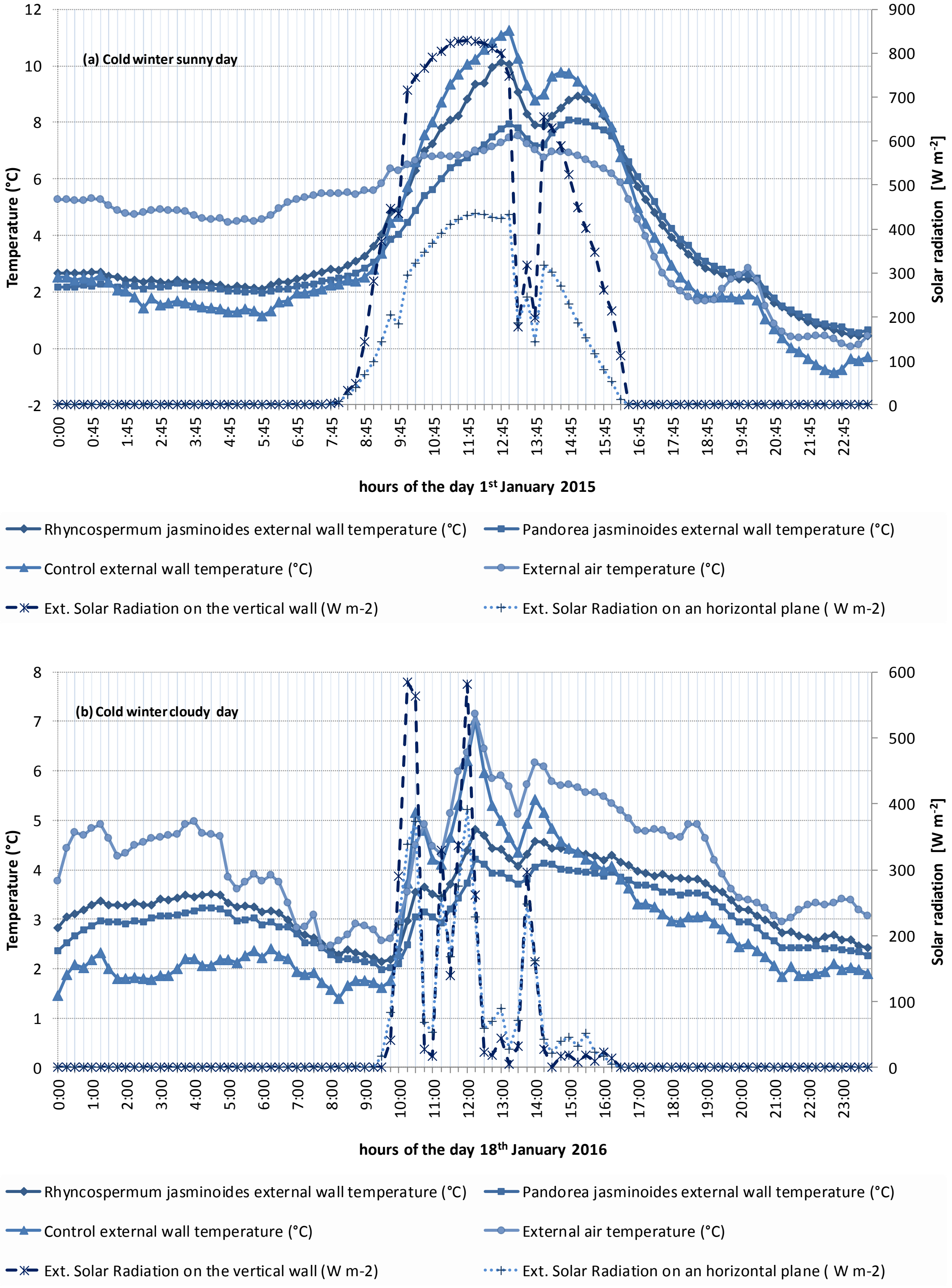

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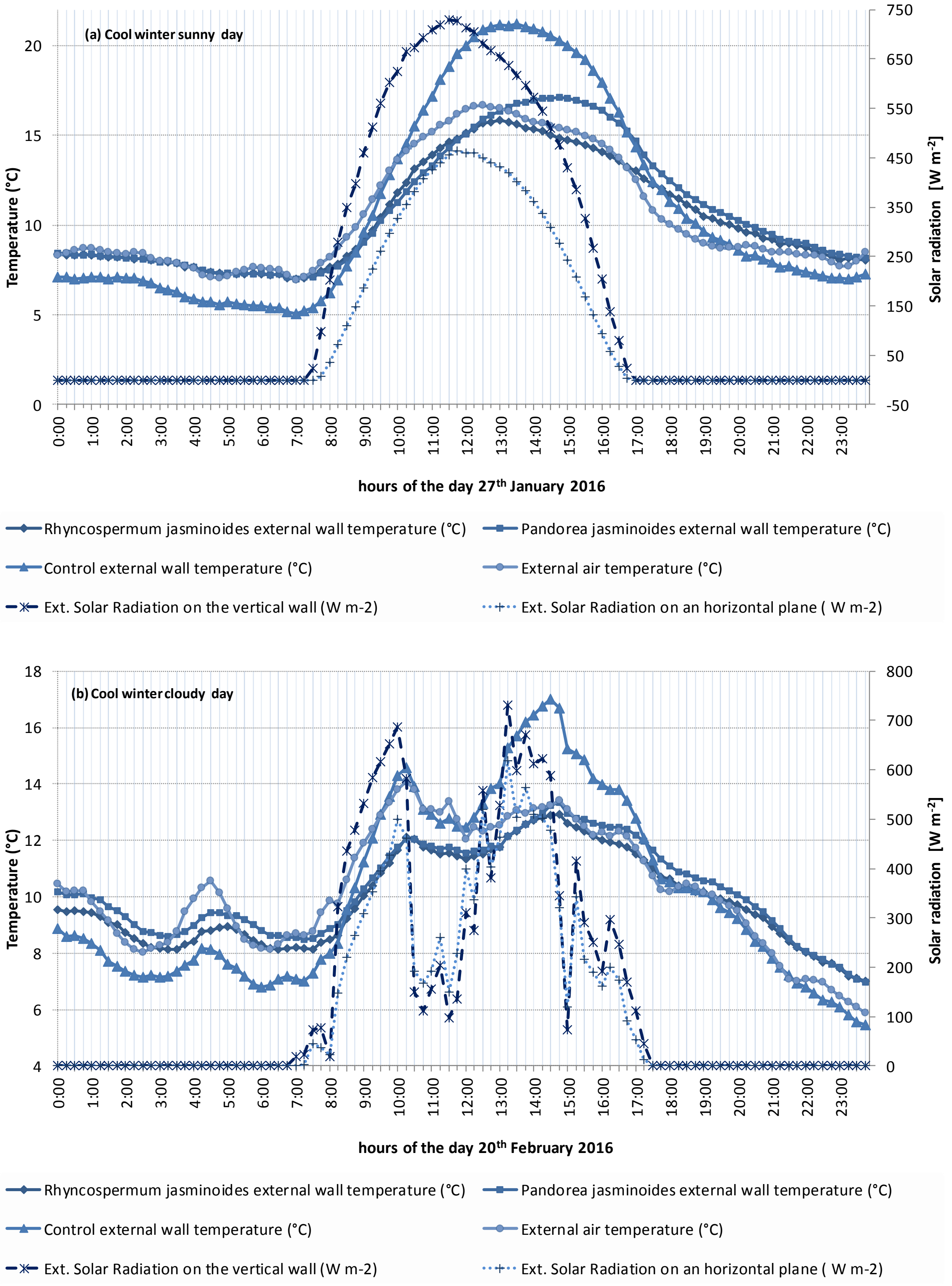

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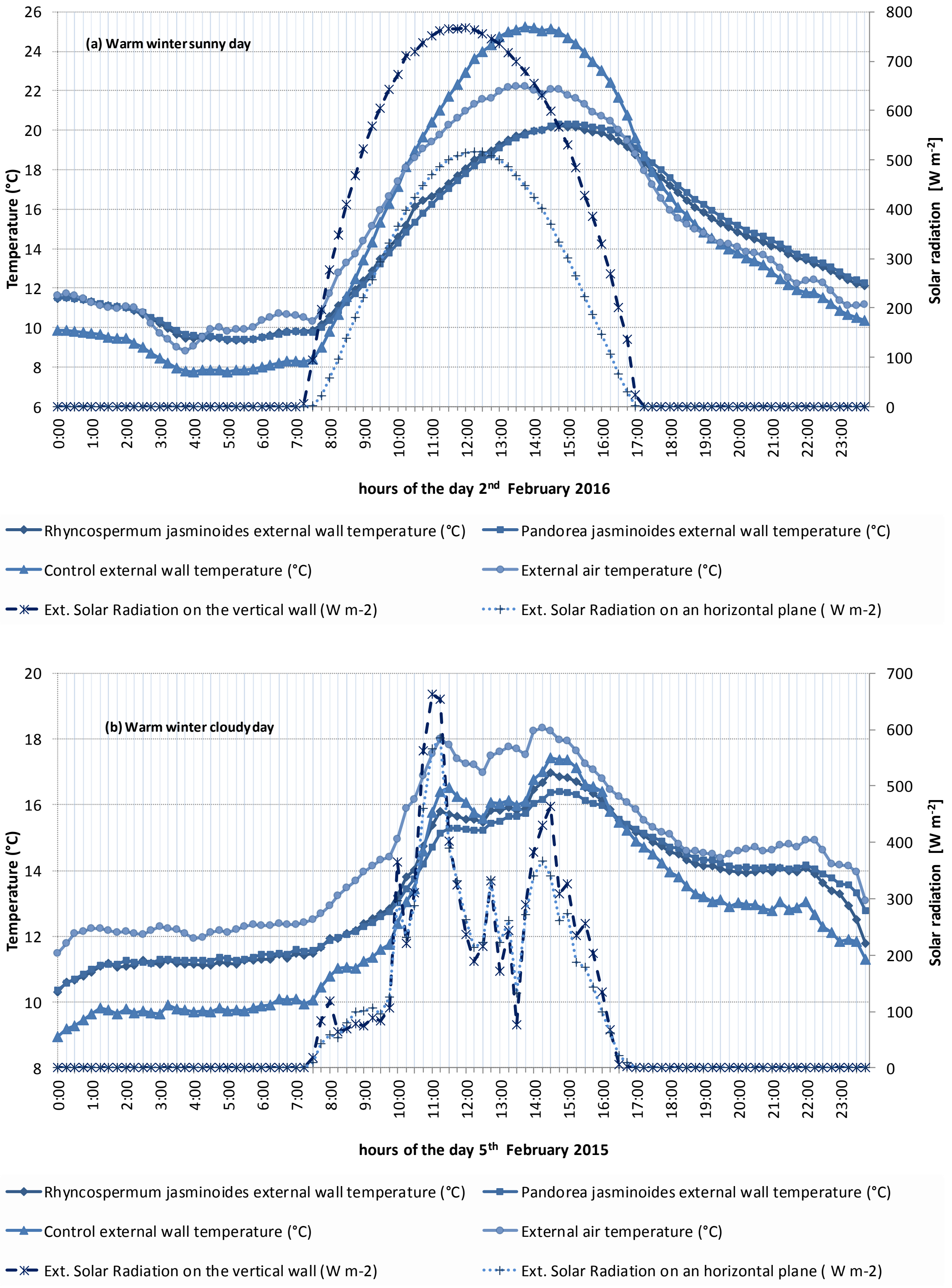

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Table 1: Average values of the maximum, minimum and mean daily external air temperature and surface temperature of the external plaster of the three walls exposed to solar radiation, and the monthly cumulative solar radiation on a horizontal plane and on the vertical wall.

	Monthly average of the daily maximum temperatures (°C)				**Monthly average of the daily minimum temperatures (°C)**				**Monthly average temperatures (°C)**				**Monthly cumulative solar radiation (MJ m^{-2})**	
Month	***Rhyncospermum jasminoides***	***Pandorea jasminoides***	**Control**	**external**	***Rhyncospermum jasminoides***	***Pandorea jasminoides***	**Control**	**external**	***Rhyncospermum jasminoides***	***Pandorea jasminoides***	**Control**	**external**	**on vertical wall**	**on horizonal plane**
Jan-15	15.1^{ab}	13.6^{b}	15.4^{a}	14.2^{ab}	5.4^{a}	5.6^{a}	4.0^{a}	5.4^{a}	9.1^{a}	8.9^{a}	8.4^{a}	9.2^{a}	197	338
Feb-15	13.6^{ab}	12.5^{b}	14.1^{a}	14.1^{a}	5.1^{a}	5.3^{a}	3.7^{b}	5.4^{a}	8.7^{ab}	8.6^{ab}	7.9^{b}	9.2^{a}	213	254
Mar-15	15.3^{a}	14.9^{a}	15.8^{a}	16.5^{a}	7.2^{ab}	7.3^{ab}	5.9^{b}	7.4^{a}	10.8^{ab}	10.8^{ab}	10.2^{b}	11.7^{a}	339	291
Apr-15	19.3^{a}	19.4^{a}	21.0^{a}	21.3^{a}	9.7^{a}	9.8^{a}	8.4^{a}	9.8^{a}	14.2^{a}	14.3^{a}	13.8^{a}	15.4^{a}	546	330
May-15	24.3^{b}	25.2^{b}	27.1^{a}	27.7^{a}	15.3^{a}	15.2^{a}	13.8^{b}	15.3^{a}	19.9^{b}	20.1^{b}	19.7^{b}	21.5^{a}	660	292
Jun-15	27.2^{b}	28.1^{b}	30.8^{a}	30.5^{a}	18.2^{a}	18.3^{a}	16.8^{b}	18.4^{a}	22.9^{b}	23.1^{b}	23.0^{b}	24.7^{a}	749	269
Jul-15	32.6^{c}	32.9^{c}	37.1^{a}	35.8^{b}	22.6^{a}	22.2^{a}	21.1^{b}	22.5^{a}	28.0^{b}	27.8^{b}	28.4^{ab}	29.5^{a}	802	304
Aug-15	30.6^{c}	30.6^{c}	35.6^{a}	33.8^{b}	22.3^{a}	22.0^{ab}	21.1^{b}	22.4^{a}	26.4^{b}	26.2^{b}	27.1^{ab}	27.8^{a}	643	344
Sep-15	27.4^{b}	27.7^{b}	32.2^{a}	30.6^{a}	18.6^{a}	18.3^{a}	17.4^{a}	18.9^{a}	22.9^{a}	22.8^{a}	23.4^{a}	24.1^{a}	462	357
Oct-15	20.7^{b}	21.2^{b}	24.2^{a}	23.6^{a}	14.3^{a}	14.2^{a}	13.1^{a}	14.7^{a}	17.3^{a}	17.4^{a}	17.4^{a}	18.4^{a}	282	321
Nov-15	17.1^{b}	17.2^{b}	20.5^{a}	19.1^{ab}	9.7^{a}	9.7^{a}	8.2^{b}	10.0^{a}	12.9^{a}	12.9^{a}	12.9^{a}	13.8^{a}	210	321
Dec-15	14.5^{c}	14.8^{bc}	18.1^{a}	15.9^{b}	7.2^{a}	7.1^{a}	5.6^{b}	7.1^{a}	10.0^{a}	10.0^{a}	10.0^{a}	10.6^{a}	179	331
Jan-16	13.2^{b}	13.2^{b}	15.9^{a}	14.7^{ab}	6.4^{a}	6.3^{a}	4.8^{a}	6.3^{a}	9.4^{a}	9.3^{a}	9.1^{a}	10.1^{a}	177	289
Feb-16	15.7^{c}	16.0^{bc}	18.8^{a}	17.6^{ab}	8.8^{a}	8.8^{a}	7.3^{a}	8.1^{a}	12.2^{a}	12.3^{a}	12.1^{a}	12.5^{a}	238	298
Mar-16	14.2^{b}	15.2^{b}	17.2^{a}	17.1^{a}	7.7^{a}	7.8^{a}	6.5^{b}	7.4^{ab}	10.8^{a}	11.1^{a}	10.8^{a}	11.6^{a}	343	276
Apr-16	20.5^{b}	21.2^{b}	24.7^{a}	24.2^{a}	11.6^{a}	11.6^{a}	10.1^{b}	11.1^{ab}	15.9^{a}	16.1^{a}	16.2^{a}	17.0^{a}	558	335
May-16	20.9^{b}	21.8^{b}	24.1^{a}	24.7^{a}	13.6^{a}	13.2^{ab}	12.1^{b}	13.2^{ab}	17.3^{a}	17.4^{a}	17.4^{a}	18.9^{a}	604	247
Jun-16	26.5^{b}	26.9^{b}	31.3^{a}	30.3^{a}	18.2^{a}	17.7^{a}	16.8^{a}	17.7^{a}	22.5^{b}	22.4^{b}	23.1^{ab}	24.0^{a}	232	657
Jul-16	30.5^{c}	31.2^{c}	35.9^{a}	33.3^{b}	21.4^{a}	21.0^{ab}	20.0^{b}	21.0^{ab}	26.1^{a}	26.1^{a}	26.9^{a}	27.4^{a}	278	760
Aug-16	28.0^{c}	28.9^{c}	33.7^{a}	30.8^{b}	20.0^{a}	19.7^{a}	18.8^{b}	19.7^{a}	24.2^{a}	24.3^{a}	25.0^{a}	25.1^{a}	334	663
Sep-16	22.6^{b}	23.2^{b}	27.7^{a}	26.6^{a}	16.6^{ab}	16.5^{ab}	15.6^{a}	16.9^{a}	19.5^{b}	19.7^{b}	20.3^{ab}	21.0^{a}	331	438
Oct-16	20.0^{b}	20.6^{b}	24.3^{a}	22.9^{a}	14.0^{a}	13.9^{a}	12.6^{a}	13.5^{a}	16.9^{a}	17.1^{a}	17.3^{a}	17.7^{a}	318	302
Nov-16	16.5^{c}	17.1^{bc}	20.9^{a}	18.7^{b}	10.8^{a}	10.8^{a}	9.5^{a}	10.3^{a}	13.4^{a}	13.6^{a}	13.7^{a}	14.0^{a}	304	207
Dec-16	12.4^{c}	13.2^{bc}	16.9^{a}	14.0^{b}	5.5^{a}	5.2^{a}	3.6^{b}	4.8^{a}	8.5^{a}	8.5^{a}	8.5^{a}	8.6^{a}	333	181

$^{a-c}$ In reference of average maximum temperature, average minimum temperature and average mean temperature, the means in the same line with different superscript letters are significantly different ($P < 0.05$).