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Vertical greenery systems for the energy retrofitting of buildings in Mediterranean climate: a case study in Catania, Italy

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Abstract. The increasing awareness of issues like climate change and reduction of available fossil resources moves scientific research into the development of new technological solutions in order to reduce the energy and environmental impact of buildings. Hence, in recent years, key concepts such as energy saving and environmental sustainability affected both the design of new buildings and the retrofitting of existing buildings.

The present study aims to evaluate the energy behavior of an existing building in Mediterranean area, and to quantify the potential contribution provided by retrofitting solutions implying the adoption of green roofs and green façades. Dynamic simulations, validated by comparison with experimental results, show that a green façade with dense foliage allows a reduction by 1.7 °C in the indoor air temperature and by 1.5 °C in the inside surface temperature, if compared to a traditional retrofit solution for the envelope. Furthermore, the outside surface temperature is reduced by 2.9 °C, and the cooling load is reduced by 32%.

These results suggest that green façades are a viable solution to mitigate current environmental issues in buildings. Lower energy consumption corresponds to lower pollutants emissions and to economic savings in the use of the building.

1. Introduction

Scientific research moves forward the development of new technological solutions in order to reduce the energy and environmental impacts of buildings [1]. In recent years, green systems are becoming widespread thanks to numerous studies confirming their multifunctional benefits at both building and urban scale, such as energy savings, mitigation of the urban heat island effect, biodiversity improvement, carbon dioxide sequestration and building acoustic insulation.

Traditionally, vertical greenery systems (VGS) are made up of climber plants growing directly on the exterior surface of buildings [2]. In recent years the construction and technological characteristics of VGS have been improved by separating the vegetation from the façade in order to avoid functional problems related to linking the building with vegetation.

Whilst green roofs are clearly distinguished into extensive and intensive, a classification for vertical greenery systems results more complex due to the different constructive systems, the variety of vegetal species, the different thermal behavior, etc. [3]. Previous research [4] proposed a classification distinguishing VGS into two categories: the green façade and the living (or green) walls.

Green façade consists of climber plants growing directly on the building vertical surface or indirectly by using support systems, such as cables or trellis made of different materials (steel, wood,



plastic, aluminum), thus creating a double skin façade. Living wall systems are based on hydroponic crops in which vegetation can grow in absence of soil thanks to nutrient solutions. These systems are usually made up of geotextile felts or prefabricated panels fixed to a vertical support or the wall structure [5].

VGS contribute to different benefits both at buildings and urban scale. Different studies [6] confirmed that greening the building envelope is a valid passive systems for energy savings thanks to the following main effects: the shadow produced by the vegetation, the thermal insulation provided by vegetation and substrate, the evaporative cooling due to the evapotranspiration process and the protection from wind action [5]. Pérez et al. [7] analyzed the shading effect of a green façade on the wall surface temperature, measuring a maximum difference of 15.2 °C by using the green façade. The air in the intermediate space between the green façade and the building wall had a lower temperature and higher humidity during summer, proving the evapotranspiration effects of plants.

The vertical greening systems, in addition, contribute to the reduction of noise pollution in urban areas thanks to the sound-proofing and sound-absorbing power provided by vegetation. Azkorra et al. [8] evaluated the acoustic impacts of eight different VGS. The results showed a stronger attenuation at low and middle frequencies due to the absorbing effect of substrate, while a smaller reduction was observed at high frequencies due to vegetation scattering. Moreover they found higher values of the sound absorption coefficient of the VGS compared with other building materials.

The urban heat island (UHI) phenomenon determines an urban microclimate characterized by higher temperatures than the surroundings rural areas. Thanks to the higher values of albedo and thermal inertia compared to the usual artificial materials, urban green plays a fundamental role in the mitigation of the UHI [9]. The research conducted by Song and Wang [10] verified an increase in air temperature in several large U.S. cities, and estimated that green areas could mitigate the UHI effect, reducing the national energy demand in air conditioning by 20% and improving the urban air quality.

Furthermore, vertical greenery systems improve the economic value of the building. Des Rosiers et al. [11] estimated an increase in the property value of 3.9%. Gao and Asami [12] found that greening walls, streets and pedestrian spaces would provide an increase in land price by 1.4% in Tokyo and by 2.7% in Kitakyushu (Japan).

However, only a few studies have experimentally quantified the benefits of green façade used for energy redevelopment of existing buildings. The present study aims to evaluate the energy behavior of an existing building in Mediterranean area and to quantify the contribution provided by the shading effect of green façade in terms of both surface temperature and energy savings. Using dynamic simulation software, various technological solutions are analyzed in order to assess the effectiveness of the green façade for the retrofitting of existing buildings, comparing the performance of different envelope solutions.

2. Material and methods

2.1. The building case of study

The experimental site is located in the city of Catania (37°31' N, 15°05' E), south of Italy. Catania is characterized by a Mediterranean climate with hot and dry summer and mild winter (Csa according to Köppen and Geiger climate classification). The hottest months are July and August, when the air temperature usually exceeds 30°C. The yearly average precipitation is around 500 mm, mainly from October to March.

The existing building has a rectangular perimeter measuring 7 x 15 m, 4 m high, and is made up of wooden structure. The main elevation of the building has an optimal exposure as it is south facing and free from obstructions (Figure 1). Internally the building consists of a single large room. A large covering shades the entire building roof. The building hosts a showroom. The aim of retrofitting is to convert the structure into offices. Table 1 shows the stratigraphy of the existing building envelope.

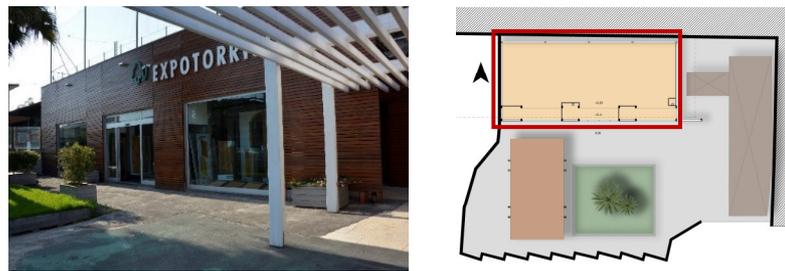


Figure 1. South elevation and plant view of the building

Table 1. Stratigraphy and thermal properties of the current envelope.

Component	Description (from ext. to int. side)	Conductivity λ [W/(mK)]	Specific heat c [J/(kgK)]	Dry density ρ [kg/m ³]	Thickness s [cm]	U -value [W/(m ² K)]
Walls	Plywood	0.15	2700	550	1.8	2.86
	Plasterboard	0.21	1000	900	1.25	
Windows	16-mm Low-e double glazing + Aluminum frame with thermal break					3.1
Roof	Laminated fir wood	0.12	1380	510	1.4	3.16
	Plasterboard	0.21	1000	900	1.25	
Foundation	Concrete slab	1.13	1000	2000	29	2.22
	Parquet	0.14	1200	650	1.5	

2.2. Experimental set-up

The internal environmental parameters were recorded using TESTO 480 data logger, placed in the center of the room. Table 2 reports the sensors used and the parameters monitored. A weather station located less than one kilometer away from the building was used to measure the outdoor air temperature. The indoor air temperature was used to validate the Energy Plus building model. Data collection began on the afternoon of 18th July 2017 until the afternoon of 21st July 2017, at 5-minute intervals. During the measurements no activities were carried out inside the building, and the entrance door was opened only in the afternoons of 19 and 20 July, from 2.30 to 6.00 pm.

Table 2. Sensors used with TESTO 480

Probe	Measure	Range
Globe Temperature (D = 150 mm)	Mean radiant temperature	0 to +120 °C
IAQ	Air temperature, humidity, CO ₂	0 to +50 °C
Thermocouple PT100	Air temperature	-50 to + 250 °C

2.3. The envelope retrofitting

In order to evaluate the energy behavior of the building and identify the solution that allows the greatest energy savings, six scenarios have been supposed for the retrofitting of the existing building envelope (Figure 2).

Scenario S1 considers a traditional retrofitting based on the insulation of the envelope components, aimed to comply with the limits of thermal transmittance defined by the Italian regulations. Scenario S2 introduces a green roof. In scenario S3, a green façade consisting of a wooden support system at 20 cm from the wall was placed to shade the south-facing wall. Furthermore, a horizontal and vertical shading of 70 cm depth protects the entrance window from direct solar radiation. The creeper supposed for the green façade is *Virginia creeper* (*Parthenocissus quinquefolia*), a deciduous plant with a great density of foliage. In scenario S3.A a low density of the foliage was supposed, which

implies a light transmission coefficient of 0.4 over the walls and 0.8 over the windows in order to ensure a better lighting of the indoor space. Conversely, in the scenario S3.B, a higher density of the foliage was supposed, defined by a light transmission coefficient of 0.2 over the walls and 0.6 over the windows. This scenario is more realistic and is closer to Pèrez et al. results [7], where the authors measured a 0.15 light transmission coefficient for *Virginia Creeper*.

Finally, Scenario S4 combines green roof and green façade. Table 3 provides the detailed stratigraphy of all components; in all the scenarios proposed, the existing covering above the roof is removed.

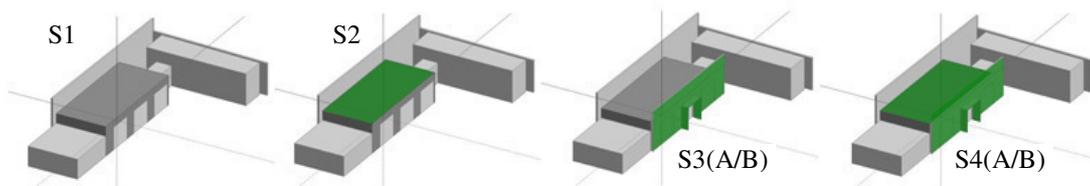


Figure 2. The different retrofitting hypothesis

Table 3. Stratigraphy and thermal properties of the different scenarios

Scenario	Component	Descriptions (from ext. to int. side)	Conductivity λ [W/(mK)]	Specific heat c [J/(kgK)]	Dry density δ [kg/m ³]	Thickness s [cm]	Total U -value [W/(m ² K)]
S1	Wall	Gypsum fiberboard	0.32	1100	1150	1.25	0.26
		Wood wool insulation	0.065	1810	360	3.5	
		OSB panel	0.1	1700	530	1.5	
		Wood fiber insulation	0.038	2100	160	10	
		OSB panel	0.1	1700	530	1.5	
		Vapor retarder					
		Non-ventilated air gap	0.55	1000	1000	2	
	Roof	Gypsum fiberboard	0.32	1100	1150	1.25	0.31
		Sheet metal covering	45	420	7680	0.05	
		Ventilated air gap	0.55	1000	1000	5	
		OSB panel	0.1	1700	530	2	
		Wood fiber insulation	0.038	2100	160	10	
		OSB panel	0.1	1700	530	2	
		Gypsum fiberboard	0.32	1100	1150	1.25	
S2	Wall	S1					0.26
	Green roof	Sedum					0.31
		Substrate	0.44	880	950	10	
		Filter layer + Drainage					
		Waterproof membrane					
		Wood fiber insulation	0.038	2100	160	10	
		Vapor barrier					
S3.A-S3.B	Wall	Green façade + S1					0.26
		S1					
	Roof	S1					0.31
		Gypsum fiberboard	0.32	1100	1150	1.25	
		OSB panel	0.1	1700	530	2	
		Vapor barrier					
		Wood fiber insulation	0.038	2100	160	10	
S4.A-S4.B	Wall	S3.A-S3.B					0.26
	Green roof	S2					0.31

2.4. Simulation set up

The environmental parameters analyzed are the indoor air temperature, the outside and inside surface temperature of the south façade and the energy needs for space cooling. These are estimated by using Energy Plus, a dynamic simulation software tool. Temperatures are evaluated in free running conditions and the simulations are performed from 18th to 21st July. On the other hand, the energy

consumption is obtained from 1st June to 30th September by means of an ideal thermostat control that keeps the indoor temperature at 26 °C and a controlled mechanical ventilation system according to the work schedule (Monday to Friday, 9.00 h to 13.00 h and 16.00 h to 19.00).

3. Results and discussion

3.1 EnergyPlus model validation

Figure 3 shows that the indoor air temperature rises rapidly from 7:00 a.m., when solar radiation hits the building and the outdoor air temperature increases, reaching a peak value at 3:00 p.m. The slight irregularities of the thermal gradient observed in the afternoon are due to the opening and closing of the entrance door. During the night the temperature keeps decreasing until dawn. Moreover, the peak of the indoor air temperature is almost in phase with the peak of the outdoor air temperature, due to the reduced thermal inertia of the existing envelope, which is typical in northern Europe but not suitable for hot climates of southern Europe. The mean radiant temperature is very close to the indoor air temperature, indicating that the inside surfaces are not significantly overheated.

The first step of the research concerned the validation of the EnergyPlus model of the building. To this aim, Figure 4 shows good accordance between the measured and simulated indoor air temperature for the current state (CS1 in Figure 4), with only small differences when the air temperature decreases.

Then, in order to compare the different proposed scenarios starting from the same boundary conditions, the behavior of the building was assessed without the shading contribution due to the fiber cement roof (CS2 in Figure 4), that must be in any case replaced. As expected, this cover plays a fundamental role: without it, the internal temperature increases by about 4 °C, now exceeding 38 °C.

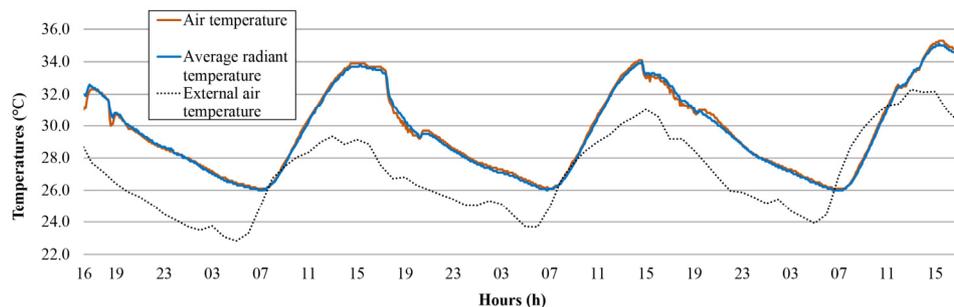


Figure 3. Temperature measured during the monitored period

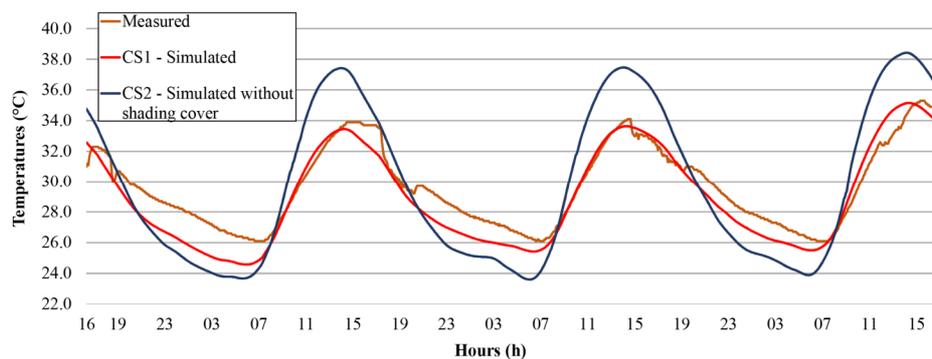


Figure 4. Energy Plus model validation – measured vs. simulated air temperature

3.2 Air temperature

Table 4 reports the maximum indoor air temperatures for the different retrofitting scenarios. In comparison with case CS2 discussed in the previous section, better results are achieved in scenario S1, i.e. by adopting a retrofitting solution based on a traditional building envelope without greenery systems. Indeed, the maximum indoor air temperature decreases from $T_{\max,CS2} = 38.4$ °C to $T_{\max,S1} =$

34.9 °C. Moreover, this scenario shows higher thermal inertia, and the indoor air temperature is less sensitive to fluctuations in the external temperature (Fig. 5).

Moreover, by using a green roof (scenario S2), the indoor temperature does not vary significantly if compared to scenario S1, and $T_{\max,S2} = 34.6$ °C. This small difference between the traditional roof retrofit (S1) and the green roof (S2) highlights the effectiveness of the micro-ventilation of the sheet roof used in scenario S1, which prevents the overheating of the lower layers. Therefore, the installation of the green roof cannot be justified only from an energy point of view.

On the other hand, the best results pertain to solution S4.B, i.e. when the green roof is coupled with the VGS having a high density of the foliage; in this case the maximum indoor air temperature decreases to around 33 °C. However, eliminating the green roof (solution S3.B) or adopting a smaller density for the foliage (solution S4.A) do not change the outcomes significantly.

Table 4. Air temperatures of the different scenarios analyzed

Case study	CS1	CS2	S1	S2	S3.A	S3.B	S4.A	S4.B
T_{\max} (°C)	35.1	38.4	34.9	34.6	33.7	33.2	33.4	32.9

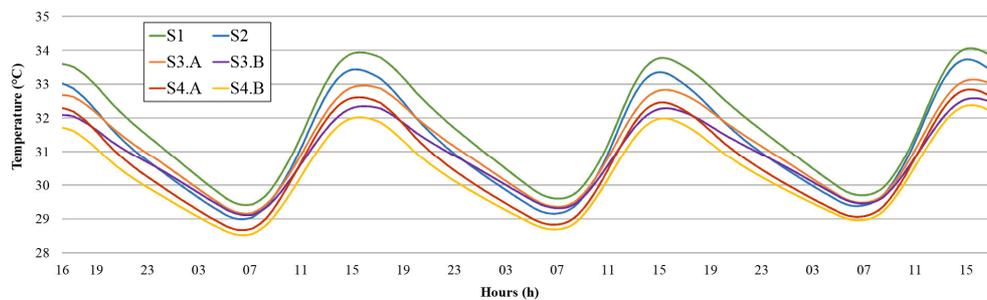


Figure 5. Indoor air temperature of the proposed scenarios

3.3 Outside and inside surface temperature

The results in terms of outside surface temperature are reported only for scenario S3.A and S3.B and compared with scenario S1 (reference building retrofitting). As Figure 6 shows, the green façade reduces outside surface temperatures by about 3 °C, from $T_{\max,S1} = 43.3$ °C without the shielding to $T_{\max,S3.A} = 40.5$ °C with the climber. The higher foliage density of scenario S3.B does not provide further reductions on the outside surface temperature (Table 5). This reduction, compared to traditional finishing materials, can contribute to mitigate the Urban Heat Island effect.

Table 5. Maximum outside surface temperature

Scenarios	S1	S3.A	S3.B
Temperature (°C)	43.4	40.5	40.5

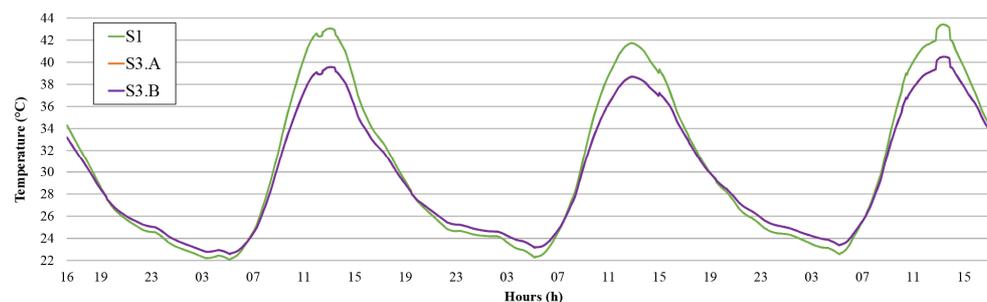


Figure 6. Outside surface temperature of the proposed scenarios

As found for the indoor air temperature, the inside surface temperature is higher in scenario S1 ($T_{\max,S1} = 34.1 \text{ }^\circ\text{C}$) than in all other scenarios. Temperatures decrease for scenarios S2, S3.A and S3.B, with a T_{\max} of $33.7 \text{ }^\circ\text{C}$, $33.1 \text{ }^\circ\text{C}$ and $32.6 \text{ }^\circ\text{C}$ respectively (Table 6).

Figure 7 shows that the lower surface temperatures are achieved by the combination of the green roof and facade ($T_{\max,S4.A} = 32.8 \text{ }^\circ\text{C}$, $T_{\max,S4.B} = 32.4 \text{ }^\circ\text{C}$). The maximum difference between the internal surface temperature of scenario S4.B (green facade with high density of foliage) and the reference scenario S1 (traditional building envelope) is $1.7 \text{ }^\circ\text{C}$.

Table 6. Maximum inside surface temperature

Scenarios	S1	S2	S3.A	S3.B	S4.A	S4.B
Temp ($^\circ\text{C}$)	34.1	33.7	33.1	32.6	32.8	32.4

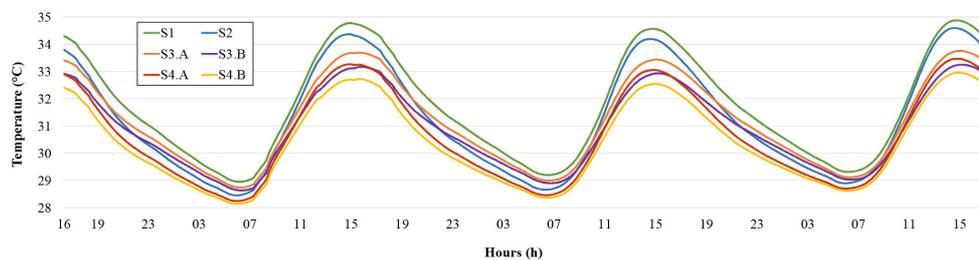


Figure 7. Inside surface temperature of the proposed scenarios

3.4 Energy cooling load

Figure 8 shows the energy needs for space cooling in kWh/m^2 , estimated by EnergyPlus under thermostatic control. Currently, the building has a cooling energy consumption of 27.9 kWh/m^2 (CS1) during the summer season. In case CS2 (without the shading of the canopy), the energy needs would be almost twice as high, which shows once again the energy benefits coming from shading the building roof from direct solar radiation. As shown in Table 7, for all the proposed retrofitting scenarios the cooling needs decrease significantly: the reduction ranges between 56% and 72%, if compared to case study CS1 (current state of the building envelope).

However, if we take scenario S1 (traditional building retrofitting solution) as a basis for comparison, the energy savings obtained for all the other retrofitting scenarios are shown in Table 8. The scenario that combines the green roof with the green facade characterized by a higher index of foliage (S4.B) has the greatest energy saving potential.

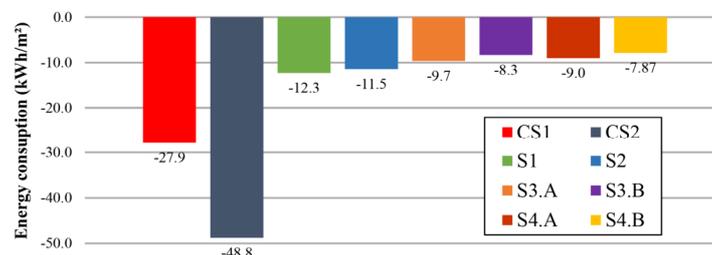


Figure 8. Energy needs for space cooling

Table 7. Percentage variation of the energy needs with respect to CS1

Scenarios	CS2	S1	S2	S3.A	S3.B	S4.A	S4.B
Variation (%)	+75%	-56%	-59%	-65%	-70%	-68%	-72%

Table 8. Percentage of energy savings with respect to S1

Scenarios	S2	S3.A	S3.B	S4.A	S4.B
Energy reduction (%)	-7%	-21%	-32%	-27%	-36%

4. Conclusions

The present study assessed a vertical greening systems as a possible passive strategy for the reduction of summer cooling load. Through dynamic simulations, the energy behavior of different building envelope solutions was evaluated for the retrofiting of an existing building. The parameters evaluated are the internal air temperature, the inside and outside surface temperature of the wall shaded by the green façade and the summer thermal load. Among the proposed scenarios the green facades have higher energy performance. The results obtained with a dense leaf cover of the creeper showed a reduction in the air temperature by 1.7 °C as well as a reduction by 1.5 °C for the inside surface temperature with respect to the traditional envelope. Furthermore, the outside surface temperature was reduced by 2.9 °C. Finally, the thermal load is reduced by 32%. These results show that shading the wall has allowed high energy savings for summer air conditioning.

Future studies should aim at a cost-benefit analysis of green facades, taking into account both construction costs and energy savings. Finally, in addition to the shading effect, the evapotranspiration process needs to be evaluated as further benefit from the green envelope.

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