

635: THERMAL PERFORMANCE OF A VEGETATED WALL DURING HOT AND COLD WEATHER CONDITIONS

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Abstract

The aim of this study is to investigate the role of climbing plants on buildings, in minimizing the extensive heat discharged to the environment and enhancing passive cooling. The analysis was based on a four month (August – December) experimental campaign that took place at a small room whose west wall was partly covered by a climbing plant. One set of instruments was installed on the vegetated façade (beneath and above the foliage) and another on the clear part of the same façade both in the indoor and outdoor environments. Results showed that the outdoor air temperatures of the vegetated wall were lower compared to those of the clear part, especially during the summer period. Furthermore, during the day and most of the night the indoor air temperatures of the vegetated wall were lower compared to those of the uncovered part, with differences of the order of 1.5 °C. The analysis of the results revealed the existence of a thermal insulation air layer beneath the plant leaves. An attempt was made to assess the heating and cooling load variations with the model TRNSYS assuming the wall is fully covered by the climbing plant or totally clear. A slight decrease in the loads was identified.

Keywords: Green walls, solar control, bioclimatic design, TRNSYS, passive cooling

1. Introduction

It is widely accepted that energy consumption of buildings for cooling (and heating) purposes must be reduced. Among other passive cooling measures such as glazing, shading, insulation and natural ventilation, researchers have proposed planting trees, green roofs or ivy walls around buildings, [1], [2]. Plants provide solar protection, while evapotranspiration can reduce urban temperatures, [3]. The local microclimatic conditions inside and around a building may be improved by vegetated walls, which help in reducing the flow of warm air indoors as well as the thermal load of the building to the outdoor environment, [4]. Most researchers have mainly studied the effects of green roofs and of planted trees in the vicinity of buildings experimentally, [5]. Others have studied theoretically by application of simulation tools the reduction of the heating and cooling loads of buildings when plants are employed, [6]. However, only Hoyano, 1988 performed an experiment to study the climatological effects of vegetated walls on buildings. The results were not directly comparable since one year elapsed between the measurements of the clear and vegetated walls. The purpose of the present work is primarily to study experimentally the effect of a vegetated wall (covered by the plant *Parthenocissus*

tricuspidata) on the indoor air temperature by taking measurements inside and outside a test room. Similar measurements were also taken on the clear part of the wall and results were directly compared. Finally, based on the experimental data set a dynamical mathematical model TRNSYS was applied in order to quantify the improvement brought by planted walls to the cooling and heating load required by the test room.

2. Experimental methodology

The wall selected for the experiment is part of an uninhabited room on the top floor of a domestic building. The wall consists of a vegetated and a clear part that are separated by a window 0.86m wide. It is more than 30m away from any other vertical surface and it is oriented towards the west (260°) which means that from noon until dawn it is charged with the largest thermal loads making it ideal for the measurement of induced heat. The wall had a total thickness of 21cm, consisting of two layers of bricks, a plaster coating and common wall paint. The ascending plant *Parthenocissus tricuspidata* may grow in an urban environment and loses its leaves in the winter.

Four Hobo electronic thermometers were located on the indoor and outdoor facades of both the clear and the vegetated parts of the wall and at a distance of 10cm from the wall. Measurements of the temperature were taken at 10 minute intervals from 3-08-2003 to 5-12-2003. Furthermore, from 11-11-03 to 5-12-03, relative humidity was also measured. Finally, from 9-08-03 until 17-08-03 the thermometer on the vegetated part of the wall was placed under the leaves in order to investigate the mechanism by which the plant influences the thermal environment. It must be noted that throughout the experimental period no extreme weather events occurred (such as heat waves coupled with low wind conditions). Meteorological data for the experimental period were provided by the national weather service station.

values were 21°C for the winter period and 27°C for the summer period.



Fig 1. Photograph of the west wall of the room.

3. TRNSYS Simulations

3.1 TRNSYS

The thermal performance of the room when the west wall is assumed totally clear or fully covered by the climbing plant was simulated with the aid of the TRNSYS 15.1 simulation program [7]. TRNSYS is a transient system simulation environment with modular structure, which facilitates the addition to the programme of mathematical models not included in the standard TRNSYS library. The main inputs required by the program are the following:

- a) the building's construction elements,
- b) the building's geometric elements,
- c) meteorological parameters (ambient temperature, relative humidity, diffuse and global radiation, wind speed and direction),
- d) the building's internal gains,
- e) the building's infiltration, ventilation, etc.

The main outputs of TRNSYS program are the indoor air temperature and the heating and cooling loads that is the energy consumption. The room's energy consumption was calculated for both the winter and summer periods, with and without a vegetated wall.

3.2 Initial conditions

The room has a total area of 9m². The vertical envelope of the room is made of double brick with no insulation between the two brick layers and external plaster. The floor was made of concrete and tile, while the roof was made of concrete with external plaster. The openings consist of two single pane windows on the west and east sides of the room and a metal door on the north side. The room has no shading devices except for the vegetated part of the western and northern walls (Fig. 1). No internal gains were created since it was uninhabited. The infiltration and natural ventilation were set equal to 0.6 air changes per hour during the day and the night. Simulations of the thermal behaviour of the room and calculations of its cooling and heating load were performed for one typical meteorological year. Meteorological data included dew point temperature, total and diffuse solar radiation and relative humidity. The set point temperature



Fig 2. Photograph of the locations of the thermometers.

4. Discussion of results

4.1 Experimental measurements

The relative humidity measurements taken during the experiment did not show an increase in the humidity of the indoor and outdoor environment due to the existence of the climbing plant and are not shown here.

The hourly evolution of the temperatures measured on the outdoor facades (clear and vegetated) is depicted in Fig.3 for 25-08-03 a day with very low winds and clear skies. Initially, until about 13:00 LST both walls have the same temperature, however at about 17:00 LST the clear wall temperature reaches 43°C while the vegetated wall 42°C, due to the plant's shading action. This difference is further enhanced after sunset because the clear part of the wall radiates back to the environment the heat stored (infrared radiation) while the thick foliage of the plant on the vegetated wall reduces significantly the discharge of heat. As seen in Fig. 4 the temperature difference between the vegetated

and the clear parts of the wall increases from 1° during the daytime to 3°C at 18:00 LST, right before sunset. In Fig. 5 the indoor facade temperatures for both walls are shown for the same day. The temperatures of the clear part range from 29 to 37°C, while the ones of the vegetated part range from 30 to 36°C. Here again it becomes clear that the plant not only helps keep the temperatures lower during daytime but also helps maintain higher temperatures during the night. This leads to the assumption that the plant acts as an extra insulating layer of the wall.

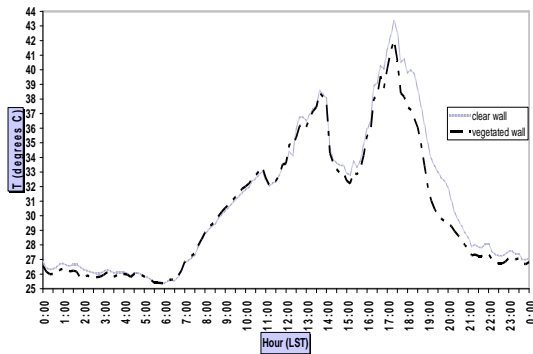


Fig 3. External wall temperatures measured on 25-08-03 on the clear and vegetated parts.

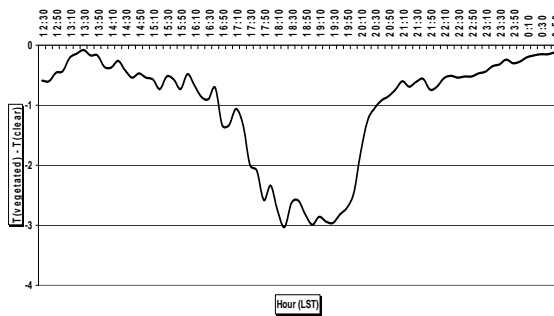


Fig 4. Evolution of external walls' temperature difference on 25-08-03.

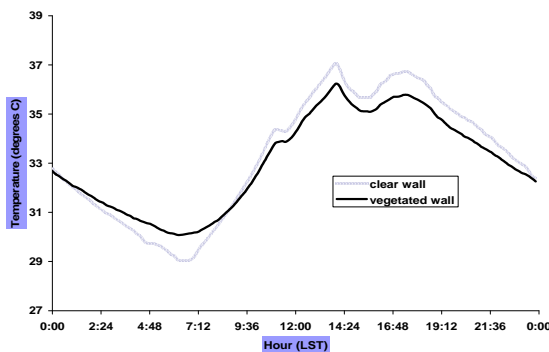


Fig 5. Internal wall temperatures measured on 25-08-03 on the clear and vegetated parts.

In order to study the insulating properties of the climbing plant, the thermometer of the vegetated wall was placed within the foliage of the plant for a week. A representative example of the measured data is given in Fig. 6. It can be seen that both indoor facade (clear and vegetated)

temperatures follow the same daily trend. The clear part exhibits higher values than the vegetated part in the afternoon hours and lower early in the morning, as expected. Furthermore, the indoor temperatures follow a smoother daily pattern ranging from 28 to 40°C. Interestingly enough, regarding the outdoor facade temperatures it seems that the air beneath the climbing plant foliage is warmer than that of the clear part of the wall. This phenomenon occurs at about 14:30 LST and continues until about 8:30 LST in the next morning. Here again both outdoor temperatures follow the same pattern and their values range from 25 to 44°C approximately.

From the results obtained above it seems that the warmer air existing beneath the ivy foliage functions as an insulating material. It “delays” the heating of the indoor air during the day and helps keep lower indoor temperatures compared to the outdoor ones. In a similar manner the plant also “delays” the indoor air cooling during the night.

Fig. 7 shows clearly that during the afternoon hours the air temperature of the foliage is higher than that measured on the clear wall, the difference being of the order of 2 to 3°C and maintains this feature until about 8:00 LST. It is cooler by about 1 to 2°C from about 8:00 LST until 15:00 LST. On the other hand the indoor temperature of the vegetated part is cooler throughout most of the day and warmer in the night. It seems logic to assume that the air beneath the foliage of the ivy warms up when the wall radiates back to the environment the heat gained during the day. This air is trapped by the leaves of the plant and acts as an insulating material, while it decreases the amount of heat radiated back to the environment from the cooling wall during the night.

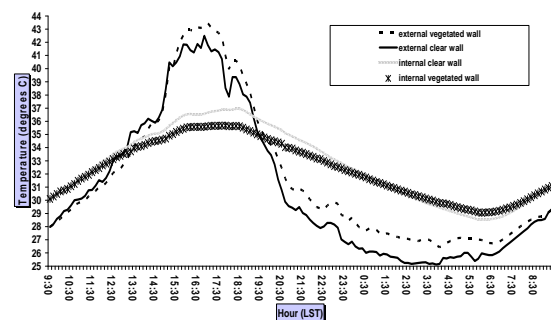


Fig 6. External and internal wall temperatures on 14 and 15-08-03, when thermometer is placed beneath the ivy foliage.

Experimental data from within the foliage of the plant were also taken in October 2003 in order to ascertain its insulating properties, Fig. 8. The outdoor air temperature is lower than the values found in the indoor air in general, while the fluctuations observed on the outdoor facade are followed by those of the indoor environment. Furthermore, the air of the indoor vegetated facade is higher than that of the clear part, by 1.5 to 2°C. Finally, it is interesting to note that the temperatures measured on both facades drop

during the night, but the ones on the vegetated side drop at a slower rate.

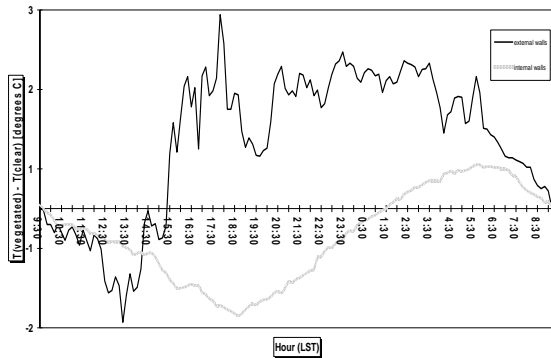


Fig 7. Difference between temperatures of internal vegetated and clear walls and external vegetated and clear walls at 14 and 15-08-03.



Fig 8. Comparison of internal air temperatures for the vegetated and clear walls at 9-10-03.

In order to make sure that the daily temperature patterns observed in the figures above are representative of the whole experimental period, scatter plots of the indoor and outdoor temperature differences are presented in fig. 9 and Fig. 10. It is obvious that the thermal behaviour of the vegetated part of the wall follows the pattern explained above, exhibiting a shading and a thermal insulation activity.

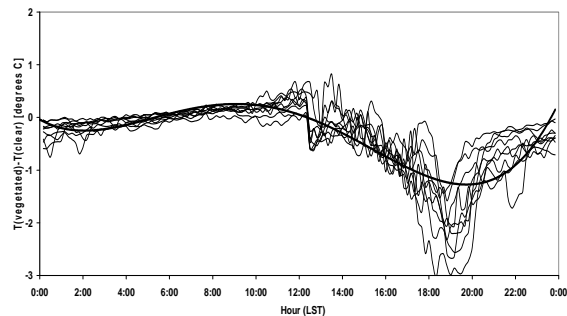


Fig 9. Scatter plot of temperature difference between the outdoor vegetated and clear walls for the period 24-08 to 1-09-03.

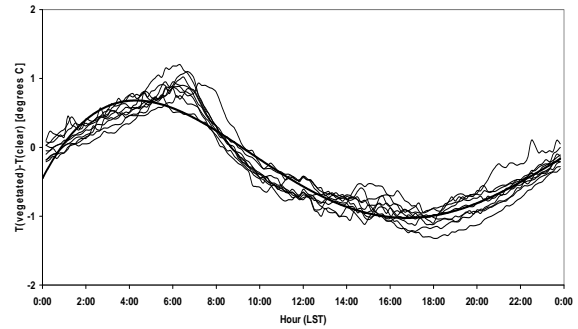


Fig 10. Scatter plot of temperature difference between the indoor vegetated and clear walls for the period 24-08 to 1-09-03.

4.2 TRNSYS Simulations

The TRNSYS model simulated the indoor temperature, and the heating and cooling loads of the room for one year. Computational results were compared to measured data in order to validate its performance. As seen in Fig. 9, computed temperatures are lower than the ones actually measured in both cases. However, TRNSYS results seem to track the variations of the measured values. The difference between computed and measured values is more pronounced in the early morning hours. An explanation for this discrepancy could be the fact that the model computes the average indoor temperatures of the room while the experimental data came from the vicinity of the indoor and outdoor facades of the room. Despite this fact the model's performance is considered good.

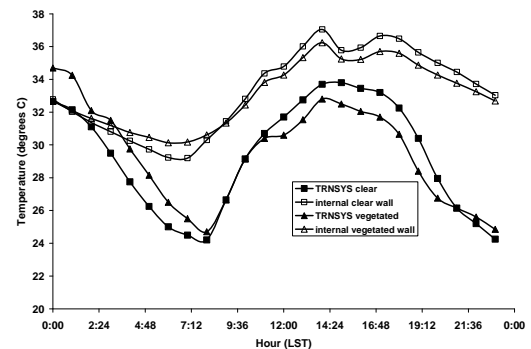


Figure 9. Computed versus measured indoor temperatures for the cases of clear and vegetated walls.

The cooling and heating loads were also computed by the model assuming the west wall is clear or totally covered by the climbing plant. This was incorporated in the model initial conditions as a surface with a lower absorptance. The results obtained are given in Table 1, where the percentage difference between the cooling and heating load with a clear wall and the cooling and heating load for a vegetated wall is presented. It can be seen that firstly the specific room requires heating from September until May, which may be attributed to the fact that it has no internal gains since it is uninhabited and that the walls are not

insulated. In this respect, simply covering one of the walls with a climbing plant could not make a great difference in indoor environment.

Table 1: Cooling and heating load variations as a percentage (cooling clear –cooling vegetated, heating clear – heating vegetated).

Month	Cooling load variation(%)	Heating load variation(%)
Jan		0.7
Feb		1.9
Mar		2.1
Apr		2.5
May	1.2	4.1
Jun	2.3	
Jul	2.3	
Aug	3	
Sep	1	3
Oct		2.8
Nov		2.2
Dec		1.6

5. Concluding Remarks

In this paper results from a four month experimental campaign that took place in an isolated room, with a partly vegetated west wall, have been presented. Analysis of the temperatures of the vegetated and clear parts of the indoor and outdoor facades revealed quite interesting aspects of the passive cooling potential of plants.

- a) The clear part of the wall reached higher indoor and outdoor temperatures throughout the day compared to the vegetated part due to its shading function.
- b) The heat discharged to the environment by the vegetated wall is less leading to the potential for improved thermal comfort conditions both in the outdoor and indoor vicinity of the façade.
- c) A thermal insulation layer is formed beneath the foliage of the climbing plant which helps the indoor air keep lower temperatures during daytime and higher during the night. This layer also minimises discharge of heat to the environment.
- d) The thermal insulation layer formed also helps to decrease the range of daily indoor temperatures thus leading to improved thermal comfort conditions.

The model TRNSYS was applied based on the experimental data set for a whole typical meteorological year. It was found that the computed results compared well with the experimental values although discrepancies found could be associated to the fact that the model computes the average room temperatures while the measured values came from the vicinity of the indoor and outdoor facades. Moreover, the experimental room had no insulation and the existence of the vegetated surface did not seem to improve dramatically the cooling and heating loads required. Further work is currently taking place in order to study more

theoretical scenarios, sensitivity analysis and perform optimisation of the computed results

6. Acknowledgement

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7. References

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