Solar Greenhouse and natural ventilation

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Abstract

The paper presents a study on the thermal behavior of a solar greenhouse set against one apartment of a residential eco-sustainable building in a temperate climate. Particular attention was given to the analysis of the contribution of solar radiation in winter heating in relation to natural ventilation. This study makes use of a transient energy simulation system named ESP-r (Environmentals System Performance - research).

The results so far have revealed that the preferred orientation of the greenhouse to maximize the solar collection in January and February (South) can cause overheating in March, as the temperature inside the room exceeds 25°C (limit of the comfort zone) for 5% of the hours, and in April when the discomfort is for 60% of the time. The final step of the study focuses on the dimensioning of the openings for the reduction of the above mentioned percentage through natural ventilation, identifying a design methodology that integrates low-energy concepts in the design process.

Keywords: Solar greenhouse, thermal comfort, natural ventilation, solar radiation.

Introduction

Representing buffer zones between inside and outside, greenhouses are helpful design solutions for the reduction of energy consumption in low-energy buildings,. Unfortunately, in temperate climates like the Mediterranean greenhouses tend to be useless in most of the months – especially in the central hours of the day – due to their overheating. This the reason why in the past climate sensitive buildings haven't widely exploited such kind of solutions. In this paper we try to analyze the role of natural ventilation in reducing the extra-heat in some of these critical periods of the year for the above mentioned areas.

Of course, a greenhouse should be considered, according to our hypothesis, non only as a heating space and/or a thermal accumulator, but also a living place of a green building where thermal comfort should be achieved. In this perspective, natural ventilation should be able to balance the rise in temperature in some critical months like March, April, September and November (mean seasons). In hot seasons from the beginning of May to the end of September, for the considered climate in the northern emisphere, the greenhouse should be continuously ventilated and protected with solar screens.

1. Design criteria for a solar greenhouse based on its thermal behavior

As a reference, we took the design of an apartment building near Rimini, in the Northern Adriatic coast of Italy. Into the ESP-r software we built a simplified model of the apartment, consisting of two heating zones: a living room of 20 m^2 and the greenhouse of 14 m^2 set against it (fig. 1). In the living space the presence of doors or windows was not considered. In such a way the results would not be influenced by the particularities of size, facing and orientation of these elements.

We connected the two zones and we established the boundary conditions of each surface: the vertical surfaces of the greenhouse are in contact with the external environment, except the wall and the transparent door between the two rooms. For all the other surfaces adjacent to spaces at the same temperature the heat transmission was set to zero. Then, we derived the thermophysical properties of the materials and the composition of the vertical section of the walls from the normally used building technology in the area (fig.2).

The available climate information for the site of Rimini is relative to the year 2005 and contains data recorded on a significant number of years, regarding air temperature [°C], direct and diffuse solar radiation [W/m^2], wind speed [m/s], wind direction and relative humidity [%]. The climatic data refer to the Italian Climatic data collection "Gianni De Giorgio" (IGDG), developed for use in simulating renewable energy technologies, and based on a 1951-1970 period of record (Mazzarella, Politecnico di Milano).

The preliminary study started with the simulation of winter climatic conditions, especially the two coldest months of January and February. In the living room we assumed a constant temperature of 20 [°C] from an operating heating system, and the absence of internal free heat inputs; in this step the contribution of natural ventilation was not considered.

First, we evaluated the behavior in terms of energy balance and temperature variations in January and February with the glass screen facing south, the best orientation for the greenhouse. As shown in the graph, representing the coldest days of January, the temperature difference between the external environment and the greenhouse varies from 7 [°C] to 18 [°C] (fig.3), creating an almost comfortable zone: the living-room temperature (blue line) exceeds 20 [°C] in the central hours of the day, and the heating demand is significantly reduced.

In a second step, in order to define more clearly some design criteria, we tested different configurations of the envelope and the orientation, varying single parameters from time to time. We identified five types of configuration (A, B, C, D, E), and for each of them four different cases (A1, A2, A3, A4, etc.), varying the position and the size of the glass surfaces and the width of the greenhouse.

As indicative of the greenhouse's thermal efficiency we considered the heating plant consumption [kWh], based on some simplifying assumption made at the beginning of the simulation. The results were collected in a table (fig. 4): every type of greenhouse has one case (the 3rd column: A3, B3, C3,..) that reveals the best performance. In this configuration, where the sides facing east and west are opaque, the energy losses, which outweigh solar gains, are limited by the thermal inertia of the walls, and the reduced glass surface of 14 m^2 is still capable of a reasonable solar captation.

Once identified types A and D as the most suitable for their energy performance, we studied their behavior in the south-east and south-west orientations (± 30° from the south); the results are shown in figure 5. In both types, south and south-west orientations have better performances, compared with south-east. These simulations are relative to January and February, when required tasks of the greenhouse are maximizing solar captation and reducing energy consumption .

In conclusion, south and south-west orientations with opaque sides meet the best performance. However, the south-east orientation should be preferable, because it creates less overheating problems over the whole year.

2. Contribution of natural ventilation

In this step, the evaluations on the behavior of the greenhouse were extended to March and April, introducing the required contribution of natural ventilation in relation to the risk of overheating. This contribution was considered in two different ways: the first considers constant-air-volume changes (ACH) according to the minimum average value of 0,3 [vol/h] set by the national legislation ; the second consists on defining an air flow network through the openings and boundary conditions..

For this simulation we chose the A3 model in the south orientation and an average minimum value of 0,3 [vol/h] for the ventilation in the living-room and in the greenhouse. The graphic of figure 6 shows that in the living-room the temperatures of January and February are contained into comfort limits (from 18 [°C] to 25 [°C]), with a maximum temperature of 23 [℃]. Keeping the same conditions for March, the living-room reaches unacceptable temperatures, going beyond the comfort zone for 7% of total hours (fig. 7). Therefore, we increased the ventilation in the greenhouse up to 0,6 vol/h, obtaining the percentage of 5%, considered more acceptable for comfort. We followed a similar process for April, obtaining an overheating of the living-room for 73% of the hours (fig. 8); increasing the ventilation in the greenhouse up to 0,9 [vol/h], we obtained the relative graphic of temperature where this percentage is reduced down to 60% (fig. 9, 10). This level should be considered unacceptable, and some corrective measurements should be adopted, like a further increase of ventilation or a complete opening of the greenhouse during the day.

The construction of an air flow network comprises 3 elements:

- Nodes: these are placed in each zone to be included in the network as well as external to the building.
- Components: these are the ventilation openings through which air flows (windows, doors, voids and cracks).
- Connections: these determine which nodes are connected by which components.

In our case, the simple air flow network model consists on 3 nodes (1 internal and 2 external to the greenhouse), 2 components (2 window openings) and 2 connections, as seen in figure 11.

The control of the flow components is needed to tell when the windows are open and when they are closed; in our case we decided to open the windows from 9.00 a.m. to 6.00 p.m. through an on/off mechanism when the greenhouse's temperature is above the temperature setpoint of 25 [°C].

In this configuration, we studied a single side ventilation through overlapped openings at an average distance of 2 [m], to maximize the pressure difference of air inlet and outlet (stack effect). As the amount of air moving vertically depends on the size of the ventilation openings, we assumed three different areas: 0,1 [m^2], 1 [m^2], and 5 [m^2] .

The results for the first type of openings are as follows: when windows are open, in the greenhouse there is a difference temperature that goes from 5 to 10 [℃], while the average temperature is about 26 [℃]

(fig. 12). In the second case, where openings are of 1 [m^2], the temperature difference varies from 8 to 13 [℃], and the greenhouse's temperature stays around 23[℃] (fig. 13).

In the third case, with the maximum area of openings (5 [m^2]), the temperature difference varies from 10 to 15 [℃] and the average temperature is about 23[℃] (fig. 14).

We can notice that openings of 0,1 [m^2] offer a less effective ventilation and do not contribute significantly to the greenhouse's temperature. The last two cases present very similar effects. This means that for a good ventilation a total opening area of 2 [m^2] is enough. The sharp temperature changes with the on-off configuration are due to the fact that in March temperature outside is still quite low, especially in some days (red line in figures 12, 13, 14), causing a rapid lowering of the greenhouse's temperature; openings are regulated by an on/off system that is always technically difficult to manage automatically. However, natural ventilation based on this air flow network has clearly helped in lowering the living-room's temperature, which does not exceed 22,4 [° C] during March and 23,4 [° C] during April.

In conclusion, the results on the effectiveness of natural ventilation through an air flow network are more significant than those obtained by ACH system. According to the simulation the automatically controlled single side ventilation gives an important contribution in March and April, reducing the overheating of the living-room and bringing the temperature within the comfort zone. The simulation also showed that for the ventilation of a south oriented greenhouse with a volume of approximately 40 [m^3], and a glazed area of approximately 15 [m^2], two horizontal openings with a total area of 2 [m^2] are enough.

References

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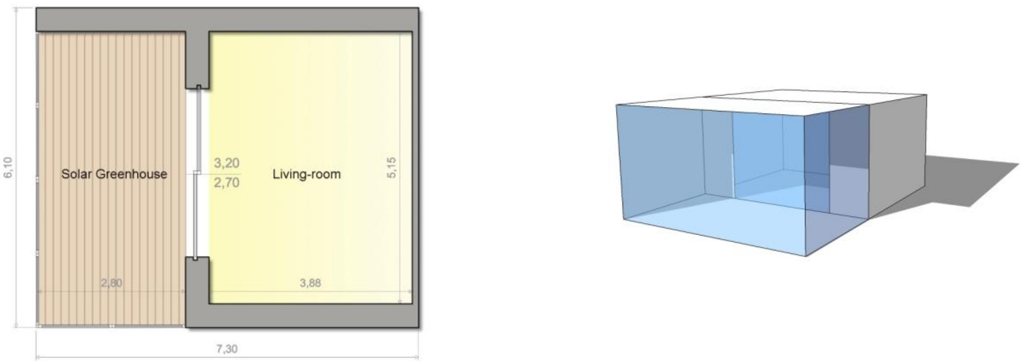
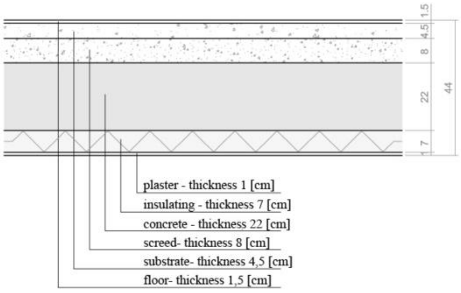
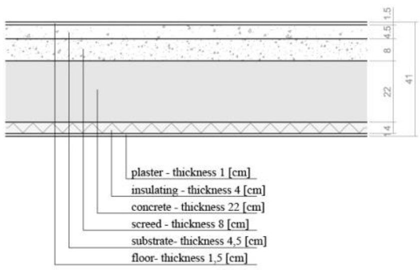


Figure 1 Plan and three-dimensional pattern of the ESP-r model

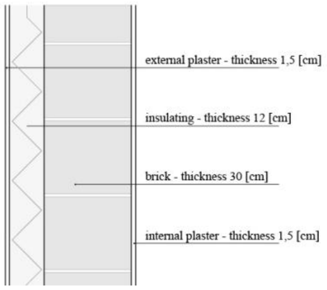
EXTERNAL FLOOR – GREENHOUSE
Transmittance K = 0,42 [W/m^2°C]



INTERNAL FLOOR – LIVING ROOM
Transmittance K= 0,63[W/m^2°C]



EXTERNAL WALL
Transmittance K= 0,18 [W/m^2°C]



INTERNAL WALL
Transmittance K= 0,8 [W/m^2°C]

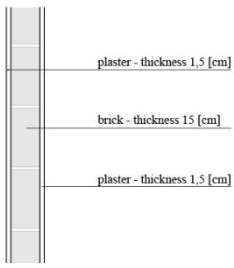


Figure 2 Composition of constructions used in the model

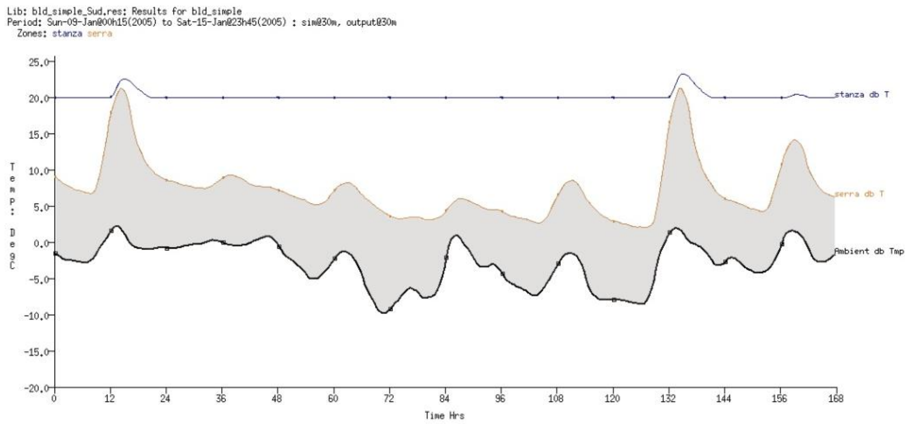


Figure 3 Graph of temperature of the coldest week of January

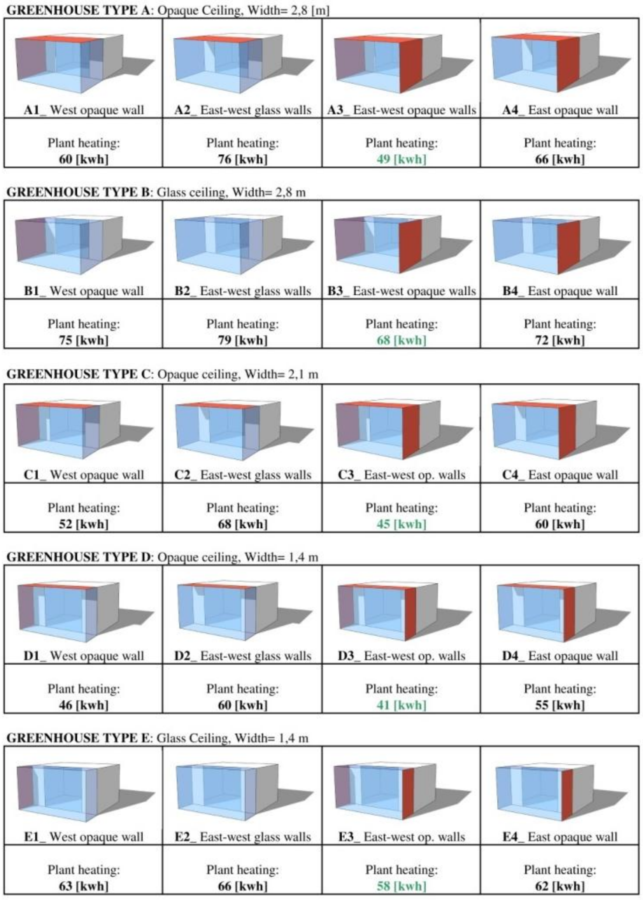


Figure 4 Study on the greenhouse's envelope: results of simulations (Orientation: South, Period: January and February)

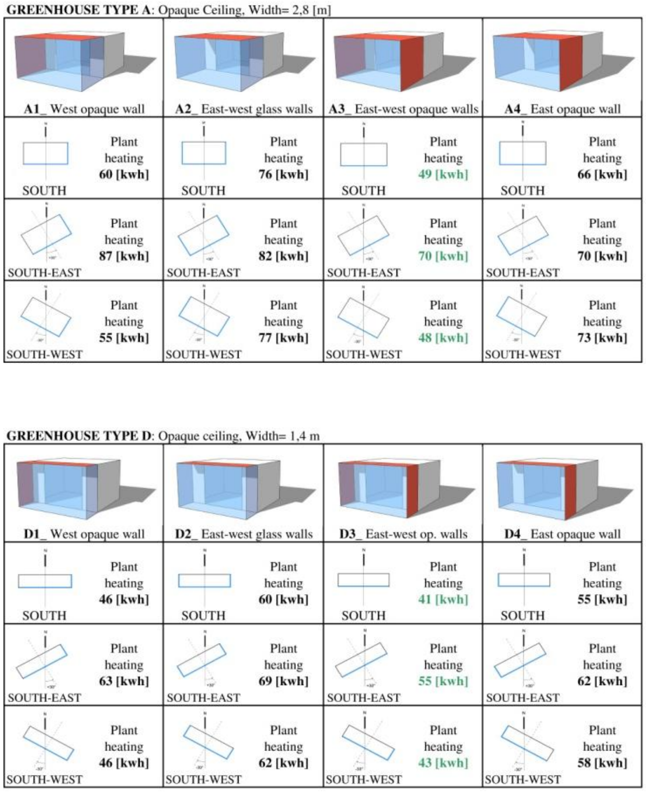


Figure 5 Study on the greenhouse's orientation: results of simulations

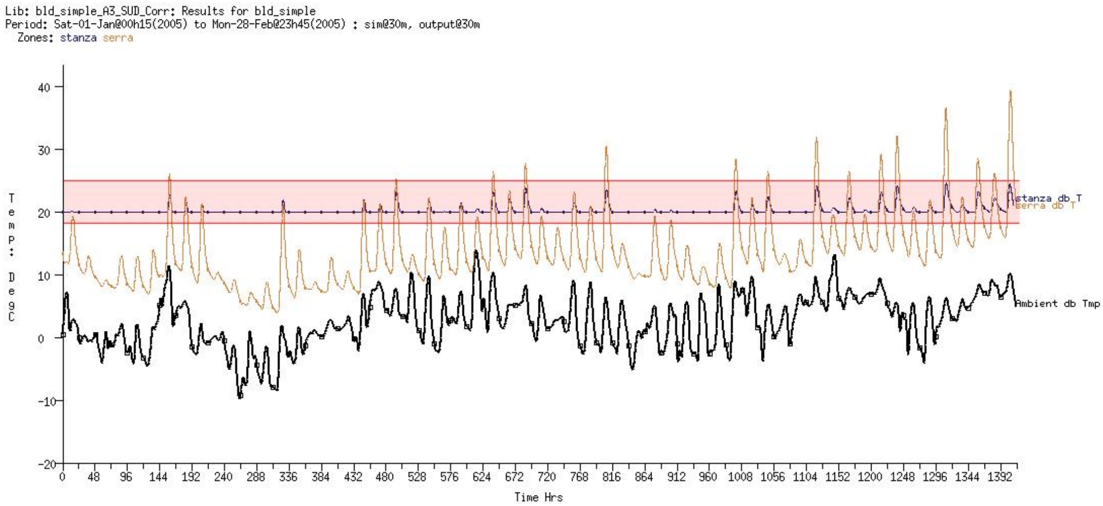


Figure 6 Graphic of January and February temperatures

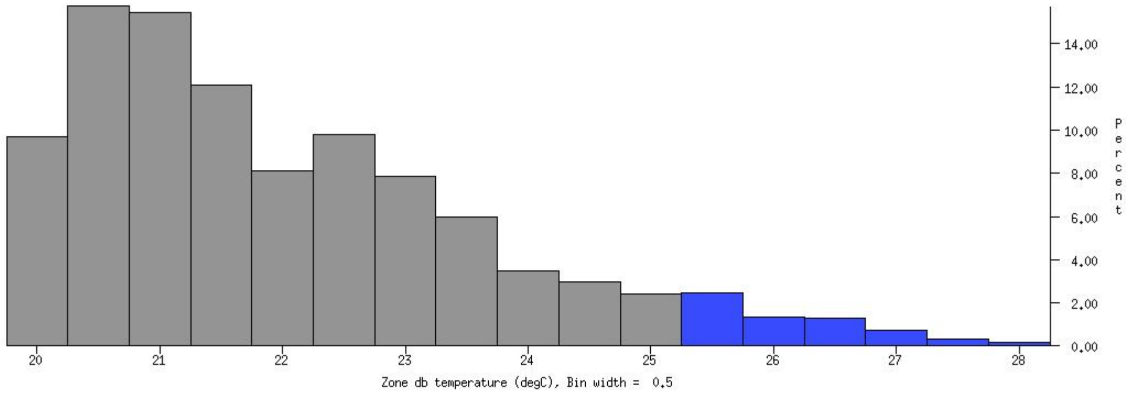


Figure 7 March's temperature distribution in the living-room

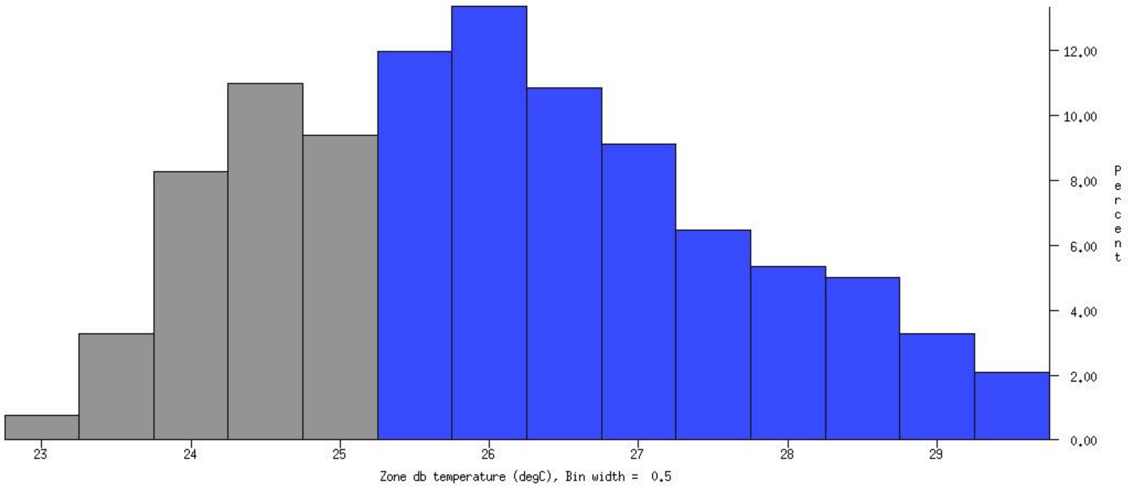


Figure 8 April's temperature distribution in the living-room

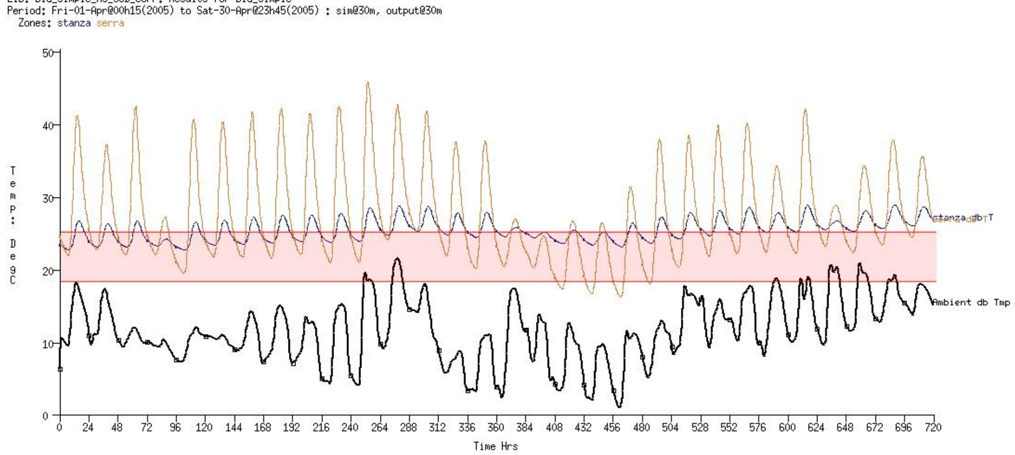


Figure 9 Graphic of April's temperatures

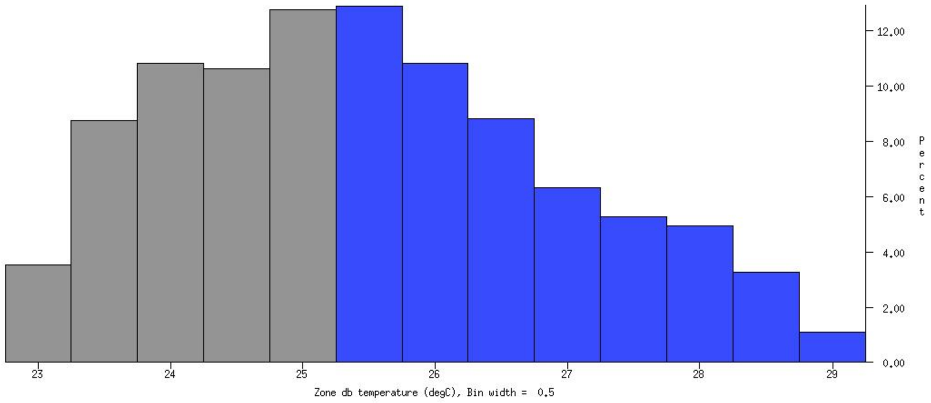


Figure 10. April's temperature distribution in the living-room with a ventilation of 0,9 [vol/h] in the greenhouse.

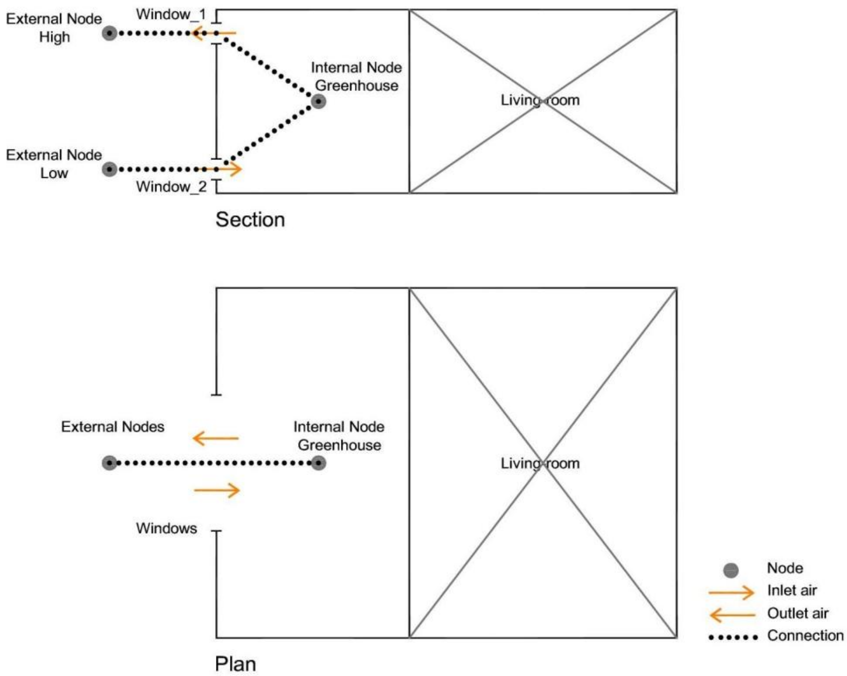


Figure 11. Air flow network scheme.

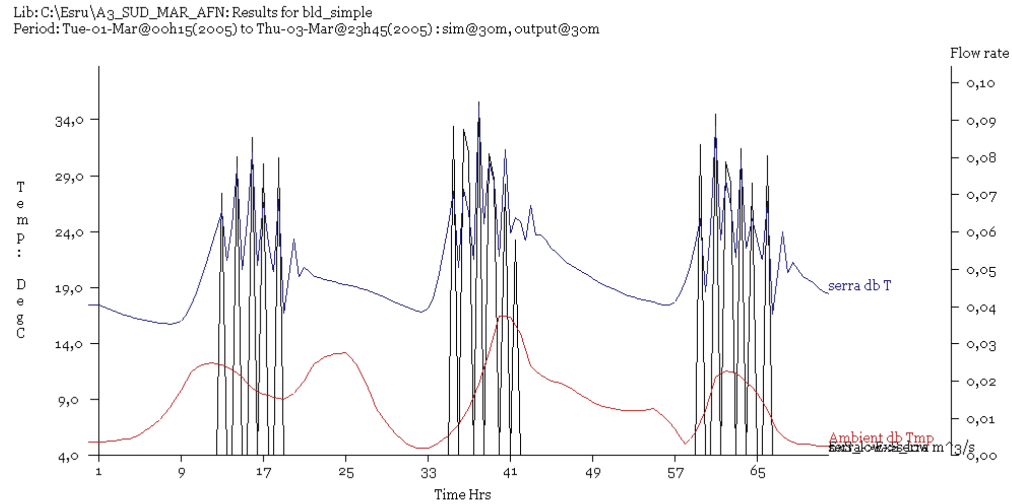


Figure 12. Greenhouse's temperature (blue line), outside ambient temperature (red line) and air flow rate of greenhouse (black lines) during 1, 2, 3 March. Opening area is of 0,1 [m^2].

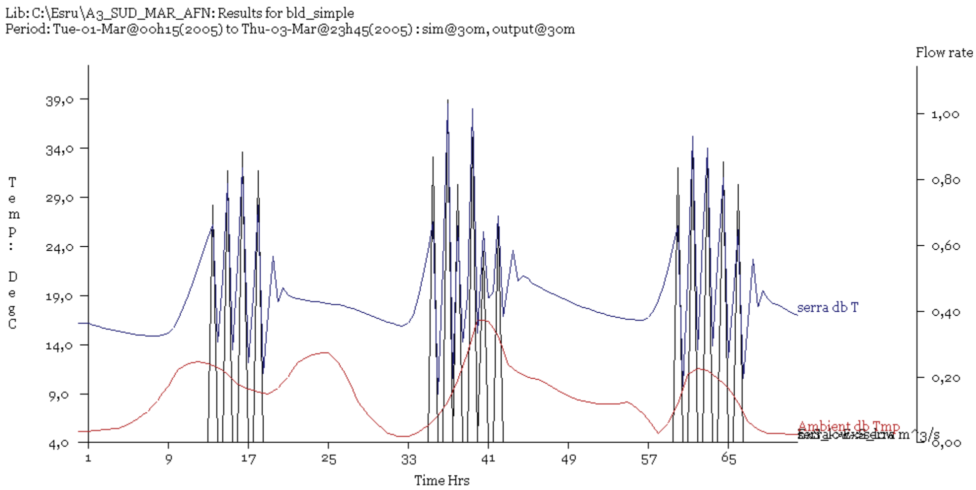


Figure 13. Greenhouse's temperature (blue line), outside ambient temperature (red line) and air flow rate of greenhouse (black lines) during 1, 2, 3 March. Opening area is of 1 [m^2].

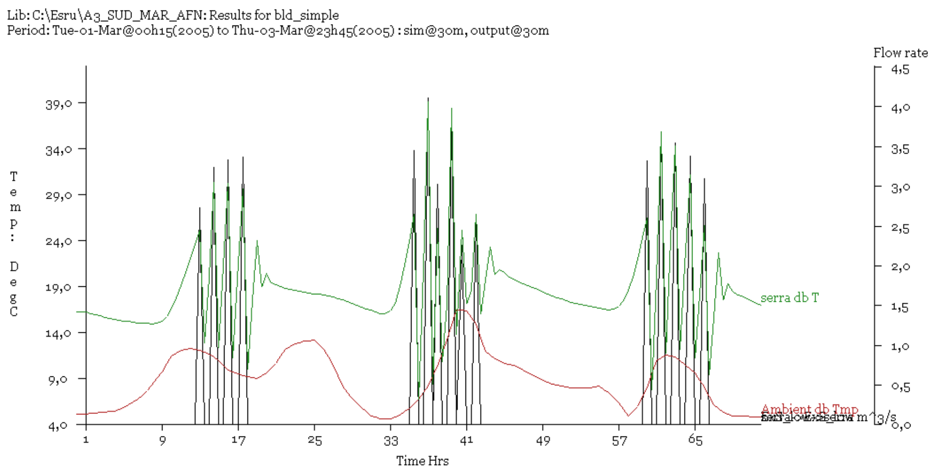


Figure 14. Greenhouse's temperature (green line), outside ambient temperature (red line) and air flow.