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# Numerical study and the vegetated south facade in hot dry climate: Measurement of energy balance

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## Abstract

The integration of vegetation into the building envelope has been studied by several researchers in order to reduce the energy consumption of a building and improve the comfort conditions of the building and its surrounding environment. These studies showed a drop in indoor temperature of a room from 4 to 6°C at the height of the summer, with a slight increase in humidity, thanks to a plant screen associated with a light facade. In a hot and dry climate, the use of a plant screen on the building envelope can increase its thermal capacity and contribute to the cooling of interior spaces in summer. The results obtained vary according to climatic conditions and constructive modes. The choice of plant type is important to meet cooling needs in summer. Nevertheless, as we shall try to demonstrate this aspect in the vegetation south façade (the street of the Mohamed cherif located in district ferhat subdivision dalaa Biskra, Algeria) leads us to illustrate clearly the benefits of vegetation in buildings. The plants act as a mask to sun and wind and as a source of control the air temperature and the temperature of the surrounding surfaces. Mitigation of air temperature in the presence of plants can be explained by the decrease in surface emperature that induces a lower air temperature. To know the real impact of vegetation on air temperature, experimental work was necessary, was carried out on the south façade of house located in el alia district in Biskra city (Algeria), and spread over a typical summer day with a measuring tool called "testo 480 – infrared sensor". We also measured the amount of $CO_2$ on the same device changing only the sensors. In order to see the amount of $CO_2$ variation in comparison to the climatic parameters at the same case study.

**Keywords :** building comfort, vegetation south facade, hot and dry climate, experimental work, testo 480 – infrared sensor. amount of $CO_2$.

## Introduction

After the era of concrete that invaded cities by creating heat islands and damaging biodiversity, urban vegetation is an advanced solution to regulate the urban microclimate. In a dense urban fabric, the use of vegetation, especially on facades, is envisaged. Plant facades have the advantage of filtering some of the solar radiation arriving on the wall without thinking too much about other buildings, nor raising its temperature significantly. They limit both the emissions of infrared radiation, due to heating of surfaces, and of radiation due to their solar reflectivity. The greening of the facades allows to better regulate the heat, and the insulation of the building. It also dresses aesthetically the buildings.

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**Problematic**

Solar radiation is the main source of heat in hot and dry climates. Heat is transmitted mainly by conduction of heat absorbed by walls and roofs. The speed of this phenomenon depends on the nature of the material (thermal conductivity) and the surface condition of the material (colour and texture) [1]. Facades play a major role in urban environments as a solar radiation receiver and heat emitter. By covering the cells where the net radiation from plants is distributed, their behaviour is profoundly altered, in particular because of the transpiration of the leaves which absorbs a large part of the incident radiation. The effects of vegetation on the urban environment are the transfer of thermal energy (infrared radiation and confection) and the production of moisture, physical phenomena whose main source of energy is solar radiation. Compared to the interior atmosphere and the energy consumption of a building, it will also act as a screen by transmitting more or less of this radiation to the wall that supports it. The leaves play the role of sun protection for the wall during the day but also prevents cooling by blocking the radiation at night. Due to their physiology, the leaves absorb a significant amount of solar radiation without raising their temperature thanks to perspiration. Finally, the presence or absence of wet substrate can also lead to passive cooling by evaporation. Plants limit convective transfers on the outside surface of the wall. [2] The temperature of the plant surface depends on the amount of incoming energy absorbed, the species and the water availability of the leaves. Numerous infrared imaging studies have been conducted to assess these temperatures. The authors agree on temperature differences between air and foliage ranging from –2°C to +2°C [3]

**Research Questions:**

- Can we obtain truly quantifiable improvements in the indoor climate, in a warm climate situation, by the introduction of climbing vegetation on a southern facade?
- Can we also achieve a positive effect on the external microclimate surrounding this plant façade?

**The parameters of the energetic balance as follows**

| | |
|---|---|
| Rn | Energy balance (W/m$^2$) |
| H | Sensible heat flow (W/m$^2$) |
| LvE | Latent heat flow (W/m$^2$) |
| G | Heat flow into the soil (W/m$^2$) |
| J | Heat flow absorbed by vegetation (W/m$^2$) |
| E | Mass flow of water vapour (W/m$^2$) |
| hc | Coefficient of thermal convection |
| Ta | Air temperature (K) |
| $T_{surf\ sol}$ | Soil surface temperature (K) |
| $V_{vent}$ | Wind speed (m/s) |
| $K_E$ | Coefficient of convective mass transfer |
| ρ | Density of air (ρ air = 1.18kg.m$^{-3}$) |
| $C_p$ | Specific heat of air ($C_p$=1004J/kg.K) |
| Lv | Latent heat of vaporization of water (Lv= 2.4*106 j/kg) |
| Mw | Molar mass of water vapour (Mw =18,01g*mol$^{-1}$) |
| R | Gas constant (R=8.32j.K-1.mol$^{-1}$) |
| Pvs | The saturation vapor pressure (kPa) |
| Pv | The vapor pressure (kPa) |
| Hr | Relative humidity (%) |
| K | Thermal conductivity of the soil (W/m/K) |
| ΔT | Coldest and Hottest temperature (K) |
| e | Level of ΔT (m) |

**Objectives:**

-Achieve truly quantifiable improvements in the climatic characteristics of a south-facing wall by introducing vegetation into warm climatic conditions.

-Determine the effect of vegetation on the interior microclimate through experimentation using the vegetated facade.

-Examine the effect of microclimate change on the indoor thermal environment.

## 1- climatic conditions

The climatic conditions of the site are subject to the arid climate. The situations that interest us correspond to a hot day under typical summer conditions. Therefore, measurements will be made during the day: 5 and 6 July 2021 (two days included in the overheated zone in the city of Biskra [4], bi-hourly measurements since 5 July 2021 at 8:00 am until 6 July 2021 at 8:00 am.

This work focuses on the influence of south-facing plant facade on air warming. It proposes to contribute to the deepening of knowledge of the mechanisms of energy exchange by following a bi-hourly measurement approach, which is based on numerical modelling using a measuring instrument testo 480 (infrared sensor), see Figure 1, to interpret the climatological parameters (air temperature, relative humidity, air speed, plant leaf temperature to calculate the energy balance of the plant facade. for sunny and hot summer days. Field of study that we used is the street of the Mohamed cherif located in district ferhat subdivision dalaa Biskra (Algeria). Figure 1

**Figure 1 :(a) views of district : ferhat subdivision dalaa, (b) Measuring instrument, infrared sensor (testo 480)**
**Source: the author**

The facade partielly colonized by a Bougainvillea plant. Using a climbing plant with climbing organs is a simple solution we can act on the summer microclimate. The bougainvillea must be planted in a warm place and must be returned in winter because it is not resistant to frost. The bougainvillea is a beautiful climbing plant with flowers that brightens the facades.

## 2. The thermal behaviour of plant facade

The use of solar radiation at plant facade level is summarized in Figure 2.

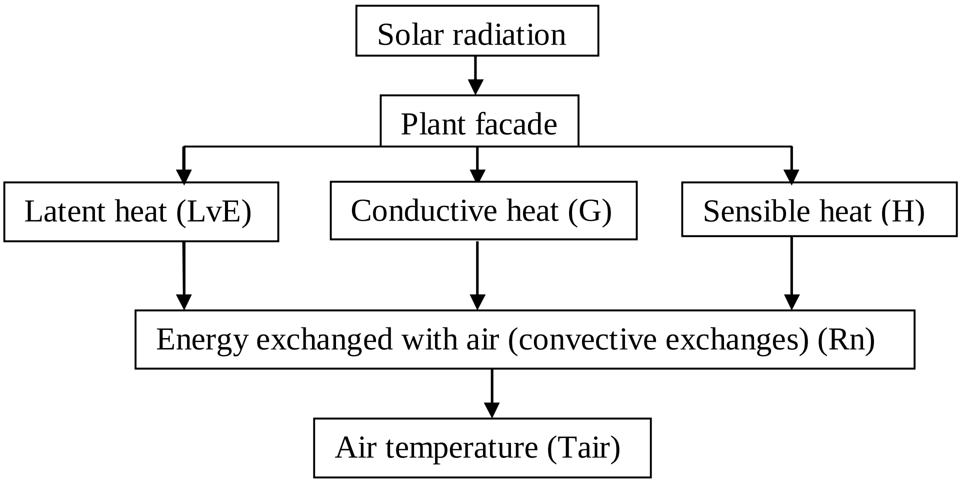


**Figure 2: Energy balance of a south-facing plant facade**
**Source: Author**

### 2.1 Calculation of the energy balance of a south-facing plant facade

The existence of air warming results from the modification of the energy balance of the plant facade. Part of the net energy arriving at the plant surface is used to heat the wall by conduction, another to evaporate the water, another to modify the atmosphere by convection. The energy balance at the plant wall scale is defined according to the following equation:

$$Rn = H + LvE + G \tag{1}$$

### 2.1.1 Sensitive heat flow on the plant facade

Sensitive heat is the energy that is transferred between the leaf surface and the atmosphere. If the temperature of the surface is greater than that of the atmosphere, a flow of energy to the environment occurs by convection. Heat stored in materials is usually released to ambient air at night as sensitive heat. [5].

**• Sensitive heat flow equation H**

This heat flux due to the convection of the wind, is calculated by the following relation:

$$H = h_c \, (Ta - T_{surf\,mur}) \tag{2}$$

$$hc = 0{,}5 + 1{,}2\sqrt{v_{vent}} \tag{3}$$

hc is the convective transfer coefficient.

### 2.1.2. Latent heat flow on the plant facade

The flow of water vapour from a plant (or latent heat flux) is called transpiration. Some leaves sweat on both sides, while others sweat only one side. Water vapour is released through small valve-like openings called stomata, which regulate the passage of water vapour from leaf tissues to the surrounding air. The degree of opening of these pores depends on several factors such as plant species and age, leaf temperature, soil moisture content, air moisture and ambient $CO_2$ concentration. In addition, in certain critical situations, such as in extreme temperature conditions or in an extremely dry environment, the plant closes its stomata to minimize the amount of water lost. [5] state that latent heat losses are greater when there is sunlight and little moisture in the atmosphere.

**• LVE Latent heat flow equation**

It is calculated by Stefan's relationship based on the mass transfer theory called also film theory given by:

$$LvE = [(Lv.K_E.M_W)/(R.Ta)] * [Pvs(T_{surf\ mur})) - Pv(Ta)] \quad (4)$$

$$P_{VS}(T) = exp^{(25,5058-(5204,9/T))} \quad (5)$$

$$P_V(T_a) = Hr\, P_{VS}(T_a) \quad (6)$$

Louis' hypothesis consists in stating that:

$$K_E = hc\ (\rho.Cp) \quad (7)$$

**2.1.3. The conductive heat flow on the plant facade**

The conductive flux depends on the surface temperature (Ts), the nature of the material and more precisely its thermal characteristics (thermal conductivity (λ), calorific capacity (Cρ) and density (ρ). The flow is a function of the temperature in the plant facade.

**• Conductive heat flow equation G**

The heat flux in the plant facade is defined by Oke according to the following equation:

$$G = -K\ (T2-T1) / (e2-e1) \quad (8)$$

By replacing each quantity in the energy balence equation (1), we can finally write the energy balance as follows :

$$Rn = \frac{L_v.K_E.M_w}{R.Ta}\left(P_{vs}(T_{surf\ sol}) - P_v(T_a)\right) + h_c.(T_a - T_{surf\ sol}) + K\frac{\Delta T}{\frac{\Delta e}{e}} \quad (9)$$

**3.2. Measuring Energy Balance on the Plant facade**

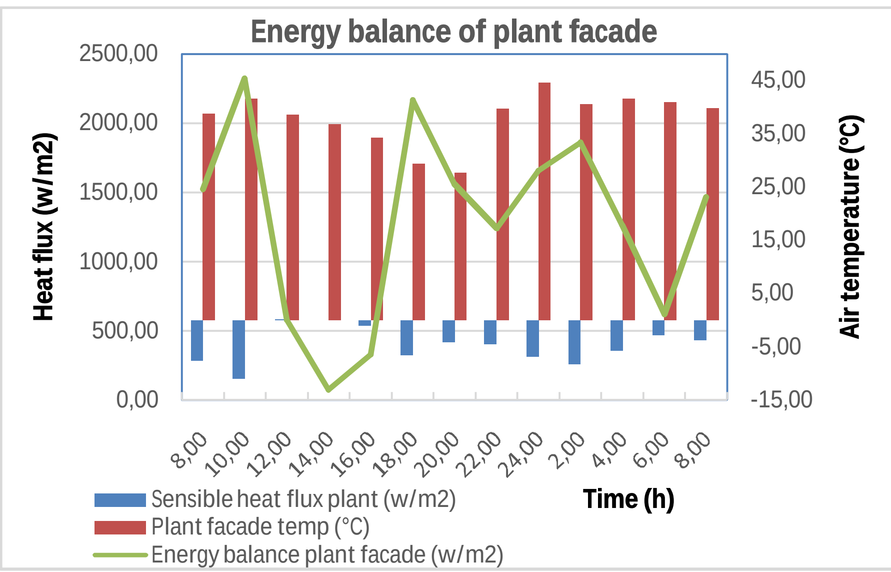


**Figure 3: Energy balance, temperature, sensitive heat flux of plant facade**
**Source : author**

The plant facade receives part of the solar radiation and absorbs a large part of it. This absorbed radiation helps to increase the temperature of the plant facade and to change the state of the liquid water into water vapour through the transpiration of the plant.
This mechanism allows it to guard against a too large increase in its temperature. Figure 3 details the evolution of all these components during the day. Thus, at the solar midday, 65% of the solar flux reaches the surface of the plant. 42% of this absorbed radiation contributes to the phenomenon of perspiration while the remaining 58% represents the sensitive heat exchanged with air for the whole plant (the vertical distribution of this sensitive heat exchanged with air being relatively heterogeneous) that contributes to air warming. At night, however, the sensitive heat exchanges are reversed so that it is the air that gives heat to the plant facade.

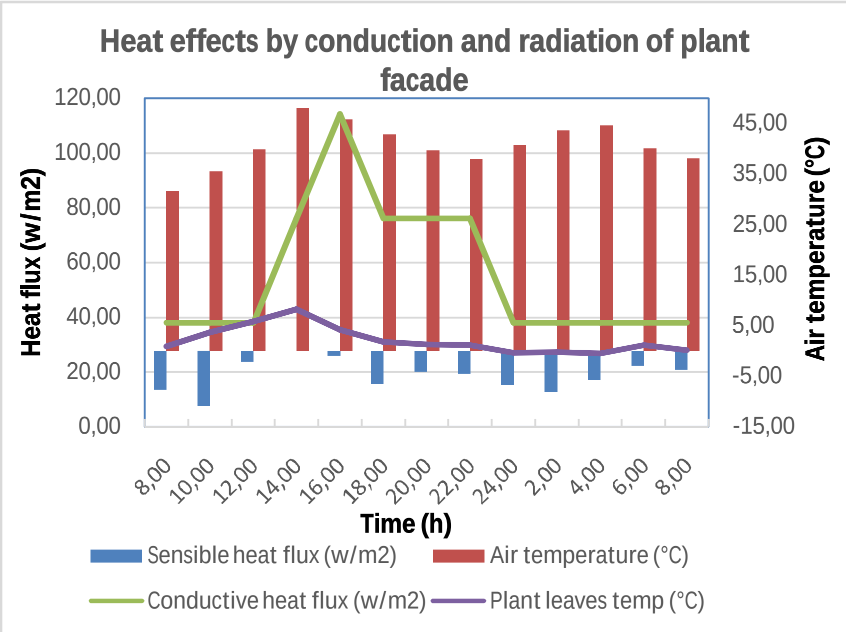


**Figure 4: Heat effect transmitted by plant leaves in the plant facade**
**Source : the author**

The energy balance (Rn) of the south-facing plant facade governs the exchange of heat within an environment. The components of this equation are shown schematically in Figure 4. From the point of view of the thermal behaviour of the plant facade there are three effects on the microclimate:
-a radiative effect: the leaves act as a protection for the facade during the day but also prevent its cooling by preventing the radiation of large wavelengths during the night. The leaves absorb a large part of the solar radiation without rising in temperature, because of their ability to sweat. In the case of wet substrate, it may also act as a passive cooling by evaporation;
-a conductive effect: vegetation and especially its substrate can isolate the wall and modify its inertia. This effect is highly dependent on the water content of the substrate,
- G increases with temperature of the air.

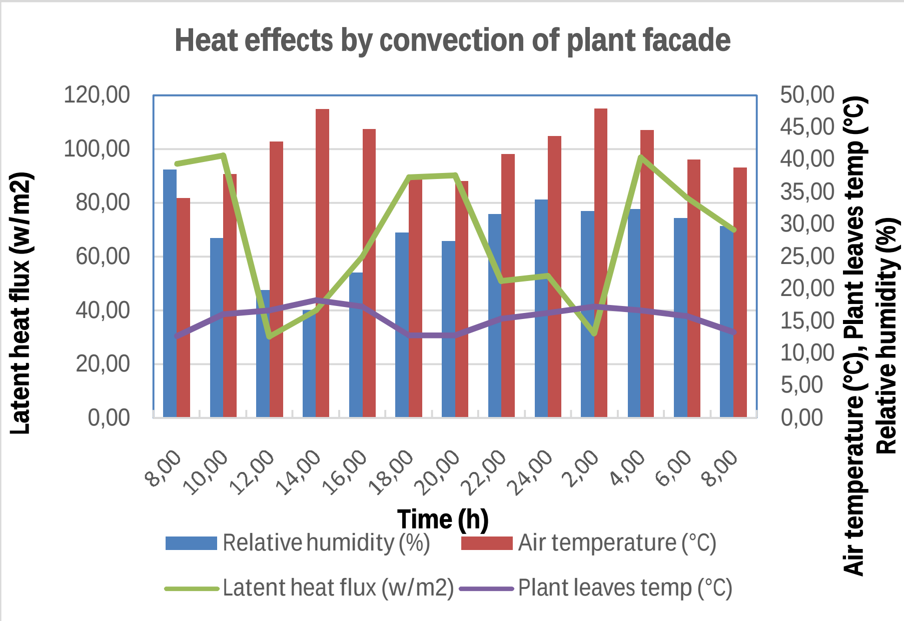


**Figure 5: Heat effect by convection of plant facade**
**Source :author**

-A convective effect:  - (LvE) grows with the amount of plant area surface: latent heat flow is related to evapotranspiration and relative humidity value. The impermeable surfaces limit the phenomena of evaporation. - (LvE) grows with the amount of plant area surface: latent heat flow (LvE) is related to evapotranspiration and relative humidity value. - In summer, trees near buildings have a negative effect on facades by limiting exchange with the sky at night.
- The temperature difference between air and surface is reduced, limiting convective exchange. – The vegetation increases the latent cold by adding moisture to the air produced by evapotranspiration. The air temperature (Tair) in the vicinity of vegetation is therefore reduced.

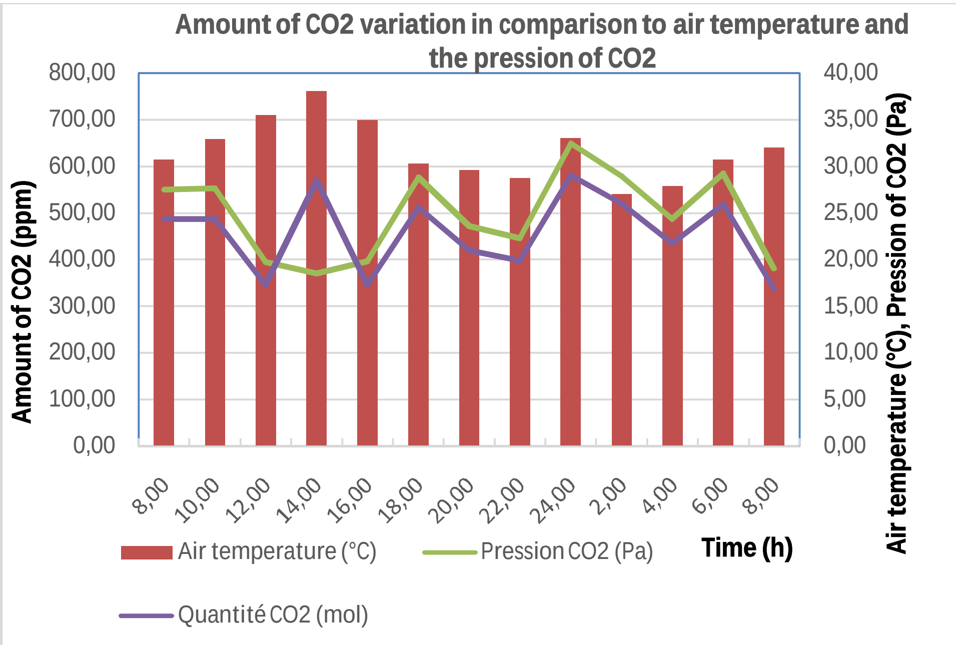


**Figure 6 :Amount of $CO_2$ variation in comparison to air temperature and the pression of $CO_2$.**
**Source : author**

The $CO_2$ content of the atmosphere is subject to temporal and spatial variations. A variation of the order of 50 ppm/day is observed. In the morning, photosynthesis begins and the $CO_2$ content decreases. In the afternoon, the daily minimum is observed. At night, the $CO_2$ level returns to its maximum. Water vapour is released through small valve-like openings called stomata, which regulate the passage of water vapour from leaf tissues to the surrounding air.
The leaves of the plants lose water mainly by evaporation through the stomata. Other parameters such as air temperature and wind speed strongly influence $CO_2$ flows in urban environments. Experimentally, an increase in $CO_2$ of about 600 ppm increases pression of $CO_2$ and air temperature.

**Conclusion**

The interaction between climate and the plant facade has logically become one of the most important concerns. Indeed, the current indoor climate is strongly disturbed by the structure of the walls, by the surface materials used and by the activities that develop there. Our contribution has enabled the development of a methodology and thermal procedures whose applications in indoor micro-climatology are immediate. We try in this study to consider the impact of plant facade on indoor climate. By placing ourselves at plant facade level, the interactions between the frame and the external environment are immediate and can induce phenomena that need to be well understood so that constructive proposals can be made to reduce the harmful consequences of air warming. Thus, we try to study the different phenomena of heat transfer through a plant wall. This theoretical knowledge allowed to define certain notions and highlighted the complexity of radiative exchanges. By analysing the main results of studies carried out in the field of Micro-climatology, we highlight the thermal behaviour of some facades.
It was also found that the increase in air temperature with $CO_2$ concentration is therefore not only a statistical correlation. This is a physical hypothesis which, for the moment, is confirmed by observations. To overcome global warming we need to know what plants provide us as a service is carbon sequestration, recreation and oxygen.

**BIBLIOGRAPHIC REFERENCES**

[1] Alain Liébard , André DE Herde : Traité d'architecture et d'urbanisme bioclimatiques, concevoir, édifier et aménager avec le développement durable. Edition le moniteur, Paris, 2005.

[2] Laurent Malys, Modélisation climatique des façades végétales : caractéristiques radiatives des couvertures végétales de façades, Thèse de Master STEU, Spécialité Ambiances et Formes Urbaines, le 24 septembre 2009 à l'École Nationale d'Architecture de Nantes

[3] Marjorie musy, Le rôle climatique de la végétation urbaine, in culture et recherche n° 113, automne 2007, CERMA, École nationale supérieure d’architecture de Nantes

[4] BOUKHABLA. Moufida, ALKAMA. Djamel, impact de la géométrie des rues sur les fluctuations thermiques extérieures, mémoire de magistère, 2010, université Mohamed khidder Biskra.

[5] [Jim and Tsang, 2010] Jim, C. and Tsang, S. (2010). Biophysical properties and thermal performance of an intensive green roof. Building and Environment, pages 1263–1274.