



THERMAL AND MOISTURE BEHAVIOR OF PREMISE EXPOSED TO REAL CLIMATE CONDITION

Nour LAJIMI¹, Nouredine BOUKADIDA¹

¹LABORATORY OF ENERGY AND MATERIALS, LabEM-LR11ES34
Rue LAMINE ABBASSI 4011 HAMMAM SOUSSE –TUNISIA

Abstract: This paper presents a numerical study of the thermal and moisture behavior of premise. Vertical walls are equipped with alveolar structure in East, South and West faces. The temperature and the relative humidity are assumed to be variable with time. The study shows that the climatic conditions and the orientation of vertical walls have a relatively influence on the inside behavior of premise. The study also show the effect of alveolar structure on the relative humidity and temperature inside the premise.

Keywords: Solar energy-Heat and moisture transfer- Relative humidity-alveolar structure.

I. State of the art in terms of heat and mass transfer in buildings

Very high or very low relative humidity and condensation phenomena can compromise building occupants' health and comfort. Controlling humidity and Maintaining a comfortable humidity range for occupants is necessary. Generally, most people will be comfortable in a humidity range of 30–80% if the air temperature is in a range of 18–24°C. There are many ways that avoid condensation and maintain relative humidity in optimal range in buildings. Since the last decade many theoretical and less experimental work of thermal and moisture behavior of building has been done. Many searchers were interested in thermal behavior, others only in moisture behavior. Among the first there are those who are focused on buildings equipped with inclined alveolar structure; among them we mention Seki S.[1] and Bairi A. [2] who experimentally studied heat transfer by natural convection in a cavity. They brought out correlations of Nusselt number type according to the Grashof number: $Nu = F(\alpha).Gr^n$, where (n) depends on the nature of the flow for different configurations by varying the angle of inclination in the cavities, the report of shape and the temperature difference (ΔT) between both warm and cold vertical walls. Bairi.A [2] showed the influence of the thermal boundary conditions at the level of the passive walls (lamelleas) on the convective heat transfer.

Zugari.MR and al [3] specified that a simple glazing equipped with inclined lamellas structure will have during one day (the incidence of radiation varying constantly) an overall efficiency upper to that of the simple glazing or double glazing.

Vullierme J.J and Boukadida N.[4] experimentally determined the global density of heat transfer flux including convection and radiation (F_a) in the crossing and insulating senses through the realized alveolar structure. These measures allowed to bring out laws for different distributions of low or high emissivity coatings of the inside faces of alveolar. These laws are defined by the following correlation:

$$F_a = \sigma(\Delta T)^{1.25} \quad (1)$$

where: σ is a constant which depends on emissivity, transfer direction and the angle of inclination.

In order to show the effect of the anti-convective structure, they [5] studied heat transfer in a room by using this alveolar structure. The aim of the work was to study the external temperature, solar flux and wall nature effects on the building thermal behavior using a structure with a diode thermal effect. The structure is conceptualized to be used for a cooling or heating application. Numerical simulations allowed to compare the thermal behavior of a building equipped with this structure on its East, South and West faces to that of standing or conventional building with large or low inertia. Simulations were made for a cooling application in a deserted zone where the thermal amplitude between day and night is sensitive. Results showed the effect of conducted and insulated wall layers thickness and the external solar flux on the premise thermal behavior. They also showed that the average inside temperature of a place equipped with this structure is slightly higher than one having high or low thermal inertia.

Lajimi N. and Boukadida N. [6] studied numerically the thermal behavior of the premises. Vertical walls are equipped with alveolar structure and/or simple glazing in East, South and West faces. The temperature of the premises is assumed to be variable with time or imposed at set point temperature. Results principally show that the simple glazing number has a sensitive effect on convection heat transfer and on inside air temperature. They also show that the diode effect is more sensitive in winter. The effect of alveolar structure and simple glazing on the power heating in case with set point temperature was also brought out. In order to optimize building energy efficiency, M. Doya and al[7] studied experimentally the effects of dense urban model and the impact of cool facades on outdoor and indoor thermal conditions. The aim of this work is to look for alternatives solutions to

improve thermal comfort and to reduce cooling energy demand, such as building morphology (for example, the orientation of the walls, in this case to study the temperature profil on the East and West sides) and surface albedo (the modification of albedo can reduce the solar radiation absorbed. However, this reduction decreases the surface temperatures, and then the longwave radiation exchanges).

Among searchers those interested in moisture behavior in buildings we mention Woloszyn M and Rode C. [8] who studied performance of tools simulation of heat, air and moisture of whole building. They specified that inside humidity depends on several factors, such as moisture sources, air change, sorption in materials and possible condensation. Since all these phenomena are strongly dependent on each other. Numerical predictions of inside humidity need to be integrated into combined heat and airflow simulation tools. The purpose of a recent international collaborative project, IEA-ECBCS (International Energy Agency- Energy Conservation in Buildings and Community Systems), has been to advance development in modeling the integral heat, air and moisture transfer processes that take place in “whole buildings” by considering all relevant parts of its constituents. It is believed that understanding of these processes for the whole building is absolutely crucial for future energy optimization of buildings, as this cannot take place without a coherent and complete description of all hygrothermal processes. They also illustrate some of the modeling work that has taken place within the project and presented some of the used simulation tools. They focused on six different works carried out in the project to compare between models and to stimulate the participants to extend the capabilities of their models. In some works, it was attempted to model the results from experimental investigations, such as climate chamber tests (for example Lenz K. [9]), it was attempted to model so-called BESTEST building of “IEA SHC Task 12 & ECBCS Annex 21” (Judkoff R. and Neymark [10]). The original BESTEST building was extended with moisture sources and material properties for moisture transport and is described in more details in [11]. Constructions were altered so they were monolithic, the material data were given as constant values or functions, and the solar gain through windows was modeled in a simplified way. From 9:00 to 17:00 every day. The air change rate was always 0.5 ach (air-exchange per hour). The heating and cooling control for all the non-isothermal cases specified that the inside temperature should be between 20 and 27°C and that the heating and cooling systems had unlimited power to ensure this. The system was a 100% convective air system and the thermostat was regulated on the air temperature. The first cases were very simple, so analytical solutions could be found. These results gave an increased belief that it was possible to predict the inside relative humidity with whole building hydrothermal calculations. In the second and the more realistic part of the exercise, the building was exposed to a real outside climate as represented by the test reference weather of Copenhagen, and a simplified modeling of radiation was adopted. The result shows the relative humidity inside the roof structure. For most of the tools, the results agreed with one another, which indicates that the simulations perform correctly when it comes to the calculation of moisture transport in the building enclosure. Woloszyn M. and Rode C. [8] clarified the models that represented heat and simple vapor diffusion in envelope parts, without considering liquid migration or hysteresis in sorption isotherm, which can give correct estimation of hydrothermal building response in many practical applications. Indeed their results were similar to those of more complex tools in the works performed. The importance of interactions in whole building HAM (heat, air and moisture) response was also shown. The relative humidity of the inside air levels are strongly dependent not only on transfer of moisture between the air and the construction of sources of moisture, but also on air flow, temperature levels and energy balances.

Moisture balance:

The simplicity of the model presented here is obtained by the use of Kirchhoff's potential, [12]. This allows to describe the moisture transport. It was originally introduced for heat transfer by Kirchhoff introduced and further developed to describe moisture transport during the past two decades (Arfvidsson J. [13]). An important result is that the average value of the Kirchhoff's potential in the material over a time period is equal to the average value of the Kirchhoff's potential. This is valid in a semi-infinite material (2).

$$\frac{\partial \phi}{\partial t} = \frac{\partial}{\partial X} \left(D \frac{\partial \phi}{\partial X} \right) \quad (2)$$

The potential ϕ can be chosen to fit a special application or measurement. Relative humidity or moisture content is often natural choices since these potentials are directly measurable.

Künzel H M. [14] studied the inside relative humidity in residential buildings. To assess the moisture performance of building envelope systems using the moisture balance (2), a boundary condition is necessary:

$$V \frac{\partial c}{\partial t} = \sum AG + W + Q \quad (3)$$

Where:

C: absolute moisture ratio of the interior air, [kg m⁻³]

G: mass flow of moisture from the inside surface into the room, [kg.m⁻² h⁻¹]

A: enclosure surfaces [m²]

W: inside mass flow of moisture generated by internal moisture sources [kg.h⁻¹]

Q: wet mass rate ventilated by air conditioning systems [kg.h⁻¹].

Fitsu T. [15] studied the whole building heat and moisture analysis. The simulation results are based on integrating analysis of three components used to compare between models. These components cover three aspects of the whole building performance assessment which are:

- Inside environment: prediction of inside temperature and relative humidity,
- Building envelope hydrothermal condition: temperature and relative humidity conditions of the outside surface of the roof,
- Energy consumption: estimation of the heating and cooling loads that are required to maintain the inside temperature in the desired range. For the second aspect, results showed that the highest moisture accumulation corresponding to 76% of relative humidity is observed at the time when the surface temperature is the lowest and the solar radiation is the highest (13:00 h), the outside surface of the roof (corresponding to as low as 15% relative humidity).

Several projects based on experimental analysis determined correlation between moisture and temperature of the air inside building. whys U. and Sauret H. [16] studied experimentally the heat and mass comfort in two different test buildings (with Nubian Vault) and (with sheet metal) by determining the temperature and relative humidity of the inside air. The measures analysis of the surface temperature and humidity shows that the temperature of the building which corresponds to "Nubian Vault" is less important compared to that of the building related to "sheet metal". It may cause an increase in the outside temperature. The variation of relative humidity surface is less important in the buildings tested under "sheet metal" than those under "Nubian Vault".

Milos J. and Robert C. [17], determined the property of the vapor diffusion in the building materials, they used an experimental method to determine the transport properties of the water vapor. This method is based on measurements in steady state under isothermal condition of water vapor, measurement of the vapor flow by diffusion through samples. Using the measured water vapor diffusion coefficient, the water vapor diffusion resistance factor, which is the parameter most frequently used in building practice, was determined as:

$R_d = \frac{D_{v0}}{D}$, where D_{v0} is the diffusion coefficient of water vapor in air, R_d is the vapor diffusion resistance factor and D is the diffusion coefficient of water vapor in the building materials.

Patrick R. and al [18] studied the modeling of uncontrolled inside humidity for (HAM) simulation of residential building; this paper examines the current approaches to modeling the inside humidity for (HAM) computer simulation use. Moisture balance methods have been developed to estimate the inside humidity in residential buildings without mechanical humidity control. This paper makes the case for establishing different parameters for hot and cold seasons. Calculations of inside humidity are presented for a representative mild marine climate and it is demonstrated that the controlling parameters must be carefully selected to produce realistic inside humidity levels. They compared the calculated relative humidity using two models, the first one being the BRE (Building Research Establishment) admittance and the second one the ashare 106P. Authors have shown the impact of inside temperatures using those models. Results illustrate the measured field data of multi-unit residential buildings in Vancouver. They have also shown a general trend in the inside-outside vapor pressure difference in measured data from Vancouver over several years of monitoring. The inside vapor pressure will nearly always be greater than the outside vapor pressure for uncontrolled inside humidity during the hot season. The difference of vapor pressure decreases over the cold season until at some point the inside vapor pressure will be close to the outside vapor pressure.

Based on formal analogy between the equation of diffusion (Fick law) and the equation of conduction (Fourier's law):

$$\vec{\phi}_t = -\lambda \overrightarrow{gradT} \quad (4)$$

$$\vec{\phi}_m = -\rho D \overrightarrow{gradC} \quad (5)$$

There is a correspondence between the following grouping $(\vec{\phi}_t, \vec{\phi}_m)$, $(\lambda, \rho D)$, (T, C) . Then, the transposition of the thermal problem of conduction into a diffusion problem is called thermo-mass diffusion analogy. Knowing the correlation quantifying heat transfer it can be deduced by analogy those that quantify mass transfer. Driss S. [19] and Rode C. [20] determined the convective moisture transfer coefficient and the surface resistance by using the Lewis relation expressed as:

$$hm = \frac{ht}{\rho c p} (Le)^{-3/4} \quad (6)$$

The exponent $3/4$ is recommended for inside surfaces in buildings by Sandberg P. [21].

There are a number of validated models for thermal building simulations as well as hydrothermal envelope calculations used in building practice today. However, working combinations of these models are not yet available for the practitioner. In principle, this combination is made by coupling existing models of both types.

Figure 1 shows the notion of such a combination where balance equations for the inside space and the different envelope parts have to be solved simultaneously.

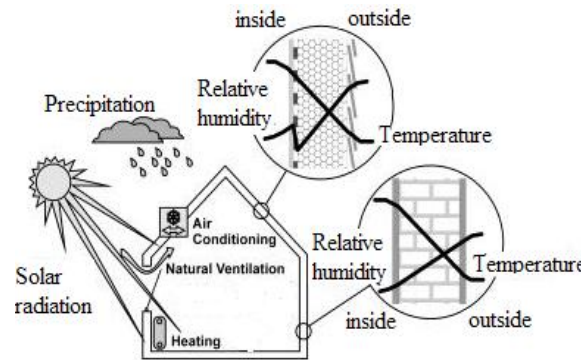


Figure 1: Hygrothermal effects of inside heat and moisture, outside climate and transient behavior of envelope components.

II. Position of the problem

To our knowledge, no experimental or numerical work has been done to study the transfer of moisture in a room with walls equipped with lamellae inclined to the horizontal plane. Based on the above and on previous work, we are interested in studying the thermal and moisture behavior of such premises. Each wall is exposed to variable solar flux and submitted to metrological condition. The area and the volume of the premise are ($S=30m^2$ and $V=300m^3$). The description of premise walls mentioned in paper [6].

III. The working assumptions

- The heat and mass transfer is unidirectional.
- The air is considered a perfectly transparent gas,
- The thermo-physical properties of materials are constant,
- The air temperature inside the room is uniform,
- The participation of the occupant energy is negligible,

IV. Formulation of the problem

The equation of the thermal balance of element 'i' is expressed as:

$$(mc)_i \frac{dT_i}{dt} = \sum_{j=1,n} C_{i,j} (T_j - T_i) + \sum_{j=1,n} K_{i,j} (T_j^4 - T_i^4) + P_i \quad (7)$$

Where T_i , $(mc)_i$, $K_{i,j}$ and P_i are respectively, the real time temperature (K), the heat capacity ($J.K^{-1}$), the conductive and/or convective coefficient between nodes i and j ($W.K^{-1}$), the radiative coupling coefficient between nodes i and j ($W.K^{-4}$) and P_i (W) the solar flux absorbed at the time (t) by node i.

The equation of the moisture balance of element 'i' [11, 13] is:

$$\frac{d\varphi_i}{dt} = \sum_{j=1,n} w_{i,j} (\varphi_j - \varphi_i) \quad (8)$$

where: Inside humidity generation by internal moisture sources and moisture supply or removal by ventilation and air conditioning systems are neglected. φ_i is the real time humidity (%) of element 'i' and $w_{i,j}$ is the diffusion and/or masse convective coefficient between nodes i and j (s^{-1})

V. Boundary conditions

A. Meteorological conditions

As far as meteorological data are concerned, real data can be used for general equations fitted to experimental data of temperature (10) and relative humidity (11). Mean values of temperature and humidity can be expressed as cosine function. These functions, which incorporate parameters such as minimum and maximum, are respectively expressed as:

$$T = A_T + B_T \cos\left(\frac{2\pi}{T} t\right) \quad (10)$$

$$HR = A_H + B_H \cos\left(\frac{2\pi}{T}t\right) \quad (11)$$

$$\text{Where: } A_T = \frac{(T_{\min} + T_{\max})}{2} \text{ and } B_T = \frac{(T_{\min} - T_{\max})}{2}$$

$$A_H = \frac{(HR_{\min} + HR_{\max})}{2} \text{ and } B_H = \frac{(HR_{\min} - HR_{\max})}{2}$$

B. Thermal boundary conditions

The convective heat transfer coefficient reflecting the exchange between the outer wall and ambient air is assumed to be uniform, we have taken the values:

- $12\text{wm}^{-2}\text{k}^{-1}$ for vertical face,
- $14\text{wm}^{-2}\text{k}^{-1}$ for the horizontal face.

• Global heat transfer coefficient inside alveolar:

We have opted for the correlation including convection and radiation, determined experimentally by Boukadida N. and Vullierme J.J [4]:

$$h_t = \gamma \Delta T^{0.25} \quad (12)$$

Where γ is Coefficient which depends on the heat direction, the angle of inclination and faces emissivity of the lamellas (low or high emissivity). It is obtained for an angle of 60° and takes the value of 2.950 in the spending direction and 1.388 in the insulating direction.

• Diode effect coefficient (Ed)

It is defined as the ratio between the time average of convective heat transfer coefficient during the day time (spending direction) and the nocturnal period (insulating direction):

$$Ed = \frac{h_{ts}}{h_{ti}} \quad (13)$$

- Coefficient of heat transfer between inside faces and air of the premises:

In order to characterize the convective heat transfer between inside faces and air, we used the classic average correlation:

$$Nu = A(Gr.Pr)^B \quad (14)$$

With: $A=0.11$, $B=0.33$ for (the vertical walls)

$A=0.27$, $B=0.25$ for Roof

$A=0.14$, $B=0.33$ for Floor

The Grashof and Nusselt numbers are respectively defined by:

$$Gr = \beta g \Delta T . L^3 / (T_m \gamma_m^2), \quad (15)$$

$$Nu = h \frac{L}{\lambda_m}$$

Where: L : The width of the Roof and Floor and $L = H$ for the vertical walls.

C. Moisture boundary conditions

The outside and inside mass convection coefficients h_{me} and h_{mi} are assumed to be related by the Lewis' relation (5).

VI. Numerical methods

The numerical method used is the nodal method, the system is divided into several elements, each one is represented by a node placed at its center and affected by the average temperature, relative humidity and specific heat capacity. To limit the number of nodes, we used the method of fictitious node to transcribe the exchange surface. The model is divided into 44 nodes. Each wall contains 7 nodes (4 nodes for the outer wall and 3 nodes for the inner wall). Outside and inside air are respectively represented by one node.

VII. Results and interpretations

A. Time evolution of outside and inside of air temperature and relative humidity during the summer and winter seasons

In view of the different figures (2-6), by comparing the different profiles, during the night period, the temporal variations in relative humidity and temperature are in the same direction. Instead, they are in opposite one during the day time.

Figs. 2a. and 2b. show the temperature and relative humidity of outside and inside air during winter season (December, January and February) and summer season (June, July, August and September). The simulation results show that the inside temperature in the winter can reach 14°C during the nocturnal period and as high as 20°C in the day time. This last increase is mainly due to solar flux variation. Whatever the season is, the minimum humidity is reached in the day time and the maximum in the nocturnal period. The inside relative humidity (fig. 2a) is brought out in the winter season (59% to 84%) and conversely minimum (fig. 2b) in the summer season (30% to 65%) is observed where the temperature is in the range of (32°C to 37°C). This is mainly due to the fact that vapor flows from the inside (high vapor pressure) to the outside surface (low vapor pressure).

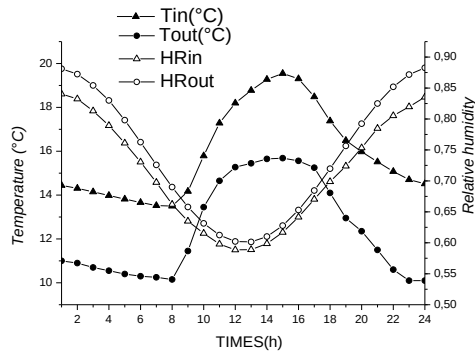


Figure 2a: Winter season

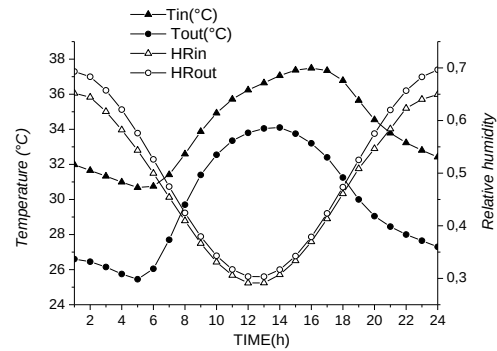


Figure 2b: Summer season

Fig.2 Time evolution of relative humidity and temperature of air during the winter and summer seasons.

B. Time evolution of temperature and relative humidity of inside faces during the summer and winter seasons

B.1 Case of North, South and Roof faces

Figs. 3a. and 3b illustrate that in winter seasons the surface temperature in the south (16°C to 25°C) (fig. 3a) is higher compared to those of the North and the Roof faces. On the contrary the relative humidity in the south (52% to 80%) is minimum and maximum in the North (62% to 85%) and in the Roof (60% to 84%). In the summer season (fig.3b), the temperature in the roof is higher (32.5°C to 41°C) compared to those of the North and the Roof faces while its relative humidity is minimum. Whatever the faces are, we observe that the relative humidity is lowest when the temperature is highest. With regard to midday and during the winter season the difference in amplitude of temperature and relative humidity between faces (North, south and Roof) is important compared to the summer season.

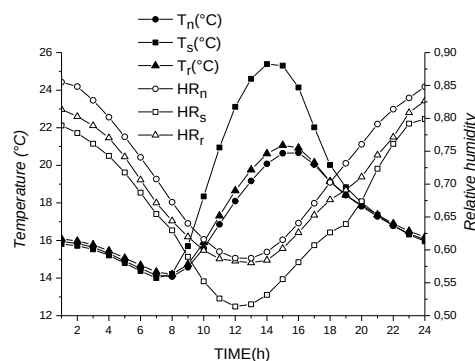


Figure 3a: Winter season

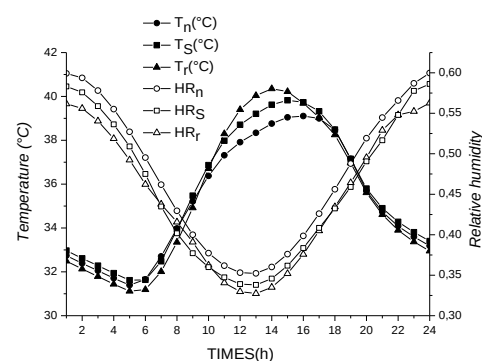


Figure 3b: Summer season

Figure 3 Time evolution of temperature and relative humidity of inside faces during the winter and summer seasons (Nord, Sud and Roof).

B.2 Case of East and West faces

For East and West faces, curves figs. 4a and 4b display the time evolution of temperature and relative humidity of inside faces during the summer and winter seasons. These results are almost similar and consistent with those of M. Doya and al [7] , the temperature profile is related to that of solar flux in each face. For winter season (fig. 4a) the results show that near midday the relative humidity can reach a minimum value of 53% in the East side and 56% in the West side, which respectively corresponds to temperatures (19.5°C, 17.8 C); we also notice that the temperature gradually increases respectively on the East and West sides to (20.7°C, 23.7°C) corresponding to the relative humidity of (62%,58%). During the nocturnal period, the temperature reaches a minimum of

(16°C) and a maximum relative humidity (80%). The increase in temperature depends on solar flux density on the East and West sides[6], hence the decrease of the relative humidity. For the summer season the simulation results show that at midday, for the East side (fig. 4b), the temperature and relative humidity can reach respectively (39.76°C and 32.4%) and on the West side are estimated respectively to reach 37.9°C and 34%. At 16h:00 the difference in temperature between the East and West sides is estimated to reach (3.6°C) and in relative humidity it is (2%), which is lower compared to the winter season; this difference is due to the diode effect.

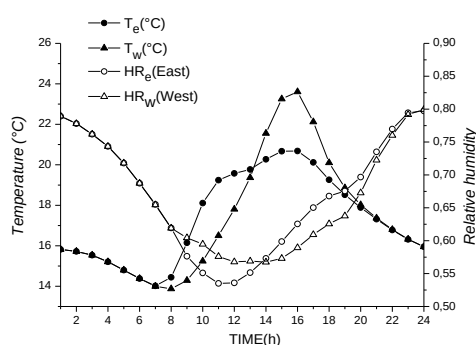


Figure 4a: winter season

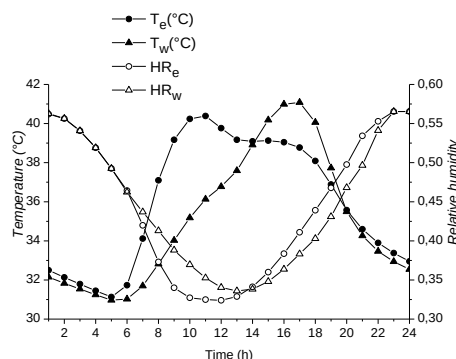


Figure 4b: Summer season

Figure 4 Time evolution of temperature and relative humidity of inside faces during the winter summer seasons (East and West).

C. Annual evolution of relative humidity and temperature of air inside the premises

In case with alveolar structure, fig.5 depict the annual evolution of average relative humidity and temperature of inside air. The average value of relative humidity varies between 43% and 77% while the average temperature varies between 15.6°C and 35°C. The difference in relative humidity and temperature between the outside and inside is estimated to (5%) (fig.5). Fig.6 show the influence of diode effect on annual evolution of relative humidity and temperature of inside air. We notice that during the spring season, the average relative humidity in case with alveolar structure is about 59%, which corresponds to an average temperature of 23.7°C compared to the average relative humidity in case without alveolar structure (fig.6) is estimated to 64% which corresponds to temperature 19°C. During the cold season the average value of temperature and relative humidity can reach respectively 17°C and 77% in case with alveolar structure, whereas the average value of temperature and relative humidity in case without alveolar structure can reach respectively (14°C and 81%) (fig.6). We can conclude that the alveolar structure allows not only maximizing the temperature of the inside air during cold and spring seasons but also limiting the penetration of moisture into the building (as we have shown in (fig.6)).

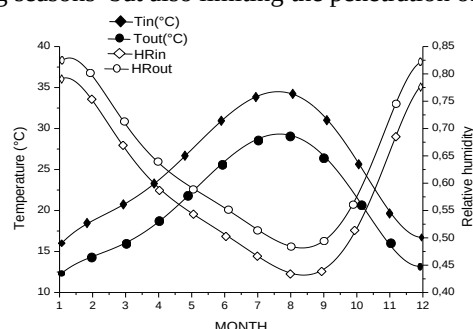


Figure 5: Annual evolution of relative humidity relative and temperature of air inside and of outside of the premise.

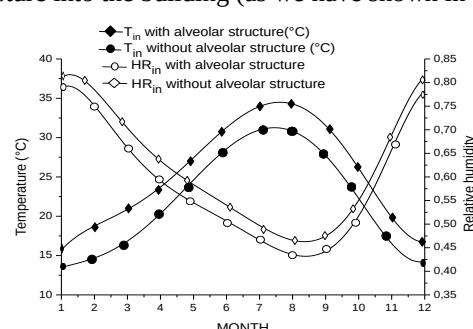


Figure 6: Effect of the alveolar structure on the relative humidity and temperature of air inside of the premise.

VIII. Conclusion

The economic crisis has raised the problematic of saving energy in any building, for that reason taking into consideration the climatic aspect is needed to assess the environmental conditions inside a building. The results of this work show that:

- The influence of climatic conditions on the building internal behavior expressed that the maximum of moisture accumulation is observed in the winter season and conversely the minimum in summer season. This is mainly due to the fact that vapor flows from the inside (high vapor pressure) to the outside surface (low vapor pressure),

-The impact of the orientation of vertical facade on temperature and relative humidity of the inside air proves that the increase in temperature depends on solar flux density on the faces [6], and therefore a decrease of the relative humidity occurs,
 -The inclined alveolar structure can limit the level of relative humidity, especially during the spring and winter seasons .
 Through all the results, we can infer that the orientation and the alveolar structure make it possible to gain energy.

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Nomenclature

T_m	Average temperature $T_m = (T_c + T_f)/2$ (°C)
T_f	Cold wall Temperature (°C)
T_c	Hot wall Temperature (°C)
h	Heat transfer coefficient ($W m^{-2}K^{-1}$)
H	Height of the cavity vertical walls (m)
L	Length for the floor and Roof (m)
HR	Relative humidity(%)
T	Temperature (°C)
In	Inside
Out	Outside
r	Roof
n	North
s	South
e	Est
w	West

Greek symbols

α	Angle of inclination
γ	Cinematic viscosity of air ($m^2 s^{-1}$)
β	Dilatation coefficient (K^{-1})
g	Acceleration of gravity (ms^{-2})
λ	Thermal conductivity of air ($W m^{-1}K^{-1}$)
μ	Dynamic viscosity of air ($kg m^{-1}s^{-1}$)