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Solar chimney for enhancing thermal comfort in individual housing in a semi-humid climate

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Abstract. Nowadays, the rational use of energy resources is placed at the center of our concerns. The use of renewable energy sources such as solar energy, wind, and geothermal energy are very interesting alternatives to meet our needs for comfort inside our homes. In semi-humid climates, natural ventilation is recommended to improve thermal comfort. In this way, natural ventilation using renewable energy without the need for mechanical equipment has gained in importance. A solar chimney is one of this technology that can be used to improve the ventilation of a residential or commercial building and uses the same principle as a chimney. In this study, the effect of the presence of a solar chimney on hygrothermal comfort was evaluated. A simulation will be carried out by EDSL TAS software; to evaluate and compare the effect of natural ventilation on hygrothermal comfort in the winter period of the individual dwelling. Four scenarios are selected; without ventilation, with cross ventilation, and by the integration of the solar chimney. Also varied shapes of canals. The results show that a solar chimney based on the thermal chimney effect can improve natural ventilation.

Keywords. Thermal Comfort ; Ventilation ; Solar Chimney ; Semi Humid

1. Introduction

The concept of sustainable development, introduced in the Brundtland report, has not many applications in contemporary "architecture". All efforts towards "sustainable architecture" in buildings, awarded by certification, usually include the use of high technology and industrial process, which, together with the construction, ensures the desirable hygrothermal comfort, exclusive to a socio-class - economic medium-high.

Passive buildings which are more economical solutions, can be distinguished by particularly high comfort and very low energy consumption. This construction standard is essentially achieved by the using of the following components (triple-glazed window, insulation, double-flow ventilation, etc.). The passive building is comfortable, economical, sustainable and ecological.

The solar chimney is one of the passive systems that provide induced natural ventilation. Since, it has been studied theoretically since 1992 [1]. "A solar chimney is basically divided into two parts: one of the solar boiler (collector) and the other of the

chimney tower (Figure.1). The system should be designed to maximize solar gain, which leads to maximizing the ventilation effect. The critical design parameters are the height, cross-section and temperature difference at the inlet and outlet of the solar heating system [2].

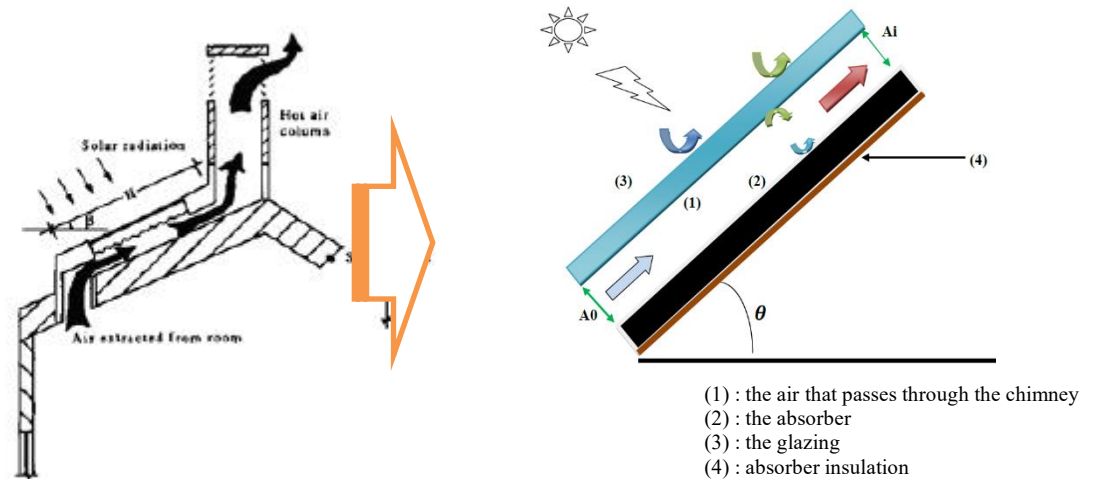


Figure.1 : Description de la cheminé so
(Bansal et al 1993)

Compared to cross-ventilation, unilateral ventilation in buildings is much less effective in this type of climate hot and humide, so these buildings usually require mechanical ventilation in addition to heating and cooling systems to maintain a comfortable indoor climate.[3, 4]. Solar chimneys use solar collectors to heat the exhaust air from a room, increasing its floatability and creating chimney pressure to raise and lower the airflow in the building. The negative pressure created within the zone to promote passive ventilation and free cooling under suitable outdoor conditions.[5, 6]

Three operation modes of the solar chimney, which are suitable for each season [7] are illustrated in figure (2).

- Case of heating: the solar chimney operates in passive heating mode. Outside air is entered into the chimney, and warmed by the absorbed solar energy. The entry of hot air into the room contributes to the reduction of a thermal load.

- Case of cooling with the outside temperature lower than the air temperature in the room: the solar chimney can work in ventilation mode and passive cooling.

- Case of cooling and the outdoor temperature is higher than the indoor temperature: the solar chimney is not used to increase ventilation because the introduction of outdoor air without pre-cooled results in an increase in temperature at inside. As a result, air enters the chimney and escapes out through the top opening. This mode of operation is known as thermal insulation. This latter has an effect of decreasing heat gain in the room through the solar chimney.

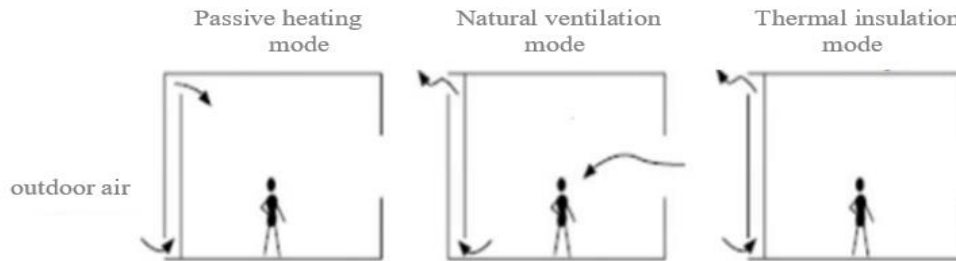


Figure.2: *Operating modes of the solar chimney*

The thermal performance of variously built solar chimneys incorporated with buildings has been extensively studied. The solar chimney has been researched and used in a variety of climatic settings, despite being created for uses in heating and ventilation in a cold climate [8]. The configuration of the chimney, the materials used in construction, and integrated renewable energy sources all affect the thermal performance in terms of volume flow rate, air velocity, and air temperature [2].

Nevertheless, other important factors must be taken into account for the performance of the solar chimney, such as: the angle of inclination [9]; insulation and absorber [10]; number of glazes [11]; mainly wind direction [12]

Many theoretical tests and very few empirical tests have been made, with positive results on the air flow, but it is difficult to find in each test the complete description of the materials, the construction system, the measurements and the results of all assumptions

Numerous topics related to the volume flow rate of solar chimneys with various layouts have been studied. For instance, research in India revealed values of 2.4-5.6 air changes each hour (ACH) for a 0.7–0.9 m² absorber area [11]. A solar chimney in the hot, dry climate of Iraq produced 4-35 ACH with an input velocity of 0.3-0.8 m/s at an angle of 60, aspect ratio of 13.3, and chimney length of 2 m [12].

The solar chimney can be classified according the position as (i) Vertical solar chimney and (ii) Inclined solar chimney.[12][13]

The experimental results according to Zhai et al (2005), show that the optimal tilt angle for natural ventilation is 45°. The optimum angle of inclination of the chimney was 60° to obtain the maximum ventilation rate. At this angle of inclination, the ventilation rate was about 20% higher than at 45°.[14][15]

Maximum air velocity for radiation intensity at 50 mm thick air gap. It was experimentally determined that a large air gap and a black color induced the highest ventilation rate.[15]

Cavity, also known as chimney width or depth of passage, Cavity space, also known as chimney width or channel depth, is the thickness of the roof duct or the distance between the interior wall and the exterior glazing. The performance of both types of solar chimneys is greatly influenced by the space between the cavities. Cavity airflow does not always increase with greater cavity gap. For example, a numerical study [16] indicated that when the width of the cavity increases from 0.15 to 0.75 m, the airflow decreases by 1.9 to 4.7%. This phenomenon is due to the presence of a reverse flow. Since the heating of the air in the cavity depends on convection, the air adjacent to the hot wall is more likely to be heated.

This research focuses on the indoor thermal quality of an individual dwelling in a semi-humid climate in Mila (Algeria) by the effect of natural ventilation with or without the introduction of a solar chimney. The objective of this work is to simulate with ADSL Tas the dynamic and thermal behavior of a solar chimney to improve natural ventilation, thus determining the shape and size of the chimney to be more efficient.

2. Case study

2.1. Climate

Mila is a city located in the North-East of Algeria (figure 3). The climate of the city through the data (Figure.2) is cold humid in winter, hot, and humid in summer (figure 5). It is expressed by intense solar radiation all the year, with very high temperatures in summer and a maximum average of 32.6°C in August. (see figure 4)

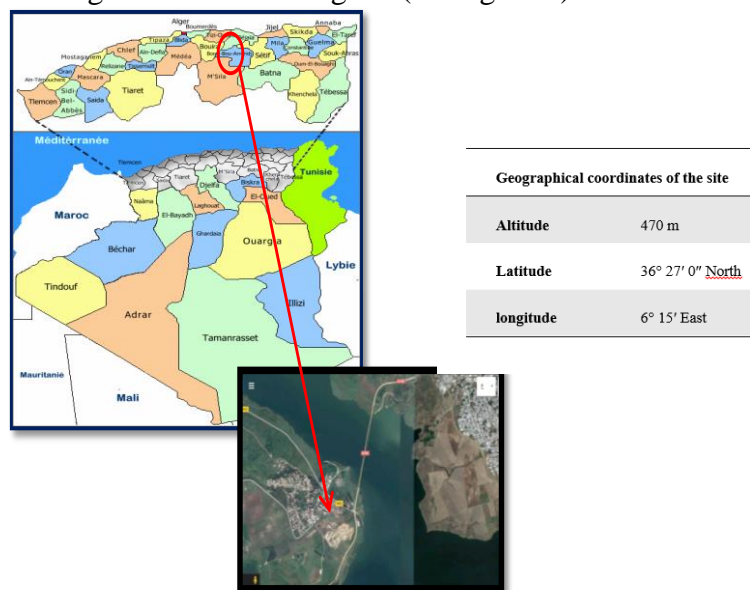


Figure 3 : Situation of the city Mila

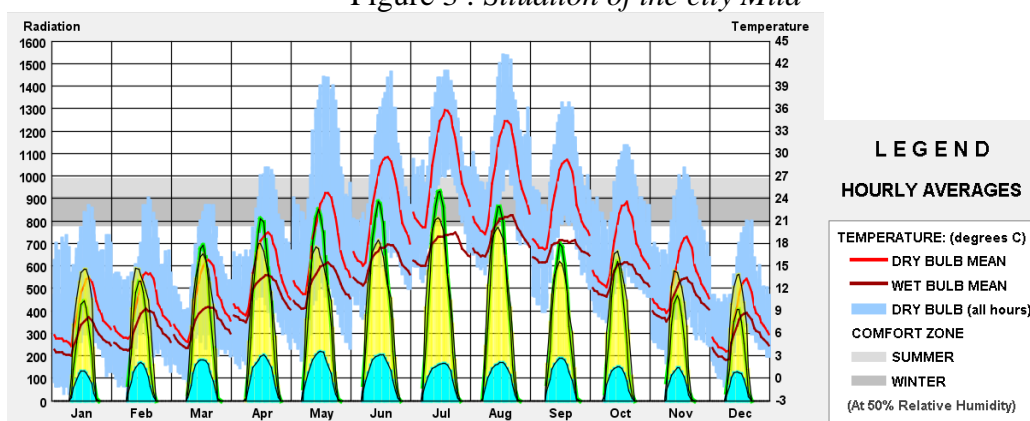
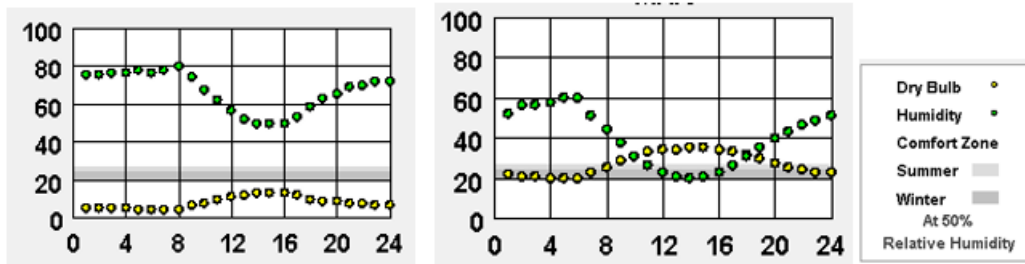


Figure.4 : Monthly diurnal average temperature and radiation at Mila city. Source : climate consultant6



a- Winter period

b- Summer period

Figure.5 : Variation de la température mensuelle et humidité relative a at Mila city.
Source : climate consultant6

High relative humidity, considerable precipitation in winter and almost rare in summer, with a very significant diurnal temperature difference and moderately low winds. Whose site has a semi-humid climate according to the Martonne aridity index: $Im = 22.9$.

2.2. Comfort and Bioclimatic analysis.

The interpretation of the psychrometric diagram of (Figure.6) applied to the city of Mila (Algeria) reveals two distinct periods, a cold period which requires passive heating, a hot period, during which the months of June, July and August that require natural and mechanical ventilation.

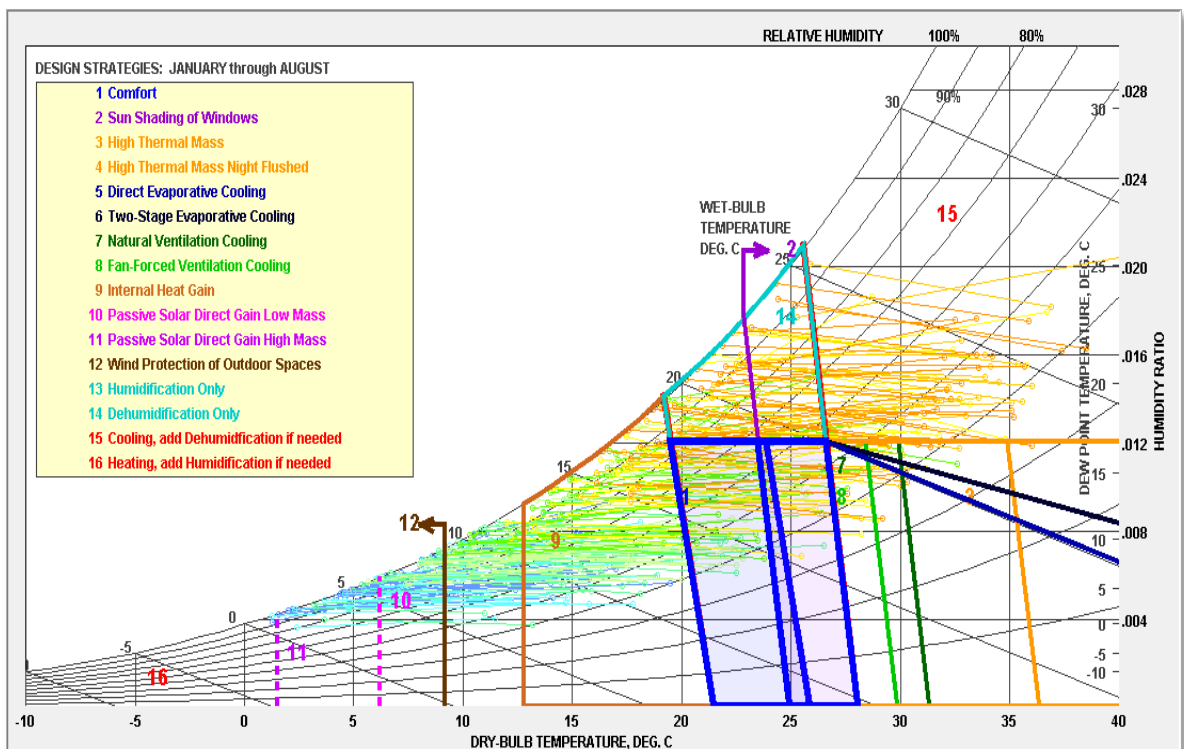


Figure.6: Diagramme Psychrométrique Appliquée à La Ville De Mila, Algérie.
Source :(Climate consultant6.0)

Natural ventilation is recommended for the hot months to ensure coolness in the summer. Also, it is recommended for the cold months to reduce the high humidity in this region. This will be ensured by the use of passive ventilation devices such as the wind tower the Canadian well the presence of green spaces, the orientation of windows to the winds, the orientation of buildings along an EAST-WEST axis.

Passive heating is recommended for most months of the year according to the choice of materials, good penetration of solar radiation.

2.3. Methodology

Our study consists in verifying if the integration of this passive ventilation system (the solar chimney) in the individual dwelling (R+1) is effective to compensate for the hygrothermal comfort in a semi humid climate (Mila, Algeria) during both of periods summer and winter. The following result is obtained from a comparative study of four scenarios:

1. Case of the house without natural ventilation
2. Case of the house with cross ventilation
3. Case of the house with thermal draft by the integration of a solar chimney
4. Case of combination between cross ventilation and thermal draft

Therefore, the research for the optimal shape of the solar chimney by simulating four variants of the angle of inclination of the chimney: vertical at 90°, inclined to 60°, 45° and 30° (figure 13).

The solar chimney integrated in the home (Table.1) facing south (Figure.7 & 8); the sunniest side of the construction, with an inclination of 30° according to the results of the researchers [4,6,7] it consists of (i) a dark absorber (ii) an air gap (iii) The transparent cover (glass) (iv) the air inlets:

- **a dark absorber** : in galvanized steel because it is available and resists corrosion in a humid environment.

- **an air gap** : which is 65 cm thick, it is located between the glass and the absorber acts as an insulator with respect to the transmission of heat by conduction.


- **The transparent cover (glass)**: Can be used because it allows the maximum solar radiation to pass through and avoids the cooling of the absorber, reducing the phenomena of air convection and creating greenhouse effect, the most used material of which is glass.

- **the air inlets**: have a dimension of 0.4m and they are placed at the top so that they can evacuate the hot air which rises at the top towards the outside.

Table1: Characteristics of the house

Typology	house R+1
surface	120m ²
Opaque materials	Cellular concrete block
Transparent materials	Double glazing

Table 2: the physical characteristics of the cellular concrete

the cellular concrete blocks used	the characteristic tensile strength	12% compressive strength.
	The characteristic tensile strength by bending	22% compressive strength.
	moisture content	+/- 23% in volume
	Volumic mass	450 kg/m ³
	The expansion coefficient	8.10-6 m/mK
	Thermal conductivity	0,12 W/m.K

3. Results and discussion

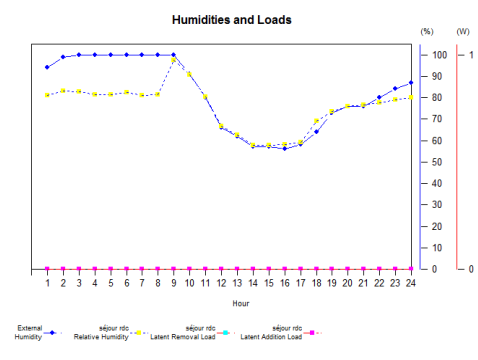
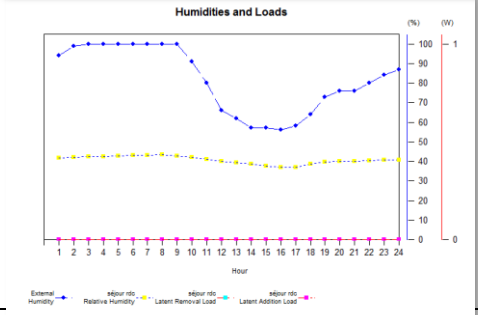
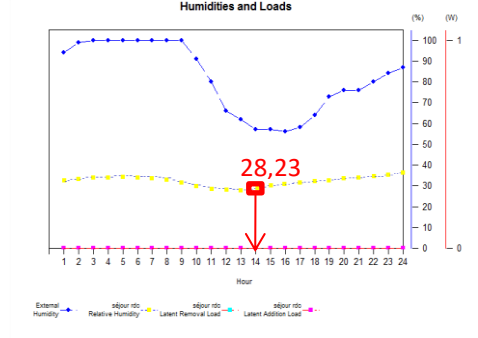
In order to quantify the impact of natural ventilation on hygrothermal comfort, it is essential to compare the results obtained by each simulation.

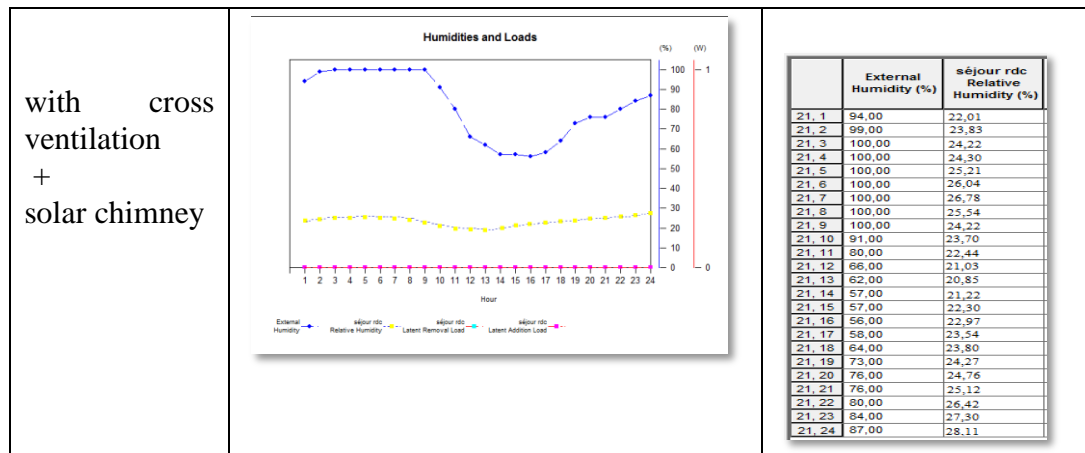
The Humidity rate ranging from 57.71 to 97.56% due to the absence of natural ventilation by closing all the windows and doors of the house and the absence of the solar chimney (Table 3)

A humidity rate that ranges between (39.45 and 43.38%) therefore the cross ventilation could show its effectiveness to bring a hygrothermal comfort by reducing the humidity rate of the living room of 17% at 14:00h

With integrating the cross ventilation and solar chimney, the results show a decrease in humidity up to 20.85%. Witch explane that the chimney is receiving maximum solar gain the temperature in the chimney is too high due to the effect of thermal draught.

Table 3: value of air humidity in different cases

Case	Humidity value	Result simulation																																																																											
without ventilation and without chimney		<table border="1"> <thead> <tr> <th></th> <th>External Humidity (%)</th> <th>séjour rdc Relative Humidity (%)</th> </tr> </thead> <tbody> <tr><td>21_1</td><td>94,00</td><td>80,89</td></tr> <tr><td>21_2</td><td>99,00</td><td>83,04</td></tr> <tr><td>21_3</td><td>100,00</td><td>82,81</td></tr> <tr><td>21_4</td><td>100,00</td><td>81,54</td></tr> <tr><td>21_5</td><td>100,00</td><td>81,33</td></tr> <tr><td>21_6</td><td>100,00</td><td>82,29</td></tr> <tr><td>21_7</td><td>100,00</td><td>80,98</td></tr> <tr><td>21_8</td><td>100,00</td><td>81,48</td></tr> <tr><td>21_9</td><td>100,00</td><td>87,56</td></tr> <tr><td>21_10</td><td>91,00</td><td>90,56</td></tr> <tr><td>21_11</td><td>80,00</td><td>80,34</td></tr> <tr><td>21_12</td><td>66,00</td><td>66,61</td></tr> <tr><td>21_13</td><td>62,00</td><td>62,63</td></tr> <tr><td>21_14</td><td>57,00</td><td>57,71</td></tr> <tr><td>21_15</td><td>57,00</td><td>57,85</td></tr> <tr><td>21_16</td><td>56,00</td><td>58,19</td></tr> <tr><td>21_17</td><td>58,00</td><td>59,09</td></tr> <tr><td>21_18</td><td>64,00</td><td>68,93</td></tr> <tr><td>21_19</td><td>73,00</td><td>73,49</td></tr> <tr><td>21_20</td><td>76,00</td><td>75,92</td></tr> <tr><td>21_21</td><td>76,00</td><td>76,55</td></tr> <tr><td>21_22</td><td>80,00</td><td>77,65</td></tr> <tr><td>21_23</td><td>84,00</td><td>78,90</td></tr> <tr><td>21_24</td><td>87,00</td><td>80,12</td></tr> </tbody> </table>		External Humidity (%)	séjour rdc Relative Humidity (%)	21_1	94,00	80,89	21_2	99,00	83,04	21_3	100,00	82,81	21_4	100,00	81,54	21_5	100,00	81,33	21_6	100,00	82,29	21_7	100,00	80,98	21_8	100,00	81,48	21_9	100,00	87,56	21_10	91,00	90,56	21_11	80,00	80,34	21_12	66,00	66,61	21_13	62,00	62,63	21_14	57,00	57,71	21_15	57,00	57,85	21_16	56,00	58,19	21_17	58,00	59,09	21_18	64,00	68,93	21_19	73,00	73,49	21_20	76,00	75,92	21_21	76,00	76,55	21_22	80,00	77,65	21_23	84,00	78,90	21_24	87,00	80,12
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21_7	100,00	34,86																																																																											
21_8	100,00	33,14																																																																											
21_9	100,00	32,56																																																																											
21_10	91,00	31,42																																																																											
21_11	80,00	31,12																																																																											
21_12	66,00	30,22																																																																											
21_13	62,00	29,52																																																																											
21_14	57,00	28,23																																																																											
21_15	57,00	29,62																																																																											
21_16	56,00	30,14																																																																											
21_17	58,00	31,56																																																																											
21_18	64,00	32,21																																																																											
21_19	73,00	33,66																																																																											
21_20	76,00	34,82																																																																											
21_21	76,00	35,22																																																																											
21_22	80,00	35,77																																																																											
21_23	84,00	36,58																																																																											
21_24	87,00	36,4																																																																											



Air temperature values in the simulated at the outlet mouth of the chimney. The canal of chimney receives the maximum solar gain which made the temperature too high, a difference about 15,66°C (figure 9) at maximum gain between external and in the chimney which give the thermal draft to the interior space. Therefore chimney can participate in the heating of interior and give comfort condition.

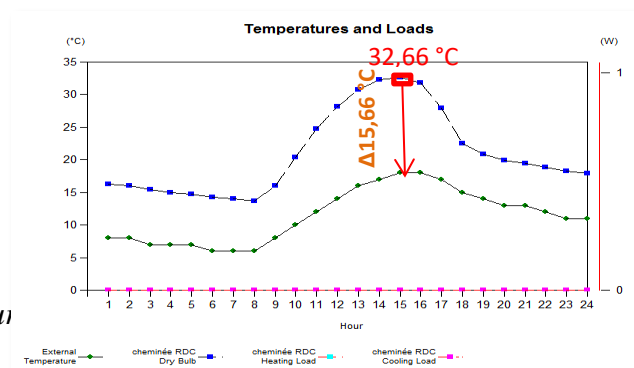


Figure 9: Air temperature

the chimney

The comparison of the results clearly shows that the humidity values in the 1st case are too high. Which varies between 57.71 and 82.29%. Then the values are reduced to 40.15% at 2 p.m. with a difference of 20% in the second case of cross ventilation, the decrease in values in the living room between the cases with and without natural ventilation, demonstrates the cooling effect of the latter by ensuring a suitable humidity level in the house. (Figure 10)

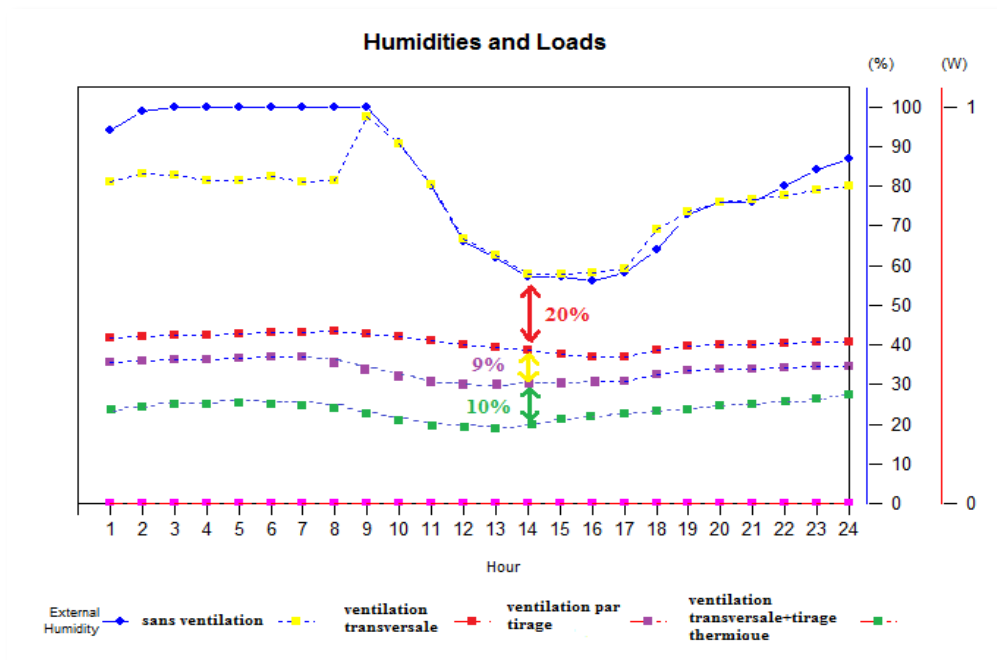


Figure.10: Comparison of simulated relative humidity values between the different cases [Winter period]

The results (figure 11) show that the differences are a little greater with ventilation by thermal draft than by transverse ventilation; this is due to several parameters, which act on the two cases of ventilation. The air movements by cross ventilation are created by the differences in pressure due to the wind between the facades, on the other hand the chimney effect (thermal draft) is due to the difference in density between the hot air and the cold air. The latter favored by the specificity of the envelope of the solar chimney [9,11], the fresh air enters through the openings of the north facade, and the hot air exits through the upper openings of the chimney. So the flow rates reached are much higher than in the case of cross ventilation, The stratification is more accentuated at 1:00 p.m. when the minimum values of relative humidity are recorded because during this hour, the sun is practically vertical and the solar chimney tilted receives the maximum of the daily gains by solar radiation [8,9,17].

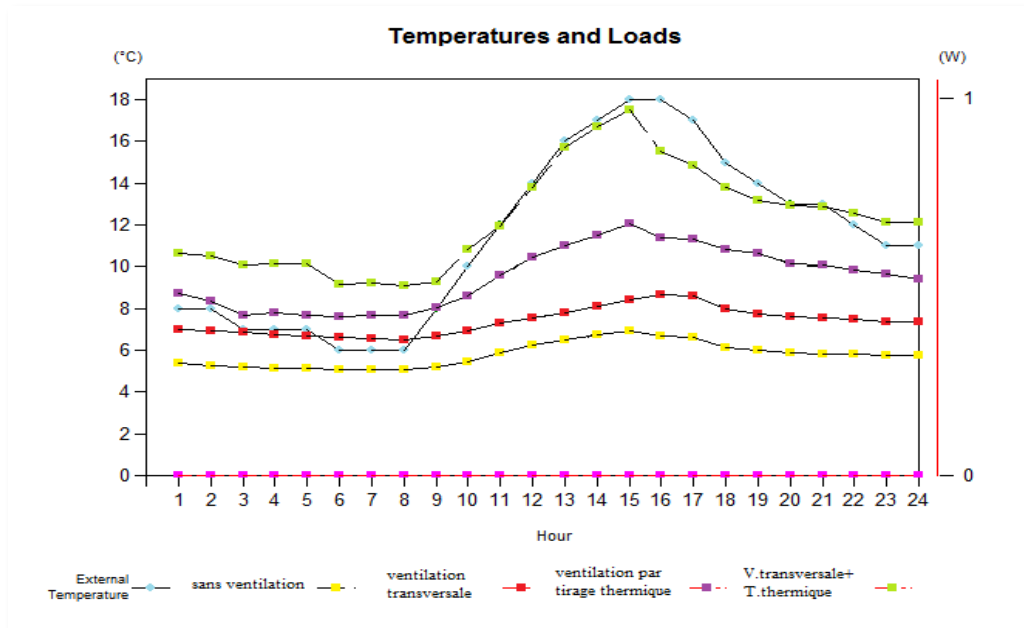


Figure.11: Comparison of simulated temperature values between the different cases [Winter period]

The latter favored by the specificity of the envelope of the solar chimney [11], the fresh air enters through the openings of the north facade, and the hot air exits through the upper openings of the chimney. So the flow rates reached are much higher than in the case of cross ventilation, The stratification is more accentuated at 1:00 p.m. when the minimum values of relative humidity are recorded because during this hour, the sun is practically vertical and the solar chimney tilted receives the maximum of the daily gains by solar radiation [17].

The angle of inclination of a solar chimney generally represents the angle between the cavity of the chimney and the horizontal. The tilt angle for a wall-type solar chimney is 90°. The majority of previous studies have obtained an optimal tilt angle of 45° [7, 14, 18, 19, 20, 21].

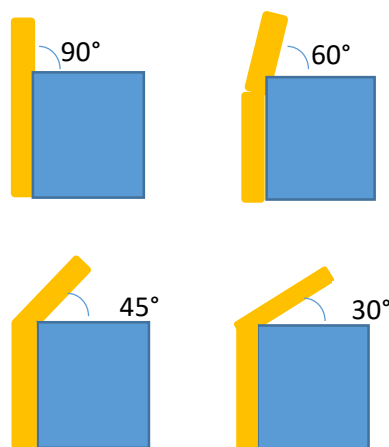


Figure.12 : The angle of inclination of a solar chimney select for simulation

The results (Figure 13) confirm that the optimal tilt angle is about 45° and 30° compared to a vertical chimney (90°) and 60° [14,15]. This can be explained by the lower pressure loss. The optimum angle should be considered with a balance between chimney pressure and convective heat transfer. For this reason, for a solar chimney at a specific location, the optimum angle of inclination is higher than the angle receiving the maximum solar radiation.

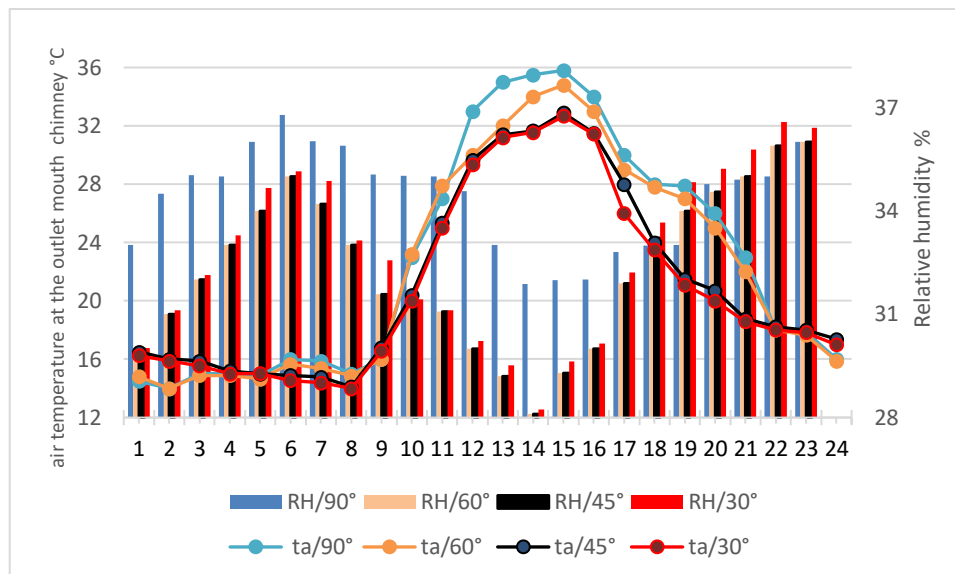


Figure.13 : Comparison of simulated relative humidity and air temperature values with different solar chimney angle of inclination

4. Conclusion

The use of a solar chimney makes it possible to benefit from ventilation and passive cooling of dwellings, thus reducing energy consumption. In order to improve natural ventilation, the dynamic and the thermal behavior of a solar chimney has been evaluated over this investigation.

To achieve this aim, a numerical simulation by the EDSL TAS software in a room equipped with a solar chimney was carried out.

The results of the simulation show that ventilation by thermal draft is effective in combating high humidity, especially during the winter period. This affirms our hypothesis: The integration of a solar chimney in the individual dwelling can create the thermal draft effect which evacuates the hot air and allows the aspiration of the fresh air, this aspiration can be used for: ventilate houses and reduce high humidity in a semi-humid climate. Optimal tilt angle is about 30° to 45° for a good pressure lower humidity and procure passive heating of spaces.

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