Experimental study for the investigation of thermal comfort and controlled habitat

A.ALAMI[1*], A.ALLALI[2], BELBACHIR S[2], B.BOUCHAM [3]

[1*]*Djillali Liabes University of Sidi Bel Abbes, Laboratory of materials and reactive systems LMSR, BP 89, Cité Ben M'Hidi Sidi Bel Abbes, 22000 – ALGERIA, Faculty of Technology.*
[2] *Laboratory of applied mechanics, Faculty of Mechanical Engineering, University of sciences and technology of Oran (USTO), B.P. 1505, Oran El M'Naouer, 31000, Oran, Algeria*
[3] *Laboratory of Mechanics of Structures and Solids (LMSS), Faculty of Technology -Department of Mechanical Engineering, University of Sidi Bel Abbes ALGERIA, BP 89 Cité Ben M'Hidi, Sidi Bel Abbès 22000, Algeria*

ABSTRACT: *Thermal comfort, has been defined as the state of satisfaction with the thermal environment established by heat exchange between the body and its environment, it is designed as a dynamic adaptive process that integrates the different physical, physiological and psychological mechanisms. This increased demand can only be met by optimizing air conditioning and heating systems, knowing all the loads that affect their function in relation to time. To this end, it is essential to know the behaviour of the air blown indoors and these main factors such as (temperature, humidity, jet speed,...etc). Our work is based on an experimental and numerical study carried out using a prototype air handling unit (T110D) and undergoes treatments that apply to the air sucked before blowing into the test chamber to ensure thermal comfort. A numerical simulation with Gambit-Fluent was performed to validate the experimental and visualize the air behaviour in the test chamber in order to evaluate the thermal comfort and obtain the lowest possible energy consumption. The numerical simulation gives us results closer to those found by experience and shows that the use of CTA T110D allows us to ensure a better thermal comfort for the habitat.*

KEYWORDS: *Thermal comfort, Air handlingunit, relative humidity, Temperature.*

I. INTRODUCTION

The building sector is the largest consumer of energy. A large part of this consumption comes from heating and air conditioning systems that ensure an indoor temperature according to comfort conditions. Algeria is experiencing an acute housing crisis whose thermal comfort does not seem to be the most important factor.

major concern of the designers. In four decades of independence, the urban and architectural landscape of Algerian urban areas has undergone an unprecedented change; no city or village has escaped this constructive model (collective housing). This phenomenon is characterized by a high demand where quantity has taken over from quality. This type of collective housing causes the problem of climate integration, which involves considerable energy consumption. The energy crisis has sharply highlighted the importance of the volume of fuel used for heating and cooling, because of this consumption, which affects the operating costs of buildings and also the country's economy as a whole[1].

In order to understand theoretical concepts and verify the criteria for thermal comfort in habitats. We did several air treatment experiments. These tests are carried out in a T110D air handling and air conditioning unit and using the existing measuring instruments in the laboratory, from which all the necessary quantities such as temperature, relative humidity, air velocity, pressure, etc. have been measured.

This work is carried out by a numerical study using a Gambit-Fluent simulation tool, which is based on the conservation equations solved by the finite volume method. The behaviour of the air diffused in a test chamber was also studied.

II. NOTIONS OF THERMAL COMFORT

The notion of thermal comfort refers to the set of multiple interactions between the occupant and his environment where the individual is considered as an element of the thermal system[2], to define it we associate several parameters, including[3]:

The physical parameter: man is represented as a thermal machine and its interactions with the environment are considered in terms of heat exchange.

The psychological parameter: It concerns the sensations of comfort experienced by man and the qualification of interior environments.

A satisfactory definition of thermal comfort must be able to integrate all these parameters, but many of the definitions put forward so far characterize the problem in the light of only one of these parameters, for example: Physiological aspect: "The conditions for which the body's self-regulatory mechanisms are a minimum level of activity"[4]

Sensory aspect: "A state of mind expressing the satisfaction of one's environment.

The individual cannot say whether he wants to be colder or warmer"[5].

Psychological and sensory aspects: "Feeling of total physical and mental well-being"[6]. Consequently, the subjective nature of the notion of thermal comfort is highlighted by all these definitions. According to Hoffmann, J. B[7], the most classic definition of thermal comfort is none other than an absence of discomfort.

To deepen this notion of thermal comfort, we will discuss in the following, the parameters affecting thermal comfort, the static approach to comfort through the phenomena of thermoregulation (physiological basis) and heat exchange (physical basis) of the human body with its external environment. Finally, we will discuss the adaptive approach of man with his environment.

The air inside buildings is usually extremely airtight and highly controlled, but may still have inadequate ventilation. The control system must regulate temperature and relative humidity (RH), air flow and dust concentration. The air flow rate in the air conditioning system must change due to changes in temperature and relative humidity (RH) between summer and winter.

The humidity parameters contain the humidity ratio (W) (or the moisture content or mixing ratio) of a given humid air sample is defined as the ratio of the mass of water vapour to the mass of dry air contained in the sample [8]:

$$W = Mw / Mda \qquad (1)$$

The moisture content (W) is equal to the mole ratio of fraction Xw / Xda multiplied by the ratio of mass molecules, namely 18.01528 / 28.9645 = 0.62198:

$$W = 0.62198 Xw / Xda \qquad (2)$$

The relative humidity Φ is the ratio of the mole fraction of water vapour Xw in a given humid air sample the molar fraction Xws in a saturated air sample at the same temperature and pressure:

$$\Phi = (Xw/Xws)\ t.p \qquad (3)$$

II.1. Factors related to the person's condition

Metabolism is related to the functioning and particular activity of the person. Human temperature is maintained at around 37.8°C regardless of outdoor conditions. Several methods have been proposed by ISO 8996[AFNOR, 1990] to determine metabolism. Three levels are classified according to the degree of precision [9] : The first level is classified by type of activity and profession. The second level corresponds to an estimate by activity components. At the 3rd level, the metabolism is determined by direct measurement [9].

II.2. Thermal comfort index

A)- Predicted Mean Vote (PMV) indices:

This index represents the average opinion of a group of people expressing a vote of thermal comfort feeling. A negative VMS value means that a majority of occupants are rather cold and a positive value indicates that they are hot (Figure 1).

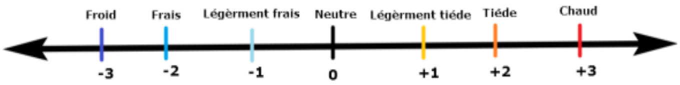


Fig. 1. Representation of index of PMV

B)- PPD indices (expected percentage of dissatisfied):

It is the percentage of people who are dissatisfied with a situation. It is based on the PMV index. The figure below shows the relationship between the PMV and PPD indices..

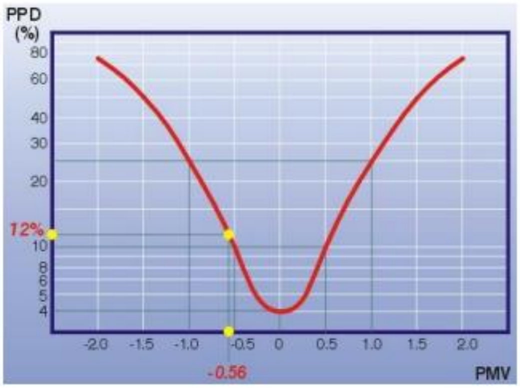


Fig. 2. PPD index representation [10]

For the neutral situation (PMV=0), the dissatisfaction rate is 4% among the occupants. On the other hand, for the situation in which the VMP is -0.56, the dissatisfaction rate is 12%. It can be concluded that the PPD increases in the same way if the VMP deviates from 0 to cold and warm and it is impossible to find a situation where the percentage of dissatisfied is 0%.

III. EXPERIMENTAL DEVICE

III.1 Description

The T110D air conditioning and air conditioning study unit presented in Figure 1 has been prepared to be included in the more advanced didactic themes.

III.2. The operating principle

An air flow produced by a centrifugal fan enters a tunnel where it undergoes a series of treatments, and arrives in a final chamber that represents the room to be cooled. Indeed the final chamber which represents the room that we want to air-condition.

III.2. Composition

1. - Variable speed centrifugal fan, 0÷2000 rpm
2. - Small boiler for steam production, 2 kg/h
3. - Steam diffuser group
4. - Evaporator and condenser with R22/air
5. - Hermetic type compressor, 750 W
6. - Filter drier
7. - Thermostatic expansion valve

8. - Heating element group with adjustable power with continuity up to 3 kW
9. - Group of water sprinklers fed by a pump and calibrated 2-litre container
10. - 2 rooms with visualization and inspection window
11. - Plastic test chamber with a volume of 0.5m3.
12. The unit includes the following instruments and controls:
13. - N. 2 digital temperature indicators and 2 selectors
14. - N. 3 psychrometers composed by dry bulb and wet bulb meters
15. - N. 4 thermo resistors Pt100
16. - 2 Ammeters
17. - Low pressure gauge 15 bar
18. - High pressure gauge 35 bar
19. - Micro differential pressure gauge
20. - Calibrated diaphragm
21. - Adjustable pressure switch
22. - Electronic thermostat 0÷99,9°C

III.4. Weight and dimensions

- Dimensions: 2450 x 480 x 1400 h mm
- Weight: 230 kg

Fig. 3. Air handling unit CTA T110D

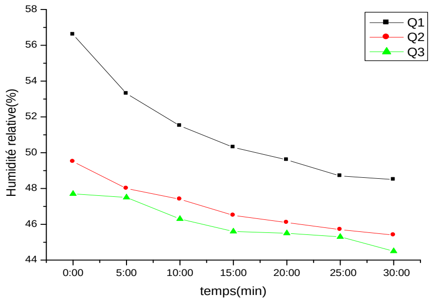
IV. OPERATIONAL MODE

The air taken from the reactor stream is heated not by burning kerosene, but by compressing the air (due to the reactor geometry) in the high pressure stages. The same conditions such as temperature and equivalent pressure are applied to our AHU in order to undergo treatment at the level after the tunnel and then injected into the test chamber which plays the role of the aircraft inside in order to have a thermal behaviour in the chamber such as,

humidity, temperature and blowing speed in unsteady conditions.
1- With three different jet flows, with heating power corresponding to 8A, which gives us a blowing temperature of 24°C. We look for the flow rate that gives us the desired blowing temperature.

Q1=22.8 m3/h ; V1=0.50 m/s
Q1=42.4m3/h ; V1=0.93 m/s
Q2=73m3/h ; V1=1.61 m/s

2- The three flows are taken for temperature differences using thermo hygrometers and thermocouples placed inside the chamber at the vertical symmetry plane in the coordinate points along the jet direction axis (ox)..



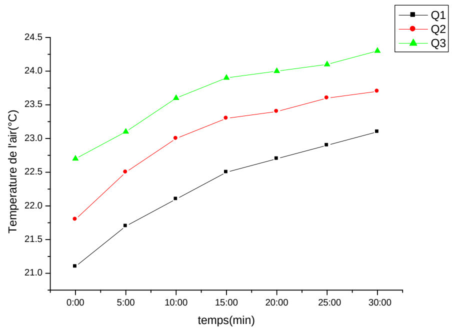


Fig. 4. Variation in the temperature of the interiorair in non stationary mode

Fig. 5. Variation of the relative humidity of theinterior ai r in non stationary mode

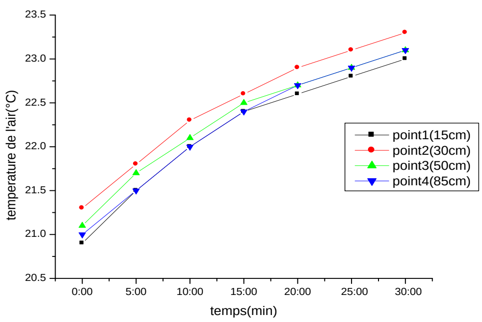


Fig. 6 The temperature distribution in the test chamber in unsteady mode

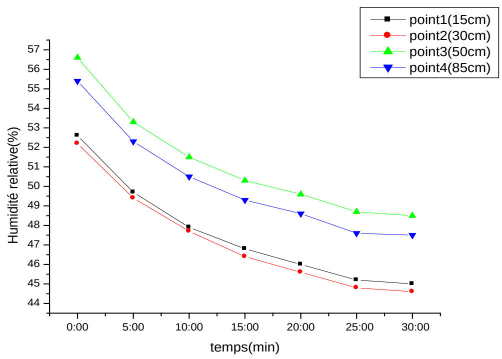


Fig. 7 The distribution of relative humidity in the test chamber under unsteady conditions

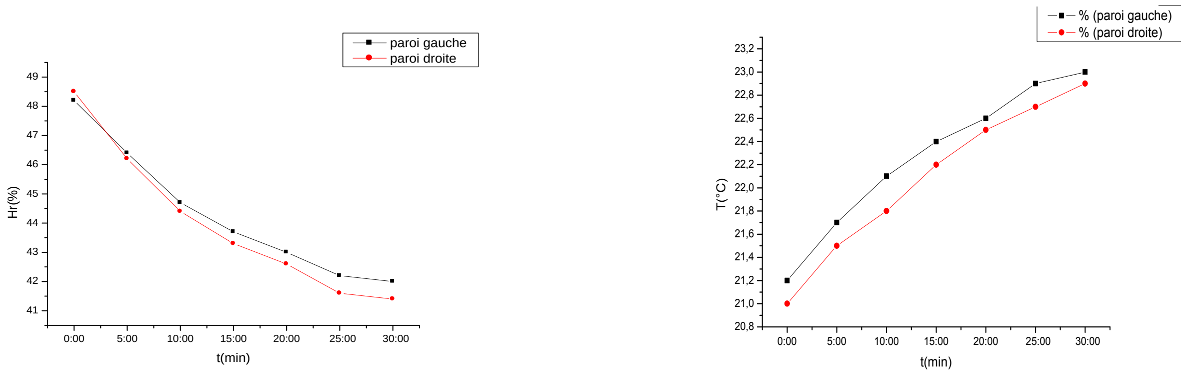


Fig. 8 The temperature and humidity distribution adjacent to the left and right walls

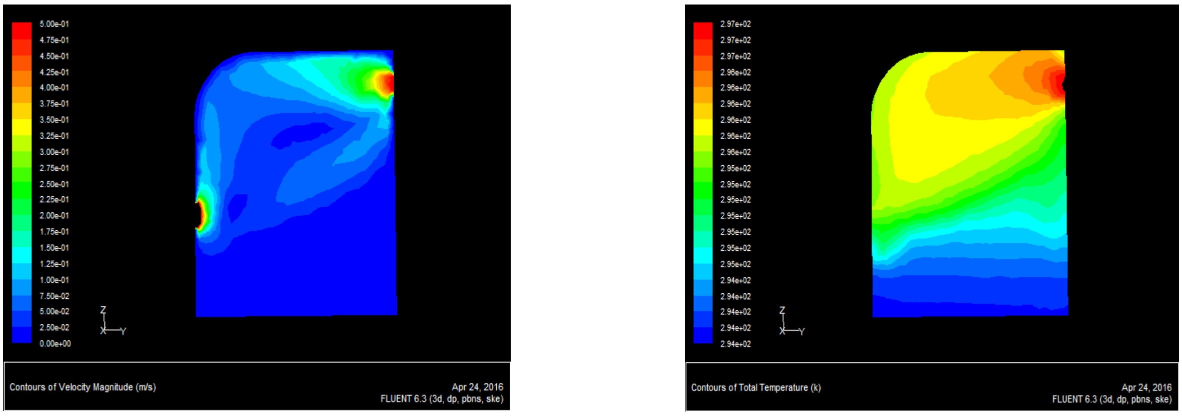


Fig. 9. Velocity and temperature contours for a flow rate of 22.68 m^3/h

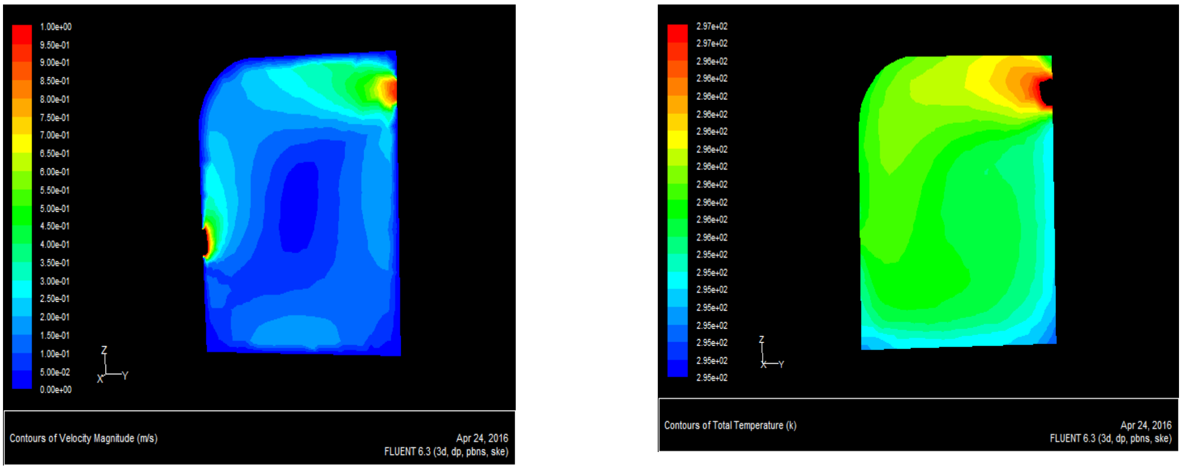


Fig. 10. Velocity and temperature contours for a flow rate of 42.4 m^3/h

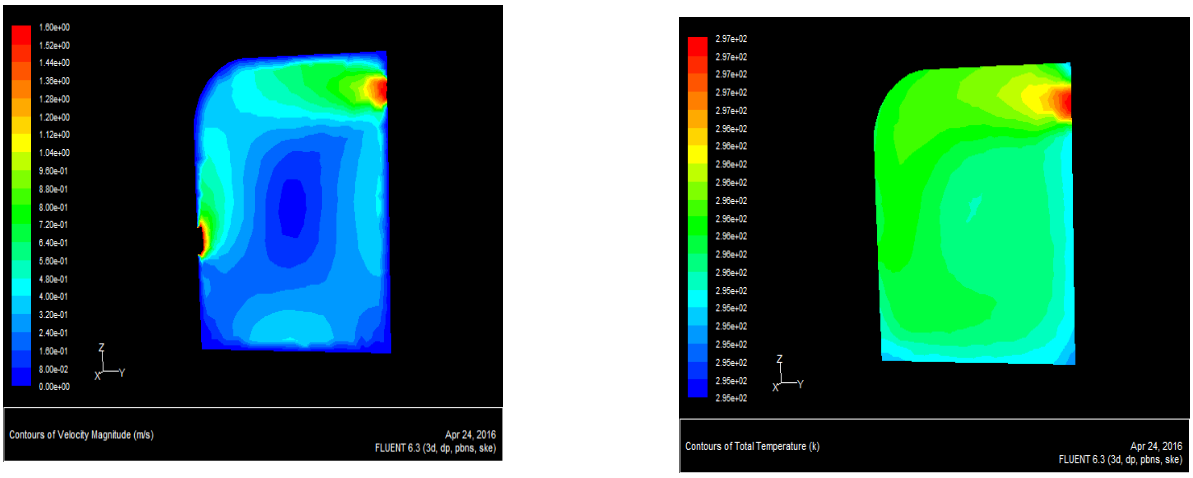


Fig. 11. Les Contours de vitesses et de températures pour un débit 73 m^3/h

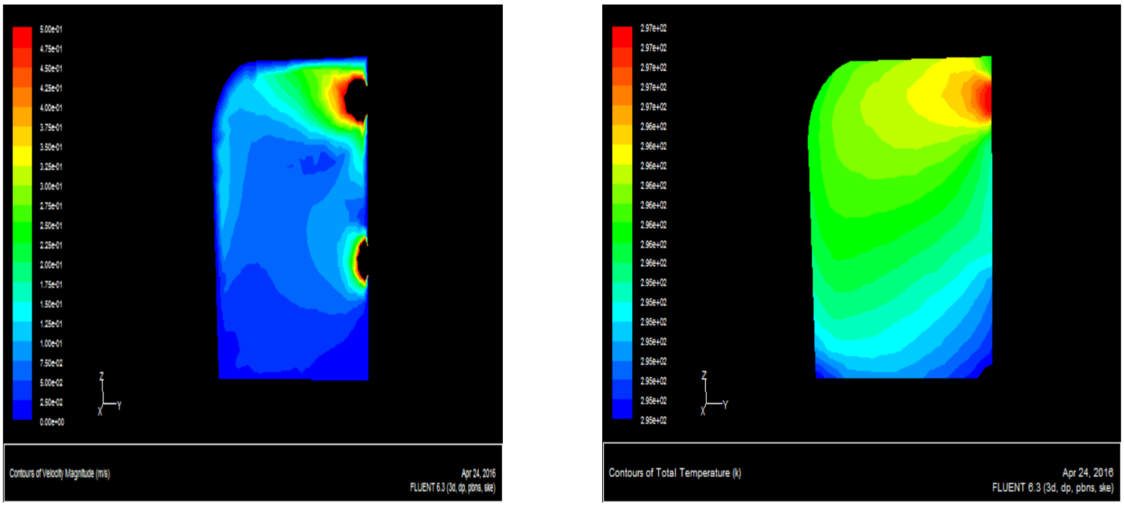


Fig. 12. The velocity and temperature contours for a flow rate of 42.4m^3/h (extraction and blowing on the same side

V. RESULTS AND DISCUSSIONS

According to the results found:

1- It can be seen that for high flow rates the desired temperature is reached in a short time. (Figure 4-5). This result is important for means of transport where it is necessary to obtain desired temperatures for the shortest possible periods of time. Moreover, the significant variation over time is a factor of discomfort, it must be avoided.

2- Inside the test chamber, it can be seen that the temperature of the far points of the jet nozzle is lower than the temperature in the near points (Figure 6-7). The nearest point of jet nozzle is located below the level of this nozzle so the temperature in this point is lower than that of the other points. Temperature deviations for all flows are acceptable because they are lower than the standard value in the case of heating.

3- From Figure 8, it can be seen that the temperature and relative humidity values at the level of the two walls are almost the same, due to the symmetry between these points with respect to the vertical symmetry plane. Also the values of the temperatures and relative humidity in
both walls are acceptable for low speeds.
On the other hand, the relative humidity is not significantly variable over time for high flows, which is not the case for low flows where more significant variations have been observed.

Air supply and exhaust on different sides (Figure 9-10-11)

- For low flows, the temperature differences in the chamber are large, but the speeds are low throughout the chamber, and there are also points that no longer receive hot air.

- For high flow rates, the air speed in the occupancy area is very important and undesirable, but the temperature is uniform throughout the room.

- For this type of heating, the air temperature is always higher than the wall temperature.

Case of air supply and exhaust on the same sides (Figure 12)

- The temperature and velocity distributions are the two uniforms in the chamber.

V.1. EVALUATION OF THERMAL COMFORT IN THE TEST CHAMBER

It is proposed that for people seated with standard winter clothing be: M=1m and H=1clo
These results are taken after stabilization so that the regime is stationary.

The calculation of the comfort indices is completed by software developed in accordance with the international standard ISO 7730.

a. **For** V_{jet}=0.93 m/s

Table. 1. calculation of comfort level for the V_{jet}=0.93m/s

Distance	0.15	0.3	0.5	0.85	P_{gauche}	P_{droite}
T (°C)	22.8	23.1	22.9	22.9	22.7	22.8
Top (°C)	/	/	/	/	22.7	
Hr (%)	45.2	44.8	48.7	47.6	42.2	41.6
V (m/s)	0.2	0.15	0.1	0.14	0.04	0.04
PMV	-0.34	-0.17	-0.13	-0.21	-0.11	-0.16
PPD(%)	7	6	5	6	5	6

b. **For** V_{jet}=1.61m/s

Table2. calculation of comfort level for theV_{jet}=1.61m/s

Distance	0.15	0.3	0.5	0.85	P_{gauche}	P_{droite}
T (°C)	22.9	23.1	23	22.9	22.8	23
Top (°C)	/	/	/	/	22.9	
Hr (%)	43.4	42.9	47.7	45.9	39.7	40.2
V (m/s)	0.45	0.36	0.18	0.30	0.07	0.07
PMV	-0.68	-0.49	-0.14	-0.5	-0.1	-0.24
PPD(%)	15	9	5	10	5	6

c. **For** V_{jet}=2.14m/s

Table.3. Calculation of comfort level for theV_{jet}=2.14m/s

Distance	0.15	0.3	0.5	0.85	P_{gauche}	P_{droite}
T (°C)	23	23.3	23.1	23	22.9	23.1
Top (°C)	/	/	/	/	23	
Hr (%)	45.2	44.8	48.7	47.6	42.2	41.6
V (m/s)	0.68	0.46	0.34	0.48	0.11	0.16
PMV	-0.77	-0.56	-0.49	-0.6	-0.16	-0.23
PPD(%)	18	11	10	12	6	6

VI.2.Comments:

- We can see that the first flow rate shows the comfort flow rate since the percentage of dissatisfaction with the ambient air is pleasant in all points by the standard.

- This flow rate is found for a chamber of 0.5 m3 volume. To generalize our study, we calculated the rate as the brewing rate. The values found for this

- experience are as follows: Q=43m3/h ;V=0.5m3 which implies =88

- It was also found that at the points on the side (left and right) that the comfort points are for all flows, because they are not directly affected by the air. One needs it in the means of transport where all people are located in its points.

VI. CONCLUSION

Based on the experimental and theoretical study using a Gambit-Fluent simulation tool, it was possible to study the movement of air inside a room to be air-conditioned, and to evaluate the thermal comfort indices. The results obtained allow us to know the flow rate that can ensure thermal comfort in the chamber.

The behaviour of the air in the chamber is influenced by several factors such as jet flow rate, jet mouth shape, jet handling...etc.

Numerical simulation gives us results closer to those found by experience, which gives us the importance of simulation tools that provide information without having to carry out experiments that are expensive and difficult to carry out in some cases in air transport.

Bibliographic reference

[1] Esteban Emilio Montenegro Iturra .« Impact de la configuration des bâtiments scolaires sur leur performance lumineuse, thermique et énergétique. » Thèse de doctorat Faculté des études supérieures de l'Université Laval. Canada .2011. p164

[2] Cantin, R. et al. « Complexité du confort thermique dans les bâtiments » in actes du 6ème congrès européen de science des systèmes, tenu à Paris du 19 au 22 septembre 2005.

[3] K.Parson. “Human thermal environments”. London : 2nd édition, 2003 cite in Thellier, F. « Modélisation du comportement thermique de l’homme et de son habitat, une approche de l’étude du confort », étude réalisée à l’université Paul Sabatier de Toulouse, France. 1989. Pages 163

[4] Givoni B., « L’homme, l’architecture et le climat » Editions du Moniteur, France. 1978. p39.

[5] ISO 7730. « Ambiances thermiques modérées – Détermination des indices PMV et PPD et spécification des conditions de confort » AFNOR, Paris. 1994

[6] l’European Passive Solar Handbook. cite in

[7] Hoffmann J. B. « ambiances climatisées et confort thermique » les actes du C.O.S.T.I.C .P110

[8] Ayad T. Mustafa. Experimental study of air flow rate effects on humidification parameters with preheating and dehumidification process changing ARPN Journal of Engineering and Applied Sciences 2011

[9] B. Moujalled, Modélisation dynamique du confort thermique dans les bâtiments naturellement ventilés, pp. 330. Thèse de doctorat, Spécialité «Génie Civil», Institut des Sciences Appliquées de Lyon, janvier 2007.

[10] ISO 7730 « Ambiances thermiques modérées – Détermination des indices PMV et PPD et spécification des conditions de confort » AFNOR, Paris.1994

Nomenclature

Ts	Dry air temperature	[°C,K]
Th	air temperature	[°C,K]
Tp	Average wall temperature (radiant temperature)	[°C,K]
Ω	Specific humidity or water content	[skin/dry gas]
Humidity level - relative humidity		[%]
Hr	Relative humidity	[%]
P	Atmospheric pressure	[Pa]
Pv	Partial water vapour pressure	[Pa]
No	Partial dry air pressure	[Pa]
m_v	The mass of water vapour	[kg]
ρ	Density	[kg/m3]
h, hs	The specific enthalpy	[kj/kgas]
M	Metabolism	[w]
Go	Air velocity	[m/s]
Q	Volume flow rate	[m3/h]
Tx	Brazing rate	

THE INDICATORS

1 State "1"
2 Status "2"
3 Status "3"
4 Status "4"
as Dry air
v Water vapour
Liq Liquid
Vap Vapour

Abbreviations

VMS Predictable average vote
PPD Expected percentage of dissatisfied