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Thermal comfort and comparison of some parameters coming from hospitals and shopping centers under natural ventilation: the Case of Madagascar island.

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Abstract

Nowadays, in several countries in the tropical islands of Indian Ocean including Madagascar island, Comores island, Seychelles island and Mayotte, no adapted and regulated buildings standards exist. This entails enormous losses for their government, a great urban disorder, and facilitates the anarchic constructions. The human health depends essentially on the internal climate. Several actions should be taken to propose solutions to this problem. The purpose of this research is to develop a database on thermal comfort in naturally ventilated buildings in order to improve indoor air, mainly in hospitals and shopping centers in the largest island of the Indian Ocean. There is not enough data regarding comfort in built environments in this region. Experimental and subjective results of field study carried out in 5 big hospitals and 50 small and big shopping centers, distributed in 25 districts of urban areas in Northern Madagascar are presented. The adaptive approach was adapted for this purpose. A specific questionnaire was elaborated for the investigation according to ISO 7730 and 10551. A total, of 400 people were investigated during rainy and dry seasons. This paper discusses the influence of gender, clothing, activities, voters' mind state and occupants' control strategies on adaptive comfort assessment and various comfort parameters calculated for these buildings. In both studied places, the lower and upper acceptable temperature for 80% of the voters were 23.2°C and 26.8°C, while the 90% of the customers and patients reported a comfortable temperature range of 24.5°C-26.2°C. This will help to define guide lines for constructing more comfortable buildings in Madagascar and other countries on the Indian Ocean.

Keywords: Thermal comfort; hospitals and shopping centers; natural ventilation; Madagascar island.

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1. Introduction

According to the literature, there is no comprehensive history of African architecture. Archaeological research has revealed that the concern to protect human groups through built shelters goes back more than one million years in East Africa. The techniques of the brick vault, known as Nubian, were already known under old Egyptian Empire and the manufacture of raw bricks existed in the Niger loop from the beginning of the Christian era. Nowadays, building design remains a major problem in sub-Saharan Africa. Several techniques used in Europe and America are not yet applicable in this region due to the lack of knowledge in the field of buildings energy efficiency and thermal comfort in sub-Saharan Africa. Materials and techniques adapted for comfort in Europe and in other regions are not always applicable and effective in several sub-Saharan Africa countries because of the great climatic varieties. Standards, such as ASHRAE [1] and ISO 7730 [2] have been established on the basis of several researches on energy efficiency and thermal comfort [3–14]. Africa is lagging behind in producing its own standards, probably because there is very little work done to improve thermal comfort in African buildings. Poor building design implies high energy demand for cooling and heating [15], while the bioclimatic design of buildings can improve their thermal performance. Bioclimatic design of buildings under hot and humid conditions has been studied in various papers, which provide interesting recommendations [16–20].

According to the United Nations Organization, today, three-quarters of the African population live on the threshold of poverty on less than a dollar a day. The four fifths of its population are essentially made up ofyoung people. Considering the high rate of poverty in this region, the price of the materials that are adaptive to this climate is very high and people cannot afford to pay for them. This situation forces African people to live in dwellings built with temporary materials. Several studies have been conducted to investigate occupant thermal comfort in African countries. In a study conducted by Ogbonna and Harris [21],a range of conditions in which occupants are comfortable in naturally ventilated buildings in Nigeria was introduced. In another study conducted in Cameroon, Djongyang et al. [22],investigated the psychological behavior of building occupants and its role on their thermal satisfaction. Jeannot [23], in a study carried out in Burkina-Faso, showed that air temperature was the main reason of discomfort among occupants and suggested to improve the design of recooling techniques in buildings. In another study performed in Cameroon, Nematchoua et al. [24] suggested to use local building materials in building construction to improve indoor air quality. In a survey conducted by Mark Olweny et al. [25]in Uganda, a wide range of comfort votes suggest diverse preferences of hot and cool, then, adaptation strategies. Ealiwa et al. [26], in a study in Libya, suggested several solutions to improve thermal comfort in North Africa. The Indian Ocean is essentially made up of five islands: the Comoros, Madagascar, Mauritius, Reunion and the Seychelles. The closest ones are 200 km apart and the farthest ones are 1800 km apart.

The choice of Madagascar as the place for this study was not made randomly. It is the biggest island of Indian Ocean and the 4th in the world. Moreover, Madagascar, according to the World Meteorological Organization, is considered as the third-ranking country in the world that is most vulnerable to climate change, which will affect considerably indoor temperature in buildings and result in thermal discomfort. Madagascar is ranked among those countries that are rich in solar energy, with an estimated potential of around 2000 kWh/m2.year. Madagascar's largely rural population mainly depends on subsistence agricultural activities, which contribute to habitat degradation, particularly loss of forest [27]. Several areas of the island have over 2800 h of sunshine per year. According to the report of the Diagnosis of Energy Sector [28], Madagascar has a potential of over 2000 MW of wind power. The country fragility in the face of multiple climates and crossing cyclone, motivates the population of northern Madagascar to build with temporary and cheapest materials on the market, generating uncomfortable residential buildings. However, the focus of this work is on hospitals and shopping centers. The choice of doing a research on hospitals and shopping centers was not random at all; indeed, these buildings are built with more care and they are places by excellence where people from different ages and from all parts of the country could be found. Moreover, no investigations on thermal comfort have been carried out previously in regularly-occupied buildings like shopping centers and hospitals in tropical sub-Saharan Africa.

The main purpose of this research is to create a comprehensive database on thermal comfort in naturally ventilated buildings in sub-Sahara Africa, in order to help in framing comfort standards for indoor climate in buildings for Madagascar and other islands of the Indian Ocean. The second goal of this study is to suggest an adaptive approach of thermal comfort for this climate region as well as a methodology for thermal studies based on analysing and combining the results of interviews of occupants and the use of mathematical models.

2.Materials and Methods

2.1. Studied region

Located between 20°00 S and 47°00 E, Madagascar lies almost entirely within the tropical region. It is an island in the Indian Ocean, covering an area of 592.000 km². It is the fourth greatest island in the world, and it is separated from Africa by the Mozambique Channel by about 400 km. There are basically two seasons in Madagascar: dry, from May to October, and rainy, from November to April. Two short seasons of approximately 1-month duration separate these two seasons. From May to October, the climate is conditioned by an anticyclone to the Indian Ocean level that directs a wind regime of trade winds South-Easton Madagascar. During this season, the eastern part of the island experiences a humid climate "in the wind", while the western part undergoes a drought-like climate termed "down wind".The study was conducted in tropical city Antsiranana (Northern region), see figure1.

Figure 1: India Ocean and studied city [28]

Antsiranana is the largest city in northern Madagascar. It is the capital of the province of Diego-Suarez. Its population was estimated at 257,163 inhabitants in 2014. The town of Antsiranana is sheltered by the bay of Diego-Suarez (156 km of coast) which shelters the second port of the country. It is the second largest bay in the world after Rio de Janeiro. 25 districts constitute the Urban Commune of Antsiranana which extends over 47 km^2. The town is bounded to the north by the coves of the Dordogne and Melville, to the south by the plateau of Antanamitarana, to the east by the bay of the French and to the west by the deltaic plain of Antomboko and the plateau of Cape Diego. Detailed characteristics of the study area is given in Table 1.

Table1: Some climatic characteristics of Antsiranana city.

				Temp. (°C)		RH(%)		Wind Speed (m/s)		precipitation (mm)	
City	Latitude	Longitude	Altitude(m)	Max.	Min.	Max	Min.	Max	min	Max	Min
Antsiranana	12°16’S	49°17’E	43.0	33.5	20.0	85.5	60.5	9.0	4.5	338.0	0.0

Average rainfall of 12.4 mm makes the month of June the driest month. In January, rainfall is the highest in the year with an average of 204.9 mm.

2.2. Expermiental design

In this work, the primary objective was to conduct a survey to collect required data for creating a database of occupant thermal comfort in naturally ventilated buildings in order to improve indoor air quality, mainly in hospitals and shopping centers in the largest island of the Indian Ocean. Some students were selected and trained to conduct this survey. The main research methods included conducting a survey questionnaire of thermal comfort, interviewing patients who could neither read nor write and doing the measurements of some physical parameters such as air temperature, air speed and relative humidity. The experimental study was carried out in 5 big hospitals and 50 small and big shopping centers, located in 25 districts of the urban area of Antsiranana. A total of 400 people were investigated with 250 interviews and 150 written questionnaires that have been completed. The sample contained 224 males and 176 females in 45 hospitals and 50 shopping rooms. Most of the selected hospitals were less than 50 years old. These hospitals were built using local materials such as concrete block and compressed stabilized earth block and also imported materials (e.g., sliding glass, marble, etc.). These hospitals were built in the form of different geometric shapes and very beautiful architectures that attract the visions of the visitors and road users(see Fig. 2). The shopping centers were located in the city center and near big crossroads.

a) An example of external view of hospital

b) Sick and Questionnaire

c)An example of internal view of hospital

d) An example of shopping center

Figure2 : Some examples of studied places

During this study, for both (hospitals and shopping centers), only naturally ventilated conditions were investigated. The study was conducted during the periods reported in table 2.

Table 2: Periods of study.

	Dry season			Rainy season		
city	Time	Month	Year	Time	Month	Year
Antsiranana						
Hospital	10 days	September	2016	8 days	December	2016
Shopping center	13 days	July	2016	10days	December	2016

2.2.2. Instruments and measures

In this study, the indoor air temperature was measured by a probe thermometer and a very sensitive infrared thermometer to measure the temperature inside of wall. Some characteristics are given in table 3. Using the infrared thermometer, the maximum, minimum and mean temperature of the studied places were also measured. Some of the specific characteristics of this infrared thermometer are the clear laser point, a wide temperature range and an adjustable emissivity (depending on the material). This device easily detected the characteristics of objects at more than 10 m. Measurements were taken every 5 min at a height of 1.5 m from the ground level according to the ASHRAE Standard 55 [1] and ISO 7730 Standard [2].

Table 3: Characteristics of the measurement system.

EMC 50081-1(model)	Function	Range	Resolution	Accuracy
Infrared thermometer	Temperature	- 50 to + 1000 °C	0.1°C	± 1.5 % R ± 0.2 °C

2.3. Survey questionnaire

The questionnaire approach was necessary in this study. It allowed to receive the subjective answers of patients (in hospitals) and customers (in shopping centers). The questionnaires were developed in previous works [29-30]. This approach was carried out in parallel with the testing of the environmental variables. The opinions and feelings of individuals were obtained by a careful analysis of the answers to these questionnaires. At total of 150 completed questionnaires were collected during both seasons: 1 person for each of the 50 shopping centers and 20 patients for each of the 5 hospitals. To encourage some patients who could neither read nor write to participate in the study, oral hearing was proposed. A total of 198 interviews in hospitals and 52 interviews in shopping centers were carried out. The main contents of this survey are developed in the following sections.

2.3.1. Background information

Questionnaires were written in both French and Malgasy language, which are the country official languages. The language preferences of the occupants were considered while distributing questionnaires.These questionnaires were subdivided into three different parts:

-Part 1 : A section with the personal data (age, gender, height, weight and the length of time in).
-Part 2 : The thermal aspects : judgement about tolerability of thermal environment, air movement, temperature difference between head and ankle, activity performed in the last period, etc.

- Part 3: Personal microclimate control strategies applied.

2.3.2. Characteristics of the voters

The surveys in the hospitals were very difficult and discouraging. More than 59% of people met in hospital refused to participate at this study; they may be concerned about their health. The questionnaires was given randomly, without any physical constraint. The voter age varied from 13 to 89. The height of the voters varied between 1.55 m and 1.80 m in shopping center and from 1.55 m to 1.78 m in the hospitals. Their weights ranged between 33 and 90kg in both. Their activities were intense in the shopping center as compared to that in the hospital ones. Some characteristics of the voters are reported in table 4.

Table 4: Characteristics of the voters (results of interviews and questionnaires)

	Occupants			Height(m)			Weight(kg)			M(met)			Age		
	M	F	T	Min	Med	Max	Min	Med	Max	Min	Med	Max	Min	Med	Max
Shopping	80	22	102	1.55	1.69	1.80	35	71	90	1.00	1.10	1.20	23	30	50
Hospital	144	154	298	1.55	1.68	1.78	33	61	90	1.00	1.00	1.10	13	45	89

2.3.3. Clothing insulation effect

Nowadays, clothing insulation can only be estimated by using thermal manikin. Indeed, in any comfort field survey, clothing insulation is always the most troublesome [40]. In ASHRAE database, for example, all clothing insulation estimations of the field surveys were converted using ASHRAE 55-1992 clo estimation method. All the other methods were almost similarly [41-44]. In this study, ASHRAE 55-2004 ,has been adopted as clo estimation method.

2.3.4. Thermal comfort field survey

The opinions of voters were obtained from analyze of questionnaires and interview responses.The thermal sensation, the humidity and air movement sensation were adopted according to American Society of Heating Refrigerating, and Air-Conditioning Engineers (ASHRAE) scale. Thermal satisfaction, preference and comfort were also estimated. The different used scales were detailed in table 5 as in [35].

Table 5. Adopted thermal scale.

Thermal Sensation	Humidity sensation	Air movement sensation	Thermal satisfaction	Thermal preference	Thermal comfort
-3cold	-3too dry	-3no wind	-2dissatisfied	-2cooler	-2very uncomfort.
-2 cool	-2dry	-2only little wind	-1slightly dissatisfied	-1slightly cooler	-1 uncomfortable
-1 Slightly cool	-1Slightly dry	-1wind not enough	0satisfied	0 no change	0 comfortable
0 neutral	0 neutral	0 just right	+1slightly satisfied	+1slightly warmer	+1very comfort.
+1Slightly warm	+1slightly humid	+1 slightly breezy	+2 very satisfied	+2 warmer	
+2 warm	+2 humid	+2too breezy			
+3 hot	+3too humid	+3much too breezy			

2.4. Mathematical model

The below parameters were estimated using many mathematical models.

2.4.1. Adaptive model and calculating the operative temperature

Mean comfort temperature was calculated according to ASHRAE [1].

The mean radiant temperature (T_r) was estimated using the following regression

model as function of the measured air temperature (T_a) proposed by Djongyang and Tchinda [31]:

T_r=0.99xT_a-0.01, R^2=0.99 (1)

The operative temperature (T_o), was determined from the measured air temperature (T_a) and the mean radian temperature (T_r) by the following relationship [38]:

T_o= A x T_a +(1-A) x T_r (2)

Where the weighting factor (A) depends on air velocity(w).

A=0.5 for w<0.2m/s ; A=0.6 for 0.2<w<0.6m/s ; A=0.7 for 0.6<w<1m/s.

2.4.2. Adaptive model and calculating the exponentially weighted running mean

Outdoor temperature

Overview, the adaptive approach assumes the neutral temperature is related to a person's thermal history with more recent experiences being more influential [32-33] . This makes the exponential weighting attractive as a weighting for past temperatures [34].The exponentially weighted running mean temperature T_{rm} for any day was expressed according to Nicol and Humphreys [36].

$$T_{rm} = (1-\alpha)\{T_{Od-1} + \alpha T_{Od-2} + \alpha^2 T_{od-3} \ldots\} \quad (3)$$

Where α is a constant (<1). T_{Od-1} etc. are the 24-h daily mean temperature for yesterday, the day before and so on. For a series of days the value of T_{rm} for any day can be simply calculated from the value of the running mean and of the mean outdoor temperature for the previous day (T_{rm-1} and T_{od-1})[37-3829].

$$T_{rm} = (1-\alpha)T_{od-1} + \alpha T_{rm-1} \quad (4)$$

This feature makes the running mean very simple to use once a starting value has been established .

The optimal value of α was used for calculating the changes in indoor neutral temperature and to correlate the value of T_{comf}. According to [39],the neutral temperature within a

free-running building is linearly related to the outdoor temperature.

2.4. 3. Other calculated parameters

Mean radiant temperature (T_{mrt}), new effective temperature (ET*), standard effective temperature (SET*), predicted mean vote (PMV), predicted percentage dissatisfied (PPD),Heat stress indess (HSI) and discomfort index (DISC) were estimated as in [1,45].The acceptable result was yielded, compared with that given by wincomf, used in RP-884 project. In the table 6, we have some mean estimated physiological data which could influence the voters' answers during the investigations.

Table 6. Some estimated parameters.

	Ta(°C)	M(w/m^{-2})	Eres (w/m^{-2})	Dry(w/m^{-2})	SSK(w/m^{-2})	Cres(w/m^{-2})	Esk(w/m^{-2})	Scr(w/m^{-2})
Hospital								
Dry season								
1	25.5	58.2	3.8	45.7	-0.7	0.7	8.7	-0.006
2	26.0	63.8	4.2	44.8	0.008	0.8	13.9	0.002
3	27.5	69.6	4.5	37.1	0.024	0.8	27.2	0.019
Rainy season								
1	25.0	58.2	3.8	44.4	0.001	0.7	09.2	0.000
2	25.5	58.2	3.8	49.5	-5.46	0.7	09.7	-0.158
3	24.5							
Shopping								
Dry season								
1	27.2	69.6	4.9	40.3	0.00	0.9	23.4	0.00
2	28.0	58.2	4.1	42.7	0.00	0.6	10.6	0.00
3	29.5	63.8	4.5	42.3	0.00	0.8	16.2	0.11
Rainy season								
1	25.6	69.6	4.8	36.6	0.002	0.8	27.3	0.01
2	26.3	58.2	4.0	34.5	0.012	0.6	19.1	0.06
3	24.5	63.8	4.4	42.3	0.006	0.8	16.4	0.02

With : ambient temperature (Ta), metabolic rate (M), Respiratory evaporative heat loss (Eres), Dry heat loss from skim surface (DRY), heat storage in the skin (SSK), Respiratory sensible heat loss (Cres), total evaporative heat heat loss at skin surface(ESK), and heat storage in the core (Scr).

3. Results and discussions

3.1. Analyze of subjective questionnaires and interviews results

3.1.1. Confrontations of the clothing thermal resistance in Hospitals and Shopping Centers

Figure 3 showes the distribution of the thermal resistance for the subjects' clothing. It was observed that, in the distribution of the clothing thermal resistance, 66% of the values were concentrated in the range of 0.7-1.3 clo in the hospital and that 78% of these values were classed in the same range in shopping centers. A mean of 0.88 and 0.79 clo were obtained in the shopping centers and hospitals, respectively, during the period under study. The clothing thermal insulation value was significantly higher in shopping centers than hospitals. It was therefore depending of the investigated place.Thermal sensation of voters may vary depending on health state and the investigation environment. It is in this sense that thermal insulation should'nt be similarly in both studied places. In addition, males and females could have different responses to cold and hot temperatures because the choices of clothing are also different between both sex. This result was similary as [46].

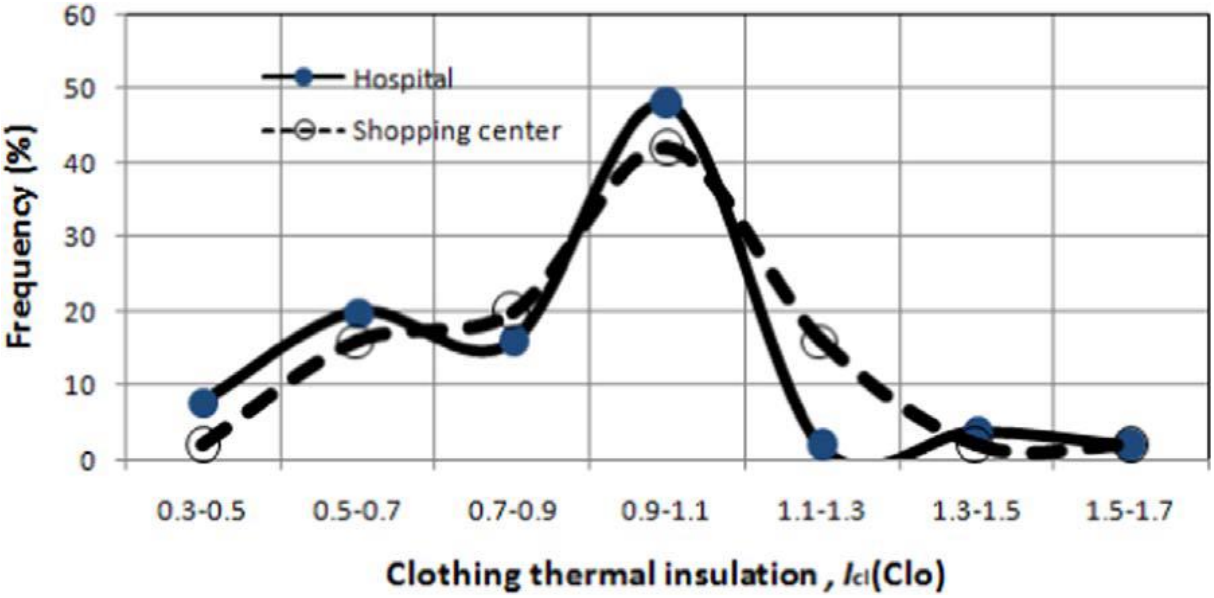

Figure 3: Distribution of clothing thermal resistance of respondents.

3.1.2. Confrontations of the thermal, humidity, and air movement sensations between the males and females

Figure 4 presents the frequency distribution of the thermal, humidity, and air movement sensations between the males and females. In this figure, it can be seen that there were no obvious differences between the males and females in their thermal sensations, humidity sensations, and air movement sensations in hospitals and shopping center. The majority of them thought the thermal environment was slightly warm and a little dry and that the wind was slightly breezy. Neverthериless, for the both sex, asmall minority of voters thought the thermal environment was cold and humid with no wind. Several studies carried out in Africa, in other types of climate, were found almost the same results [47-48].

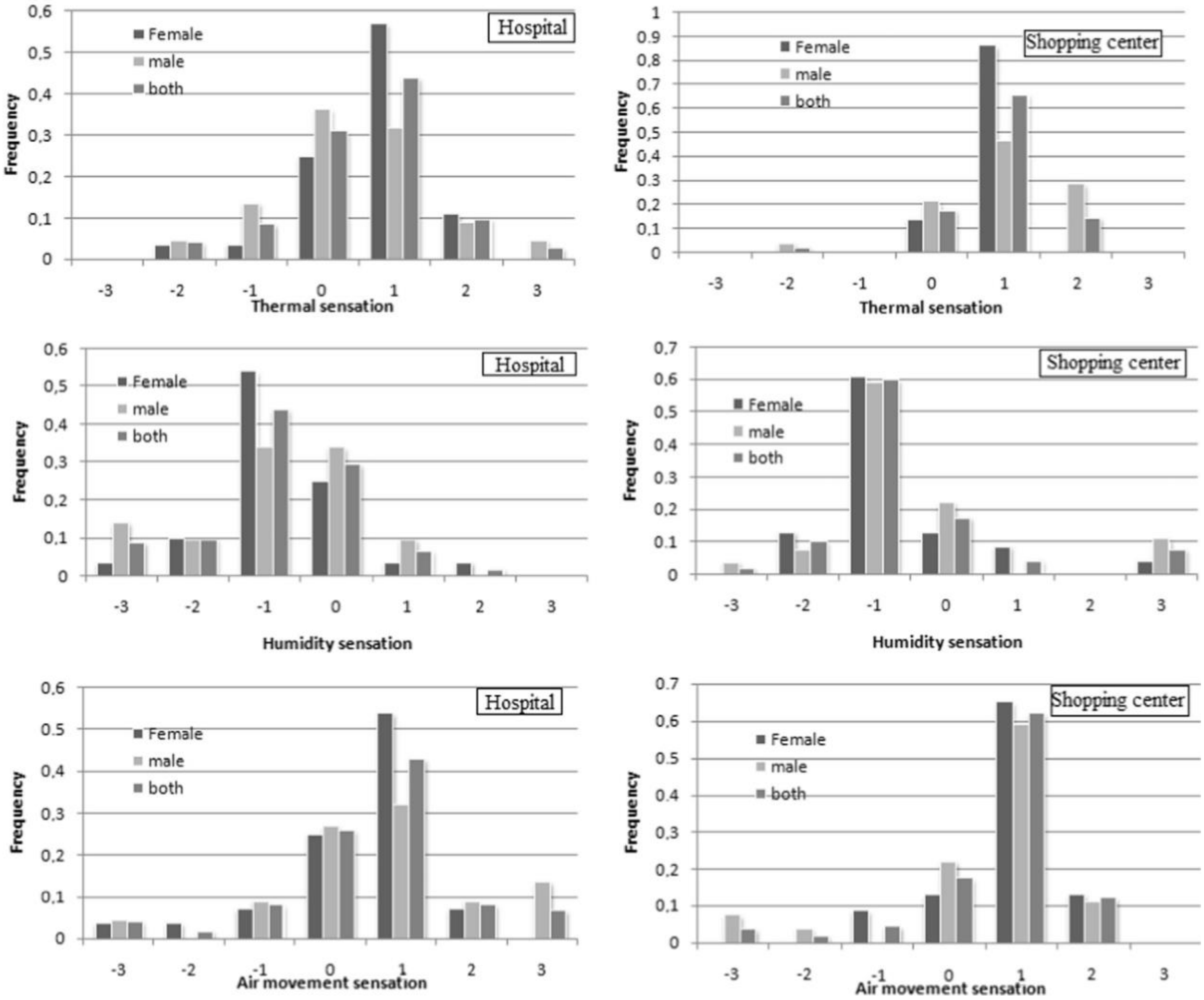

Figure 4: The frequency distribution of thermal, humidity and air movement sensations in hospitals and shopping centers.

3.1.3. Confrontations of the thermal satisfactions, thermal preferences, and thermal comforts between the males and females

Figure 5 shows the frequency distribution of the thermal satisfaction levels, thermal preferences, and thermal comforts between the males and females in hospitals and shopping centers. In the hospitals, there were no obvious differences between the males and females in their thermal preferences and thermal comfort, since most of them thought the thermal environment was comfortable and preferred it to be no change, but their thermal satisfaction levels showed great differences. For the males, a great number of them were satisfied of their thermal environment. However, the majority of the females felt dissatisfied. In the shopping centers, there were no obvious differences between the males and females in their thermal satisfactions, thermal preferences, and thermal comfort, since most of them thought the thermal environment was slightly satisfied, and wanted it to be slightly warmer. For both sex, their environment was considereted as comfortale. These conclusions confirm the results found by Shilei and al.[35] in a tropical island undernatural ventilation. In the both studied places, a small minority of voters found the thermal environment uncomfortable and should prefer it to be cooler.

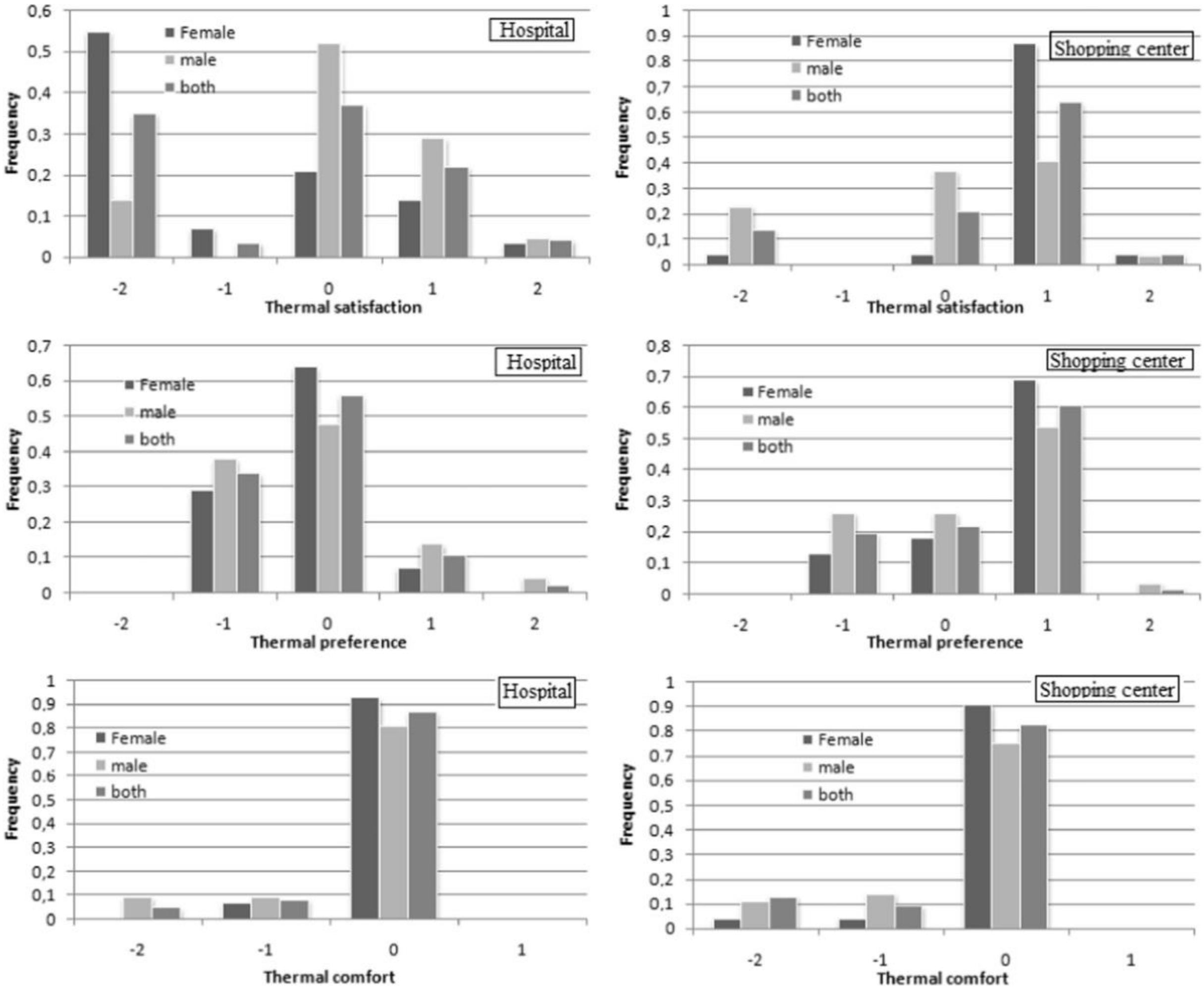

Figure 5: The frequency distribution of thermal satisfaction levels, thermal preferences and thermal comfort in hospitals and shopping centers.

3.2. Preferred temperature

Figure 6 shows the preferred temperature based on Probit analysis. As shown in this figure, we have two curves explaining different thermal preferences in the studied places. Indeed, the right sigmoid curve line correspond to the group who want tobe cooler, meanwhile left curve line for those who want to be warmer. Between 19.5 and 21.9°C, the 100% of voters preferred a warmer environment, nevertheless, from 29.5 to 31.8°C, all these same voters wanted a cooler environment.The intersection point indicates the temperature where an equal percentage of people who want to be “warmer” and“ cooler” is found. Both curve lines intersect at temperature point of 26.41°C. This temperature is assumed as preferred temperature because at this point people prefer neither warmer nor cooler.This value of preferred temperature is higher by 0.38°C compared to this found by Feriady and Wong [49].

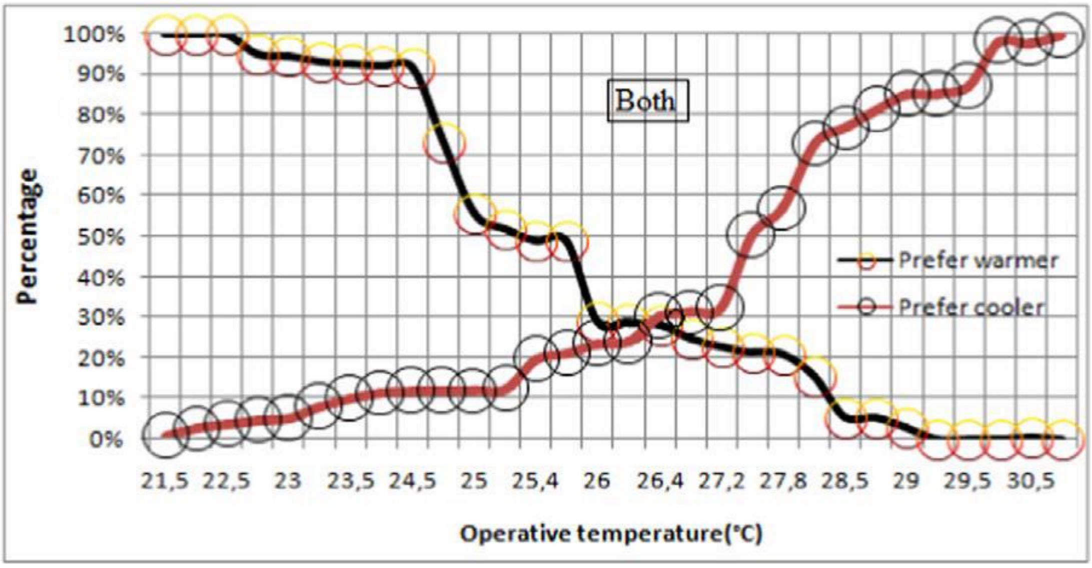

Figure 6: Preferred temperature based on Probit analysis.

3.3. Predicting the comfort from the running mean outdoor temperature

The performance plotted against the adaptive comfort criteria is shown in Figure 7. For running mean outdoor temperature between 20.3 and 29.5°C, thermal comfort temperature was between 23.4 and 26.8°C in hospitals and between 22.2 and 26.4°C in shopping centers.

Adaptive thermal comfort criteria for building occupants was established in many works 36, [39, 40, 50-52]. In previous researches, it was seen that the data varied according to the studied environment and climate type .As an illustration, the thermal performances of our studied places were assessed using several thermal comfort temperature scales. It's interressant to noticed that many good linearly correlations were obtained (R^2=0.89; R^2 =0.92).The adaptive criteria can be easily applied in buildings design to assess comfort performance of design options.

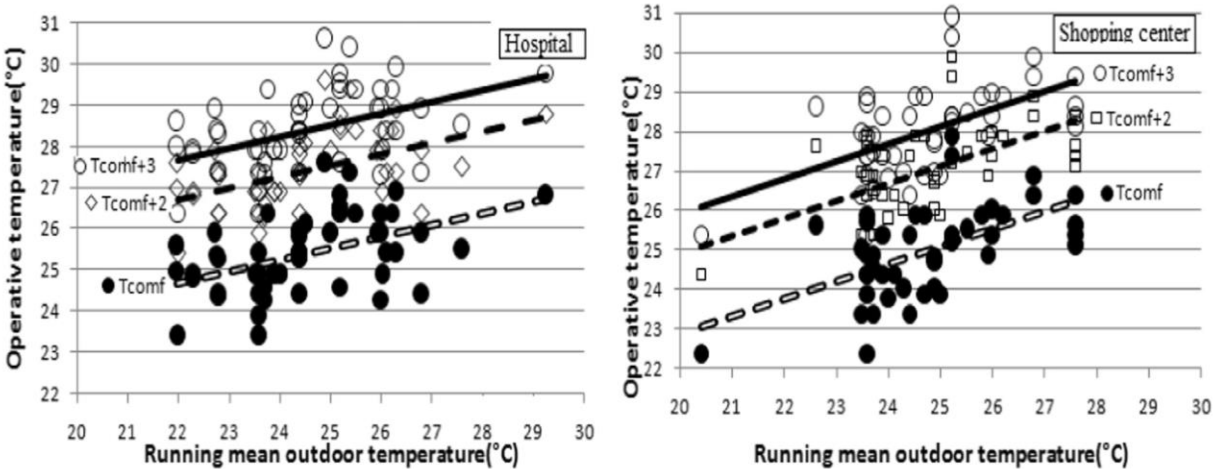

Figure 7: The plotted performance of the adaptive comfort criteria: comparison between the hospitals (left) and shopping centers (right).

3.4. Mean neutral temperature

This paragraph discusses on the observed mean neutral temperature (operative temperature, ET*, SET* and DICS) with a natural ventilation. In this study as in [40,52], probit analysis is used to find a comfortable temperature, at which the largest proportion of subjects is comfortable, using Bedford thermal scale and regression analysis to calculate a neutral temperature, which is the temperature at which the average person votes neutral on the 7-points thermal sensation scale.

3.4.1. Mean neutral operative temperature

Neutral operative temperature calculated in this sub-section was only the mean neutral value corresponding to an indoor temperature range [40].As shown in figure 8, mean thermal sensation vote varied according to sex. In the hospitals (see figure 8a), for operative temperature values between 23.5 and 27.6°C, mean neutral operative temperature obtained for women was 23.65°C. For men, it was 24.2°C when operative temperature varied from 23.5 to 27.9°C. However, it is interressant to notice a good linearly correlations (R^2=0.691, R^2= 0.673) for the mean neutral operative temperatures in shopping centers: the mean neutral operative temperatures were 24.2°C and 23.6°C for men and women, respectively. This result showed an equality of neutral temperature between the voters with same sex in the two studied places. The thermal neutral temperature was higher by 0.6°C for men than women. Actually, the neutral temperature believed to change as people adapt to the changing environment by modifying their activities, clothing as well as their expectation [40].Many works have showed that relative humidity and air speed could modify the thermal neutral comfort temperature in buildings [30, 53-55].

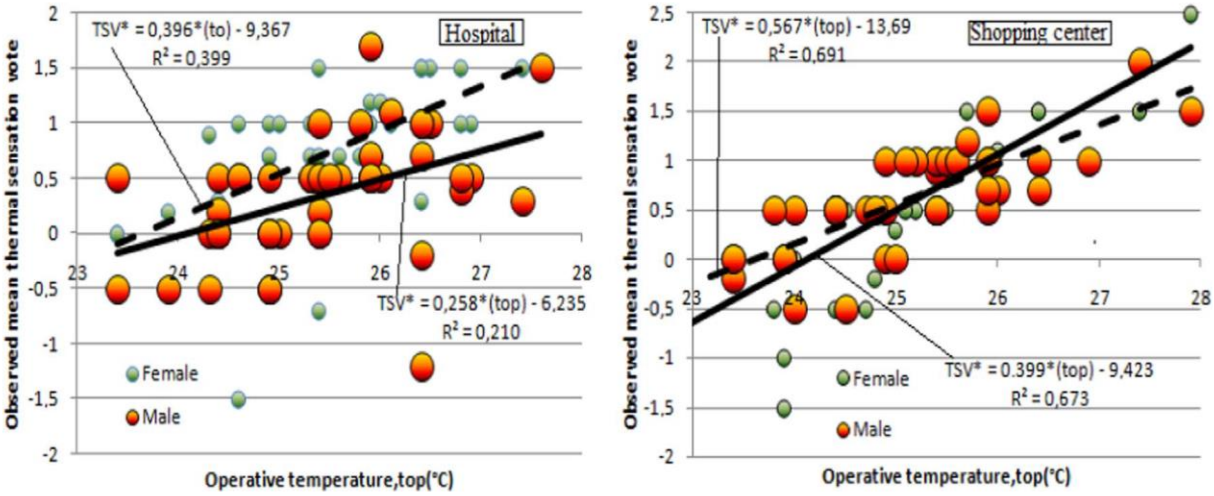

Figure 8: Weighted regression of mean operative temperature versus mean observed thermal sensation vote in hospitals (left) and shopping centers (right).

3.4.2. Mean neutral effective temperature ET*

As shown in figure 9, in both studied places, for a variation of effective temperature (ET*) from 22.3 to 31.9°C, mean neutral ET* was 24.26 and 25.90°C , in hospitals and shopping centers, respectively. The regression equations between both places were nearly similar. An acceptable correlation obtained in hospitals can explain a strong convergence of environmental parameters.

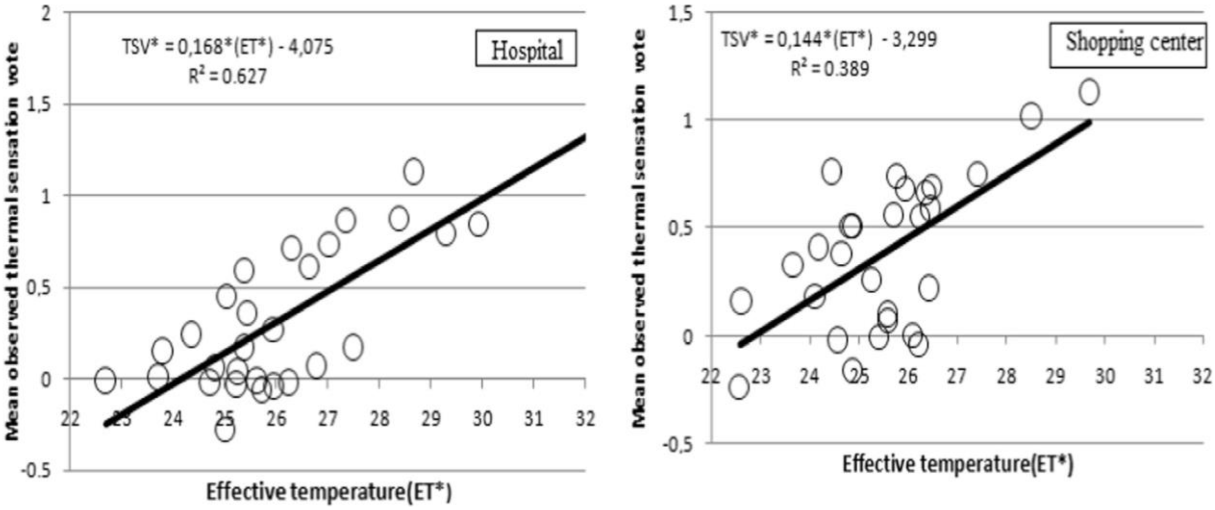

Figure 9: Weighted regression of mean effective temperature versus mean observed thermal sensation vote in hospitals (left) and shopping centers (right).

3.4.3.Mean neutral standard effective temperature SET*

The variation of mean standard effective temperature versus predicted mean vote and discomfort index in hospital and shopping center was shown in figure 10. In the hospital, for predicted mean vote between -2.4 and +1.5, the standard effective temperature was about 25.4-32.9°C, with a standard deviation of 2.86 (SD=2.86). In the shopping, SET* varied from 25.0 to 29.6°C, with a standard deviation of 2.27 (SD=2.27); while PMV was estimated tobe between -1.5 and +1.5. The mean standard effective temperature was 25.46°C and 26.1°C, in hospital and shopping center, respectively. The analysis of these results shows that SET* was higher in shopping center than hospital. This difference can be due to intense activity in shopping center. The variation of PMV was uncertain, strongly depending on the environment. For a total comfort, PMV =0, given a mean neutral SET* around 25.1-26.0°C, in the two cases. This observed neutral temperature was near to this found by Nguyen et al [40] in naturally ventilated buildings and very close to the neutral temperature found by Fanger [56]. The discomfort index was slightly weaker in shopping centers than hospitals, showing that voters were more comfortable in shopping centers than hospitals.

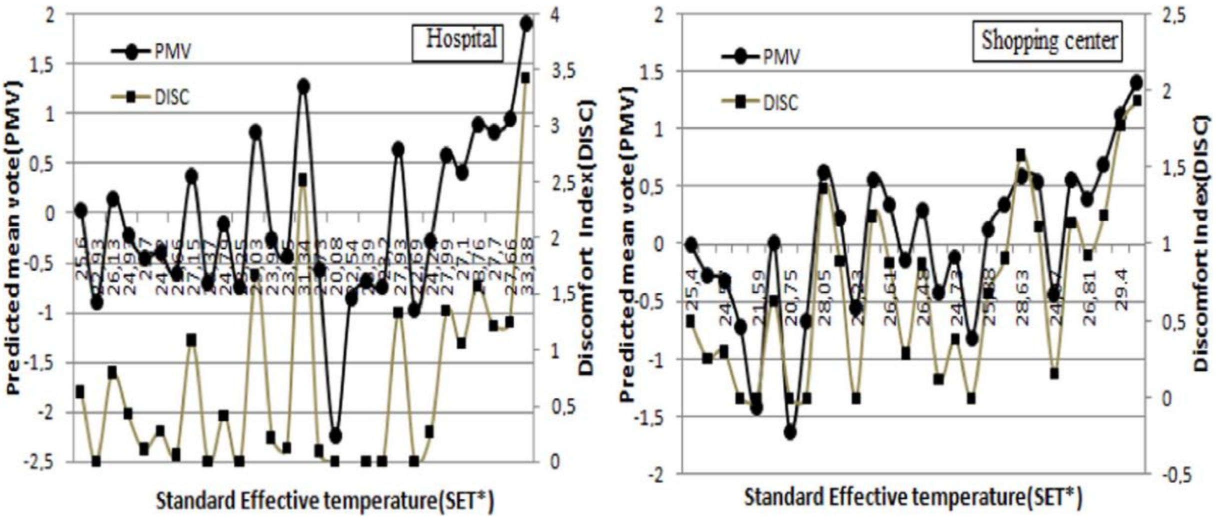

Figure 10: Weighted regression of mean standard effective temperature versus predicted mean vote and discomfort index in hospitals (left) and shopping centers (right).

3.5. Thermal acceptance rate and comfort range

Fanger [56], in several investigations, found that PMV values ±3 (hot and cold) and ±2 (warm and cool), indicate that the thermal environment was uncomfortable and that from -1 to +1 (slightly cool, neutral and slightly warm), indicate that thermal environment was acceptable. These results were confirmed by Mcintyre [58] and in several other researches [59-66-]. In this study, it is not always verified in the hospitals. Figure 11 gives the relations obtained by regression between PPD* and indoor air for hospitals and shopping centers.

$PPD^* = 1.539t_a^2 - 73.56t_a + 886.8$, $R^2 = 0.827$ (Hospital).

$PPD^* = 2.220t_a^2 - 112.2t_a + 142.8$, $R^2 = 0.730$ (Shopping center).

As shown in figure11a, in the hospitals, for relative humidity between 55% and 65%, and air speed from 0.2 to 0.46 m/s, the lower and upper acceptable temperatures for 80% of the patients were 21.0°C and 26.8°C. The 90% of the patients reported a comfortable temperature range between 22.4°C and 25.3°C. In the shopping centers, the lower and upper acceptable temperature for 80% of the customers were 23.2°C and 27.1°C, while the 90% of the customers reported a comfortable temperature range from 24.5°C to 26.2°C . In both study places, for these different indoor temperatures, PMV was estimated to be between -1 and +1. This conclusion was similarly at those in [46].

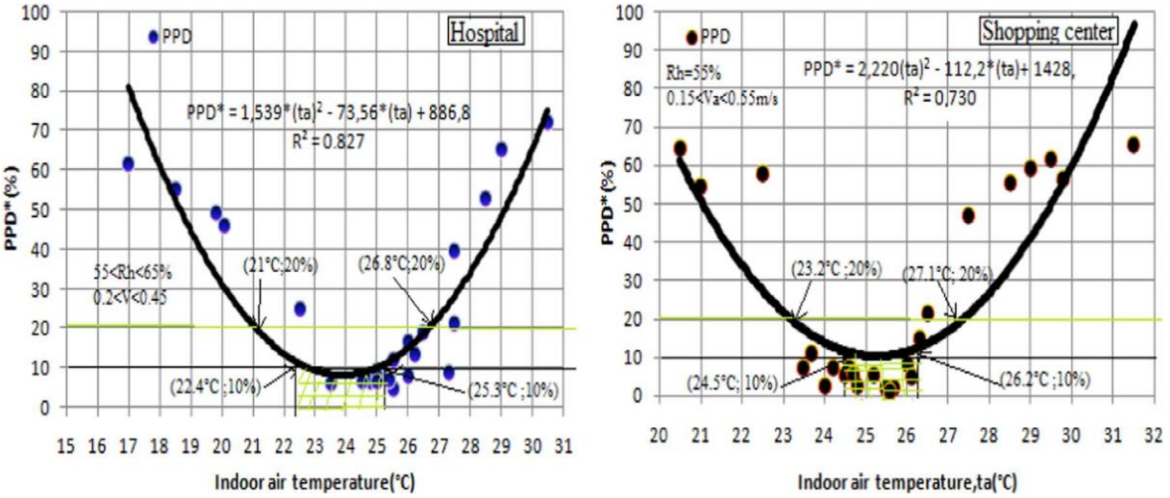

Figure 11: Predicted percentage dissatisfied (PPD) and thermal comfort range in hospitals (left) and shopping centers (right).*

3.6. Voters' mind state as non-negligible parameter in adaptive comfort

This section regards on some data of the voters' mind state during the experimental study. In both places, as shown in figure 12, it was noticed several linearly curves with a good correlation (R2=0.86, R2= 0.65). It was interressant to see that heat stress indess (HSI*) is depending on skin and core temperature. The voters were more stressed in the hospitals than in the shopping centers. It could also be seen that the level of stress varied according to the health state of the voters. This may explain the divergence of the subjective responses of voters in the study sites. For example, during the investigation, some voters having chosen a "comfortable environment" as thermal sensation, nevertheless, wanted a cooler and sometimes warmer environment as thermal preference. In the hospitals, 99% of hospitalized patients found their environment always comfortable, even when the heat degree was unbearable. These results confirms other research results on the influence of voters' mind state [39, 50, 57].

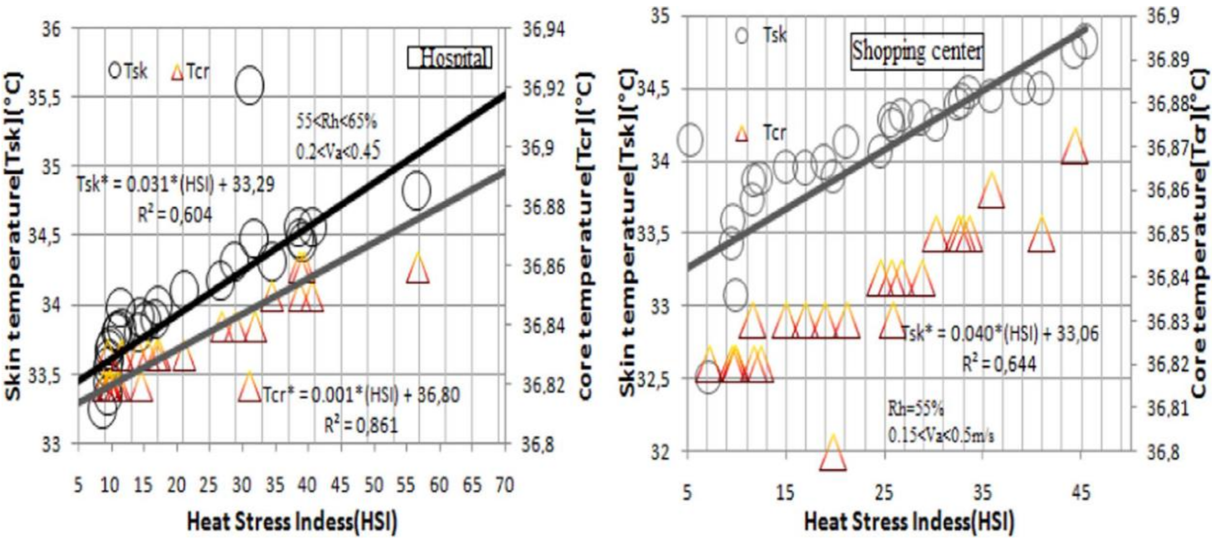

Figure 12: Weighted regression of heat stress indess versus skin temperature and core temperature in hospitals (left) and shopping centers (right).

3.7. Occupants control strategies

In this section, it is studied how the occupant behaviour can influence its comfort degree. It is also an important parameter which can help us to understand the subjective responses of voters.

Figure 13 explains the list of various adaptive actions commonly occurring in both studied places and the percentage of people who choose to employ them. In the hospitals, the environment control by opening the curtains is highly preferred by patients with the percentage of 98%. Other favoured adaptive actions are putting fan and opening internal door with the percentage of 82% and 69%, respectively. However, in the shopping centers, the environment control by opening the curtains and internal door constitutes about the same percentage of 100%. It is also interressant to notice that opening the window and external door wasused with a same percentage of 75%. The least favourable action was adjusted thermostat which showed only about 15%. The above findings might be used not only as information on the percentage of " likeliness to happen" but also on the people's preference in choosing various adaptive actions to make their living environment more comfortable. The action of people on their environment varies according to daily activity. In this sense, Feriady and Wong [49] explained that, in many case, occupants prefer to employ environmental control strategy (such as window opening) before their personal adjustment, which will involve some thermoregulatory responses of their bodies.

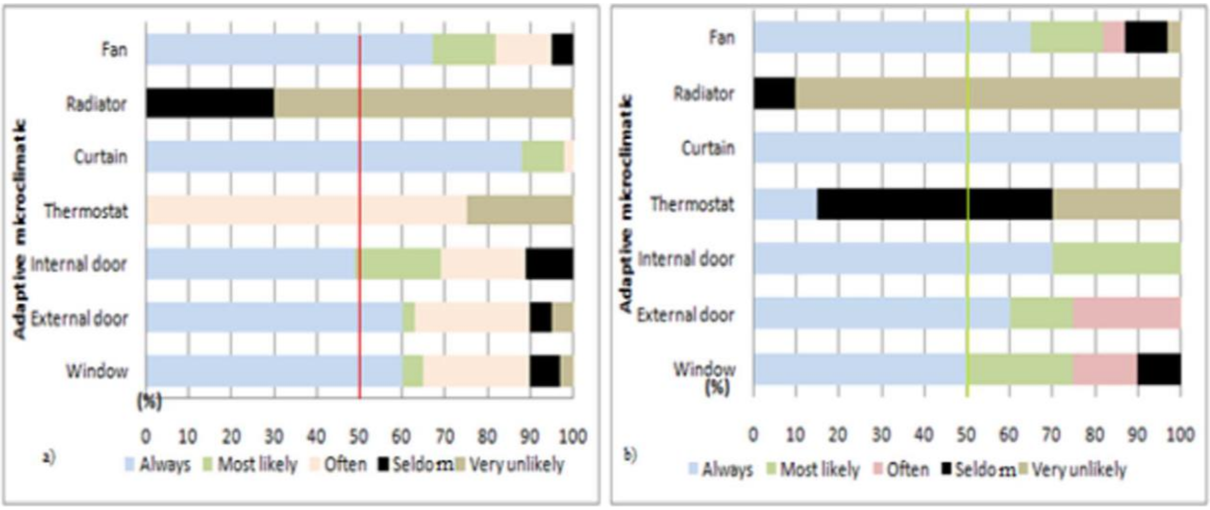

Figure 13: Adaptive behaviours through occupants control strategies in hospitals (a: left) and shopping centers (b: right).

4. Conclusion

In this research, an adaptive approach, based on the analysis of questionnaires and mathematical models, was applied to evaluate thermal comfort in naturally ventilated buildings in Madagascar. The experimental study was conducted in 5 big hospitals and 50 shopping centers under the tropical climate of the Indian ocean. A total of 400 people were investigated during rainy and dry seasons. It can be seen that there were no obvious differences between the menand women in their thermal sensations, humidity sensations, and air movement sensations as well as thermal preferences and thermal comfort assessment, in hospitals and shopping centers. The majority of them thought the thermal environment was slightly warm and a little dry and that the wind was slightly breezy. Between 19.5 and 21.9°C, the 100% of voters preferred a warmer environment, while from 29.5 to 31.8°C the same voters wanted a cooler environment. The variation of PMV was uncertain, strongly depending on the environment. It was noticed that the discomfort index was slightly weaker in shopping centers than hospitals .The 90% of the customers and patients reported a comfortable temperature range of 24.5°C-26.2°C. In both studied places, the lower and upper acceptable temperatures for 80% of the voters were 23.2°C and 28.8°C. This study discussed also the influence of clothing, activities, occupants control strategies and voters' mind state on adaptive comfort assessment in naturally ventilated buildings: these are non negligeable parameters. These results can help frame thermal comfort standards for indoor climate for naturally ventilated buildings in the future in several islands of the India ocean and in the world.

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