# 285: Hourly Thermal Neutral Temperatures of Natural-Ventilated Buildings in Colima, Mexico.

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**Abstract**

The scope of this study is to demonstrate the validity of the Roriz hypothesis (Roriz, 2003) that suggests neutral temperature has an hourly variation, in opposition to the commonly accepted idea that neutral temperature remains steady throughout the whole day, and even through longer periods.
In this study, 40 volunteers chose 1412 thermal comfort votes at different hours through 53 consecutive days. The field study was conducted in fifteen natural-ventilated houses in Colima City, Mexico. The thermal parameters of dry bulb temperatures, globe temperature, relative humidity, and wind speed were monitored indoors.
The method used for this study has its basis on the adaptive approach of thermal comfort, which recognizes differences due to geographic and cultural subjective issues. To determine appropriate thermal conditions, the research team referred to standards such ISO Standard 7730 and ISO Standard 10551.
The thermal neutral temperatures presented constant variations by the hour. This wide oscillation of temperatures at different times of the day validated the Roriz hypothesis. Hourly neutral temperatures highly correlated to hourly outdoor temperatures (r=0.81).
This paper shows the need to adopt an hourly thermal neutral temperature standard to determine the thermal performance of buildings while still at the designing stage.

Keywords: hourly thermal comfort, adaptive approach, comfort range.

## 1. Introduction

An area that urgently requires more investigation is indoor thermal comfort. The high-energy consumption required by mechanically conditioned environments in poorly designed buildings to provide comfortable living conditions to inhabitants contribute a great deal to global warming, affecting wide areas of the world as a result.
The setting of standard temperatures for "designing" buildings, conventionally known as neutral temperatures, should be established according to the thermal comfort of each region. This standardization could relieve the escalating demands of energy used in mechanically conditioned buildings to provide comfort. For this reason, it is imperative to run investigations to determine the preferences in thermal comfort of inhabitants adapted to the climate conditions of each area.
However, the comfort sensation perceived by people does not always correspond to a single temperature but to a variety of temperatures that can be experienced without discomfort. This variation is called comfort range. The higher the use of mechanically conditioned environments, the more restricted the range of temperatures in which people feel comfortable. To the contrary, the occupants adjusted to natural-ventilated buildings will accept a higher range of comfort temperatures without triggering thermo-regulating physiological responses, e.g. sweating or shivering.
The fact is that there is not a general agreement about the range of temperatures for thermal comfort. Neither is there an agreement on how to determine this range.
Nicol (1993) for instance, proposed that this range depends on the adaptation time inhabitants have toward their environment. That is, the longer this adaptation time is, the easier changes can be assimilated without significantly reducing the comfort sensation. Therefore, Nicol proposed that ±2K is an acceptable magnitude of variation for a 24-hour period, but this range could widen, for instance, up to ±5K if the analysis period is longer than a week.
Auliciems and Szokolay (1997) coincided in Nicol's argument, but differed in magnitude by suggesting a ±1.75K variation when the time period is a month or less, and a ±2K for an annual time period. Olgyay (1963) considered a larger variation for annual time periods: ±3.2K. Givoni (1968) proposed, in turn, that people not adapted to mechanically controlled environments could register amplitudes up to ±4.5K.

## 2. The Roriz Hourly Comfort Hypothesis.

With such diverse proposals and a lack of agreement, the Brazilian researcher Mauricio Roriz (2003) projected a working hypothesis that

suggested that neutral temperatures undergo variations throughout the day with a clear dependency on the hourly outdoor temperature rate.
This hypothesis is based on Nicol and Humpreys (2001), who suggested that the variation of thermal comfort could be determined by the fluctuation of the average outdoor temperature. This implies, according to Nicol and Humpreys, that an adaptable algorithm could be formulated. This algorithm would be prone to being used to calculate an internal variable thermostat related to the outdoor temperature.
Roriz questioned the conventional methods used to determine the neutral temperature from the dependency of steady values through long time periods such as the daily, monthly, or annual average temperature. To accord the hypothesis a foundation, Roriz asserted that environmental temperature could change in very significant ways throughout a day and could have periods of extreme cold and hot conditions.
Likewise, the customs inhabitants have developed to adapt to an environment are manifested as different activities throughout the day, for instance, at night the use of pyjamas or other warm clothing that might allow toleration of lower temperatures without discomfort. Since there is an adaptation to changing weather conditions, inhabitants might feel warm if they were placed into a warmer environment, supposedly one more comfortable. On the other hand, midday habits could become abruptly different, both on clothing and on some daily routines such as adjusting windows or operating fans. If these conditions were shifted into a more comfortable environment, cold could be experienced once routines were changed.
Roriz also asserted that human bodies undergo variations in metabolism throughout the day in significant ways. For instance, when inhabitants sleep, their bodies secrete hormones that lower body temperature thus their neutral temperature descends. At other times, during intense activities, the metabolic rate raises, thus the neutral temperature of comfort would also raise.
Concluding, Roriz asserted that comfort temperature varies in significant ways according to time of day, whether by dependency on the outdoor temperature, as well as metabolic factors, and environmental adaptation.

## 3. Research Purpose and Approach

Based on the Roriz hypothesis, a field study was conducted were a group of volunteers living in natural-ventilated houses recorded thermal comfort based on a thermal value scale at different hours of the day, to determine if neutral temperature varied throughout the day. In which case, the comfort temperature standard values for Colima City would be established.
The purpose of this study, as in Roriz hypothesis, is based on the adaptive approach of thermal comfort that involves the interaction of physical and biological variables— weather, metabolism, thermal isolation —as well as psychological variables— adaptation, tolerance, expectation —. Therefore, the outcome differs from individual to individual, from area to area and even from one socio-cultural background to another, Brager and De Dear (2003). This is especially true since culturally developed habits such as clothing, food, time of naps, and work schedules affect people's expectations and thermal comfort sensations. From this point of view, the hourly variation of neutral temperature is more suitable than the conventional hypothesis of establishing a singular neutral temperature for long time periods.
As a particular hypothesis of this research, the variation magnitude of thermal neutral temperatures throughout the day could be considered as the comfort range of an analyzed area and, therefore, as a reference to determine the structural properties of buildings. In this way, the thermal inertia of buildings would moderate their internal temperatures to make them fall within the neutral temperature range to guarantee thermal comfort to inhabitants without having to activate mechanical conditioning devices.

The field study was conduced in Colima City, Mexico (latitude: 19 N; longitude 104 W; altitude 520 meters above sea level). The climate of Colima is considered as warm sub-humid, with a rain season of five months.

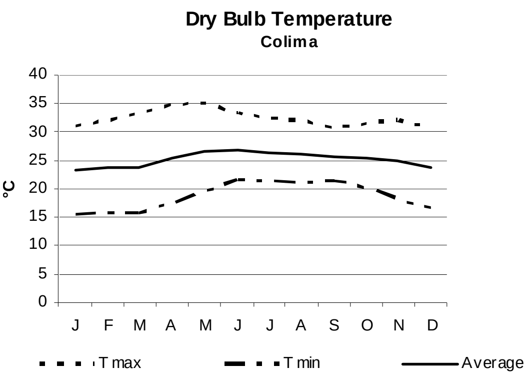


*Fig 1. Annual Dry Bulb Temperature in Colima, Mexico*

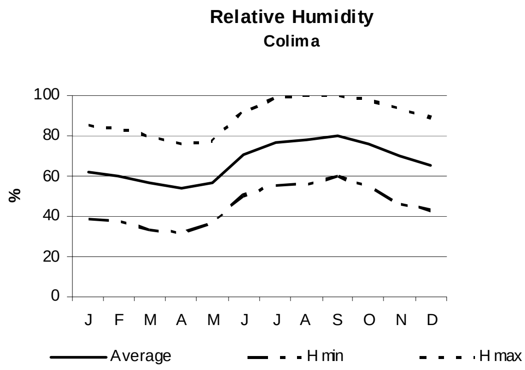


*Fig 2. Annual Relative Humidity in Colima, Mexico*

A preceding version of this report was conducted from 600 collected surveys. That previous report was presented and published during a research forum in Mexico. (Gomez-Azpeitia, 2008).

## 4. Methods and Material

For the development of the study, fifteen families consisting of forty volunteers (28 women and 12 men, age between 15 and 55 years old) were chosen. Each volunteer received training about the research goals, the use of the climatic recording equipment, the multiple choice scale of thermal comfort vote, and the way to register answers and climatic data on a previously designed log sheet. Each volunteer was asked to record a comfort vote from the scale along with other required data on the survey as many times as possible throughout the day (hourly, if possible) while they were inside the house. This study was conducted for 53 consecutive days—from October 31 through December 22, 2007 — at different hours throughout the day. This time period is considered the winter transition for the region. At the end of the study, 1412 logs were registered by the volunteers.

All the single-family homes used in the study were natural-ventilated houses and had no mechanical conditioning. The walls of the houses were made of bricks or cement blocks with a mortar finish (with a thickness between 15 and 25 cm) and roofed with reinforced concrete. Each had either sliding windows or jalousie windows with a single 3 mm glass layer thickness. The surveys were based on the main common area of the house, the living room. The livable surface of the houses varies from 55 to 250 m2 and has an average indoor height of about 2.7 meters.

The survey was designed according to ISO Standard 7730 (ISO, 2005) and ISO Standard 1051 (ISO, 1995). These standards define the multiple choice comfort scale that could be applied to inhabitants. These standards are based on a scale model developed by Bedford (Table1).

Table 1: Thermal value scale based on Bedford (1936).

| Value | Evaluation or “thermal comfort vote” |
|---|---|
| 3 | Hot |
| 2 | Warm |
| 1 | Sightly warm |
| 0 | Neutral |
| -1 | Slightly cool |
| -2 | Cool |
| -3 | Cold |

During the study, an operating data logger, model H8-004-002 (Onset HOBO) with measuring sensors for dry bulb temperature, globe temperature and relative humidity was placed within each house. In addition, a very simple and low-cost anemometer was also placed within each house. This is a dumper omnidirectional anemometer and it was designed and built by the research team as suggested by B. Givoni during a visit to the University of Colima back in 2003. The dumper omnidirectional anemometer is able to log slow wind velocities, as lower than 1 m/s. The range of logging of the dumper anemometer is 0 to 6.5 m/s.

*Fig. 3: Dumper omnidirectional anemometer based in an idea suggested by Givoni.*

Each time a volunteer recorded a thermal comfort vote, they also registered the wind speed provided by the anemometer as well as the time of log. Then, the research team retrieved the rest of the information from the data logger according to the time registered previously by the volunteer.

Even though the volunteers were instructed to record a log every hour this was not accomplished as expected, thus there were time periods where the data recorded was very sparse. Consequently, the comfort data was classified into three-hour groups in order to obtain enough information that would determine neutral temperature for a given time lapse. Moreover, no records were logged during sleeping times, between 01:00 to 06:00.

The studied time groups were six:

- From 07:00 to 09:59
- From 10:00 to 12:59
- From 13:00 to 15:59
- From 16:00 to 18:59
- From 19:00 to 21:00
- From 22:00 to 00:59

The procedure to obtain the neutral temperature value (Tn) for each time group was accomplished by the movable mean regression method (Gomez-Azpeitia, et al., 2008) where Tn is the result of the intersection of value 0 (thermal neutral) of ordinates and the regression line of dry bulb temperatures average values (DBT) obtained on each comfort choice group.

## 5. Results

The neutral temperature obtained from 1412 records was 26.28°C (Figure 4)

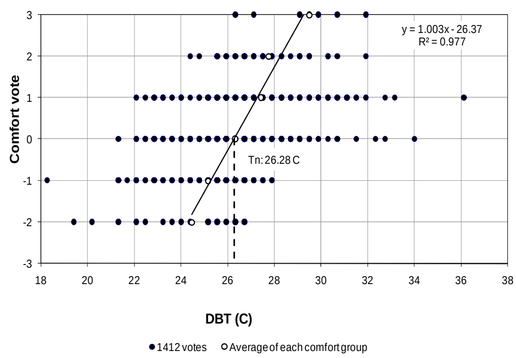


*Fig.4: Neutral temperature obtained by means of the movable mean regression method (constructed from self-collected data).*

However, for each one of the time groups a different Tn was acquired (table 2)

*Table 2: Neutral Temperature Value (Tn) in Celsius degrees for each time group (constructed from self-collected data).*

| Time-table | Tn (C) |
|---|---|
| 7:00 a 9:59 hrs. | 24.49 |
| 10:00 a 12:59 hrs. | 26.19 |
| 13:00 a 15:59 hrs. | 27.96 |
| 16:00 a 18:59 hrs. | 27.52 |
| 19:00 a 21:00 hrs. | 26.93 |
| 22:00 a 0:59 hrs. | 26.01 |

It can be appreciated that Tn has a tendency to increase toward noon time, in the same way the daily rate of environmental temperature does (DBT). This suggests a dependency of both variables. Consequently, the outdoor temperature records for the study's span were requested from the National Meteorology Service (SMN), located in Colima, City.
In figure 5, the rate of outdoor temperature (DBT) can be appreciated throughout an average day during the research timeframe, as well as the rate of neutral temperature value (Tn) acquired through the study.

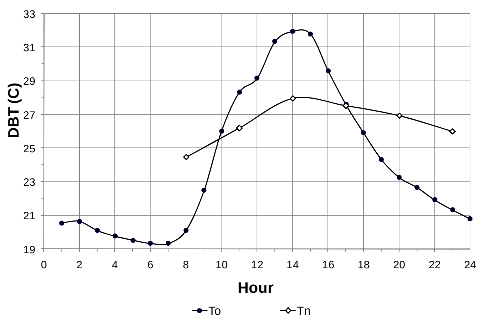


*Fig. 5: Outdoor temperature rate of an average day (provided by National Meteorological Service SMN), and neutral temperatures by time group (constructed from self-collected data).*

Due to the similitude of both curves, a calculation to the factual correlation between both variables was run. The result confirmed the bias. The found correlation was high r = 0.81 (figure 6).

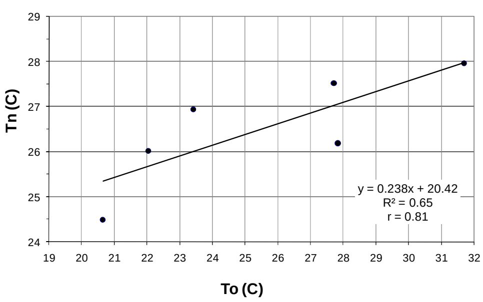


*Fig. 6: Correlation between outdoor temperature (To), and neutral temperature values (Tn) registered during the study.*

Thus, it is possible to determine the neutral temperature values from the rest of the day by applying the regression lineal equation to the correlation result with an agreeable certainty of accuracy.

$$Tn_n = 0.238\,(To_n) + 20.42$$

where:

$Tn_n$ = Neutral temperature at n hour
$To_n$ = Outdoor temperature at n hour

In figure 7, the hourly rate of neutral temperatures computed on the equation oscillates within a 3.2 K range (between 25.03°C and 28.04°C) having 26.16°C as the average value. This is very close to the Tn obtained for the 1412 records (figure 4), and not registering at the middle of the range but with a tendency to the low side, showing a higher tolerance toward temperatures above Tn than toward the ones below.

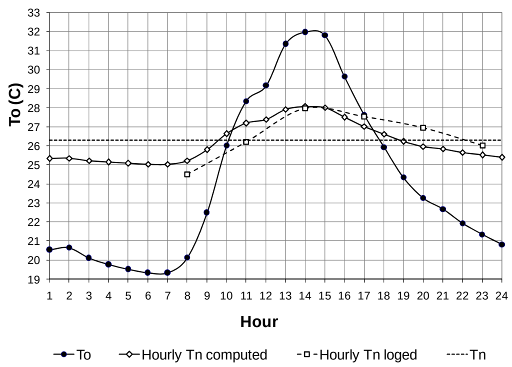


*Fig. 7: Computed neutral temperatures and oscillation range (constructed from self-collected data).*

## 6. Conclusions

The obtained data assesses the validity of Roriz hypothesis. Neutral temperature values from hour groups show a significant variation and a high correlation to outdoor temperatures.
The standardization of hourly thermal comfort is useful as a reference to determine the thermal performance of buildings while still at the designing stage, besides adjusting closer to the adaptive model conditions.
The indoor temperature rate (Ti) of natural-ventilated buildings is similar to the outdoor temperature rate with two main differences. The indoor maximum temperatures occur after the outdoor maximum temperatures are registered. This phenomenon is known as thermal delay and is measured in hours. Besides, the indoor maximum temperatures are usually less severe than the outdoor maximum temperatures, even though it depends on the type of building. Light buildings have wider temperature oscillations than massive buildings and can even register more extreme indoor temperatures than outdoor temperatures.
As can be seen, the regimen of indoor temperatures in natural-ventilated buildings undergoes a dynamic process. Therefore, it is more congruent to compare it to an equally dynamic thermal comfort regimen than to a fixed thermal rate, which is currently being use to

determine the requirements for mechanical conditioning.

For instance, the thermal performance of two buildings were compared: a light building such as a hut with bajareque walls and covered with straw; and a massive building such as a house with brick walls and roofed with reinforced concrete. The indoor and outdoor temperatures were monitored in both buildings through November 2002 (Alcantara, 2004). The collected data conforms in time with the study of 2007.

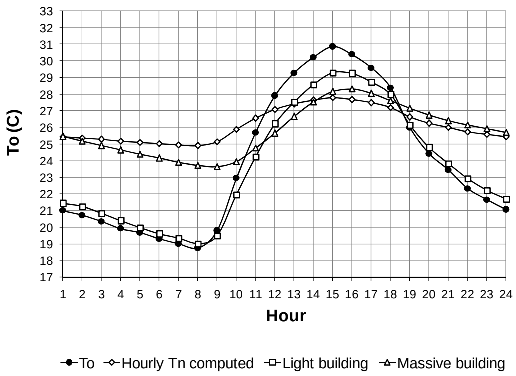


*Fig. 8: Thermal performance of a light and a massive building in relation to an hourly comfort rate (constructed from self-collected data).*

In figure 8, the monitoring temperature data was superimposed to the historical temperature rate from November and to the estimated hourly neutral temperature. Note that the massive building shows a better adjustment to the neutral temperature curve. The light building, on the other hand, shows a better adjustment to outdoor temperatures, moving away from the possibility to provide comfort, consequently.

This kind of analysis can help architects make decisions while designing the structural properties of a building.

## 7. Acknowledgements

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