RESEARCH ARTICLE OPEN ACCESS

Climatology Applied To Architecture: An Experimental Investigation about Internal Temperatures Distribution at Two Test Cells

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ABSTRACT
Data were analyzed en relative spatial distribution of the internal surface temperature (IST) and internal air temperature or dry bulb (TBS), in two different test cells, for a typical experimental day under the influence of tropical mass. The main goal of this research is to provide guidelines to collect temperature data experimentally since there is not an appropriate standard to guide this methodological procedure in buildings. The data series of dry bulb temperature and internal surface temperatures were measured in a test cell with a green roof and the other with conventional ceramic roof by thermocouples installed at predetermined locations. The data of solar radiation and the main climatic variables were recorded by the automatic weather station at the Center of Science Engineering Applied to the Environment (CCEAMA), School of Engineering of São Carlos (EESC-USP). The results led to the conclusion that the distribution of the internal surface temperature is almost uniform in the two test cells, but in relation to the dry bulb temperature there is a small vertical temperature gradient in the conventional cell. This work will contribute significantly to future studies in the area of human comfort and environmental suitability of buildings.

***Keywords* -** Dynamic climatology, Test Cells, Spatial distribution, Internal temperatures

I. INTRODUCTION

The starting point for this research was the need to establish more precise parameters for methodological procedures of acquiring internal temperature data, which could lead to more adequately experimental studies. Furthermore, it must take into account the existing climate reality, since numerous studies conducted experimentally do not treat this issue with due importance.

However, the methodological procedures to collect meteorological data applied to buildings (temperature, humidity, ventilation, etc.), do not have precise standardization, which could enable the understanding of the atmospheric fluctuations in buildings and help the exchange of information among researchers. There are, in fact, the international standards ISO 7726[1] and ASHRAE 55[2], and the Brazilian standard ABNT NBR 15575 [3], which specify the position of the measuring equipment of the internal air temperature.

These standards differ in some issues, making it difficult to choose the most appropriate by researchers. The ISO 7726 standard is a benchmark for the standards ASHRAE 55 and ABNT NBR 15575[1, 2, 3], and establishes the procedures for measurements and instruments to be used, and differentiates the places in homogeneous and heterogeneous. Moreover, ISO 7726[1] does not specify the locations of the equipment inside the places [4].

In the case of the standard ASHRAE 55 [2], it is applied to studies about thermal performance and comfort when there is human occupancy and presents the evaluation of limits parameters for internal air temperature, mean radiant temperature, air velocity, between others. This standard recommends that the equipment location is at the center of the place to be measured, in the case of only one measuring point, or 1.00 m apart from each inner wall if there are more measuring points. Regarding the height of the equipment, the standard ASHRAE 55 [2] uses the same recommendations in ISO 7726 [1].

The Brazilian performance standard for residential buildings, ABNT NBR 15575 [3], provides two procedures for determining the thermal performance of sealing and roofing systems: the procedure #1, simplified and normative, which evaluates the thermos energetic performance of the building through computer simulation (it recommends the use of Energy Plus software), and the procedure #2, for information only, which should be done in buildings or prototypes in full scale through dry bulb temperature measurements in the center of living rooms and bedrooms, at 1.20m from the floor.

In this second procedure for evaluation purposes is considered a typical day, summer or winter, according to the outdoor air temperature. For both procedures, the standard establishes the use of information from some Brazilian cities, such as geographic location and climate data, according to the bioclimatic zone of the country [5].

If the architectural project is for a city that does not have available climate data, the NBR 15575-1[3] recommends the use of data from a nearby town with similar climatic characteristics, and is located in the same bioclimatic zone.

The lack of more detailed requirements and the simplification of the climate data use in the thermal performance analysis show the limitation of Brazilian standards on adequacy of buildings to actual weather conditions.

This feature present in the ABNT standards clearly shows that climate approach used in most studies on thermal performance and comfort is the Classical Climatology, which simplifies the most of use of climate variables values, and works with an "average condition" of atmosphere, i.e., the local climate is only a combination of some weather elements, according to the needs of each study, to reach a specific and particular objective. Classical climate approach is, therefore, artificial and generic, once it adopts an abstract scenario of climate conditions. In other words, it does not take into account the usual fluctuation of types of weather [6, 7].

Thus, in order to establish a more appropriate method for evaluating thermal performance and comfort, according to the types of weather, Dynamic Climatology seeks to identify a more appropriate interpretation of the climate, so as to align it to needs of architecture.

The concept of climatic rhythm based on the foundations of Dynamic Climatology and defines climate as the succession of atmospheric events expressed by fluctuations in weather elements that act interdependently on a region [8].

For the Dynamic Climatology, in these terms, the succession of weather types is due to the movement of air masses, specifically the polar mass, which allows the weather identification knowing the air mass origin, trajectory, and its dynamic properties [7, 8].

Authors[9], analyzed the climate dynamics of South and Central America based on rainfall data coupled with the atmospheric circulation features. They recognize the complexity of the interaction between climatic elements at different scales of time and space.

The concept of air masses is not accurate because the atmosphere is not divided simply. However, it adopts the didactic representation of a polar or tropical mass as a unitary portion of air, which remained stationary over one place (continental or maritime) and period, and acquired unique thermodynamic properties of temperature, humidity and atmospheric pressure [9, 10].

Therefore, climate analysis to understanding the succession of weather types that occur on a particular site, it is made from the application of representative episodes, relating the phenomena of atmospheric circulation to the records obtained in surface and, thus, understanding the pace of time fluctuations and cycles of these variations throughout the year.

After analyzing the representative episode of climate, it is possible to elect an experimental typical day for more visibility of weather events.

In this sense, this research work is developed in order to contribute in the search for more suitable conditions for human comfort, knowing the existing climate reality.

Nevertheless, this work does not intend to carry out a complex climate analysis, but present to construction professionals (Architecture and Engineering) the possibility of understanding the weather and its influence on buildings. This basic notion about the weather can help in designing more appropriate architectural projects to the site and enable the validation of energy efficiency simulation software.

II. METHODOLOGICAL PROCEDURES

The investigation was carried out about the distribution of internal temperatures, in two test cells with different roofs, based on comparative analysis of thermal performance in a heat situation. This paper aimed to verify if the positions where the sensors were installed is significant to collect temperature data.

This research was based on Dynamic Climatology, which prescribes the experimental typical summer day for obtaining analysis results. In this work, temperature data were collected using thermocouples installed at predetermined locations in two test cells, on a green roof and on a conventional ceramic roof. The data regarding the main climatic variables for the experimental typical day were collected by an automatic weather station at the Center of Science Engineering Applied to the Environment (CCEAMA), School of Engineering of São Carlos (EESC), University of Sao Paulo (USP).

Fig. 1 Experimental plot at CCEAMA/USP - (a) Green roof test cell - (b) Ceramic roof test cell

The IST and DBT values from test cell were collected through thermocouples type T copper-constantan, 2x24 AWG, with measurements at intervals of 30 minutes, recorded and stored by a CR10X datalogger. All equipment and sensors in the automatic weather station, as well as 12V rechargeable battery, solar panel, and CR10X datalogger, are from Campbell Scientific Inc. company, responsible for the collection and storage of external climate data.

All measurements in the test cells were performed with doors and windows closed to check the temperature without the influence of air flow on the records collected.

2.1 Test cells and the automatic weather station

The study was conducted at the experimental plot at CHREA, in Itirapina city, Sao Paulo State, Brazil.

The test cells are constructions in masonry massive ceramic bricks, internal dimensions of 2.00 m x 2.50 m, with a default wooden door of 2.10 m x 0.60 m (South facade) and a wooden window of 1.0 m x 0.70 m (North facade). The only variation involves the different types of roof. They were designed to ensure equivalence to a real situation in data acquisition and they have the same incidence of solar radiation without casting shadows on each other.

The test cell with a green roof has a preformed slab (12.25 m2 area), 23% slope and 0.40m ledge for green roof support. Therefore, the test cell with green roof stayed with the maximum ceiling height of 2.86 m and minimum of 2.54 m (Fig. 1(a)).

Green roof is made up of common grass (Paspalum notatum), a substrate, MacDrain 2L geocomposite as drainage blanket (in partnership with Maccaferri do Brasil Ltda.) and a waterproofing layer, a polyurethane resin derived from castor oil (Ricinus communis), developed by the Group of Analytical Chemistry and Technology of Polymers, Chemistry Institute of São Carlos-USP, Brazil. It is designed to be equivalent to the weight own weight of a conventional roof system with wooden frame and ceramic tiles [11].

The conventional test cell has a ceramic roof with a wooden structure above a preformed concrete slab. The ceiling height is 2.40 m roof with 26% slope. This test cell represents the cover system widely used in the Brazilian civil construction (Fig. 1(b)).

2.2 Installation of temperature sensors inside test cells

To assess the indoor air temperature (DBT), thermocouples were installed in the middle of the cell, varying the heights (0.10 m, 0.60 m, 1.10 m, 1.70 m and 2.10, all of them from the floor). These heights were defined exclusively for this research in investigative character and the sensors could be well distributed in the area of the building which occurs the activities of users. Other two sensors were included in this evaluation: IST 14 in the ceiling and IST 32 on the floor (Fig. 2 and 3). The difference between values of indoor air temperature has fundamental importance to the stress heat feeling in indoor environments [12]. In total, there are five sensors for data acquisition of DBT with PVC shelters and insulated with foil blanket.

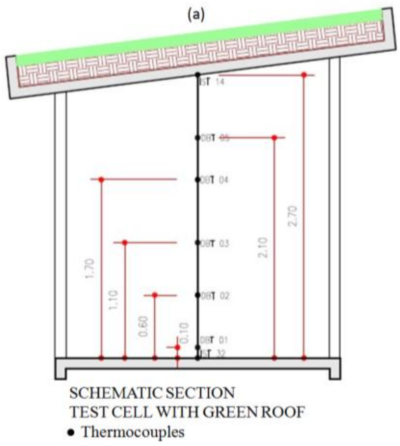


Fig. 2 Schematic section for both test cells - DBT and IST sensors (a)

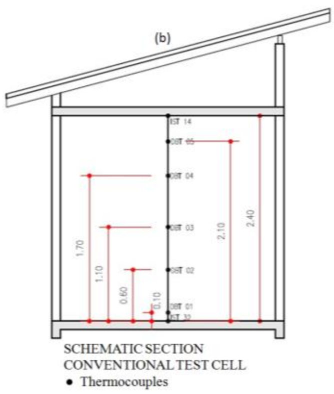
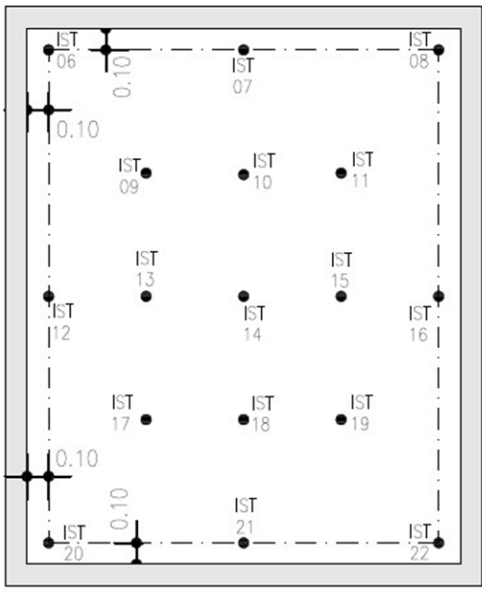


Fig. 3 Schematic section for both test cells - DBT and IST sensors (b)

The thermocouples for internal surface temperature (IST) in both test cells ceiling were installed as shown in Figure 4. With this distribution of sensors in the ceiling surface, we intended spatial measurement to check if there is a significant difference between the temperature values of sensors. The sensors farthest from the middle point were positioned 10 cm from each wall. In the diagonal and perpendicular lines, there is a sensor equidistant from the middle point and its respective sensor close to the wall. In total there are 17 points of IST sensors in the test cell (Fig. 4). The location of each sensor was established in investigative character and enough to perform the analysis.



SCHEMATIC INTERNAL ROOF PLANT
CONVENTIONAL TEST CELL
● Thermocouples

Fig. 4 Internal coverage plan for IST sensors

All thermocouples installed on surfaces were placed in a simple way, with a small hole on the surface to fit the sensor tip and covered with thermal paste to avoid interference in the data records.

2.3 Analysis of Summer Episode - Brazil's Southeast region

Data collected refer to the fluctuations of the meteorological weather between February 26th to March 24th, 2013 (Julian days 58 to 83), corresponding to the summer period in the Southern Hemisphere.

According to the recorded climatic events, by analyzing meteorological variables and confirming satellite images (Fig. 5), we extracted the experimental typical summer day, which showed maximum solar radiation, higher outside air temperature, and clear skies. Such are the basic conditions for evaluating the behavior and thermal performance of buildings for a heat situation.

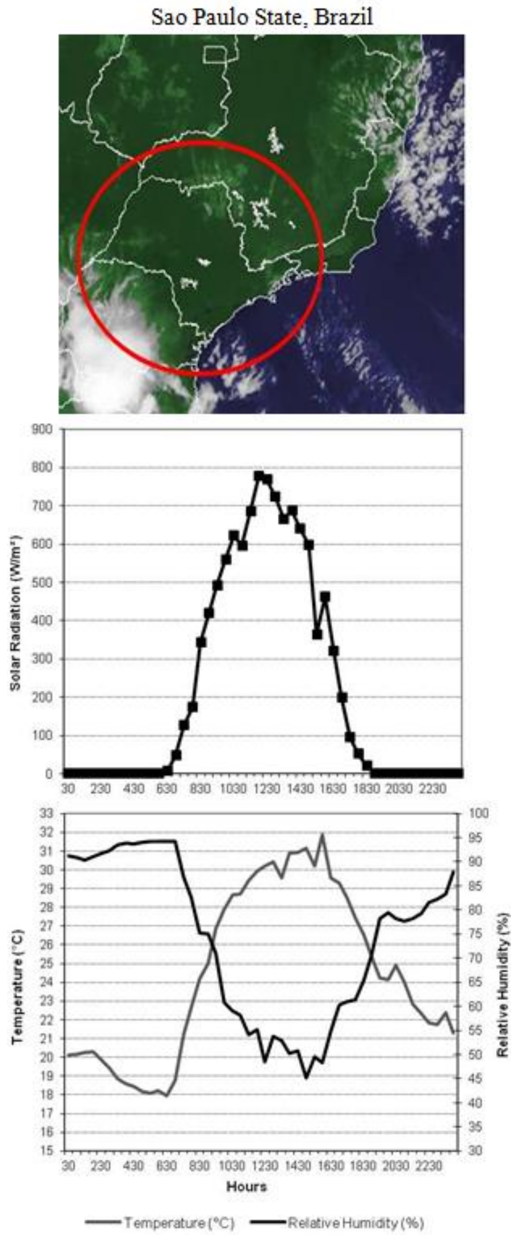


Fig. 5 Experimental typical day summer - March 4th, 2013

On March 4th, 2013 (63rd Julian day) was taken as the experimental typical day due to its remarkable heat characteristic that surpasses the value of 27 °C, which is the average maximum of Climatological Normals obtained in Itirapina city region from 1961 to 1990. The temperature range recorded on this day was 13.93 °C, with a minimum temperature of 17.94 °C and a maximum of 31.87 °C. The day was cloudless, with values of global solar radiation that reached 779W/m2.

III. RESULTS AND DISCUSSION

Figure 4 refers to the data cell with the green roof and show the daily variation of the dry bulb temperature and internal surface temperatures of the floor and ceiling.

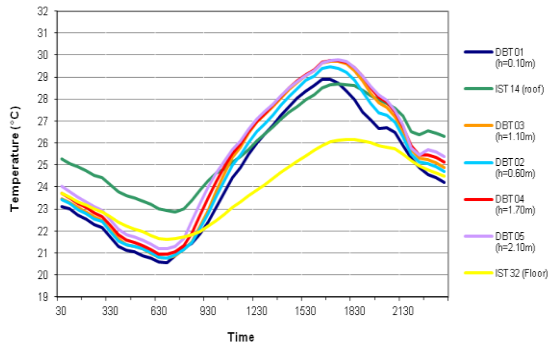


Fig. 4 Dry Bulb Temperatures chart - Green roof - March 4th, 2013

Regarding the data of the green roof, sensors located at 1.10 m, 1.70 m and 2.10 m from the floor recorded the highest temperature 30 °C and higher temperature range at 9 °C.

The closest sensors from the floor, 0.10 and 0.60 m (DBT 01 and 02, respectively) had temperature variations somewhat smaller, about 8.5 °C. The floor sensor, followed by the sensor installed in the ceiling, had the lowest maximum temperatures and smaller temperature variations compared with the outside air temperature.

The difference between the outside air temperature sensor and the ceiling (IST 14) was 3.5 °C, whereas between outside air temperature and the sensors to 1.10 m, 1.70 m and 2.10 m (DBT 03, 04 and 05, respectively) was approximately 2 °C. The analyzes from comparisons between the dry bulb temperature sensors revealed that the vertical temperature gradient is almost uniform.

For the test cell with the ceramic roof was elaborated the graph of Figure 5 for better data visualization.

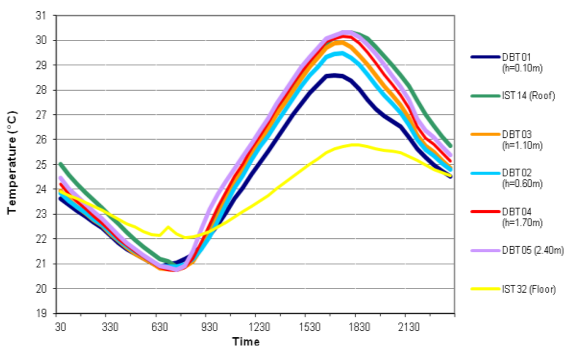


Fig. 5 Dry Bulb Temperatures chart - Ceramic roof - March 4th, 2013

In the analysis for the conventional test cell, the floor sensor (IST 32) had lower temperature range (4 °C) compared to all other sensors. The sensors 1,10 m (DBT 03) and 1.70 m (DBT 04) recorded temperature ranges of 9 °C, while the sensors at 2.10 m (DBT 05) and the ceiling (IST 14) had the higher temperature range among all sensors, approximately at 9.5 °C. This shows that the vertical temperature gradient in this test cell is not uniform, since the maximum temperature values increased as the proximity of the cover system.

The difference between the outside air temperature and the sensors at 1.10 m and 1.70 m was approximately 2 °C, and compared to the value collected by the roof sensor (IST 14), the outside air temperature was 1.5 °C higher.

In comparison of the thermal performance of both test cells, the roof sensor (IST 14) installed at green roof recorded maximum temperature 2 °C lower than the same sensor at conventional test cell. Therefore, the temperature range for this sensor at the green roof was 4 °C lower than the registered in the other test cell.

3.1 Internal Surface Temperature Analysis - Roof systems

The most complex analysis of internal surface temperature (IST) involves the roofing system and understanding the spatial distribution on the ceiling surface under the influence of solar radiation. The coverage system is the constructive element that receives higher incidences of radiation.

To facilitate the interpretation and analysis of data collected by these sensors, two graphs were drawn for each cell, one for the closest sensors to the walls: those located at 0.10 m from each wall, and one for the more internal sensors located at equidistant points between the sensors closer to the walls and the middle sensor on imaginary lines (transverse, longitudinal, and two diagonals). Middle point data were included in both charts (Fig. 6).

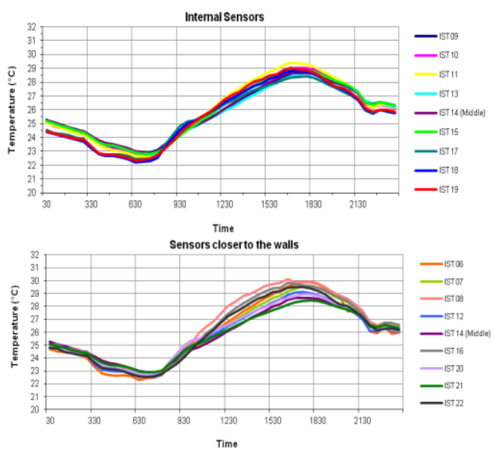


Fig. 6 Internal Surface Temperatures charts - Green roof - March 4th, 2013

The central sensor (IST 14) recorded a maximum temperature lower than all sensors. The internal sensors showed maximum temperatures slightly lower compared to those sensors closest to the walls.

In the case of external sensors, thermocouples positioned near the North and West facades recorded maximum temperatures slightly larger than thermocouples facing the south and east walls, possibly due to the sun's apparent path, which may have influenced the incidence of solar radiation on the green roof. The lowest maximum temperature was IST21 sensor compared with sensors positioned in the same region. The temperatures can probably have been influenced by a small accumulation of water near the IST 21 sensor during the period. Therefore, the draining next to this sensor is not identical to the others sensors.

Also, the biggest differences between all surface temperature sensors were no more than 1.5 °C, and the temperature range also had a little variation. However, this variation has no a physical sense, because it is not perceived by users in thermal comfort studies. Thus, the spatial distribution of maximum internal surface temperature may be considered uniform, even though conditions such as substrate saturation and its drainage capacity have not been controlled and may have influenced the recorded temperatures.

In the analysis of the internal surface temperature for the conventional test cell, was elaborated the graphs in Figure 7.

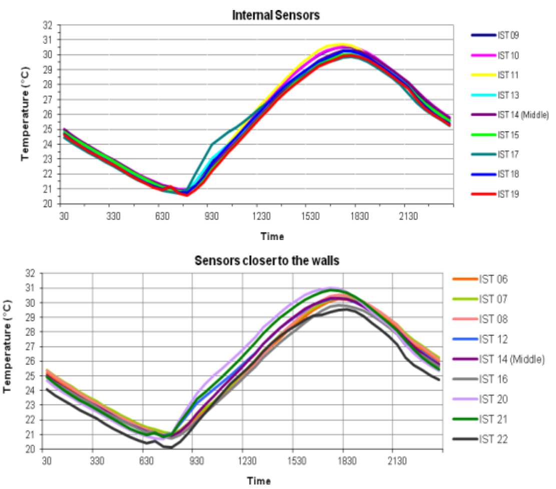


Fig. 7 Internal Surface Temperatures chart - Ceramic roof - March 4th, 2013

In conventional test cell, the spatial distribution of surface temperatures was also uniform, varying from 0.5 to 1.5 °C between the maximum of some sensors. The existence of the attic with permanent ventilation among the roof and the slab, assured the condition of uniformity for all maximum temperatures, except for IST 22 sensor, which may have suffered a bit of rust during the data collection period, so recorded temperatures a little smaller than the other sensors.

In both test cells, the internal surface temperature distribution of the ceiling were uniform, but as was expected the maximum values were lower in green cover. In addition, the ceiling sensors in green roof presented a lower temperature range compared to the outside air temperature, approximately 7 °C less. In relation to the conventional test cell, the ceiling sensors had 2 °C temperature range lower than outside air temperature. This fact demonstrates the best performance of green roof because delaying the heat input to the internal environment during the day and mostly reduce the heat loss by night irradiation.

IV. CONCLUSION

When this research was started, we tried to analyze the recorded data by thermocouples in each test cell, in order to better understand the internal thermal distribution in these buildings. However, the similarity in the data showed that the spatial distribution of surface temperatures in each test cell was practically uniform. The same happened to the dry bulb temperature, which also reported not significant differences between the five sensors in each test cell.

For measurements of internal surface temperatures (IST), any point can be considered, since the surfaces are uniform, and the sensors are protected by thermal paste.

In the case of dry bulb temperature measurement is important that the sensors are placed in thermally insulated experimental shelters, and equidistant from the surfaces that may influence the data collected, such as walls exposed to the north and west facades (South hemisphere). In this type of measurement, it is also necessary to check all possible influences that may occur during this process, such as ventilation or the habits of users, since this research the only controlled variable and evaluated was the temperature in both closed test cells. The height for installation of dry bulb sensors can be variable because it depends on the study, which shows the differences between the specifications of the standards mentioned in the work.

For both types of measurement is also necessary to respect the following guidelines: the sensors must be protected from solar radiation and the requirements for installation and maintenance of thermocouples need to be followed, according to each manufacturer [11, 12]. But it is important to know the usual rhythm of atmospheric processes in the study area, for the performance and comfort show results consistent with the actual local situation, always considering solar radiation as the main triggering factor of heat exchange processes between internal and external environments, and not the outside air temperature.

Therefore, this work contributes significantly to future studies of dynamic climatology applied to the architecture.

ACKNOWLEDGEMENTS

The authors wish to thank CNPq for their financial support and the staff of the Climatological Station CCEAMA-USP, for their collaboration on technical issues and on research execution.

The Center for Studies and Research and Urban Mobility - NEPMOUR the Meridional Faculty for their support during the tabulation and interpretation of data.

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