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Learnings from Thermal Comfort Adaptation of Jain Ascetics During Heat Waves

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Highlights

- Severe heat waves are affecting a large vulnerable population in India, impacting their health and well-being.
- The Jain monks and nuns in India have been leading their lives without electricity use for hundreds of years.
- This study went beyond the India Model for Adaptive Comfort range for indoor operative temperatures.
- 90% of the surveyed subjects expressed acceptability of the thermal conditions in the strong heat stress range. of UTCI
- Improved adaptive thermal comfort range can help bring down the cooling related energy consumption significantly.

Abstract

Climate change is leading to severe heat waves in India, affecting a large vulnerable population and impacting their health and well-being. The recent adaptive thermal comfort research for Indian climates suggested that the people living in residential buildings can adapt to indoor temperatures upto 35 °C. The Jain ascetics in India have been leading their life without the use of electricity for hundreds of years, irrespective of the temperatures. In this study, thermal comfort surveys with 20 monks and nuns were carried out during summer for the composite climate of Delhi. 90% of the subjects expressed acceptability of the thermal conditions while the indoor operative temperatures varied between 35 °C and 40 °C. This study should offer hope to people globally that if we can gradually adapt to the rising temperatures, we may be able to move on with our lives without affecting our comfort or health.

Keywords: Adaptive thermal comfort, ascetics, UTCI, health and wellness, heat waves

Introduction

Climate change is leading to severe heat waves in India, with higher temperatures that arrive earlier and last longer in recent times [1]. These heat waves could break the human survivability limit in the coming years. More than two-thirds of the Indian population earns less than USD 2 per day, and it may not be able to afford active cooling. Temperatures beyond the thermal comfort range [2] could result in extreme heat stress and severely affect the health and well-being of individuals. Even those who may be able to afford active cooling solutions may suffer from sick building syndrome with the use of cooling systems such as split air-conditioners, as these systems reduce the fresh air delivery in indoor spaces.

The science to combat climate change for energy use in buildings the world over has focussed broadly on the three principles of passive solar architecture, energy efficiency of equipment, and using clean sources of energy [3]. The science should also urge people to reduce energy consumption, which is also related to UN sustainable development goal no. 12 of “Responsible consumption and production” [4]. Prof Chetan Singh Solanki [5] recently suggested that human beings should avoid one-third of their energy consumption by changing their lifestyles. The Jain monks and nuns in India have been leading their lives without the use of energy for thermal comfort for hundreds of years [6]. In an experiment carried out on Tibetan monks by Mind/Body Medical Institute at Beth Israel Deaconess Medical Centre in Boston [7], the monks performed G Tummo meditation and were able to dry up ice-cold water sheets from the heat being radiated from the monk’s body. G tummo yoga technique trains the mind to regulate the internal body temperature to attain thermal comfort. Wim Hof [8] has also designed a self-tested three-step method – breathing, cold therapy and commitment to adapt to extreme cold conditions and the same is taught to other individuals.

People feel thermally comfortable in buildings when they don’t feel hot or cold. ISO standard 7730 definition [9] suggests thermal comfort to be the “condition of mind which expresses satisfaction with the thermal environment”. It is assessed using subjective evaluation in the form of surveys about a person feeling hot or cold [10]. Two types of approaches to thermal comfort have been studied over the past decades - the heat balance and the adaptive thermal comfort approach. The heat balance approach was led by Prof Fanger [2] in the early 1970s. It is based on climate chamber experiments and indicates that the thermal sensation is related to the thermal load on the human thermoregulatory system. It helps the HVAC engineers to design the optimum thermal environment by working with air temperature, humidity, mean radiant temperature and air speed. The concerns with this approach have been about the chamber experiments not reflecting the real world experience of the occupant or taking into account the cultural, climatic, and social contexts of the occupants. Moreover, this approach relies on mechanical ventilation systems to provide thermal comfort, which is energy-intensive [11]. The adaptive thermal comfort approach suggests that the past thermal history and context can influence occupants' thermal preferences. People living in warmer climates would prefer higher indoor temperatures than cold climatic zones. The thermal adaptation lessens the human response to continuous environmental stimulation. It can be behavioural (clothing, windows), physiological (acclimatization), and psychological (cultural and social context) [12]. The perception can also vary depending on whether the buildings are naturally ventilated, air-conditioned, or in mixed mode. This approach helps with reducing the need of energy for heating and cooling, thereby helping with the issue of global warming. This approach has been based on field studies using regression models relating the indoor temperature as a function of outdoor air temperature. India's model of adaptive thermal comfort (IMAC) was developed based on the adaptive thermal comfort model [13]. It was based on field surveys in three seasons and five different climatic zones of India. It found that the occupants in naturally ventilated offices in India were more adaptive than the existing ASHRAE and EN models. It found the neutral temperature in naturally ventilated buildings to vary from 19.6 to 28.5 ℃ for 30-day outdoor running, with mean air temperatures ranging from 12.5 to 31 ℃. Another adaptive model was constructed for Indian residences – the India Model for Adaptive Comfort - Residential (IMAC-R) based on year-long field surveys across five climate zones of India [14]. It found that more than 80% of the residential occupants in India experienced a neutral temperature in the indoor temperature range of 16.3–35 ℃ for a 5.5–33 ℃ variation in the 30-day outdoor running mean temperature.

There have been limited studies of people being able to withstand colder temperatures wilfully without any active means of heating and no scientific studies of people being able to withstand higher temperatures beyond the adaptive thermal comfort range to the best of our knowledge. In this paper, we would like to study the adaptive thermal comfort-based lifestyles of Jain monks and nuns to learn from them. Why do they live without the use of any energy for heating or cooling? How are they able to persevere? Is the wider thermal comfort range acceptable to them? Do they feel uncomfortable? Is it possible to have a higher adaptive thermal comfort range for Indians than what is suggested by IMAC-R? This research would help the vulnerable populations in India to increase their adaptive thermal comfort range thereby helping them to be in a better situation to sustain the effects of heat waves. It would also help the world in general to reduce the consumption-based lifestyles [15].

Methods

The research design, field surveys, and data analysis are based on the ASHRAE RP-884 document [12]. This paper is based on the data collected over a survey campaign in residential buildings in the composite climate of Delhi [14], lasting for two consecutive days in the month of May, which has hot and dry weather. The surveys were administered in naturally ventilated buildings. The subjects were interviewed in six buildings, with three of them being multi-storied residential buildings and three of them being Jain Sthanaks, buildings specially designed for the stay of Jain monks and nuns. The Jain Sthanaks have been designed for natural ventilation and have higher window to wall ratios, typically over 65%. The building material for the Jain Sthanak appeared to be similar to that of other typical buildings.

The thermal comfort point in time surveys were based on the surveys in [14] and were conducted with occupants to have responses from them about their thermal sensation vote, thermal preference vote, thermal acceptance vote, air movement acceptance vote, air movement preference vote, and overall comfort. The surveys also had questions about their age, gender, weight, height, and activity 15, 30 and 60 minutes before the survey. Building information was also sought. Indoor

Table 1: Instrumentation details

Device	Indoor parameters	Range	Accuracy	Resolution
Testo 400 CO_2 probes	CO_2 (ppm)	0-10000 ppm	±(50 ppm + 3 % of mv) (0 to 5000 ppm) ±(100 ppm + 5 % of mv) (5001 to 10000 ppm)	1 ppm
Testo 400 CO_2 probes	Air Temperature (℃)	0 to 50 ℃	±0.5 ℃	0.1 ℃
Testo 400 CO_2 probes	Relative Humidity (%)	5 to 95 %	±3 %rH (10 to 35 %rH) ±2 %rH (35 to 65 %rH) long-term stability: ±1 %RH/ year Hysteresis: ±1.0 %rH ±3 %rH (65 to 90 %rH) ±5 %rH (Remaining Range) ±0.06 %RH/K (0 to +50 °C)	0.10%
Testo 400 hot wire probe	Air velocity (m/s)	0 to 50 m/s	±(0.03 m/s + 4 % of mv) for (0 to 20 m/s) ±(0.5 m/s + 5 % of mv) for (20.01 to 30 m/s)	0.01 m/s
Testo 400 globe	Globe Temperature (℃)	0 to 120 ℃	Type K thermocouple, class1. Approximately 30 minutes adjustment time	0.1 ℃

climate measurements were recorded using hand-held devices placed near the occupant while the survey response was taken, meaning that each set of measurements was spatio-temporally coincident with the occupant's location. All instruments were ensured of calibration before each campaign. Table 1 provides details of the sensors used for measurement. Testo 400 transmitter was used with 2 wireless Testo CO_2 probes that measured CO_2, air temperature, and Rh, another wired Testo probe measured globe temperature, and two other wireless Testo probes measured air speed. The average value of the measurements was taken for each parameter. ASHRAE Standard 55-2017 [10] methodology was used for operative temperature calculations. Meteorological data for air temperature and relative humidity was publicly available and was obtained from the closest Central Pollution Control Board (CPCB) Air Quality Monitoring Station (AQMS) in Rohini, Delhi, to the sites for the TCS surveys. The CPCB AQMS was about 5 km away from the sites. The raw data was checked for errors, after which the survey responses and the measured sensor data were merged using a time stamp to create a single row of data corresponding to each subject. This led to one set (row) per survey of results in the final data matrix which was used for the thermal comfort analysis. PMV, PPD thermal comfort indices for each survey entry were calculated using the ASHRAE Thermal Comfort Tool developed by UC Berkeley [16] with indoor air temperature, relative humidity, mean radiant temperature, air speed, clothing insulation, and metabolic rate as the inputs. The UTCI thermal comfort index was computed using the UTCI calculator [17].

Results and Discussion

The interviewed subjects were monks and nuns from the Jain Sthanakvasi sect of Shvetambara Jainism [18]. The subjects had vowed not to use any electricity from the time of their monkhood. The average years of monkhood in the subjects was 24 years. The monks and nuns wear white clothes, as shown in Figure 1. The clo values for the clothing for the monks were interpolated from the clo values for the existing garments from ASHRAE Standard 55-2017 and were assumed to be 0.54 clo for monks. The clo values for nuns was assumed to be 0.62 based on the research done for finding clo values for an Indian sari [19]. The checklist of activities was provided in the TCS form to document the subjects' activities in the hour preceding the survey, divided into three time brackets of 15/30/60 minutes before the interview. Most of the subjects were sitting for most of the time before the interview. Some of them were standing, walking, or washing utensils or clothes during or before the interview. The activities were translated into metabolic rates based on the tables published in ASHRAE Standard 55-2017.

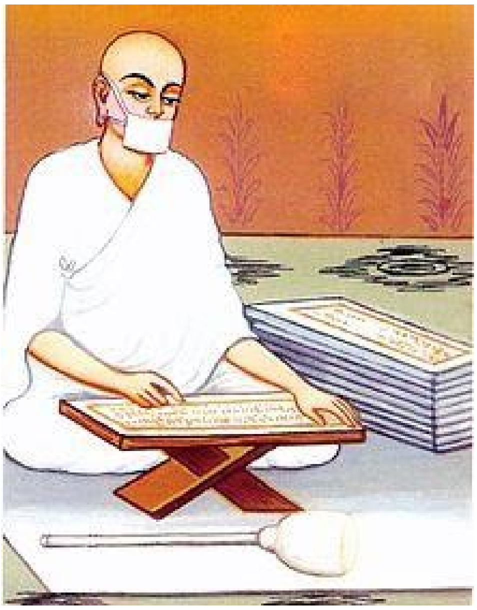

Figure 1: Painting of a Jain Sthanakvasi Monk [18]

The thermal comfort surveys (TCS) and the measurements of indoor climate parameters of the monks and nuns surveyed went hand in hand. The measured parameters included air temperature, relative humidity, and air speed. The globe temperature was measured for the first case, and it was found to be similar to the air temperature so it wasn't measured for the rest of the surveys as there seemed to be a general absence of sources of radiation across all the buildings surveyed. For the indoor spaces where there is no direct solar radiation coming from the survey location, the mean radiant temperature can be assumed to be equal to the air temperature. A brief interview was also conducted with the willing monks and nuns to understand how they managed thermal comfort over the past five years since they didn't use any electricity, irrespective of the weather conditions. A total of 20 TCS were gathered from 6 buildings. Of the 20 TCS, 11 were gathered from monks and 9 from nuns. Table 2 describes the surveyed residential buildings. All the subjects were staying on a higher floor of the building. The survey campaign lasted for two days during a heat wave condition in Delhi. 9 out of 20 subjects were females in the age groups of 22 to 64 years. 11 out of 20 subjects were males in the age groups of 18 to 84 years. The BMI of the subjects varied between 18 and 33. The surveys were conducted during the morning, afternoon, and evening, with the majority of them during the afternoon.

For both days of the survey campaign, three researchers were involved. The team approached the willing occupants and asked if the time was convenient for the survey. Two of the researchers interviewed the monks and the nuns for the instantaneous survey and the long-term thermal comfort management, while the other researcher took environmental measurements as close to the position of the respondent as feasible. Additional information about the building was also recorded, and the respondent's location was marked on the floor plan.

Table 2: Description of surveyed residential buildings

Building type	**Floor**	**Surveyed Monks**	**Surveyed Nuns**	**Total subjects surveyed**	**Survey Time**	**Survey Date**
Multi-storied residential building	Second	3	2	5	3:15 pm to 5:15 pm	22nd May 2023
Jain Sthanak	Second	0	3	3	7:15 pm to 7:45 pm	22nd May 2023
Multi-storied residential building	Second	1	2	3	10:30 am to 11:15 am	23rd May 2023
Jain Sthanak	Second	4	0	4	1 pm to 2 pm	23rd May 2023
Jain Sthanak	First	3	0	3	3:30 pm to 4:45 pm	23rd May 2023
Multi-storied residential building	First	0	2	2	6:15 pm to 6:35 pm	23rd May 2023

The surveys happened during the heat wave in Delhi. Figure 2 shows the outdoor air temperature and the outdoor relative humidity variation for the days of the survey. The minimum outdoor air temperature was calculated as 27.4℃, the mean as 37.5 ℃, and the maximum as 43.5℃. The minimum outdoor relative humidity was recorded as 26.1%, the mean as 31.6%, and the maximum as 56.6%. The weather in the evening of 23rd May 2023 became windy with higher chances of rain, which cooled down the temperatures. The minimum indoor operative temperature was calculated as 35.1℃, the mean as 37.7 ℃, and the maximum as 39.9℃. The minimum indoor relative humidity was recorded as 23.8%, the mean as 32.7%, and the maximum as 41.7%. The indoor air velocity was below 0.2 m/s for 95% of the cases since the fans were not used. For most of the cases, the indoor operative temperature was below the outdoor air temperature.

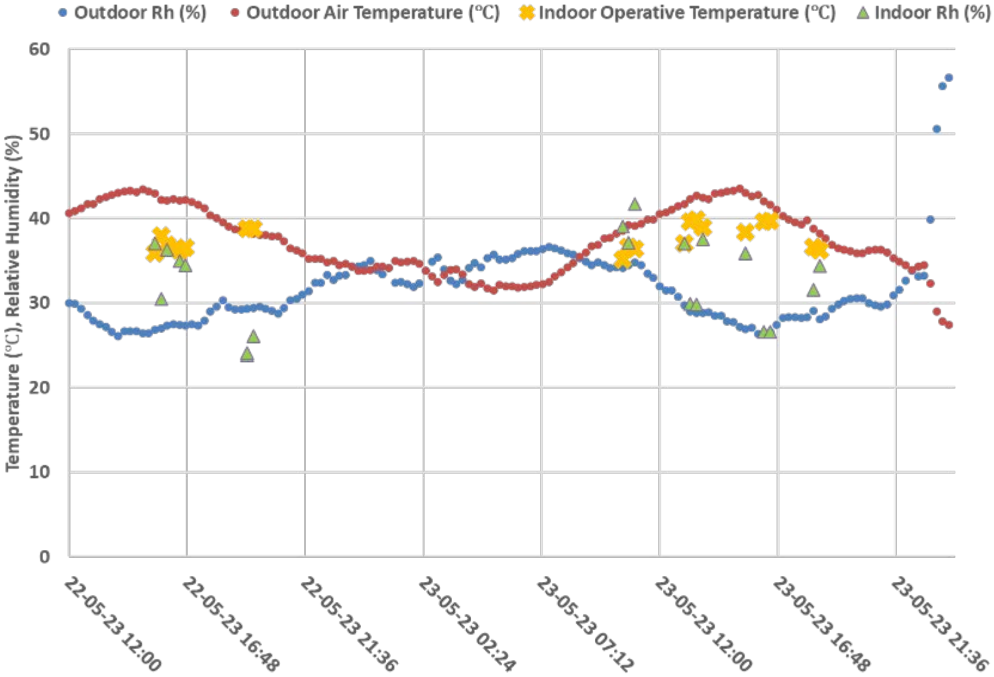

Figure 2: Indoor and outdoor temperature and relative humidity data

Figure 3 shows the results from the TCS point in time survey when the indoor operative temperatures ranged from 35 ℃ to 40 ℃. 60% of them expressed a neutral thermal sensation (Figure 3(a)), with 45% of them suggesting no change in thermal preference (Figure 3(b)) and 90% of them finding the thermal conditions to be acceptable (Figure 3(c)).

PMV was computed using the Berkeley thermal comfort tool, with the minimum PMV being 1.8, the mean PMV being 3.7, and the maximum PMV being 4.6. The percentage of people dissatisfied (PPD) was above 98% for 90% of the subjects. Figure 4 shows that the calculated PMV had a statistically significant non-zero slope in the equation with the indoor operative temperature (T_{op}). Figure 4 also shows that the observed TSV had a zero slope in the equation with T_{op}. 30-day outdoor running mean temperature ($T_{out-30DRM}$) was computed with α = 0.8 [14]. The neutral temperature was computed by using those indoor operative temperatures for TSV=0 and performing a linear regression with $T_{out-30DRM}$.

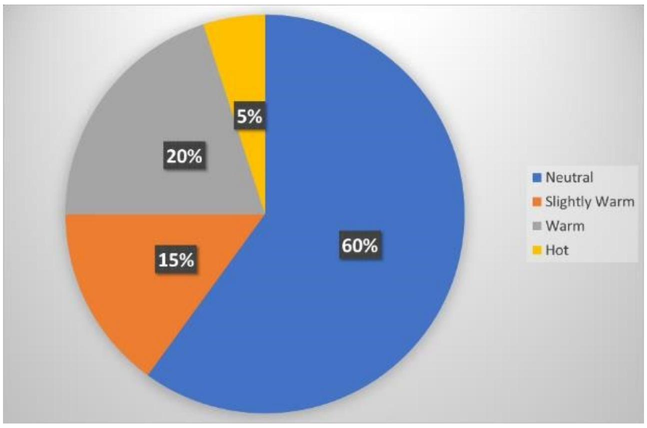

Figure 3(a): Thermal Sensation Votes (TSV)

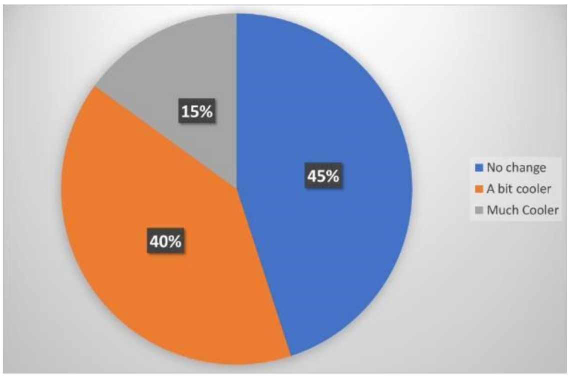

Figure 3(b): Thermal Preference Votes (TPV)

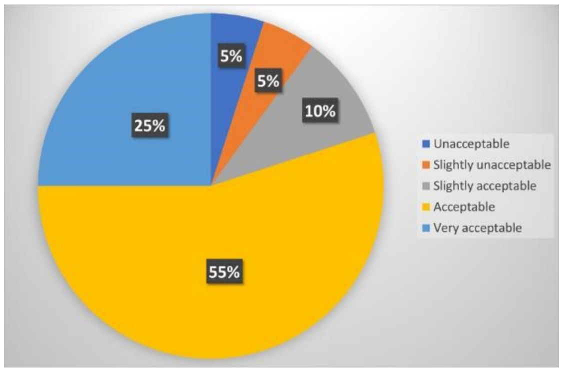

Figure 3(c): Thermal Acceptability Votes (TAV)

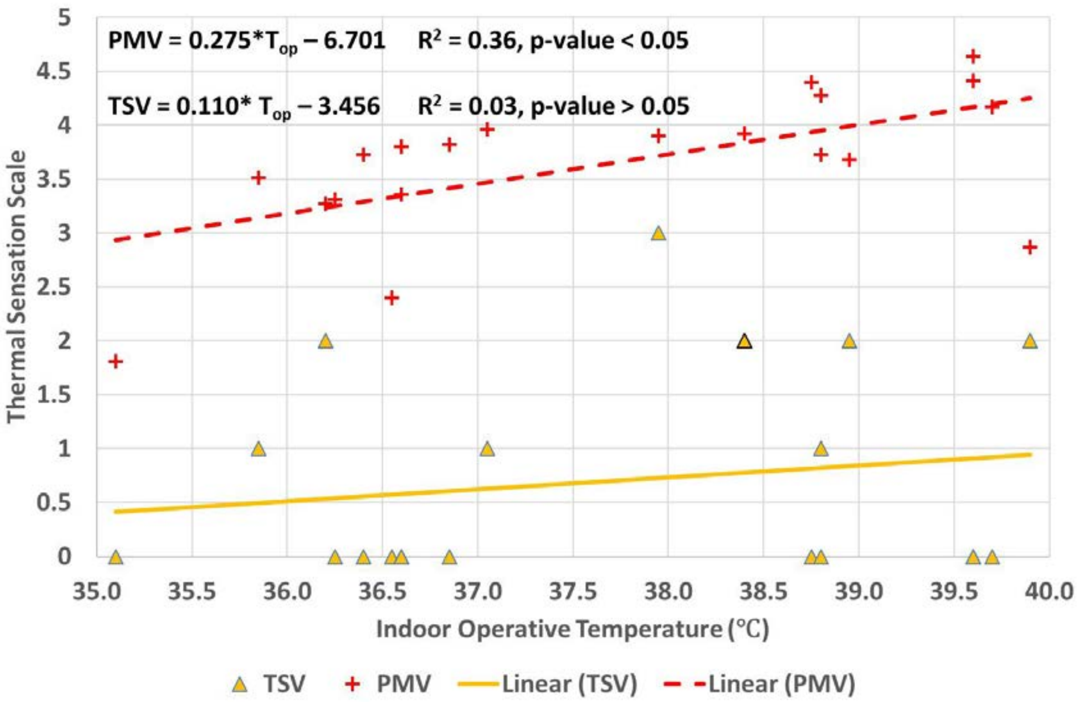

Figure 4: Comparing observed TSV and calculated PMV with Indoor Operative Temperature

Figure 5 shows that the adaptive thermal comfort model with the neutral temperature as a function of $T_{out\text{-}30DRM}$ is not statistically significant with a zero slope. Figure 6 shows the points on the UTCI vs. TSV graph marked separately for monks and nuns. Most of the subjects expressed a neutral thermal sensation even though the UTCI was in the range of strong to very strong heat stress.

IMAC-R model [14] suggests that 80% or more occupants from Indian residential buildings in naturally ventilated or mixed mode buildings felt a neutral thermal sensation for the indoor operative temperature of 16.3–35 °C for a 5.5–33 °C variation in the 30-day outdoor running mean temperature. Our survey data for neutral thermal sensation for indoor operative temperatures (Figure 5) from 35.1 °C to 39.7 °C is beyond the range of the IMAC-R adaptive thermal comfort model. One of the two data points for the outdoor running mean temperature is also greater than 33 °C. But observing the data for $T_{out\text{-}30DRM}$ of 32.6 °C, we are able to find 4 out of 8 cases having a neutral thermal sensation for a T_{op} up to 38.8 °C. Figure 4 shows that the linear regression model of TSV as a function of T_{op} had a zero slope since there were many neutral thermal sensation points among the data. On the contrary, the PMV predicted a thermal sensation beyond 3 (‘Hot’) for 17 out of the 20 subjects. PMV underpredicted the adaptability of the subjects significantly when compared to TSV. The UTCI, which takes into account the effect of air temperature, mean radiant temperature, relative humidity, and air speed for the neutral thermal sensation, also ranged in the strong to very strong heat stress range (Figure 6), suggesting that there is scope to work on the UTCI index for subjects from tropical climates.

We may wonder why we are getting neutral thermal sensations for these subjects in the strong heat stress range. We may want to think of these subjects as the exceptions not falling in the 80% acceptability range of the adaptive thermal comfort model with them being more adaptive thermally. The surveyed Jain monks and nuns have vowed not to use electricity from monkhood, and so they must have gone through behavioural, psychological, and physiological adaptation over the years. When asked the question about the thermal sensation they had for the present temperature corresponding to their TSV, some of them said that they remain equanimous no matter what the thermal conditions are. In our case, equanimity would translate to a neutral thermal sensation. They have been living without electricity for many years so they must have become acclimatized physically and accustomed psychologically. During a survey, one of them mentioned that 50-60 years ago, many villages in India didn't have access to electricity, and people lived comfortably without it. The heat waves and urbanization may not have been so intense earlier, but it did get hot in the hot and dry climates of India. A couple of them also mentioned that due to past health conditions, they are not able to withstand so much heat. Others said that mentally, they are neutral with the thermal sensation, but physiologically, they did feel slightly warm or warm. They said that physiologically, they have similar experiences as the rest of us, but psychologically, they are more adaptive. However, we can also think of these subjects as an inspiration to the country and the world to improve our thermal adaptation.

The ascetics have taken it as a constraint to live in sync with nature and not use any electricity. Within this constraint, they explore behavioural adaptation methods to feel better, such as moving to a room that is cooler in a building or going to a place that is breezy, or using the evaporative cooling from a wet cloth put on the body when it gets hot. Some of the subjects suggested that the use of a wet cloth for cooling was typically done during the night time to get a better sleep. The ascetics also preferred to stay on higher floors of the building as there is a greater probability of the higher floors being airy. The Jain Sthanaks, where the ascetics prefer to stay, have a much higher window-to-wall ratio, typically 65% or higher. Some of the Sthanaks had such high window-to-wall ratios on two or more facades. This building architecture

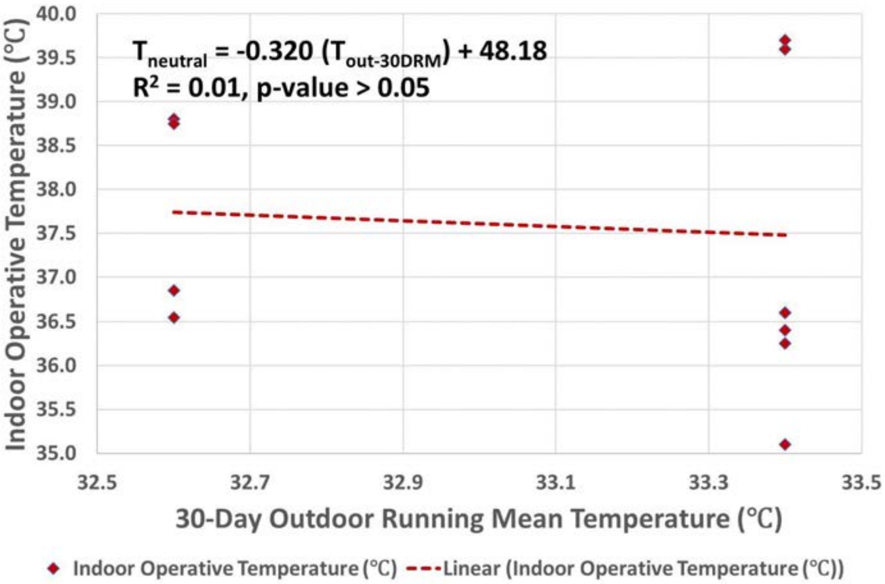

Figure 5: The adaptive thermal comfort model with neutral temperature = f($T_{out-30DRM}$)

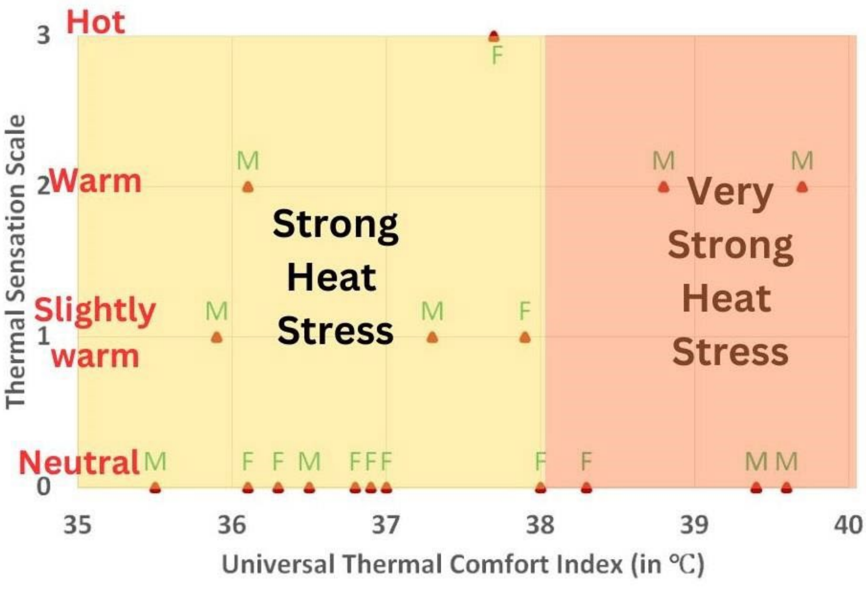

Figure 6: TSV vs. UTCI for monks and nuns

leads to higher cross-ventilation rates and may help them with higher comfort levels without the need of energy. It raises a question about the architecture of the buildings designed for air-conditioning. These buildings would have lower window-to-wall ratios to reduce the cooling loads, and it may be more difficult to operate them in natural ventilation mode. Further studies are suggested to compare the impact of window-to-wall ratios on the thermal comfort of the occupants.

These behavioural adaptations can help the vulnerable populations in India to adapt to the heat waves when they can't afford active cooling. The vulnerable populations would include the poor people suffering from the heat waves amidst the increased urban heat island effect due to rapid urbanization in India. It would also include the labourers who have to work in hot temperature conditions without access to cooling. It could also include the prisoners who may not have access to thermal comfort for cooling. This can also help the folks living in the colder climates in the West to know that there are human beings who can withstand higher temperatures in the heat stress range comfortably. Increased thermal adaptation can bring energy consumption down to meet the world's cooling needs. The research scholars conducting the surveys also felt that they were surprised that they could withstand such a high temperature without even the use of fans. Not using the fans is another notable difference from the IMAC-R model, where the air speed from the fans would have helped the subjects to be comfortable. They only get higher air speed due to the occasional wind from the windows. The survey was done during the heat wave, and during this time of the year, the wind that comes during the day time is hot, which doesn't provide comfort, so most of the surveyed subjects didn't prefer the wind.

This study also shows how significant the effect of culture can be in adaptive thermal comfort. One of the principles followed by the Jain ascetics is not to harm any living beings or the environment. They think that using electricity harms living beings. This vow helps them with improving their adaptive thermal comfort. On a minor note, it also can create discomfort for some of them. One of the nuns said that it can be more discomfortable during the night time over day time during this time of the year. The reason is that during this time of the year, there are insects affecting their sleep. Since culturally they wouldn't kill them so, some of them would use mosquito nets to prevent insects from biting them. This, however, reduces the airflow to them and makes it uncomfortable for them to sleep. It is important to have a way to make these measurements during the night time as well as to capture the thermal sensations at that time. A monk suggested doing an outdoor thermal comfort study with them since that might be more intense since they walk barefoot. They don't cook their food and some of them have to go out barefoot and walk on the hot asphalt roads during the days in the summer to get their food. They also don't cover their heads while walking in the summer sun in north India, so they would be experiencing high mean radiant temperatures due to the effect of the sun. Studying their outdoor thermal comfort can help understand their adaptation amidst high mean radiant temperatures and high metabolic rates. It is also worth noting that the Jain ascetics eat lacto-vegetarian food that they get from their households. They don't keep leftover portions for the night, so they tend to take smaller portions of food per person. They also tend to fast more often. It would be worth studying the impact of their food intake on their thermal comfort in the future.

While the lifestyle of these ascetics is inspiring, can we generalize the results we have achieved to the larger population of India, having diverse lifestyles interlinked with varied cultural and religious backgrounds? For instance, the food intake and the activities of vulnerable groups such as labourers may be quite different, so an in-depth study would be needed to find out how the lifestyles of these ascetics would help the other population groups to improve their thermal adaptation. This study was the first step to find out through scientific methods if they lead an extremely adaptive thermal comfort based lifestyle by correlating the TCS and the interview scripts with actual measurements. As a next step, we need to have a bigger sample size and study these subjects in other seasons as well to have an informed understanding of their adaptation. After that, we can conduct experiments with typical people in controlled conditions after letting them know about the lifestyle of these ascetics. Based on the findings from these experiments in controlled conditions, TCS could be performed in the field where people actually live their lifestyles in the real world. These people could be introduced to some of these behavioural and psychological adaptations of the ascetics before the survey, and they could be observed longitudinally to find out if they are able to adapt better than before. However, it is possible that the ascetics living a lifestyle of choice of not using energy may not work for the vulnerable population with a lifestyle that is "given" to them. Even the people who can afford cooling may not be able to get rid of mechanical cooling altogether, but it is possible that they may be able to reduce their cooling needs from before. It might be difficult for people who can afford air-conditioning to give it up as opposed to our grandparents who lived in times when it didn't exist. When the ascetics were asked for advice on how other people could reduce their cooling needs, some of them suggested that they could start by reducing their cooling needs by 5%, and then, depending on their adaptation, they could keep on widening their thermal comfort range. The objective of this study is not to interfere in the lifestyles of people but to take cues from these findings to know what is possible to improve adaptation and reduce energy consumption since climate change is a serious concern, and we have to explore all the ways that can help.

Conclusion

This study helped in understanding the thermal comfort adaptation in the heat wave conditions of Jain monks and nuns. Their thermal comfort was in the heat stress range as per the present thermal comfort indices. The sample size for this study was 20, and the study was done in the composite climate of Delhi during the hot and dry summer days. Future studies should be done to capture the effect of monsoon and winter on their thermal comfort indoors as well as outdoors. These studies should also be conducted in other climates of India with them. This study would also open doors for exploring other aspects of their lifestyles and comparing them with people leading a conventional life through the life cycle assessment framework to help the majority of our population to find sustainable ways of living through scientific understanding. It is also suggested to study other communities and professionals who undergo thermal adaptation and learn from them. The objective of this study was to show that it was humanly possible in the present times to have a neutral thermal sensation during heat waves in tropical cities such as Delhi when the cooling demand is much higher. It should offer hope to people from all around the world that if we can gradually adapt to the rising temperatures, we may be able to move on with our lives without it affecting our comfort or health.

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Nomenclature

BMI: Body Mass Index

PMV: Predicted Mean Vote

PPD: Percent People Dissatisfied

TAV: Thermal Acceptability Vote

TCS: Thermal Comfort Surveys

TSV: Thermal Sensation Vote

TPV: Thermal Preference Vote

Top: Indoor operative temperature

$T_{out-30DRM}$: 30 day outdoor running mean temperature

UTCI: Universal Thermal Climate Index

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