Learnings from the extreme thermal comfort adaptation of Jain ascetics during the summer and the monsoon months in India

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1. Abstract

Heat waves are rising in intensity and frequency. They could break the human survivability limit in India in the coming years. The goal of this paper is to understand the extreme thermal comfort adaptation of ascetics from Jain Svetambara sects in hot and dry as well as warm and humid weather in India to help the vulnerable populations beat the heat. A total of 65 subjects were interviewed in Delhi, Jodhpur, Siriyari and Ahmedabad between May and September 2023. Surveys were carried out with measurements of the indoor environment according to the adaptive thermal comfort methodology. Around 75% of the subjects had a neutral or a cooler thermal sensation while the thermal comfort index, UTCI, was in the strong to very strong heat stress range. Ninety percent of the subjects found these thermal environments to be acceptable. Two-third of the subjects preferred no change in the humid conditions when more than 50% of them acknowledged the presence of higher humidity in their indoor environment. An adaptive thermal comfort model proposed in this study suggests that it is possible to go beyond the IMAC-R model to further reduce the cooling needs of the warming world.

Keywords - adaptive thermal comfort, ascetics, UTCI, health and wellness, IMAC-R.

2. Introduction

Today, the world collectively emits over 50 billion tonnes of CO2 equivalent every year (Our World in Data, 2023). Many of the countries have pledged to bring down emissions to net zero levels by 2070 to keep the global temperature rise to less than the safe limit of 1.5 °C by the turn of this century (United Nations, 2023). Buildings are responsible for about half of the total electricity consumption in the world (International Energy Agency, 2022). Space heating and cooling accounts for nearly half of this consumption. The demand for space cooling is predicted to be more than three times by 2050 in the base case scenario due to the warming planet (International Energy Agency, 2018). While the cooling energy consumption can be brought down to a certain extent by passive solar architecture techniques and energy efficiency of cooling equipment, there is significant potential for increasing the adaptive thermal comfort range of people to reduce the need for cooling. Adaptive thermal comfort approach suggests that people in warmer climates can withstand higher indoor temperatures than the people from colder climatic zones. This approach suggests that people can undergo physiological (bodily responses to prevailing ambient thermal conditions or acclimatization), psychological (subjective preferences for a thermal sensation) and behavioural (occupant level changes such as clothing or envelope level interventions such as opening windows) thermal adaptation with their environment leading to reduced energy needs for heating and cooling (de Dear & Brager, 1997). India Model for Adaptive Comfort-Residential (IMAC-R) was developed with year long field surveys across all the Indian climates. It found 80% or more residential occupants expressing satisfaction with indoor temperature range of 16.3-35 °C for a 5.5-33 °C variation in the outdoor running mean temperature (Rawal et al., 2022). Jain ascetics have been experiencing comfort at the extreme, living without the use of any energy for hundreds of years (Muni Sheelgun Vijayji, 2023). In a study involving thermal comfort surveys of 20 Jain monks and nuns during the heatwave conditions in May 2023 with hot and dry weather in the composite climate of Delhi, 90% of the ascetics expressed acceptability of the thermal conditions with the indoor operative temperatures (Top) varying between 35 °C and 40 °C (Dhariwal & Gangrade, 2023). The work in this paper is being extended to understand their thermal comfort adaptation during the warm and humid weather conditions as well. To the best of the understanding of the authors, there is no other known work about people being able to withstand hotter temperatures beyond the adaptive thermal comfort range for the warm and humid conditions, which are increasing in intensity and lasting longer.

3. Methods

The research methodology, thermal comfort surveys and data analysis is inspired from the ASHRAE RP-884 document (de Dear & Brager, 1997). The thermal comfort right here right now surveys (Manu et al., 2016) were the basis for the surveys in this study. The responses were asked about the subjects' personal information, activity, building information, thermal sensation, air movement, humidity and overall comfort. They were also asked about their long term thermal comfort management strategies and concerns. Indoor environment measurements were recorded using sensor monitors near the occupants at the same time when the surveys were conducted. Testo 400 monitor was used with two wireless CO2 probes measuring air temperature and relative humidity, one wireless probe measuring air speed and another wired probe measuring globe temperature (Table 1). Testo 400 devices came with a calibration certificate during the purchase. They were also tested for accuracy before the experiments.

The indoor operative temperature (Top) calculations were based on ASHRAE Standard 55 methodology (ANSI/ASHRAE Standard 55-2017, 2017). The outdoor air temperature and relative humidity data was publicly available from the Central Pollution Control Board (CPCB) website (Central Pollution Control Board, 2023). The meteorological data was taken from the Air Quality Monitoring Station (AQMS) in Rohini, Delhi for the Delhi sites, AQMS in Collectorate, Jodhpur for the Jodhpur sites, AQMS in Indira Nagar, Pali for Siriyari and Kamlighat sites and Sardar Vallabhbhai Patel Stadium, Ahmedabad AQMS for the Ahmedabad sites. The air temperature data for the dates of the field survey was not available for the Pali AQMS so, this data was taken from the nearest AQMS at Jodhpur. There was a quality check for the data from the surveys and the sensors after which this data was merged to create a row of data per subject with a timestamp. ASHRAE Thermal Comfort Tool (Tartarini et al., 2020) was used to compute the PMV, PPD thermal comfort indices. The UTCI calculator was used to calculate the UTCI thermal comfort index (UTCI, 2023).

Table 1: Details of the instruments used

Device	Indoor parameters	Range	Accuracy	Resolution
Testo 400 CO_2 probes	Air Temperature (°C)	Air Temperature (°C)	±0.5 °C	0.1 °C
Testo 400 CO_2 probes	Relative Humidity (%)	5 to 95 %	±3 %RH (10 to 35 %RH) ±2 %RH (35 to 65 %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 probes	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 (°C)	0-120 °C	Type K thermocouple, class1. Approximately 30 minutes adjustment time	0.1 °C

4. Results

The surveyed subjects were monks and nuns from the Sthanakvasi, Terapanth and Murtipujaka sects of Svetambara Jainism (Jainism Global Resource Center, 2023b). A total of 65 subjects were interviewed with 37% of them being monks and the rest being nuns. We had 22 out of 65 subjects from the Sthanakvasi and Terapanth sects each and 21 out of 65 subjects from the Murtipujaka sect. The total number of surveys was 70 having 5 subjects interviewed twice with 40% of the surveys done for the monks and the rest for the nuns. The ascetics interviewed two times were surveyed once each in the hot and dry weather in May 2023 and warm and humid weather in September 2023 in Delhi. The subjects did not use any electricity from the time of their "Diksha" (monkshood or nunhood). Some of them would not allow the visitors to use fans or lights in their presence but

others would allow them to do so. The fan at a low speed was on during the time of the survey only for 16/22 surveys from the Terapanth sect, 4/21 surveys from the Murtipujaka sect and for none of the 27 surveys from the Sthanakvasi sect. 3/20 of the surveys, where the fan was on, were old and had medical conditions. The average years of "Diksha" in the subjects was 26 years with a standard deviation of 18 years. The monks and nuns of Svetamabara Jainism wear white clothes (Figure 1). The clo values for the clothing for the monks was interpolated from the clo values for the existing garments from ASHRAE Standard 55-2017 and was assumed to be 0.54 clo. The clo values for nuns was assumed to be 0.62 based on the research done for finding clo values for an Indian sari (Indraganti et al., 2015). The nuns were in the age groups of 12 to 85 years with the average age of 46 years, while the age of the monks varied from 18 to 86 years with the average age of 47 years. The BMI of the subjects varied between 17.8 (5th percentile) and 32.5 (95th percentile) with an average of 25. The map in Figure 2 represents the five climatic zones of India (Nayak & Prajapati, 2006) having the details of the field survey locations and the dates of the surveys. The surveys were conducted in the composite climate region of Delhi during May and September 2023 and hot and dry climatic zones of Jodhpur, Siriyari and Kamlighat (a rural area near Siriyari) in June 2023 and Ahmedabad in July 2023 (Figure 2).

Figure 1: Photo of Svetambara sect nuns (Wikipedia, 2023)

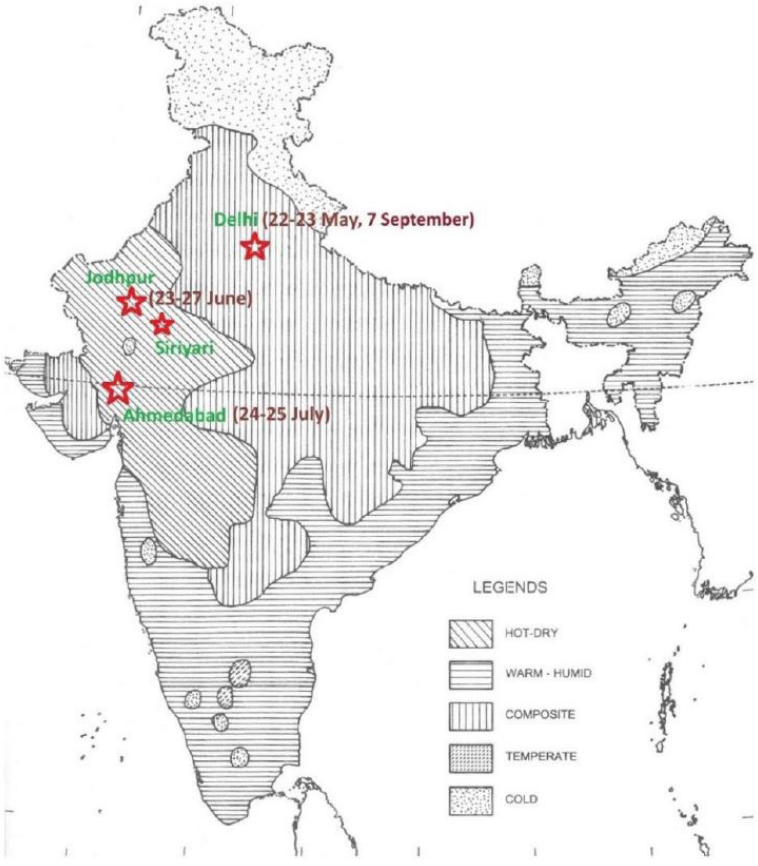

Figure 2: Field surveys in Delhi, Jodhpur, Siriyari and Ahmedabad during 2023

The surveys were administered in buildings using natural ventilation during the time of the survey. The subjects were interviewed in 22 buildings with six of them being multi-storied residential buildings, four being Dharamshalas and the rest twelve of them being Upashrays (Table 2). Dharamshalas were buildings where the ascetics stay but these buildings also have rooms for others to stay. Upashrays are buildings specially designed for the stay of Jain monks and nuns in between their travel from one place to another. The Jain Upashrays have been designed for natural ventilation and have higher window to wall ratios, typically over 50%. The building material for the Dharamshalas and the Upashrays appeared to be concrete based, which is similar to the other typical buildings of the area. The surveys were conducted from 8:45 am in the morning till 10:15 pm in the night with over 50% of the surveys in the afternoon. 26/70 surveys happened in Delhi, 21/70 subjects in Ahmedabad and 23/70 of them were from Jodhpur and Siriyari area in the state of Rajasthan.

Table 2: Description of the buildings where the surveys were conducted

Place	Building type	Floor	Surveyed Monks	Surveyed Nuns	Survey Time	Survey Date
Delhi	Residential	2	3	2	3:15 pm to 5:15 pm	22nd May 2023
Delhi	Upashray	2	0	3	7:15 pm to 7:45 pm	22nd May 2023
Delhi	Residential	2	1	2	10:30 am to 11:15 am	23rd May 2023
Delhi	Upashray	2	4	0	1 pm to 2 pm	23rd May 2023
Delhi	Upashray	1	3	0	3:30 pm to 4:45 pm	23rd May 2023
Delhi	Residential	1	0	2	6:15 pm to 6:35 pm	23rd May 2023
Jodhpur	Upashray	0	0	1	1:30 pm to 2:30 pm	23rd June 2023
Siriyari	Residential	0	2	0	10:30 am to 11:30 am	25th June 2023
Kamlighat	Residential	0	2	4	1:30 pm to 4 pm	25th June 2023
Jodhpur	Residential	0	0	3	1 pm to 2:30 pm	26th June 2023
Jodhpur	Residential	0	0	4	3:30 pm to 4:30 pm	26th June 2023
Jodhpur	Upashray	0	0	2	12:30 pm to 1:15 pm	27th June 2023
Jodhpur	Upashray	0	0	5	1:45 pm to 2: 45 pm	27th June 2023
Ahmedabad	Upashray	0	1	0	11:30 am to 11:40 am	24th July 2023
Ahmedabad	Upashray	0	2	0	12:05 pm to 12:30pm	24th July 2023
Ahmedabad	Upashray	0	0	2	1:00 pm to 1:30pm	24th July 2023
Ahmedabad	Upashray	0	3	0	1:40 pm to 2:30 pm	24th July 2023
Ahmedabad	Upashray	0	0	6	5:10 pm to 6:15 pm	24th July 2023
Ahmedabad	Residential	0	0	5	8:30 pm to 10:15 pm	24th July 2023
Ahmedabad	Residential	1	2	0	8:45 am to 9:30 am	25th July 2023
Delhi	Upashray	2	5	0	1:00 pm to 3:00 pm	7th Sept 2023
Delhi	Upashray	2	0	1	4:30 pm to 5:00 pm	7th Sept 2023

There were questions in the thermal comfort survey (TCS) form to document the subjects' activities in the hour preceding the survey. Most of the subjects were sitting before the interview. Some of them were standing, walking, and some had come back after getting food or Gochari (Jainism Global Resource Center, 2023a), doing yoga or washing utensils or clothes during or before the interview. ASHRAE Standard 55-2017 tables were used to translate the activities into metabolic rates. The surveys of the ascetics and the measurements of air temperature, relative humidity and air speed went hand in hand. The black globe thermometer used to compute the globe temperature takes time to reach equilibrium. So, 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. There is a possibility of the concrete based walls radiating heat during the time of the survey but the subjects had the choice of moving around in the buildings if they felt the radiant temperatures to be higher. The researchers seemed to feel a general absence of sources of radiation near the survey spaces so, the mean radiant temperature was assumed to be the same as the air temperature. Figure 3 shows the comparison between the air temperature and the relative humidity between the outdoor weather station and the indoor spaces for all the survey towns and cities. The weather in Delhi was hot and dry during the month of May but warm and humid in Rajasthan, Ahmedabad and Delhi in June, July and September respectively. The indoor temperature and humidity was close to the outdoor conditions in most of the cases owing to natural ventilation in the buildings. About 5 of the ascetics were sitting in the veranda during the survey. The Berkeley thermal comfort tool was used to compute the thermal comfort index, Predicted Mean Vote (PMV).

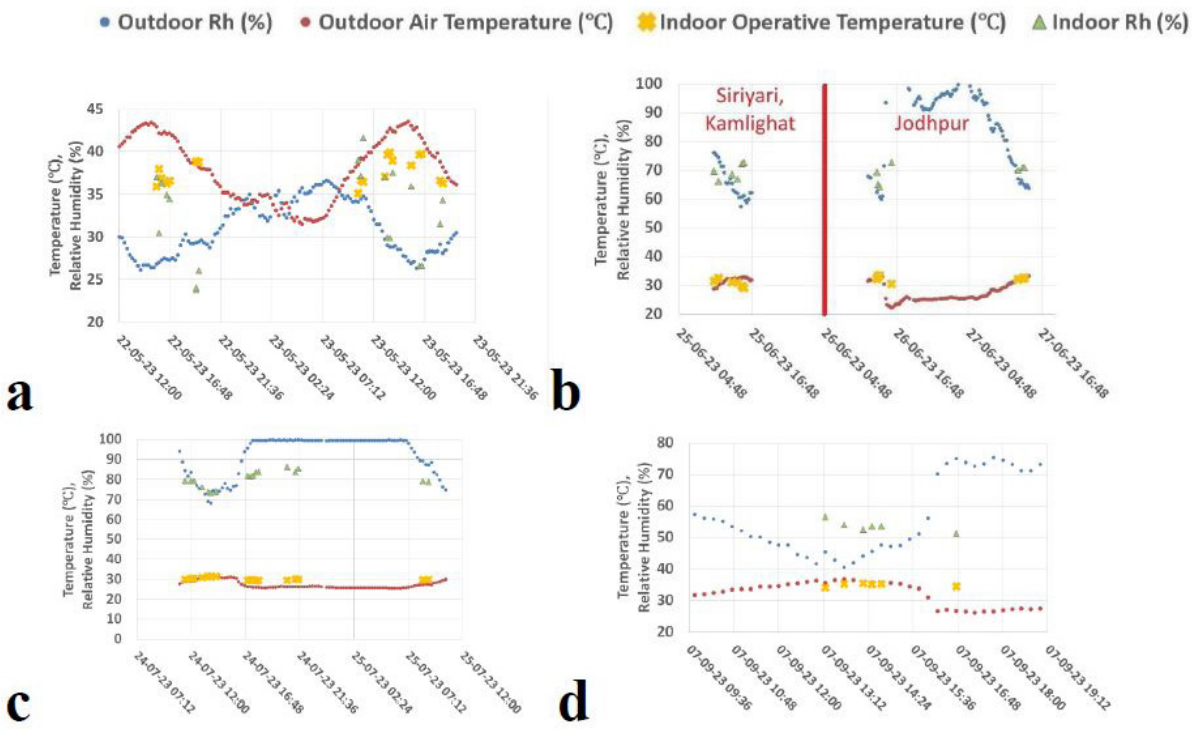

Figure 3: Outdoor, indoor air temperature and relative humidity vs. time at a) Delhi b) Rajasthan c) Ahmedabad d) Delhi

Figure 4 shows that the slope of the linear regression model of TSV with Top was non zero but much lower than the linear regression model based PMV slope with Top. The slope was lower for the TSV model owing to the neutral thermal sensation expressed by most of the subjects. PMV underpredicted the adaptability of the subjects significantly when compared to TSV. The percent people dissatisfied (PPD) calculated by the Berkeley thermal comfort tool was above 80% for over sixty percent of the subjects.

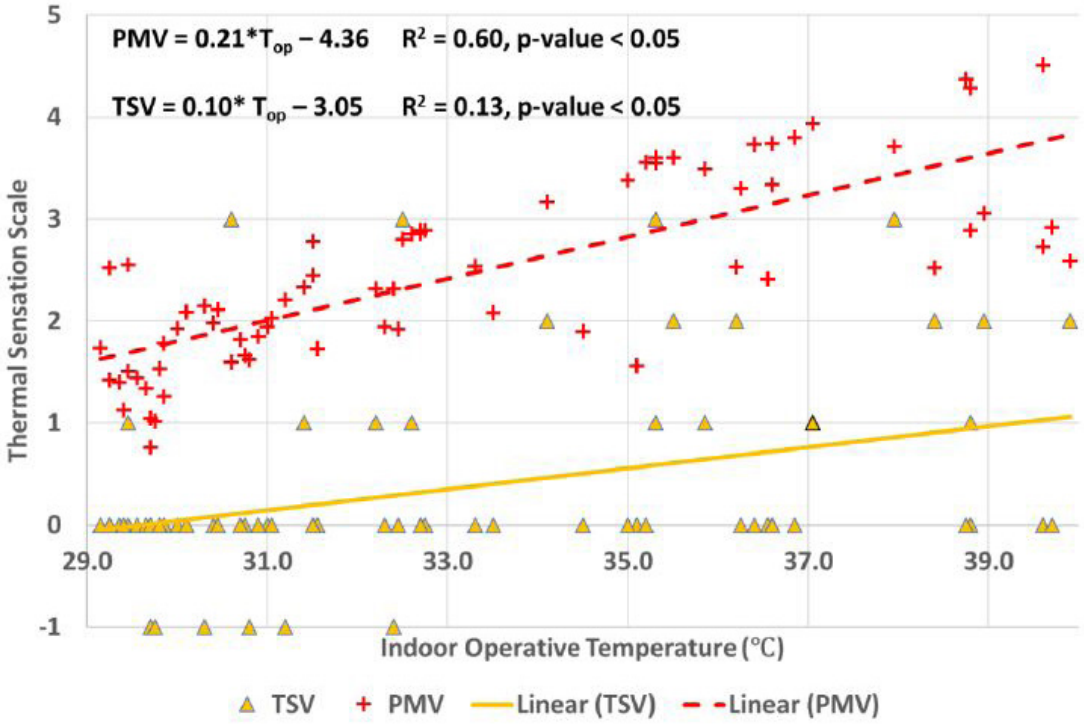

Figure 4: Observed TSV and calculated PMV vs. Indoor Operative Temperature

Figure 5 shows the points on the UTCI vs. TSV graph marked with "H" for the humid conditions from June to September 2023 and "D" for the dry conditions in May 2023. The relative humidity was greater than 50% for the humid conditions during the survey. About 75% of the subjects expressed a neutral or slightly cool thermal sensation even though the UTCI was in the strong to very strong heat stress range. All the surveys in the "Very Strong Heat Stress" UTCI conditions were for the dry conditions from Delhi and all the surveys in the humid conditions happened in the "Strong Heat Stress" UTCI conditions in Jodhpur, Siriyari, Ahmedabad and Delhi.

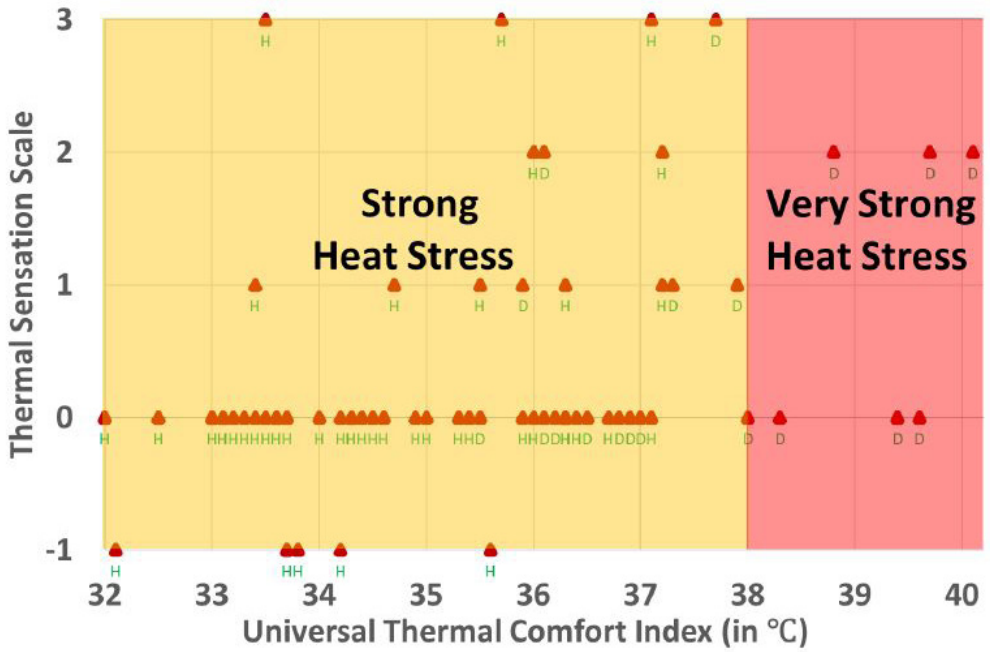

Figure 5: TSV vs. UTCI for the surveyed monks and nuns

90% of the subjects accepted the thermal conditions as per the Thermal Acceptability Vote (TAV) and less than 40% of the subjects preferred cooler thermal conditions as per the Thermal Preference Vote (TPV) in Figure 6. During the humid conditions from June to September during the surveys, less than half of the subjects experienced the weather conditions to be neither humid or dry as per the Humidity Sensation Vote (HSV). But about 64% of them were also accepting of the humid conditions and preferred no change in them as per the Humidity Preference Vote (HPV) in Figure 6. TAV and TPV results in Figure 6 are based on all the 70 surveys, whereas HSV and HPV in Figure 6 are based on the 50 surveys during the warm and humid survey conditions from June to September.

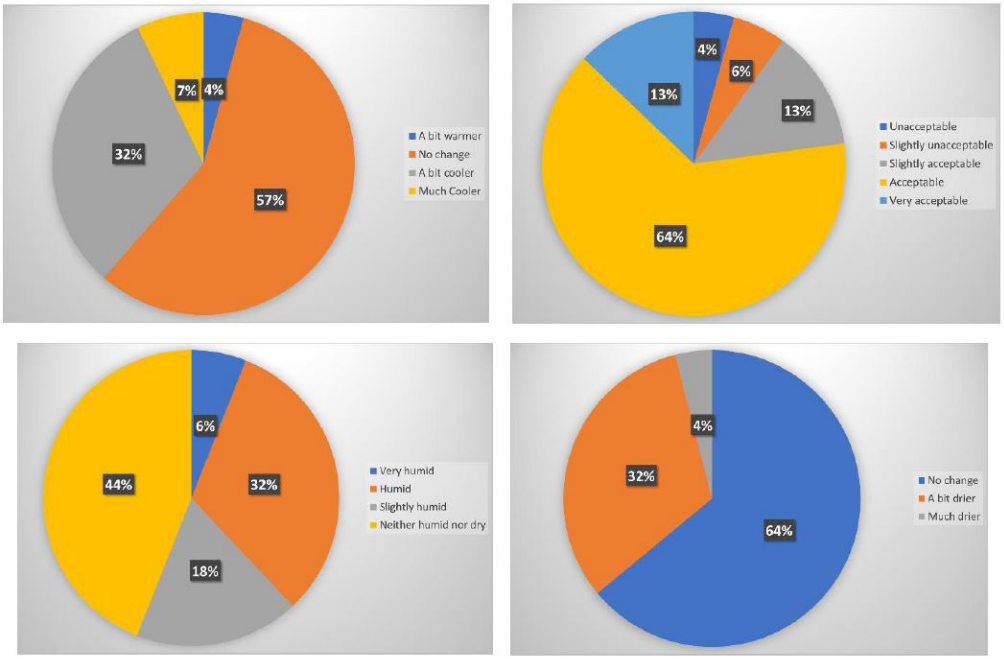

Figure 6: TPV in the top left figure, TAV in the top right figure, HSV in the bottom left figure, HPV in the bottom right figure

A 30 day outdoor running mean temperature (Tout-30DRM) was found using the outdoor weather data from the AQMS in the survey cities taking $\alpha = 0.8$ (Rawal et al., 2022). The AQMS data from Rohini, Delhi AQMS was not available from 8th to 11th August 2023 so the outdoor running mean temperature was based on data for 26 days. A neutral temperature was found by performing a linear regression of Top (where TSV = 0) with Tout-30DRM. This model was called MACS (Model for Adaptive Thermal Comfort for a Sustainable world) and compared with IMAC-R (Figure 7). The slope of MACS is much higher than IMAC-R suggesting that the ascetics have a higher thermal adaptation than predicted by the IMAC-R model.

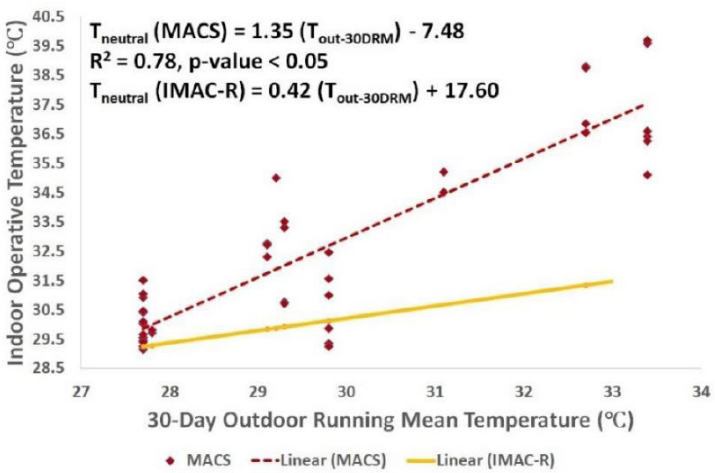

Figure 7: The adaptive thermal comfort model based on this study with neutral temperature = f(Tout-30DRM)

5. Discussion

The proposed MACS model shows that it is humanly possible for this "mindful" community to go beyond the IMAC-R model to have a neutral thermal sensation at a higher Top. This has implications for the possibility of reduction in cooling energy needs for the world. This community has vowed to live a life in sync with nature ever since they attained "Diksha". They have been practising this psychological adaptation from the day of their "Diksha" which was over 25 years on average for the surveyed subjects. It came to light during the survey that many of the ascetics had a lifestyle which included the use of air conditioners (ACs) in their homes and cars before their "Diksha". Committing to the lifestyle of a Jain monk or a nun is not an instantaneous act, instead they go through a phase of adaptation that can last for years in which they reduce their dependency on external means like the use of ACs incrementally for being comfortable. This suggests adoption of a lifestyle reducing the usage of ACs and increasing the thermal comfort range of individuals is possible over a certain time period. Some of them suggested that other living beings such as animals, birds and insects try to adapt to the changing climate without any external means of thermal comfort, so humans can also adapt to the natural environment if they mentally commit to it. One of them said that many of the villages in India didn't have access to electricity 50-60 years ago. We can also learn from people of the older generations about how they managed their lives in eco-friendly ways in earlier times.

One of the important questions to answer for the scientific community is about the temperatures that were safe decades ago, are they still safe now or the people in these communities are getting exposed to unhealthy conditions due to global warming? Apart from the planet warming up due to climate change, the cities are also heating up because of the densification of the built up area leading to an increased urban heat island effect. There are an increasing number of infrastructure projects and migration of people moving from rural to urban areas in search of better opportunities. The temperatures in Delhi have increased by 10°C in the past twenty years (Singh et al., 2022). Some of the ascetics are hopeful that most of the people in the world would be able to adapt themselves to the rising temperatures. One of them who doesn't use any electricity for him or his visitors said that they can bear up to 40°C temperatures but beyond that, they have to bear the hotter conditions until they last. While the focus of this study was on indoor thermal comfort, but many of them are used to much more extreme thermal conditions as a part of their daily routine. Many of them are used to going out in the scorching sun barefoot and an uncovered head every day to get "Gochari" or food for them. Their outdoor thermal comfort should be studied to get more insights about their thermal adaptations. The ascetics from some of the Jainism sects have recently let their visitors use fans for thermal comfort due to a warming planet. Some of the ascetics have also started wearing slippers when they go out in the scorching sun on the hot asphalt roads. But other ascetics argue that their foot sole skin becomes dead with their barefoot walking habits and it acts like slippers so they don't feel the need for slippers.

Since they have vowed to not use energy (psychological adaptation), so they remain equanimous irrespective of the thermal conditions which translates to a neutral thermal sensation. It must also be noted that they don't like to unnecessarily suffer from the uncomfortable weather conditions. Many of them would work on behavioural adaptation methods to keep themselves comfortable. They would move to a cooler room, a room which has breeze or use a wet cloth providing evaporative cooling. One of them was also observed cleaning his armpits with a wet cloth, may be to prevent body odours. This aspect should also be understood in the context of them using minimal water for their daily use. Another of the strategies used by the ascetics during the less bearable thermal conditions during the night was to distract oneself with reading of books or meditation until one was able to sleep. Another redeeming feature of their habitat is the architecture of the buildings called "Upashrays", especially built for their stay. These buildings have a high window to wall ratio (WWR) leading to good cross ventilation. These buildings are also largely empty since the ascetics have very minimal belongings. This might lead to a lower thermal mass of things in the building to heat up. We should study the spatio-temporal thermal characteristics of the buildings to understand whether the lack of thermal mass of things is helpful or not. Talking to some of them revealed that they sleep on a cardboard sheet on the floor. Having a bed made of something like a timber takht with string bases may help them to lose heat in all directions but they keep minimal belongings so they can't avail this option. Some of the ascetics also said that they prefer staying in these buildings than the building of a householder. The buildings made for air-conditioning would have much lower

window to wall ratios and would be less comfortable to be used in natural ventilation mode. Another takeaway from this study is to consider the architecture of "Upashrays" for health and wellness. The naturally ventilated buildings with high WWR provide adequate amount of fresh air and need very less energy for thermal comfort (even if fans are used) with less capital cost and running cost for cooling needs. The air conditioned buildings would provide thermal comfort in a narrower range with lesser fresh air and much higher energy needs and costs.

The UTCI for warm and humid conditions was in the "Strong Heat Stress" range based on our measurements. There were more warm and humid conditions in the surveyed cities when the surveys couldn't be conducted. Surveys under these conditions could give better insights. It is difficult to predict weather and it rained during some of the surveys leading to more pleasant conditions. This study also suggests that thermal comfort indices such as PMV and UTCI developed with the subjects from the colder climates may not reflect the adaptive thermal comfort of the people from the hotter climates very well. It should also be brought out that monks from some of the sects, leading a more extreme life, requested not to participate in the surveys. Their reason was that they were principally not fine with us recording the weather measurements while we surveyed them. Their point was that this would make them indirectly responsible for energy consumption, which they have pledged not to use. They suggested for us to stay with them for a few days to observe their routine instead of recording the measurements for the point in time TCS. The researchers plan to stay with the ascetics for a few days continuously and share the findings in a future study. It should also be noted that the research scholars involved in the experiments were pleasantly surprised not to feel much discomfort during the interviews with the subjects. We would need to find out whether it was the presence of the ascetics being equanimous in those conditions, low metabolic rates of the research scholars, the architecture of the buildings or something else. This provides hope for the possibility of thermal adaptation of the normal people.

6. Conclusion

This paper helped in understanding the thermal comfort adaptation of 65 ascetics from Svetambara Jain sects in hot and dry as well as warm and humid weather conditions in Delhi, Jodhpur, Siriyari and Ahmedabad. 90% of them found the thermal conditions to be acceptable when the UTCI was in the strong to very strong heat stress range. The MACS model of adaptive thermal comfort suggests that it is possible to have a neutral thermal sensation at a higher indoor operative temperature than IMAC-R to further reduce cooling needs. Future work should involve having a higher sample size for thermal comfort surveys in hotter weather conditions, exploring their thermal comfort in winter conditions and finding out if these thermal comfort adaptations could become a part of normal householders. Learning from the thermal comfort at the extreme of these 'mindful' communities would open the doors for studying their low resource use lifestyles for other aspects such as minimal electrical energy use, water use, transport energy use, product use and so on. It is the need of the hour to make our planet cleaner and greener.

7. Acknowledgements

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8. References

ANSI/ASHRAE Standard 55-2017. (2017). Thermal Environmental Conditions for Human Occupancy. www.ashrae.org/technology.

Central Pollution Control Board. (2023, August 27). Central Control Room for Air Quality Management - All India. https://airquality.cpcb.gov.in/ccr/#/caaqm-dashboard-all/caaqm-landing de Dear, R., & Brager, G. S. (1997). Developing an adaptive model of thermal comfort and preference.

hariwal, J., & Gangrade, S. (2023, November 1-4). Learnings from thermal comfort adaptation of Jain ascetics during heat waves. Energise 2023 Conference, Goa, India.

Indraganti, M., Lee, J., Zhang, H., & Arens, E. A. (2015). Thermal adaptation and insulation opportunities provided by different drapes of Indian saris. Architectural Science Review, 58(1), 87–92. https://doi.org/10.1080/00038628.2014.976540

International Energy Agency. (2018). The Future of Cooling: Opportunities for energy efficient air conditioning. https://www.iea.org/reports/the-future-of-cooling

International Energy Agency. (2022). World Energy Balances (database). https://www.iea.org/data-andstatistics/data-product/world-energy-balances#documentation

Jainism Global Resource Center. (2023a, August 27). Jain Monks and Nuns. https://jainworld.com/societiessanghs/jain-monks-and-nuns/
Jainism Global Resource Center. (2023b, September 10). Jain Sects. https://jainworld.com/societies-sanghs/jainsects/

Manu, S., Shukla, Y., Rawal, R., Thomas, L. E., & de Dear, R. (2016). Field studies of thermal comfort across multiple climate zones for the subcontinent: India Model for Adaptive Comfort (IMAC). Building and Environment, 98, 55–70. https://doi.org/10.1016/j.buildenv.2015.12.019

Muni Sheelgun Vijayji. (2023, August 30). Ahimsa Vrat. https://medium.com/muni-speaks/ahimsa-vratcbcbc196598e

Nayak, J. K., & Prajapati, J. A. (2006). Handbook on Energy Conscious Buildings.

Our World in Data. (2023, August 30). Global greenhouse gas emissions. https://ourworldindata.org/greenhouse-gas-emissions

Rawal, R., Shukla, Y., Vardhan, V., Asrani, S., Schweiker, M., de Dear, R., Garg, V., Mathur, J., Prakash, S., Diddi, S., Ranjan, S. V., Siddiqui, A. N., & Somani, G. (2022). Adaptive thermal comfort model based on field studies in five climate zones across India. Building and Environment, 219. https://doi.org/10.1016/j.buildenv.2022.109187

Singh, P., Sarkar Chaudhuri, A., Verma, P., Singh, V. K., & Meena, S. R. (2022). Earth observation data sets in monitoring of urbanization and urban heat island of Delhi, India. Geomatics, Natural Hazards and Risk, 13(1), 1762–1779. https://doi.org/10.1080/19475705.2022.2097452

Tartarini, F., Schiavon, S., Cheung, T., & Hoyt, T. (2020). CBE Thermal Comfort Tool: Online tool for thermal comfort calculations and visualizations. SoftwareX, 12, 100563. https://doi.org/10.1016/j.softx.2020.100563

United Nations. (2023, September 10). Net Zero Coalition. https://www.un.org/en/climatechange/net-zerocoalition of 11

UTCI. (2023, August 27). UTCI calculator. http://www.utci.org/utcineu/utcineu.php
Wikipedia. (2023, August 27). Aryika. https://en.wikipedia.org/wiki/Aryika