Thermal comfort in low-income housing in informal settlements in Lima, Peru
Towards a localised adaptive comfort standard

Argyris Oraiopoulos[1], Martin Wieser[2], Marion Verdiere[2], Pamela Fennell[1], Paul Ruyssevelt[1]
[1]Energy Institute, University College London, London, UK
[2]Department of Architecture, PUCP University, Lima, Peru

Abstract

The rapid urbanisation of the Global South is of growing concern to policy makers especially since the formation of informal settlements is the prevalent pattern of growth. Housing conditions in these settlements are largely precarious and health hazards, for the low-income urban dwellers, are part of their daily living experiences. This work explores thermal comfort of the houses in some largest informal settlements using hourly measured internal temperatures from 30 homes in Lima, Peru. The results reveal the magnitude of exposure to adverse indoor environmental conditions in these homes. This first step in understanding some of the key issues these communities are facing, is critical in improving the planning decisions towards dignified housing in low-income communities in the Global South.

Highlights

- Internal temperatures in homes in informal settlements were found to be outside a comfort zone, based on adaptive criteria
- Internal temperatures below the lower limit of the adaptive criteria were recorded for all construction types
- Occupants expressed satisfaction despite measured data indicating otherwise

Introduction

The Global South is expected to be receiving over 90% of the growth in urban population from 4 billion to almost 7 billion by 2050. It is therefore imperative housing conditions are studied extensively, to increase the awareness around the health hazards often experienced in these settlements, mainly due to the inappropriate design and construction of houses. In addition, since the majority of these houses are lacking the existence of any heating or cooling related appliances, it is important to explore the risks associated with a potential uptake, especially in air-conditioning systems, which nonetheless is already taking place in households of higher income. This first step in understanding some of the key issues these communities are facing, is critical in improving the planning decisions towards dignified housing and secure infrastructure.

In Lima the population has doubled since 1980, to around 10 million inhabitants by 2022, with 50% living in self-constructed, low-income houses in informal settlements, mainly in the hillside areas of the Peruvian Andes. The inhospitable terrain together with the economic struggle of the local communities, have resulted in poor housing conditions that have adverse health impacts on large parts of the population (Gutiérrez et al. 2021).

This work is part of a larger project aiming to investigate the access to dignified housing and energy justice in informal settlements in the Global South. This paper presents one of This paper presents one of the first studies of thermal comfort, making use of quantitative as well as qualitative data from indoor environmental conditions in informal settlements in Lima. There have been no previous studies on the thermal comfort of dwellings in marginal neighbourhoods in the urban areas of Peru.

Background

Thermal comfort has been a subject of research for many decades (Haldane (1905); Winslow et al. (1937); Gagge et al. (1969)), with two main approaches, the steady state model and the adaptive model, which is mainly based on the theory that the human body adapts to the outdoor conditions (Nicol (1993)). With the most widely accepted definition "*a condition of mind which expresses satisfaction with the thermal environment*" (ISO (1990)), revealing its rather complicated and multidisciplinary nature. According to Rupp et al. (2015) there may be a number of factors that influence the sensation of thermal comfort, like cultural and behavioral aspects, age, gender, space layout, possibility of control over the environment, user's thermal history and individual preferences. Taleghani et al. (2013) noted that the prediction of thermal comfort is rather difficult and apart from cultural influences it depends on environmental and personal factors.

The majority of thermal comfort theories, however, have been developed based on studies in the Global North. The adoption of these from international bodies, such as the ASHRAE, and their widespread implementation to cities across the Global South has, in many cases, resulted to the design of indoor environments, which are failing to meet the needs of the local population. Alnuaimi and Natarajan (2020) reported the consistent mechanical over-cooling of indoor spaces across four cities in India, Philippines, and Thailand. Although the observed temperatures were considered appropriated based on design recommendations from standards such as the ASHRAE-55, thermal comfort data from real buildings suggest excessive discomfort due to cooler temperatures than desired by occupants. With the globally rising demand for cooling threatening the future of climate change mitigation polices, it is important to be able to provide factual estimations of cooling needs. The parsimonious installation of air conditioning units will play a significant role in achieving the United Nations' Sustainable Development Goal for electricity access (SDG7) in the Global South (Mastrucci et al. (2019)).

Such findings are also supported by research in North-East India, where researchers attempted the development of thermal comfort models taking into consideration variables like local indoor and outdoor temperature, relative humidity and clothing patterns (Singh et al. (2015)). The authors concluded that it is not possible to obtain a generalized thermal comfort model for all climatic zones. Further research making use of questionnaire-based field surveys indicated that preferred temperatures were 2.8°C lower than the comfort temperatures (Singh et al. (2017)). Similarly, Manu et al. (2016) found that occupants in naturally ventilated Indian offices were more adaptive than the prevailing ASHRAE and EN models would suggest, leading to the development of the India Model for Adaptive Comfort (IMAC).

In South America, Natarajan et al. (2015) compared thermal comfort data gathered in office buildings in Bogota, Colombia, and found the ASHRAE adaptive model underestimating discomfort in the natural ventilated offices due to lack of perceived or actual control. Molina and Yaguana (2018) focused on defining indoor environments comfort standards of urban dwellings in the city of Cuenca, Ecuador, taking into consideration factors such as temperature, air quality, and natural lightning. The authors reported that the levels of thermal comfort accepted by local users differ from those in international standards including ASHRAE-55. Rijal (2021) conducted thermal measurements and a thermal comfort survey during the winter in traditional vernacular houses, in the extreme cold climate of the Himalayan region of Nepal. Residents of houses with thick brick walls and mud roofs were highly satisfied with mean comfort temperature at 10.7°C, much lower than the thermal comfort standards recommendations.

Since thermal comfort is intrinsically subjective it is important to explore the thermal adaptation of people in different regions to allow for the development of localised adaptation policies for low energy building design (Yao et al. (2022)). The adaptive thermal comfort is a function of regional and local parameters, since the adaptation process, as well as the expectations and perceptions of people, are region specific and governed by local socio-cultural requirement. Therefore, more climate- and culture-localized standards should be given priority in the Global South.

In the case of Peru, there are few studies on local thermal comfort, most focusing on higher altitude regions in the Andean Highlands and in the Northern region Resano et al. (2022); Perleche (2019). Notably there have been no previous studies on thermal comfort in houses in the marginal neighbourhoods in urban areas of Lima, a coastal region with a subtropical coastal climate. This paper contributes to this knowledge gap by presenting a thermal comfort analysis of hourly measured indoor temperatures in low-income houses in informal settlements in the marginal neighbourhoods in urban areas of Lima, Peru.

Methodology

Context

Lima is Peru's capital city and the second driest metropolis in the world. Over the last decades, Lima has seen its population more than double to almost 10 million, from 1980 to 2020. This rapid growth is mainly due to internal migration, which thus is a phenomenon that has occurred since the middle of the twentieth century, but with more recent years taking an exponential growth both in terms of outward expansion and inward densification. The way land is often occupied, sees people settling first and basic infrastructure arriving second, enabling precarious living conditions for many years and exposing people to everyday risks (Lambert and Allen (2017)).

Currently, an estimated 30% of the population occupies land on the steep peripheral slopes, beyond the metropolitan boundaries, in self-constructed neighbourhoods. One of them is José Carlos Mariátegui (JCM), located about 20 km from the sea, 400 meters above sea level and is on the slopes of the first Andean foothills. José Carlos Mariátegui gradually expanded from the lowest slopes of San Juan de Lurigancho, upwards since 1985 and is rapidly being urbanised. It is a neighbourhood that emerged as a result of informal occupations in recent decades, by people in search of better living conditions and job opportunities and is made up of houses in rather precarious conditions. Currently, it continues to grow on the upper part of the hills, where communities organize themselves to improve access to energy and basic services. The steep slopes make it difficult to access many areas, where homes are in critical need of improvements to ensure better living standards.

Another area which houses a large part of the population in Lima and presents a number of energy- and housing-related challenges is Barrios Altos, located in the Cercado de Lima district of the historic centre of Lima. The neighbourhood was built during colonial times and was declared a World Heritage Site by UNESCO in 1991. Barrios Altos is a historic neighbourhood with quintas (type of housing complex) and residential mansions from the colonial era (1500). Given the dilapidated nature of these historic buildings, the residents of the quintas face risks from unstable and unsafe buildings, and overcrowded conditions. Energy infrastructures, such as electrical connections, are also in poor condition. Given the central location of Barrios Altos, residents face constant risks of eviction from private developments and land traffickers. Ongoing private development is also causing the risks of fire and collapse. In these conditions of vulnerability, people constantly have to face risks, resist evictions and resist the loss of heritage in the neighbourhood.

This work concentrates on these two areas, José Carlos Mariátegui and Barrios Altos, which are essential in the development of Lima and make up for a significant part of its population.

Temperature data

Hourly measured internal air temperatures were measured from the main living space of 15 houses, in each of the settlements of José Carlos Mariátegui and Barrios Altos, from December 2021 until January 2023, using data loggers. During this time external temperatures were also measured in both sites. In Lima the hottest months of the year are usually February and March, while the coldest are July and August. The external weather data instrumentation as well as the data logger inside the homes is shown in Figure 1.

Figure 1: External weather data instrumentation (left), data logger inside the homes (right)

Survey data

The surveys were administered by Pontificia Universidad Católica del Perú in Lima, and were conducted with the aid of the local NGOs [1]. All surveys were conducted within the period of temperature measurements. In José Carlos Mariátegui the survey was managed over an extended period between December 2021 and January 2023, while in Barrios Altos it was completed between March 2022 and December 2022. The main focus of the surveys was thermal comfort, allowing insights regarding perception of comfort both at the time of the survey but also throughout the summer and winter periods. Amongst many questions that were asked in terms of thermal comfort, the main question which this paper focused on are the following:

- *In general terms, how satisfied are you with the internal temperature of the house throughout the year?*

Buildings

In parallel to recording data on thermal comfort, during the surveys building envelope related data were also collected, categorising buildings in terms of thermal mass into *light* (wood construction or drywall without insulation with lightweight corrugated sheets of metal or fibre cement for roof), *medium* (hollow clay brick construction with lightweight corrugated sheets of metal or fibre cement for roof), *heavy* (hollow clay brick construction with reinforced concrete slab for roof), and, for the case of Barrios Altos, also in *traditional* (adobe construction with wooden slabs with mud on top) (shown in Figure 2). This was important in relating the perception of comfort to the built environment of the occupants.

Thermal comfort criteria

For the assessment of thermal comfort inside the homes the theory of adaptive comfort was used and more specifically the ASHRAE Standard 55-2017 (2017) ASHRAE (2020), since there are no national standards or norms in Peru, which determine a certain comfort zone. The adaptive comfort approach, developed by de Dear and Brager (1998) and Humphreys et al. (2016) analysed data from naturally ventilated buildings and concluded that indoor temperatures, which considered to be most comfortable increased significantly in warmer climates and decreased in colder contexts, indicating that humans have an inherent ability to adapt to environmental fluctuations and especially to seasonal variations of external weather conditions (Dear and Brager (2002); Kim et al. (2018); Martins et al. (2022); Fennell, Ruyssevelt, Rawal, and Poola (Fennell et al.)).

The equipment that was used to measure the internal temperatures in the homes is capable of recording the internal mean radiant temperature and relative hu-

[1] The design of the survey was based on the official ASHRAE Standard 55 document: https://www.ashrae.org/technical-resources/bookstore/standard-55-thermal-environmental-conditions-for-human-occupancy

Figure 2: Building types categorised by construction (thermal mass) in José Carlos Mariátegui and Barrios Altos. (a)Light (b)Medium (c)Heavy (d)Traditional

midity. Yet, the ASHRAE Standard 55 requires the operative temperature to be applied. The CBE Thermal Comfort Tool Tartarini et al. (2020) was used to calculate the upper and lower limits of the adaptive comfort standard can also infer the operative temperature as an average of the air and radiant temperatures as long as:

- the occupants perform a quasi-sedentary physical activity
- they are not exposed to direct sunlight
- they are not exposed to air speeds greater than 0,10 m/s [2]

The tool can be applied only for naturally conditioned spaces controlled by the occupants and if the following criteria are met:

- there is no mechanical cooling or heating system in operation
- metabolic rates ranging from 1.0 to 1.3 met
- Occupants are free to adapt their clothing to indoor and/or outdoor thermal conditions within a range of at least 0.5-1.0 clo.

Under these considerations, the formulas used to define the upper T_{upper} and lower T_{lower} limits are:

$$T_{upper} = 0,31x(T_m + 21,3) \quad (1)$$

$$T_{lower} = 0,31x(T_m + 14,3) \quad (2)$$

where T_m is the mean outdoor temperature, an arithmetic average of the daily mean outdoor temperatures for the month. Applying the above formulas, the upper and lower limits of the adaptive comfort standard were calculated for each calendar month between December 2021 and January 2023.

[2]there where no means of mechanical ventilation installed in any of the houses and also none of the houses had large unglazed openings

Results

External weather conditions

Before analysing the results for thermal comfort in homes, is it essential to inspect the external weather conditions in the two informal settlements. Figure 3 shows the external air temperature and relative humidity in of José Carlos Mariátegui and Barrios Altos.

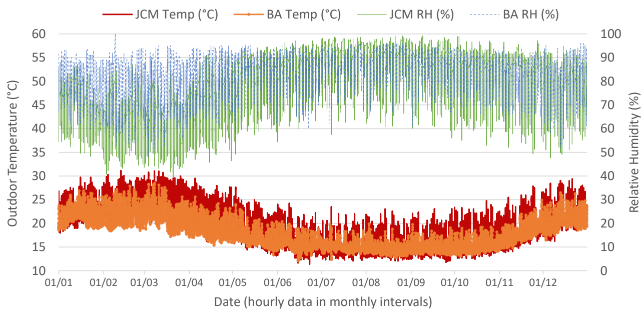

Figure 3: Hourly measured external temperature and relative humidity in José Carlos Mariátegui and Barrios Altos

In general, it can be observed that external temperature in José Carlos Mariátegui has a larger daily spread than in Barrios Altos, for most of the year. During the warmer months of February and March, the temperature in José Carlos Mariátegui presents higher daily peaks, with the maximum difference compared to Barrios Altos being 7.7°C at 12 in the noon on 21/03/2021. The humidity on the other hand drops considerably compared to Barrios Altos, giving overall a drier and hotter summer in José Carlos Mariátegui. During the colder months between June and October, the minimum external temperature in José Carlos Mariátegui drops lower than in Barrios Altos, where temperature daily fluctuations are much smaller. These observations could mean that the light thermal mass buildings in José Carlos Mariátegui could present higher risks in terms of adverse health impacts, compared to Barrios Altos, especially during the warmer periods of the year.

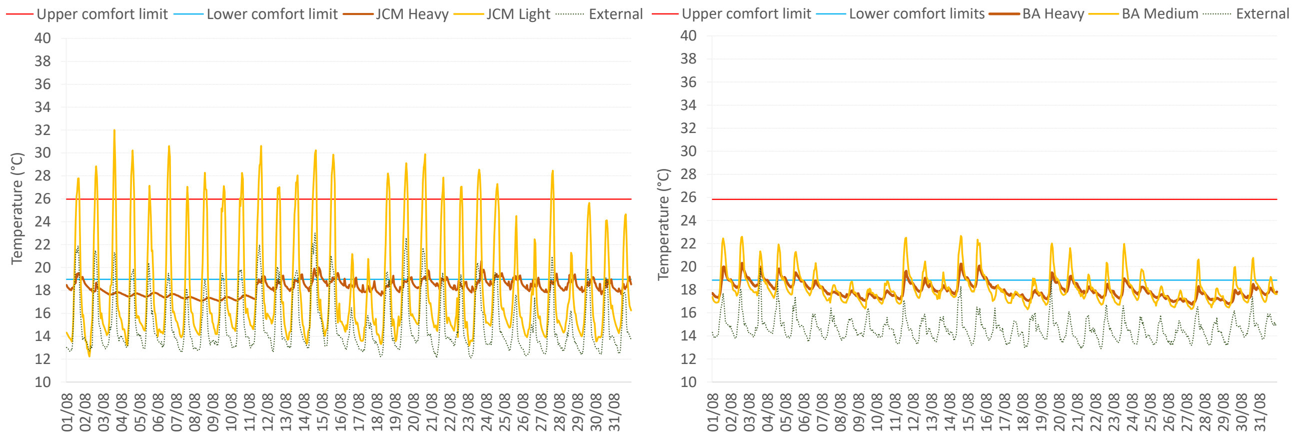

Figure 4: Hourly measured internal temperature data during August 2022 for different constructions in Jose Carlos Mariategui (left) and Barrios Altos (right) (the upper and lower limits of the ASHRAE-55 adaptive comfort standard and the measured external temperature are also presented)

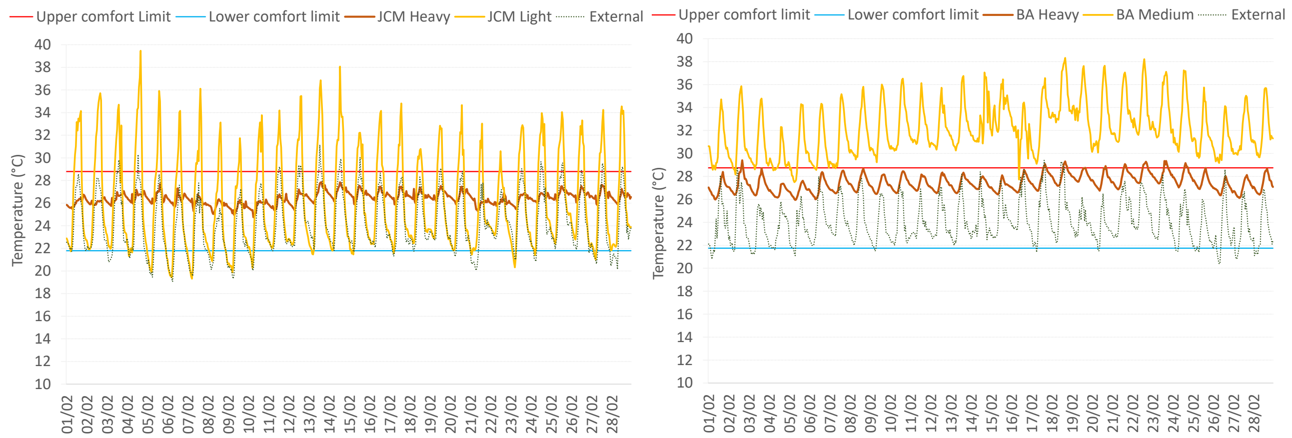

Figure 5: Hourly measured internal temperature data during February 2022 for different constructions in Jose Carlos Mariategui (left) and Barrios Altos (right) (the upper and lower limits of the ASHRAE-55 adaptive comfort standard and the measured external temperature are also presented)

Measured internal temperatures and adaptive comfort limits

Internal temperatures in homes without mechanical cooling or heating, were measured throughout the year in the two informal settlements. Theses where analysed based on the construction of the house as Figures 4 and 5 show. It can be observed that in the case of Jose Carlos Mariátegui, the light construction house presents a very wide range of temperatures both in winter and summer, while the heavy construction results in a much more tight range in both settlements. During summer (February) the internal temperatures in the light construction house exceed 30°C on a daily basis, often going above 35°C, even reaching 39.5°C in the case of Jose Carlos Mariátegui. In the case of Barrios Altos the medium construction house presents smaller daily variation, especially in the winter month of August, possibly due to reduced solar heat gains, since Barrios Altos has higher building density and is located in much closer to the coast, compared to Jose Carlos Mariátegui. One thing to note is the adaptive comfort envelope (based on the ASHRAE-55 standard), which for winter (August) is between 19°C and 26°C, while for summer (February) is between 21°C and 28°C, despite a difference of around 7°C in mean external temperature. The similarities in the ranges of these envelopes, between winter and summer, operate in favour of summer in terms of adaptive comfort, as it can be seen in Figures 4 and 5, meaning it is more likely to report comfort during summer than during winter.

Thermal comfort evaluation - Survey responses and adaptive criteria

This work combines hourly measured internal temperatures, for the duration of a year, together with survey responses from the occupants of the homes. After careful inspection of the data, the authors decided to omit data from three homes in Jose Carlos

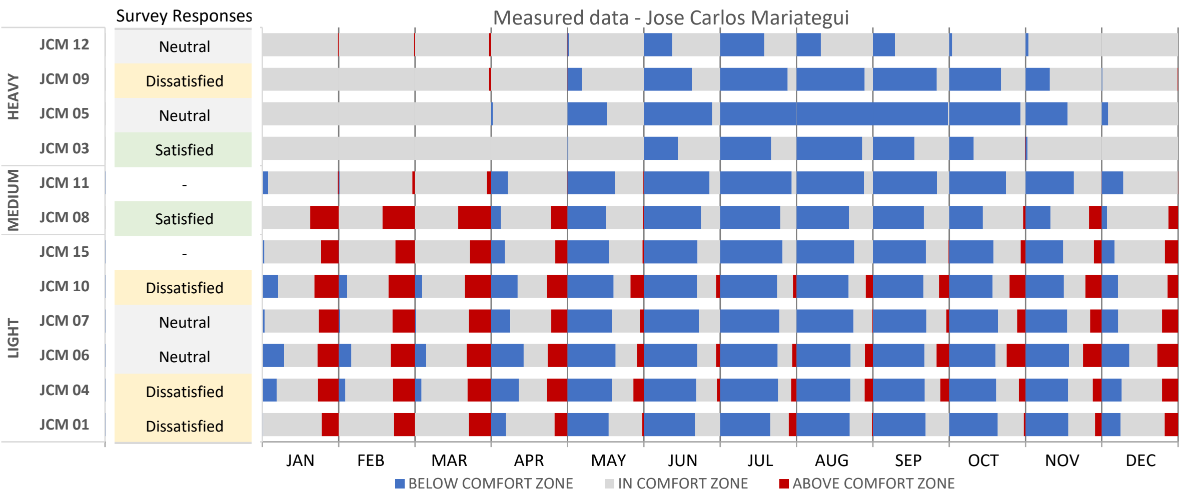

Figure 6: Survey responses on annual overall perception of comfort and percentage of hours in a month when hourly internal temperatures are above or below the upper or lower limits of the ASHRAE-55 adaptive comfort standard, using measured data from 12 homes in Jose Carlos Mariategui.

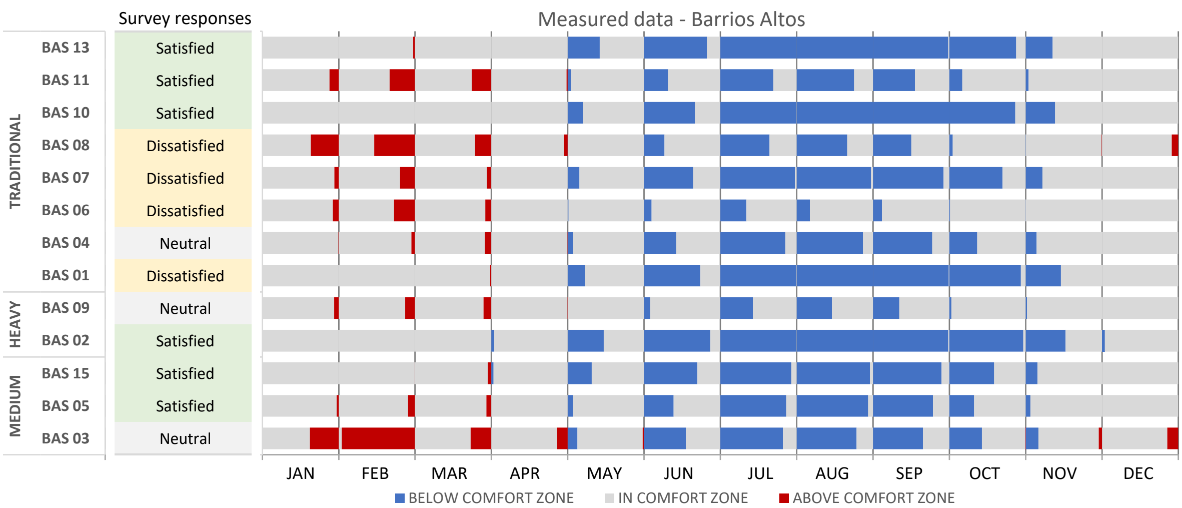

Figure 7: Survey responses on annual overall perception of comfort and percentage of hours in a month when hourly internal temperatures are above or below the upper or lower limits of the ASHRAE-55 adaptive comfort standard, using measured data from 13 homes in Barrio Altos.

Mariátegui and two in Barrios Altos, as some anomalies were detected for which further investigation is required before they can be made public.

The ASHRAE-55 adaptive comfort criteria were applied to the measured temperatures and the percentage of time during which the temperatures were above or below the adaptive comfort limits was calculated are presented in Figures 6 and 7, for 12 homes in Jose Carlos Mariátegui and 13 homes in Barrios Altos respectively.

Overall, it can be observed that the dominant problem, in most homes across both settlements, has to do with temperatures below the lower adaptive limit (blue bars) for most of the time during the colder months June-October. In Jose Carlos Mariátegui there seems to be a more pronounced issue with heat, especially in the light construction homes.

The responses of the occupants however vary greatly, with many households stating rather satisfied with the internal temperatures throughout the year, a result which contradicts the outcome from the application of the ASHRAE-55 adaptive comfort criteria. One of the possible reasons for this discrepancy between the survey responses and the measured temperature data, could be the fact that many of the occupants in informal settlements migrate from regions

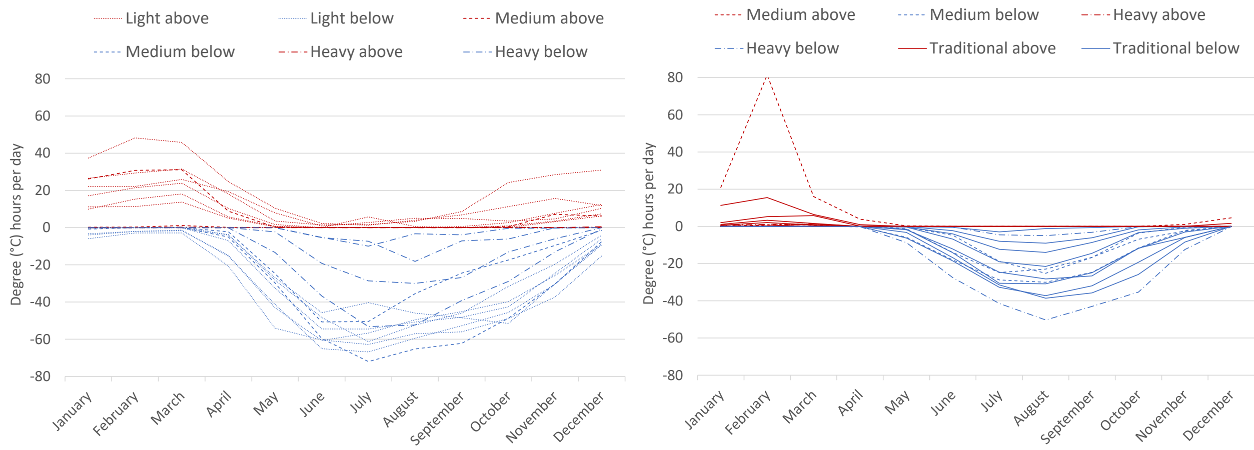

Figure 8: Degree °C hours above or below the upper or lower limit of the ASHRAE-55 for an average day, for every month in the year, for Jose Carlos Mariátegui (left) and Barrios Altos (right)

higher up in the Andean slopes, where the climate is considerably colder throughout the year and have therefore been accustomed to lower temperatures for many years prior to migrating.

Thermal comfort evaluation - Severity

When considering adverse health impacts in terms of thermal discomfort, the severity of the discomfort is often of interest to researchers and policy makers. Figure 8 captures the severity of discomfort by presenting the degree hours above or below the upper or lower limit of the ASHRAE-55 for an average day, for every month in the year[3]. This has been calculated by aggregating all the degree °C hours in a month and diving by the days in that month. This way an overall outcome on the severity of discomfort can be examined across the year. It can be observed that in Jose Carlos Mariátegui the health risks are much higher, especially during the colder months and for light construction houses. In Barrios Altos there is a single house with medium construction which presents 81 degree °C hours above 10°C, where further investigation is required to explain why this particulate house had such high temperatures in February 2022.

Conclusion

This work is one of the few studies that combine hourly measured internal temperatures, for the duration of a year, together with survey responses from the occupants of homes, and the only one in informal settlements in Lima, Peru. Although the sample size is relatively small for the extend of the communities in Jose Carlos Mariátegui and Barrios Altos, it allows for some robust conclusions to be made.

Firstly, it was observed that, despite the external weather conditions in both settlements were rather mild (minimum winter daily temperatures around 12°C and maximum daily summer temperatures slightly above 30°C), internal temperatures in homes were outside what could be considered a comfort zone, based on adaptive criteria. In some houses with medium construction (heavy walls + light roof) the minimum hourly internal temperatures were kept well above 30°C throughout the day and night during the hottest month of February. In light construction houses, the temperatures during summer could reach almost 40°C but they would drop below 24°C over night, allowing the dissipation of heat to some extend. It is evident that the light roofs contribute greatly to thermal discomfort, and future improvements of building envelopes should focus on retrofitting higher thermal mass materials on roofs.

Secondly, although severely high internal temperatures during summer are extremely worrying, especially for more vulnerable occupants, it was the low temperatures observed for many months of the year (May-November) which were highlighted in this study, in both informal settlements. Internal temperatures below the lower limit of the adaptive criteria (ASHRAE-55) were recorded for all construction types (light, medium, heavy, traditional), raising the need for better housing conditions as well as access to heating equipment and therefore to energy related infrastructure.

Thirdly, regardless of the outcome based on measured data, the survey responses allowed for further insights to thermal comfort in the informal settlements. These revealed the subjective nature of thermal comfort. Many of the occupants expressed they were rather satisfied with the thermal conditions in the houses, despite the measured data indicating otherwise. This could be attributed to the fact that many of the

[3]The Annex F Method B, 'Degree-hours criteria' in BS EN 15251 British Standards Institution (BSI) (2007), proposes a degree-hours method for taking into account both severity and occurrence of indoor overheating, which can have adverse health impacts

dwellers migrated from regions higher up in the Andean slopes, and therefore are accustomed to colder climates than the one they experience in either Jose Carlos Mariátegui or Barrios Altos.

It has to be noted that this study took place during the years of the COVID-19 pandemic and accessing occupant's home to place monitoring equipment and carry-out face to face surveys was a great challenge. The sample size does not allow making inferences across the population, still important insights have been collected. Future research should extend the questionnaire survey to capture socio-economical related variables as well as increasing the sample size.

Overall, this work contributed critical evidence to the continuous investigation of thermal comfort in the Global South. The outputs of the research will be used as inputs to calibrate Urban Building Energy Models, which will enable the simulation of large parts of the informal settlements. These models will then be used for the analysis of future scenarios in terms of climate change, impacts of heating and cooling equipment uptakes and health risk mapping, contributing to inclusive decision making towards dignified housing and habitat for all.

Acknowledgment

This work was funded through a UKRI collective fund as part of the GEMdev project, GEMDdev: Grounded Energy Modelling for equitable urban planning development in the global South [ES/T007605/1]. The support of the Economic and Social Research Council (ESRC) is gratefully acknowledged.

References

Alnuaimi, A. N. and S. Natarajan (2020, 5). The energy cost of cold thermal discomfort in the global south. *Buildings 10.*

ASHRAE (2020). ASHRAE Standard 55-2017.

British Standards Institution (BSI) (2007). BS EN 15193:2007: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.

de Dear, R. J. and G. S. Brager (1998). Developing an adaptive model of thermal comfort and preference. *ASHRAE Transactions 104.*

Dear, R. J. D. and G. S. Brager (2002). Thermal comfort in naturally ventilated buildings: revisions to ashrae standard 55. *Energy and Buildings 34*, 549–561.

Fennell, P. J., P. A. Ruyssevelt, R. Rawal, and V. Poola. Determining the most appropriate form of urban building energy simulation model for the city of ahmedabad.

Gagge, A. P., J. A. J. Stolwijk, and Y. Nishi (1969). The prediction of thermal comfort when thermal equilibrium is maintained by sweating. *ASHRAE Transactions 75*, 108 – 125. Cited by: 28.

Haldane, J. S. (1905). The influence of high air temperatures no. i. *Journal of Hygiene 5*, 494–513. Cited by: 108; All Open Access, Green Open Access.

Humphreys, M., F. Nicol, and S. Roaf (2016). *Adaptive thermal comfort: foundations and analysis.* Routledge.

ISO (1990). International standard 7730.

Kim, J., S. Schiavon, and G. Brager (2018, 3). Personal comfort models – a new paradigm in thermal comfort for occupant-centric environmental control. *Building and Environment 132*, 114–124.

Manu, S., Y. Shukla, R. Rawal, L. E. Thomas, and R. de Dear (2016, 3). Field studies of thermal comfort across multiple climate zones for the subcontinent: India model for adaptive comfort (imac). *Building and Environment 98*, 55–70.

Martins, L. A., V. Soebarto, and T. Williamson (2022, 1). A systematic review of personal thermal comfort models.

Mastrucci, A., E. Byers, S. Pachauri, and N. D. Rao (2019, 3). Improving the sdg energy poverty targets: Residential cooling needs in the global south. *Energy and Buildings 186*, 405–415.

Molina, F. Q. and D. B. Yaguana (2018, 7). Indoor environmental quality of urban residential buildings in cuenca-ecuador: Comfort standard. *Buildings 8.*

Natarajan, S., J. Rodriguez, and M. Vellei (2015, 12). A field study of indoor thermal comfort in the subtropical highland climate of bogota, colombia. *Journal of Building Engineering 4*, 237–246.

Nicol, F. (1993). *Thermal comfort: a handbook for field studies toward an adaptive model.* University ofEast London.

Perleche, M. P. (2019). Effects of the placement of the typical social housing module on the thermal comfort in the federico villarreal urbanisation of chiclayo, peru. *Paideia XXI 9*, 105–125.

Resano, D., R. Rodriguez, and O. Guillen (2022, 1). Passive comfort strategies for typical peruvian meso-andean houses. Volume 943. IOP Publishing Ltd.

Rijal, H. B. (2021, 1). Thermal adaptation of buildings and people for energy saving in extreme cold climate of nepal. *Energy and Buildings 230.*

Rupp, R. F., N. G. Vásquez, and R. Lamberts (2015, 8). A review of human thermal comfort in the built environment. *Energy and Buildings 105*, 178–205.

Singh, M. K., R. Ooka, H. B. Rijal, and M. Takasu (2017, 11). Adaptive thermal comfort in the offices of north-east india in autumn season. *Building and Environment 124*, 14–30.

Singh, R., X. Wang, J. C. Mendoza, and E. K. Ackom (2015). Electricity (in)accessibility to the urban poor in developing countries. *Wiley Interdisciplinary Reviews: Energy and Environment 4*, 339–353.

Taleghani, M., M. Tenpierik, S. Kurvers, and A. V. D. Dobbelsteen (2013). A review into thermal comfort in buildings.

Tartarini, F., S. Schiavon, T. Cheung, and T. Hoyt (2020, 7). CBE Thermal Comfort Tool: Online tool for thermal comfort calculations and visualizations. *SoftwareX 12*.

Winslow, C.-E. A., L. P. Herrington, and A. P. Gagge (1937). Physiological reactions of the human body to varying environmental temperatures. *The American Journal of Physiology 120*.

Yao, R., S. Zhang, C. Du, M. Schweiker, S. Hodder, B. W. Olesen, J. Toftum, F. R. d'Ambrosio, H. Gebhardt, S. Zhou, F. Yuan, and B. Li (2022, 6). Evolution and performance analysis of adaptive thermal comfort models – a comprehensive literature review.