# Wintertime patterns of residential electricity use and indoor temperature in the composite climate of India

**Rajat Gupta, Matt Gregg and Anu Antony**

Low Carbon Building Research Group, Oxford Institute for Sustainable Development, Oxford Brookes University, Oxford, UK

E-mail: rgupta@brookes.ac.uk

**Abstract**. Wintertime electricity use in India has received little attention due to the growth of residential air conditioning (AC) in the summer and monsoon seasons. This paper combines monitoring (time-series) and survey (contextual) data to examine the wintertime pattern of daily electricity current, indoor temperature, and relative humidity profiles across a sample of 64 dwellings in the city of Hyderabad representing the composite climate of India. Monitoring data were recorded for 31 days (December 2021 with a mean daily outdoor temperature of 25°C) using a CT clamp meter and Bluetooth enabled sensors. Contextual data covered dwelling and household characteristics, and use of appliances. The winter peak period of electricity use was found to occur from 6:30 -10:30 in the morning, likely to be for hot water (geysers) and cooking. This is different to the late evening/night-time peak observed in the summer due to use of air conditioning (AC). Only one dwelling showed potential signs of using space heating. Higher electricity use aligned with lower peak temperatures in some homes particularly in the high-income group, indicating the potential use of AC during winter. The wintertime morning electricity peak in India could be managed using thermal stores in geysers through pre-heating which could also offer demand response opportunities.

## 1. Introduction

The residential sector in India accounts for 24% of electricity consumption [1] and nearly 30% of total final energy consumption. Though residential energy consumption is still largely dominated by traditional use of bioenergy (68%), the share of oil (16%) and electricity (14%) are growing rapidly. In 2019 coal remained the predominant fuel source in the power sector, contributing to over 70% of total generation [2]. Household electrification has been a strong driver of electricity demand growth [3]; from 2012-17 residential electricity consumption increased by 53% while bioenergy and waste declined by 14%. Through 2019-20, India achieved a landmark of reaching near-universal household connectivity to electricity (97%). That is, over 900 million citizens have gained electricity connection to their households since the year 2000. However, 76% of households must cope with outages at least once per day. Outages are highest among the highly populated composite climate states in the north [2, 4].

As regional growth and climates are different in India, it is necessary to characterise residential energy use across different climatic zones and seasons (summer, monsoon, winter) to understand their contribution to annual energy use. For example, in the composite climatic zone, residential energy consumption was found to be highest in summer and over the entire year in dwellings with and without air conditioning (AC) [5]. The cold climatic zone had the highest energy consumption in the winter season [1]. Understanding the changing patterns in India's residential electricity consumption can help in three major ways: (1) contribute to better energy efficiency and conservation policies and program; (2) help energy authorities, e.g., the Central Electricity Authority in creating better estimations regarding electricity growth, demand forecasting, and better planning so that all households can have access to reliable and sustainable energy; (3) help integrate changing technology, policy and business models [6] to improve efficiency and equitable access to energy.

Within this context, this study conducts statistical analyses of concurrent time-series data on residential electricity current, indoor temperature, and relative humidity (RH) to investigate wintertime daily pattern of electricity consumption and indoor environment measured in a sample of 64 dwellings located in the city of Hyderabad, representing the composite climate in India.

## 2. Evidence to date

There is an abundance of thermal comfort studies covering Indian households located in the cold climate [7], composite [8-10], and warm-humid [11, 12] climate zones. Since residential AC ownership is expected to grow substantially [13], it is reasonable that most research to date has focused on characterizing cooling demand during the summer and monsoon seasons [13-15]. However, little attention has been paid to residential electricity consumption in the winter season. Why should winter electricity use in other than cold climates be studied? Since 97% of homes are connected to the electricity grid and appliance use continues to grow, there is a possibility that higher peaks or a new peak period could develop leading to blackouts and brownouts. Two studies on wintertime energy consumption cover the composite [16], warm-humid and hot-dry [17] climatic zones. However, none of these studies capture the relationship of indoor and outdoor temperature and daily electricity demand in winter.

Several studies looking at high-level national data have established that the share of winter electricity consumption is negligible in relation to annual residential demand, primarily due to the warm climatic zones (hot dry, warm humid, composite) that cover majority of the country [18, 19]. However, by simply observing heating degree days (HDD) and studies demonstrating presence of space and water heating in some northern states [20, 21], it is reasonable to assume that energy use will vary between the climate regions in winter. This is especially true as wealth increases, which has been revealed as a strong driver for increased comfort-consuming [21, 22].

In discussing the difference between energy use in summer and winter, and from where future increase in consumption might arise, it is important to establish appliance usage in Indian dwellings. An electricity load survey of approximately 400 households located across 21 localities of Gujarat found that winter residential energy was half that of summer regardless of location. Space cooling dominated summer peaks whilst geyser and technology/entertainment devices dominated winter peaks. Kitchen appliance loads were found to be constant throughout the year. In the winter season, refrigerators contributed to most of the total load, followed by ceiling fans and lights [17]. A pan-India survey of over 5,000 households found that appliance use (e.g., washing machine, vacuum cleaner) in homes increased with income. Ownership of heating and cooling systems increased with both family size and income. The highest penetration was with ceiling fans and air-coolers (also known as desert coolers) [1].

Previously the end use of residential lighting dominated the residential electricity use. Fans were a close second at the time [6]. However a more recent study of over 1200 households across Pune, Talegaon, and Ahmednagar, found that fans were by far the largest end-use of electricity use (15%). Refrigerators followed at 8% and next was lighting at 4%. According to this study, lighting energy consumption was lower due to the high adoption of LED bulbs through national energy efficiency programs. [23]. Appliance penetration rates in the National Capital Region (NCR) were revealed by Khosla and Bhardwaj [24]. Almost every house was found to have a fan (99.4%), followed closely by TV (97%). Fridges are in 87% of households and active cooling systems are notably widespread (air-coolers (82%) and AC (19%). Less common were washing machines (50%) and water purifiers (38%). No mention was made about devices used for space or water heating. A few studies have provided insight into this area of residential energy consumption.

Hot-water and space heating services were found to be more prominent in northern states in India where outside temperature falls below 15°C in the winter season. Hot water usage is based on behavior and seasonal characteristics (mostly used in winter). The energy consumption for hot-water service was seasonal for two to four months in winter and it was also location dependent concentrated mostly in colder regions [25]. According to Yawale *et al.* [25], space heating had a small share in total household energy consumption since India has short cold seasons in most states; therefore space heating has not been a prominent area of concern for research in India. Overall, around 2% of Indian households use some form of energy to keep homes warm in winter.

Electricity is the least used fuel type for space heating. Himachal Pradesh, which can experience extreme winters had the highest share of households using electric space heating (85%). This is followed by other northern states including Delhi, Punjab, and Uttarakhand (12-14%) (survey did not include Jammu & Kashmir, Sikkim, Arunachal Pradesh, and other mountainous territories). In the remaining states, less than three per cent of households reported using electric space heating. On average, households use electric room heaters for three hours a day during winter months [20].

In a field study of five naturally ventilated multi-story apartments in Roorkee and Chandigarh (composite climates), Singh [26] observed the combined use of blinds and heaters to reduce heat loss at night where the outdoor temperature can drop to around 5-7°C. Heater use votes came into play when the indoor temperature reached 19°C and below (15.2°C minimum recorded). At 17°C almost 80% of subjects were using heaters. In contrast to space heating, water heating for bathing was found to be more prevalent in Indian homes. The practice was more common in urban areas and a moderate correlation was found between household income and share of households using water heating [20]. Among 3000 households surveyed in Maharashtra and Uttar Pradesh, water heating, where used, has also been found to contribute significantly to total energy consumption; however, fewer households use electricity to heat water (highest in high-income households, though still a minority). In this study, water heating by electricity (16%) trailed significantly behind water heating by LPG (64% - percent of households that use LPG for water heating). The study also found that colder weather was not a significant influence over whether hot water was used for bathing; income appeared to be a greater driver [21].

Considering this background, it is important to understand what the winter peaks are, when they occur, and find common patterns of usage,  given the absence of residential studies on electricity use and indoor environment during the winter season in India. The current paper intends to fill the gap.

## 3. Methodology

### *3.1. Monitoring data*

Concurrent monitoring of electricity current, indoor temperature and RH were undertaken using Bluetooth enabled battery-operated data loggers measuring half-hour intervals through the month of December 2021. The month of December was selected to represent the winter season in Hyderabad. The wall mounted data loggers were installed in the most occupied room or alternatively the room with AC present. Electricity current was measured through CT clamp loggers on householders' electricity meter. Outdoor temperature and RH data were obtained from Indian government loggers provided by the Central Pollution Control Board of India.

### *3.2. Survey data*

The survey questionnaire covered contextual information about the dwellings including physical (e.g., construction typology), sociodemographic (e.g., tenure, income), and energy related (e.g., appliances) variables (table 1). The appliance data were collected to complement the energy behaviour collected through daily electricity profiles. The questionnaire data were gathered using online Google Forms. Selected and trained survey researchers completed each question online while reading out the survey questions to the participant. In addition, each participant's electricity consumption bills for an year were obtained for analysis.

**Table 1.** Variables gathered in the survey

| Survey variables | Categories |
|---|---|
| Dwelling form | Stand alone, house (one common wall with adjacent house), row house, apartment block (less than four storeys), apartment block (greater than four storeys) |
| Dwelling size | 1BHK, 2BHK, 3BHK, 4BHK, 5BHK or more |
| Number of rooms | Drawing room, dining room, kitchen, bedroom 1, bedroom 2, bedroom 3, study, balcony/garden, other |
| Tenure | Self-owned, rented |
| House floor level | Ground floor, ground floor above parking, middle floor, top floor |
| Age of dwelling | <3 years, 3-5 years, 6-10 years, 11-15 years, >15 years, unknown |
| Income group | Low-income group (LIG), Medium-income group (MIG), High-income group (HIG) |
| Family size | Respondent provides number |
| Electric heating appliances | Number of room heaters, geyser |
| Other appliances | Number of TVs, refrigerator, desert coolers, washing machine |
| Cooling appliances | Number of AC units |

## 4. Physical context

### *4.1. Composite climate*

The Indian National Building Code (NBC) defines composite climate (covering 30% of India) as one which does not have the prevalence of any of the other four climates (hot-dry, warm-humid, temperate, cold) for six or more months in a year. Composite climate locations typically experience hot summers with daily outdoor temperature maximum of about 40°C - 44°C and temperature minimum of about 27°C - 32°C. Some locations with the composite climate can also experience relatively cold winters where the min. falls to 3°C - 10°C. Summers are dry with RH ranging from 20% - 30% when direct solar radiation is high; however, post-summer RH can range between 60% - 90%. Rijildas and Rajasekar [27] found significant variation between cold season minimums for various cities throughout the composite climate. As examples, Hyderabad can experience peak summer temperatures of 41°C and a peak winter min. temperature of 12°C, whereas Saharanpur can experience peak summer temperatures of 42°C and a peak winter min. temperature of 0°C.

The climate in Hyderabad is predominantly warm throughout winter as temperatures range between 28 - 29°C. Although temperatures in Hyderabad are not very low, it can be uncomfortable due to the high humidity. Figure 1 shows the daily variation in temperature and RH for the month of December. Higher temperatures are recorded during the summer months between April to June, peaking in the month of May. May is the hottest month with the monthly average daily maximum temperature reaching as high as 45°C, coupled with RH of about 60% during daytime. The average daily temperature in the city ranges from 32 - 45°C. The maximum daily average temperature is seen to rise again from October to December (known as October heat), after the monsoon months. India has one of the highest cooling degree days (CDD) in the world; Hyderabad is one of the cities with the highest at 3221 [13].

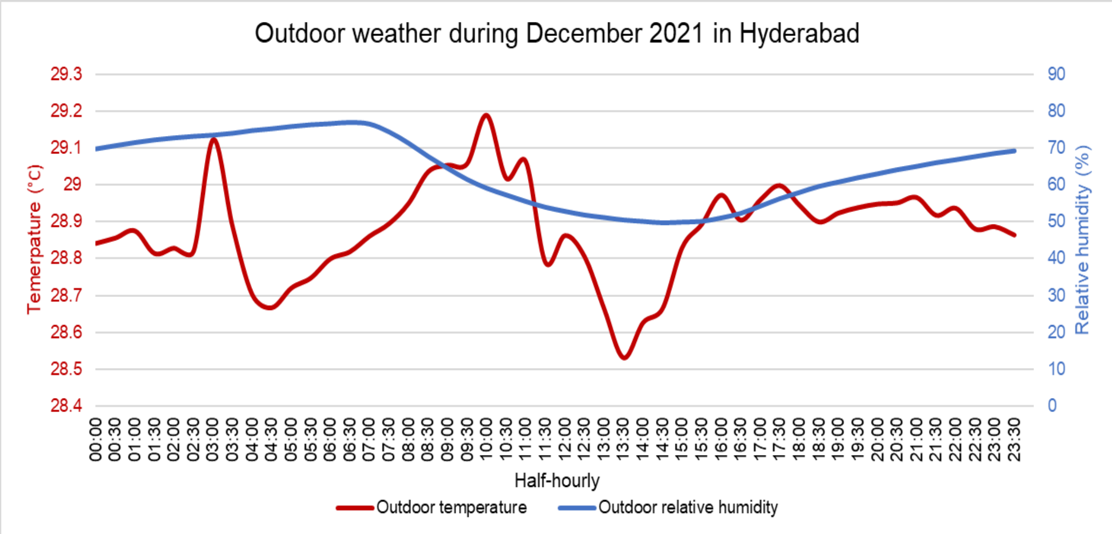


**Figure 1.** Mean outdoor daily temperature and relative humidity for December in Hyderabad

### *4.2. Case study dwellings*

The study sample of 64 dwellings consisted of 46 standalone houses, 17 apartments, and one row house. Figure 2 shows images from a few of the standalone houses. The following section provides more details on the physical characteristics of the case study dwellings.

**Figure 2.** Exterior and interior images of surveyed buildings in Hyderabad

## 5. Results

### *5.1. Key characteristics*

As noted above, most of the survey dwellings were houses (n=46). Most were also two-bedroom (n=40), 11 one-bed, and 13 three-bed dwellings. The majority had AC installed (n=44) and about half of these only had a single AC unit (n=23). Fourteen dwellings had two ACs and seven had three or more ACs installed. All but 15 dwellings had electric geysers installed and only two dwellings surveyed (HIG) had room heaters in their home. Most of the dwellings surveyed were in the middle income group (MIG) (n=35), 19 were in the low income group (LIG) and 10 were in the high income group (HIG). Table 2 indicates the number of dwellings in each income group with and without ACs installed.

**Table 2.** Key characteristics of study sample

| | House | Count | Apartment | Count |
|---|---|---|---|---|
| LIG | AC | 5 | AC | 1 |
| | No AC | 10 | No AC | 3 |
| MIG | AC | 21 | AC | 7 |
| | No AC | 5 | No AC | 2 |
| HIG | AC | 6 | AC | 4 |
| | No AC | 0 | No AC | 0 |

*5.2. Distribution of monitored variables*
The descriptive statistics of indoor temperature across the 64 dwellings show that the indoor temperature ranged from 21°C - 34°C for apartments, and 15°C - 31°C for houses indicating a lower temperature range in houses likely due to more exposed surface area (table 3). Higher maximum electricity current was observed in the houses (19.5A) than in apartments (15.1A); however, the mean was about equal (1A).

**Table 3.** Descriptive statistics of monitored variables across built forms

| | | Indoor temp. (˚C) | Outdoor temp. (˚C) | Indoor RH (%) | Outdoor RH (%) | Electricity current (mA) |
|---|---|---|---|---|---|---|
| Apartment (n=17) | Mean | 25 | 24 | 60 | 54 | 1072 |
| | Min. | 21 | 16 | 35 | 16 | - |
| | Max. | 34 | 31 | 78 | 84 | 15071 |
| | SD | 1 | 3 | 8 | 16 | 1384 |
| House (n=47) | Mean | 25 | 24 | 61 | 54 | 980 |
| | Min. | 15 | 16 | 33 | 16 | - |
| | Max. | 31 | 31 | 97 | 84 | 19537 |
| | SD | 1 | 3 | 7 | 16 | 1385 |

Descriptive statistics were characterised by income group. Most notably the HIG dwellings maintained a lower maximum indoor temperature (28°C) and a higher maximum E-current (19.5A) than the MIG (34°C /15.6A) and LIG (31°C /13.4A) dwellings. The lower maximum temperature and higher mean and maximum E-current in the HIG dwellings would suggest a higher use of electricity to maintain comfort. It is notable that all HIG homes had at least one AC installed. The importance of income on the temperature-energy demand relationship was also studied by [22]. As expected, households with higher income have more choices to regulate indoor temperature and maintain desired comfort than LIG dwellings.

*5.3. Indoor and outdoor variables*
There was weak correlation (r = 0.28) observed between indoor and outdoor temperatures. Between houses (r=0.28) and apartments (r=0.29) there was little difference. The largest difference was between

HIG (r=0.24) and LIG/MIG homes (both r=0.29). Indoor temperature poorly correlated with outdoor temperature may also suggests use of mechanical systems to maintain comfort temperatures. Since the R-value was lower in the HIG dwellings, they were likely to use electrical heaters to achieve a comfortable environment, irrespective of outdoor conditions.

Exterior temperatures ranged from 16°C - 31°C. Lows of 16˚C only occurred for two nights. The mean overnight low was 20.4°C and the rounded mode low was 22°C. At the 16°C lows there was little difference in overnight indoor temperatures between dwelling types and income groups. The minimum indoor temperatures for the LIG, MIG and HIG were 22.3°C, 22.2°C, and 22.1°C respectively. This would suggest that there was no use of heaters confirming an assumption that an outdoor overnight low of 16°C was not low enough to trigger the use of a heater. There was, however, a greater difference in the daytime highs and overnight lows between the income groups when the daytime and overnight temperatures were highest. This suggested possible use of AC in the HIG dwellings and found lower set points more acceptable, whereas other income groups did not regularly use AC or had higher set points due to cost concerns. Figure 3 shows a similar pattern among only the AC users, indicating the above presumption may be correct.

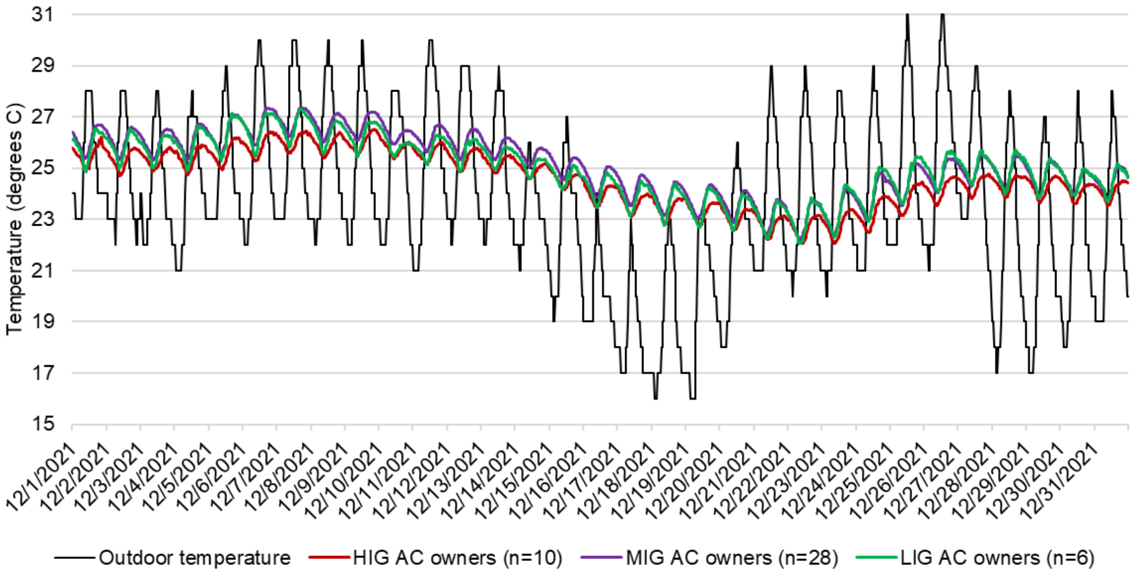


**Figure 3.** Temperature variation for AC owners by income group

### *5.4. Electricity consumption*

The hourly electricity current, indoor temperature and RH profiles were plotted separately for houses and apartments in Figure 4. A similar pattern of morning peak between 8:00 – 9:00 AM and evening peak between 18:00 – 19:00 was also seen in all income groups and all number of bedroom groups when plotted individually (not shown). The magnitude of the peak, however, was different. Morning peak was highest in the HIG dwellings at 2.5A and lowest in the MIG dwellings at 1.5A. Evening peak was highest in the HIG dwellings at 1.7A and lowest in the LIG dwellings at 1.2A. In all cases like the overall plot, morning peak was higher than evening.

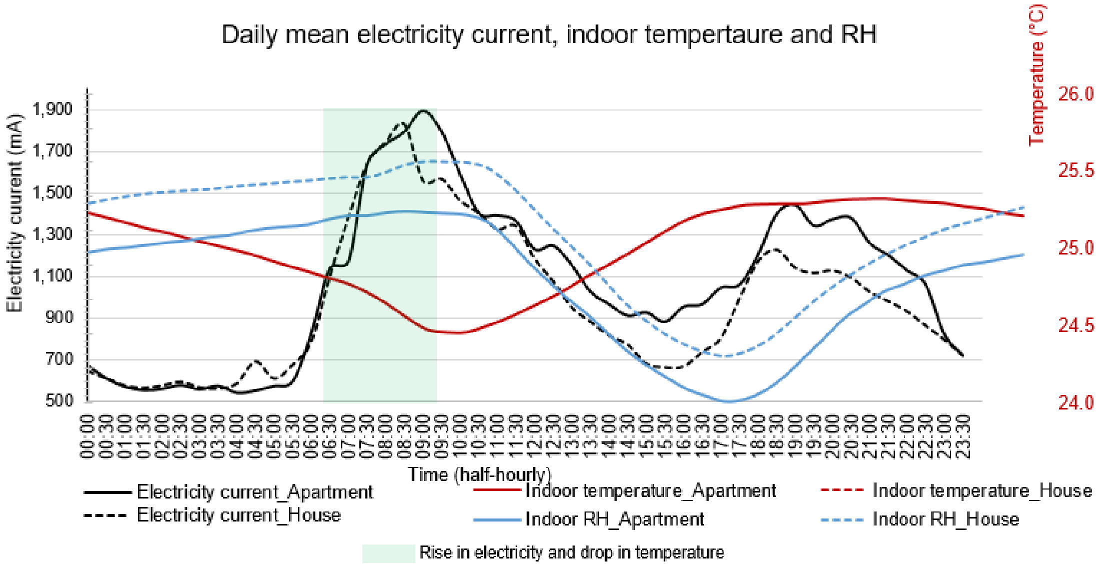


**Figure 4.** Daily mean variation of electricity current, indoor temperature, and RH by built form

The primary peak period of wintertime electricity use was observed to occur in the morning between 6:30 – 10:30 indicating geyser use for hot water in addition to cooking and potentially TV, with a smaller peak in the evening likely to be due to television and cooking. Chunekar *et al.* [28] found the use of geysers to be most dominant from 5:00-10:00am on winter mornings. Figure 5 shows the daily mean current for homes with no, one, two and three geysers. As number of geysers increased so did the magnitude of the peak and percent of morning peak period that contributed to the total daily electricity current. In homes with no geyser, the morning peak period contributed to 19% of total mean daily electricity current. In homes with one geyser, this was 21% and in homes with two geysers, this was 23%. Only one dwelling had three geysers. Though it has a much higher peak in the morning, the total morning peak contribution to the daily mean total was only 17%.

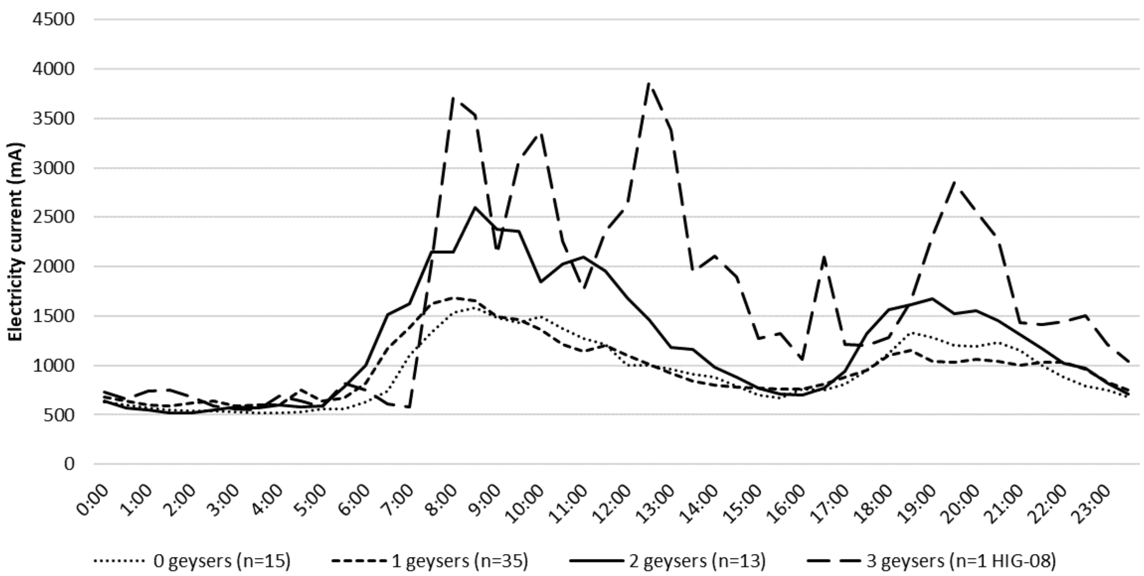


**Figure 5.** Daily mean variation of electricity current by no. of geysers

Only two dwellings had room heaters. Both dwellings were HIG dwellings and one of them was the dwelling shown above with three geysers installed (HIG-08). Figure 6 shows the two dwellings with room heaters along with the daily mean pattern of another HIG dwelling that had the highest total daily electricity current. Both dwellings with room heaters had higher morning and evening peaks; however, the mean daily temperature pattern indicated that HIG-08 may be the only dwelling using the room heater consistently. This is theorised by the steady temperature rise and hold in the early morning hours (23:00-6:00) at 25˚C followed by a clear drop-off. This is contrasted with the natural drop in temperature seen in the other two dwellings. Sharp morning peaks in HIG-02 and HIG-08 are most likely from the use of geysers.

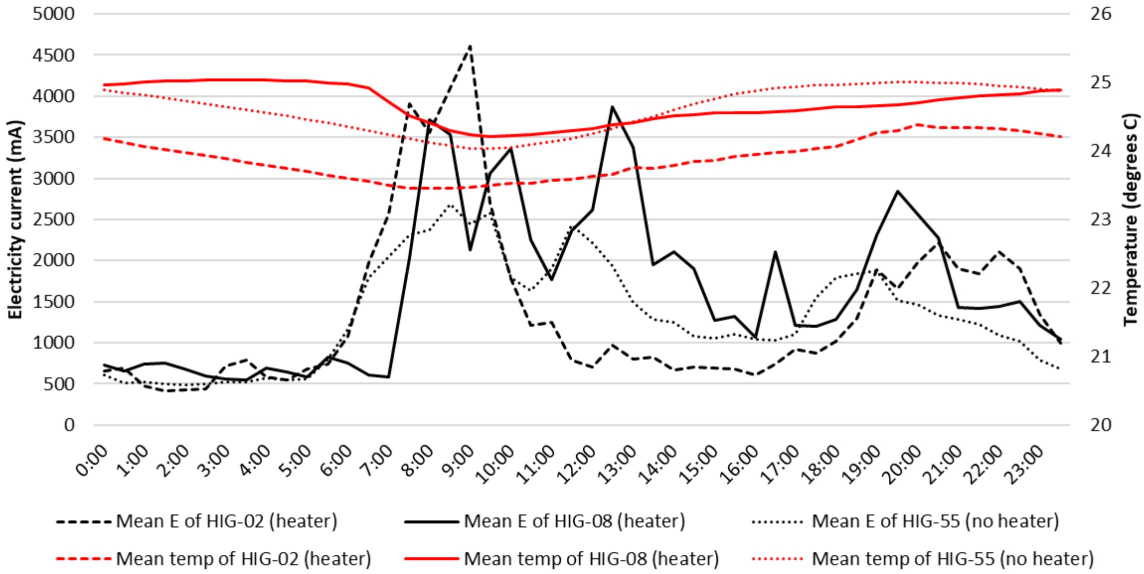


**Figure 6.** Daily mean variation of electricity current and indoor temperature: heater vs. no heater

Though the monitored period was over winter, the question remains, was there AC use in dwellings during this period? Figure 7 shows daily mean electricity and temperature in all dwellings with AC, all dwellings without AC and HIG dwellings with AC (i.e., all HIG dwellings). The figure indicates that there is a slightly lower temperature and slightly higher electricity use in the AC dwellings versus non-AC dwellings overall. This alone may not be enough; however, when HIG dwellings are extracted, the difference is quite clear. It is highly probable that several of these HIG dwellings were using ACs during this period.

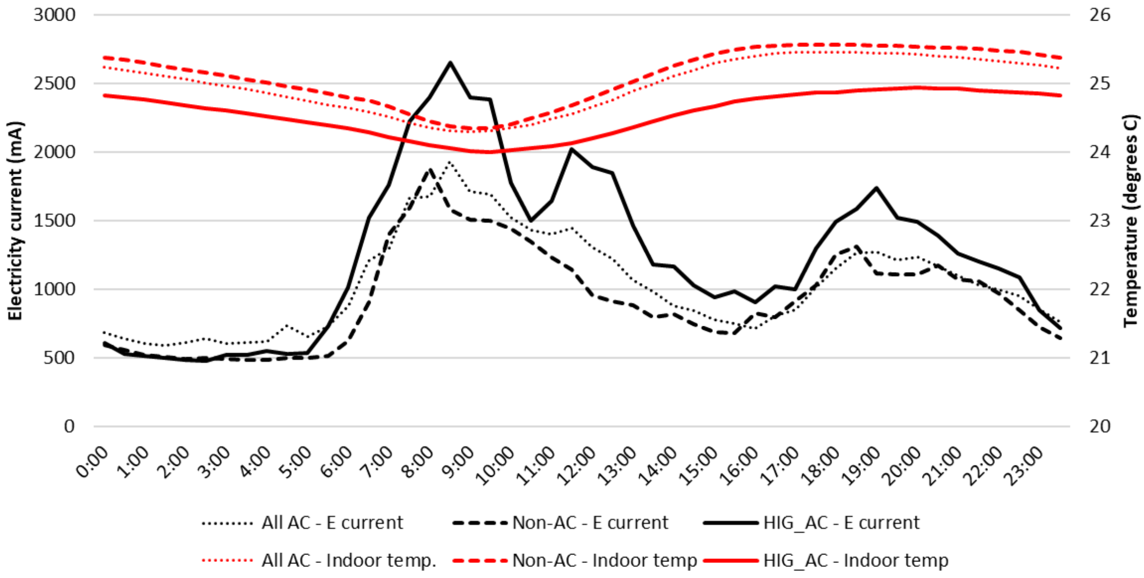


**Figure 7.** Daily mean variation of electricity current and indoor temperature: AC vs. non-AC dwellings

## 6. Discussion

The composite climate in India is typically marked by hot summers and cool winters. However, as the climate varies significantly between locations, it is not clear whether space heating is widely used. Across the case study dwellings in Hyderabad, space heating was not found to be the dominant energy end use in December. Electric geysers, used to heat water in the morning hours, were theorised to be the source of majority demand. The highest winter peaks were observed during 6:30-10:30 in the morning, whereas the evening peak was 1.4 times lower. This is in contrast with the national peak for India which occurs from 18:00 – 22:00 which corresponds to the summertime peak found by Gupta *et al.* while studying the difference in summertime energy use between dwellings with and without ACs in Hyderabad [5]. The HIG dwellings maintained slightly lower indoor temperatures and RH which could indicate a lower tolerance to changes in indoor conditions; and therefore, more space conditioning.

Although a few room heaters were used in this study sample, it is safe to assume that more heaters may be acquired as households increase in affluence. Currently the Indian Bureau of Energy Efficiency (BEE) rating program does not provide energy ratings for room heaters. Without regulation on the efficiency of room heaters this may present a blind spot with respect to energy management. Energy efficiency awareness is currently low with respect to water heating and space conditioning [28]; necessitating the need for energy awareness measures. Along with this, improving building fabric thermal performance through insulation standards will be needed. By reducing heat transfer through the building envelope, the need of energy used for space heating and cooling can be minimised. Renewable energy solutions will also be helpful in the current situation with hot water demand. As domestic solar panel systems typically have a capacity of between 1 kW and 4 kW, winter electricity consumption could be covered by solar panels.

## 7. Conclusion

This paper has presented statistical analysis of time-series data on indoor temperature, RH, and electricity current for 64 dwellings located in the city of Hyderabad representing the composite climate of India. The analysis focussed on the winter season with data collected during the month of December 2021. Over the period of study, the mean indoor temperature was observed to be 25°C while the mean indoor RH was 60%, although the variation across the dwelling sample was wide-ranging. Winter primary peak period was observed to occur from 6:30 - 10:30 am in the morning as opposed to late evening for the summer season. During winter season, the use of geyser for hot water was a key end use of energy in the morning. Only one dwelling showed potential signs of using space heating. Higher electricity use aligned with lower peak temperatures in some homes indicated AC use during winter, particularly in the high-income group.

These findings can help to inform the development of energy efficiency policy to curb the wintertime energy demand in Indian dwellings. The wintertime morning electricity peak in India can be managed using thermal stores in geysers through pre-heating which could also offer demand response opportunities. This is an area of further research.

## 8. Acknowledgement
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