Feasibility study of ground source heat pumps for different building types under Indian climate zones

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ABSTRACT

Ground source heat pump (GSHP) systems are gaining popularity and being considered as a serious alternative to traditional heating and cooling systems in India. The adaptability of GSHP systems across India depends on climate and geological factors. A simulation study was conducted to evaluate the feasibility of implementing GSHP systems for providing heating and cooling in 16 cities across India, considering various climate conditions and five different building typologies. The heating and cooling loads of these buildings (i.e., residential, office, supermarket, educational, and hospital) in the selected cities are simulated using EnergyPlus software. Simulation results analysed each location's heating and cooling loads, monthly peak electricity demand, and peak loads for the selected climate zones for summer and winter design days. It is found that GSHP systems may be feasible for cities in warm marine and mixed dry climate conditions (3C and 4B zones according to ASHRAE standards), particularly those in the northern region of India, because of alternate heating and cooling demand. The implementation of GSHP provides a feasible option for other climates in India by adopting special design techniques or including additional hybrid energy sources.

Keywords: Ground source heat pump, Indian climate zones, peak loads, building typologies, sustainable development, EnergyPlus

1. Introduction

Over 30% of global energy consumption is accounted for by the building sector. The global energy demand for the building sector is anticipated to increase by more than 60% between 2007 and 2050. The energy usage for space cooling has been increasing more quickly than for any other end-use in buildings because of climate change, and this pattern is set to continue for the coming decades (Chakraborty et al. 2021). Due to their scarcity and rising environmental pollution, governments across the world are shifting towards renewable energy technologies to minimize its dependency on fossil fuels. Renewable energy sources such as wind, water, solar, biomass, ocean (tide and wave), and geothermal energy are limitless. As a result, both developed and developing nations are working to create renewable energy sources to meet the world's growing energy needs. China, the United States, Brazil, Canada, Iceland, Denmark, Sweden, Norway, Germany, Finland, Austria, Belgium, Spain, France, Italy, Russia, the United Kingdom, Turkey, Japan, Australia, and India are among the leading nations in the production of renewable energies (Secretariat 2023). The seventh sustainable development goal (SDG) is to improve international cooperation by 2030 to facilitate access to clean energy research and technology, including renewable energy, energy efficiency, and advanced and cleaner fossil-fuel technology. It also encourages investment in energy infrastructure and clean energy technology, expands infrastructure, and upgrades technology for providing modern and sustainable energy services for everyone, particularly in developing countries.

One of the economies in the world with the quickest growth is India. Nearly every sector of the economy has benefited from globalization. The energy sector in India is one of the most important parts of the country's infrastructure that significantly influences economic growth. India is the sixth-largest energy user, accounting for roughly 3.4% of worldwide energy consumption, and has the fifth-largest electrical generation capacity. The past 30 years have seen a 3.6% annual increase in India's energy needs (Kumar et al. 2014). After industry, the building sector in India is the highest consumer of energy. Around 46% of the power consumed is in the industrial sector, while 29% is used in the building sector. The Indian building sector can be divided into two categories: residential buildings and commercial buildings. Around 45% of the energy used in the residential sector is used for space conditioning, heating, and cooling. About 32% of the energy utilized in the commercial sector goes toward heating, ventilation, and air conditioning (Sivasakthivel et al. 2014).

The winter session in India begins in late November and lasts until the middle of March. Most of the northern Indian states need space heating systems during the winter. Electric heating is primarily used for this heating. The annual minimum required amount of electricity for space heating is around 1416.9 GW (Sivasakthivel et al. 2012). Evaporative coolers and air conditioners are typically utilized to cool the building envelope. The conventional system generates significant amounts of energy use, water use, and carbon emissions (Ralegaonkar et al. 2014). To maintain the required comfort, the installation of air conditioning systems in buildings has increased exponentially. As a result, the total energy consumed by the air-conditioning units has steadily increased from

2308 GWh (2006) to 5099 GWh (2011), and by 2030, it is predicted to reach 50 TWh/y (Panchabikesan et al. 2017).

In India, the demand for heating and cooling is often met by using conventional technologies like electric heaters and air conditioners during the winter and summer. Northern India has a continental climate with extreme summer and winter weather, whereas the southern and coastal parts of the nation experience a warm and humid environment all year round. Different requirements are needed to provide space cooling and heating in buildings because of the wide variations in climatic conditions across the country (Panchabikesan et al. 2017). India's climate varies from region to region. Most of the regions in the nation require both heating and cooling, but certain areas of the nation only need cooling. In this study, an effort is made to emphasize the potential use of water-to-air ground source heat pumps (GSHP) for all types of climate conditions in India, by ASHRAE standard 169-2013 (ASHRAE 2020). The investigation was also done for five different building typologies (residential, office, supermarket, educational, and hospital).

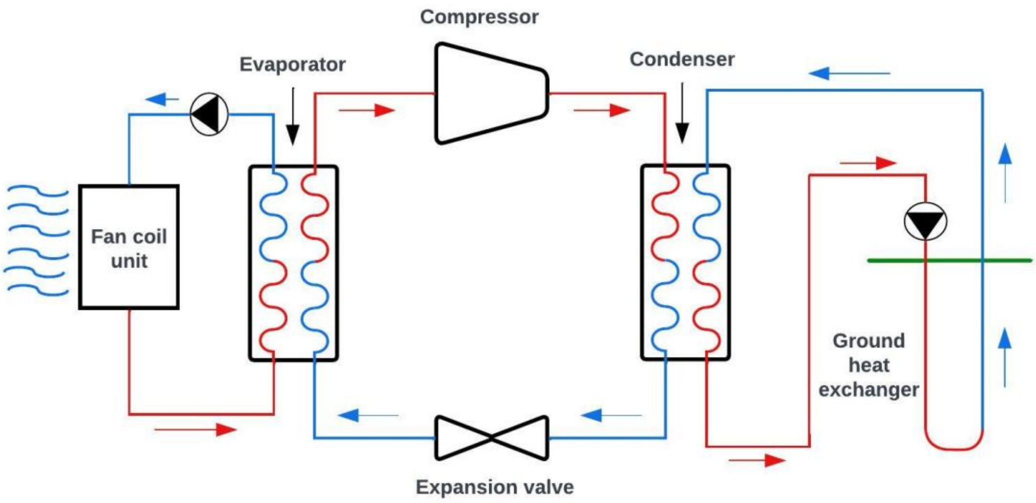


Fig. 1 Traditional GSHP system

A traditional GSHP system as shown in **Fig. 1** consists of three main components, namely (a) the primary circuit, which is a closed ground heat exchanger (GHE) in the ground, (b) one or more heat pumps, either water-to-air or water-to-water, integrated into the primary and secondary circuits, and (c) a secondary circuit which is a closed-circuit pipe with heat-carrying liquid (mainly water with antifreeze) embedded in the receiving infrastructure elements. GSHP can function both in heating and cooling mode and the switching can be done using a reversing valve. While in heating mode, GSHP draws heat from the earth and distributes it to the room. It absorbs heat from space and rejects it into the earth while in cooling mode. Either an open loop system or a closed loop system can be used with the GSHP. Water bodies serve as the primary source or sink for the system in an open loop system. Several analytical and numerical approaches have been developed over the years to simulate and design the GSHP system. Walch et al, proposed a new approach to quantify the technical potential of GSHPs, accounting for the effects of seasonal regeneration, and estimating the useful energy to supply building energy demands at a regional scale. The case study in western Switzerland suggests that seasonal regeneration allows for annual maximum heat extraction densities above 300 kWh/m^2 at heat injection densities above 330 kWh/m^2 (Walch et al. 2022). A geo-heat pump system was set up at Kasetsart University, Bangkok using a horizontal piping system and obtained good results a high COP of 3-4 and stable underground temperature. A Shallow (1-2 m) depth is the lowest temperature zone in a tropical land and is easy to construct at a low cost (Takashima et al. n.d.). Yusof et al. (2014) discussed the potential of the implementation of ground thermal storage by using a ground heat exchanger (GHE) to supply passive cooling for any application. The analysis had been conducted based on an empirical equation from conduction heat transfer for depths of up to 30 m and thermal diffusivities from 0.04 to 0.1 m^2 /day (Yusof et al. 2014). The Elizabeth Blackburn School of Sciences geothermal experiment was set up to study a full-scale commercial GSHP system under real-life thermal loads for a school building in climatic and geological conditions typical of Melbourne, Australia (Mikhaylova et al. 2015). An analysis of the application of GSHP systems to different temperature zones in China was carried out (Bi et al. 2009). The vertical loop geothermal heat pump (GHP) system coupled with a normal air conditioner was installed in an experimental room in the Parot Racha Building, Chulalongkorn University, Bangkok, Thailand (Chokchai et al. 2018). A ground source-air source combined heat pump system implemented in the Sustainable Buildings Research Centre (SBRC) at the University of Wollongong, the experiment was carried out to investigate the effects of the operating configurations of GHEs (i.e., series and parallel) and the water flow rate in the GHEs on the overall performance of the GSHP system (Huang 2014). The GSHP system of water-to-refrigerant type was installed in a school building of Pusan National University, Korea to analyse its technical and economic aspects under the actual operating condition (Kim et al. 2012). An experimental analysis was performed on the GSHP system set up in the Energy Laboratory on the campus of Ataturk University to evaluate the performance and energy analysis of the vertical ground-source heat pump (GSHP) for winter climatic conditions of Erzurum, Turkey (Ozyurt and Ekinci 2011). A case study was done on a residential building in Korea to provide a model that maximizes the total life cycle cost (LCC) by considering various costs and efficiencies depending on the capacity and efficiency of the photovoltaic (PV) and GSHP systems and optimization analysis using the heuristic solution and multi-objective genetic algorithm (Sim and Suh 2021).

Some of the applications of GSHP are examined to determine how well they adapt to India's various climatic conditions. Sivasakthivel et al. (2015) has examined the potential application of GSHP technology in 10 cities in and around India's Himalayan regions, where both heating and cooling are needed. A thorough analysis of the annual electricity and CO2 savings from using GSHP during the winter in India's northern area was conducted. Ten states are taken into account for the analysis, with the first category consisting of states with extremely cold weather and the second category consisting of states with moderately cold weather. An experiment was conducted to examine the thermal performance of a ground source heat pump system placed in the Indian city of Roorkee, which is located in the Himalayas, for a composite climate (Sivasakthivel et al. 2016). In ten major cities with tropical and subtropical climates, a feasibility study was conducted on the installation and performance of vertical ground source heat pump (GSHP) systems for heating and cooling a typical 9000 m^2 office building (Roy et al. 2020).

According to a thorough literature review of GSHP applications in India, the northern area of the country has been the subject of the majority of investigations. Secondly, the analysis was conducted solely for office building typology. Nowadays, GSHP systems are often of the water-to-water variant. The fan coil unit (FCU), provides energy as cold and hot water is produced by a heat pump to the entire building. Recently, a GSHP system of the water-to-air type has been developed. The Ground heat exchanger (GHE) is the same in a water-to-air type heat pump system as it is in a water-to-water type system, but the inside units exchange heat using air instead of water to cool the system. Due to water pipe corrosion and leak issues, the water-to-water heat exchanger also requires a circulating pump to transfer water to the FCU, which requires routine maintenance. However, the circulating pump that sends water to the FCU is not required in the water-to-air type system, eliminating the pump's cost and maintenance (Kim et al. 2012).

Simulation studies of viability of GSHP systems for providing heating and cooling in various building types across India have not been conducted as per the authors' knowledge. Based on available literature, there is limited research on GSHP feasibility in southern Indian regions as well. In the present study, the heating and cooling loads, monthly peak electricity demand, and peak loads are calculated for five standard building types across 16 cities in India operating with a GSHP system.

2. Research Methods

2.1 Climate zones in India

India has a wide range of climates that are roughly divided into five regions, each of which has a different climate. There are five different climate zones: hot and dry, warm, and humid, composite, temperate, and cold (NBC, 2016). According to the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) Standard 169-2013 (ASHRAE 2020), there is a classification of climate that is globally accepted. This classification is based on cooling, heating degree-days, and precipitation quantity and is standardized by numeric values from 0 to 8 and letters (A, B, and C). By ASHRAE Standard 169-2013 (ASHRAE 2020), Indian cities are categorized into eight climate zones, which are illustrated in Table 1 (Bhatnagar et al. 2018).

Table 1 ASHRAE Standard 169-2013 climate zones for India (ASHRAE 2020)

Sl.no	Climate zone	Abbreviation
1	Extreme hot humid	0A
2	Extreme hot dry	0B
3	Very hot humid	1A
4	Very hot dry	1B
5	Hot humid	2A
6	Hot dry	2B

7	Warm marine	3C
8	Mixed dry	4B

Table 2 Description of selected cities

City	Climate Zone	Climate	Latitude/ Longitude	HDD/CDD	Design days Winter/summer
Panjim	0A	Extreme hot and humid	15.48/73.82	0/6371	FEB 23 / MAY 05
Ratnagiri			16.98/73.33	0/6083	FEB 22 / MAY 05
Ahmedabad	0B	Extreme hot and dry	23.07/72.63	13/6289	DEC 31 / MAY 13
Sholapur			17.67/75.90	0/6270	DEC 19 / MAY 16
Kolkata	1A	Very hot and humid	22.65/88.45	18/5931	JAN 06 / MAY 12
Jagdalpur			19.08/82.03	22/5275	JAN 03 / MAY 08
Varanasi	1B	Very hot and dry	25.45/82.87	180/5697	JAN 17 / MAY 10
Lucknow			26.75/80.88	203/5307	JAN 13 / JUN 20
Tezpur	2A	Hot and humid	26.62/92.70	72/4994	JAN 20 / JUN 02
Jorhat			26.90/94.20	174/4816	JAN 08 / JULY 22
Amritsar	2B	Hot and dry	31.38/74.87	107/4947	JAN 02 / MAY 26
Dumka			24.27/87.25	102/5585	JAN 9 / JUNE 9
Shillong	3C	Warm marine	25.57/91.88	1454/1791	JAN 2 / AUG 13
Shimla			31.10/77.17	1391/2350	JAN 30 / JUNE 27
Srinagar	4B	Mixed dry	34.05/74.80	2273/1981	JAN 13 / JULY 18
Bhuntar			31.83/77.17	2520/1316	DEC 29/ MAY 26

Error! Reference source not found. lists the cities, climates and climate zones, global location, heating degree d ays (HDD) (i.e., the number of days in a year for which an HVAC system for heating is required), cooling degree days (CDD) (i.e., the number of days in a year for which heating ventilation and air conditioning (HVAC) systems for cooling are required), design days and dry bulb temperature (for summer and winter) of these cities.

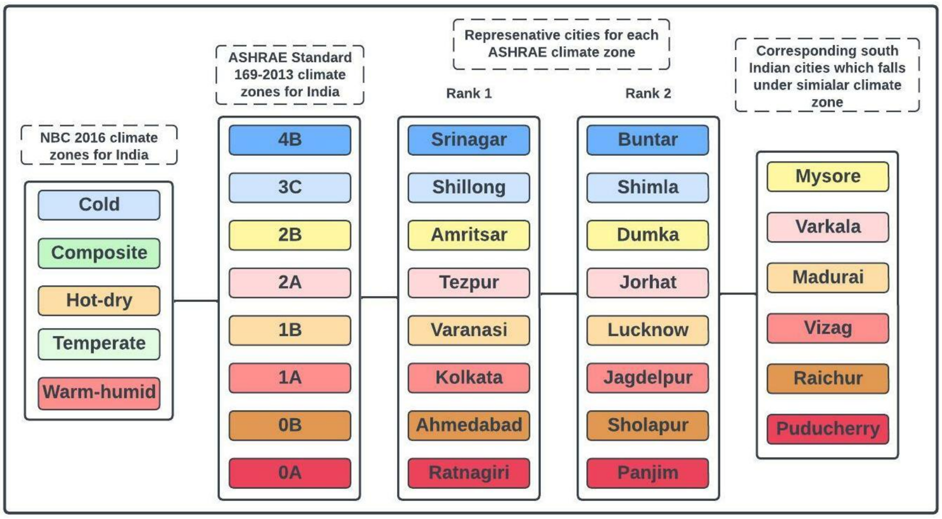
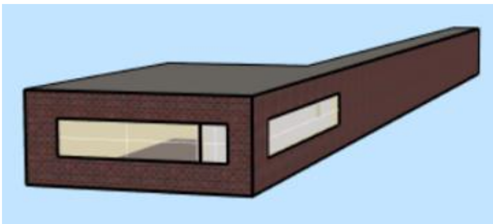
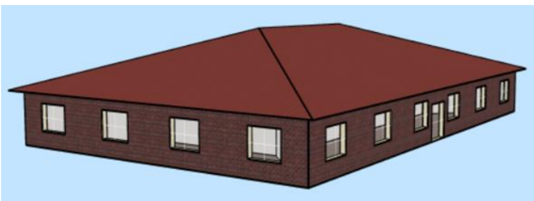
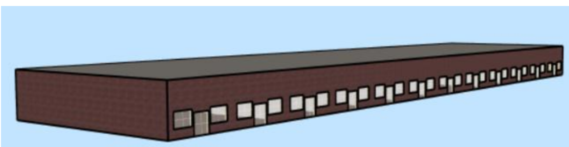


Fig. 2 Selection criteria for cities

According to the ASHRAE standard 169-2013's (ASHRAE 2020) classification of cities into different climate zones, the Euclidean distance approach has been used to analyse meteorological data from those cities. In a climate zone, the city that is closest to the fewest other cities is considered to be centrally positioned. The closest city to every other city in a given climate is ranked "1" and is regarded as a representative city. It is so because, in terms of climatic factors, the city with the shortest distance from the centre of the climate zone is depicted(Bhatnagar et al. 2018). Two cities for each climate zone have been chosen for our study based on the rankings as indicated in **Fig. 2**. Further, corresponding cities in the south are considered which have similar climate zones. The cities which experience extreme climate conditions in the particular climate zone are taken into account for simulation (rank 1 and rank 2).

2.2 Description of building typologies

 **Fig. 3** Residential building	Building type: Residential (ASHRAE standard) Floor area: 113.5 (m2) Floor-to-roof height: 3 (m) Window wall ratio (%): 30 Occupancy rate: 0.0215 (people/m2) Building operating hours: 00:00 to 24:00
 **Fig. 4** Office building	Building type: Office (ASHRAE standard) Floor area: 1033.9 (m2) Floor-to-roof height: 3.5 (m) Window wall ratio (%): 30 Occupancy rate: 0.0538 (people/m2) Building operating hours: 08:00 to 18:00
 **Fig. 5** Supermarket	Building type: Supermarket (ASHRAE standard) Floor area: 1993.7 (m2) Floor-to-roof height: 5 (m) Window wall ratio (%): 30 Occupancy rate: 0.0861 (people/m2) Building operating hours: 09:00 to 21:00

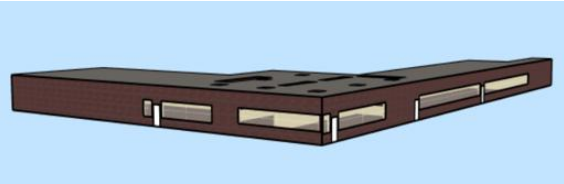
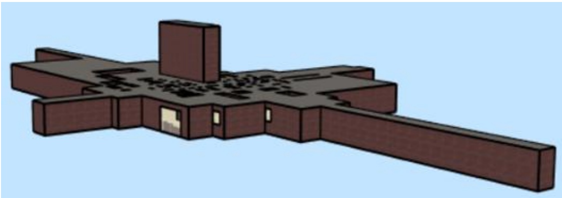
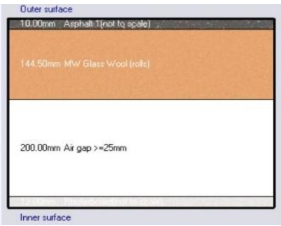
 **Fig. 6** Educational building	Building type: Educational (ASHRAE standard) Floor area: 921.6 (m2) Floor-to-roof height: 4 (m) Window wall ratio (%): 30 Occupancy rate: 0.6997 (people/m2) Building Operating Hours: 08:00 to 18:00
 **Fig. 7** Hospital	Building type: Hospital (ASHRAE standard) Floor area: 716 (m2) Floor-to-roof height: 5 (m) Window wall ratio (%): 30 Occupancy rate: 0.07 (people/m2) Building operating hours: 00:00 to 24:00

Table 3 Building construction parameters

Element cross-section	Layers		Thickness (m)	Density (kg/m3)	Thermal conductivity (W/m-K)	Specific heat (J/kg-K)
Wall 	1*	Brickwork	0.1	1700	0.8400	800
	2*	XPS Extruded polystyrene	0.0795	35	0.0340	1400
	3*	Concrete block	0.1000	1400	0.5100	1000
	4*	Gypsum plastering	0.0130	1000	0.4000	1000
Roof 	1*	Asphalt	0.0100	2100	0.7000	1000
	2*	MW Glass Wool	0.1445	12	0.0400	840
	3*	Air gap	0.2000	-	-	-
	4*	Plasterboard	0.0130	2800	0.2500	896
Floor 	1*	Urea-formaldehyde foam	0.0869	10	0.0400	1400
	2*	Cast concrete	0.1000	2000	1.1300	1000
	3*	Floor/Roof screed	0.0700	1200	0.4100	1200
	4*	Timber flooring	0.0300	650	0.1400	1200

*1-outermost layer; 2 – second layer; 3- third layer; 4- innermost layer

2.3 Modelling detail

To perform the energy simulations of the selected buildings, the relevant weather data and building templates are taken from the ASHRAE standard (version 169-2017) (ASHRAE 2020) and ISHRAE standard (ISHRAE 2017). **Fig. 3** to **Fig. 7** depict and describe the chosen building types. Table 3 presents the construction materials and parameters of the chosen buildings.

Simulations are carried out for calculating the hourly thermal loads (kW) of the building during the conditioned period of summer and winter design days. To utilize the HVAC throughout the year, it should be designed for two representative days termed 'summer design day' and 'winter design day' with all possible maximum thermal conditions. Accordingly, building peak heating and cooling loads (kW) are obtained. Further, the annual energy simulations are performed to obtain the annual heating and cooling loads (kWh) of the building. These analyses are carried out based on the yearly climatic data of respective cities obtained from the ISHRAE weather data (ISHRAE 2017).

3 Results and discussion

This study embraced five building typologies that cover residential, office, supermarket, educational, and hospital facilities whose construction characteristics and energy usage profiles were developed based on ASHRAE standards 169-2013 (ASHRAE 2020). About ASHRAE standards 169-2013 (ASHRAE 2020), India has 8 climate zones and for this study, 16 cities were selected. Among them, 2 cities were selected to represent each climate zone.

Each building typology appearing below has a set of simulation outcomes. Each cluster has two columns and three rows of the results. For comparison, these columns indicate selected cities that fall into the related climate zone. The three rows of six graphs included in each cluster represent the annual system load, electricity consumption, and peak load. The system load covers the energy demand for space heating and cooling of the building. The peak heating and cooling load were derived from summer and winter design days. In these graphs, heating loads are depicted with red lines, and cooling loads using blue lines.

It should also be noted that maximum heating loads occur during the winter season (December, January and February) while maximum cooling loads occur in summer (April, May and June) in all cases in the present study.

3.1 Residential buildings

Space cooling and heating for residential buildings depend upon regional and application factors. In the present study, the building under consideration the occupancy rate is only 0.0215 (people/m2) with availability of installation space for GSHP to provide combination of heating and cooling.

From **Fig. 8** the maximum annual cooling load for the residential building is obtained at Ahmedabad (31,183 kWh) followed by Kolkata (30,056.1 kWh) and Varanasi (27,720.6 kWh). These three cities have high CDD and hence would require constant space cooling throughout the year. However, it is observed that cities in climate zone 0A like climate zone 0B have lower cooling load requirements than Kolkata and Varanasi despite having higher CDD. Further, cities like Amritsar (27,715.4 kWh) in climate zone 2B has a higher a higher cooling load than Panjim (27,013.7 kWh) in climate zone 0A. The corresponding annual electricity consumption for space cooling follows the same trend with highest consumption for Ahmedabad (8,909.421 kWh) followed by Kolkata (8,587.455 kWh) and Varanasi (7,920.18 kWh) as observed in **Fig. 9**.

In contrast, it is seen from **Fig. 8** the maximum heating load is obtained at Buntar (5,557.696 kWh) followed by Srinagar (4,874.35 kWh), Shimla (3,286 kWh), and Shillong (3,267.709 kWh). These four cities lie in climate zone 3C and 4B and have equitable number of HDD and CDD which renders them favourable for GSHP installation. The corresponding electricity consumption for heating is highest at Buntar (1,984.891 kWh) followed by Srinagar (1,740.839 kWh), Shimla (1,173.585 kWh), and Shillong (1,167.039 kWh) as evident from **Fig. 9**. Cities like Jorhat (578.8855 kWh), Dumka (463.3072 kWh), and Tezpur (256.6372 kWh) also require a small amount of annual heating load as per the results.

Daily peak cooling loads occur in daytime between 6:00 hours and 18:00 hours with maximum cooling load requirements on a given design day occurring at cities like Ahmedabad, Kolkata, Lucknow and Sholapur **(Fig. 10)**. Daily peak heating loads occur at early morning and late night with maximum heating load on a given design day occurring at Srinagar, Shimla, Buntar and Shillong **(Fig. 10)**.

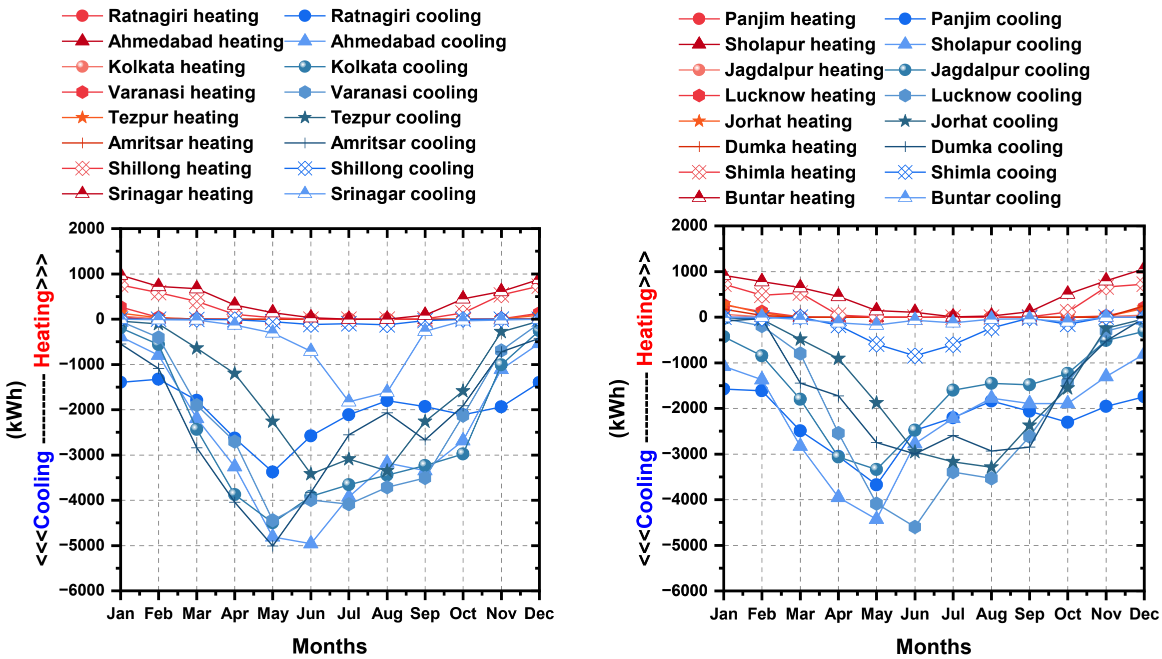


Fig. 8 Annual monthly heating and cooling loads for residential buildings

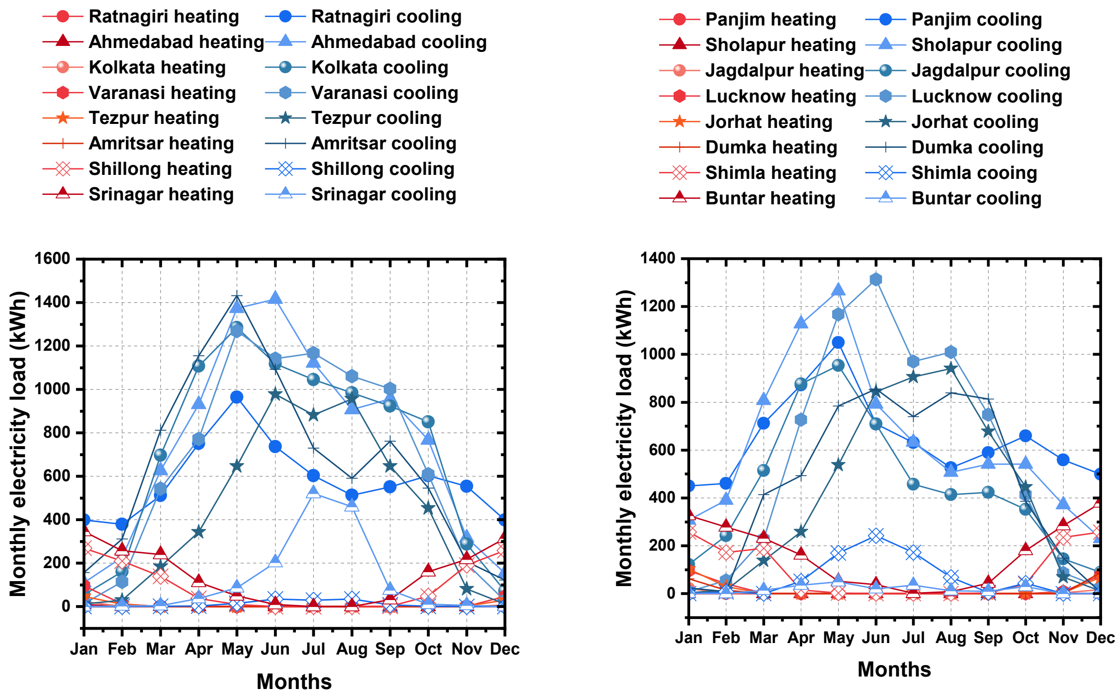


Fig. 9 Annual monthly electrical loads for residential buildings

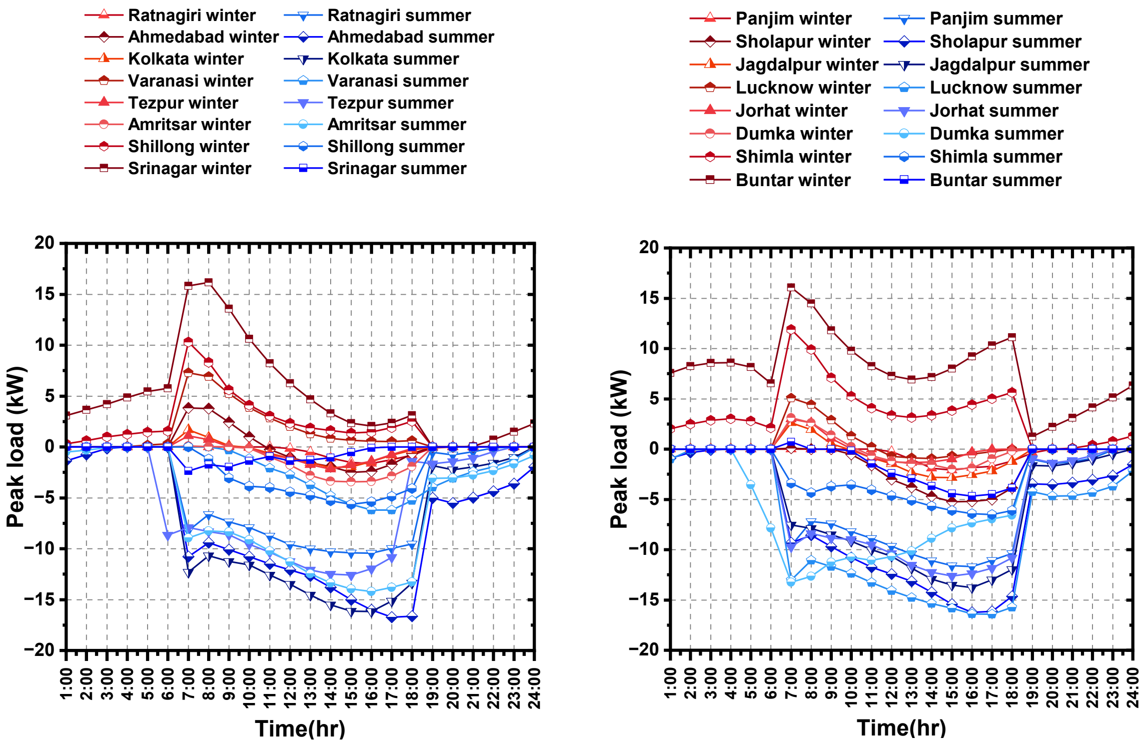


Fig. 10 Daily peak loads for residential buildings

3.2 Office buildings

Office buildings are fundamentally the most complex buildings to design due to high occupancy rate, multiple zones, ownership and location. The occupancy rate for the building in the present study is 0.0538 (people/m2) which is twice that of a residential building.

The maximum annual cooling load for the office building is observed at Kolkata (57,828.13 kWh) followed by Ahmedabad (57,414.95 kWh) and Amritsar (55,843.71 kWh) as shown in **Fig. 11**. A similar trend to the annual cooling load in residential buildings is observed as cities in climate zone 0A like climate zone 0B have lower cooling load requirements than Kolkata and Varanasi despite having higher CDD. The corresponding annual electricity consumption for cooling is highest at Kolkata (16,522.32 kWh) followed by Ahmedabad (16,404.27 kWh) and Amritsar (15,955.35 kWh) (**Fig. 12**).

From **Fig. 11** the maximum heating load is obtained at Srinagar (1,954.36 kWh) followed by Buntar (1,390.80 kWh), Shillong (149.12 kWh), and Shimla (41.35 kWh). This trend is again similar to residential buildings. The corresponding electricity consumption for heating is highest at Srinagar (697.99 kWh) followed by Buntar (801.46 kWh), Shillong (53.26 kWh), and Shimla (91.39 kWh) as seen in **Fig. 12**.

Maximum value of peak cooling loads as observed in **Fig. 13** occur in daytime between 6:00 hours and 18:00 hours with maximum cooling load requirements on a given design day occurring at cities like Ahmedabad, Varanasi, Lucknow and Sholapur. Peak heating loads occur at early morning and late night with maximum heating demand on a given design day occurring at Srinagar, Shimla, Buntar and Shillong. However, these peak loads are lower than those for a residential building. It is important to note that there is a constant need for heating at these four locations throughout the day.

3.3 Supermarkets

Supermarkets are usually wholly owned by a single company and chains have similar design, construction and layout. The higher occupancy rate (0.0861 (people/m2)) is a standard given value. There are a number of refrigerated display items and sometimes the doors might even require some heating to prevent fogging. These may have an effect on heating loads and energy consumption.

The maximum annual cooling load for the supermarket building is obtained at Kolkata (3,07,526.82 kWh) followed by Panjim (3,03,267.47 kWh) and Ahmedabad (2,95,718.22 kWh) as seen in **Fig. 14**. Panjim which lies in climate zone 0A has the highest CDD out of all cities considered in the present study and the high humidity coupled with high occupancy rate in supermarkets demands a higher need for space cooling. The corresponding electricity consumption for cooling is as follows Kolkata (87,864.80 kWh) followed by Panjim (84,647.84 kWh) and Ahmedabad (84,490.92 kWh) (**Fig. 15**).

Peak heating loads again do not vary with other building types as Buntar (29,215.78 kWh) followed by Srinagar (21,595.24 kWh), Shimla (9,071.40 kWh) and Shillong (3,924.97 kWh) observe the highest demand for heating as shown in **Fig. 14**. The corresponding electricity consumption for cooling is as follows Buntar (10,434.21 kWh) followed by Srinagar (7,712.59 kWh), Shimla (3,239.79 kWh), and Shillong (1,401.77 kWh) (**Fig. 15**).

Daily peak load trends are similar to office buildings albeit with peak heating loads nearly twice to four times higher with maximum cooling load requirements on a given design day occurring at cities like Ahmedabad, Varanasi, Lucknow and Sholapur and maximum heating demand on a given design day occurring at Srinagar, (**Fig. 16**). Buntar experiences a steady rise in heating load throughout the day with peak at 17:00 hours post which there is a drop for two hours until the supermarket shuts down (**Fig. 16**).

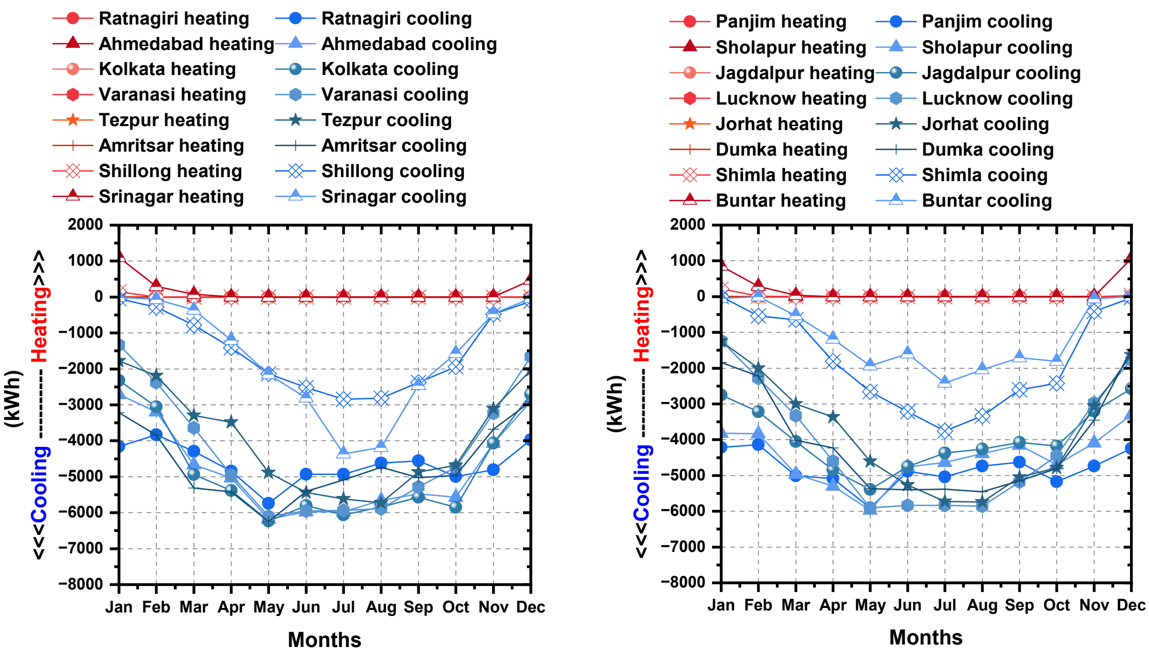


Fig. 11 Annual monthly heating and cooling loads for office buildings

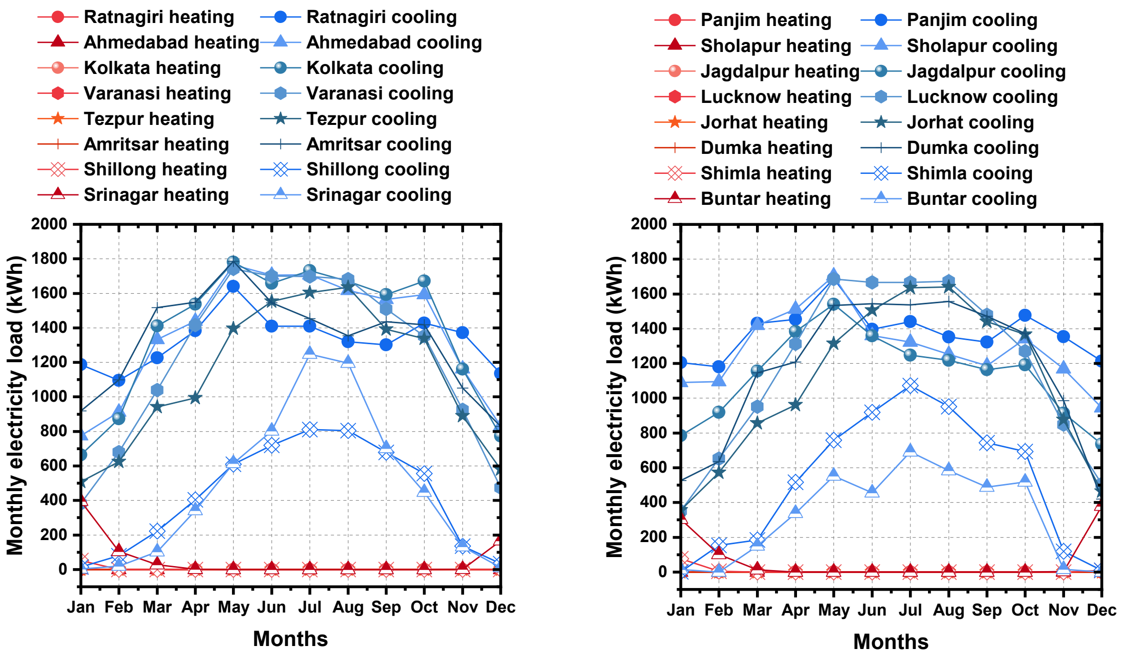


Fig. 12 Annual monthly electrical loads for office buildings

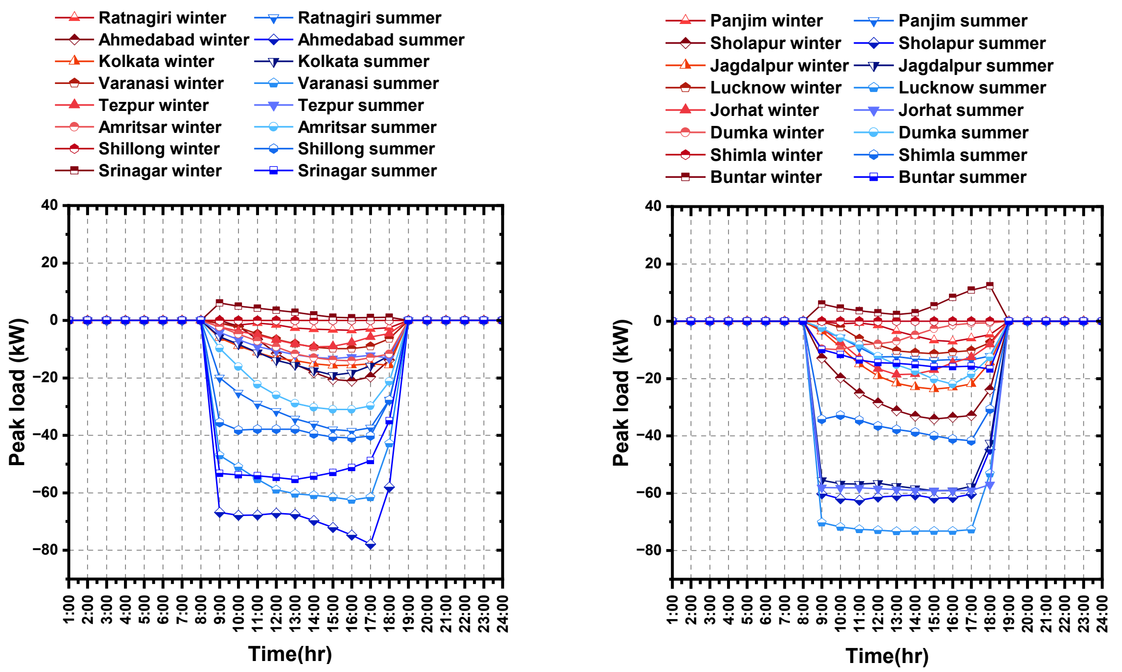


Fig. 13 Daily peak loads for office buildings

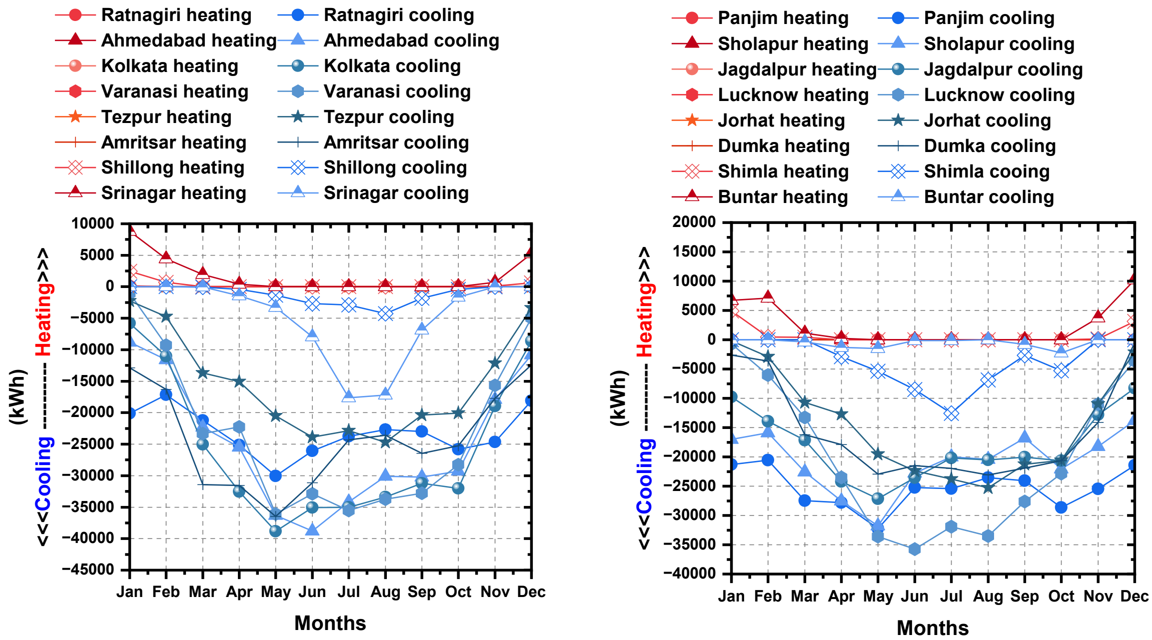


Fig. 14 Annual monthly heating and cooling loads for supermarket

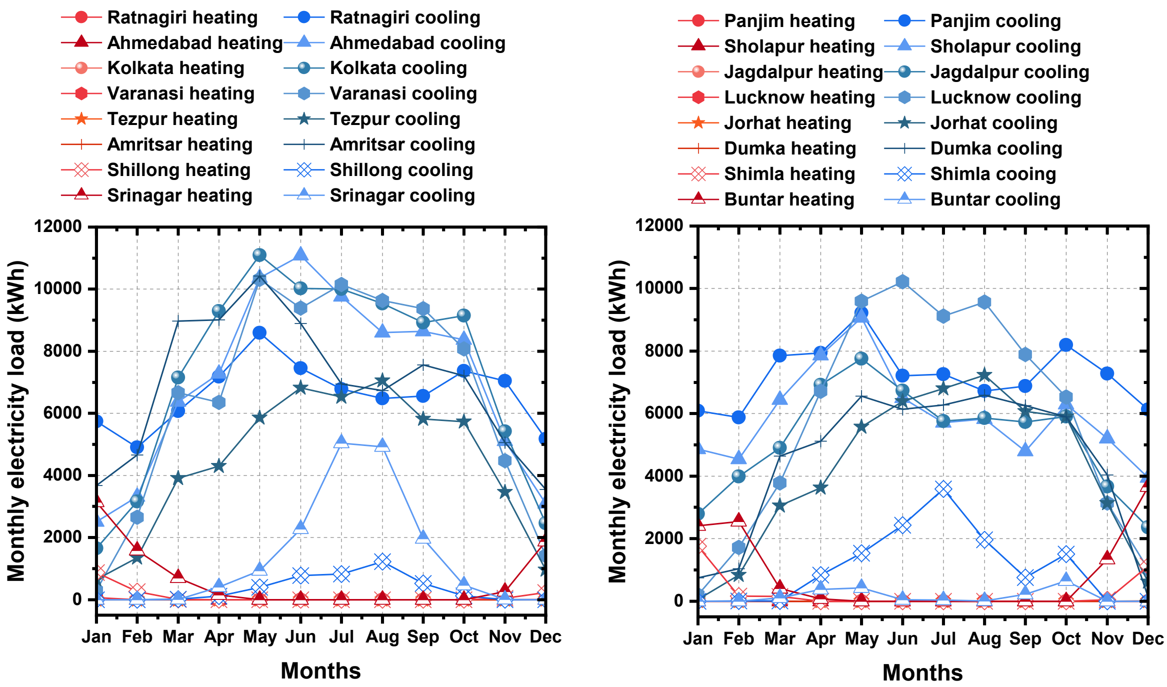


Fig. 15 Annual monthly electrical loads for supermarket

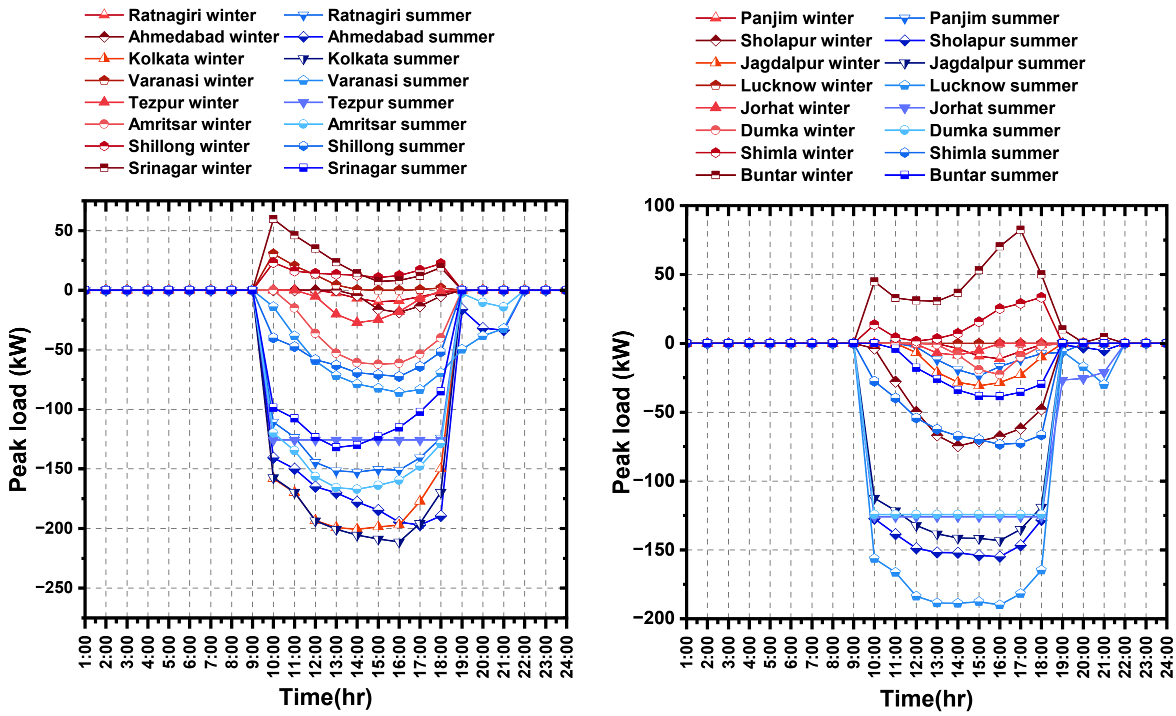


Fig. 16 Daily peak loads for supermarket

3.4 Educational buildings

Educational buildings like pre-school, kindergarten and K-12 schools have wide varieties of architectural and space cooling and heating requirements. Multiple facilities such as gymnasiums, cafeterias, libraries, classrooms, locker rooms etc. demand the need for safe and economical systems. The occupancy rate of the standard educational building in the present study is 0.6997 (people/m2) which is the highest.

The trends are similar to supermarkets in this case with maximum annual cooling load for the educational building observed at Kolkata (2,54,633.11 kWh) followed by Panjim (2,32,788.95 kWh), Ahmedabad (2,26,110.41 kWh) indicating higher cooling requirements for high occupancy rate buildings (**Fig. 17**). The corresponding electricity consumption for cooling is as follows Kolkata (72,752.32 kWh) followed by Panjim (66,511.13 kWh) and Ahmedabad (64,602.97 kWh) as seen in **Fig. 18**.

The heating loads are maximum at Srinagar (15,690.36 kWh) followed again by Buntar (15,200.90 kWh), Shimla (3,561.34 kWh), and Shillong (1,376.06 kWh) as observed in **Fig. 17**. The corresponding electricity consumption for cooling is as follows Srinagar (5,603.70 kWh) followed by Buntar (5,428.89 kWh), Shimla (1,271.91 kWh), and Shillong (491.45 kWh) (**Fig. 18**).

Peak loads occur during operating hours which are from 8:00 hours to 18:00 hours as seen in **Fig. 19**. It is observed that the maximum daily peak load for cooling occurs in educational buildings particularly in cities like Ahmedabad, Varanasi, Lucknow and Sholapur. Daily heating load trends follow trends similar to supermarkets with Srinagar and Buntar experiencing the maximum peak loads at start of occupancy and prior to end of occupancy in the evening hours.

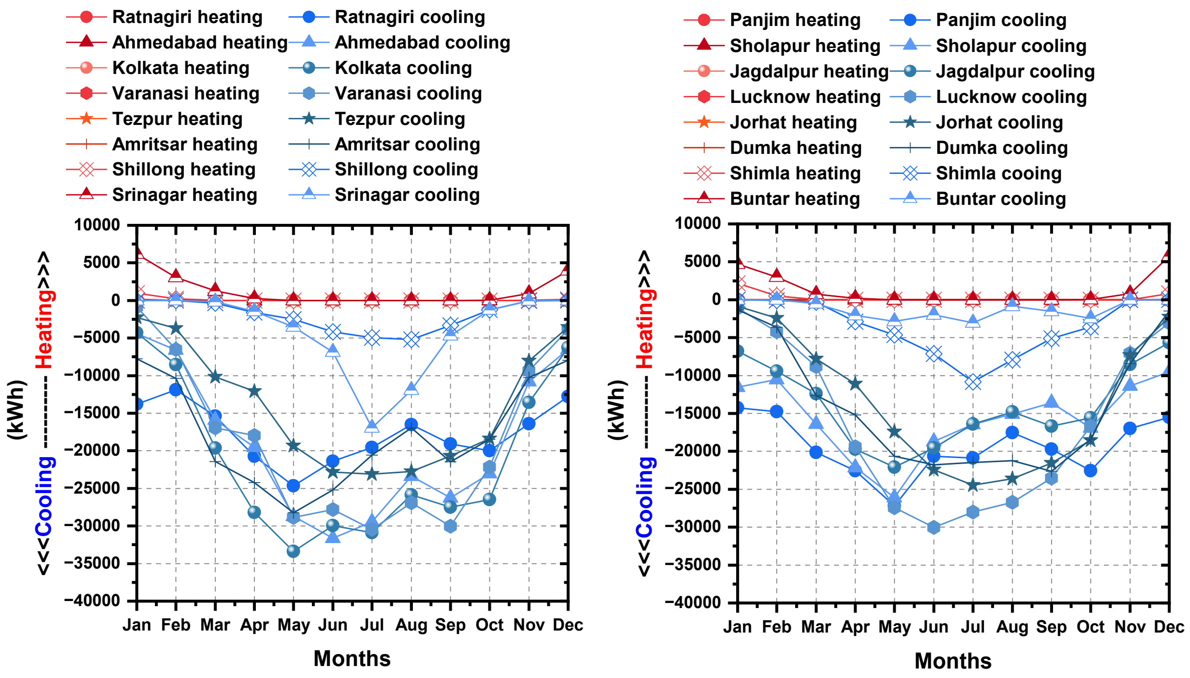


Fig. 17 Annual monthly heating and cooling loads for educational building

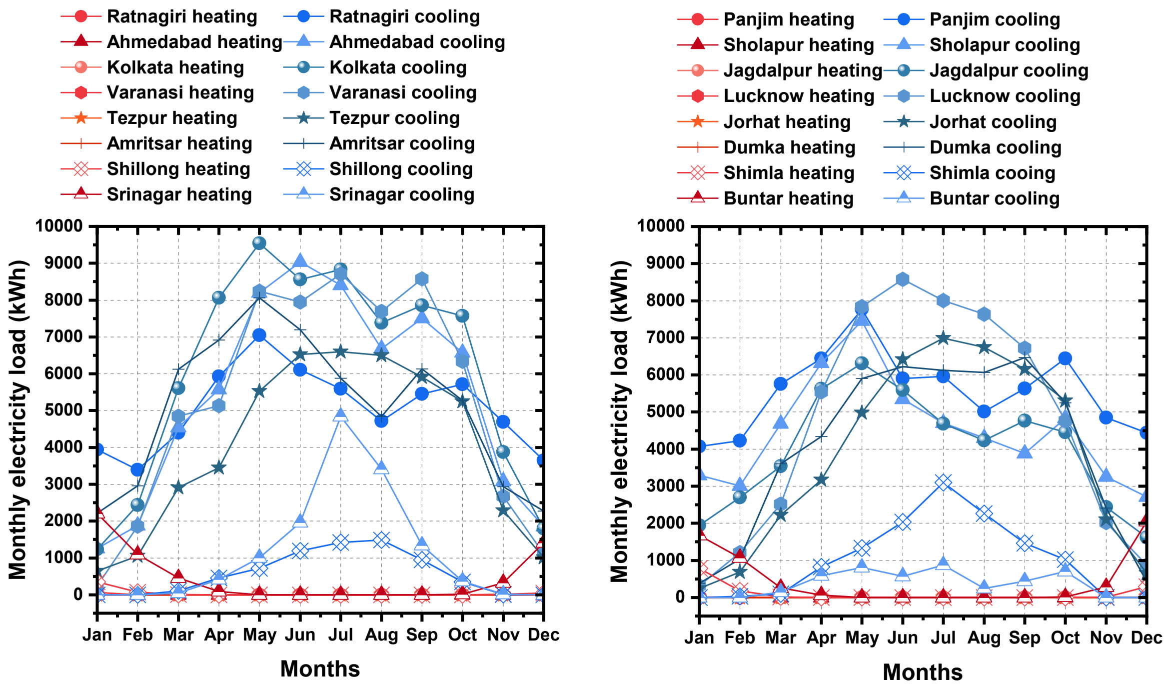


Fig. 18 Annual monthly electrical loads for educational building

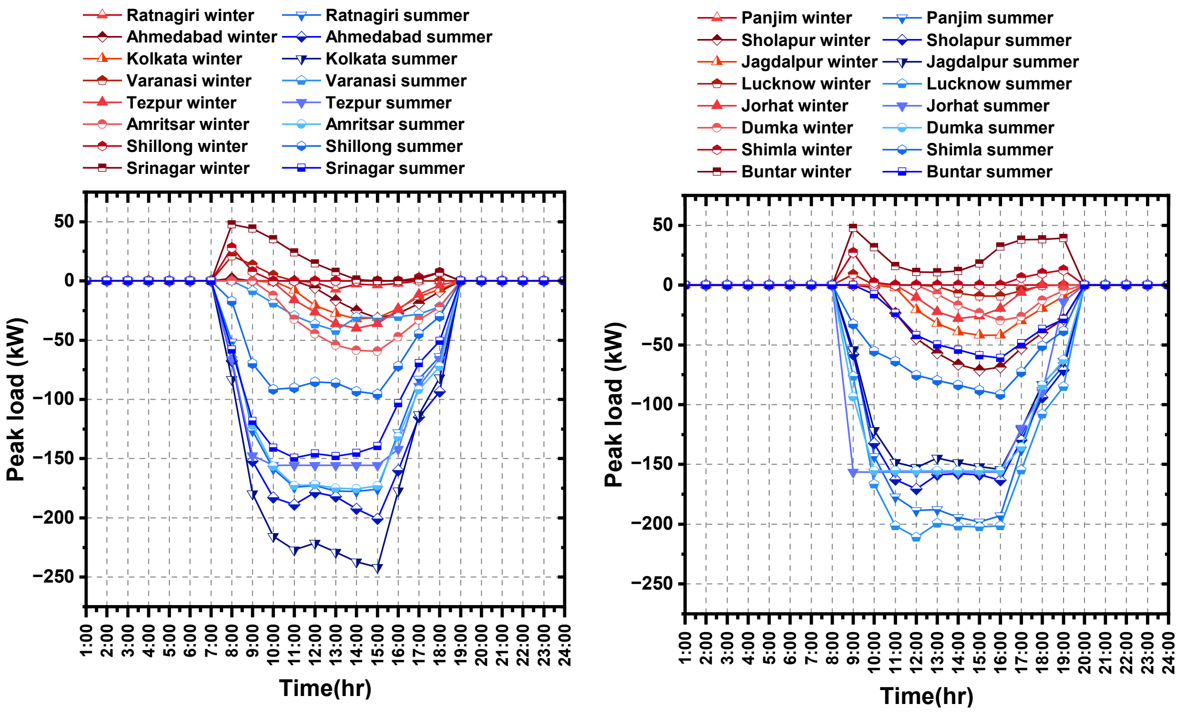


Fig. 19 Daily peak loads for educational building

3.5 Hospitals

The critical criteria for hospitals' cooling and heating needs arise in the air-side filtration and need to curb air movement between different medical departments. The hospital building occupancy rate requires careful consideration before design. Multiple hospitals prioritise integrating acute care with outpatient facilities which demands a provision for clean and conditioned air alongside critical care facilities, laboratories and sterile testing rooms using energy efficient equipment.

The maximum annual cooling load for the hospital building is obtained at Kolkata (1,97,594.44 kWh) followed by Panjim (1,94,900.03 kWh) and Ahmedabad (1,83,834.82 kWh) as seen in **Fig. 20**. The corresponding annual electricity consumption for cooling is as follows Kolkata (56,455.56 kWh) followed by Panjim (55,685.72 kWh), and Ahmedabad (52,524.23 kWh) as observed in **Fig. 21**.

The maximum annual heating load is obtained at Buntar (5,965.50 kWh) followed by Srinagar (4,854.34 kWh), Shimla (496.27 kWh), and Shillong (68.43 kWh) but these loads are much lower than for other building types due to the presence of sterile departments and laboratories (**Fig. 20)**. The corresponding annual is as follows Buntar (2,130.54 kWh) followed by Srinagar (1,733.69 kWh), Shimla (177.24 kWh), and Shillong (24.44 kWh) (**Fig. 21)**.

The daily cooling peak load trends for hospitals vary considerably with other building types considered in this study. Since there is a constant need for safe and conditioned air throughout the day, all cities experience high daily cooling loads throughout the day with the maximum peak loads occurring at different times of the day due to varying demand from multiple facilities inside the hospital. Heating peak load trends also show a similar wave like pattern to cooling peak loads with maximum peak load values observed in Buntar during early morning and late-night hours (**Fig. 22**).

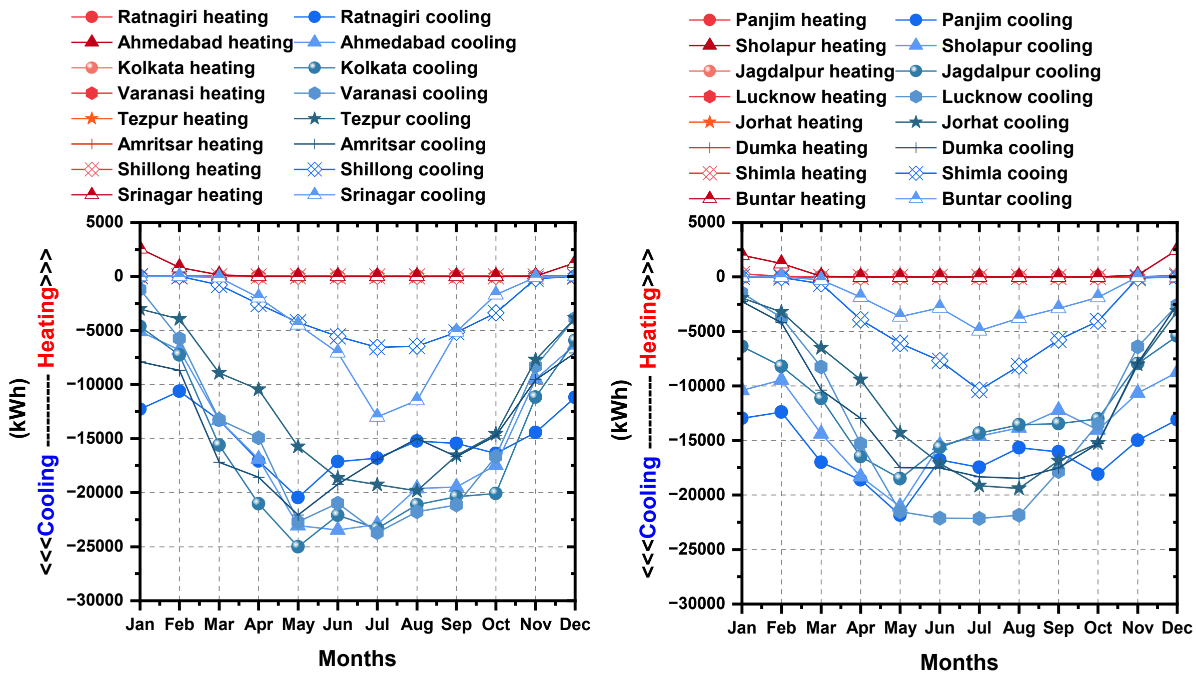


Fig. 20 Annual monthly heating and cooling loads for hospital

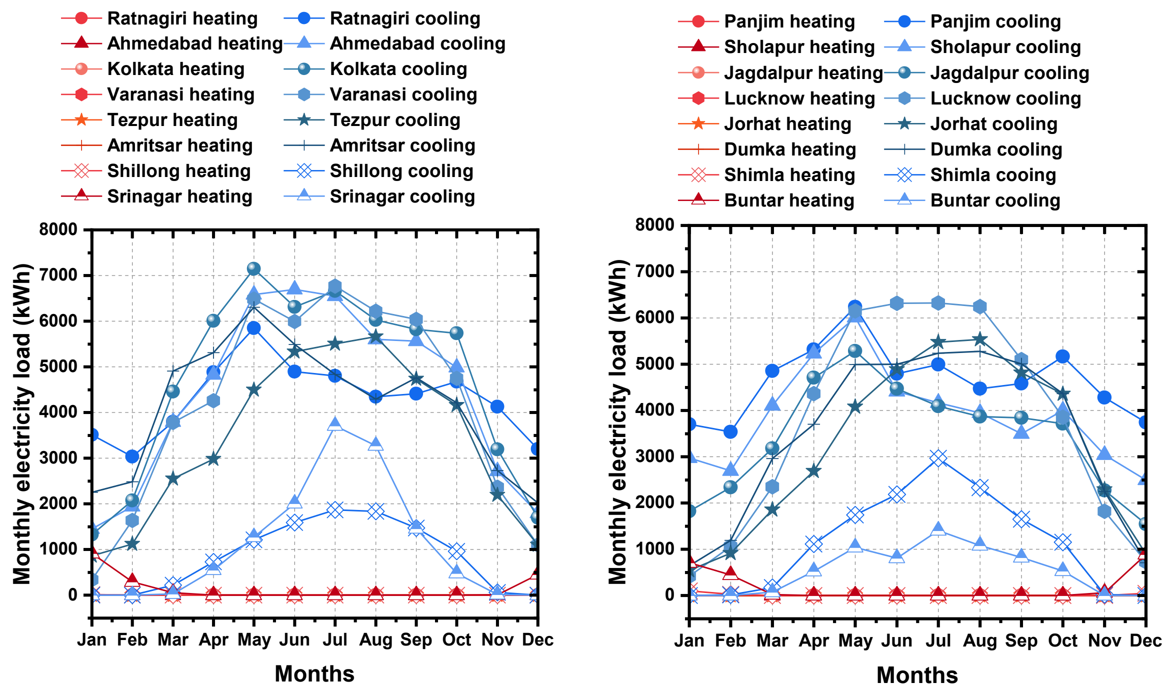


Fig. 21 Annual monthly electrical loads for hospital

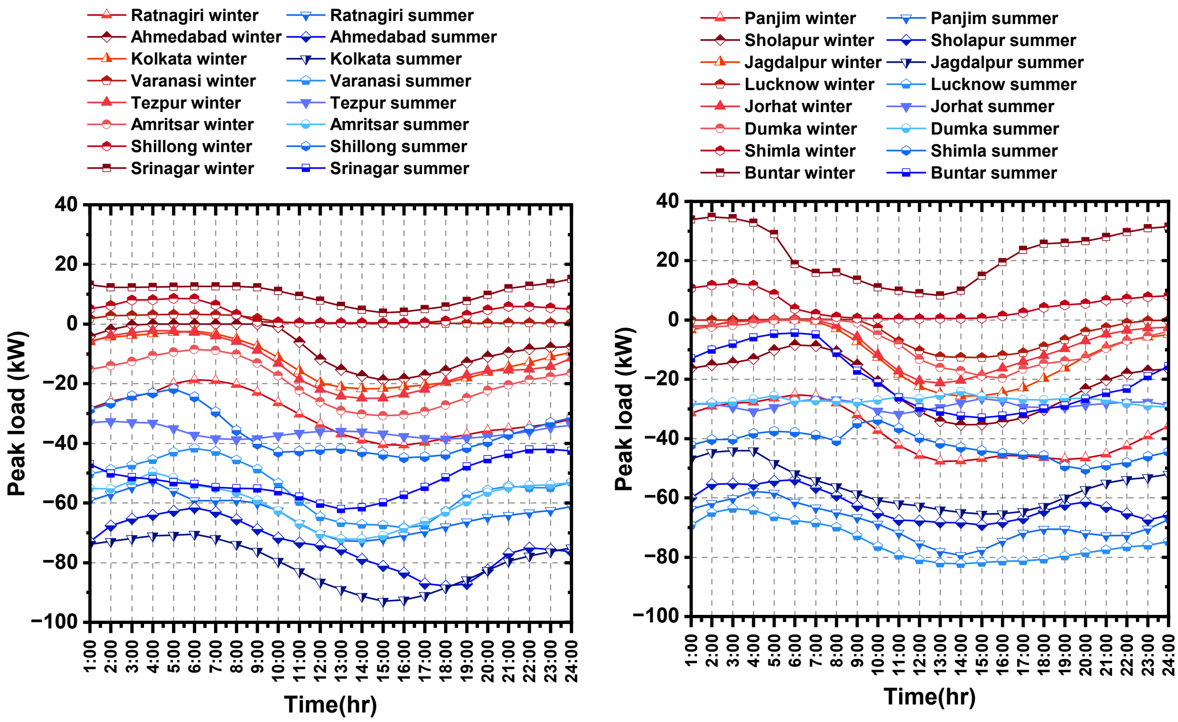


Fig. 22 Daily peak loads for hospital

3.6 Annual peak electricity consumption per m^2 (Cooling)

From **Fig. 23** the results from the previous sections are used to derive the peak electricity consumption per m^2 which is used to analyse the effect of space cooling in the standard building types. It is observed that residential buildings have the highest peak electricity consumption per m^2 in all cities except for Shillong, Buntar, Srinagar and Shimla. The maximum value for residential buildings is observed for Amritsar with 12.8 kWh/m^2. Hospitals and educational buildings' peak consumption per m^2 vary only slightly for all cities with the largest deviation seen for Tezpur, Shillong and Shimla. It should also be noted that hospitals and educational buildings in climate zones 3C and 4B have higher peak consumption than residential buildings. Office buildings have the lowest peak electricity consumption per m^2 with a slight perturbance for Shillong where the peak is slightly higher than residential buildings.

Table 4 Summer design day peak loads for space cooling (kW)

Cities	Peak loads for space cooling (kW)				
	Residential	Office	Educational	Supermarket	Hospital
Ratnagiri	10.5	38.5	177.8	152.6	72.8
Ahmedabad	16.7	77.8	200.7	197.1	87.7
Kolkata	16.2	15.6	241.8	211.2	92.9
Varanasi	6.2	62.5	41.8	85.7	68.2
Tezpur	12.6	13.2	155.6	125.6	38.7
Amritsar	14.2	31	175.6	163.8	72
Shillong	5.6	40.8	91.6	72.5	43
Srinagar	2	54	148	131.8	62
Panjim	11.6	13.6	198.2	23	79.3
Sholapur	16.3	62.5	170.5	154.9	69
Jagdalpur	13.8	59	154.3	143.2	65.4
Lucknow	16.4	73.3	210.8	189.8	82.2
Jorhat	12.6	59	156.4	125.8	31.7

Dumka	13	22	155.2	124.2	28
Shimla	6.5	42	91.5	73.4	50.3
Buntar	4.6	16	61.1	38.4	32.9

Table 5 Winter design day peak heating loads (kW)

Cities	Peak load for heating (kW)				
	Residential	Office	Educational	Supermarket	Hospital
Varanasi	7.2	-	20.6	30.6	3.2
Shillong	10	4	28.23	23.3	8.6
Srinagar	16.1	-	47.67	59.8	15.1
Shimla	11.9	6	27.4	33.3	12.3
Buntar	16	12.4	47.64	85.6	34.7

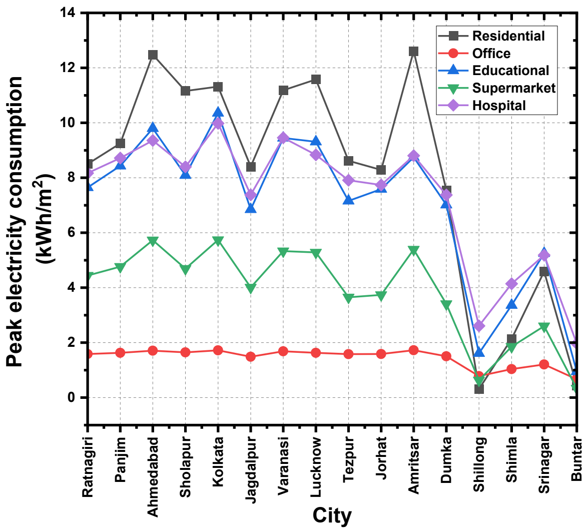


Fig. 23 Peak electricity consumption of buildings for space cooling

Table 6 Annual peak electricity consumption for space cooling (kWh)

City	Annual peak electricity consumption (kWh)				
	Residential	Office	Supermarket	Education	Hospital
Ratnagiri	965.03	1640.53	8589.48	7048.37	5847.7
Panjim	1049.73	1687.38	9211.78	7770.91	6241.27
Ahmedabad	1416.46	1764.16	11082.39	9031.22	6698.6
Sholapur	1266.2	1704.61	9073.84	7458.82	6013.66
Kolkata	1284.78	1780.34	11091.52	9541.4	7143.49
Jagdalpur	954.11	1540.38	7752.59	6312.17	5284.11
Varanasi	1269.5	1742.22	10313.68	8705.25	6770.48
Lucknow	1314.07	1686.57	10215.39	8580.19	6326.29
Tezpur	978.01	1635.38	7058.82	6595.74	5664.07
Jorhat	940.51	1639.92	7226.76	6992.65	5538.82
Amritsar	1431.42	1785.53	10427.32	8063.45	6304.36
Dumka	856.02	1557.53	6589.73	6465.28	5279.79
Shillong	35.28	811.54	1223.39	1486.21	1869.82
Shimla	242.73	1072.96	3585.56	3097.53	2967.19
Srinagar	520.75	1247.39	5034.48	4837.87	3711.15

Table 7 Annual peak electricity consumption for space heating (kWh)

City	Annual peak electricity consumption (kWh)				
	Residential	**Office**	**Supermarket**	**Education**	**Hospital**
Ratnagiri	0	0	0	0	0
Panjim	0	0	0	0	0
Ahmedabad	9.56	0	0	0	0
Sholapur	0.53	0	0	0	0
Kolkata	23.43	0	0	0	0
Jagdalpur	21.53	0.08	0	0.8	0
Varanasi	96.33	0.03	60.19	68.24	0
Lucknow	95.86	0.16	0	17	0
Tezpur	47.35	0	0	0	0
Jorhat	103.23	0.28	0	2.04	0
Amritsar	4.11	0	0	0	0
Dumka	88.6	0	5.35	0	0
Shillong	269.37	52.5	872.63	349.06	18.5
Shimla	258.03	76.62	1758.93	780.33	99.91
Srinagar	346.2	395.74	3142.61	2210.07	919.59

3.6 Annual peak electricity consumption per m^2 (Heating)

The annual peak electricity consumption per m^2 for heating in residential buildings are low to negligible for most cities in India. Four Cities in climate zones 3C and 4B (Shillong, Buntar, Srinagar and Shimla) have the highest peaks but are still much lower than those observed for cooling. Other building types have zero or close to zero annual peak electricity consumption per m^2 for cities not lying in climate zones 3C and 4B. The trends vary a bit with those for cooling with residential building having the highest peak consumption per m^2 followed by educational buildings and supermarkets while offices having the lowest peak consumption per m^2.

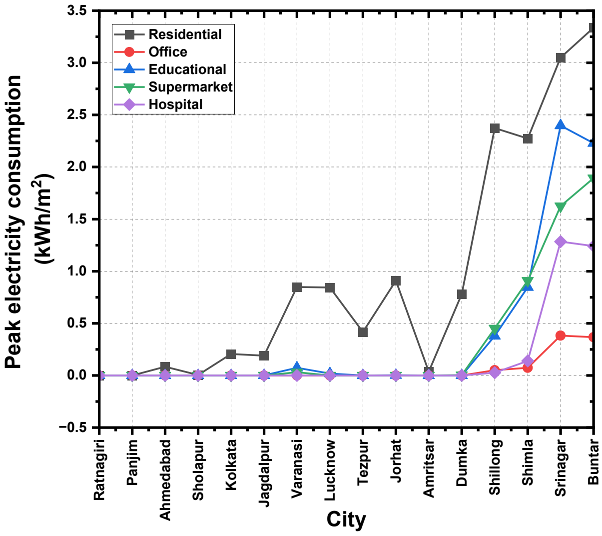


Fig. 24 Peak electricity consumption of buildings for space heating

Conclusions

In consideration of the need for ground source heat pump (GSHP) studies for space heating and cooling of various building typologies and climate zones in India, this study overviewed the feasibility of water-to-air GSHP for five building typologies selected in the eight climate zones based on ASHRAE standards.

The study was carried out for the selected cities using the EnergyPlus software, based on the cooling-heating demand and energy consumed over a year.

- The demand for heating and cooling is often met by using traditional technologies like electric heaters and air conditioners mostly using fossil fuels during the winter and summer.
- GSHP reduces the dependency on these traditional technologies.
- Heating and cooling loads are affected by climate conditions and building typologies.
- The system is most viable for buildings that demand both heating and cooling loads throughout the year.
- The system is more viable for buildings that have higher heating loads than cooling dominant ones.

This study provides the tendencies of applying GSHP in all climate conditions in India. It suggests that GSHP systems are a viable option for cities in warm marine and mixed dry conditions, particularly those in the northeastern part of India, where more balance between heating and cooling loads exist. The implementation of such a technology will be more convenient for some of the climate zones which are highly cooling dominant if special design techniques or additional hybrid energy sources are adopted.

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.