ALMIPL SOLAR

Powering The New Age (Energy)

DESIGN GUIDELINES

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Solar Energy

CHAPTER - 5

CHAPTER 5

DESIGN GUIDELINES

Contents:

1.1 INTRODUCTION

This chapter presents guidelines for designing buildings for six climatic conditions of India from the perspective of energy conservation. The guidelines are presented in two parts for each climate. The first part provides general recommendations based on various aspects of building design as discussed in Chapters 2 and 3; the second part is more specific, dealing with particular building types, and is based on studies conducted using simulation tools explained in Chapter 4. The actual methodology adopted for developing the specific guidelines is discussed in section 5.3 of this chapter. Three types of buildings have been considered for the purpose: commercial, industrial and residential.

The guidelines formulated are based on detailed thermal performance studies (also referred to as simulation studies) using the commercial software, TRNSYS (version 14.2) [1]. In order to establish confidence in the simulation results of TRNSYS, we have validated the predictions of this software in the following way. The room temperatures of different floors of a commercial building located in Mumbai city were measured for a week and then compared with the predictions of TRNSYS. Based on this comparison, the input parameters of the simulation tool were calibrated so that the maximum deviation of the prediction from the actual measurement was less than 5%, and the average deviation (over a 24 hour period) did not exceed 2% [2]. Having calibrated the simulation software predictions, various calculations were carried out to determine the heating and cooling load, and/or room temperatures of buildings. For example, it is important to know how much heat is being lost or gained from the various components of the building envelope (i.e., walls, roof, windows, etc.). What affects the building heating and cooling loads more the building envelope or the internal gains? Is the top floor more comfortable than the ground or intermediate floors? And so forth.

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Based on the results, several parameters pertaining to building design and usage have been identified for improving the thermal performance of each building type, along with recommendations for energy conservation measures for the six climatic conditions of India. The cities of Jodhpur, Delhi, Mumbai, Pune, Srinagar and Leh (respectively representing hot and dry, composite, warm and humid, moderate, cold and cloudy, and cold and sunny) have been selected for the investigation. The building plans considered for this purpose are types that are commonly observed; they are briefly described in the following section. However, the recommendations are limited to these particular types of buildings, and may give incorrect results if applied blindly for other cases.

The proposed design guidelines are to be used as a starting point for commencing design of other types of buildings. In such cases, we recommend that a simulation tool be used to ascertain the performance for best results

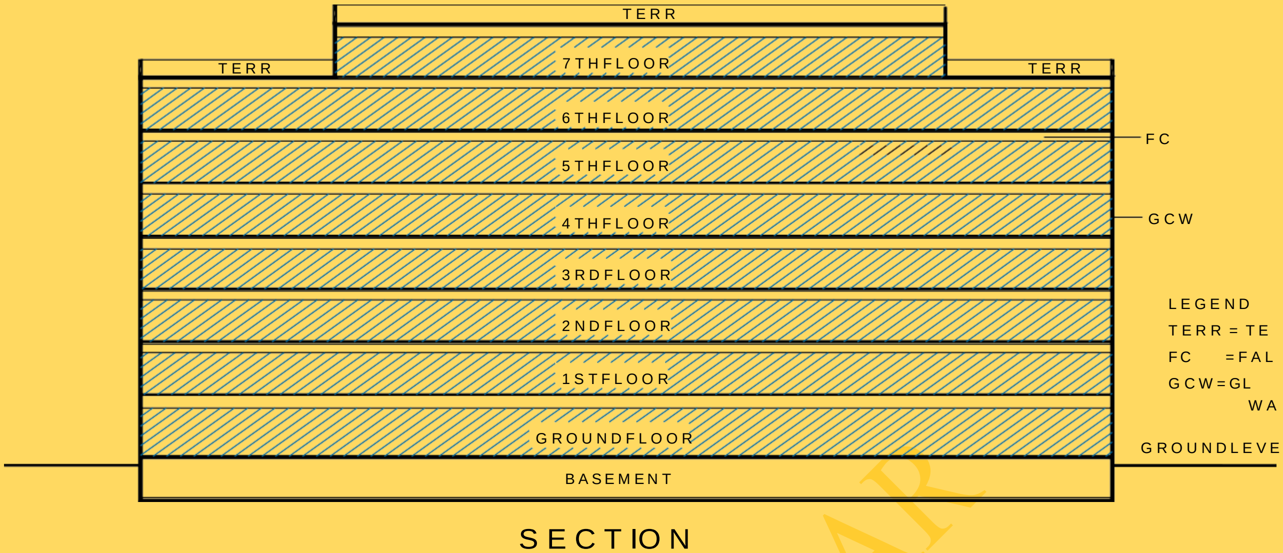
2.2 DESCRIPTION OF BUILDINGS

5.2.1 Commercial building

Commercial buildings use air-conditioning (AC) by mechanical means for providing thermally comfortable indoor conditions. This is mainly aimed at promoting productivity among occupants. However, the process is energy intensive and the running costs are generally very high. The monthly electricity bills of a typical commercial building can run into lakhs of rupees. The options for energy conservation are limited once a building is constructed, especially when aspects of optimal energy use have not been taken into account in building design. Considering that many such buildings are being constructed all over India, there is an urgent need to study their thermal behaviour and explore various means to reduce the AC load. We have analysed an existing commercial building in Mumbai for this purpose. The building has a basement and 8 floors (ground and 7 upper floors). A block plan and section of the building is shown in Fig. 5.1. The typical cross section of the roof, wall and floor are shown in Fig. 5.2. It is a reinforced cement concrete (RCC) framed structure with brick and concrete block infill panel walls. The building is rectangular with its longer axis oriented along the northwest and southeast direction.

Most of the southwest, southeast, and northwest façades are glazed. The southwest façade is fully glazed with reflective coating on the glass panels. The circulation spaces such as the lift lobbies and staircases are located on the north side of the building. While most of the spaces are open plan offices, cabins are located on the periphery of the building and are separated from the main office hall by means of glass partitions. Most of the building is generally occupied only during the daytime on weekdays. The ground, second and third floors are occupied for 24 hours throughout the week including Saturdays, Sundays and national holidays. The total built-up area of the building including the circulation and service areas (but excluding the basement) is approximately 7074 m^2. Out of this area, about 5400 m^2 of carpet area is centrally air-conditioned. The first to seventh floors are fully air-conditioned whereas the ground and basement are partly air-conditioned. All floors have an air change rate of one per hour except for the ground floor where it is 5 per hour. A higher air change rate is specified on the ground floor as it is used for loading and unloading of materials, entailing frequent opening of large doors at the two ends of the building. These assumptions are based on the calibration of the simulation software TRNSYS (section 5.1).

The upper floors are provided with false ceiling to conceal service ducts and reduce cooling loads. Lighting is provided mostly by fluorescent tube-lights. On a regular weekday, about 560 people occupy the building. The internal load is due to the convective load (gain due to occupants and equipment) and radiative load (lighting). A building automation system has been provided to control the air-conditioning system. The occupancy and the internal gains have been appropriately scheduled for all zones. The heat storage capacities of furnishings and structures in the building have also been considered.



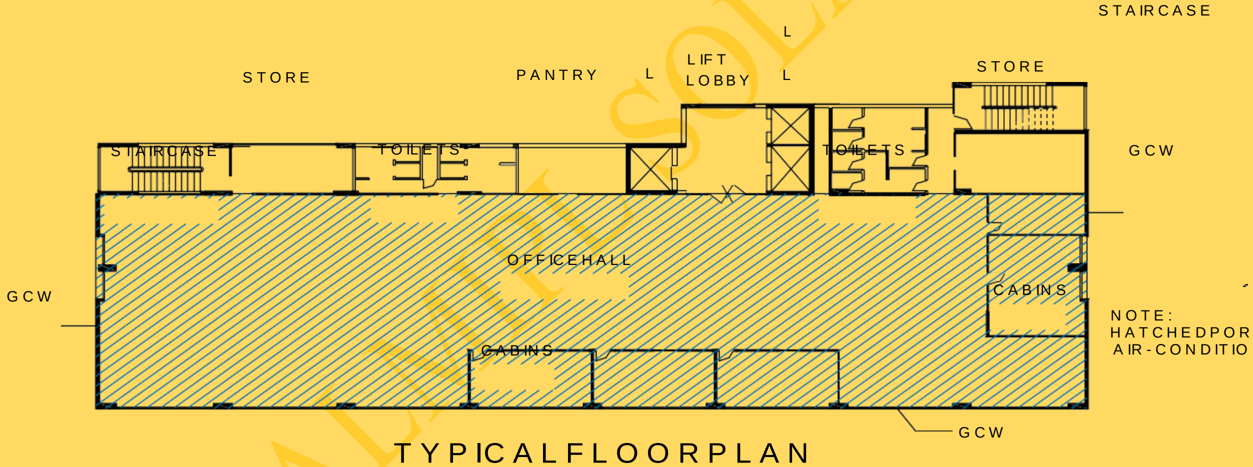


Fig. 5.1 Block plan and section of the commercial building

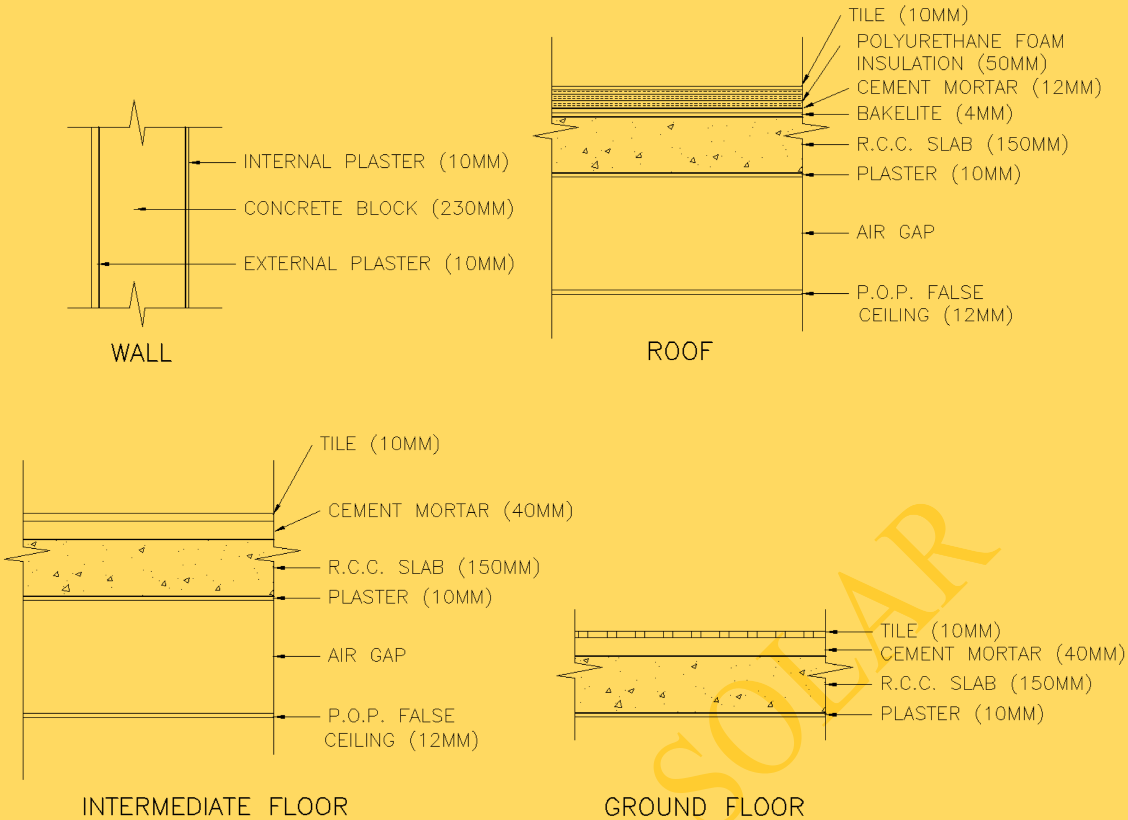


Fig. 5.2 Cross section of typical wall, roof and floor of the commercial building

5.2.2 Industrial Building

An existing industrial building in Daman (Union Territory) has been the subject of study. A block plan of the building is shown in Fig. 5.3. The building is a ground and partly one storeyed structure. It is an RCC framed structure with brick infill panel walls.

The cross-sectional details of the roof, wall and floor are shown in Fig. 5.4. Most of the south, east, and west façades are glazed. The building is rectangular, having its longer axis oriented along the north-south direction with most of the windows facing east and west. It consists of a large shed (59.77m X 18.77m) on the ground floor and a smaller store room (9.77m X 18.77m) on the first floor. The height of the shed is 3.65m and that of the store is 3.05m. The flat roof is made of RCC slabs with brick-bat-coba waterproofing on top. The shed houses 24 machines of rated capacity of 7.5 kW each. It is considered that at a time, 50% of the machines are in operation. 45 persons work for six days a week. There are 80 tube lights of 40W each in the shed to provide illumination. The store is considered to be occupied by a single person. Occupancy, equipment and lighting are considered to be ON for 24 hours on each working day. Windows are provided as per factory standards, i.e. 20% of floor area to provide sufficient light and ventilation. The occupancy and the internal gains have been appropriately scheduled for all zones. The heat storage capacities of furnishings and structures in the building have also been considered.

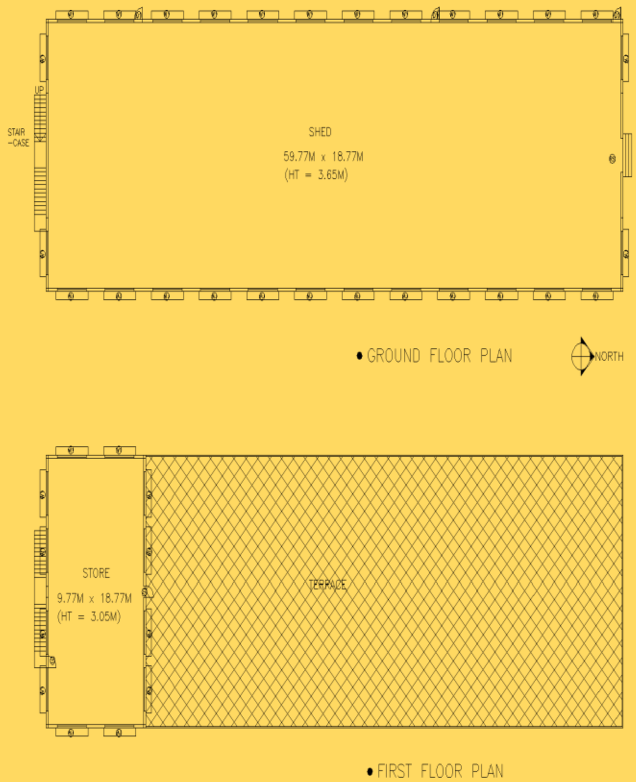


Fig. 5.3 Block plans of the industrial shed

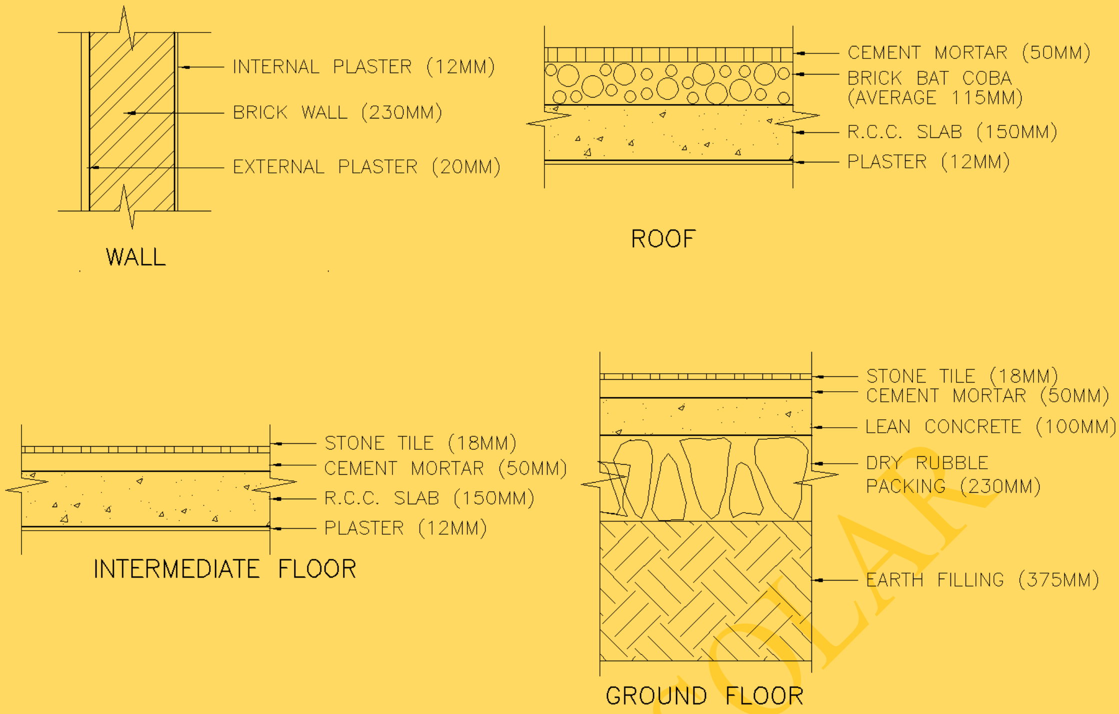


Fig. 5.4 Cross section of typical wall, roof and floor of the industrial building and residential bungalow

5.2.3 Residential Building (Bungalow)

The building considered under this category is a ground and one storied structure. It is a single-family dwelling commonly referred to as a bungalow. The construction details are similar to those of the industrial building as shown in Fig. 5.4. The block plans of the building are given in Fig. 5.5. The building is an RCC structure with brick infill panel walls.

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Windows consist of single clear glazed panes and are openable. The total built-up area of the building is about 288 m^2 (145 m^2 on ground and 143 m^2 on the first floor). It is a rectangular structure with its longer axis along the east-west direction. The ground floor consists of a common living and dining hall, which is partly of double height; the kitchen and stores are on the east side, and there is a master bedroom wth attached toilet on the northwest corner. Most of the living-dining area faces south; the dining portion faces north. A circular open-well staircase on the south side connects the ground floor with the first. It is considered to be part of the living-dining area. The first floor consists of four bedrooms with attached toilets. Three bedrooms are located on the northeast, southeast and northwest corners of the building with windows on the adjacent external walls. Thus, there is good potential for cross ventilation in these rooms. The fourth bedroom has only one external wall facing north. There is an open family room on the southwest corner. This space is contiguous with that of the living-dining area on the ground floor as there is free exchange of air. Hence, the living-dining area on ground floor and the

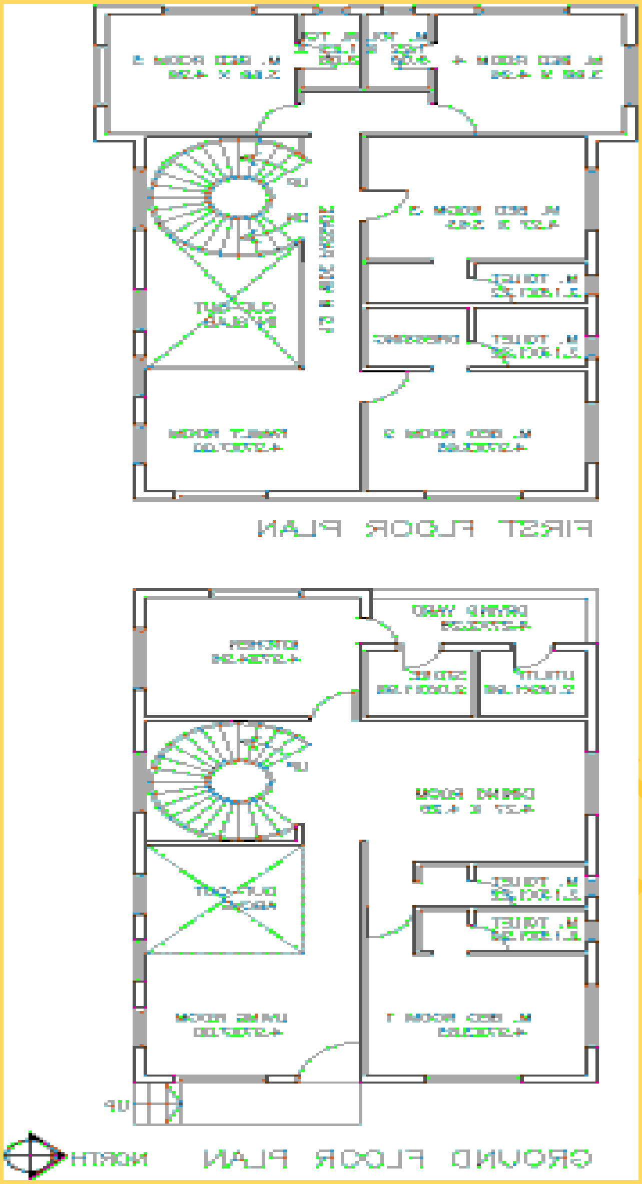

Fig. 5.5 Block plans of the bungalow

family area including circulation areas are considered as a single thermal zone. The bedrooms are assumed to be occupied only at nights on weekdays. On weekends, they are occupied in the afternoon hours as well. Two occupants, a television, a fan and a tubelight are considered for the internal gains of the bedroom whenever it is occupied. The kitchen is occupied by a single person during breakfast, lunch and dinner times. A hotplate, a tubelight and a fan are considered as internal gains when occupied. In addition, a refrigerator is assumed to be working throughout the day. The living room is considered to be occupied by a maximum of 5 persons during mealtimes and for a few hours on weekdays. On weekends, this room is considered to be used for a longer period. The internal gains in this room are due to the occupants, 4 fans, 8 tubelights and a television. The occupancy and the internal gains have been appropriately scheduled for all zones. The heat storage capacities of furnishings and structures in the room have also been considered.

3.3 METHODOLOGY

The performance studies of the buildings were carried out using TRNSYS. The weather data for the calculations have been taken from handbooks [3,4].

The methodology adopted was based on two assumptions, namely, (i) the building is conditioned and (ii) the building is not conditioned. The commercial building has been considered to be conditioned and the industrial building, not conditioned. The residential building has been investigated under both conditions. Comfort requirements are stringent in the conditioned commercial building, hence set points for heating and cooling were taken as 21 and 24°C respectively. For the conditioned bungalow, however, they were relaxed to 20°C for heating and 25°C for cooling. For the ground floor of the commercial building, the corresponding values were 19 and 26°C. This is because the ground floor is used for loading and unloading of materials and hence, the shutters are opened more frequently to ambient conditions. The monthly as well as annual cooling and heating loads for each building type and for each of the six cities mentioned earlier, are presented graphically. The share of loads through various building components is also given. The components are: (i) surfaces: heat transfer from all surfaces to the room air, (ii) air exchanges: the heat transfer caused by air exchanges, and (iii) internal gain: the convective heat gains due to metabolic heat released by occupants and that released by equipment and lights.

The percentage-wise heat gains and losses due to the components on a monthly basis are presented graphically for easier interpretation. It may be noted that the percentage values are based on absolute numbers.

In the case of non-conditioned buildings, the room temperatures have been calculated. From these, the yearly minimum, maximum and average temperatures of each room are used for comparison. Additionally, two other performance indicators have been used for comparison. One of them is the percentage of hours in a year that each room is within the comfortable temperature range. This range is based on the monthly adaptive comfort temperature (ACT) of a place [5], which is defined as:

$$ACT = 16.2 + 0.41\ T_m \qquad (5.1)$$

where, T_m is the monthly mean ambient dry bulb temperature. For annual percentage, the lower limit of the range is ACT-2.2^{o}C for the coldest month of the place, and the upper limit is ACT+2.2^{o}C for the hottest month of the place.

The other parameter used for comparison of non-conditioned buildings is the comfort fraction i.e. CF, which is defined as [5]:

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The other parameter used for comparison of non-conditioned buildings is the comfort fraction i.e. CF, which is defined as [5]:

CF = 1 - Discomfort Degree Hours / 105.6 (5.2)

where, discomfort degree hours (DDH) is the sum of the hourly room air temperatures outside the comfort zone defined by ACT ± 2.2 °C.

The procedure for calculation of the comfort fraction is explained as follows:

- Calculate monthly ACT from Eq. 5.1 and plot ACT ± 2.2 °C against the hour of the day. The zone defined by ACT ± 2.2 °C is called as comfort zone. (Figure 5.6 shows an example).
- Find out the hourly room air temperature for the average day of the month and plot it in the same figure.
- Find out the deviations (absolute values) of room air temperatures from the comfort zone. (Values are tabulated along the side of the plot in Fig. 5.6 for the example case).
- The sum of these values are the discomfort degree hours.
- Calculate the comfort fraction using Eq. 5.2.

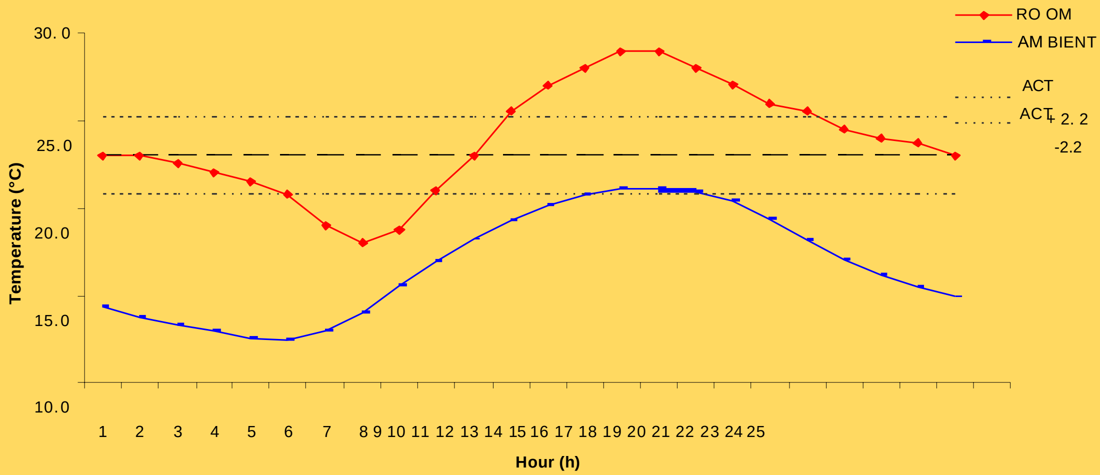
The maximum value of CF is 1, which means quite comfortable. A negative value of CF indicates acute discomfort. On the other hand, a value approaching 1 indicates comfort.

The graphs for hourly variation of room temperatures for a typical day of January and that of May representing winter and summer months respectively, are also presented along with the corresponding ambient temperature and comfort zone. This provides a direct comparison of room conditions vis-à-vis ambient along with the comfort requirements (based on ACT).

Following this methodology, the results have been generated both for conditioned and non- conditioned buildings. Such results have been grouped as "base case studies". The parameters considered for the base case are listed in Table 5.1 for all the three buildings. In order to ascertain the effects of various design and operational parameters on the thermal performance of a building, parametric studies have been carried out. The design parameters include building orientation, window area, window types, shading, roof types, wall-types and colour of external surfaces. The operational parameters include air change rate with its scheduling effect, internal gain and set points (in conditioned building), etc.

In the commercial building, the scheduling of air changes has been carried out on all floors except the ground floor.

This is because ground floor doors are frequently opened and closed due to user requirements. Hence, controlling air change rates at specific times would be difficult in practice. The effect of window area was investigated only in the case of commercial building; the base case of this building refers to the design where the window height is of full height, extending from ceiling to the floor. The effect of reducing its size to 1.2 m was studied. The window types include plain glass, single reflective coated glass, double glazing, double glazing with one pane of low-emissivity (low-E) glass and double glazing with one pane of reflective coated glass. Shadings of 10, 20 and 50 % of window area for the commercial building and bungalow, and 10 and 20 % for the industrial building were considered. The apartment building has horizontal overhangs on the windows; the effect of the absence of the overhangs (i.e., no-shading) is investigated for this building. The roof types include RCC roof with brick-bat-coba waterproofing, plain RCC roof with bitumen felt



TIME (h)	TEMPERATURE (°C)					DDH
	ROOM	AMBIENT	ACT	ACT+2.2	ACT-2.2	
1	23.0	14.3	23.1	25.3	20.9	0.0
2	23.0	13.8	23.1	25.3	20.9	0.0
3	22.5	13.3	23.1	25.3	20.9	0.0
4	22.0	12.9	23.1	25.3	20.9	0.0
5	21.5	12.6	23.1	25.3	20.9	0.0
6	20.8	12.5	23.1	25.3	20.9	0.1
7	19.0	12.9	23.1	25.3	20.9	1.9
8	18.0	14.1	23.1	25.3	20.9	2.9
9	18.7	15.6	23.1	25.3	20.9	2.2
10	21.0	17.0	23.1	25.3	20.9	0.0
11	23.0	18.2	23.1	25.3	20.9	0.0
12	25.5	19.3	23.1	25.3	20.9	0.2
13	27.0	20.2	23.1	25.3	20.9	1.7
14	28.0	20.8	23.1	25.3	20.9	2.7
15	29.0	21.1	23.1	25.3	20.9	3.7
16	29.0	21.2	23.1	25.3	20.9	3.7
17	28.0	21.0	23.1	25.3	20.9	2.7
18	27.0	20.4	23.1	25.3	20.9	1.8
19	26.0	19.4	23.1	25.3	20.9	0.7
20	25.5	18.2	23.1	25.3	20.9	0.2
21	24.5	17.0	23.1	25.3	20.9	0.0
22	24.0	16.2	23.1	25.3	20.9	0.0
23	23.7	15.5	23.1	25.3	20.9	0.0
24	23.0	14.9	23.1	25.3	20.9	0.0
				SUM DDH =		**24.6**

Average monthly temperature (Tm)= 16.8 ℃

ACT = **23.1** ℃

CF = **0.8**

DDH = Discomfort Degree Hours

Fig. 5.6 Example of calculation of Adaptive Comfort Temperature (ACT) and Comfort Fraction (CF)

Table 5.1 Parameters of base case

Parameters		Commercial building	Industrial building	Bungalow
Glazing type		Reflective coated (single pane)	Clear glass (single pane)	Clear glass (single pane)
Roof type		RCC with brick-bat-coba waterproofing	RCC with brick-bat-coba waterproofing	RCC with brick-bat-coba waterproofing
Wall type		Concrete block wall	Brick	Brick
Colour of external surface		White	Brick red	Brick red
Air exchange rate (ach)		5.0 (ground floor) 1.0 (Rest floors)	6.0	Conditioned: 0.5 (Srinagar & Leh) 1.0 (other places) Non-conditioned: 1.5 (Srinagar) 0.5 (Leh) 3.0 (other places)
Building orientation (longer axis)		Northwest-southeast	North-south	East-west
Set point (ºC)	Heating	19 (Ground floor) 21 (Rest floors)	[illegible]	20
	Cooling	26 (Ground floor) 24 (Rest floors)	[illegible]	25
Shading		No shading	No shading	No shading

waterproofing and RCC roof with polyurethane foam (PUF) insulation. The wall types considered were brick wall, concrete block wall, autoclaved cellular concrete block wall (e.g. Siporex) and brick wall with expanded polystyrene insulation. Four colours, namely, white, cream, brick red (puff shade) and dark grey were considered for the external wall surfaces. Table 5.2 lists various options investigated for different cases. It also lists the variations studied for air change rates, internal gain, orientation and set points. The results of the parametric studies are presented in tabular form for each building type for each of the six cities. The effects of the various parameters are compared vis-à-vis the base case. In the conditioned buildings, the energy saved annually is presented in terms of loads (MJ) and percentage savings (%). A positive value indicates a saving whereas a negative value shows that the base case is better. In non-conditioned buildings, the results are presented in terms of the number of comfortable hours in a year. This is also presented as a percentage improvement over the base case. A positive percentage value means an increase in number of comfortable hours with respect to the base case. A negative value indicates that the number of comfortable hours has reduced.

Based on these predictions, specific recommendations are made for each building type, for each of the six climates vis-à-vis their design and operational parameters. Additionally, this information has been summarised in tabular form at the end of this chapter (under section 5.6) for the reader's convenience and for quick reference. From the study of individual parameters, the best condition is identified and the combined effects of such parameters (excluding building orientation and internal gain) are investigated. This result is termed as the "best case". In addition to design and operational parameters listed in Table 5.2, the roof surface evaporative cooling technique has been evaluated for two building types in warm climates (Jodhpur, Mumbai, Pune and New Delhi). The performance results for these building types (industrial and residential bungalow) are presented in Appendix V.1.

The commercial building investigated has large internal gains, a fact that has a significant bearing on the performance of the building. Therefore, the parametric performance of this building with zero internal gains was also investigated. Appendix V.2 presents the results of such calculations for a composite climate (New Delhi).

4.4 GENERAL RECOMMENDATIONS

The general recommendations based on climatic requirements are discussed in this section.

These are applicable to almost all types of building designs.

5.4.1 Hot and Dry Climate

The hot and dry climate is characterized by very high radiation levels and ambient temperatures, accompanied by low relative humidity. Therefore, it is desirable to keep the heat out of the building, and if possible, increase the humidity level. The design objectives accordingly are:

(A) Resist heat gain by:

- Decreasing the exposed surface
- Increasing the thermal resistance
- Increasing the thermal capacity
- Increasing the buffer spaces
- Decreasing the air-exchange rate during daytime
- Increasing the shading

Building type	Design parameters							Operational parameters		
	Glazing type	Wall type	Colour of external surface	Roof type	Building Orientation	Air exchange* (ach)	Shading (% of window area)	Internal gain (% of base case)	Set point (°C)	
									cooling	heating
Commercial**	A	concrete block wall, Autoclaved cellular concrete block wall	White, Dark Grey	RCC with brick-bat-coba waterproofing	Northwest-southeast; East-west; North-south; Northeast-southwest	0.5, 1.0, 2.0, 4.0	0, 10, 20, 50	0, 10, 50	24 25	21 20
Industrial	A	B	C	D	Northwest-southeast; East-west, North-south; Northeast-southwest	3.0, 6.0, 9.0, 12.0	0, 10, 20	20, 40	----	-----
Bungalow (Conditioned)	A	B	C	D	East-west; North-south	0.5, 1.5	0, 10, 20, 50	0, 50	25 26	20 19
Bungalow (Non-conditioned)	A	B	C	D	East-west; North-south	0.5, 1.5, 3.0+, 6.0+, 9.0+	0, 10, 20, 50	0, 50	----	------

Table 5.2 Parameters investigated

A	B	C	D
Single pane clear glass	Brick wall	Brick Red	RCC with brick-bat-coba waterproofing
Single pane reflective coated glass	Brick wall with expanded polystyrene insulation (inner side)	White	RCC with Bitumen felt water proofing
Double pane clear glass	Autoclaved cellular concrete block wall	Cream	RCC with polyurethane foam insulation
Double pane reflective coated glass	Concrete block wall	Dark Grey	
Double pane low-E glass			

*Scheduling of air exchanges are considered for all buildings (promoting air exchanges when ambient air is comfortable compared to room air)
** Reduction of window height to 1.2 m in place of fully glazed curtain walls considered as an additional parameter for the commercial building
+ Not considered for Srinagar and Leh

(B) Promote heat loss by:

(a) Ventilation of appliances

(b) Increasing the air exchange rate during cooler parts of the day or night-time

(c) Evaporative cooling (e.g. roof surface evaporative cooling)

(d) Earth coupling (e.g. earth-air pipe system)

The general recommendations for the climate are summarised as follows:

(1) Site

(a) **Landform:** Regions in this zone are generally flat, hence the surrounding areas tend to heat up uniformly. In case of an undulating site, constructing on the leeward side of the slope is preferred so that the effect of hot dusty winds is reduced. In case ventilation is assured, then building in a depression is preferable as cool air tends to sink in valleys (Fig. 5.7).

(b) **Waterbodies**: Waterbodies such as ponds and lakes not only act as heat sinks, but can also be used for evaporative cooling. Hot air blowing over water gets cooled which can then be allowed to enter the building. Fountains and water cascades in the vicinity of a building aid this process (Fig. 5.8 and 5.9).

(c) **Street width and orientation**: Streets must be narrow so that they cause mutual shading of buildings (Fig. 5.10). They need to be oriented in the north-south direction to block solar radiation.

(d) **Open spaces and built form**: Open spaces such as courtyards and atria are beneficial as they promote ventilation. In addition, they can be provided with ponds and fountains for evaporative cooling. Courtyards act as heat sinks during the day and radiate the heat back to the ambient at night. The size of the courtyards should be such that the mid-morning and the hot afternoon sun are avoided. Grass can be used as ground cover to absorb solar radiation and aid evaporative cooling (Fig. 5.11). Earth-coupled building (e.g. earth berming) can help lower the temperature and also deflect hot summer winds.

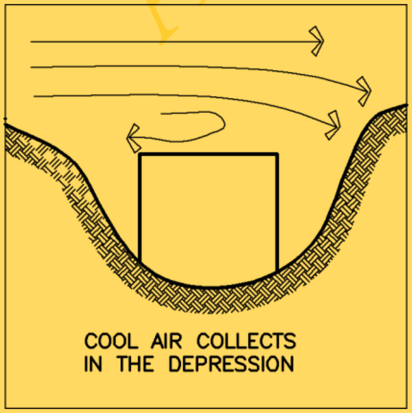


Fig. 5.7

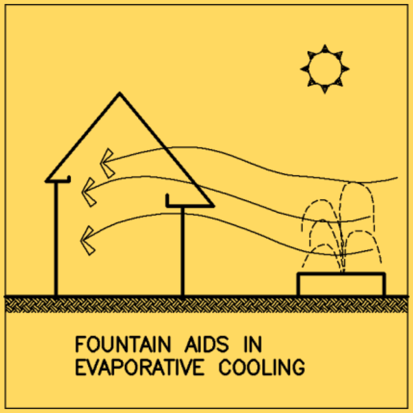


Fig. 5.8

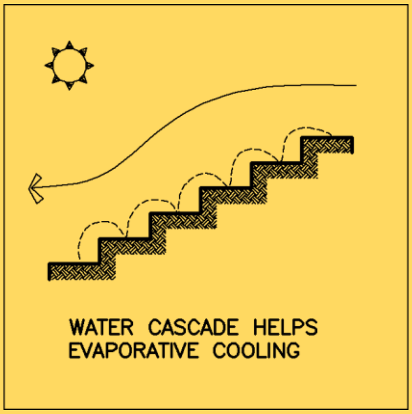


Fig. 5.9

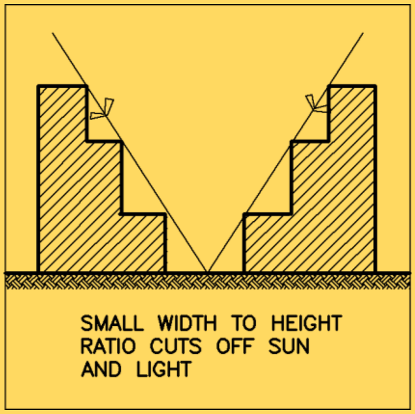


Fig. 5.10

(2) Orientation and planform

An east-west orientation (i.e. longer axis along the east-west), (Fig. 5.12) should be preferred. This is due to the fact that south and north facing walls are easier to shade than east and west walls. It may be noted that during summer, it is the north wall which gets significant exposure to solar radiation in most parts of India, leading to very high temperatures in north-west rooms. For example, in Jodhpur, rooms facing north-west can attain a maximum temperature exceeding 38 ºC. Hence, shading of the north wall is imperative. The surface to volume (S/V) ratio should be kept as minimum as possible to reduce heat gains (Fig. 5.13). Cross-ventilation must be ensured at night as ambient temperatures during this period are low.

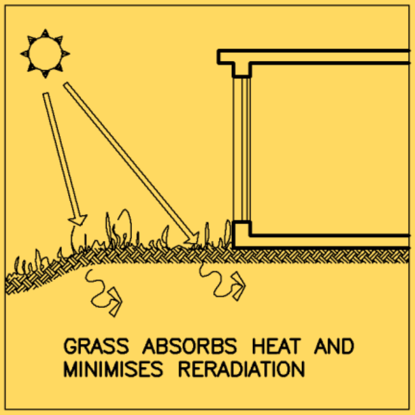


Fig. 5.11

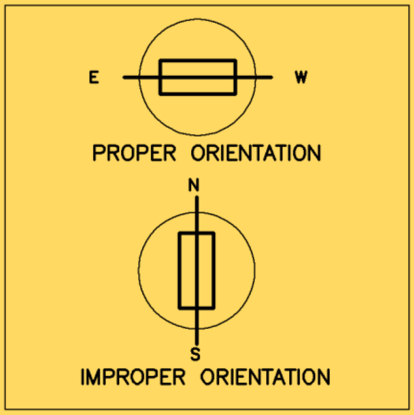


Fig. 5.12

(3) Building envelope

(a)Roof: The diurnal range of temperature being large, the ambient night temperatures are about 10 ºC lower than the daytime values and are accompanied by cool breezes. Hence, flat roofs may be considered in this climate as they can be used for sleeping at night in summer as well as for daytime activities in winter. The material of the roof should be massive; a reinforced cement concrete (RCC) slab is preferred to asbestos cement (AC) sheet roof. External insulation in the form of mud phuska with inverted earthen pots is also suitable. A false ceiling in rooms having exposed roofs can help in reducing the discomfort level [6]. Sodha et al. [7] have reported that the provision of roof insulation yields greater lifecycle savings compared to walls in this climate.

Evaporative cooling of the roof surface and night-time radiative cooling can also be employed. In case the former is used, it is better to use a roof having high thermal transmittance (a high U-value roof rather than one with lower U-value). The larger the roof area, the better is the cooling effect.

The maximum requirement of water per day for a place like Jodhpur is about 14.0 kg per square metre of roof area cooled. Spraying of water is preferable to an open roof pond system [7]. One may also consider of using a vaulted roof (Fig. 5.14) since it provides a larger surface area for heat loss compared to a flat roof.

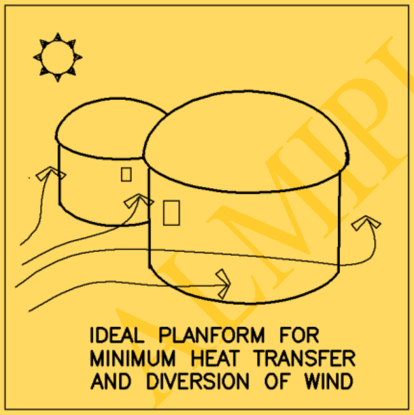


Fig. 5.13

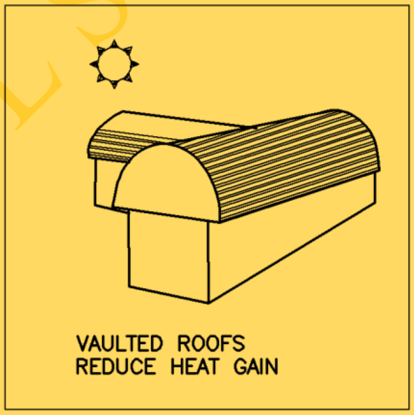


Fig. 5.14

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(a) **Walls:** In multi-storeyed buildings, walls and glazing account for most of the heat gain. It is estimated that they contribute to about 80% of the annual cooling load of such buildings [6]. So, the control of heat gain through the walls by shading is an important consideration in building design. One can also use a wall with low U-value to reduce the heat gain. However, the effectiveness of such walls depends on the building type. For example, in a non-conditioned building, autoclaved cellular concrete block wall is not recommended; whereas it is desirable in a conditioned building.

(b) **Fenestration:**In hot and dry climates, minimising the window area (in terms of glazing) can definitely lead to lower indoor temperatures. It is found that providing a glazing size of 10% of the floor area gives better performance than that of 20% [6]. More windows should be provided in the north facade of the building as compared to the east, west and south as it receives lesser radiation during the year (Fig. 5.15). All openings should be protected from the sun by using external shading devices such as chajjas and fins (Fig. 5.16-5.17). Moveable shading devices such as curtains and venetian blinds can also be used.

Openings are preferred at higher levels (ventilators) as they help in venting hot air. Since daytime temperatures are high during summer, the windows should be kept closed to keep the hot air out and opened during night-time to admit cooler air.

The use of ‘jaalis’(lattice work) made of wood, stone or RCC may be considered as they allow ventilation while blocking solar radiation. Scheduling air changes (i.e. high air change rate at night and during cooler periods of the day, and lower ones during daytime) can

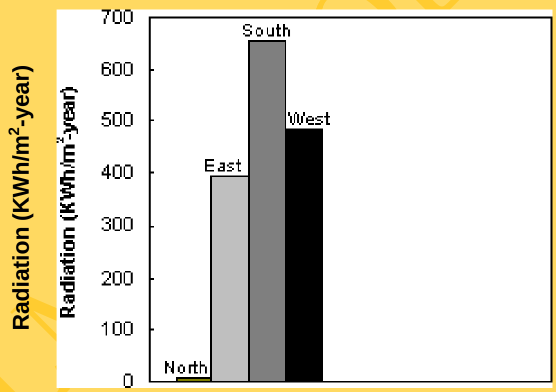


Fig. 5.15 Yearly beam radiation incident on an unshaded window (1.2m x 1.2 m)

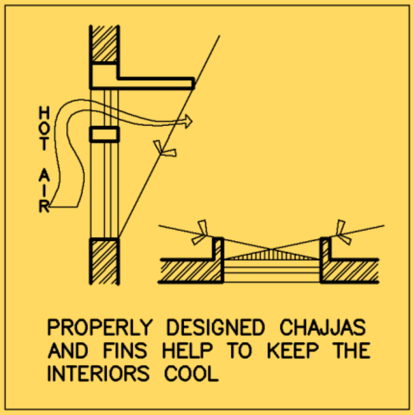


Fig. 5.16

Fig. 5.17

significantly help in reducing the discomfort. The heat gain through windows can be reduced by using glass with low transmissivity.

(a) Colour and texture: Change of colour is a cheap and effective technique for lowering indoor temperatures. Colours having low absorptivity should be used to paint the external surface. Darker shades should be avoided for surfaces exposed to direct solar radiation. The surface of the roof can be of white broken glazed tiles (china mosaic flooring). The surface of the wall should preferably be textured to facilitate self shading.

Remarks: As the winters in this region are uncomfortably cold, windows should be designed such that they encourage direct gain during this period.

Deciduous trees can be used to shade the building during summer and admit sunlight during winter. There is a general tendency to think that well-insulated and very thick walls give a good thermal performance. This is true only if the glazing is kept to a minimum and windows are well-shaded, as is found in traditional architecture. However, in case of non-conditioned buildings, a combination of insulated walls and high percentage of glazing will lead to very uncomfortable indoor conditions. This is because the building will act like a green house or oven, as the insulated walls will prevent the radiation admitted through windows from escaping back to the environment. Indoor plants can be provided near the window, as they help in evaporative cooling and in absorbing solar radiation. Evaporative cooling and earth-air pipe systems can be used effectively in this climate. Desert coolers are extensively used in this climate, and if properly sized, they can alleviate discomfort by as much as 90% [7].

5.4.2 Warm and Humid Climate

The warm and humid climate is characterized by high temperatures accompanied by very high humidity leading to discomfort.

Thus, cross ventilation is both desirable and essential. Protection from direct solar radiation should also be ensured by shading.

The main objectives of building design in this zone should be:

(A) Resist heat gain by:

(a) Decreasing exposed surface area
(b) Increasing thermal resistance
(c) Increasing buffer spaces
(d) Increasing shading
(e) Increasing reflectivity

(B) To promote heat loss by:

(a) Ventilation of appliances
(b) Increasing air exchange rate (ventilation) throughout the day
(c) Decreasing humidity levels

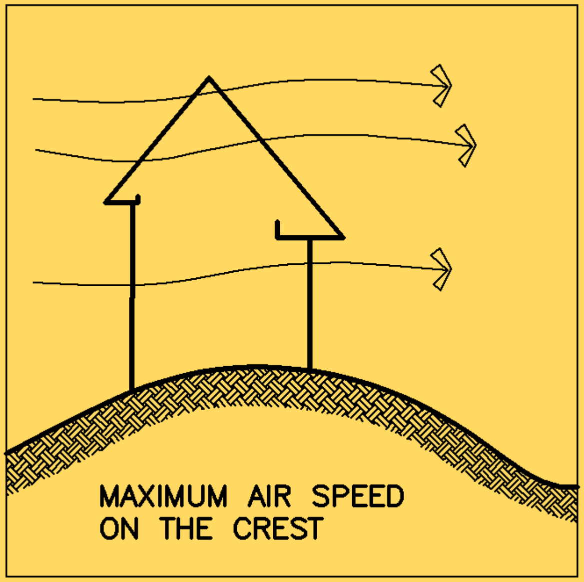
The general recommendations for building design in the warm and humid climate are as follows:

(1) Site

(a) Landform: The consideration of landform is immaterial for a flat site. However, if there are slopes and depressions, then the building should be located on the windward side or crest to take advantage of cool breezes (Fig. 5.18).

(b) Waterbodies: Since humidity is high in these regions, water bodies are not essential.

(c) Open spaces and built form: Buildings should be spread out with large open spaces for unrestricted air movement (Fig. 5.19). In cities, buildings on stilts can promote ventilation and cause cooling at the ground level.



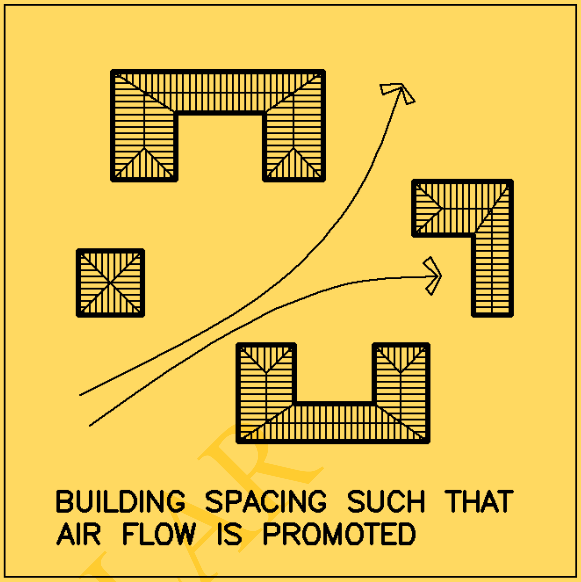


Fig. 5.18 **Fig. 5.19**

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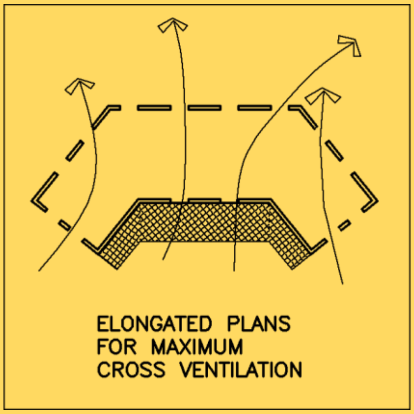


Fig. 5.20

Fig. 5.21

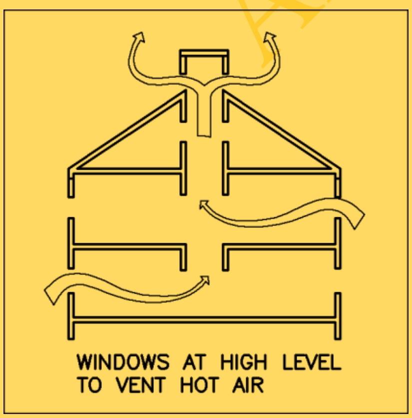


Fig. 5.22

(d) Street width and orientation: Major streets should be oriented parallel to or within 30º of the prevailing wind direction during summer months to encourage ventilation in warm and humid regions. A north-south direction is ideal from the point of view of blocking solar radiation. The width of the streets should be such that the intense solar radiation during late morning and early afternoon is avoided in summer.

(2) Orientation and planform

Since the temperatures are not excessive, free plans can be evolved as long as the house is under protective shade. An unobstructed air path through the interiors is important. The buildings could be long and narrow to allow cross-ventilation. For example, a singly loaded corridor plan (i.e. rooms on one side only) can be adopted instead of a doubly loaded one (Fig. 5.20). Heat and moisture producing areas must be ventilated and separated from the rest of the structure (Fig. 5.21) [8]. Since temperatures in the shade are not very high, semi- open spaces such as balconies, verandahs and porches can be used advantageously for daytime activities. Such spaces also give protection from rainfall. In multi-storeyed buildings a central courtyard can be provided with vents at higher levels to draw away the rising hot air (Fig. 5.22).

(3) Building envelope

(a) Roof: In addition to providing shelter from rain and heat, the form of the roof should be planned to promote air flow. Vents at the roof top effectively induce ventilation and draw hot air out (Fig. 5.23). As diurnal temperature variation is low, insulation does not provide any additional benefit for a normal reinforced cement concrete (RCC) roof in a non-conditioned building [6]. However, very thin roofs having low thermal mass, such as asbestos cement (AC) sheet roofing, do require insulation as they tend to rapidly radiate heat into the interiors during daytime. A double roof with a ventilated space in between can also be used to promote air flow.

(a) **Walls**: As with roofs, the walls must also be designed to promote air flow. Baffle walls, both inside and outside the building can help to divert the flow of wind inside (Fig. 5.24). They should be protected from the heavy rainfall prevalent in such areas. If adequately sheltered, exposed brick walls and mud plastered walls work very well by absorbing the humidity and helping the building to breathe. Again, as for roofs, insulation does not significantly improve the performance of a non-conditioned building [6].

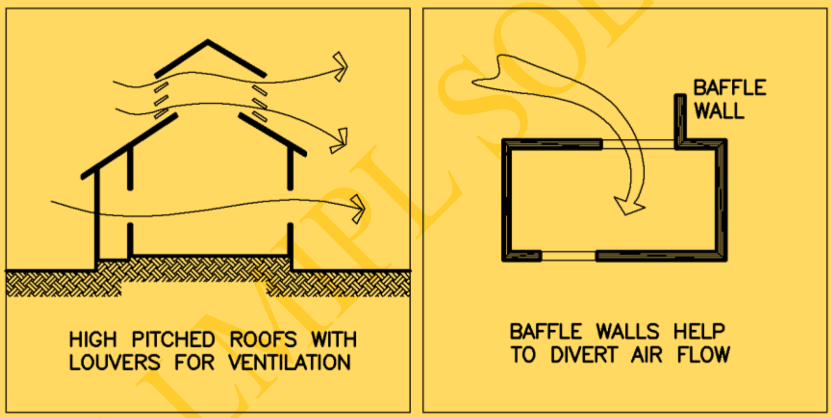
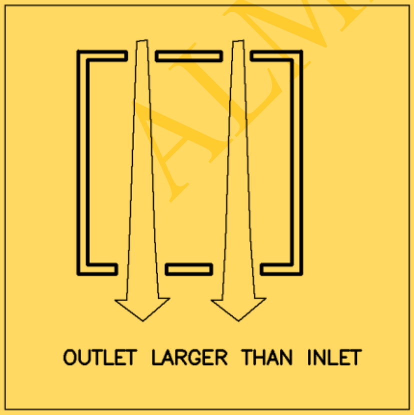


Fig. 5.23 Fig. 5.24

(b)Fenestration: Cross-ventilation is important in the warm and humid regions. All doors and windows are preferably kept open for maximum ventilation for most of the year. These must be provided with venetian blinds or louvers to shelter the rooms from the sun and rain, as well as for the control of air movement [9]. Openings of a comparatively smaller size can be placed on the windward side, while the corresponding openings on the leeward side may be bigger for facilitating a plume effect for natural ventilation (Fig. 5.25). The openings should be shaded by external overhangs. Outlets at higher levels serve to vent hot air (Fig. 5.26). A few examples illustrating how the air movement within a room can be better distributed, are shown in Fig. 5.27 - 5.29.



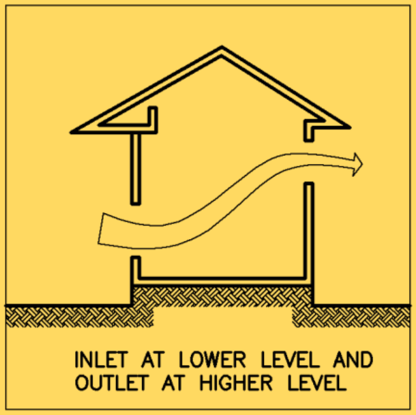


Fig. 5.25 Fig. 5.26

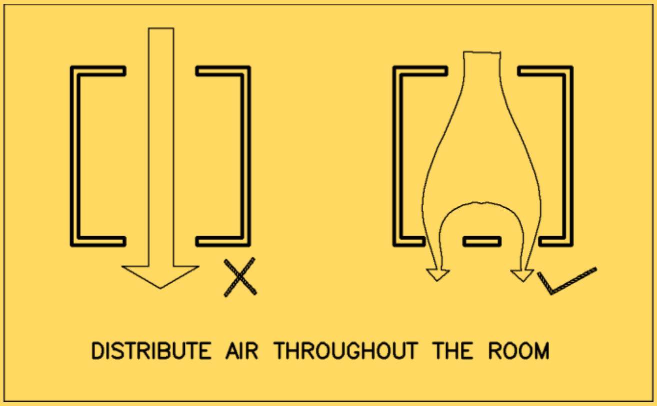


Fig. 5.27

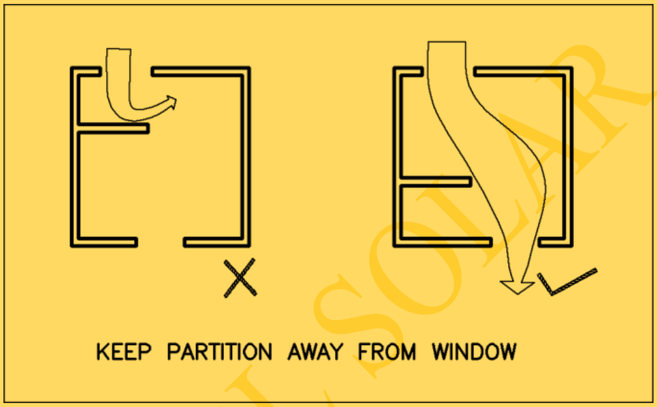


Fig. 5.28

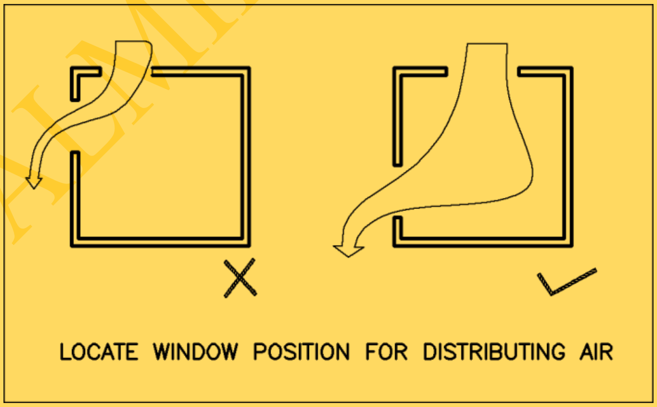


Fig. 5.29

(b) **Colour and texture:** The walls should be painted with light pastel shades or whitewashed,

while the surface of the roof can be of broken glazed tile (china mosaic flooring). Both techniques help to reflect the sunlight back to the ambient, and hence reduce heat gain of the building. The use of appropriate colours and surface finishes is a cheap and very effective technique to lower indoor temperatures. It is worth mentioning that the surface finish should be protected from/ resistant to the effects of moisture, as this can otherwise lead to growth of mould and result in the decay of building elements.

Remarks: Ceiling fans are effective in reducing the level of discomfort in this type of climate. Desiccant cooling techniques can also be employed as they reduce the level. Careful water proofing and drainage of water are essential considerations of building design due to heavy rainfall. In case of air- conditioned buildings, dehumidification plays a significant role in the design of the plant.

5.4.3 Moderate Climate

Temperatures are neither too high nor too low in regions with a moderate climate. Hence, simple techniques are normally adequate to take care of the heating and cooling requirements of the building. Techniques such as shading, cross ventilation, orientation, reflective glazing, etc. should be incorporated in the building. The thermal resistance and heat capacity of walls and roofs need not be high. These simple measures can reduce the number of uncomfortable hours in a building significantly. For example, in Pune, the 'uncomfortable' hours in a year can be reduced by as much as 89% by incorporating simple techniques in building design [6]. The room temperature can be brought within the comfort limit (i.e. less than 30 ºC) even in the month of May [6].

The main objectives while designing buildings in this zone should be:

(A) Resist heat gain by:

(a) Decreasing the exposed surface area

(b) Increasing the thermal resistance

(c) Increasing the shading

(B) Promote heat loss by:

(a) Ventilation of appliances

(b) Increasing the air exchange rate (ventilation) In this region, the general recommendations are as follows:

(1) Site

(a) Landform: Building the structure on the windward slopes is preferable for getting cool Breezes (Fig. 5.30).

(b) Open spaces and built form: An open and free layout of the buildings is preferred. Large open spaces in the form of lawns can be provided to reduce reflected radiation.

.28

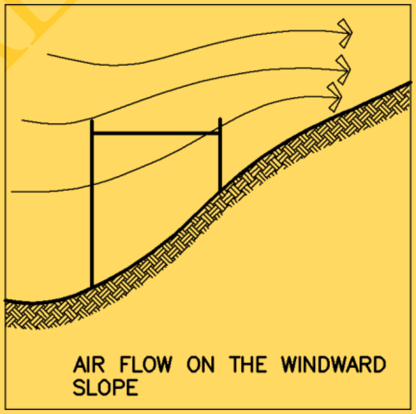


Fig 5.30

(2) Orientation and planform

It is preferable to have a building oriented in the north-south direction. Bedrooms may be located on the eastern side, and an open porch on the south - southeast side, while the western side should ideally be well-shaded. Humidity producing areas must be isolated. Sunlight is desirable except in summer, so the depth of the interiors may not be excessive [10].

(3) Building envelope

(a) Roof: Insulating the roof does not make much of a difference in the moderate climate [6].

(b) Walls: Insulation of walls does not give significant improvement in the thermal performance of a building. A brick wall of 230 mm thickness is good enough [6].

(c) Fenestration: The arrangement of windows is important for reducing heat gain. Windows can be larger in the north, while those on the east, west and south should be smaller. All the windows should be shaded with chajjas of appropriate lengths. Glazing of low transmissivity should be used.

(d) Colour and texture: Pale colours are preferable; dark colours may be used only in recessed places protected from the summer sun.

5.4.3 Cold and Cloudy, and Cold and Sunny Climates

These regions experience very cold winters, hence, trapping and using the sun's heat whenever it is available, is of prime concern in building design. The internal heat should not be lost back to the ambient. The insulation of building elements and control of infiltration help in retaining the heat. Exposure to cold winds should also be minimized.

The main objectives while designing buildings in these zones are:

(A) Resist heat loss by:

(a) Decreasing the exposed surface area
(b) Increasing the thermal resistance
(c) Increasing the thermal capacity
(d) Increasing the buffer spaces
(e) Decreasing the air exchange rate

(B) Promote heat gain by:

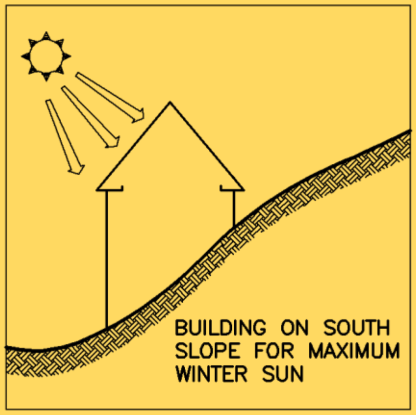
(a) Avoiding excessive shading
(b) Utilising the heat from appliances
(c) Trapping the heat of the sun.

The general recommendations for regions with a cold and cloudy, or cold and sunny climate are given below.

(1) Site

(a)Landform: In cold climates, heat gain is desirable. Hence, buildings should be located on the south slope of a hill or mountain for better access to solar radiation (Fig. 5.31). At the same time, the exposure to cold winds can be minimized by locating the building on the leeward side. Parts of the site which offer natural wind barrier can be chosen for constructing a building.

(b)Open spaces and built forms: Buildings in cold climates should be clustered together to minimize exposure to cold winds (Fig. 5.32). Open spaces must be such that they allow maximum south sun. They should be treated with a hard and reflective surface so that they reflect solar radiation onto the building (Fig. 5.33).



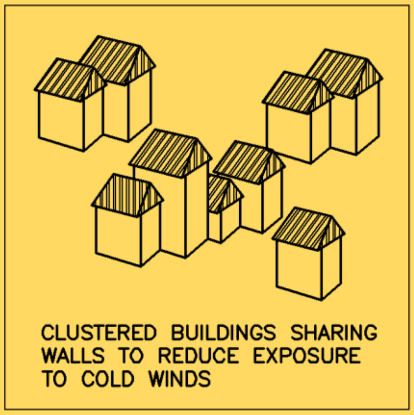
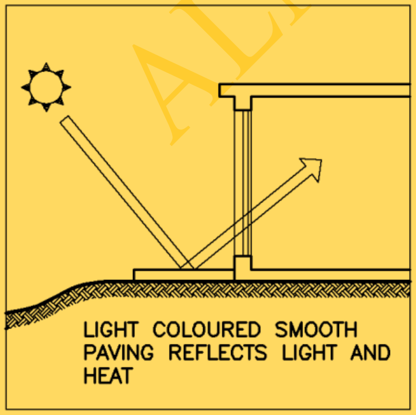


Fig. 5.31 Fig. 5.32

(2) **Street width and orientation:** In cold climates, the street orientation should be east-west to allow for maximum south sun to enter the building. The street should be wide enough to ensure that the buildings on one side do not shade those on the other side (i.e. solar access should be ensured) (Fig. 5.34).



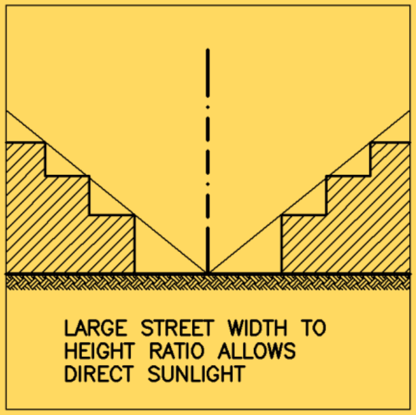


Fig. 5.33 Fig. 5.3

(3)Orientation and planform

In the cold zones, the buildings must be compact with small S/V ratios (Fig. 5.35). This is because the lesser the surface area, the lower is the heat loss from the building. Windows should preferably face south to encourage direct gain. The north side of the building should be well-insulated. Living areas can be located on the southern side while utility areas such as stores can be on the northern side. Air-lock lobbies at the entrance and exit points of the building reduce heat loss. The heat generated by appliances in rooms such as kitchens may be recycled to heat the other parts of the building.

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Fig. 5.35

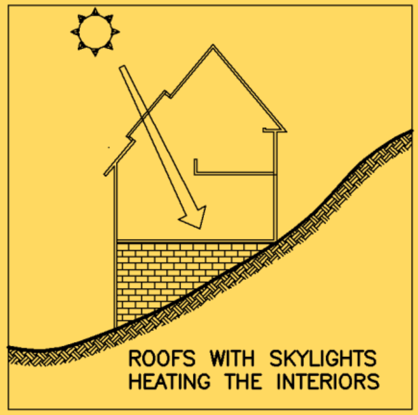

Fig. 5.36

(3) Building envelope

(a) **Roof**: False ceilings are a regular roof feature of houses in cold climates. One can also use internal insulation such as polyurethane foam (PUF), thermocol, wood wool, etc. An aluminium foil is generally used between the insulation layer and the roof to reduce heat loss to the exterior. A sufficiently sloping roof enables quick drainage of rain water and snow. A solar air collector can be incorporated on the south facing slope of the roof and hot air from it can be used for space heating purposes. Skylights on the roofs admit heat as well as light in winters (Fig. 5.36). The skylights can be provided with shutters to avoid over heating in summers.

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(b) **Walls**: Walls should be of low U-value to resist heat loss. The south-facing walls (exposed to solar radiation) could be of high thermal capacity (such as Trombe wall) to store day time heat for later use. The walls should also be insulated. The insulation should have sufficient vapour barrier (such as two coats of bitumen, 300 to 600 gauge polyethylene sheet or aluminium foil) on the warm side to avoid condensation. Hollow and lightweight concrete blocks are also quite suitable [11]. On the windward or north side, a cavity wall type of construction may be adopted.

(c) **Fenestration**: It is advisable to have the maximum window area on the southern side of the building to facilitate direct heat gain. They should be sealed and preferably double glazed. Double glazing helps to avoid heat losses during winter nights. However, care should be taken to prevent condensation in the air space between the panes. Movable shades should be provided to prevent overheating in summers

(d) **Colour and texture**: The external surfaces of the walls should be dark in colour for high absorptivity to facilitate heat gains.

5.4.4 Composite Climate

The composite climate displays the characteristics of hot and dry, warm and humid as well as cold climates. Designs here are guided by longer prevailing climatic conditions. The duration of ‘uncomfortable’ periods in each season has to be compared to derive an order of priorities. India being a tropical country, most of the design decisions would pertain to cooling. For example, the general recommendations for hot and dry climates would be applicable for New Delhi for most of the year except monsoon, when ventilation is essential.

5.5 SPECIFIC GUIDELINES

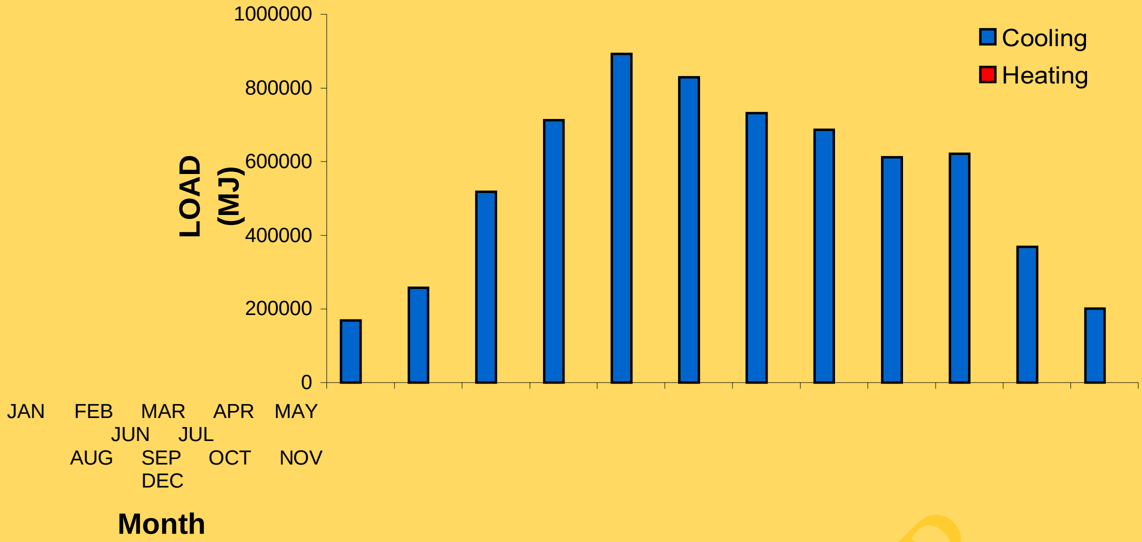
The specific guidelines for a commercial building (conditioned), an industrial building (non-conditioned) and a residential building (conditioned and non-conditioned) have been formulated based on simulation studies, and are discussed in this section.

5.5.1Hot and Dry Climate (Representative city: Jodhpur)

1.5.1.1 Commercial Building

A large multi-storeyed building (Fig. 5.1) has been considered as an example of a commercial building; it is assumed to be centrally air-conditioned. Figure 5.37 presents the heating and cooling loads of the building on a monthly as well as annual basis for Jodhpur (hot and dry climate). The heating load is negligible whereas the cooling load is dominant, cooling being required throughout the year. The load profiles generally follow the climatic conditions; the highest cooling load occurs in summer (May), lower loads during monsoon (August and September) and the lowest loads in winter (December, January and February). The monthly variation of the percentage of loads through various building components is shown in Fig. 5.38. It is seen that the cooling requirement is primarily because of the heat gains from the surfaces and internal gains due to equipment and people. Thus, the building construction could be made more resistant to heat gain by choosing appropriate materials and paints, by shading external surfaces of the building, by reducing exposed glazing area, etc. Energy efficient equipment and lighting systems may be used to reduce the internal gains. Scheduling of air changes to promote air exchanges from November to February, when the ambient air is cooler and more comfortable compared to room air, would help to reduce the cooling loads. In summer months, air exchanges add to the cooling loads and hence need to be controlled.

Table 5.3 shows the floor-wise distribution of loads. It is seen that the usage pattern of the building has a significant impact on the loads. For instance, the energy required for cooling is maximum on the ground floor. This is because of the frequent opening of the shutters on ground floor, resulting in a high heat gain due to air exchanges. Besides, there is a significant internal gain due to operation of equipment and a high occupancy level. Similarly, the cooling loads of the second and third floors are significantly higher than those of other floors as they are occupied on a 24-hour basis throughout the week. The gain due to air exchanges may be reduced by preventing the leakage of hot ambient air from entering the building by sealing all cracks and providing air-lock lobbies on the ground floor.



100%
80%
60%
40%
20%

ANNUAL LOAD

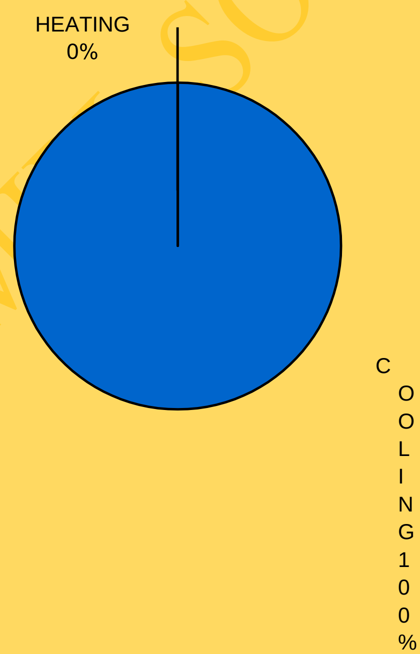


Fig. 5.37 Monthly and annual heating and cooling loads of the commercial building -Jodhpur (hot and dry climate)

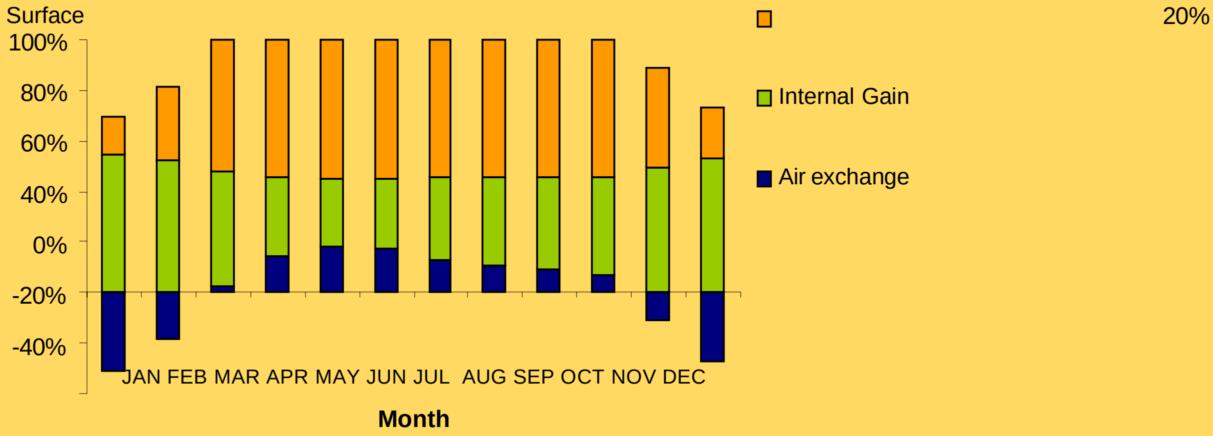


Fig. 5.38 Component-wise distribution of percentage heat gains and losses on a monthly basis of the commercial building- Jodhpur (hot and dry climate)

Table 5.3-Floorwise distribution of monthly and annual loads of the commercial building – Jodhpur (hot and dry climate)

Month	Cooling load (MJ)								
	GR	F1	F2	F3	F4	F5	F6	F7	Total
JAN	11044	23877	31676	32906	26290	15262	22024	5407	168486
FEB	33614	29955	46404	47009	32841	23368	31969	12660	257819
MAR	99715	47829	89831	91138	53215	45454	58930	31078	517190
APR	162474	57586	120609	123121	65744	61059	77418	45044	713055
MAY	208599	70259	148179	151518	81004	77330	97427	58629	892943
JUN	199222	62770	140774	144185	72729	69448	87696	52430	829255
JUL	166567	58184	124788	127597	67132	62433	79505	45738	731944
AUG	148625	57450	116923	119163	65656	59721	76557	43093	687189
SEP	135993	49582	107131	109458	56474	51120	65379	36736	611873
OCT	121739	55810	105610	107427	63100	56316	71415	39934	621350
NOV	53564	39640	65444	65913	43798	34396	44968	21124	368847
DEC	19623	25765	37659	38606	28286	18191	25204	8187	201521
Total	**1360779**	**578707**	**1135027**	**1158040**	**656269**	**574097**	**738493**	**400061**	**6601472**

Month	Heating load (MJ)								
	GR	F1	F2	F3	F4	F5	F6	F7	Total
JAN	0	0	0	0	0	0	0	64	64
FEB	0	0	0	0	0	0	0	0	0
MAR	0	0	0	0	0	0	0	0	0
APR	0	0	0	0	0	0	0	0	0
MAY	0	0	0	0	0	0	0	0	0
JUN	0	0	0	0	0	0	0	0	0
JUL	0	0	0	0	0	0	0	0	0
AUG	0	0	0	0	0	0	0	0	0
SEP	0	0	0	0	0	0	0	0	0
OCT	0	0	0	0	0	0	0	0	0
NOV	0	0	0	0	0	0	0	0	0
DEC	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**64**	**64**

GR=Ground Floor, F1=First floor, F2=Second floor, F3=Third Floor,

F4=Fourth floor, F5=Fifth floor, F6=Sixth Floor, F7=Seventh floor

The effects of building parameters on the annual loads of the building are presented in Table 5.4. The consequent percentage load reduction for each parameter compared to the base case is also tabulated. It may be noted that the total annual load of the building is quite high. Even a one percent reduction in this load would result in significant energy savings. The following guidelines are recommended for a commercial building in a hot and dry climatic region like Jodhpur:

(a) Design Parameters

(i) Building orientation

Appropriate orientation of the building can reduce the annual load significantly. The building (Fig.5.1) with its glazed curtain wall facing northwest shows a substantial reduction in load compared to the southwest orientation (base case) the percentage reduction being 9.4. The west and north orientations are also better than the base case.

(ii) Glazing type

Double glazing with reflective coated glass gives the best performance. It reduces the load by 2.1% compared to single pane reflective coated glass (base case). Single pane clear, double pane clear and double low-E glass increase the annual load by 10.1, 8.0 and 1.4% respectively and hence are not recommended.

(a)Window size

The reduction of the glazing size to a 1.2 m height compared to a fully glazed curtain wall decreases the annual load by 7.0%. This is due to the reduction in solar gain, and thus the use of larger expanses of glass in such a building is not desirable as it leads to higher annual loads.

(iv) **Shading**

The reduction in solar gain by shading of windows (by means of external projections such as chajjas) causes a decrease in the heat gain and hence the annual load is reduced. If 50% of the window areas are shaded throughout the year, the percentage load reduction is 9.2.

(v) **Wall type**

A wall having low U-value (insulating type such as autoclaved cellular concrete block) reduces the load compared to the concrete block wall (base case) by 2.1%. Thus, insulation of walls is recommended.

(vi) **Colour of the external surface**

Dark colours on the walls of such a commercial building should be avoided. For example, if dark grey is used, the percentage increase in load is 4.3 compared to a white surface (base case).

(vii) **Air exchanges**

A lower air change rate of 0.5 ach is preferable compared to 1, 2 and 4 ach. The percentage reduction in the annual load is 2.0 compared to the base case of 1 ach.

(a) **Operational Parameters**

The operational parameters such as internal gain, set point and scheduling of air changes can help in reducing the annual load of the building. The effects are summarised as follows.

(i) **Internal gain**

The lower the internal gain, the better is the performance of the building in reducing the annual load.

Table 5.4 Annual savings due to building design and operational parameters for the commercial building- Jodhpur (hot and dry climate)

Parameter	Annual load (MJ)			Energy saving	
	Cooling	Heating	Total	(MJ)	(%)
Base case	6601472	64	6601536	--	--
Orientation (longer axis)					
North-south	6088713	1850	6090563	510973	7.7
Northeast-southwest	5978737	1476	5980213	621323	9.4
East-west	6385516	389	6385905	215631	3.3
Glazing type					
Single clear	7269940	0	7269940	-668404	-10.1
Double clear	7128218	0	7128218	-526682	-8.0
Double low-E	6690662	0	6690662	-89126	-1.4
Double reflective coated	6465326	0	6465326	136210	2.1
Glazing size (restricted to 1.2m height)	6139193	14	6139207	462329	7.0
Shading					
10%	6479553	167	6479720	121816	1.8
20%	6357878	287	6358165	243371	3.7
50%	5995191	949	5996139	605397	9.2
Wall type					
Autoclaved cellular concrete	6460568	20	6460588	140948	2.1
Colour of external surface					
Dark grey	6883389	1	6883390	-281854	-4.3
Air exchange rate					
0.5	6469405	0	6469405	132131	2.0
2	6886651	1297	6887948	-286412	-4.3
4	7524210	28560	7552770	-951234	-14.4
Internal gain					
10%	3578640	25472	3604112	2997424	45.4
50%	4857419	1513	4858932	1742604	26.4
No internal gain	3278665	43330	3321995	3279541	49.7
Set point cooling: 25 °C heating: 20 °C	6161889	0	6161889	439647	6.7
Scheduling of air exchanges	6429115	15621	6444735	156801	2.4

(ii) **Set Point**

The annual load of the building reduces if the set points for comfort cooling and heating are relaxed. If the cooling and heating set points of 25 and 20^{0}C respectively are used (compared to 24 and 21^{0}C), the percentage reduction in annual load is 6.7. Thus, a change in the expectation of comfort can lead to significant savings.

(a) Scheduling of air exchanges

The scheduling of air changes to promote air entry during cooler periods (such as nights or winters) and controlling it during warmer periods (during daytime or summer) can lead to significant reduction of annual load the percentage reduction being 2.4.

The combination of all design and operational parameters discussed (excluding building orientation and internal gain), results in a load reduction of 26.1 percent.

2.5.1.2 Industrial Building

Figure 5.3 shows the plan of an industrial building investigated for developing design guidelines. It is a non-conditioned building and hence indoor room temperatures are estimated. Table 5.5 presents the yearly minimum, maximum and average temperatures. It also shows the yearly comfortable hours, both in numbers as well as percentage, of the shed and store for the Jodhpur climate. It has been found that the maximum temperatures of the rooms (i.e. the shed on ground floor and store on first floor) can exceed 40 °C. The yearly average room temperature of the shed is 34.5 °C and is about 7.6 °C above the yearly average ambient temperature. Thus, the emphasis should be on cooling considerations. Overheating in the shed occurs due to high internal gains because of the operation of large machines, occupants, and lighting. The number of comfortable hours in a year does not exceed 35% for both the shed and the store. In other words, the shed and store are uncomfortable for more than 65% of the year.

Table 5.5 Performance of the industrial building on an annual basis- Jodhpur (hot and dry climate)

Room	Yearly room temperature (°C)			Comfortable hours in a year (h)	Percentage of yearly comfortable hours
	MIN	MAX	AVG		
Shed	22.0	45.1	34.5	3098	35
Store	17.1	40.2	30.2	4098	47
Ambient	11.4	40.3	26.9	4838	55

MIN = Minimum, MAX = Maximum, AVG = Average

Table 5.6 Performance of the industrial building on a monthly basis-Jodhpur (hot and dry climate)

Comfort index	Month	Room	
		Shed	Store
Comfort fraction	JAN	0.79	0.72
	FEB	0.56	0.91
	MAR	-0.06	0.80
	APR	-0.81	0.28
	MAY	-1.22	-0.15
	JUN	-1.19	-0.15
	JUL	-0.82	0.25
	AUG	0.02	0.19
	SEP	-0.54	0.54
	OCT	-0.36	0.66
	NOV	0.32	0.95
	DEC	0.72	0.80

Table 5.6 shows the monthly performance of the shed and store in terms of the comfort fraction. The shed is extremely uncomfortable from March to July, and from September to October. The store is relatively more comfortable during the same period. The hourly variation of room temperatures for a typical winter day of January and summer day of May are presented in Fig. 5.39 and 5.40 respectively. The figures show that in January, both the shed and the store are within or close to the comfort zone. The shed is mostly comfortable at night, while the store is mostly comfortable

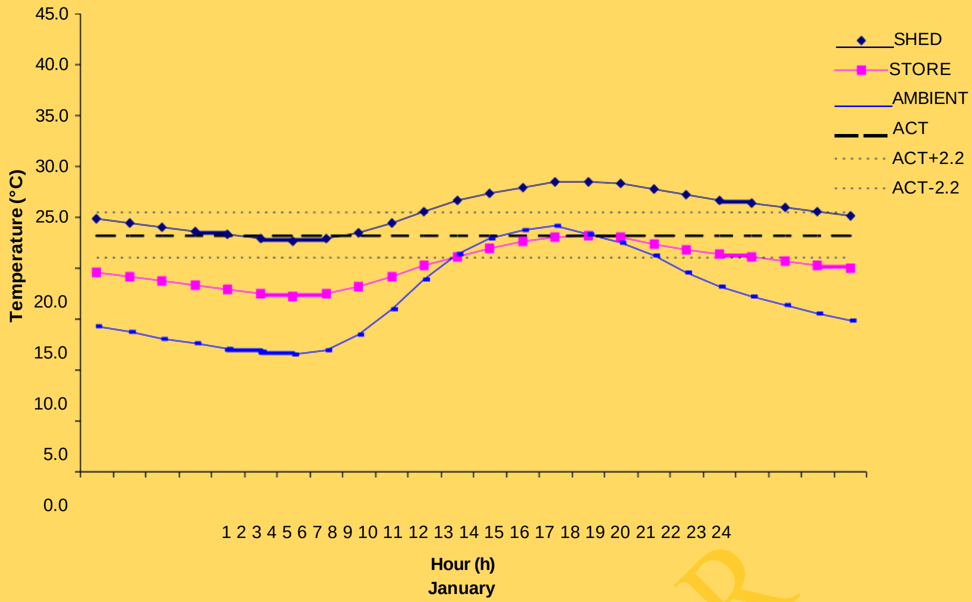


Fig. 5.39 Hourly variation of room temperatures of the industrial building in January - Jodhpur (hot and dry climate)

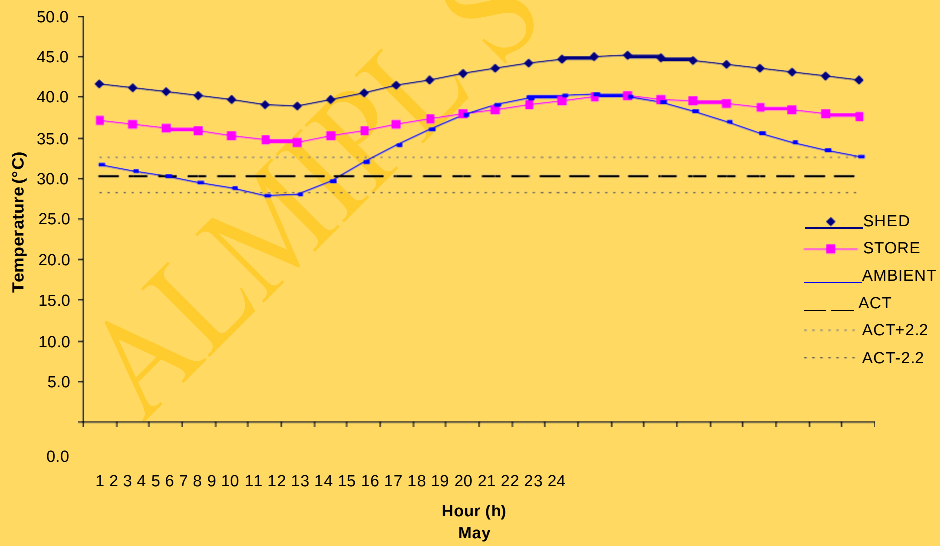


Fig. 5.40 Hourly variation of room temperatures of the industrial building in May - Jodhpur (hot and dry climate)

during daytime. In May, both the rooms are well above the comfort zone. The store temperature exceeds 35 °C almost throughout the day. The shed is even worse, with temperatures exceeding 40°C and almost touching 45 °C. Thus both rooms are extremely hot in May. The main reason for such thermal behaviour of the building is because of its large internal gains due to equipment and occupancy level. The results show that cooling is a prime consideration for design. Comfortable conditions could be achieved by reducing heat gains and promoting heat loss. Heat gain from the building surfaces may be reduced by appropriate orientation, shading, glazing, colour, etc. Energy efficient equipment could be used for reducing the internal heat gains. Further, ventilation can promote heat loss during cooler periods (such as nights or winters) and control heat gain during warmer periods (during daytime or summers). Higher air change rates (compared to the base case of 6 ach) is recommended for all hours of the day in the summer months, and between 12 to 18 hours in the winter months (Fig. 5.39 and 5.40).

Table 5.7 presents the number of comfortable hours in a year due to various parameters for the shed. The corresponding percentage increase or decrease (-) in comfortable hours compared to the base case is also presented in the table.

(a) **Design Parameters**

(i) **Building orientation**

The building orientation has no significant because the building has substantial internal gains.

(ii) **Glazing type**

Single pane reflective coated glass is recommended over plain glass (base case) because it shows a marginal increase (about 3.4%) in yearly comfortable hours.

(iii) **Shading**

The shading of windows reduces heat gain and increases the yearly comfortable hours.

(iii) **Wall type**

A concrete block wall is better than the brick wall (base case); the performance improves by about 4.7%.

(iv) **Roof type**

Insulation of the roof is not desirable. An RCC roof with bitumen felt water proofing layer increases the yearly comfortable hours by 4.1% compared to RCC with brick-bat- coba water proofing.

(v) **Colour of the external surface**

White and cream colours are desirable over puff shade (base case) or dark grey. The percentage increase in comfortable hours due to these colours compared to the base case are 6.2 and 4.4 respectively.

(vi) **Air exchanges**

Higher air change rates are desirable; air change rates of 9 and 12 ach compared to the base case oh 6 ach improve the performance by about 12.9 and 19.1% respectively.

(b) **Operational Parameters**

(i) **Internal gain**

The lower the internal gain, the better is the performance of the building.

(ii) **Scheduling of air exchanges**

Promoting higher air change rates when the ambient air temperature is within the comfortable range as compared to the indoor temperature improves the performance of the building by 30.9% compared to a constant air change rate. However, in the reverse situation, air exchange needs to be minmised.

The combinations of all design and operational parameters discussed, (excluding building orientation and internal gain) significantly improves the yearly comfortable hours in the industrial shed; the percentage increase is 43.8 compared to the base case.

Table 5.7 Improvement of in the performance of the industrial building due to design and operational parameters- Jodhpur (hot and dry climate)

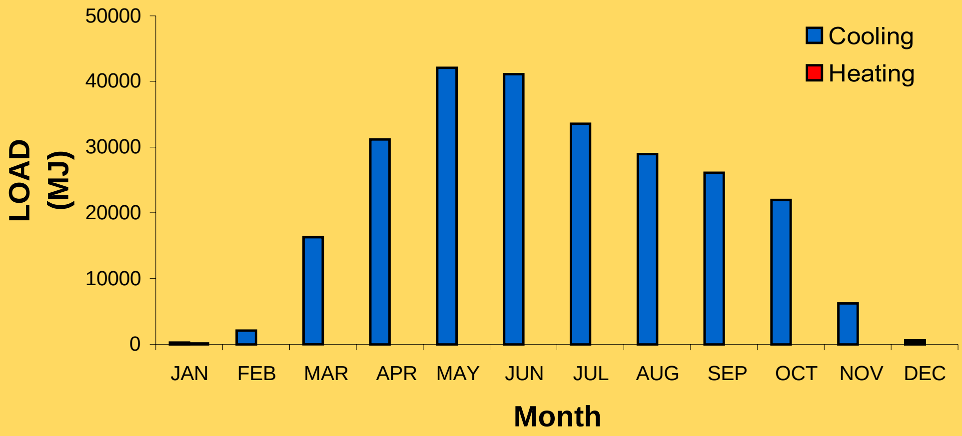
Parameter	Comfortable hours in a year (h)	Percentage increase in Comfortable hours
Base case	3089	-
Orientation		
Northwest-southeast	3106	0.6
Northeast-southwest	3110	0.7
East-west	3100	0.4
Glazing type		
Single reflective	3195	3.4
Double clear	2953	-4.4
Double low-E	2973	-3.8
Double reflective coated	3029	-1.9
Shading		
10%	3133	1.4
20%	3157	2.2
Wall type		
Thermocol (EPS) insulated brick wall	2909	-5.8
Concrete block wall	3234	4.7
Autoclaved cellular concrete block	2929	-5.2
Roof type		
RCC with bitumen felt water proofing	3215	4.1
RCC with PUF insulation	2796	-9.5
Colour of external surface		
White	3282	6.2
Cream	3224	4.4
Dark grey	2934	-5.0
Air exchanges		
3 ach	2186	-29.2
9 ach	3486	12.9
12 ach	3678	19.1
Internal gain		
20%	4569	47.9
40%	4029	30.4
Scheduling of air exchanges	4043	30.9

3.5.1.3 Residential Building (Bungalow)

Figure 5.5 shows the plan of the bungalow chosen for developing design guidelines. Both conditioned as well as non-conditioned options are considered for the building.

(A) Conditioned building

Figure 5.41 shows the distribution of the annual and monthly heating and cooling loads of the building for the Jodhpur climate. Clearly, the building requires cooling throughout the year. The general features are similar to those observed in the case of the commercial



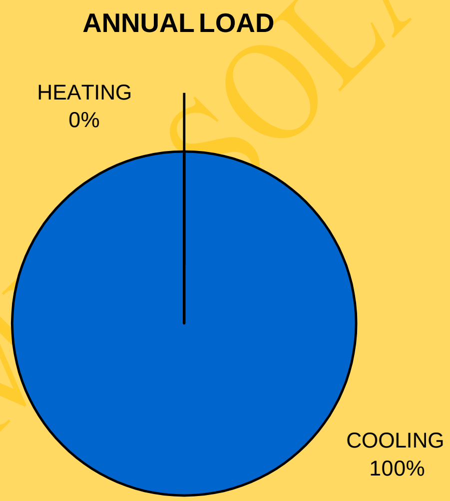


Fig. 5.41 Monthly and annual heating and cooling loads of the conditioned bungalow- Jodhpur (hot and dry climate)

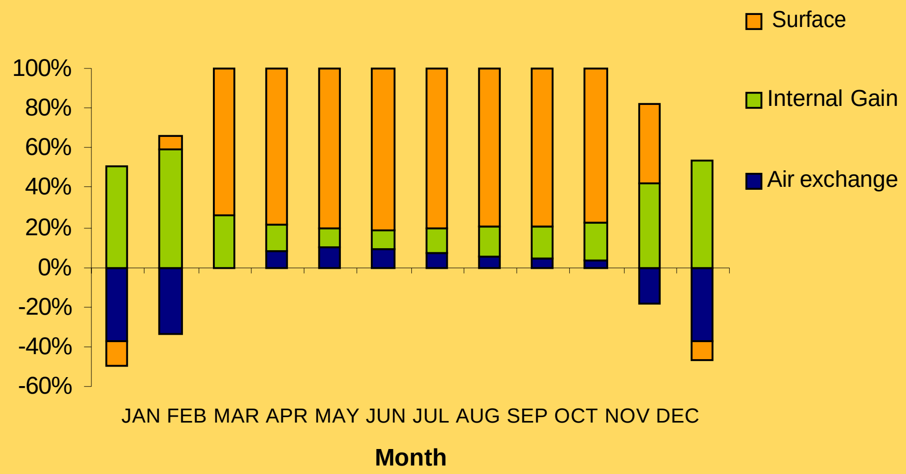


Fig. 5.42 Component-wise distribution of percentage heat gains and losses on a monthly basis of the conditioned bungalow - Jodhpur (hot and dry climate)

building (section 5.5.1.1). The highest cooling load occurs in the summer months and the lowest load in the winter months. The monthly variation of the percentage of loads through various building components is presented in Fig. 5.42. The cooling requirement is primarily due to surface gains. Hence it is essential to decrease the heat gain by choosing appropriate materials, shading, colour, reducing exposed glazing area, etc. In summer months, air exchanges add to cooling loads and hence need to be controlled. The scheduling of air change rates could reduce cooling loads. Decreasing lighting and equipment loads through energy efficient devices can reduce the internal gain.

The room-wise behaviour is presented in Table 5.8. It may be noted that the usage of the building and the configuration of spaces affect the loads. For instance, the cooling load of the living room is higher than that of other rooms. This is because of the fact that this room is partly double storeyed and has a large volume. Similarly the cooling load of the kitchen is also very high due to operation of various appliances.

The effects of building parameters on the annual loads are presented in Table 5.9. The consequent percentage load reduction due to each parameter, compared to the base case are also shown in the table. The following recommendations are made for a conditioned bungalow in Jodhpur:

(a) Design Parameters

(i) Building orientation

Changing the orientation of the building does not increase the load significantly.

(ii) Glazing type

Double glazing with reflective coated glass gives the best performance. It gives a saving of 13.5% in comparison with plain glass (base case). Single reflective coated glazing shows an improvement of 9.0%. Double low-E glass and double glazing with clear glass can also be used to reduce the loads by 10.6% and 4.1% respectively.

Table 5.8 Room-wise distribution of monthly and annual loads of the conditioned bungalow - Jodhpur (hot and dry climate)

Month	Cooling load (MJ)							
	BED1	LIVDIN	KIT	BED2	BED3	BED4	BED5	Total
JAN	0	0	264	0	0	0	0	264
FEB	8	1151	775	0	8	6	124	2071
MAR	1135	6576	2630	1519	1353	1441	1665	16318
APR	2429	12229	4118	3411	2738	3070	3164	31159
MAY	3362	16432	5308	4762	3745	4221	4244	42073
JUN	3313	15960	5156	4692	3679	4136	4136	41073
JUL	2712	12886	4392	3810	3022	3368	3377	33567
AUG	2310	11118	3951	3225	2583	2857	2887	28932
SEP	2014	10249	3592	2797	2277	2516	2658	26102
OCT	1566	9158	3269	2067	1780	1918	2239	21997
NOV	217	3277	1506	182	258	223	561	6224
DEC	0	51	488	0	1	0	3	543
Total	19066	99089	35448	26465	21443	23755	25058	250324

Month	Heating load (MJ)							
	BED1	LIVDIN	KIT	BED2	BED3	BED4	BED5	Total
JAN	2	35	0	95	1	9	0	141
FEB	0	0	0	1	0	0	0	1
MAR	0	0	0	0	0	0	0	0
APR	0	0	0	0	0	0	0	0
MAY	0	0	0	0	0	0	0	0
JUN	0	0	0	0	0	0	0	0
JUL	0	0	0	0	0	0	0	0
AUG	0	0	0	0	0	0	0	0
SEP	0	0	0	0	0	0	0	0
OCT	0	0	0	0	0	0	0	0
NOV	0	0	0	0	0	0	0	0
DEC	0	0	0	0	0	0	0	0
Total	2	35	0	96	1	9	0	142

BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5

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(iii) Shading

The reduction in solar gain by shading of windows (by means of external projections such as chajjas) can significantly reduce the heat gain and consequently the annual load. If 50% of the window areas are shaded throughout the year, the percentage load reduction is 11.7.

(iv) Wall type

Insulation of walls helps to improve the performance appreciably. Thermocol insulation can save annual loads by upto 12.0% and autoclaved cellular concrete block walls (e.g., Siporex) can save 10.1% as compared to a brick wall (base case).Plain concrete block wall increases cooling load by 9.5% and hence needs to be avoided.

Table 5.9 Annual savings due to building design and operational parameters for the conditioned bungalow - Jodhpur (hot and dry climate)

Parameter	Annual load (MJ)			Energy saving	
	Cooling	Heating	Total	(MJ)	(%)
Base case	250324	142	250466	--	--
Orientation (longer axis)					
North-south	927	250535	251462	-996	-0.4
Glazing type					
Double clear	240182	0	240182	10284	4.1
Single reflective coated	226874	1020	227894	22572	9.0
Double reflective coated	216658	12	216670	33795	13.5
Double low-E	224032	0	224032	26433	10.6
Shading					
10%	244027	283	244310	6155	2.5
20%	237835	500	238335	12131	4.8
50%	219795	1453	221247	29218	11.7
Wall type					
Thermocol (EPS) insulated brick wall	220314	3	220316	30149	12.0
Concrete block wall	272527	1828	274354	-23888	-9.5
Autoclaved cellular concrete block	225114	2	225116	25350	10.1
Roof type					
Uninsulated RCC roof	261057	551	261608	-11143	-4.4
PUF insulated RCC roof	228671	32	228703	21763	8.7
Colour of external surface					
White	237743	530	238273	12192	4.9
Cream	241921	367	242288	8178	3.3
Dark grey	263125	43	263168	-12702	-5.1
Air exchanges					
0.5 ach	245244	40	245283	5182	2.1
1.5 ach	255363	509	255872	-5406	-2.2
Internal gain					
50%	229586	587	230173	20293	8.1
No internal gain	210426	1564	211989	38476	15.4
SET POINT cooling: 26 ºC heating: 19 ºC	220150	0	220150	30316	12.1
Scheduling of air exchanges	245211	38	245250	5216	2.1

(v) **Roof type**

Insulation of the roof improves the performance of the building. Polyurethane foam insulation (PUF) brings down the cooling loads by 8.7%. In contrast, a plain uninsulated RCC slab increases the cooling load by 4.4%.

(iii)Colour of the external surface

Light colours are suitable due to their lower absorptivity. White improves performance by upto 4.9%. Similarly, cream colour also improves performance by 3.3%. Dark colours must be avoided as the performance decreases by 5.1%.

(iv)Air exchanges

A lower air change rate of 0.5 ach is desirable for reducing loads; the reduction is 2.1% as compared to the base case of 1.0 ach. Increasing the air change rate to 1.5 increases the load by 2.2%. Although lower air change rates decrease the load, they may be undesirable for reasons of health.

(vi) **Colour of the external surface**

Light colours are suitable due to their lower absorptivity. White improves performance by upto 4.9%. Similarly, cream colour also improves performance by 3.3%. Dark colours must be avoided as the performance decreases by 5.1%.

(vii) **Air exchanges**

A lower air change rate of 0.5 ach is desirable for reducing loads; the reduction is 2.1% as compared to the base case of 1.0 ach. Increasing the air change rate to 1.5 increases the load by 2.2%. Although lower air change rates decrease the load, they may be undesirable for reasons of health.

(b) **Operational Parameters**

The operational parameters such as internal gain, set point and scheduling of air changes can help in reducing the annual load of the building. The effects are summarised as follows.

(i) **Internal gain**

The lower the internal gain, the better is the performance of the building in reducing the annual load. The annual load can be reduced by 8.1% if internal gains are reduced by 50%. Therefore, more energy efficient equipment should be used.

(ii) **Set point**

Lowering the operating parameters for comfort cooling and heating can reduce the cooling loads by 12.1%. Thus a change in the expectation of comfort can lead to significant savings.

(iii) **Scheduling of air exchanges**

The scheduling of air changes to promote air entry during cooler periods (such as nights or winters) and controlling air entry during warmer periods (during daytime or summer) can reduce the annual load by 2.1 percent.

By combining all design and operational parameters discussed (excluding building orientation and internal gain), an appreciable load reduction of 60.7% can be obtained in a conditioned bungalow for Jodhpur climate.

(B) **Non-conditioned building**

Table 5.10 gives the yearly minimum, maximum and average temperatures, and the number of comfortable hours in a year for all the rooms of a non-conditioned bungalow, for the Jodhpur climate. The maximum temperatures of all rooms exceed 37.8 °C in a year, indicating acute discomfort. The average room temperatures are generally high, ranging from 29.2 °C to 30.2 °C. Thus, cooling of the building is required in summers.

The range of comfortable hours for all the rooms lies between 46 to 55% only. In other words, all rooms are uncomfortable for more than 45% of the year. Table 5.11 presents the performance of the building for each room on a monthly basis in terms of the comfort fraction (CF). It is seen that most of the rooms are comfortable in the months of February and November (having CF values of more than 0.9). December, January, March and October are also comparatively comfortable months. Most rooms are uncomfortable from April to July. June is the most uncomfortable month with values of CF ranging from -0.1 to 0.11. Thus a change in design is desirable to reduce discomfort.

The hourly values of room temperatures for a typical winter day of January and summer day of May are plotted in Figs. 5.43 and 5.44 respectively. In January, all rooms are close to the lower limit of the comfort zone, hence some heating may be required. In May, all the rooms are well above the comfort zone with temperatures exceeding

Table 5.10 Performance of the non-conditioned bungalow on an annual basis - Jodhpur (hot and dry climate)

Room	Yearly room temperature (°C)			Comfortable hours in a year(h)	Percentage of yearly comfortable hours
	MIN	MAX	AVG		
BED1	18.1	37.8	29.2	4745	54
LIVDIN	18.1	38.5	29.6	4911	56
KIT	19.2	39.6	30.2	4788	55
BED2	17.5	38.8	29.5	3997	46
BED3	18.2	38.4	29.5	4168	48
BED4	18.0	38.2	29.6	4141	47
BED5	18.5	38.3	30.1	4530	52
Ambient	11.4	40.3	26.9	4838	55

MIN = Minimum, MAX = Maximum, AVG = Average
BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5

Table 5.11 Performance of the non-conditioned bungalow on a monthly basis - Jodhpur (hot and dry climate)

Comfort index	Month	Room						
		BED1	LIVDIN	KIT	BED2	BED3	BED4	BED5
Comfort fraction	JAN	0.73	0.8	0.91	0.6	0.67	0.71	0.88
	FEB	0.95	0.96	1	0.93	0.97	0.97	0.99
	MAR	0.97	0.88	0.85	0.95	0.97	0.95	0.86
	APR	0.50	0.48	0.37	0.37	0.37	0.35	0.31
	MAY	0.14	0.12	0.01	-0.06	-0.04	-0.04	-0.04
	JUN	0.11	0.10	0	-0.10	-0.08	-0.07	-0.05
	JUL	0.46	0.46	0.34	0.29	0.32	0.32	0.33
	AUG	0.64	0.63	0.5	0.49	0.51	0.51	0.5
	SEP	0.76	0.69	0.58	0.65	0.65	0.63	0.56
	OCT	0.90	0.75	0.71	0.87	0.87	0.86	0.70
	NOV	0.99	0.99	0.99	0.98	1	1	1
	DEC	0.83	0.88	0.96	0.74	0.81	0.84	0.94

35 °C. Thus heat gain needs to be reduced in May, and heat loss promoted. Since temperatures are in excess of 35 °C, additional cooling features are required for alleviating discomfort.

Table 5.12 presents the change in the number of comfortable hours in a year due to various parameters for a bedroom (Bed2). The numbers in brackets show the percentage increase or decrease (-) of comfortable hours compared to the base case.

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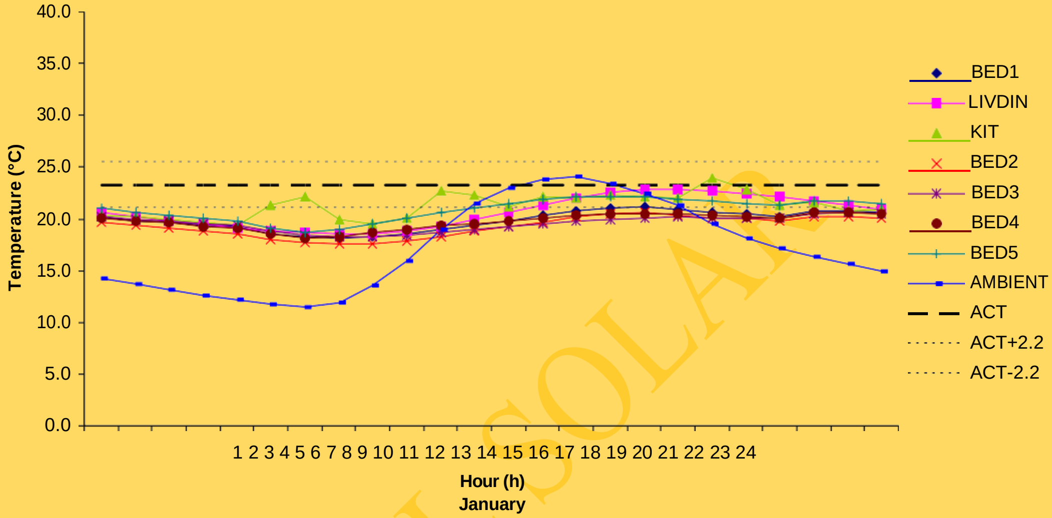
(a) Design Parameters

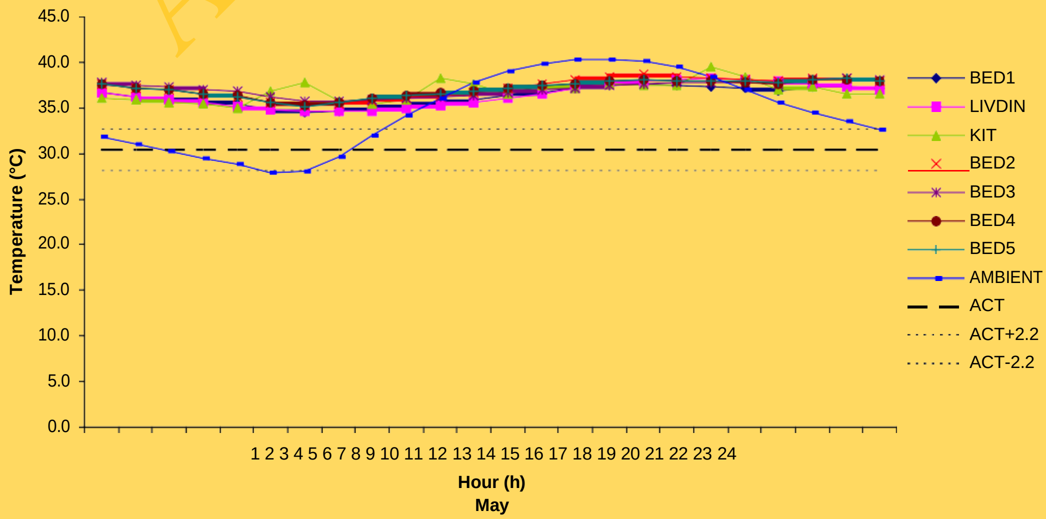
(i) Building orientation

The north-south orientation of the building vis-à-vis the base case (east-west) reduces the yearly comfortable hours by 5.9 percent.



BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5

Fig. 5.43 Hourly variation of room temperatures of the non-conditioned bungalow in January - Jodhpur (hot and dry climate)



BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5

Fig. 5.44 Hourly variation of room temperatures of non-conditioned bungalow in May - Jodhpur (hot and dry climate)

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Table 5.12 Improvement in the performance of the non-conditioned bungalow due to building design and operational parameters - Jodhpur (hot and dry climate)

Parameter	Comfortable hours in a year(h)	Percentage increase in comfortable hours
Base case	3997	-
Orientation (longer axis)		
North-south	3761	-5.9
Glazing type		
Double clear	3874	-3.1
Double low-E	3996	0.0
Single reflective coated	4181	4.6
Double reflective coated	4132	3.4
Shading		
10%	4077	2.0
20%	4133	3.4
50%	4327	8.3
Wall type		
Concrete block wall	4102	2.6
Thermocol (EPS) insulated brick wall	4014	0.4
Autoclaved cellular concrete block	4001	0.1
Roof type		
Uninsulated RCC roof	3940	-1.4
PUF insulated RCC roof	4245	6.2
Colour of external surface		
Cream	4085	2.2
Dark grey	3913	-2.1
White	4125	3.2
Air exchanges		
0.5 ach	3744	-6.3
1.5 ach	3763	-5.9
6 ach	4270	6.8
9 ach	4590	14.8
Internal gain		
No internal gain	4206	5.2
50%	4123	3.2
Scheduling of air exchanges	5072	26.9

(ii) Glazing type

A single pane reflective coated glass increases the yearly comfortable hours by 4.6% compared to plain glass (base case). This type of glazing is therefore recommended.

(iii) Shading

Reduction in solar radiation by shading windows can reduce the heat gain and consequently increase comfort. If windows are shaded by 50% throughout the year, the number of comfortable hours can be increased by 8.3%.

(iv) Wall type

A concrete block wall increases the yearly comfortable hours by 2.6% compared to the brick wall (base case). Wall insulation is not recommended.

(v) Roof type

Insulating the roof with polyurethane foam insulation (PUF) increases performance by 6.2% as compared to a roof with brick-bat-coba waterproofing. However, an uninsulated roof i.e., plain RCC roof having a higher U-value decreases the number of comfortable hours by about 1.4%.

(vi) **Colour of the external surface**

White and cream colours are desirable rather than puff shade (base case) or dark grey. The percentage increase in comfortable hours compared to the base case is 3.2 and 2.2 respectively.

(vii) **Air exchanges**

An air change rate of 9 ach is better than both 6 and 3 ach (base case); it gives an improvement of about 14.8%. Comparatively, an air change rate of 6 ach gives an improvement of 6.8%. Reducing air change rate reduces the yearly comfortable hours.

(b) **Operational Parameters**

(i) **Internal gain**

The lower the internal gain, the better is the performance. The performance increase is about 3.2% if the internal gains are reduced by 50%. Thus, energy efficient lights and equipment should be employed to reduce discomfort.

(ii) **Scheduling of air changes**

Scheduling of air changes to promote more air during cooler periods and controlling it during warmer periods (during daytime or summers) can increase the number of comfortable hours by about 26.9%.

Combining all the best parameters (excluding building orientation and internal gain) can significantly improve the building's performance, resulting in a 37.3% increase in the yearly number of comfortable hours in a non-conditioned bungalow in Jodhpur.

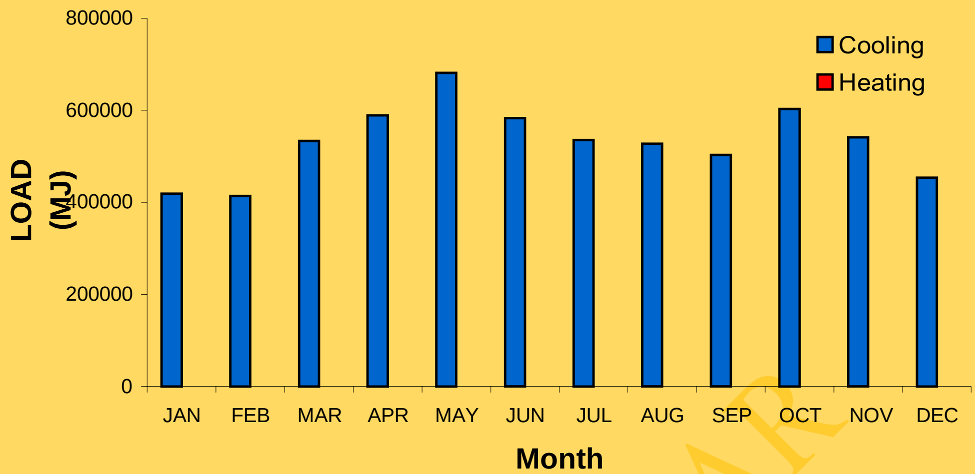
5.5.2 Warm and Humid Climate (Representative city: Mumbai)

5.5.2.1 Commercial Building

A distribution of the annual and monthly heating and cooling loads of the commercial building in Mumbai is shown in Fig. 5.45. On an annual basis, the heating load is zero and the cooling load is predominant. The monthly load profiles generally follow the climatic conditions; the highest cooling load occurs in May (summer), the lowest in January (winter), and relatively lower cooling loads occur during the monsoons (June to September). Figure 5.46 shows the monthly variation of the percentage of loads through various building components. The heat gain through surfaces dominates from February to December (i.e. eleven months). However in January, the convective heat gain due to people and equipment is higher.

In the months from April to June, air exchanges cause significant heat gain, while they reduce cooling loads from December to February. Hence, a scheduling of air changes (more in winter and less in summer) could lead to a reduction in cooling loads.

It is essential to reduce surface gains in all months to bring down the cooling loads. This could be achieved by reducing glazing areas and by shading of surfaces exposed to direct solar radiation.



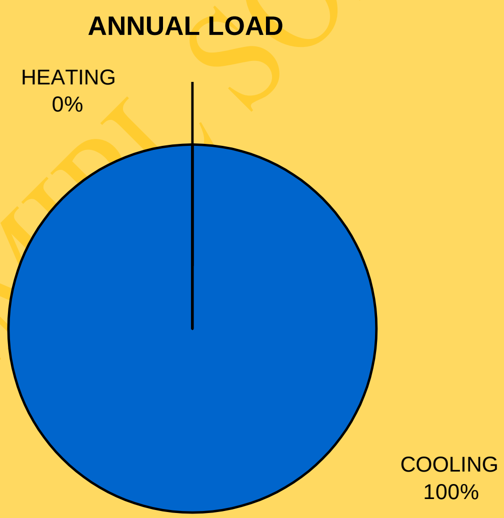


Fig. 5.45 Monthly and annual heating and cooling loads of the commercial building -Mumbai (warm and humid climate)

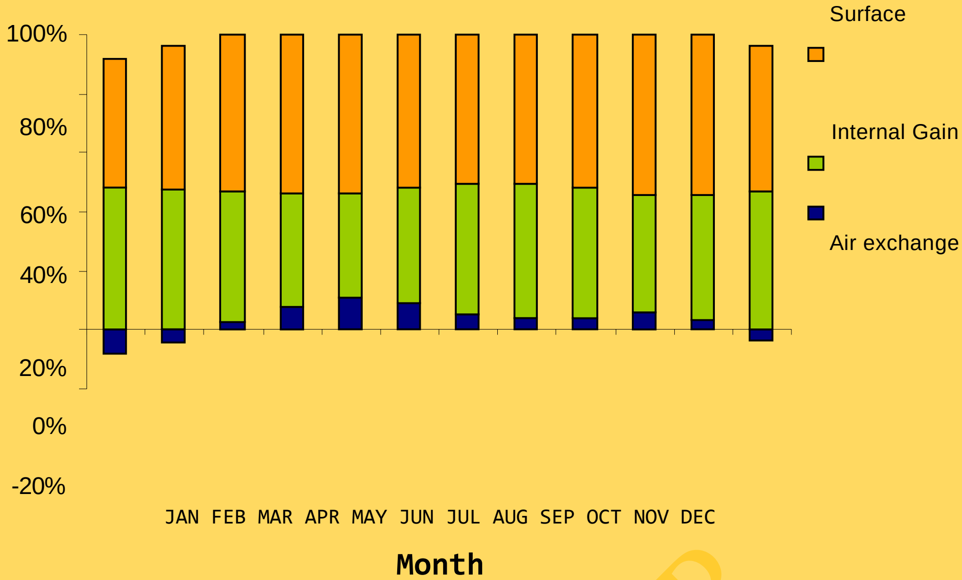


Fig. 5.46 Component-wise distribution of percentage heat gains and losses on a monthly basis of the commercial building - Mumbai (warm and humid climate)

The floor-wise monthly and annual loads are presented in Table 5.13. It is seen that the usage pattern of the building has a significant impact on the loads. For instance, the energy required for cooling is maximum on the ground floor. This is because of the frequent opening of the shutters on the ground floor resulting in a high heat gain due to air exchanges. Besides, there is a significant internal gain due to operation of equipment and a high occupancy level.

Similarly, the cooling loads of the second and third floors are significantly higher than those of other floors, as they are occupied on a 24-hour basis throughout the week. The heat gain due to air exchanges may be reduced by preventing the leakage of hot ambient air into the building by sealing all cracks and providing air-lock lobbies on the ground floor.

Table 5.14 presents the effects of building parameters on the annual loads of the building. The consequent percentage load reduction for each parameter compared to the base case are also tabulated. It may be noted that the total annual load of the building is quite high. Even a one percent reduction in this load would result in a significant energy saving. The following guidelines are recommended for a commercial building in a warm and humid place like Mumbai:

(a) Design Parameters

(i) Building orientation

Appropriate orientation of the building can reduce the annual load significantly. The building (Fig.5.1) with its glazed curtain wall facing northwest shows a substantial reduction in load compared to the base case (southwest orientation); the percentage reduction being 7.7. The west and north orientations are also better than the base case.

(ii) Glazing type

Double glazing with reflective coated glass gives the best performance. It reduces the load by 2.2% compared to single pane reflective coated glass (base case). Single pane clear glass, double pane clear glass and double low-E glass increase the annual load by 9.3, 6.9 and 0.9% respectively, and hence are not recommended.

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Table 5.13-Floorwise distribution of monthly and annual loads of the commercial building
- Mumbai (warm and humid climate)

Month	Cooling load (MJ)								
	GR	F1	F2	F3	F4	F5	F6	F7	Total
JAN	63878	43936	73654	74247	48404	39123	51070	24833	419144
FEB	70627	40956	72662	73512	45207	37590	48882	24797	414232
MAR	103451	48620	92718	94162	54319	46871	60836	32231	533207
APR	125044	50069	101305	103159	56709	50748	65563	35974	588571
MAY	147294	57340	115473	117634	65336	59358	76643	42895	681973
JUN	129676	48239	101056	102988	54892	48833	63268	34207	583158
JUL	114413	46072	93601	95163	52262	45253	58999	30421	536185
AUG	107454	47059	91791	93103	53085	45294	59327	30162	527274
SEP	107236	42681	89342	90985	48199	41685	54246	28213	502587
OCT	118927	53848	103541	105250	60870	53958	69072	37730	603195
NOV	102219	49975	93345	94776	55988	48677	62227	33656	540863
DEC	80902	43263	80849	82028	47986	40190	51772	26514	453505
Total	1271121	572056	1109337	1127008	643258	557579	721904	381631	6383894

Month	Heating load (MJ)								
	GR	F1	F2	F3	F4	F5	F6	F7	Total
JAN	0	0	0	0	0	0	0	0	0
FEB	0	0	0	0	0	0	0	0	0
MAR	0	0	0	0	0	0	0	0	0
APR	0	0	0	0	0	0	0	0	0
MAY	0	0	0	0	0	0	0	0	0
JUN	0	0	0	0	0	0	0	0	0
JUL	0	0	0	0	0	0	0	0	0
AUG	0	0	0	0	0	0	0	0	0
SEP	0	0	0	0	0	0	0	0	0
OCT	0	0	0	0	0	0	0	0	0
NOV	0	0	0	0	0	0	0	0	0
DEC	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0	0

GR=Ground Floor, F1=First floor, F2=Second floor, F3=Third Floor, F4=Fourth floor, F5=Fifth floor,
F6=Sixth Floor, F7=Seventh floor

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(i) Window size

The reduction of the glazing size to a 1.2 m height, compared to a fully glazed curtain wall, decreases the annual load by 6.5%. This is due to the reduction in solar gain, and thus the use of larger expanses of glass in such buildings can lead to higher annual loads.

(ii) Shading

The reduction in solar gain by shading of windows (by means of external projections such as chajjas) causes a decrease in the heat gain and hence reduces annual loads. If 50% of the window areas are shaded throughout the year, the percentage load reduction is 8.5.

(iii) Wall type

A wall having low U-value (insulating type such as autoclaved cellular concrete block) reduces the load compared to the concrete block wall (base case) by 2.4%.

Table 5.14 Annual savings due to building design and operational parameters for the commercial building- Mumbai (warm and humid climate)

Parameter	Annual load (MJ)			Energy saving	
	Cooling	Heating	Total	(MJ)	(%)
Base case	6383894	0	6383894	- -	--
Orientation (longer axis)					
North-south	6002430	0	6002430	381464	6.0
Northeast-southwest	5892333	0	5892333	491561	7.7
East-west	6252495	0	6252495	131400	2.1
Glazing type					
Single clear	6979643	0	6979643	-595749	-9.3
Double clear	6826246	0	6826246	-442352	-6.9
Double low-E	6441024	0	6441024	-57130	-0.9
Double reflective coated	6244698	0	6244698	139196	2.2
GLAZING SIZE(restricted to 1.2m height)	5970620	0	5970620	413274	6.5
Shading					
10%	6274825	0	6274825	109069	1.7
20%	6165743	0	6165743	218151	3.4
50%	5838423	0	5838423	545471	8.5
Wall type					
Autoclaved cellular concrete block	6233224	0	6233224	150670	2.4
Dark grey	6642237	0	6642237	-258342	-4.0
AIR CHANGE RATE					
0.5	6276724	0	6276724	107170	1.7
2	6605700	0	6605700	-221806	-3.5
4	7072726	0	7072726	-688832	-10.8
Internal gain					
10%	3091302	0	3091302	3292592	51.6
50%	4527790	0	4527790	1856104	29.1
No internal gain	2738870	0	2738870	3645024	57.1
Set point - cooling: 25 ℃ - heating: 20 ℃	5929078	0	5929078	454816	7.1
Scheduling of air exchanges	6293870	0	6293870	90024	1.4

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(iv) Colour of the external surface

Dark colours on the walls of such a commercial building should be avoided. For example, if dark grey is used, the percentage increase in load is 4.0 compared to white colour (base case).

(v) Air exchanges

A lower air change rate of 0.5 ach is better than higher rates of 1, 2 and 4 ach. The percentage reduction in the annual load is 1.7 compared to the base case of 1 ach.

(b) Operational Parameters

The operational parameters such as internal gain, set point and scheduling of air changes can help in reducing the annual load of the building. The effects are summarised as follows.

(vi)Internal gain

The performance of the building in reducing annual loads is better when the internal gains are lower.

(vii)Set Point

The annual load of the building reduces if the set points for comfort cooling and heating are relaxed. If the cooling and heating set points of 25 and 20^{0}C respectively are used (compared to 24 and 21^{0}C), the percentage reduction in annual load is 7.1. Thus, a change in the expectation of comfort can lead to significant energy savings.

(viii)Scheduling of air exchanges

The scheduling of airchanges to promote air entry during cooler periods (such as nights or winters) and controlling during warmer periods (during daytime or summer) can reduce annual load by 1.4%.

The combination of all design and operational parameters discussed so far (excluding building orientation and internal gain), results in a significant load reduction of 23.2 percent in the commercial building.

1.5.2.1 Industrial Building

Table 5.15 presents the yearly minimum, maximum and average temperatures for the industrial building. It also shows the yearly comfortable hours, both in numbers as well as in percentage, of the shed and store for the Mumbai climate. It is found that the maximum temperatures of the rooms (i.e. the shed on the ground floor and store on the first floor) can exceed 35°C.

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The yearly average room temperature of the shed is 34.4°C, which is about 7.6 °C above the yearly average ambient temperature. Thus, the emphasis should be on cooling considerations. Overheating in the shed occurs due to high internal gains because of the operation of large machines, occupants and lighting. The number of comfortable hours in a year does not exceed 8% for the shed; the store relatively more comfortable (about 57% of the year). In other words, the building is uncomfortable for more than 86% of the year.

Table 5.15 Performance of the industrial building on an annual basis- Mumbai (warm and humid climate)

Room	Yearly room temperature (°C)			Comfortable hours in a year (h)	Percentage of yearly comfortable hours
	MIN	MAX	AVG		
Shed	27.8	39.5	34.4	711	8
Store	23.5	35.7	30.1	5011	57
Ambient	18.4	32.4	26.8	6394	73

MIN = Minimum, MAX = Maximum, AVG = Average

Table 5.16 shows the monthly performance of the shed and store in terms of the comfort fraction. The shed is extremely uncomfortable from March to July, and from September to November. The store is relatively more comfortable during the same period. The hourly variation of room temperatures for a typical winter day of January and summer day of May are presented in Fig. 5.47 and 5.48 respectively. The figures show that in January, the store is within or close to the comfort zone unlike the shed. In May, both the rooms are hot and well above the comfort zone — the store touching $36^{\circ}C$ and the shed reaching $40^{\circ}C$. The main reason for such thermal behaviour of the building is the large internal gain due to equipment and occupancy. The results show that the prime consideration for design is cooling, which could be achieved by reducing heat gains and promoting heat loss.

Heat gain from the building surfaces may be reduced by appropriate orientation, shading, glazing, colour, etc. Energy efficient equipment could be used for reducing the internal heat gains. Further, higher air change rates can be encouraged to promote heat loss.

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Table 5.16 Performance of the industrial building on a monthly basis- Mumbai (warm and humid climate)

Comfort index	Month	Room	
		Shed	Store
Comfort fraction	JAN	0.18	0.95
	FEB	0.14	0.90
	MAR	-0.14	0.8
	APR	-0.50	0.62
	MAY	-0.70	0.41
	JUN	-0.50	0.61
	JUL	-0.30	0.83
	AUG	0.46	0.71
	SEP	-0.25	0.84
	OCT	-0.37	0.70
	NOV	-0.21	0.79
	DEC	0.04	0.91

Table 5.17 presents the change in the number of comfortable hours in a year due to various parameters for the industrial shed. The corresponding percentage increase or decrease (-) of comfortable hours compared to the base case is also presented in the table.

(a)Design Parameters

(i) Building orientation

There is an improvement of 3.7 and 3.4 %, if the building orientation is taken as northeast- southwest or northwest-southeast compared to north-south (base case) orientation.

(ii) Glazing type

Single pane reflective coated glass is recommended. It increases the yearly comfortable hours by 13.1% compared to the single pane clear glass (base case).

(iii) Shading

The shading of windows reduces heat gain and increases the yearly comfortable hours.

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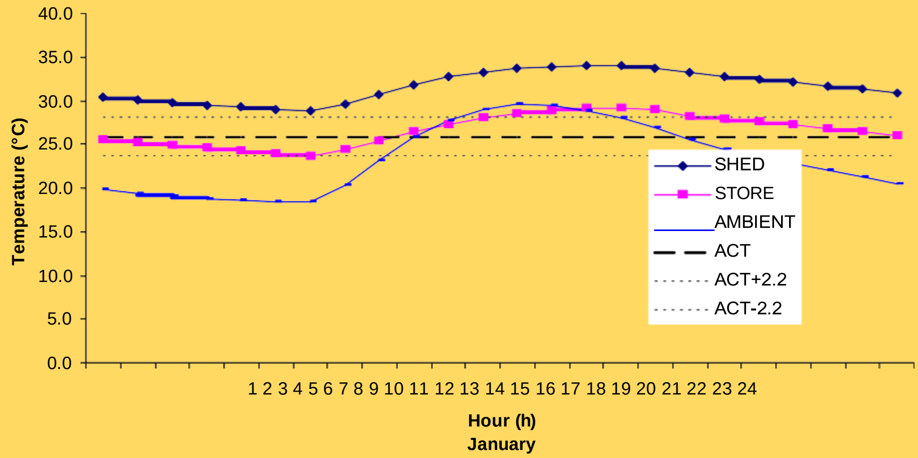

Fig. 5.47 Hourly variation of room temperatures of the industrial building in January - Mumbai (warm and humid climate)

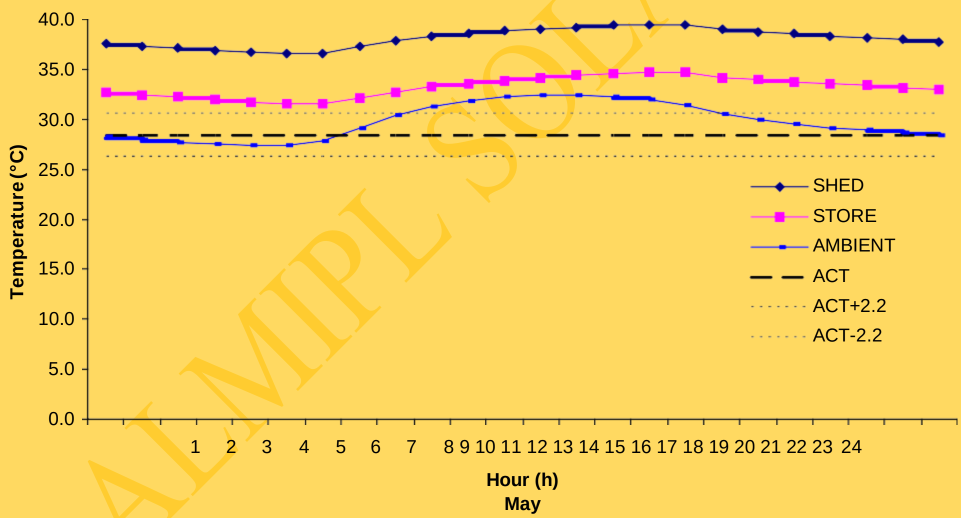

Fig. 5.48 Hourly variation of room temperatures of the industrial building in May - Mumbai (warm and humid climate)

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(i) **Wall type**

A concrete block wall is better than the brick wall (base case); the performance improves by about 32.9%.

(ii) **Roof type**

Insulation of the roof is not desirable. An RCC roof with bitumen felt water proofing layer increases the yearly comfortable hours by 34.6% compared to RCC with brick- bat-coba water proofing.

(iii) **Colour of the external surface**

White and cream colours are desirable rather than puff shade (base case) or dark grey. The increase in comfortable hours due to these colours compared to the base case are

40.9 and 25.3 respectively.

Table 5.17 Improvement in the performance of the industrial building due to building design and operational parameters- Mumbai (warm and humid climate)

Parameter	Comfortable hours in a year (h)	Percentage increase in comfortable hours
Base case	711	-
Orientation		
Northwest-southeast	735	3.4
Northeast-southwest	737	3.7
East-west	710	-0.1
Glazing type		
Single reflective	804	13.1
Double clear	516	-27.4
Double low-E	543	-23.6
Double reflective coated	586	-17.6
Shading		
10%	733	3.1
20%	754	6.0
Wall type		
Thermocol (EPS) insulated brick wall	563	-20.8
Concrete block wall	945	32.9
Autoclaved cellular concrete block	548	-22.9
Roof type		
RCC with bitumen felt water proofing	957	34.6
RCC with PUF insulation	361	-49.2
Colour of external surface		
White	1002	40.9
Cream	891	25.3
Dark grey	516	-27.4
Air exchanges		
3 ach	94	-86.8
9 ach	1548	117.7
12 ach	2353	230.9
Internal gain		
20%	6190	770.6
40%	3885	446.4

(iv) **Air exchanges**

There is a good improvement in the number of yearly comfortable hours when the air changes are higher. The number of such hours increase from 711 h to 1548 h for air change rate of 9 ach, and from 711 to 2353 h for 12 ach.

(b)Operational Parameters

(iv)Internal gain

The reduction in the internal gain substantially improves the building performance. If 20% of the base case internal gain exists, there is a nine-fold increase in the yearly comfortable hours (from 711 h to 6190 h)., whereas if it is 40%, the yearly comfortable hours increase only 3.5 times. Thus, the lower the internal gain, the better is the performance of the building.

The combination of all design and operational parameters discussed (excluding building orientation and internal gain) results in a five-fold increase in the yearly comfortable hours in the shade (from 711 h to 3624 h).

2.5.2.2 Residential Building (Bungalow)

(A) Conditioned building

Figure 5.49 shows the distribution of the annual and monthly heating and cooling loads of a conditioned bungalow for the Mumbai climate. The figure shows that the building requires cooling throughout the year. The general features are similar to those observed in the case of the commercial building (section 5.5.2.1). The highest cooling load occurs in summer months and the lowest in winter months. The monthly variation of the percentage of loads through various building components is presented in Fig. 5.50, which shows that the cooling requirement is primarily due to surface gains. Hence, decreasing the heat gain by choosing appropriate materials, shading, colour, reducing exposed glazing area, etc. is essential. Likewise, the internal gain needs to be reduced by decreasing lighting and equipment loads through energy efficient devices. The room-wise behaviour is presented in Table 5.18.

It may be noted that the usage of the building and the configuration of spaces have an impact on the loads. The cooling load of the living room is higher than that of other rooms. This is because this room is partly double storeyed and has a large volume. The cooling load of the kitchen is also very high due to operation of various appliances.

The effects of building parameters on the annual loads are presented in Table 5.19. The table also shows that the consequent percentage load reduction compared to the base case. Accordingly, the following recommendations can be made for a conditioned bungalow:

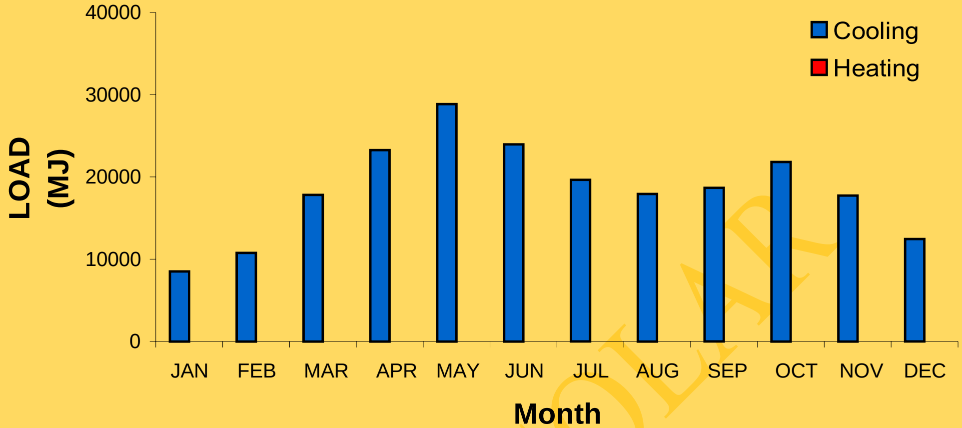
(i) **Design Parameters**

(i) **Building orientation**

Changing the building orientation with respect to the base case (east-west) does not increase the load significantly.

(ii) **Glazing type**

Double glazing with reflective coated glass gives the best performance. It gives a saving of 12.9% in comparison with plain glass (base case). Single reflective coated glazing shows an improvement of 12.3%. Double low-E glass and double glazing with clear glass can also be used to reduce the loads by 8.5% and 1.3% respectively.



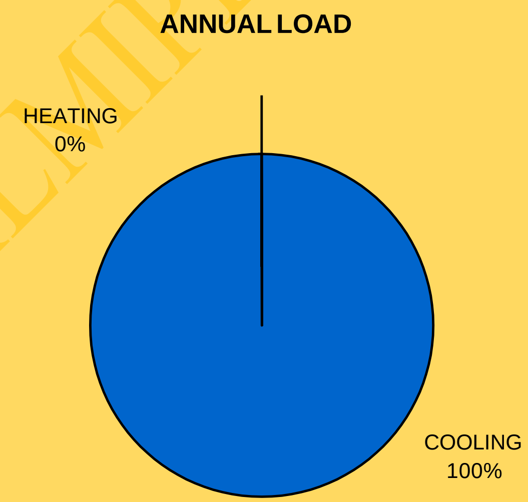


Fig. 5.49 Monthly and annual heating and cooling loads of the conditioned bungalow - Mumbai (warm and humid climate)

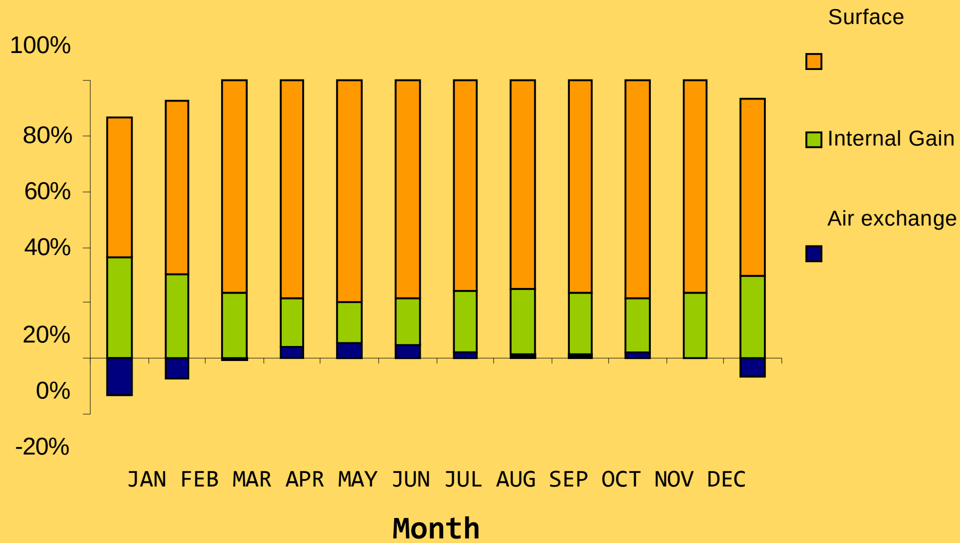


Fig. 5.50 Component-wise distribution of percentage heat gains and losses on a monthly basis of the conditioned bungalow - Mumbai (warm and humid climate)

Table 5.18-Room-wise distribution of monthly and annual loads of the conditioned bungalow - Mumbai (warm and humid climate)

Month	Cooling load (MJ)							
	BED1	LIVDIN	KIT	BED2	BED3	BED4	BED5	Total
JAN	426	3939	1824	471	568	488	822	8540
FEB	683	4566	1967	853	844	808	1063	10786
MAR	1310	7021	2777	1794	1537	1616	1773	17827
APR	1826	8918	3253	2582	2088	2273	2319	23259
MAY	2311	11030	3889	3287	2619	2863	2851	28850
JUN	1941	9026	3409	2697	2174	2372	2357	23976
JUL	1599	7236	2992	2179	1784	1936	1935	19660
AUG	1446	6592	2844	1958	1620	1748	1755	17963
SEP	1487	7046	2814	2035	1673	1793	1843	18693
OCT	1635	8747	3201	2230	1861	1983	2167	21824
NOV	1223	7461	2806	1592	1423	1481	1789	17774
DEC	754	5496	2273	888	917	880	1257	12466
Total	16641	87078	34048	22567	19107	20243	21933	221617

4th Floor 4B, Mandira Apartments,
North Boag Road, T-Nagar Chennai- 600 017
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Month	Heating load(MJ)							
	BED1	LIVD IN	KIT	BED2	BED3	BED4	BED5	Total
JAN	0	0	0	0	0	0	0	0
FEB	0	0	0	0	0	0	0	0
MAR	0	0	0	0	0	0	0	0
APR	0	0	0	0	0	0	0	0
MAY	0	0	0	0	0	0	0	0
JUN	0	0	0	0	0	0	0	0
JUL	0	0	0	0	0	0	0	0
AUG	0	0	0	0	0	0	0	0
SEP	0	0	0	0	0	0	0	0
OCT	0	0	0	0	0	0	0	0
NOV	0	0	0	0	0	0	0	0
DEC	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0

BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5

Table 5.19 Annual savings due to building design and operational parameters for the conditioned bungalow - Mumbai (warm and humid climate)

Parameter	Annual load (MJ)			Energy saving	
	Cooling	Heating	Total	(MJ)	(%)
Base case	221617	0	221617	--	--
Orientation (longer axis)					
North-south	219606	0	219606	2011	0.9
Glazing type					
Double clear	218761	0	218761	2856	1.3
Single reflective coated	194390	0	194390	27227	12.3
Double reflective coated	193129	0	193129	28488	12.9
Double low-E	202750	0	202750	18867	8.5
Shading					
10%	214403	0	214403	7214	3.3
20%	207234	0	207234	14383	6.5
50%	185830	0	185830	35787	16.1
Wall type					
Thermocol (EPS) insulated brick wall	200848	0	200848	20769	9.4
Concrete block wall	232880	0	232880	-11263	-5.1
Autoclaved cellular concrete block	205102	0	205102	16515	7.5
Roof type					
Uninsulated RCC roof	229563	0	229563	-7946	-3.6
PUF insulated RCC roof	203093	0	203093	18524	8.4
Colour of external surface					
White	207068	0	207068	14549	6.6
Cream	211869	0	211869	9748	4.4
Dark grey	236069	0	236069	-14452	-6.5
Air exchanges					
0.5 ach	220817	0	220817	800	0.4
1.5 ach	222415	0	222415	-798	-0.4
Internal gain					
50%	196190	0	196190	25427	11.5
No internal gain	171078	0	171078	50539	22.8
Set point - cooling: 26 °C - heating: 19 °C	183290	0	183290	38327	17.3
Scheduling of air exchanges	218542	0	218542	3075	1.4

(iii) Shading

Shading of windows (by means of external projections such as chajjas) can significantly reduce the solar heat gain and consequently the annual load. If 50% of the window areas are shaded throughout the year, the load reduction is 16.1%.

(iv) Wall type

Insulation of walls helps to improve the thermal performance. Thermocol insulation can save annual loads by upto 9.4% and autoclaved cellular concrete block walls (e.g., Siporex) can save 7.5% as compared to a brick wall (base case). A plain concrete block wall increases the cooling load by 5.1% and hence should be avoided.

(iv) Roof type

Insulation of the roof improves the performance of the building. Polyurethane foam insulation (PUF) brings down the cooling loads by 8.4%, whereas, a plain uninsulated RCC slab increases the cooling load by 3.6%.

(v) Colour of the external surface

Light colours are suitable due to their lower absorptivities.

White improves performance by upto 6.6%. Similarly, cream colour also improves performance by 4.4%. Dark colours should be avoided as the performance decreases by 6.5%.

(vi) Air exchanges

A lower air change rate of 0.5 ach is desirable for reducing loads; the resultant reduction is 0.4% as compared to the base case of 1.0 ach. Increasing the air change rate to 1.5 increases the load by 0.4%. Thus, there is no significant effect on loads; the rate can be decided on the basis of creating a healthier indoor environment.

(b) Operational Parameters

The operational parameters such as internal gain, set point and scheduling of air changes can help in reducing the annual load of the building. The effects are summarised as follows.

(i) Internal gain

The lower the internal gain, the better is the performance of the building in reducing the annual load. The annual load is reduced by 11.5%, if internal gains are reduced by 50%. Therefore, more energy efficient equipment should be used.

(ii) Set point

Lowering the operating parameters for comfort cooling and heating can reduce the cooling loads by 17.3%. Thus, a change in the expectation of comfort can lead to significant savings.

(iii) Scheduling of air exchanges

The scheduling of air changes to promote air entry during cooler periods (such as nights or winters) and controlling it during warmer periods (during daytime or summer) can lead to a 1.4% reduction of annual load.

The combination of all design and operational parameters discussed so far (excluding building orientation and internal gain), results in a significant load reduction. The percentage load reduction is 58.6.

(A) Non-conditioned building

Table 5.20 gives the yearly minimum, maximum and average temperatures, and the number of comfortable hours in a year for all the rooms in a non-conditioned bungalow for the Mumbai climate. It is seen that the maximum temperatures of all rooms exceed 33.5 °C.

The average room temperatures are generally high, ranging from 29.2 °C to 30.0 °C. The performance of the building on a monthly basis is presented in terms of the comfort fraction (CF) in Table 5.21. The table shows that the rooms are mostly comfortable in the winter months of November to March, and in the monsoon months of July to September (i.e. CF values of more than 0.9). Generally, the house is comfortable throughout the year except in summer i.e. April and May. May is the most uncomfortable month with values of CF ranging from 0.44 to 0.62. The hourly values of room temperatures for a typical winter day of January and summer day of May are plotted in Figs. 5.51 and 5.52 respectively. The figures show that in January, all rooms are mostly comfortable, whereas in May, all the rooms are well above the comfort zone by about 2 to 3 °C. The room temperatures exceed 30 °C, indicating discomfort. Thus heat gain needs to be reduced and heat loss must be promoted by higher air change rates.

Table 5.20 Performance of the non-conditioned bungalow on an annual basis -- Mumbai (warm and humid climate)

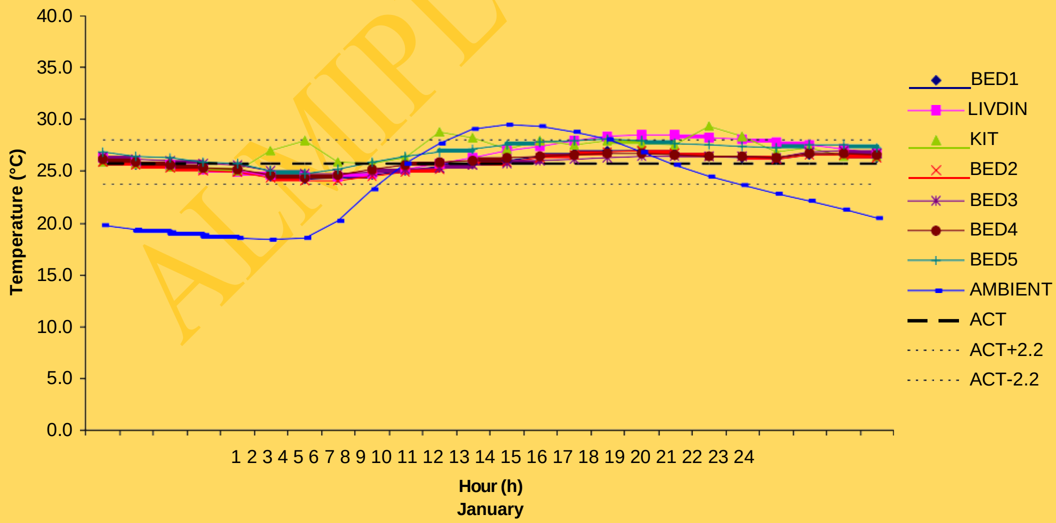
Room	Yearly room temperature(°C)			Comfortable hours in a year(h)	Percentage of yearly comfortable hours
	MIN	MAX	AVG		
BED1	24.1	33.5	29.2	6756	77
LIVDIN	24.1	33.7	29.4	6472	74
KIT	24.9	34.8	30.0	5473	62
BED2	24.0	34.4	29.5	6263	71
BED3	24.7	34	29.5	6297	72
BED4	24.2	33.9	29.6	6264	72
BED5	24.6	33.8	29.9	5891	67
Ambient	18.4	32.4	26.8	6394	73

MIN = Minimum, MAX = Maximum, AVG = Average
BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5

Table 5.21 Performance of the non-conditioned bungalow on a monthly basis -- Mumbai (warm and humid climate)

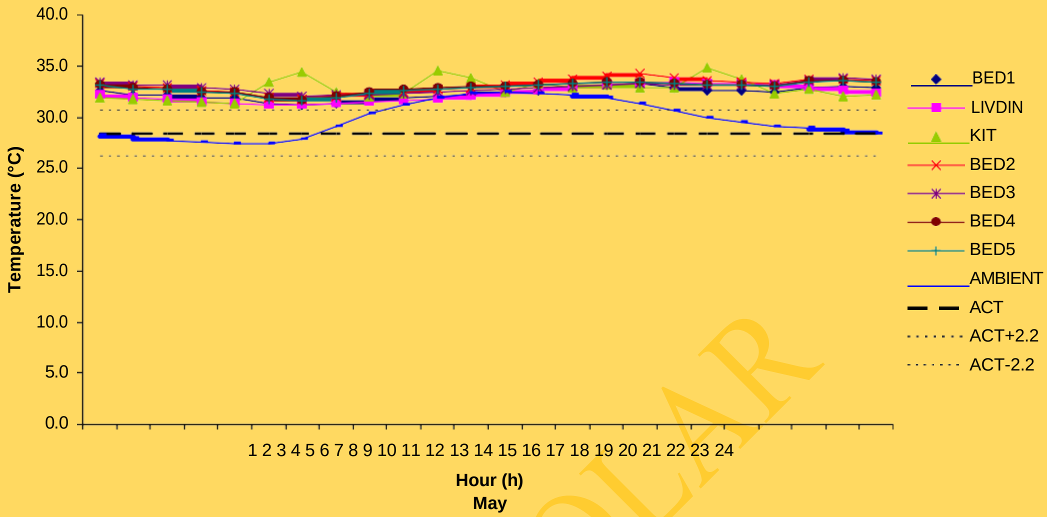
Comfort index	Month	Room						
		BED1	LIVDIN	KIT	BED2	BED3	BED4	BED5
Comfort fraction	JAN	1	0.98	0.97	1	1	1	1
	FEB	1	0.95	0.93	1	1	1	0.97
	MAR	0.96	0.89	0.84	0.92	0.94	0.93	0.86
	APR	0.78	0.77	0.69	0.65	0.67	0.66	0.65
	MAY	0.61	0.62	0.51	0.44	0.47	0.47	0.49
	JUN	0.77	0.80	0.65	0.64	0.66	0.66	0.68
	JUL	0.96	0.96	0.84	0.89	0.91	0.90	0.90
	AUG	0.99	0.98	0.87	0.94	0.95	0.94	0.94
	SEP	0.96	0.94	0.85	0.89	0.92	0.91	0.89
	OCT	0.89	0.81	0.74	0.82	0.83	0.83	0.74
	NOV	0.98	0.85	0.82	0.97	0.97	0.97	0.83
	DEC	1	0.94	0.93	1	1	1	0.96

BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5



BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5

Fig. 5.51 Hourly variation of room temperatures of the non-conditioned bungalow in January - Mumbai (warm and humid climate)



BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5

Fig. 5.52 Hourly variation of room temperatures of the non-conditioned bungalow in May - Mumbai (warm and humid climate)

Table 5.22 presents the change in the number of comfortable hours in a year due to various parameters for a bedroom (Bed2). The numbers in brackets show the percentage increase or decrease (-) in comfortable hours compared to the base case.

(a) **Design Parameters**

(i) **Building orientation**

Changing the orientation of the building with respect to the base case does not affect its thermal performance.

(ii) **Glazing type**

A single pane reflective coated glass increases the yearly comfortable hours by 10.3% compared to plain glass (base case). This type of glazing is, therefore, recommended.

(iii) **Shading**

Reduction in solar radiation by shading windows can reduce the heat gain and consequently increase the comfort. An increase of 12.6% in the number of comfortable hours can be achieved, if windows are shaded by 50% throughout the year.

(iv) **Wall type**

A concrete block wall increases the yearly comfortable hours by 2.8% compared to the brick wall (base case). However, wall insulation is not recommended.

(v) Roof type

Insulating the roof using polyurethane foam insulation (PUF) increases performance by 2.2% as compared to a roof with brick-bat-coba waterproofing. However, an uninsulated roof i.e. plain RCC roof having a higher U-value decreases the number of comfortable hours by about 16.8%.

Table 5.22 Improvement in the performance of non-conditioned bungalow due to building design and operational parameters - Mumbai (warm and humid climate)

Parameter	Comfortable hours in a year (h)	Percentage increase in comfortable hours
Base case	6263	-
Orientation (longer axis)		
North-south	6210	-0.8
Glazing type		
Double clear	5698	-9.0
Double low-E	6172	-1.5
Single reflective coated	6906	10.3
Double reflective coated	6472	3.3
Shading		
10%	6442	2.9
20%	6599	5.4
50%	7054	12.6
Wall type		
Concrete block wall	6438	2.8
Thermocol (EPS) insulated brick wall	5433	-13.3
Autoclaved cellular concrete block	5506	-12.1
Roof type		
Uninsulated RCC roof	5208	-16.8
PUF insulated RCC roof	6401	2.2
Colour of external surface		
Cream	6448	3.0
Dark grey	5800	-7.4
White	6565	4.8
Air exchanges		
0.5 ach	4148	-33.8
1.5 ach	5337	-14.8
6 ach	6849	9.4
9 ach	7010	11.9
Internal gain		
No internal gain	6849	9.4
50%	6585	5.1
Scheduling of air exchanges	7215	15.2

(vi) **Colour of the external surface**

White and cream colours are desirable compared to puff shade (base case) or dark grey. The percentage increase in comfortable hours compared to the base case are 4.8 and 3.0 respectively.

(vii) **Air exchanges**

An air change rate of 9 ach is better than 3 ach (base case), giving an improvement of about 11.9%. An air change rate of 6 ach gives an improvement of 9.4%. The reduction of air change rate below 3 ach is not desirable.

(b) **Operational Parameters**

(i) **Internal gain**

The lower the internal gain, the better is the performance. The performance increase is about 5.1% if the internal gains are reduced by 50%. Thus, energy efficient lights and equipment should be employed to reduce internal gains and subsequently improve comfort.

(ii) **Scheduling of air changes**

Air change rates of 3 ach during cooler periods and 9 ach during warmer and humid periods lead to an increase in the number of comfortable hours by about 15.0%.

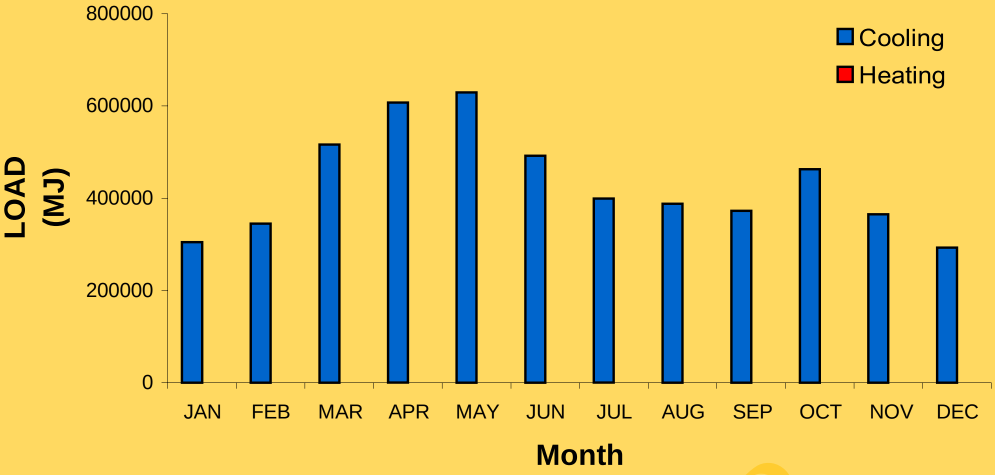
Combining all the best parameters (excluding building orientation and internal gain) can significantly improve the buildings performance, resulting in a 28.6% increase in the yearly number of comfortable hours.

5.5.3 Moderate Climate (Representative city: Pune)

1.5.3.1 Commercial Building

A distribution of the annual and monthly heating and cooling loads of the commercial building is shown in Fig. 5.53 for the Pune climate. On an annual basis, the heating load is zero and the cooling load is predominant. The monthly load profiles generally follow the climatic conditions; the highest cooling load occurs in May (summer) and the lowest cooling load occurs in December (winter). Relatively lower cooling loads occur during the monsoons (June to September). Figure 5.54 shows the distribution of percentage of loads through various building components on a monthly basis. Convective heat gain dominates from July to February (i.e. eight months). This indicates that the cooling requirements are primarily due to internal gains, which need to be dissipated.

In contrast, in the summer months from March to June, the surface gains are more. Air exchanges help to reduce heat gains in the 8 months from July to February. In the summer months, infiltration adds to the cooling loads. Hence, a scheduling of air changes to promote ventilation from July to February and the control of infiltration in summer could reduce cooling loads. Additionally, it is essential to reduce surface gains in all months to aid the cooling process. This could be achieved by reducing glazing areas and shading of surfaces exposed to direct solar radiation. The floor-wise monthly and annual loads are presented in Table 5.23. It is seen that the usage pattern of the building has a significant impact on the loads. For instance, the maximum energy required for cooling is on the ground floor. This is because the shutters are frequently opened here, resulting in a high heat gain due to air exchanges. Additionally, there is a significant internal gain due to operation of equipment and a high occupancy level. Similarly, the cooling loads of the second and third floor are much higher than those of other floors as they are occupied on a 24-hour basis throughout the week. The gain due to air exchanges may be reduced by preventing the leakage of hot ambient air into entering the building by sealing all cracks and providing air lock lobbies on the ground floor.



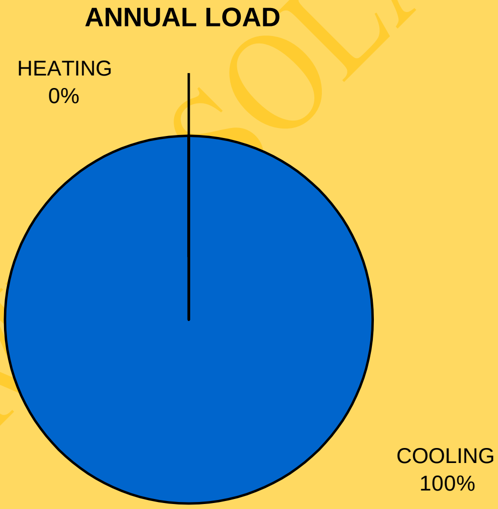


Fig. 5.53 Monthly and annual heating and cooling loads of the commercial building -Pune (moderate climate)

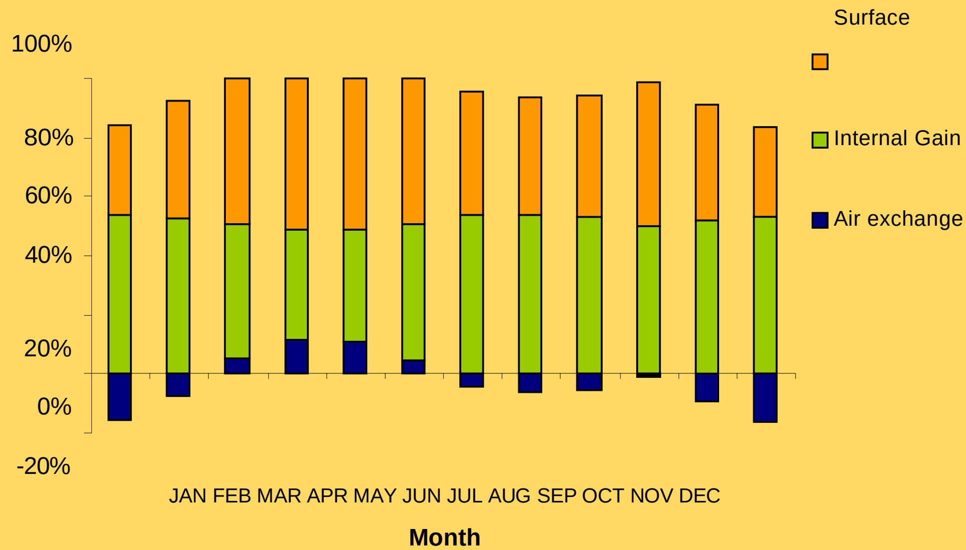


Fig. 5.54 Component-wise distribution of percentage heat gains and losses on a monthly basis of the commercial building - Pune (moderate climate)

Table 5.23 Floor wise distribution of monthly and annual loads of the commercial building - Pune (moderate climate)

Month	Cooling load (MJ)								
	GR	F1	F2	F3	F4	F5	F6	F7	Total
JAN	39660	34426	53481	54629	39196	28498	38914	16031	304835
FEB	55746	35206	59772	60748	40034	31524	42040	19727	344797
MAR	99113	47121	88910	90530	53517	45796	59855	31536	516380
APR	130446	50901	103158	105360	58529	52711	68140	37946	607192
MAY	130746	54214	105858	107962	62307	55661	72614	39955	629316
JUN	98045	43254	86047	87731	49552	42485	56319	29027	492459
JUL	69526	38064	71601	72664	43340	34786	47184	21601	398767
AUG	62226	38774	69732	70557	43896	34530	47202	21083	388000
SEP	65412	35331	67738	68870	39982	32069	43452	20185	373038
OCT	77635	44941	80920	82089	50921	42359	56020	28044	462929
NOV	52855	38249	64760	65522	43316	33979	45314	20961	364956
DEC	39849	32095	52742	53722	36402	26735	36331	15074	292949
Total	921259	492576	904719	920382	560992	461134	613386	301171	5175618

Month	Heating load (MJ)								
	GR	F1	F2	F3	F4	F5	F6	F7	Total
JAN	0	0	0	0	0	0	0	0	0
FEB	0	0	0	0	0	0	0	0	0
MAR	0	0	0	0	0	0	0	0	0
APR	0	0	0	0	0	0	0	0	0
MAY	0	0	0	0	0	0	0	0	0
JUN	0	0	0	0	0	0	0	0	0
JUL	0	0	0	0	0	0	0	0	0
AUG	0	0	0	0	0	0	0	0	0
SEP	0	0	0	0	0	0	0	0	0
OCT	0	0	0	0	0	0	0	0	0
NOV	0	0	0	0	0	0	0	0	0
DEC	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0	0

GR=Ground Floor, F1=First floor, F2=Second floor, F3=Third Floor, F4=Fourth floor, F5=Fifth floor, F6=Sixth Floor, F7=Seventh floor

The effects of building parameters on the annual loads of the commercial building are presented in Table 5.24 for Pune. The consequent percentage load reduction for each parameter compared to the base case are also tabulated. It may be noted that the total annual load of the building is quite high. Even a one percent reduction in this load would result in significant energy savings. The following guidelines are recommended for a commercial building located in Pune, which has a moderate climate.

(a)Design Parameters

(i)Building orientation

Appropriate orientation of the building can reduce the annual load significantly. The building (Fig.5.1) with its glazed curtain wall facing northwest shows a substantial reduction in load compared to the southwest orientation (base case) the percentage reduction being 9.2. The west and north orientations are also better than the base case.

(ii)Glazing type

Single pane reflective coated glass (base case) is recommended for the moderate climate. All other glazing types increase the annual load of the building.

(iii)Window size

The reduction of the glazing size to a 1.2 m height, compared to a fully glazed curtain wall, decreases the annual load by 6.3%. This is due to the reduction in solar gain, and thus the use of larger expanses of glass in such a building is not desirable as it leads to higher annual loads.

(a)Shading

Shading of windows (by means of external projections such as chajjas) reduces solar gains and subsequently the heat gain, and hence the annual load is also reduced. If 50% of the window areas are shaded throughout the year, loads can be reduced by 10.6%.

(b)Wall type

A wall having a low U-value (insulating type such as autoclaved cellular concrete block) increases the load compared to the concrete block wall (base case) by 2.2%. Thus insulation of walls is not recommended.

(c)Colour of the external surface

Dark colours on the walls of such a commercial building should be avoided. For example, using dark grey increases the cooling load by 5% compared to white (base case).

(d)Air exchanges

A lower air change rate of 0.5 ach is more effective than 1, 2 and 4 ach. The percentage reduction in the annual load is 1.0 compared to the base case of 1 ach.

(b) Operational Parameters

The operational parameters such as internal gain, set point and scheduling of air changes can help in reducing the annual load of the building. The effects are summarised as follows.

(i) Internal gain

The lower the internal gain, the better is the performance of the building in reducing annual loads.

Table 5.24 Annual savings due to building design and operational parameters for the commercial building- Pune (moderate climate)

Parameter	Annual load (MJ)			Energy saving	
	Cooling	Heating	Total	(MJ)	(%)
Base case	5175618	0	5175618	--	--
Orientation (longer axis)					
North-south	4794997	0	4794997	380621	7.4
Northeast-southwest	4701236	0	4701236	474382	9.2
East-west	5032393	0	5032393	143225	2.8
Glazing type					
Single clear	5774996	0	5774996	-599378	-11.6
Double clear	5773435	0	5773435	-597817	-11.6
Double low-E	5413338	0	5413338	-237720	-4.6
Double reflective coated	5198221	0	5198221	-22603	-0.4
Glazing size (restricted to 1.2m height)	4847464	0	4847464	328154	6.3
Shading					
10%	5065938	0	5065938	109680	2.1
20%	4956314	0	4956314	219304	4.2
50%	4628063	0	4628063	547555	10.6
Wall type					
Autoclaved cellular concrete block	5291517	0	5291517	-115899	-2.2
Colour of external surface					
Dark grey	5434774	0	5434774	-259156	-5.0
Air exchange rate					
0.5	5123889	0	5123889	51729	1.0
2	5298637	0	5298637	-123019	-2.4
4	5604347	720	5605068	-429450	-8.3
Internal gain					
10%	2084676	0	2084676	3090941	59.7
50%	3389009	0	3389009	1786609	34.5
No internal gain	1788504	106	1788611	3387007	65.4
Set point - cooling: 25 ºC - heating: 20 ºC	4725865	0	4725865	449753	8.7
Scheduling of air exchanges	5004165	124	5004289	171329	3.4

(ii) Set Point

The annual load of the building reduces if the set points for comfort cooling and heating are relaxed. If cooling and heating set points of 25 and 20^{0}C respectively are used (instead of 24 and 21^{0}C), the percentage reduction in annual load is 8.7. Thus, a change in the expectation of comfort can lead to significant savings.

(iii) Scheduling of air exchanges

The scheduling of air changes to promote air entry during cooler periods (such as nights or winters) and controlling the same during warmer periods (during daytime or summer) can reduce the annual load significantly the percentage load reduction being 3.4.

The combination of all design and operational parameters discussed (excluding building orientation and internal gain), results in a significant load reduction 24.7%.

2.5.3.2 Industrial Building

Table 5.25 gives the yearly minimum, maximum and average temperatures, and the number of comfortable hours in a year for the shed and store for the Pune climate. The average temperature of the store room is about 3.2 °C higher than the ambient, while that of the shed is about 7.5 °C. The yearly maximum temperatures of both rooms exceed 35 °C, indicating acute discomfort. The comfortable hours in a year for the shed is about 25% indicating acute discomfort. The store is more comfortable i.e. for 72% of the year. The monthly comfort fractions (Table 5.26) show that the shed is acutely uncomfortable in the months from March to June and October (negative values indicate discomfort). It is most uncomfortable in the month of May (CF=-0.58). August is the most comfortable month (CF=0.76). The store is generally much more comfortable than the shed with CF values ranging from 0.51 in April to 0.98 in July. The hourly values of room temperatures for a typical winter day of January and summer day of May are plotted in Figs. 5.55 and 5.56 respectively. It is seen that in January, the store is within or close to the comfort zone. The shed temperature is mostly above the comfort zone except in the morning.

Hence, it is desirable to have higher air change rates during periods (10 h to 24 h) when the shed temperature is higher than the comfort zone. In May, both the rooms are above the comfort zone. So, a higher change rate throughout the day would be desirable.

Table 5.25 Performance of the industrial building on an annual basis- Pune (moderate climate)

Room	Yearly room temperature (°C)			Comfortable hours in a year(h)	Percentage of yearly comfortable hours
	MIN	MAX	AVG		
Shed	24.6	40.8	32.5	2155	25
Store	20.1	35.5	28.2	6326	72
Ambient	13.4	37.3	25.0	5000	57

MIN = Minimum, MAX = Maximum, AVG = Average

Table 5.26 Performance of the industrial building on a monthly basis- Pune (moderate climate)

Comfort index	Month	Room	
		Shed	Store
Comfort fraction	JAN	0.44	0.90
	FEB	0.30	0.88
	MAR	-0.09	0.75
	APR	-0.57	0.51
	MAY	-0.58	0.52
	JUN	-0.29	0.77
	JUL	0.03	0.98
	AUG	0.76	0.93
	SEP	0.07	0.96
	OCT	-0.05	0.88
	NOV	0.24	0.95
	DEC	0.45	0.93

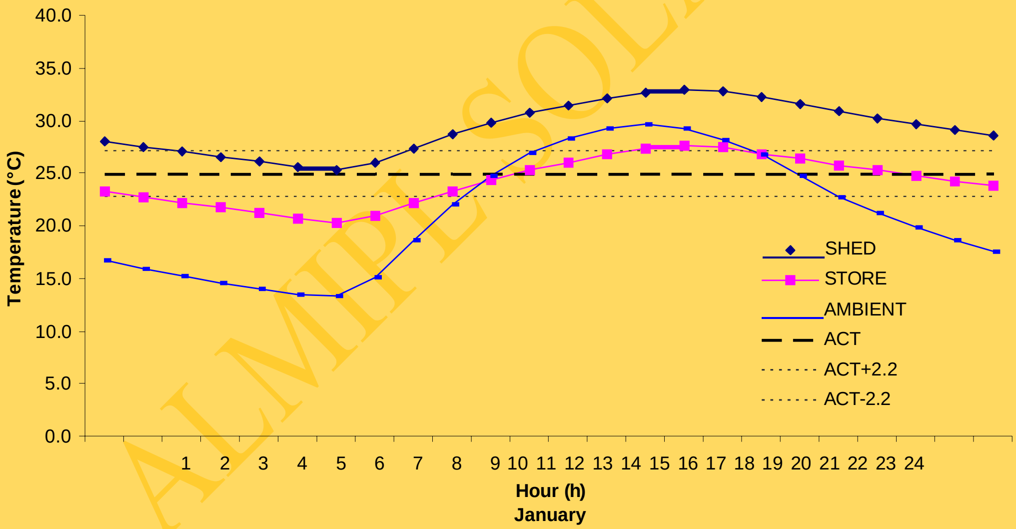


Fig. 5.55 Hourly variation of room temperatures of the industrial building in January - Pune (moderate climate)

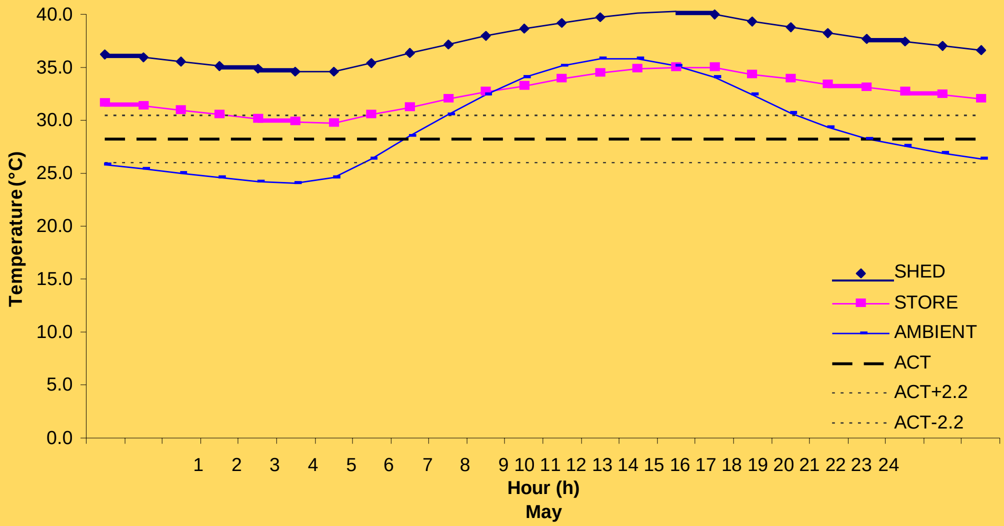


Fig. 5.56 Hourly variation of room temperatures of the industrial building in May - Pune (moderate climate)

Table 5.27 presents the number of comfortable hours in a year due to various parameters for the shed. The corresponding percentage increase or decrease (-) in comfortable hours compared to the base case is also presented in the table.

(a) Design Parameters

(i) Building orientation

There is a marginal improvement in performance if the building orientation is taken as northeast-southwest or northwest-southeast compared to the north-south (base case) orientation.

(ii) **Glazing type**

Single pane reflective coated glass is recommended, it increases the yearly comfortable hours by 11.6% compared to the single pane clear glass (base case).

(iii) **Shading**

The shading of windows reduces heat gain and increases the yearly comfortable hours.

(iv) **Wall type**

A concrete block wall is better than the brick wall (base case); the performance improves by about 18.9%. Insulation on walls is not recommended.

(v) **Roof type**

An RCC roof with a bitumen felt water proofing layer increases the yearly comfortable hours by 19.9% compared to one with brick-bat-coba water proofing. Insulation of the roof is not desirable.

(vi) **Colour of the external surface**

White and cream colours are desirable compared to puff shade (base case) or dark grey. The percentage increase in comfortable hours due to these colours as compared to the base case is 23.6 and 15.6 respectively.

Table 5.27 Improvement in the performance of the industrial building due to building design and operational parameters- Pune (moderate climate)

Parameter	Comfortable hours in a year (h)	Percentage increase in comfortable hours
Base case	2155	--
Orientation		
Northwest-southeast	2202	2.2
Northeast-southwest	2199	2.0
East-west	2188	1.5
Glazing type		
Single reflective	2405	11.6
Double clear	1930	-10.4
Double low-E	1970	-8.6
Double reflective coated	2058	-4.5
Shading		
10%	2204	2.3
20%	2293	6.4
Wall type		
Thermocol (EPS) insulated brick wall	1933	-10.3
Concrete block wall	2563	18.9
Autoclaved cellular concrete block	1928	-10.5
Roof type		
RCC with bitumen felt water proofing	2583	19.9
RCC with PUF insulation	1695	-21.3
Colour of external surface		
White	2664	23.6
Cream	2492	15.6
Dark grey	1876	-12.9
Air exchanges		
3 ach	617	-71.4
9 ach	4015	86.3
12 ach	4953	129.8
Internal gain		
20%	6658	209.0
40%	6137	184.8
Scheduling of air exchanges	5089	136.1

(b) Air exchanges

Higher air change rates will considerably improve the number of yearly comfortable hours. Compared to the base case air change rate of 3 per hour (that yields 2155 comfortable hours in a year), promoting air change rates of 9 and 12 per hour will yield 4015 and 4953 hours respectively.

(c) Operational Parameters

(i) Internal gain

The building performance improves substantially when internal gains are reduced.

(ii) Scheduling of air exchanges

Promoting higher air change rates when the ambient air temperature is within the comfortable range as compared to the indoor temperature improves the performance of the building significantly. It shows approximately a two and half-fold increase over the base case of 2155 h. However, when the ambient temperatures not within the comfortable range, then the air exchange needs to be restricted.

The combination of all design and operational parameters discussed (excluding building orientation and internal gain), results in a significant improvement in the yearly comfortable hours of the shed the increase is about three-fold, from 2155 h to 6115 h in a year.

3.5.3.3 Residential Building (Bungalow)

(A) **Conditioned building**

Figure 5.57 shows the distribution of the annual and monthly heating and cooling loads of the conditioned residential building for the Pune climate. Clearly, the building requires cooling throughout the year. The general features are similar to those observed in the case of the commercial building (section 5.5.3.1). The highest cooling load occurs in the summer months and the lowest in the winter months. The monthly variation of the percentage of loads through various building components is presented in Fig. 5.58, which shows that the cooling requirement is primarily due to surface gains.

Hence it is essential to decrease heat gain by choosing appropriate materials, shading, colour, reducing exposed glazing area, etc. The internal gain needs to be reduced by decreasing lighting and equipment loads through energy efficient devices.

Table 5.28 presents the room-wise behaviour. It may be noted that the usage of the building and the configuration of spaces appreciably affect the loads. For instance, the cooling load of the living room is higher than that of other rooms. This is because of the fact that this room is partly double storeyed and has a large volume. Similarly, the cooling load of the kitchen is also very high due to the operation of various appliances.

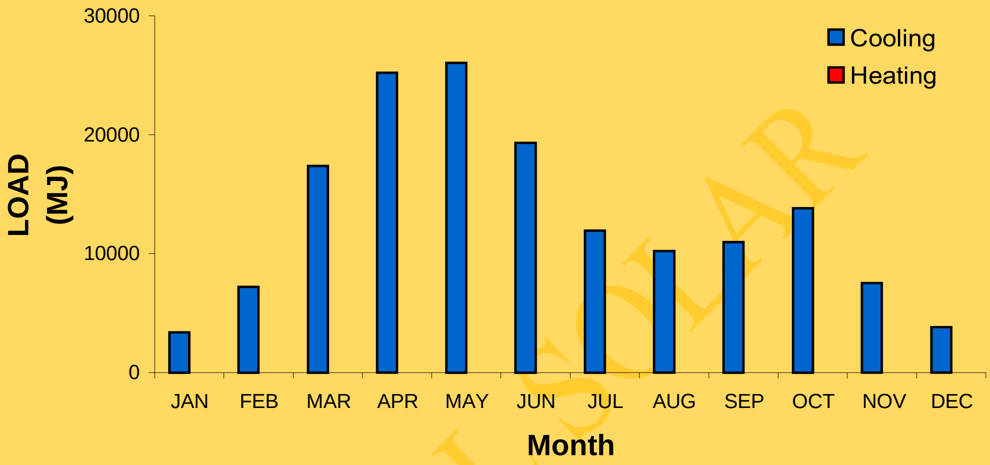
Table 5.29 presents the effects of building parameters on the annual loads. The percentages of the consequent load reduction due to these parameters compared to the base case are also shown in the table. The following recommendations are made based on the results, for a conditioned bungalow in the Pune climatic conditions:

4th Floor 4B, Mandira Apartments,
North Boag Road, T-Nagar Chennai- 600 017
Email: Solarbazaarpl@gmail.com
Web: www.almipl.com
Mobile: 94452 30332 /9383132332

(a) **Design Parameters**

(i) **Building orientation**

Changing the orientation of the building with respect to the base case (east-west) does not increase the load significantly.



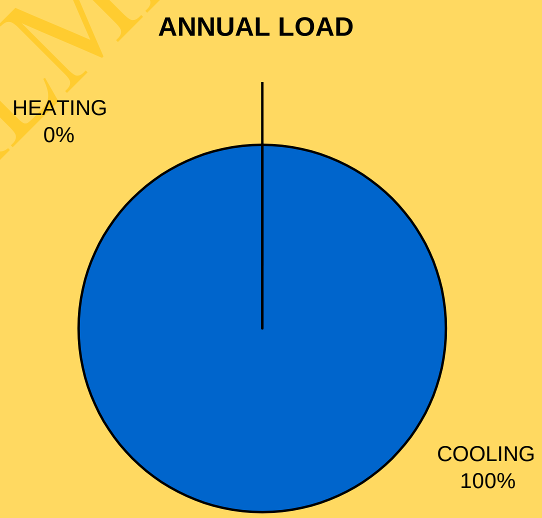


Fig. 5.57 Monthly and annual heating and cooling loads of the conditioned bungalow- Pune (moderate climate)

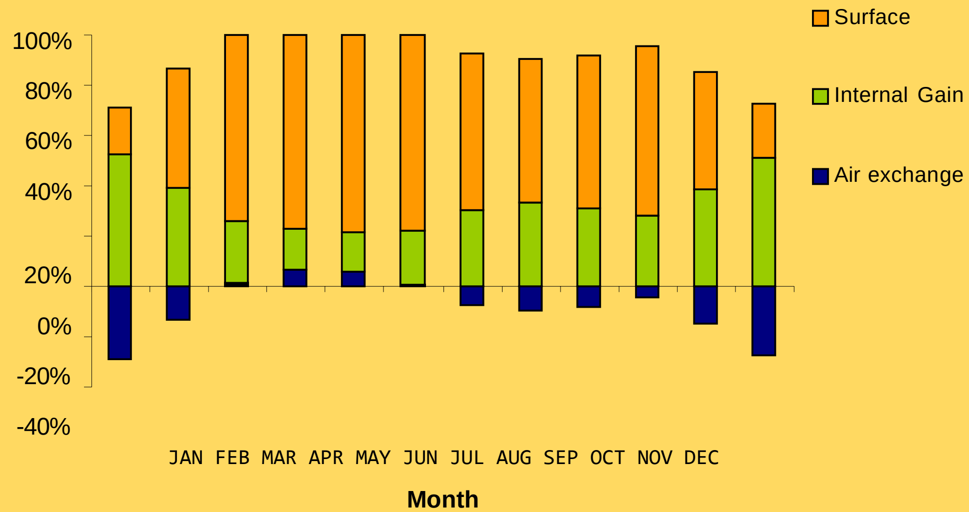


Fig. 5.58 Component-wise distribution of percentage heat gains and losses on a monthly basis of the conditioned bungalow - Pune (moderate climate)

Table 5.28 Room-wise distribution of monthly and annual loads of the conditioned Bungalow - Pune (moderate climate)

Month	Cooling load (MJ)							
	BED1	LIVDIN	KIT	BED2	BED3	BED4	BED5	Total
JAN	29	1998	1023	9	44	28	226	3357
FEB	319	3503	1485	387	427	414	663	7198
MAR	1241	6839	2722	1701	1491	1604	1772	17371
APR	1956	9654	3485	2772	2261	2525	2568	25221
MAY	2046	9846	3637	2917	2377	2625	2606	26054
JUN	1530	7155	2921	2132	1777	1907	1884	19306
JUL	951	4132	2179	1264	1117	1152	1147	11941
AUG	793	3465	2018	1045	955	969	974	10219
SEP	819	3913	2035	1102	1001	1032	1082	10984
OCT	948	5453	2387	1264	1166	1213	1406	13837
NOV	350	3497	1648	393	478	429	720	7514
DEC	58	2168	1130	23	83	54	277	3793
Total	11038	61623	26670	15009	13179	13952	15327	156798

Month	Heating load (MJ)							
	BED1	LIVDIN	KIT	BED2	BED3	BED4	BED5	Total
JAN	0	0	0	0	0	0	0	0
FEB	0	0	0	0	0	0	0	0
MAR	0	0	0	0	0	0	0	0
APR	0	0	0	0	0	0	0	0
MAY	0	0	0	0	0	0	0	0
JUN	0	0	0	0	0	0	0	0
JUL	0	0	0	0	0	0	0	0
AUG	0	0	0	0	0	0	0	0
SEP	0	0	0	0	0	0	0	0
OCT	0	0	0	0	0	0	0	0
NOV	0	0	0	0	0	0	0	0
DEC	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0

BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5

Table 5.29 Annual savings due to building design and operational parameters for the conditioned bungalow - Pune (moderate climate)

Parameter	Annual load (MJ)			Energy saving	
	Cooling	Heating	Total	(MJ)	(%)
Base case	156798	0	156798	--	--
Orientation (longer axis)					
North-south	156279	0	156279	519	0.3
Glazing type					
Double clear	161446	0	161446	-4648	-3.0
Single reflective coated	131052	0	131052	25745	16.4
Double reflective coated	136708	0	136708	20089	12.8
Double low-E	147103	0	147103	9695	6.2
Shading					
10%	149955	0	149955	6843	4.4
20%	143111	0	143111	13687	8.7
50%	123066	0	123066	33731	21.5
Wall type					
Thermocol (EPS) insulated brick wall	150178	0	150178	6619	4.2
Concrete block wall	161525	0	161525	-4727	-3.0
Autoclaved cellular concrete block	153101	0	153101	3697	2.4
Roof type					
Uninsulated RCC roof	163082	0	163082	-6285	-4.0
PUF insulated RCC roof	144658	0	144658	12140	7.7
Colour of external surface					
White	142979	0	142979	13819	8.8
Cream	147583	0	147583	9215	5.9
Dark grey	170869	0	170869	-14071	-9.0
Air exchanges					
0.5 ach	158718	0	158718	-1920	-1.2
1.5 ach	155209	0	155209	1588	1.0
Internal gain					
50%	133253	0	133253	23544	15.0
No internal gain	111028	0	111028	45770	29.2
Set point - cooling: 26 °C - heating: 19 °C	122370	0	122370	34428	22.0
Scheduling of air exchanges	150669	0	150669	6128	3.9

(ii) **Glazing type**

Single pane reflective coated glass gives the best performance; it gives a saving of 16.4% in comparison with plain glass (base case). Double pane reflective coated glazing and double low-E glass show an improvement of 12.8 and 6.2% respectively.

(iii) **Shading**

The reduction in solar gain by shading of windows (by means of external projections such as chajjas) can significantly reduce the heat gain and consequently the annual load. If 50% of the window areas are shaded throughout the year, the load can be reduced by 21.5%.

(iv) **Wall type**

Insulation of walls helps to improve the thermal performance of the building. Thermocol insulation can save annual loads by upto 4.2%, and autoclaved cellular concrete block walls (e.g., Siporex) can save 2.4% as compared to the base case (brick wall). A plain concrete block wall increases the cooling load by 3.0% and hence should be avoided.

(v) Roof type

Insulation of the roof improves the performance of the building. Polyurethane foam (PUF) insulation brings down the cooling load by 7.7%. In contrast, a plain uninsulated RCC slab increases the cooling load by 4.0%.

(vi) Colour of the external surface

Light colours are suitable due to their lower absorptivities. White improves the performance by upto 8.8%. Similarly, cream colour also improves the performance by 5.9%. Dark colours should be avoided as the performance decreases by 9.0%.

(vii) Air exchanges

A higher air change rate of 1.5 ach (compared to base case of 0.5 ach) is desirable in this climate as the ambient conditions are quite comfortable. Bringing the ambient air into the building is recommended.

(b) Operational Parameters

The operational parameters such as internal gain, set point and scheduling of air changes can help in reducing the annual load of the building. The effects are summarised as follows.

(i) Internal gain

Lowering the internal gain, improves the performance of the building in reducing the annual load. The annual load reduces by 15.0% if internal gains are reduced by 50%. Therefore, more energy efficient equipment should be used.

(ii) Set point

Lowering the operating parameters for comfort cooling and heating can reduce the cooling loads by 22.0%. Thus, a change in the expectation of comfort can bring about good savings.

(iii) Scheduling of air exchanges

The scheduling of air changes to promote air entry during cooler periods (such as nights or winters) and controlling the same during warmer periods (during daytime or summer) can reduce of annual load by 3.9%.

The combination of all design and operational parameters discussed (excluding building orientation and internal gain), results an appreciable reduction of 68.4%.

(B) Non-conditioned building

Table 5.30 gives the yearly minimum, maximum and average temperatures, and the number of comfortable hours in a year for all the rooms of a non-conditioned bungalow for the Pune climate. It is seen that the maximum temperatures of all rooms exceed 33.0 °C in a year, indicating acute discomfort. The average temperatures are quite comfortable ranging from 27.4 °C to 28.3 °C. Thus, cooling may be required only in summers. Table 5.31 presents the performance of the building on a monthly basis in terms of the comfort fraction (CF). It is seen that the rooms are comfortable in the winter months of November to February, and in the monsoon months of July to October (indicated by CF values of more than 0.9). Generally, the house is comfortable throughout the year except in summer from April and May. April is the most uncomfortable month with values of CF ranging from 0.57 to 0.72. The hourly variation of room temperatures for a typical winter day of January and summer day of May are plotted in Figs. 5.59 and 5.60 respectively. It is seen that in January, all the rooms are comfortable throughout the day.

In May, all the rooms are above the comfort zone by about 2 to 3 °C. Hence, it is desirable to have lower air change rates during periods (11 h to 17 h) when the ambient temperature is higher than the comfort zone, and higher air change rates during remaining hours.

Table 5.32 presents the change in the number of comfortable hours in a year due to various parameters for a bedroom (Bed2). The numbers in brackets show the percentage increase or decrease (-) in comfortable hours compared to the base case.

(a) **Design Parameters**

(a) **Building orientation**

Changing the orientation of the building does not affect its thermal performance. The base case is in fact marginally better.

(b) **Glazing type**

A single pane reflective coated glass increases the yearly comfortable hours by 4.8% compared to the plain glass base case. This type of glazing is therefore recommended.

(iii) Shading

Reducing solar radiation by shading windows can reduce the heat gain and consequently increase the comfort. If windows are shaded by 50% throughout the year, the number of comfortable hours can be increased by 4.7%.

(c) **Wall type**

A brick wall (base case) is better than other wall types.

(d) **Roof type**

Insulating the roof with polyurethane foam (PUF) insulation increases performance by 3.1% as compared to a roof with brick-bat-coba waterproofing. However, an uninsulated roof i.e. plain RCC roof decreases the number of comfortable hours.

(vi)Colour of the external surface

White and cream colours are desirable as compared to puff shade (base case) or dark grey. The percentage increases in comfortable hours due to these colours compared to the base case are 2.6 and 2.4 respectively.

Table 5.30 Performance of the non-conditioned bungalow on an annual basis - Pune (moderate climate)

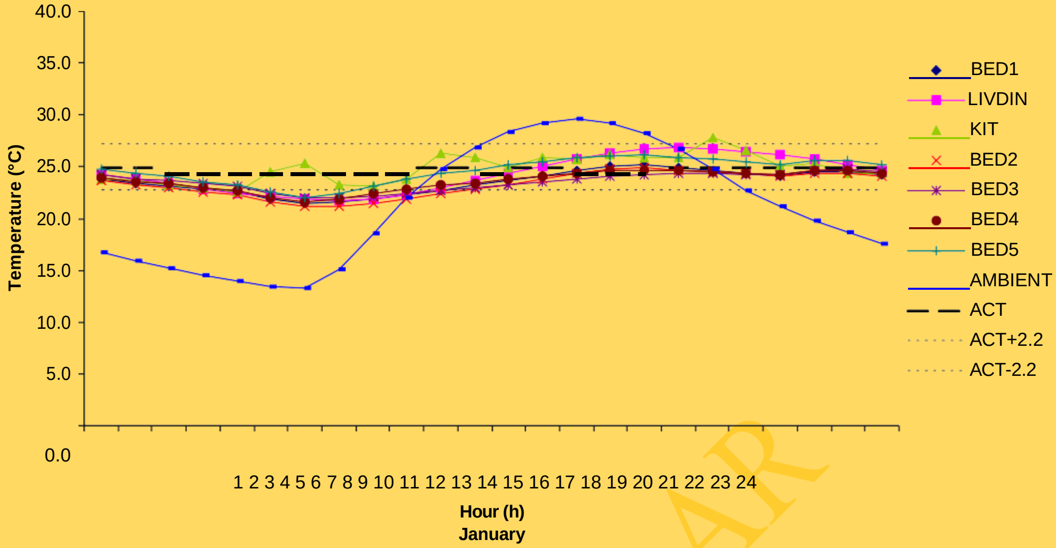
Room	Yearly room temperature(°C)			Comfortable hours in a year(h)	Percentage of yearly comfortable hours
	MIN	MAX	AVG		
BED1	21.4	33.2	27.4	7159	82
LIVDIN	21.3	33.9	27.6	7072	81
KIT	22.4	34.9	28.3	6853	78
BED2	21.1	34.0	27.6	6612	75
BED3	21.9	33.3	27.7	6887	79
BED4	21.5	33.6	27.8	6836	78
BED5	21.9	33.7	28.2	6741	77
Ambient	13.4	37.3	25.0	5000	57

MIN = Minimum, MAX = Maximum, AVG = Average
BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5

Table 5.31 Performance of the non-conditioned bungalow on a monthly basis - Pune (moderate climate)

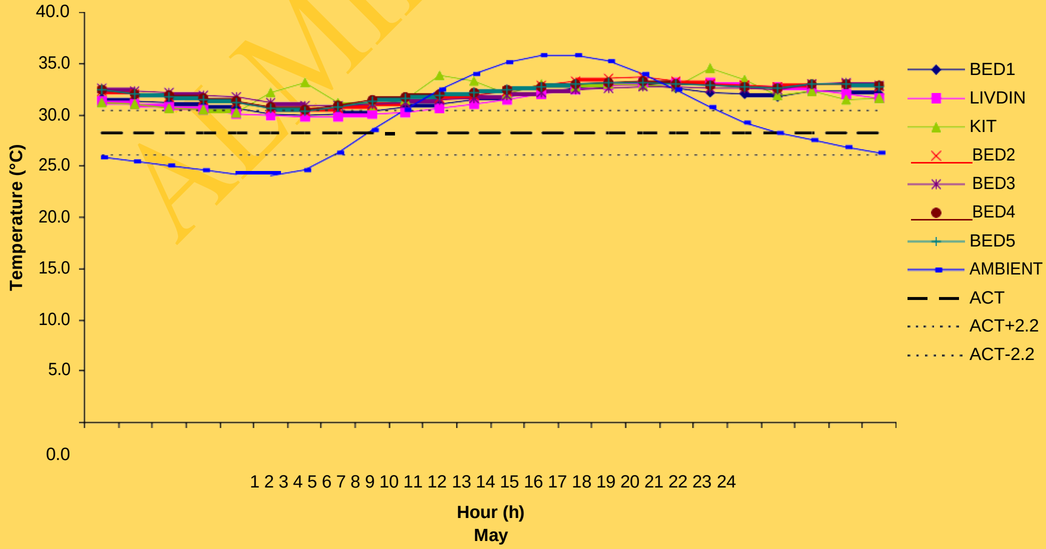
Comfort index	Month	Room						
		BED1	LIVDIN	KIT	BED2	BED3	BED4	BED5
Comfort fraction	JAN	0.96	0.97	0.99	0.94	0.98	0.97	0.99
	FEB	0.99	0.97	0.97	0.99	1	1	1
	MAR	0.94	0.86	0.83	0.91	0.94	0.91	0.84
	APR	0.72	0.69	0.60	0.61	0.62	0.58	0.57
	MAY	0.73	0.74	0.61	0.60	0.62	0.58	0.60
	JUN	0.90	0.90	0.79	0.81	0.84	0.82	0.83
	JUL	1	1	0.95	1	1	1	1
	AUG	1	1	0.97	1	1	1	1
	SEP	1	1	0.96	1	1	1	1
	OCT	1	0.95	0.91	0.99	1	0.99	0.94
	NOV	1	0.99	0.98	1	1	1	1
	DEC	0.98	0.99	0.99	0.96	0.99	0.99	1

BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5



BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5

Fig. 5.59 Hourly variation of room temperatures of the non-conditioned bungalow in January - Pune (moderate climate)



BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5

Fig. 5.60 Hourly variation of room temperatures of the non-conditioned bungalow in May - Pune (moderate climate)

Table 5.32 Improvement in the performance of the non-conditioned bungalow due to building design and operational parameters - Pune (moderate climate)

Parameter	Comfortable hours in a year (h)	Percentage increase in comfortable hours
Base case	6612	-
Orientation (longer axis)		
North-south	6547	-1.0
Glazing type		
Double clear	6493	-1.8
Double low-E	6686	1.1
Single reflective coated	6932	4.8
Double reflective coated	6863	3.8
Shading		
10%	6719	1.6
20%	6829	3.3
50%	6921	4.7
Wall type		
Concrete block wall	6516	-1.5
Thermocol (EPS) insulated brick wall	6447	-2.5
Autoclaved cellular concrete block	6418	-2.9
Roof type		
Uninsulated RCC roof	6504	-1.6
PUF insulated RCC roof	6815	3.1
Colour of external surface		
Cream	6771	2.4
Dark grey	6416	-3.0
White	6787	2.6
Air exchanges		
0.5 ach	6392	-3.3
1.5 ach	6429	-2.8
6 ach	6712	1.5
9 ach	6732	1.8
Internal gain		
No internal gain	6812	3.0
50%	6724	1.7
Scheduling of air exchanges	7426	12.3

(vii) Air exchanges

The effects of higher air change rates are marginal. For an air change rate of 9 per hour, the number of yearly comfortable hours increases by 1.8 over the base case of 3 ach; for 6 ach, the corresponding increase over the base case is 1.5%.

(b) Operational Parameters

(a) Internal gain

Reducing internal gains increases the performance. The performance increase is about 1.7% if the internal gains are reduced by 50%. Thus, energy efficient lights and equipment should be considered to reduce discomfort.

(ii) Scheduling of air changes

Scheduling of air changes to promote more air during cooler periods (nights or winters) and controlling it during warmer periods (during daytime or summers) can increase the number of comfortable hours by about 2.3%.

Combining all the best parameters (excluding building orientation and internal gain) can significantly improve the buildings performance and increase the yearly number of comfortable hours by 11.6% in Pune's climate.

5.5.4 Composite Climate (Representative city: New)

1.5.4.1 Commercial Building

A distribution of the annual and monthly heating and cooling loads of the commercial building in New Delhi is shown in Fig. 5.61. On an annual basis, the heating load is negligible and the cooling load is predominant. The monthly load profiles generally follow the climatic conditions, the highest cooling load occurring in June (summer) and the lowest in January (winter). In fact, some heating is also required in December and January. The months from April to October display relatively higher cooling loads. Lesser cooling is required in the winter months of November to March. The table shows that the cooling loads of May and June are almost equal to the sum of the cooling loads of the five cooler months. Figure 5.62 shows the distribution of percentage of loads through various building components on a monthly basis. The convective heat gain dominates from November to March (five months), whereas from April to October, the surface gains are more. Air exchanges help to reduce heat gains from November to March, while it adds to the cooling loads during the other months. Hence, a scheduling of air changes to promote ventilation from November to March and control of infiltration in summer could lead to a reduction in cooling loads.

It is also essential to reduce surface gains in all months except December and January, to reduce the cooling loads. This can be achieved by reducing glazing areas and shading of surfaces exposed to direct solar radiation.

The floor-wise monthly and annual loads of the commercial building are presented in Table

5.33. It is seen that the usage pattern of the building has a significant impact on the loads. For instance, the energy required for cooling is maximum on the ground floor. This is because of the high heat gain due to air exchanges caused by the frequent opening of the shutters on ground floor. Besides, there is a significant internal gain due to operation of equipment and a high occupancy level. Similarly, the cooling loads of the second and third floors are significantly higher than those of other floors as the former are occupied on a 24-hour basis throughout the week. The heat gain due to air exchanges may be reduced by preventing the leakage of hot ambient air into the building by sealing all cracks and providing air lock lobbies on the ground floor.

of other floors as the former are occupied on a 24-hour basis throughout the week. The heat gain due to air exchanges

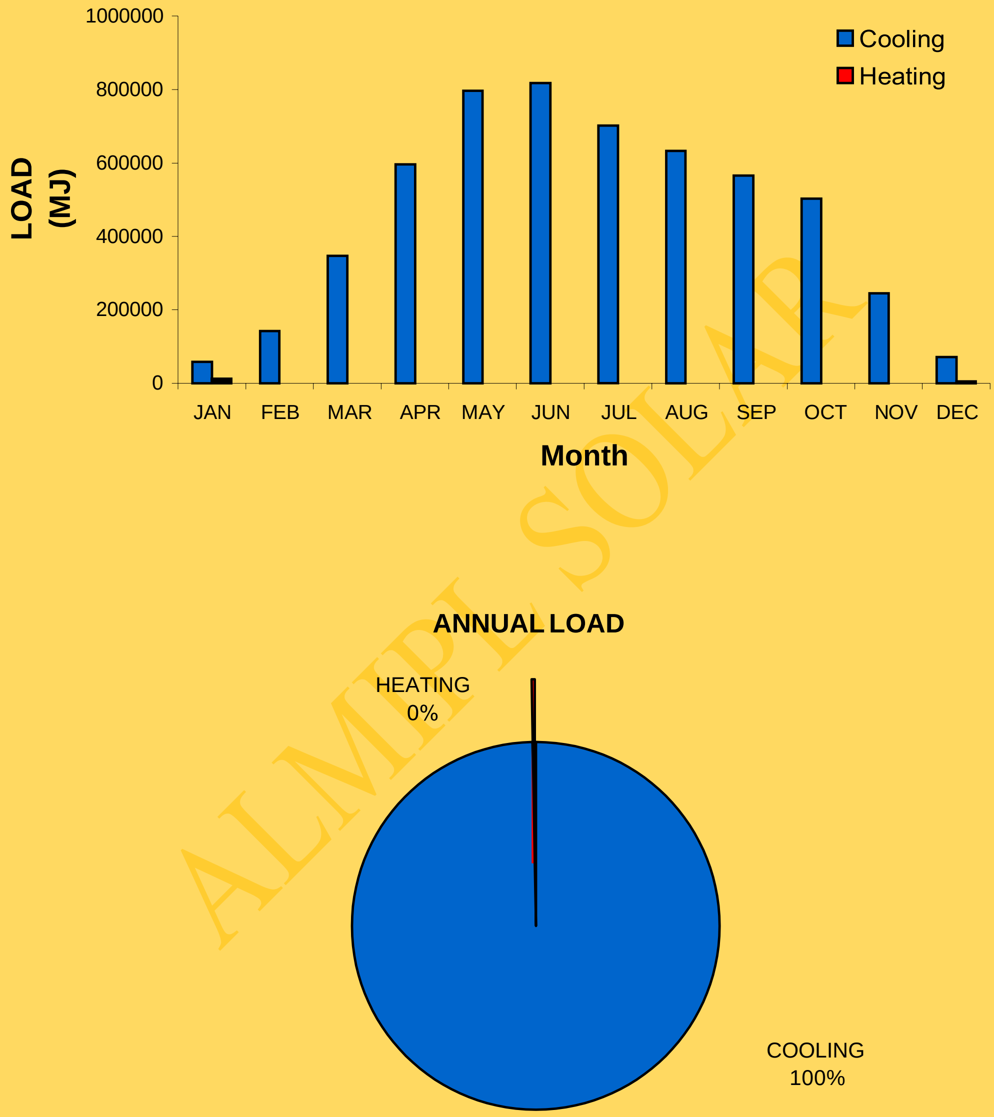


Fig. 5.61 Monthly and annual heating and cooling loads of the commercial building -New Delhi (composite climate)

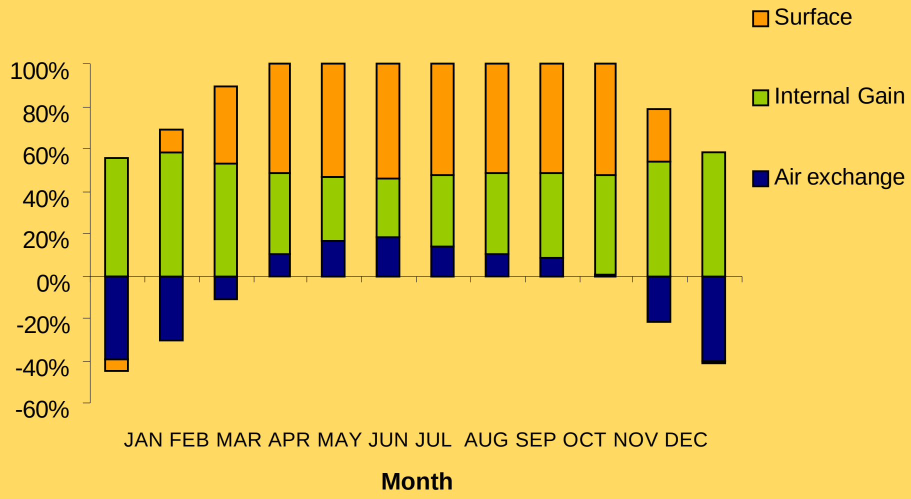


Fig. 5.62 Component-wise distribution of percentage heat gains and losses on a monthly basis of the commercial building – New Delhi (composite climate)

Table 5.33 Floor wise distribution of monthly and annual loads of the commercial building - New Delhi (composite climate)

Month	Cooling load (MJ)								
	GR	F1	F2	F3	F4	F5	F6	F7	Total
JAN	0	9473	12849	14683	12233	2894	6423	0	58557
FEB	8694	19394	27126	28415	22338	12626	19076	4213	141882
MAR	50245	36431	62380	63129	41177	31572	43002	19037	346974
APR	124501	50414	102382	104513	57973	52021	67132	37277	596214
MAY	176467	64293	133099	136203	74723	69966	89101	52372	796222
JUN	192241	61932	138818	142454	72613	69193	87508	52295	817054
JUL	156901	55512	120234	123234	65118	60141	76880	43637	701657
AUG	132146	53123	108588	110882	61724	55245	71386	39047	632142
SEP	120884	46214	100080	102492	53513	47741	61554	33738	566215
OCT	84925	47710	87763	89299	54610	46621	60460	31546	502935
NOV	23878	29759	44457	45468	33957	23358	32313	12000	245188
DEC	12	11595	14991	16665	14228	5037	9121	30	71679
Total	1070894	485851	952766	977437	564208	476415	623956	325192	5476720

Month	Heating load (MJ)								
	GR	F1	F2	F3	F4	F5	F6	F7	Total
JAN	236	7	2230	3518	142	1373	1154	3093	11753
FEB	0	0	0	0	0	0	0	32	32
MAR	0	0	0	0	0	0	0	0	0
APR	0	0	0	0	0	0	0	0	0
MAY	0	0	0	0	0	0	0	0	0
JUN	0	0	0	0	0	0	0	0	0
JUL	0	0	0	0	0	0	0	0	0
AUG	0	0	0	0	0	0	0	0	0
SEP	0	0	0	0	0	0	0	0	0
OCT	0	0	0	0	0	0	0	0	0
NOV	0	0	0	0	0	0	0	0	0
DEC	0	0	853	1313	2	645	461	1813	5087
Total	236	7	3084	4831	144	2017	1614	4938	16872

GR=Ground Floor, F1=First floor, F2=Second floor, F3=Third Floor, F4=Fourth floor, F5=Fifth floor, F6=Sixth Floor, F7=Seventh floor

The effects of building parameters on the annual loads of the building are presented in Table 5.34 for the New Delhi climatic conditions. The consequent percentages of load reduction due to these parameters compared to the base case are also tabulated. It may be noted that the total annual load of the building is quite high. Significant savings are possible by effecting even a one percent reduction in total loads. The following guidelines are recommended for a commercial building in New Delhi, which has a composite climate:

(a) Design Parameters

(i) Building orientation

Appropriate orientation of the building can reduce the annual load appreciably. The building (Fig.5.1) with glazed curtain wall facing northwest shows a substantial reduction in load compared to southwest orientation (base case); the percentage reduction being 8.6. The west and north orientations are also better than the base case.

(ii) Glazing type

Double glazing with reflective coated glass gives the best performance. It reduces the load by 1.4% compared to single pane reflective coated glass (base case). Plain glass, double glazing and double low-E glass increase the annual load by 10.7, 9.5 and 2.5% respectively and hence are not recommended.

(iii) **Window size**

The reduction of the glazing size to a height of 1.2 m instead of a fully glazed curtain wall, decreases the annual load by 7.2%. This is due to the reduction in solar gain, and thus the use of larger expanses of glass in such a building is not desirable as it leads to higher annual loads.

(iv) **Shading**

The reduction in solar gain by shading of windows (by means of external projections such as chajjas) causes a decrease in the heat gain, hence reducing the annual loads. If 50% of the window areas are shaded throughout the year, loads can be reduced by 9.3%.

(v) **Wall type**

A wall having a low U-value (insulating type such as autoclaved cellular concrete block) increases the load compared to the concrete block wall (base case) by 0.3%.

(vi) **Colour of the external surface**

Dark colours on the walls of such a commercial building should be avoided. For example, if dark grey is used in place of white (base case), the increase in load is 4.3%

(vii) **Air exchanges**

A lower air change rate of 0.5 ach is better than higher rates of 1, 2 and 4 ach. The percentage reduction in the annual load is 1.7 compared to the base case of 1 ach.

Operational Parameters

The operational parameters such as internal gain, set point and scheduling of air changes can help in reducing the annual load of the building. The effects are summarised as follows:

Table 5.34 Annual savings due to building design and operational parameters for the commercial building- New Delhi (composite climate)

Parameter	Annual load (MJ)			Energy saving	
	Cooling	Heating	Total	(MJ)	(%)
Base case	5476720	16872	5493592	--	--
Orientation (longer axis)					
North-south	5066737	45454	5112191	381402	6.9
Northeast-southwest	4976333	46828	5023161	470431	8.6
East-west	5299057	28293	5327351	166241	3.0
Glazing type					
Single clear	6073518	5849	6079368	-585776	-10.7
Double clear	6018065	21	6018086	-524494	-9.5
Double low-E	5633546	65	5633611	-140019	-2.5
Double reflective coated	5417676	452	5418128	75465	1.4
GLAZING SIZE (restricted to 1.2m height)	5093091	7577	5100668	392924	7.2
Shading					
10%	5369469	19776	5389245	104347	1.9
20%	5263000	23096	5286096	207496	3.8
50%	4948807	35581	4984387	509205	9.3
Wall type					
Autoclaved cellular concrete block	5503977	7244	5511221	-17629	-0.3
Colour of external surface					
Dark grey	5720660	10504	5731164	-237572	-4.3
Internal gain					
10%	2805208	242265	3047473	2446119	44.5
50%	3897213	87621	3984834	1508758	27.5
No internal gain	2552194	300215	2852410	2641182	48.1
AIR CHANGE RATE					
0.5	5393737	6260	5399997	93596	1.7
2	5677914	58825	5736739	-243147	-4.4
4	6158970	181916	6340886	-847294	-15.4
Set point - cooling: 25 °C - heating: 20 °C	5062976	3574	5066550	427042	7.8
Scheduling of air exchanges	5379180	73365	5452545	41047	0.8

(viii) **Internal gain**

Lower the internal gain, better is the performance of the building in reducing the annual load.

(ix) **Set Point**

The annual load of the building reduces if the set points for comfort cooling and heating are relaxed. If cooling and heating set points of 25 and 20^{0}C respectively are used (compared to 24 and 21^{0}C), the percentage reduction in annual load is 7.8. Thus, a change in the expectation of comfort can lead to significant energy savings.

(x) **Scheduling of air exchanges**

The scheduling of air changes to promote air entry during cooler periods (such as nights or winters) and controlling it during warmer periods (during daytime or summer) does not show any significant load reduction; the percentage of load reduction is 0.8.

The combination of all design and operational parameters discussed (excluding building orientation and internal gain), results in a significant load reduction 23.0%.

2.5.4.2 Industrial Building

Table 5.35 gives the yearly minimum, maximum and average temperatures, and the number of comfortable hours in a year for the shed and store for the New Delhi climate.

The average temperature of the store room is about 3.3 °C higher than the ambient, while that of the shed is about 7.6 °C. The yearly maximum temperatures of both rooms exceed 39 °C, indicating acute discomfort. Even the average temperatures are quite high more than 28 °C in the store and 32 °C in the shed. The shed is comfortable for about 42% in terms of number of comfortable hours in a year indicating acute discomfort for more than half the year. The store is only slightly better, being comfortable for 46% of the year. The values of monthly comfort fractions (Table 5.36) show that the shed is acutely uncomfortable in the months from April to July, September and October (as shown by negative CF values) and is most uncomfortable in the month of June (CF = -1.16). In contrast, January is the most comfortable month (CF = 0.97). The store is generally more comfortable than the shed with CF values ranging from -0.15 in June to 0.96 in March. The hourly values of room temperatures for a typical winter day of January and summer day of May are plotted in Figs. 5.63 and 5.64 respectively. It is seen that in January, the shed is within or close to the comfort zone. The store is cool, with temperatures going below the comfort zone. In May, the shed is very uncomfortable with temperatures exceeding 38 °C and reaching a high of 44 °C.

At this time, the store temperature ranges between 32 °C and 38 °C. Thus both rooms are extremely hot in May. Consequently, higher air change rate is desirable to promote heat loss in summer, while in winter, higher air change between 13 and 17 h would reduce discomfort.

Table 5.37 presents the change in the number of comfortable hours in a year due to various parameters for the shed. The corresponding percentage increase or decrease (-) of comfortable hours compared to the base case is also shown in the table. The effect of building orientation, glazing type, wall type, roof type, colour of external surfaces, air exchanges and shading of windows do not show any significant effect in this climate due to large internal gain of the building. If the internal gain is 20% of the base case, then the performance of the building improves by 28%.

Promoting higher air changes when the ambient air temperature is within the comfortable range as compared to the indoor temperature improves the performance of the building by 25%. However, when the reverse situation prevails, then the air exchange needs to be minimized.

Table 5.35 Performance of the industrial building on an annual basis- New Delhi (composite climate)

Room	Yearly room temperature(°C)			Comfortable hours in a year(h)	Percentage of yearly comfortable hours
	MIN	MAX	AVG		
Shed	18.9	44.1	32.5	3662	42
Store	13.9	39.9	28.2	3982	46
Ambient	8.7	38.5	24.9	5146	59

MIN = Minimum, MAX = Maximum, AVG = Average

Table 5.36 Performance of the industrial building on a monthly basis- New Delhi (composite climate)

Comfort index	Month	Room	
		Shed	Store
Comfort fraction	JAN	0.97	0.35
	FEB	0.80	0.78
	MAR	0.35	0.96
	APR	-0.52	0.53
	MAY	-0.99	0.07
	JUN	-1.16	-0.15
	JUL	-0.76	0.31
	AUG	0.19	0.35
	SEP	-0.43	0.62
	OCT	-0.09	0.84
	NOV	0.61	0.90
	DEC	0.95	0.45

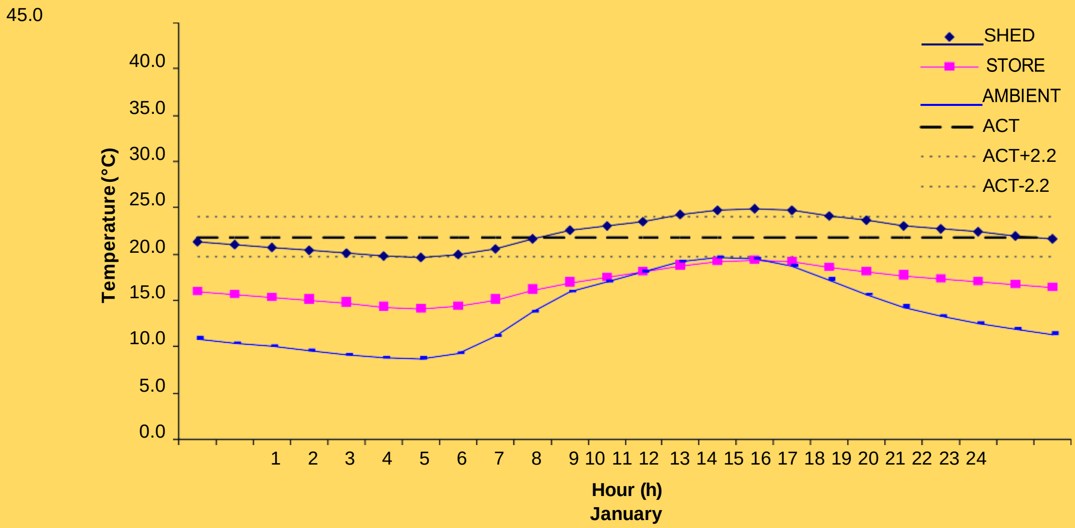


Fig. 5.63 Hourly variation of room temperatures of the industrial building in January - New Delhi (composite climate)

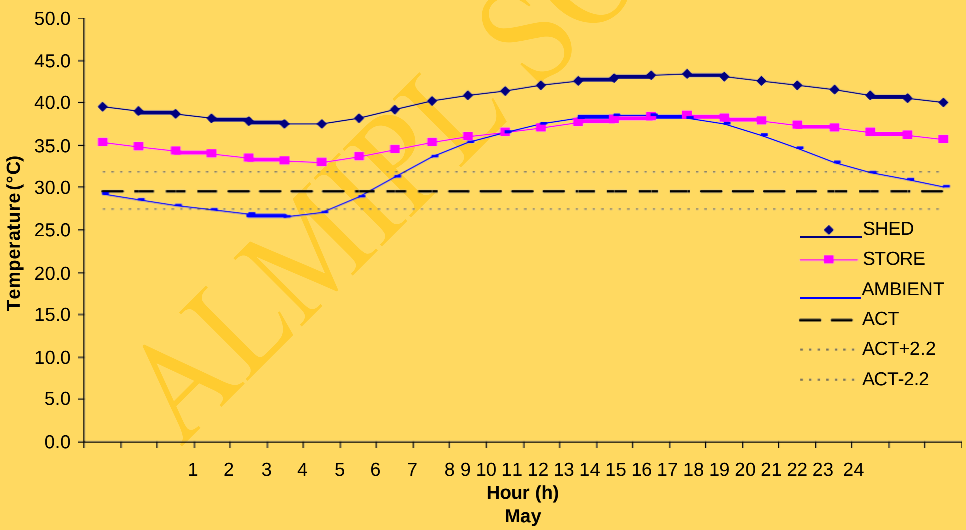


Fig. 5.64 Hourly variation of room temperatures of the industrial building in May - New Delhi (composite climate)

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Table 5.37 Improvement in the performance of the industrial building due to building design and operational parameters- New Delhi (composite climate)

Parameter	Comfortable hours in a year (h)	Percentage increase in comfortable hours
Base case	3662	--
Orientation		
Northwest-southeast	3677	0.4
Northeast-southwest	3678	0.4
East-west	3706	1.2
Glazing type		
Single reflective	3648	-0.4
Double clear	3663	0.0
Double low-E	3672	0.3
Double reflective coated	3688	0.7
Shading		
10%	3671	0.2
20%	3659	-0.1
Wall type		
Thermocol (EPS) insulated brick wall	3647	-0.4
Concrete block wall	3563	-2.7
Autoclaved cellular concrete block	3621	-1.1
Roof type		
RCC with Bitumen felt water proofing	3571	-2.5
RCC with PUF insulation	3517	-4.0
Colour of external surface		
White	3666	0.1
Cream	3672	0.3
Dark grey	3641	-0.6
Air exchanges		
3 ach	2996	-18.2
9 ach	3622	-1.1
12 ach	3735	2.0
Internal gain		
20%	4689	28.0
40%	4158	13.5
Scheduling of air exchanges	4577	25.0

The combination of all design and operational parameters discussed (excluding building orientation and internal gain), results in an increase in the yearly comfortable hours of the shed by 27.2% compared to the base case.

Residential Building (Bungalow)

(A) Conditioned building

Figure 5.65 shows the distribution of the annual and monthly heating and cooling loads of the conditioned bungalow for the New Delhi climate. The building requires cooling throughout the year and the general features are similar to those observed in the case of the commercial building (section 5.5.4.1). The highest cooling load occurs in the summer months and the lowest in the winter months. The monthly variation of the percentage of loads through various building components is presented in Fig. 5.66. As the cooling requirement is primarily due to surface gains, it is essential to reduce the heat gain by choosing appropriate materials, shading, colour, reducing exposed glazing area, etc. In summer months, air exchanges add to cooling loads and hence need to be controlled. The scheduling of air change rates can reduce cooling loads. The internal gain during winter months is responsible for cooling loads and hence can be reduced by decreasing lighting and equipment loads through energy efficient devices. The room-wise distribution of monthly and annual loads is presented in Table 5.38. It may be noted that the usage of the building and the configuration of spaces have a significant impact on the loads.

The cooling load of the living room is higher than that of the other rooms. This is because of the fact that this room is partly double storeyed and has a large volume. The cooling load of the kitchen is also very high due to operation of various appliances.

Table 5.39 presents the effects of building parameters on the annual loads of a conditioned bungalow. The consequent percentages of load reduction due to these parameters as compared to the base case are also shown in the table. The following recommendations are made for such a building for the New Delhi climatic conditions:

(a) **Design Parameters**

(i) **Building orientation**

Changing the orientation of the building does not increase the load significantly. In fact, the east-west orientation (base case) is better than the north-south orientation.

(ii) **Glazing type**

Double glazing with reflective coated glass gives the best performance. It gives a saving of 13.9% in comparison with plain glass (base case).

Single reflective coated glazing shows an improvement of 7.0%. Double low-E glass and double glazing with clear glass can also be used to reduce the loads by 11.9% and 6.3% respectively.

(iii) Shading

The reduction in solar gain by shading of windows (by means of external projections such as chajjas) can significantly reduce the heat gain and consequently the annual load. If 50% of the window areas are shaded throughout the year, the percentage load reduction is 8.9.

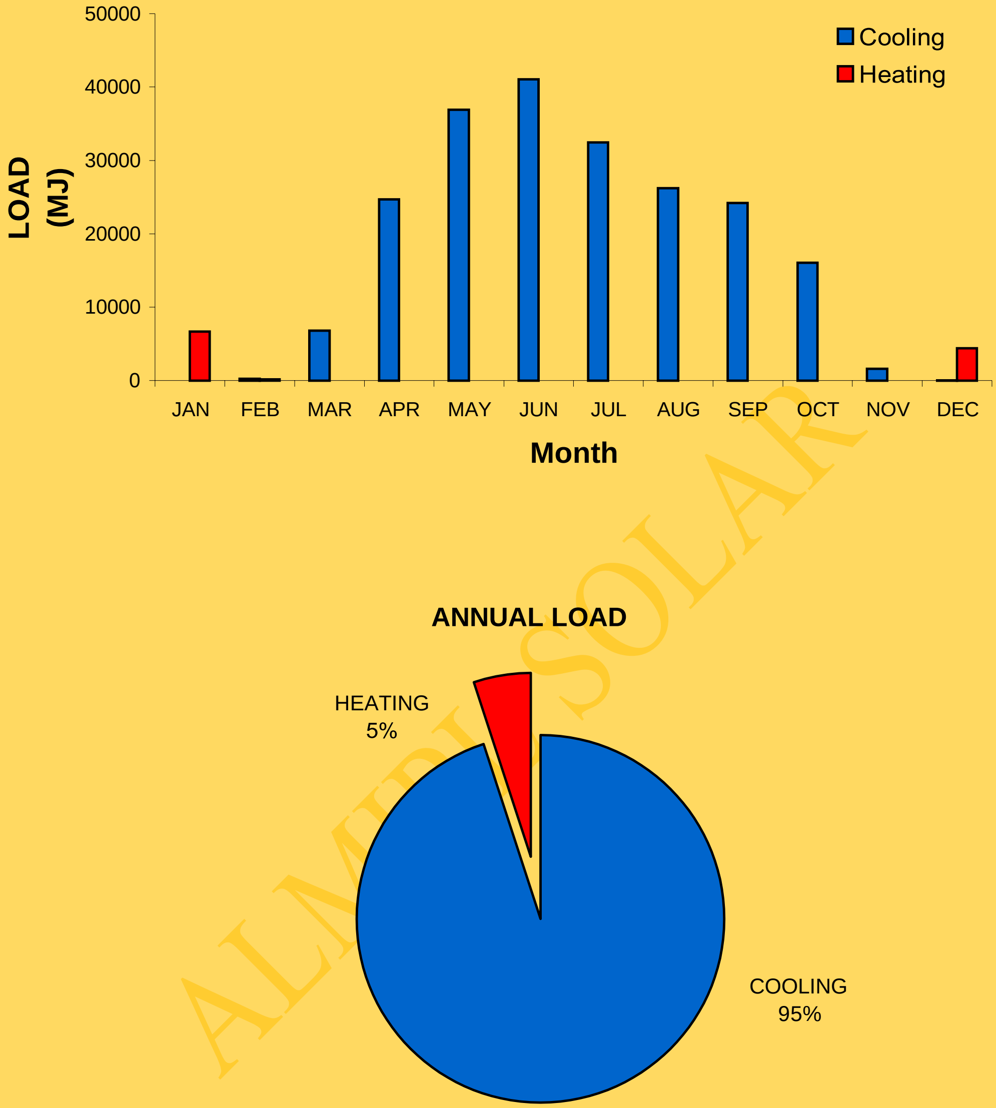

Fig. 5.65 Monthly and annual heating and cooling loads of the conditioned bungalow - New Delhi (composite climate)

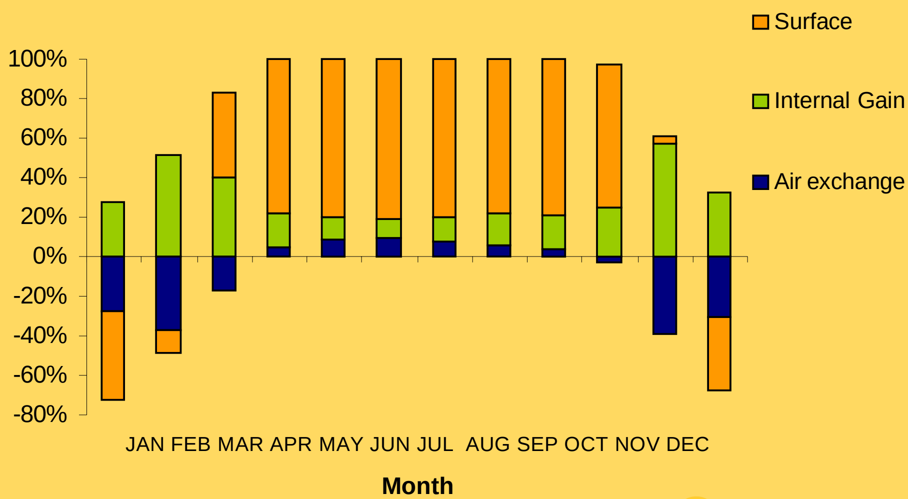

Fig. 5.66 Component-wise distribution of percentage heat gains and losses on a monthly basis of the conditioned bungalow – New Delhi (composite climate)

(iv) Wall type

Insulation of walls helps to improve the building's thermal performance significantly. Thermocol insulation can save annual loads by upto 13.9% and autoclaved cellular concrete block walls (e.g., Siporex) can save 12.0% as compared to a brick wall (base case). Plain concrete block wall increases the cooling load by 11.4% and hence needs to be avoided.

(v) Roof type

Insulation of the roof improves the performance of the building. Polyurethane foam (PUF) insulation brings down the cooling loads by 9.7%. In contrast, a plain uninsulated RCC slab increases the cooling load by 5.0%.

(vi) Colour of the external surface

Light colours are suitable due to their lower absorptivities. White improves the performance by 3.9%. Similarly, cream colour improves the performance by 2.6%. Dark colours should be avoided as the performance decreases by 4.0%.

(vii) Air exchanges

A lower air change rate of 0.5 ach is desirable for reducing the loads; the reduction is 2.7% as compared to the base case of 1.0 ach. Increasing the air change rate to 1.5 increases the load by 2.7%. Although, lower air change rates decrease the load, they may be undesirable for reasons of health.

Table 5.38 Room-wise distribution of monthly and annual loads of the conditioned bungalow - New Delhi (composite climate)

Month	Cooling load (MJ)							
	BED1	LIVDIN	KIT	BED2	BED3	BED4	BED5	Total
JAN	0	0	0	0	0	0	0	0
FEB	0	0	296	0	0	0	0	296
MAR	319	3017	1537	404	458	435	634	6803
APR	1881	9670	3435	2639	2164	2393	2494	24676
MAY	2916	14434	4779	4133	3289	3680	3710	36940
JUN	3296	16055	5197	4653	3660	4104	4112	41077
JUL	2624	12428	4309	3668	2912	3248	3261	32450
AUG	2089	10041	3696	2902	2336	2579	2616	26258
SEP	1869	9495	3414	2581	2112	2321	2455	24247
OCT	1090	6691	2641	1406	1283	1333	1629	16073
NOV	13	772	770	12	20	15	59	1661
DEC	0	0	38	0	0	0	0	38
Total	16097	82602	30112	22398	18234	20108	20969	210520

Month	Heating load (MJ)							
	BED1	LIVDIN	KIT	BED2	BED3	BED4	BED5	Total
JAN	619	2369	275	1287	699	900	556	6704
FEB	13	69	5	30	14	17	13	161
MAR	0	0	0	0	0	0	0	0
APR	0	0	0	0	0	0	0	0
MAY	0	0	0	0	0	0	0	0
JUN	0	0	0	0	0	0	0	0
JUL	0	0	0	0	0	0	0	0
AUG	0	0	0	0	0	0	0	0
SEP	0	0	0	0	0	0	0	0
OCT	0	0	0	0	0	0	0	0
NOV	0	0	0	0	0	0	0	0
DEC	370	1620	183	951	418	599	284	4425
Total	1002	4058	463	2268	1131	1516	852	11290

BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5

Table 5.39 Annual savings due to building design and operational parameters for the conditioned bungalow - New Delhi (composite climate)

Parameter	Annual load (MJ)			Energy saving	
	Cooling	Heating	Total	(MJ)	(%)
Base case	210520	11290	221810	--	--
Orientation (longer axis)					
North-south	211536	13744	225280	-3470	-1.6
Glazing type					
Double clear	202246	5566	207812	13998	6.3
Single reflective coated	191024	15177	206201	15609	7.0
Double reflective coated	182608	8437	191045	30765	13.9
Double low-E	188869	6444	195313	26497	11.9
Shading					
10%	205267	12179	217446	4364	2.0
20%	200027	13152	213179	8631	3.9
50%	185162	16871	202033	19777	8.9
Wall type					
Thermocol (EPS) insulated brick wall	185365	5617	190982	30828	13.9
Concrete block wall	228622	18571	247193	-25383	-11.4
Autoclaved cellular concrete block	189369	5739	195108	26702	12.0
Roof type					
Uninsulated RCC roof	219638	13286	232924	-11113	-5.0
PUF insulated RCC roof	191699	8546	200245	21565	9.7
Colour of external surface					
White	199945	13242	213187	8623	3.9
Cream	203436	12556	215991	5819	2.6
Dark grey	221290	9486	230776	-8966	-4.0

Air exchanges					
0.5 ach	206859	8900	215759	6051	2.7
1.5 ach	214225	13655	227879	-6069	-2.7
Internal gain					
50%	192340	14203	206544	15266	6.9
No internal gain	175219	18152	193371	28439	12.8
Set point - cooling: 26 °C - heating: 19 °C	183830	6590	190420	31390	14.2
Scheduling of air exchanges	206834	9023	215858	5953	2.7

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(b) **Operational Parameters**

The operational parameters such as internal gain, set point and scheduling of air changes can help in reducing the annual load of the building. The effects are summarised as follows:

(i) **Internal gain**

Lower the internal gain, better is the performance of the building in reducing the annual load. The annual load can be reduced by 6.9% if internal gains are reduced by 50%. Therefore, more energy efficient equipment should be used to facilitate load reduction.

(ii) **Set point**

Lowering the operating parameters for comfort cooling and heating can reduce the cooling loads by 14.2%. Thus, a change in the expectation of comfort can lead to significant savings.

(iii) **Scheduling of air exchanges**

The scheduling of air changes to promote air entry during cooler periods (such as nights or winters) and controlling air entry during warmer periods (during daytime or summer) can lead to a 2.7% reduction of the annual load.

The combination of all design and operational parameters discussed (excluding building orientation and internal gain), results in a significant load reduction of 62.6%.

(B) Non-conditioned building

Table 5.40 gives the yearly minimum, maximum and average temperatures, and number of comfortable hours in a year for all the rooms of a non-conditioned bungalow for New Delhi. It is seen that the maximum temperatures of all rooms exceed 37.0 °C in a year, indicating acute discomfort. The average temperatures are quite comfortable ranging from 27.4 °C to 28.3 °C. Thus, cooling may be required only in summers. The percentage of comfortable hours in a year for all rooms is between 49 and 56 only. In other words, all rooms are uncomfortable for more than 44% of the year. Thus, a change in design is indicated to reduce discomfort. The performance of the building on a monthly basis is presented in terms of the comfort fraction (CF) in Table 5.41. It is seen that the rooms are comfortable in the months of March, October and November. Generally, June is the most uncomfortable month with values of CF ranging from -0.11 to 0.10. Most rooms are also uncomfortable in the months of January, May and December. The hourly variation of room temperatures for a typical winter day of January and summer day of May are plotted in Figs. 5.67 and 5.68 respectively.

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It is seen that in January, all the rooms are uncomfortably cold throughout the day with temperatures ranging from 15 to 20°C. Thus, heating is required in winter and lower air change rates throughout the day is desirable. In May, all the rooms are well above the comfort zone by about 2 to 3 °C.

The room temperatures

exceed 32.5 °C, indicating acute discomfort. Thus, heat gain needs to be reduced in May, and heat loss promoted. Higher air change rates during nights, and lower air change rates during days are desirable in summers.

Table 5.40 Performance of the non-conditioned bungalow on an annual basis - New Delhi (composite climate)

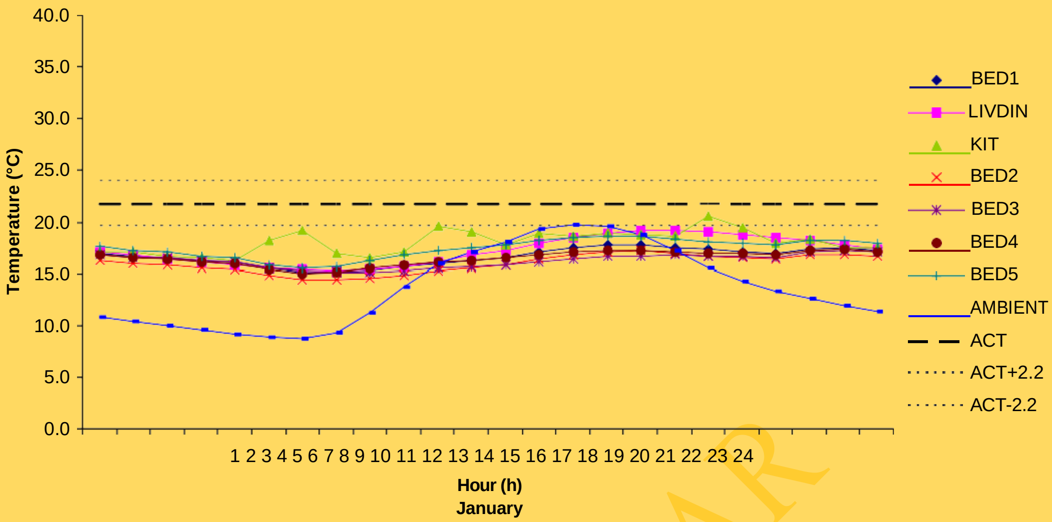
Room	Yearly room temperature(°C)			Comfortable hours in a year(h)	Percentage of yearly comfortable hours
	MIN	MAX	AVG		
BED1	15.0	37.6	27.4	4918	56
LIVDIN	14.9	38.1	27.7	4783	55
KIT	16.0	39.3	28.3	4700	54
BED2	14.3	38.6	27.6	4276	49
BED3	15.0	38.3	27.7	4605	53
BED4	14.9	38.1	27.8	4505	51
BED5	15.3	38.1	28.2	4360	50
Ambient	8.7	38.5	24.9	5146	59

MIN = Minimum, MAX = Maximum, AVG = Average
BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5

Table 5.41 Performance of the non-conditioned bungalow on a monthly basis - New Delhi (composite climate)

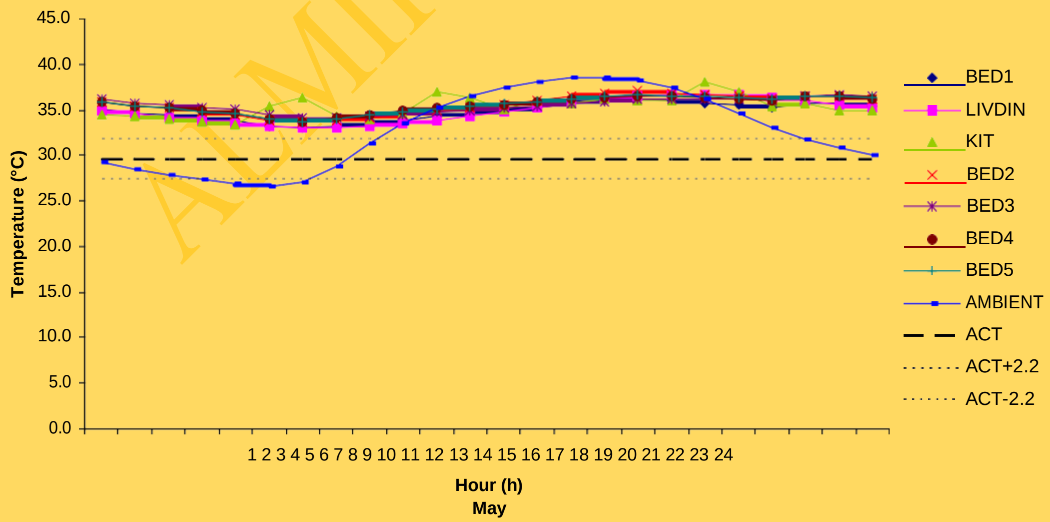
Comfort index	Month	Room						
		BED1	LIVDIN	KIT	BED2	BED3	BED4	BED5
Comfort fraction	JAN	0.32	0.45	0.63	0.17	0.23	0.29	0.5
	FEB	0.82	0.84	0.94	0.74	0.79	0.84	0.92
	MAR	1	1	0.98	1	1	1	1
	APR	0.73	0.68	0.60	0.62	0.62	0.60	0.55
	MAY	0.32	0.30	0.18	0.14	0.16	0.15	0.15
	JUN	0.1	0.09	-0.01	-0.11	-0.09	-0.07	-0.06
	JUL	0.52	0.51	0.38	0.36	0.38	0.38	0.39
	AUG	0.75	0.75	0.61	0.63	0.64	0.63	0.62
	SEP	0.82	0.76	0.65	0.72	0.72	0.71	0.64
	OCT	0.99	0.89	0.87	0.98	0.99	0.99	0.88
	NOV	0.93	0.95	1	0.89	0.94	0.95	0.98
	DEC	0.43	0.58	0.73	0.28	0.35	0.39	0.62

BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5



BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5

Fig. 5.67 Hourly variation of room temperatures of the non-conditioned bungalow in January - New Delhi (composite climate)



BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5

Fig. 5.68 Hourly variation of room temperatures of the non-conditioned bungalow in May - New Delhi (composite climate)

Table 5.42 Improvement in the performance of the non-conditioned bungalow due to building design and operational parameters - New Delhi (composite climate)

Paramete r	Comfortable hours in a year (h)	Percentage increase in comfortable hours
Base case	4276	-
Orientation (longer axis)		
North-south	4192	-2.0
Glazing type		
Double clear	4129	-3.4
Double low-E	4398	2.9
Single reflective coated	4747	11.0
Double reflective coated	4629	8.3
Shading		
10%	4382	2.5
20%	4557	6.6
50%	4778	11.7
Wall type		
Concrete block wall	4245	-0.7
Thermocol (EPS) insulated brick wall	4004	-6.4
Autoclaved cellular concrete block	4015	-6.1
Roof type		
Uninsulated RCC roof	4019	-6.0
PUF insulated RCC roof	4488	5.0
Colour of external surface		
Cream	4392	2.7
Dark grey	4090	-4.3
White	4506	5.4
Air exchanges		
0.5 ach	3660	-14.4
1.5 ach	3945	-7.7
6 ach	4630	8.3
9 ach	4751	11.1
Internal gain		
No internal gain	4625	8.2
50%	4467	4.5
Scheduling of air exchanges	5171	20.9

Table 5.42 presents the change in the number of comfortable hours in a year due to various parameters for a bedroom (Bed2). The numbers in brackets show the percentage increase or decrease (-) of comfortable hours compared to the base case.

(a) **Design Parameters**

(i) **Building orientation**

East-west orientation of the building is better than the north-south orientation.

(ii) **Glazing type**

Single pane reflective coated glass is recommended over plain glass (base case). It shows an increase in the yearly comfortable hours by 11.0%. Insulation in the form of double glazing with reflective coated glass and double low-E glass improve the performance by 8.3 and 2.9% respectively.

(ii) **Shading**

Reducing solar radiation by shading windows can reduce heat gain and consequently increase the comfort. If windows are shaded by 50% throughout the year, an increase of 11.7% in the number of comfortable hours can be achieved.

(iii) **Wall type**

A brick wall (base case) is better than all other wall types.

(iv) **Roof type**

Insulating the roof with polyurethane foam (PUF) insulation increases performance by 5.0% as compared to a roof with brick-bat-coba waterproofing. However, an uninsulated roof i.e., plain RCC roof decreases the number of comfortable hours by about 6.0%.

(v) **Colour of the external surface**

White and cream colours are preferable to puff shade (base case) or dark grey. The percentage increases of comfortable hours compared to the base case are 5.4 and 2.7 respectively.

(vi) **Air exchanges**

An air change rate of 9 ach is better than one of 3 ach (base case). It gives an improvement of about 11.1%. Comparatively, an air change rate of 6 per hour gives an improvement of 8.3%.

(b) **Operational Parameters**

(a) **Internal gain**

Lowering the internal gain betters the performance. The performance increase is about 4.5% if the internal gains are reduced by 50%. Thus, energy efficient lights and equipment may be considered to reduce discomfort.

(ii) Scheduling of air changes

Scheduling of air changes to promote more air during cooler periods and controlling it during warmer periods (during daytime or summers) can lead to an increase in the number of comfortable hours by about 18.8%.

Combining all the best parameters (excluding building orientation and internal gain) can significantly improve the non-conditioned building's performance, resulting in an increase in the yearly number of comfortable hours by 27.9% in New Delhi.

5.5.5 Cold and Cloudy Climate (Representative city: Srinagar)

1.5.5.1 Commercial Building

A distribution of the annual and monthly heating and cooling loads of the commercial building in Srinagar is shown in Fig. 5.69. Although the heating load is predominant on an annual basis, the building tends to overheat in summer and hence cooling is also required (922.79 GJ/year). The heating season starts from November and ends in March, the heating load being highest in January. Heating as well as cooling loads are small in April, May and October.

The cooling requirement is predominant from June to September, the cooling load being highest in July. June and August also display significantly high cooling loads. Out of twelve months, five months require only heating, four months require only cooling, and in remaining three months both heating and cooling are required. Figure 5.70 shows the distribution of percentage of loads through various building components on a monthly basis. The building loses net heat from October to April primarily due to air exchanges and surface losses. The heat loss through surfaces is generally higher than that through air exchanges. The building gains net heat from May to September, the main gain being from people and equipment. In the months of July and August, heat is also gained through surfaces. Air exchanges help to lose heat in these months and hence, a scheduling of air changes to promote ventilation in July and August, and their control in other months could lead to a reduction in the annual loads. It is essential to reduce surface gains and losses in all months to reduce the heating and cooling loads. This could be achieved by reducing glazing areas, using appropriate building materials, and through control of surfaces exposed to direct solar radiation.

Table 5.43 gives the floor-wise monthly and annual loads for the commercial building. It is seen that the usage pattern of the building has a significant impact on the loads. For instance, the energy required for heating is maximum on the ground floor. This is because the shutters are opened frequently on ground floor resulting in high heat loss due to air exchanges. Such loss may be reduced by sealing all cracks, providing air lock lobbies, etc. on ground floor. Similarly, the loads of the second and third floor are significantly higher than those of other floors as they are occupied on a 24-hour basis throughout the week.

The effects of building parameters on the annual loads of the building are presented in Table 5.44 for the Srinagar climatic conditions. The consequent percentage load reduction for each parameter compared to the base case are also tabulated. It may be noted that the total annual load of the building is quite high. Energy can be well saved by even one percent reduction in this load. The following guidelines are recommended for a commercial building in Srinagar, which belongs to cold and cloudy climatic zone:

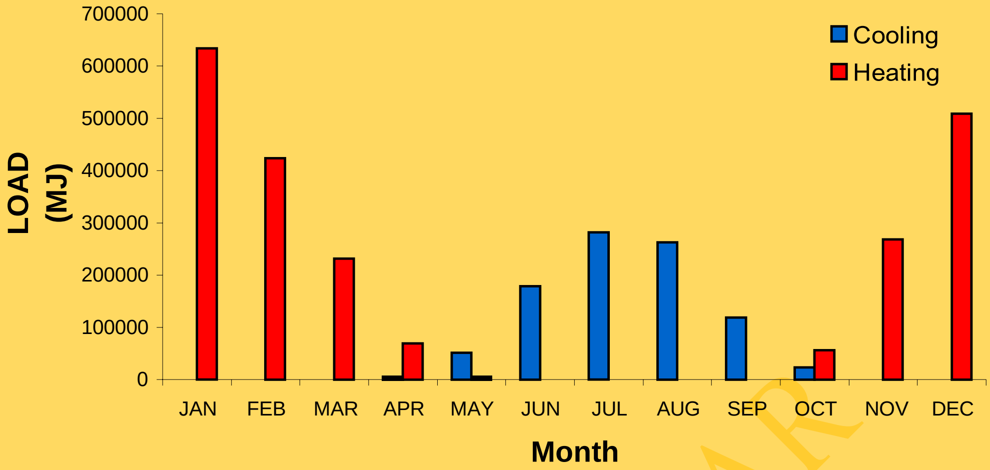
(b) Design Parameters

(i)Building orientation

The building (Fig.5.1) with its glazed curtain wall facing south-west (base case) is recommended. Other orientations show an increase in annual loads.

(ii)Glazing type

A double glazing with low-E glass gives the best performance. It reduces the load by 20.6% compared to single pane reflective coated glass (base case). Double glazing and double reflective coated glass decrease the annual load by 16.0 and 20.1 respectively.



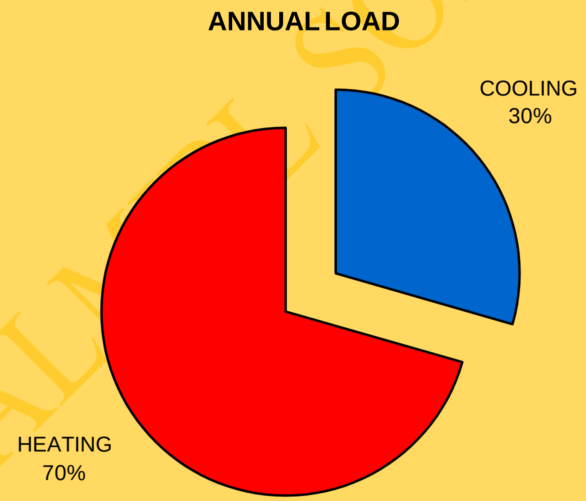


Fig. 5.69 Monthly and annual heating and cooling loads of the commercial building -Srinagar (cold and cloudy climate)

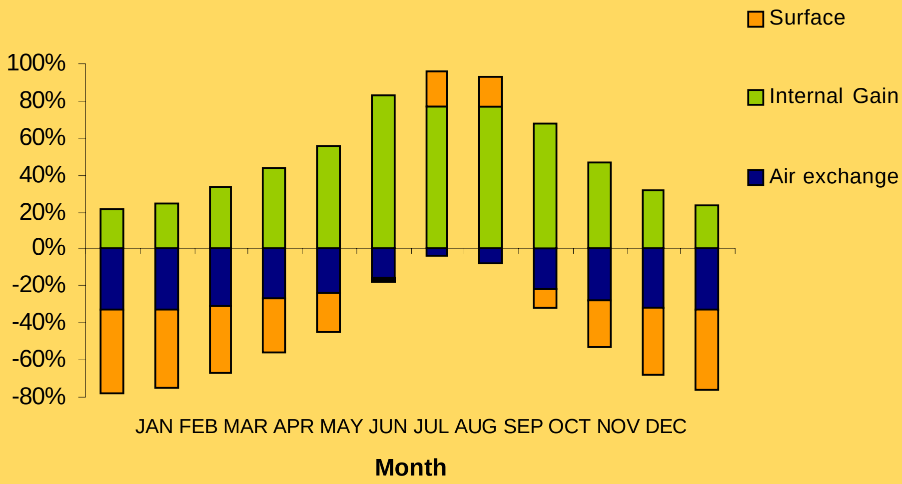

Surface
Internal Gain
Air exchange
100%
80%
60%
40%
20%
0%
-20%
-40%
-60%
-80%
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
Month

Fig. 5.70 Component-wise distribution of percentage heat gains and losses on a monthly basis of the commercial building – Srinagar (cold and cloudy climate)

(i)Window size

The reduction of the glazing size to 1.2 m height, compared to a fully glazed curtain wall, decreases the annual load by 11.8%. Thus, the use of larger expanse of glass in such a building is not desirable as it leads to higher annual loads. This is due to high internal gains of the commercial building.

(ii)Shading

The shading effect is insignificant in this climate for the commercial building because the internal gain of the building is very high.

(iii)Wall type

Walls having a low U-value (insulating type such as autoclaved cellular concrete block) reduce the load compared to the concrete block wall (base case) by 10.9%. Thus insulation of walls is recommended.

(i)Colour of the external surface

Dark colour of the external surfaces does not show any significant effect as the building has high internal gains.

(ii)Air exchanges

A lower air change rate of 0.5 ach is better than air change rates of 1, 2 and 4 ach. The percentage reduction in the annual load is 8.8 compared to the base case of 1 ach.

(b) Operational Parameters

The operational parameters such as internal gain, set point and scheduling of air changes can help in reducing the annual load of the building. The effects are summarised as follows.

(i) **Internal gain**

In cold climates, the internal gains help to keep the building warm and hence are preferable.

Table 5.43 Floor wise distribution of monthly and annual loads of the commercial building - Srinagar (cold and cloudy climate)

Month	Cooling load (MJ)								
	GR	F1	F2	F3	F4	F5	F6	F7	Total
JAN	0	0	0	0	0	0	0	0	0
FEB	0	0	0	0	0	0	0	0	0
MAR	0	0	0	0	0	0	0	0	0
APR	0	0	1478	3339	1229	0	0	0	6047
MAY	0	3517	11508	14201	11829	2142	7977	0	51173
JUN	9883	17572	34228	36904	27459	17183	27999	7399	178626
JUL	25395	26280	53368	55946	37098	27543	40478	15708	281816
AUG	19102	25444	49888	52270	36722	26267	39097	14207	262997
SEP	1092	12179	23721	26577	21004	11248	19520	3214	118555
OCT	0	583	6454	8913	6040	95	1489	0	23575
NOV	0	0	0	0	0	0	0	0	0
DEC	0	0	0	0	0	0	0	0	0
Total	55472	85575	180645	198149	141382	84479	136559	40528	922789

Month	Heating load (MJ)								
	GR	F1	F2	F3	F4	F5	F6	F7	Total
JAN	178128	35510	101613	104134	35993	57958	60757	59898	633991
FEB	123511	21975	70088	71399	20343	37772	37959	40963	424010
MAR	67180	9604	41164	42306	6464	20666	17327	26949	231659
APR	17256	2278	14728	15328	1092	4683	3067	10709	69141
MAY	938	91	1205	1325	3	270	62	1332	5226
JUN	0	0	0	0	0	0	0	0	0
JUL	0	0	0	0	0	0	0	0	0
AUG	0	0	0	0	0	0	0	0	0
SEP	0	0	0	0	0	0	0	0	0
OCT	18088	2170	11088	12006	864	3431	2474	6473	56594
NOV	84242	11018	45823	46936	8254	22645	20549	28866	268332
DEC	147753	25877	86554	88122	24981	43914	45030	46678	508909
Total	637097	108521	372262	381556	97994	191339	187225	221867	2197862

GR=Ground Floor, F1=First floor, F2=Second floor, F3=Third Floor, F4=Fourth floor, F5=Fifth floor, F6=Sixth Floor, F7=Seventh floor

Table 5.44 Annual savings due to building design and operational parameters for the commercial building- Srinagar (cold and cloudy climate)

Parameter	Annual load (MJ)			Energy saving	
	Cooling	Heating	Total	(MJ)	(%)
Base case	922789	2197862	3120651	--	--
Orientation (longer axis)					
North-south	834912	2386840	3221752	-101100	-3.2
Northeast-southwest	798639	2398312	3196951	-76299	-2.4
East-west	889677	2298717	3188394	-67743	-2.2
Glazing type					
Single clear	1171012	1989599	3160611	-39959	-1.3
Double clear	1290793	1329102	2619895	500756	16.0
Double low-E	1149217	1327081	2476298	644353	20.6
Double reflective coated	1039267	1452705	2491972	628679	20.1
Glazing size (restricted to 1.2m height)	845570	1906361	2751931	368721	11.8
Shading					
10%	879800	2238764	3118564	2087	0.1
20%	837786	2280564	3118350	2301	0.1
50%	718081	2410994	3129074	-8423	-0.3
Wall type					
Autoclaved cellular concrete block	1380828	1399604	2780432	340219	10.9
Colour of external surface					
Dark grey	1020408	2094909	3115317	5334	0.2
Air change rate					
0.5	956856	1890403	2847259	273392	8.8
2	879446	2813760	3693206	-572555	-18.3
4	852113	4034756	4886869	-1766218	-56.6
Internal gain					
10%	109948	4140111	4250060	-1129408	-36.2
50%	371609	3187899	3559509	-438858	-14.1
No internal gain	68812	4405124	4473937	-1353285	-43.4
Set point - cooling: 25 °C - heating: 20 °C	739562	1971306	2710868	409783	13.1
Scheduling of air exchanges	907997	1971302	2879299	241352	8.4

(ii) Set Point

The annual load of the building reduces if the set points for comfort cooling and heating are relaxed. If the cooling and heating set points of 25 and 20⁰C respectively are used (compared to 24 and 21⁰C), the annual load is reduced by 13.1%. Thus, a change in the expectation of comfort can lead to significant savings.

(iii) Scheduling of air exchanges

The scheduling of air changes to control air entry during cooler periods (such as nights or winters) and promote the same during warmer periods (during daytime or summer) can reduce annual loads by 8.4%.

The combination of all design and operational parameters discussed (excluding building orientation and internal gain) results in a load reduction of 38.4%.

2.5.5.2 Industrial Building

Table 5.45 gives the yearly minimum, maximum and average temperatures, and the number of comfortable hours in a year for the shed and store of the industrial building for the Srinagar climate. The average temperature of the store room is about 3.1 °C higher than the ambient, while that of the shed is about 7.5 °C. The winters are very cool and minimum temperatures can be as low as 1.6 °C in store and 5.3 °C in the shed, making heating essential in winters.

The yearly maximum temperatures of both rooms exceed 29.8 °C and the shed can attain a temperature as high as 34.1 °C. Hence cooling is required in summers to alleviate discomfort. The shed is comfortable for about 49% in terms of number of comfortable hours in a year indicating discomfort for nearly half the time. The store is slightly more comfortable i.e. for 53% of the year. The values of the monthly comfort fractions (Table 5.46) show that the shed is very uncomfortable in the month of January with a CF of -0.23 (negative values of CF indicate acute discomfort). It is comfortable in the months of April, May, August and October (CF values being more than 0.9). The store is uncomfortably cold for a number of months (November to March), January being the most uncomfortable month. June to September are comfortable months for the store. The hourly values of room temperatures for a winter typical day of January and summer day of May are plotted in Figs. 5.71 and 5.72 respectively. It is seen that in January, both the rooms are extremely cold and well below the comfort zone. The temperature in the store is always lower than 5 °C, while the shed temperature varies and is about 10 °C. Hence, heating is required in January and the air change rate should be minimum in this month. In May, both the rooms are more or less comfortable.

Table 5.47 presents the change in the number of comfortable hours in a year due to various parameters for the shed. The corresponding percentage increase or decrease (-) of comfortable hours compared to the base case is also shown in the table. The effect of building orientation, glazing type, wall type, roof type, colour of external surfaces, air exchanges and shading of windows do not show any significant effect in this climate due to the large internal gain of the building. Single pane reflective coated glass is marginally better in increasing the yearly comfortable hours (by about 2%) than plain glass. Having an insulated roof increases the yearly comfortable hours by 2.6% compared to the base case.

If the internal gain is 20% of the base case, then the performance of the building improves by 14.5%. Promoting higher air changes when the ambient air temperature is within the comfortable range compared to indoor temperature improves the performance of the building by 31.8% compared to a constant air change rate.

Table 5.45 Performance of the industrial building on an annual basis- Srinagar (cold and cloudy climate)

Room	Yearly room temperature(°C)			Comfortable hours in a year(h)	Percentage of yearly comfortable hours
	MIN	MAX	AVG		
Shed	5.3	34.1	20.4	4245	49
Store	1.6	29.8	16.0	4666	53
Ambient	-1.1	28.8	12.9	3911	45

MIN = Minimum, MAX = Maximum, AVG = Average

Table 5.46 Performance of the industrial building on a monthly basis- Srinagar (cold and cloudy climate)

Comfort index	Month	Room	
		Shed	**Store**
Comfort fraction	JAN	-0.23	-1.59
	FEB	0.07	-1.12
	MAR	0.70	-0.38
	APR	1	0.26
	MAY	0.90	0.75
	JUN	0.48	0.99
	JUL	0.19	0.95
	AUG	0.98	0.96
	SEP	0.73	0.91
	OCT	0.98	0.30
	NOV	0.60	-0.60
	DEC	0.02	-1.29

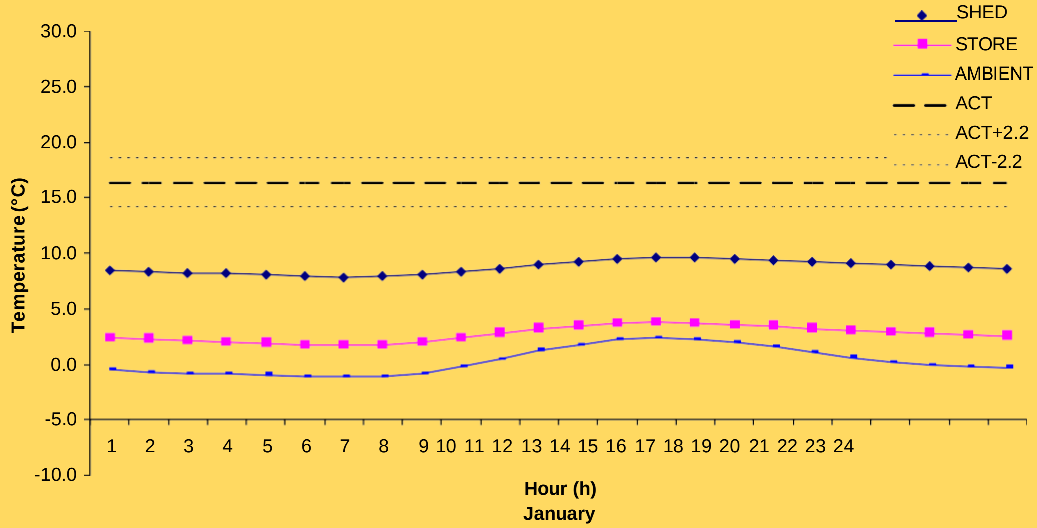


Fig. 5.71 Hourly variation of room temperatures of the industrial building in January - Srinagar (cold and cloudy climate)

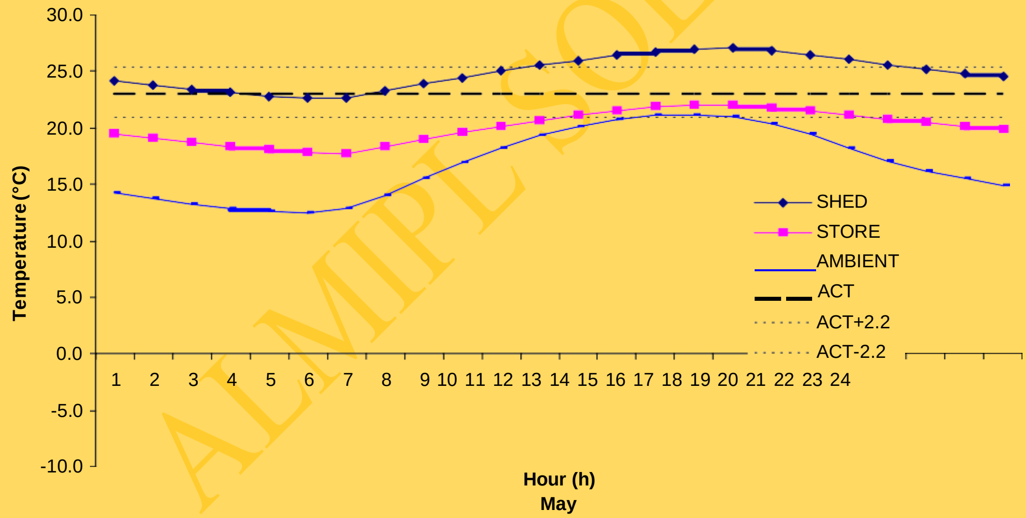


Fig. 5.72 Hourly variation of room temperatures of the industrial building in May - Srinagar (cold and cloudy climate)

Table 5.47 Improvement in the performance of the industrial building due to building design and operational parameters- Srinagar (cold and cloudy climate)

Parameter	Comfortable hours in a year (h)	Percentage increase in comfortable hours
Base case	4245	--
Orientation		
Northwest-southeast	4266	0.5
Northeast-southwest	4253	0.2
East-west	4301	1.3
Glazing type		
Single reflective	4330	2.0
Double clear	4254	0.2
Double low-E	4264	0.4
Double reflective coated	4267	0.5
Shading		
10%	4265	0.5
20%	4288	1.0
Wall type		
Thermocol (EPS) insulated brick wall	4246	0.0
Concrete block wall	4279	0.8
Autoclaved cellular concrete block	4238	-0.2
Roof type		
RCC with bitumen felt water proofing	4221	-0.6
RCC with PUF insulation	4355	2.6
Colour of external surface		
White	4382	3.2
Cream	4360	2.7
Dark grey	4160	-2.0
Air exchanges		
3 ach	4363	2.8
9 ach	4495	5.9
12 ach	4675	10.1
Internal gain		
20%	4862	14.5
40%	4796	13.0
Scheduling of air exchanges	5595	31.8

The combined effect of all the best design and operational parameters (excluding building orientation and internal gain), results in an increase of the yearly comfortable hours of the shed by 40.4% compared to the base case.

3.5.5.3 Residential Building (Bungalow)

(A) Conditioned building

A distribution of the annual and monthly heating and cooling loads of the conditioned bungalow in Srinagar is shown in Fig. 5.73. The figure shows that on an annual basis, the heating load is predominant (91%) with heating being required throughout the year except in June, July and August. The load profiles generally follow the climatic conditions. For example, the highest heating load occurs during the peak winter period in January. The heating load in December is also quite high. Only cooling loads occur in the summer months from June to August. The monthly variation of the percentage of loads through the various building components is presented in Fig. 5.74. The heating requirement is primarily due to surface losses. During most of the year, the combined heat loss through surfaces and air exchanges is higher than heat gain due to people and equipment. Therefore, insulation of surfaces and control of air exchanges could lower the heating loads. In May and September, which represents the spring and autumn months respectively, the heat gains and losses more or less balance each other and hence, the loads are small.

In the summer months of July and August, heat gain through surfaces needs to be minimised. It could be done by reducing the glazing area and by shading of surfaces exposed to direct solar radiation.

Table 5.48 presents the room-wise annual loads for the conditioned bungalow in Srinagar. It is seen that the heating load of the living and dining room is significantly higher than that of other rooms. This is because of the fact that this room is very large and is also partly double storeyed. The heating load of the kitchen is the least due to internal gains from appliances (refrigerator and cooking range). A comparison of the bedrooms shows that the first floor bedroom (Bed3) facing north and having only one window is the warmest. The ground floor bedroom (Bed1) in the northwest corner of the house is also warm. The bedroom located directly above it is the coolest. This is primarily due to heat losses from larger exposed surfaces and glazed area.

The effects of building parameters on annual loads are presented in Table 5.49. The table also shows the consequent percentage load reduction for each parameter compared to the base case. Based on the results, the following are recommended for a conditioned bungalow in Srinagar:

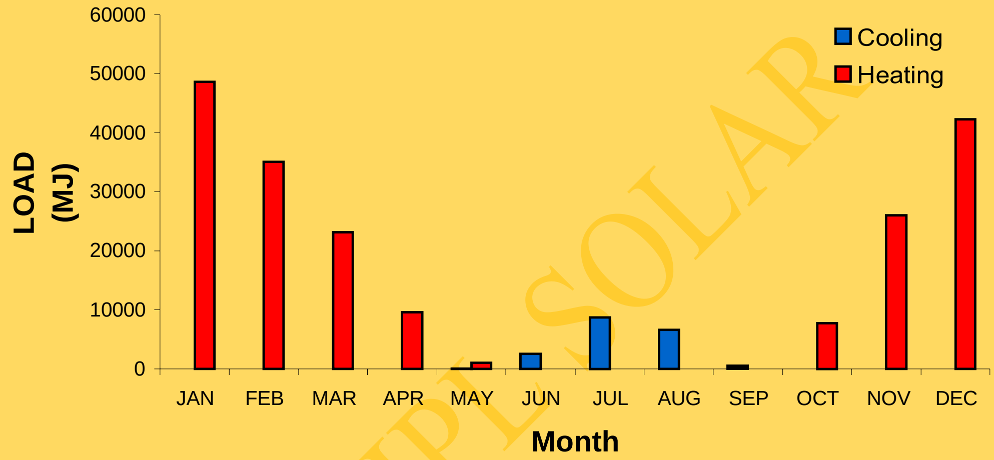
(a) Design Parameters

(i) Building orientation

East-west orientation (base case) is better than a north-south orientation.

(ii) Glazing type

Double-glazing with low-E coated glass gives the best performance. It reduces the load by 20.2% in comparison with plain glass (base case). Single reflective coated glazing is not recommended. Double-glazing with reflective coated glass and double-glazing with clear glass can also be used to reduce the loads by 16.7 and 19.1% respectively.



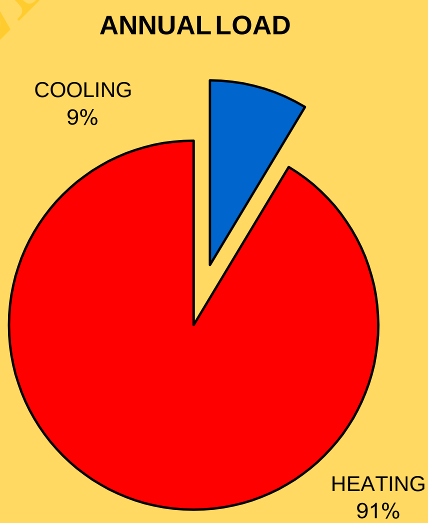


Fig. 5.73 Monthly and annual heating and cooling loads of the conditioned bungalow - Srinagar (cold and cloudy climate)

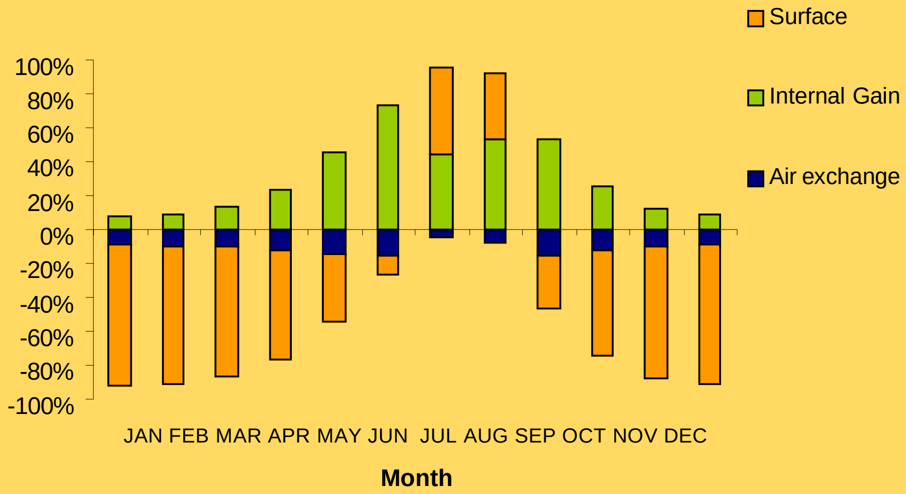

Surface
Internal Gain
Air exchange
100%
80%
60%
40%
20%
0%
-20%
-40%
-60%
-80%
-100%
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
Month

Fig. 5.74 Component-wise distribution of percentage heat gains and losses on a monthly basis of the conditioned bungalow- Srinagar (cold and cloudy climate)

Table 5.48 Room-wise distribution of the monthly and annual loads of the conditioned bungalow - Srinagar (cold and cloudy climate)

Month	Cooling load (MJ)							
	BED1	LIVDIN	KIT	BED2	BED3	BED4	BED5	Total
JAN	0	0	0	0	0	0	0	0
FEB	0	0	0	0	0	0	0	0
MAR	0	0	0	0	0	0	0	0
APR	0	0	0	0	0	0	0	0
MAY	0	0	60	0	0	0	0	60
JUN	47	713	789	277	316	197	203	2542
JUL	459	2851	1497	1119	1019	883	900	8728
AUG	270	2252	1297	780	772	602	659	6633
SEP	1	9	487	6	12	4	6	525
OCT	0	0	7	0	0	0	0	7
NOV	0	0	0	0	0	0	0	0
DEC	0	0	0	0	0	0	0	0
Total	777	5825	4137	2182	2119	1686	1769	18495

Month	Heating load (MJ)							
	BED1	LIVDIN	KIT	BED2	BED3	BED4	BED5	Total
JAN	4187	20852	2908	6	4223	5299	5219	48634
FEB	3094	14916	2011	4	3040	3864	3757	35029
MAR	2112	10079	1134	3	1935	2561	2461	23168
APR	964	4262	467	1	686	1043	977	9592
MAY	59	737	119	0	13	24	23	1010
JUN	0	3	0	0	0	0	0	3
JUL	0	0	0	0	0	0	0	0
AUG	0	0	0	0	0	0	0	0
SEP	0	0	0	0	0	0	0	0
OCT	864	3005	382	1	628	984	731	7768
NOV	2429	10712	1302	3	2330	3037	2752	26026
DEC	3724	17860	2409	5	3711	4690	4541	42225
Total	17434	82426	10731	24	16565	21502	20461	193452

BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5

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Table 5.49 Annual savings due to building design and operational parameters for the conditioned bungalow - Srinagar (cold and cloudy climate)

Parameter	Annual load (MJ)			Energy saving	
	Cooling	Heating	Total	(MJ)	(%)
Base case	18495	193452	211948	--	--
Orientation (longer axis)					
North-south	19860	197797	217657	-5710	-2.7
Glazing type					
Double clear	20635	150914	171549	40399	19.1
Single reflective coated	12540	207456	219996	-8048	-3.8
Double reflective coated	14725	161847	176572	35376	16.7
Double low-E	17355	151847	169202	42746	20.2
Shading					
10%	16847	197154	214001	-2053	-1.0
20%	15239	200872	216110	-4163	-2.0
50%	10978	212205	223183	-11235	-5.3
Wall type					
Thermocol (EPS) insulated brick wall	20055	135295	155350	56598	26.7
Concrete block wall	18461	241827	260288	-48340	-22.8
Autoclaved cellular concrete block	20176	139658	159834	52114	24.6
Roof type					
Uninsulated RCC roof	20096	206701	226797	-14849	-7.0
PUF insulated RCC roof	15791	168847	184637	27310	12.9
Colour of external surface					
White	15137	201122	216259	-4311	-2.0
Cream	16228	198554	214782	-2834	-1.3
Dark grey	22063	186040	208103	3845	1.8
Air exchanges					
1.0 ach	17444	211442	228886	-16938	-8.0
1.5 ach	16525	228943	245469	-33521	-15.8
Internal gain					
50%	12331	207650	219981	-8033	-3.8
No internal gain	7689	222912	230601	-18653	-8.8
Set point - cooling: 26℃ - heating: 19℃	175620	11120	186740	25208	11.9
Scheduling of air exchanges	17152	193458	210610	1338	0.6

(ii) Shading

Shading of windows is not desirable in this cold and cloudy climate. If 50% of the window areas are shaded throughout the year, the annual load increases by 5.3%.

(iii) Wall type

Insulation of walls helps to improve the performance significantly. Thermocol insulation can save annual loads by 26.7% and autoclaved cellular concrete block walls (e.g., Siporex) can save 24.6% as compared to a brick wall (base case).

Plain concrete block wall increases the load by 22.8% and hence needs to be avoided.

(iv) Roof type

Insulation of the roof improves the performance of the building. Polyurethane foam (PUF) insulation brings down the load by 12.9%. In contrast, a plain uninsulated RCC roof increases the load by 7.0%.

(v) Colour of the external surface

Dark grey colour is suitable due to its higher absorptivity.

(vi) Air exchanges

A lower air change rate of 0.5 ach is desirable for reducing the loads.

- Srinagar (cold and cloudy climate)

Room	Yearly room temperature(°C)			Comfortable hours in a year(h)	Percentage of yearly comfortable hours
	MIN	MAX	AVG		
BED1	2.6	27.6	15.6	5112	58
LIVDIN	2.3	28.3	15.8	5134	59
KIT	3.4	29.5	16.7	5090	58
BED2	1.8	28.7	15.8	5035	57
BED3	2.2	28.7	15.9	5053	58
BED4	2.4	28.3	15.9	5128	59
BED5	2.5	28.4	16.3	5138	59
Ambient	-1.1	28.8	12.9	3911	45

MIN = Minimum, MAX = Maximum, AVG = Average
BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5

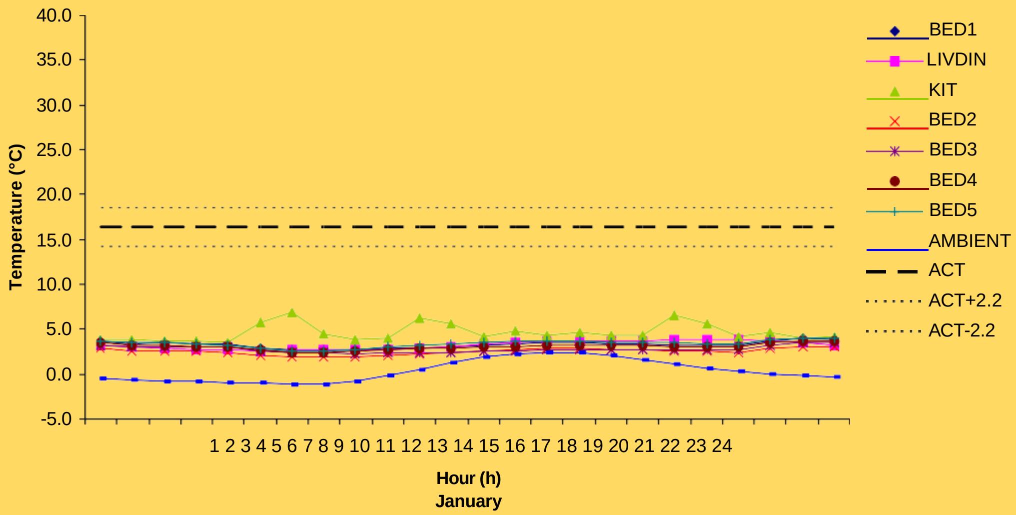
Table 5.51 Performance of the non-conditioned bungalow on a monthly basis
(b) Srinagar (cold and cloudy climate)

Comfort index	Month	Room						
		BED1	LIVDIN	KIT	BED2	BED3	BED4	BED5
Comfort fraction	JAN	-1.48	-1.49	1.18	-1.65	-1.59	-1.53	-1.46
	FEB	-1.02	-0.99	0.72	-1.13	-1.08	-1.03	-0.94
	MAR	-0.36	-0.32	0.09	-0.38	-0.34	-0.31	-0.24
	APR	0.27	0.28	0.45	0.32	0.35	0.36	0.40
	MAY	0.71	0.73	0.84	0.84	0.84	0.84	0.86
	JUN	1	1	1	1	1	1	1
	JUL	1	1	0.98	1	1	1	1
	AUG	1	1	0.99	1	1	1	1
	SEP	0.93	0.94	0.98	0.97	0.99	0.98	0.99
	OCT	0.21	0.36	0.51	0.23	0.29	0.28	0.44
	NOV	-0.61	-0.45	0.26	-0.71	-0.63	-0.61	-0.41
	DEC	-1.2	-1.17	0.88	-1.36	-1.29	-1.24	-1.13

BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5

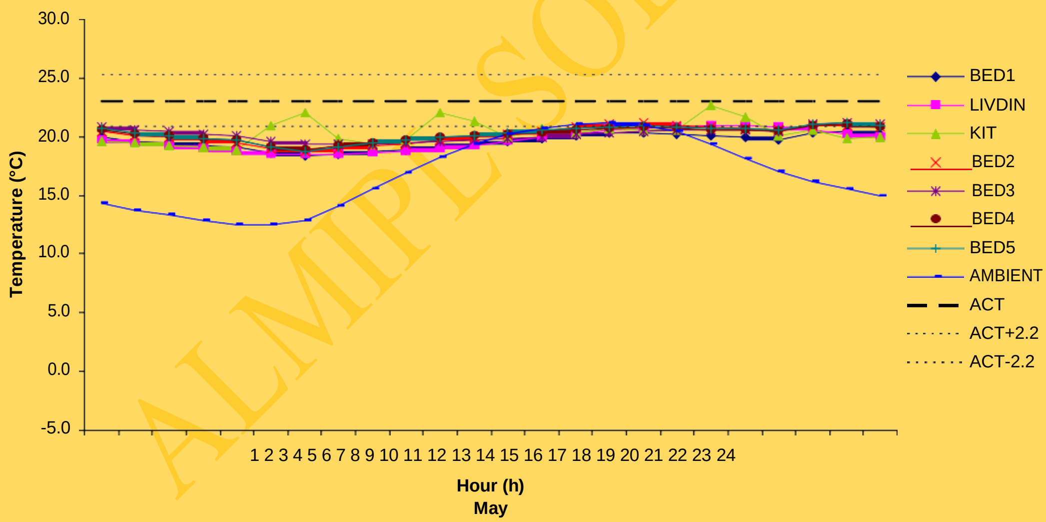
all the rooms are comfortable for 57 to 59% of the time. In other words, all rooms are uncomfortable for more than 40% of the year. The performance of the building on a monthly basis is presented in terms of the comfort fraction (CF) in Table 5.51. It is seen that the rooms are very uncomfortable in winters (November to March), as negative CF values indicate acute discomfort. January is the most uncomfortable month with CF values ranging from -1.18 to -1.59. Hence, heating is a prime requirement from the design point of view. The house is comfortable from June to September. The hourly variation of room temperatures for a typical winter day of January and summer day of May are plotted in Figs. 5.75 and 5.76 respectively. It is seen that in January, all the rooms are uncomfortably cool throughout the day with temperatures being less than 5°C.

Thus, heating is required in winter and the air change rate should be minimum in this season. In May, all the rooms are very close to the lower limit of the comfort zone.



BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5

Fig. 5.75 Hourly variation of room temperatures of the non-conditioned bungalow in January - Srinagar (cold and cloudy climate)



BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5

Fig. 4.76 Hourly variation of room temperatures of the non-conditioned bungalow in May - Srinagar (cold and cloudy climate)

Table 5.52 presents the change in the number of comfortable hours in a year due to various parameters for a bedroom (Bed2). The corresponding percentage increase or decrease (-) in comfortable hours compared to the base case is shown in the table. None of the parameters show any significant effect, which implies that the **base case design** of the bungalow is reasonably satisfactory in this climate.

Table 5.52 Improvement in the performance of the non-conditioned bungalow due to building design and operational parameters - Srinagar (cold and cloudy climate)

Parameter	Comfortable hours in a year (h)	Percentage increase in comfortable hours
Base case	5035	-
Orientation (longer axis)		
North-south	4893	-2.8
Glazing type		
Double clear	4852	-3.6
Double low-E	5045	0.2
Single reflective coated	5103	1.4
Double reflective coated	5116	1.6
Shading		
10%	5107	1.4
20%	5110	1.5
50%	5061	0.5
Wall type		
Concrete block wall	4937	-1.9
Thermocol (EPS) insulated brick wall	4747	-5.7
Autoclaved cellular concrete block	4805	-4.6
Roof type		
Uninsulated RCC roof	4861	-3.5
PUF insulated RCC roof	5071	0.7
Colour of external surface		
Cream	5101	1.3
Dark grey	4861	-3.5
White	5105	1.4
Air exchanges		
0.5 ach	4869	-3.3
1.0 ach	4925	-2.2
Internal gain		
No internal gain	5078	0.9
50%	5092	1.1

5.5.6 Cold and Sunny Climate (Representative city: Leh)

1.5.6.1 Commercial Building

Figure 5.77 shows a distribution of the annual and monthly heating and cooling loads of a commercial building located at Leh. On an annual basis, the heating load is predominant. It is significantly high during the months from October to April, being maximum in January. The months from May to September require comparatively less heating. In addition to heating, cooling is also required for about four months, from June to September. Figure 5.78 shows the distribution of percentage of loads through various building components on a monthly basis. The building loses net heat throughout the year primarily due to air exchanges and surface losses. The heat loss through surfaces is generally higher than that through air exchanges. In the months of July and August, the heat gains and losses more or less balance each other out, the main gain being due to people and equipment. During the other months, annual loads can be reduced by controlling air exchanges and surface losses. This could be achieved by reducing glazing areas, using appropriate building materials, and controlling the surfaces exposed to direct solar radiation.

The floor-wise monthly and annual loads are presented in Table 5.53 It is seen that the usage pattern of the building has a significant impact on the loads. For instance, the energy required for heating is maximum on the ground floor. This is because the shutters are frequently opened on ground floor, resulting in a high heat loss due to air exchanges. Measures such as sealing all cracks, providing air lock lobbies, etc. on ground floor can reduce such heat loss. Similarly, the loads of the second and third floor are significantly higher than those of the other floors as they are occupied on a 24-hour basis throughout the week.

Table 5.54 presents the effects of building parameters on the annual loads of the commercial building for Leh conditions. The consequent percentage load reductions compared to the base case are also tabulated. It may be noted that the total annual load of the building is quite high and hence even a one percent reduction in this load would result in significant energy savings. The following guidelines are recommended for improving the performance of the commercial building for the Leh climate:

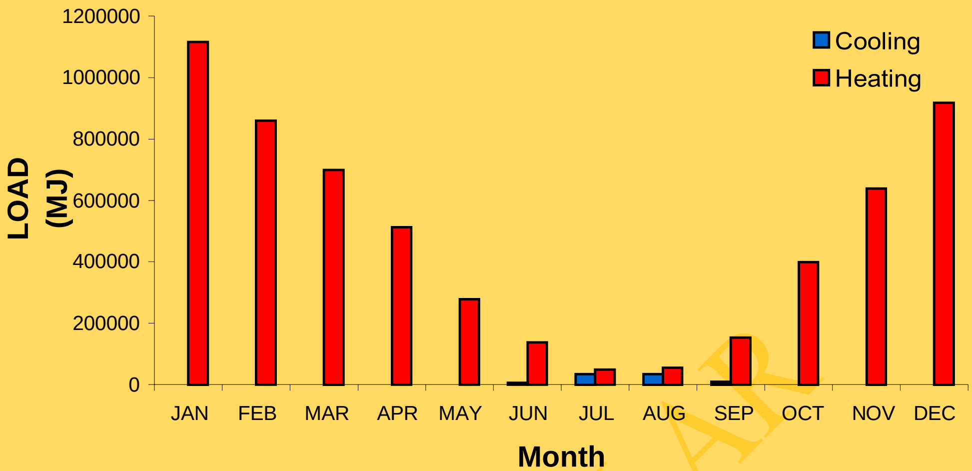
(a) Design Parameters

(i) Building orientation

Appropriate orientation of the building can reduce the annual load significantly. The building (Fig.5.1) with its glazed curtain wall facing south-west (base case) is recommended over other orientations.

(ii) Glazing type

Both double-glazing with low-E glass and double clear glass perform better than single pane reflective coated glass (base case); the annual load is reduced by 29.7% in both cases. Plain glass and double reflective coated glass also decrease the annual load by 7.2 and 25.4 respectively.



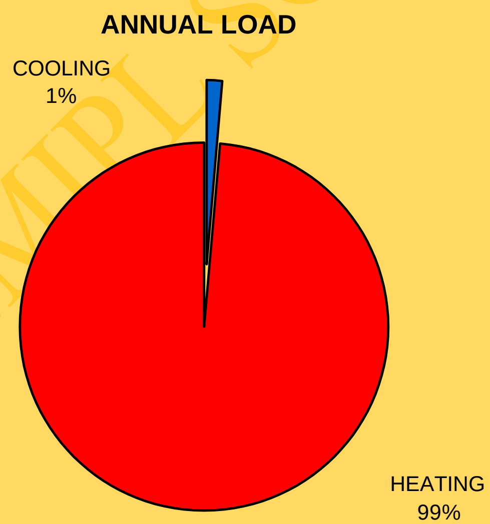


Fig. 5.77 Monthly and annual heating and cooling loads of the commercial building -Leh (cold and dry climate)

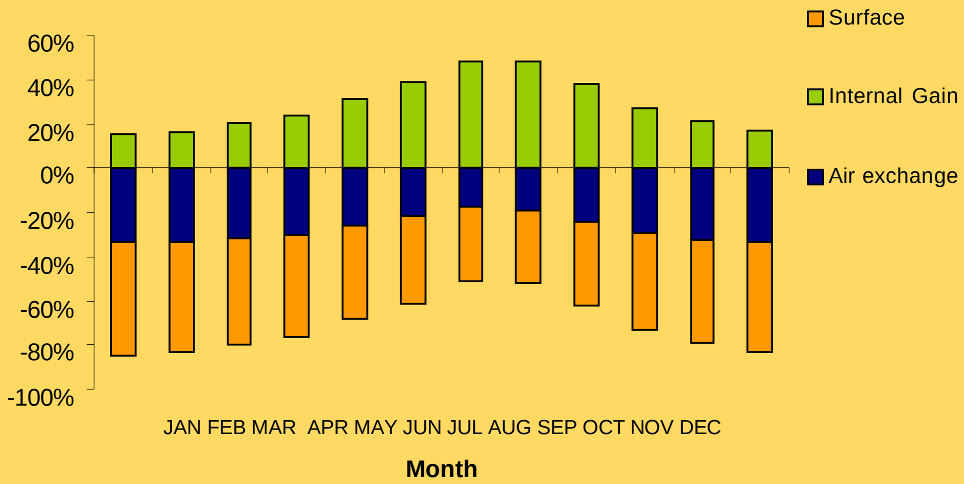


Fig. 5.78 Component-wise distribution of percentage heat gains and losses on a monthly basis of the commercial building – Leh (cold and dry climate)

Table 5.53 Floor wise distribution of the monthly and annual loads of the commercial building - Leh (cold and dry climate)

Month	Cooling load (MJ)								
	GR	F1	F2	F3	F4	F5	F6	F7	Total
JAN	0	0	0	0	0	0	0	0	0
FEB	0	0	0	0	0	0	0	0	0
MAR	0	0	0	0	0	0	0	0	0
APR	0	0	0	0	0	0	0	0	0
MAY	0	0	0	6	0	0	0	0	6
JUN	0	0	1534	3401	957	0	0	0	5893
JUL	0	454	8087	10949	8154	790	5437	0	33871
AUG	0	396	8308	11282	8412	745	5158	0	34301
SEP	0	0	2383	4206	1583	0	33	0	8205
OCT	0	0	0	15	0	0	0	0	15
NOV	0	0	0	0	0	0	0	0	0
DEC	0	0	0	0	0	0	0	0	0
Total	0	850	20312	29860	19106	1535	10628	0	82291

Month	Heating load (MJ)								
	GR	F1	F2	F3	F4	F5	F6	F7	Total
JAN	335259	63826	174469	178341	66427	95462	106071	95428	1115284
FEB	268276	47500	138344	140984	48059	70437	76172	70219	859990
MAR	223315	38232	114101	115390	35279	56810	58422	57821	699369
APR	167668	26507	85522	86725	22043	41009	39571	43124	512171
MAY	94480	13758	47187	47344	8414	21792	17109	27757	277840
JUN	49381	6303	25935	25867	2694	8189	5788	13583	137740
JUL	19402	2243	9720	9749	351	2039	1100	4117	48720
AUG	23316	2674	9972	10116	369	2302	1360	4657	54766
SEP	56770	6912	28752	28541	3260	8792	6843	13299	153167
OCT	138321	20098	65259	65704	14216	31100	28992	36117	399806

NOV	210467	34418	101885	103109	30414	51515	53521	53524	638853
DEC	287767	49286	151585	154298	49934	73305	79488	72890	918553
Total	1874423	311756	952731	966167	281459	462751	474437	492535	5816259

GR=Ground Floor, F1=First floor, F2=Second floor, F3=Third Floor, F4=Fourth floor, F5=Fifth floor, F6=Sixth Floor, F7=Seventh floor

Table 5.54 Annual savings due to building design and operational parameters

for the commercial building- Leh (cold and dry climate)

Parameter	Annual load (MJ)			Energy saving	
	Cooling	Heating	Total	(MJ)	(%)
Base case	82291	5816259	5898550	--	--
Orientation (longer axis)					
North-south	56723	6312067	6368790	-470240	-8.0
Northeast-southwest	41363	6378534	6419897	-521347	-8.8
East-west	77314	6057868	6135182	-236632	-4.0
Glazing type					
Single clear	168325	5307770	5476094	422456	7.2
Double clear	241331	3907648	4148979	1749571	29.7
Double low-E	181171	3963253	4144425	1754126	29.7
Double reflective coated	136910	4264346	4401255	1497295	25.4
Glazing size (restricted to 1.2m height)	65854	5271611	5337465	561086	9.5
Shading					
10%	70201	5914816	5985017	-86467	-1.5
20%	59284	6014895	6074179	-175629	-3.0
50%	33554	6324528	6358082	-459532	-7.8
Wall type					
Autoclaved cellular concrete block	343802	3855500	4199302	1699248	28.8
Colour of external surface					
Dark grey	107487	5567823	5675310	223240	3.8
Air exchange rate					
0.5	97199	5192740	5289939	608611	10.3
2	62926	7043581	7106507	-1207956	-20.5
4	43126	9444231	9487358	-3588807	-60.8
Internal gain					
10%	0	8840177	8840177	-2941626	-49.9
50%	324	7422661	7422985	-1524435	-25.8
No internal gain	0	9209868	9209868	-3311317	-56.1
Set point - cooling: 25 ºC - heating: 20 ºC	32268	5434517	5466785	431766	7.3
Scheduling of air exchanges	96520	5320991	5417511	481039	8.2

(i)Window size

Compared to a fully glazed curtain wall, the reduction of the glazing size to a 1.2 m height decreases the annual load by 9.5%. Thus, the use of larger expanse of glass in such a building is not desirable as it leads to higher annual loads. This is due to high internal gains of the commercial building.

(ii)Shading

The shading of windows in this climate is not desirable. If 50% of the window areas are shaded throughout the year, the percentage load increase is 7.8.

(iii)Wall type

Walls having a low U-value (insulating type such as autoclaved cellular concrete block) reduce loads compared to the concrete block wall (base case) by 28.8%. Thus, insulation of walls is recommended.

(iv)Colour of external surface

Dark colours should be preferred for external surfaces due to their high absorptivities. For example, if dark grey is used, the percentage reduction in load is 3.8 compared to white surfaces (base case).

(v)Air exchanges

A lower air change rate (0.5 ach) is more effective than higher ones of 1, 2 and 4 per hour. It reduces the annual load by 10.3% compared to the base case of 1 ach.

(c) Operational Parameters

The operational parameters such as internal gain, set point and scheduling of air changes can help in reducing the annual load of the building. The effects are summarised as follows.

(i)Internal gain

In cold climates, the internal gains help to keep the building warm and hence are preferable.

(ii)Set Point

The annual load of the building reduces if the set points for comfort cooling and heating are relaxed. If the cooling and heating set points of 25 and 20^{0}C respectively are used (compared to 24 and 21^{0}C), the percentage reduction in annual load is 7.3. Thus, a change in the expectation of comfort can lead to significant savings.

(iii)Scheduling of air exchanges

The scheduling of air changes to control air entry during cooler periods (such as nights or winters) and promote it during warmer periods (during daytime or summer) can lead to significant reduction of annual load; the percentage load reduction is 8.2.

The combination of all design and operational parameters discussed (excluding building orientation and internal gain), results in a significant load reduction of 62.3% for the commercial building at Leh.

2.5.6.2 Industrial Building

The yearly minimum, maximum and average temperatures, and the number of comfortable hours in a year for the shed and store are given in Table 5.55 for the Leh climate. Winters are very cold with the minimum temperature going as low as -8.7 °C in store and -3.4 °C in the shed, making heating essential in this season. The yearly maximum temperatures of both rooms are quite comfortable, ranging from 22.7 to 27.7 °C, and the average temperatures are quite cool 7.7 °C in Table 5.55 Performance of the industrial building on an annual basis- Leh (cold and dry climate)

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Room	Yearly room temperature(°C)			Comfortable hours in a year (h)	Percentage of yearly comfortable hours
	MIN	MAX	AVG		
Shed	-3.4	27.7	12.2	4535	52
Store	-8.7	22.7	7.7	3769	43
Ambient	-13.9	24.5	4.5	2839	32

MIN = Minimum, MAX = Maximum, AVG = Average

Table 5.56 Performance of the industrial building on a monthly basis- Leh (cold and dry climate)

Comfort index	Month	Room	
		Shed	Store
Comfort fraction	JAN	-1.41	-2.74
	FEB	-1.13	-2.3
	MAR	-0.44	-1.55
	APR	0.16	-1.01
	MAY	0.72	-0.23
	JUN	0.91	0.25
	JUL	0.87	0.65
	AUG	0.91	0.83
	SEP	0.83	0.08
	OCT	0.35	-0.76
	NOV	-0.36	-1.55
	DEC	-1.01	-2.29

the store and 12.2 °C in the shed. The shed is comfortable for about 52% in terms of number of comfortable hours in a year. The store is slightly less comfortable i.e. for 43% of the year. The values of monthly comfort fractions (Table 5.56) show that the shed is very uncomfortable in the months from November to March (negative values of CF indicate acute discomfort).

January is the most uncomfortable month with CF value of -1.41; June and August are relatively comfortable months. The store is very uncomfortable from October to May, January being the most uncomfortable month. August is the most comfortable month for the store. The hourly values of room temperatures for a typical winter day of January and summer day of May are plotted in Figs. 5.79 and 5.80 respectively.

It is seen that in January, both the rooms are close to or below the freezing line, indicating acute discomfort. The shed temperature varies between -2.5 to 2.5 °C. The store temperature is much lower, varying between -7.5 to -4.0 °C. However, the temperatures of both rooms are higher than the ambient. In May, the shed is comfortable in the late afternoons and evenings.

During nights and early mornings, the shed temperature is below the comfort zone. The store temperature in May ranges between 10 and 15 °C and is therefore quite uncomfortable. Thus, heating is required and the air change rate should be minimum

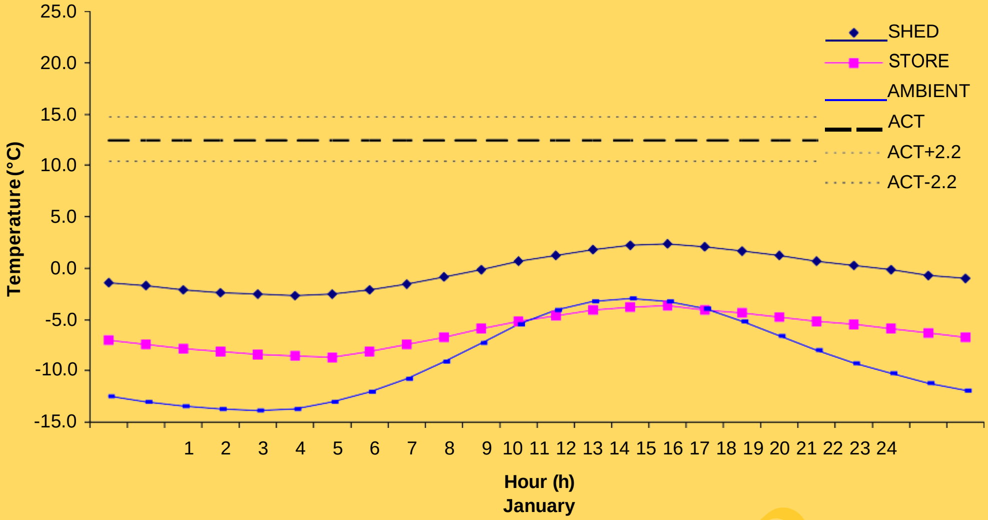


Fig. 5.79 Hourly variation of room temperatures of the industrial building in January - Leh (cold and dry climate)

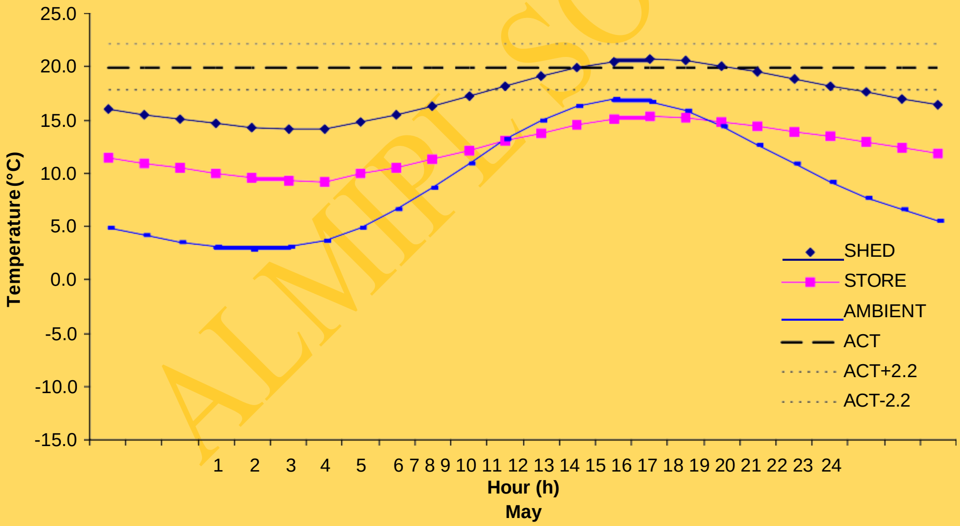


Fig. 5.80 Hourly variation of room temperatures of the industrial building in May - Leh (cold and dry climate)

Table 5.57 Improvement in the performance of the industrial building due to building design and operational parameters- Leh (cold and dry climate)

PARMETERS	Comfortable hours in a year (h)	Percentage increase in comfortable hours
Base case	4535	--
Orientation		
Northwest-southeast	4539	0.1
Northeast-southwest	4536	0.0
East-west	4579	1.0
Glazing type		
Single reflective	4417	-2.6
Double clear	4633	2.2
Double low-E	4631	2.1
Double reflective coated	4585	1.1
Shading		
10%	4512	-0.5
20%	4471	-1.4
Wall type		
Thermocol (EPS) insulated brick wall	4624	2.0
Concrete block wall	4376	-3.5
Autoclaved cellular concrete block	4619	1.9
Roof type		
RCC with bitumen felt water proofing	4534	0.0
RCC with PUF insulation	4760	5.0
Colour of external surface		
White	4357	-3.9
Cream	4386	-3.3
Dark grey	4643	2.4
Air exchanges		
3 ach	4674	3.1
9 ach	4137	-8.8
12 ach	4031	-11.1
Internal gain		
20%	3623	-20.1
40%	3971	-12.4

Table 5.57 presents the change in the number of comfortable hours in a year due to various parameters for shed. The corresponding percentage increase or decrease (-) in comfortable hours compared to the base case is shown in the table.

(a) Design Parameters

5.80

(i)Building orientation

The effect of building orientation does not show any significant effect. East-west orientation is better than the north-south (base case) orientation.

(ii)Glazing type

There is no significant effect of different glazing types compared to plain glass (base case). Double-glazing with clear glass as well as with low-E glass show a marginal increase (about 2.2 %) in yearly comfortable hours.

(iii)Shading

Shading of windows is not desirable in this climate, since the solar gain is needed in this climate. If 20% of the window areas are shaded throughout the year, the annual load increases by 1.4%.

(iv)Wall type

Insulation of walls shows a marginal increase in yearly comfortable hours compared to brick walls (base case).

(v)Roof type

Insulation of the roof improves the performance of the building. Polyurethane foam (PUF) insulation increases the yearly comfortable hours by 5.0%.

(vi)Colour of the external surface

Dark grey is suitable due to its higher absorptivity as compared to light colours.

(Vii)Air exchanges

Air change needs to be reduced compared to the base case of 6 ach.

(a)Operational Parameters

(i)Internal gain

In cold climates, internal gains help to keep the building warm and hence are preferable.

The combination of all design and operational parameters discussed (excluding building orientation and internal gain), results in a 7.9% increase in the yearly comfortable hours for the shed compared to the base case design.

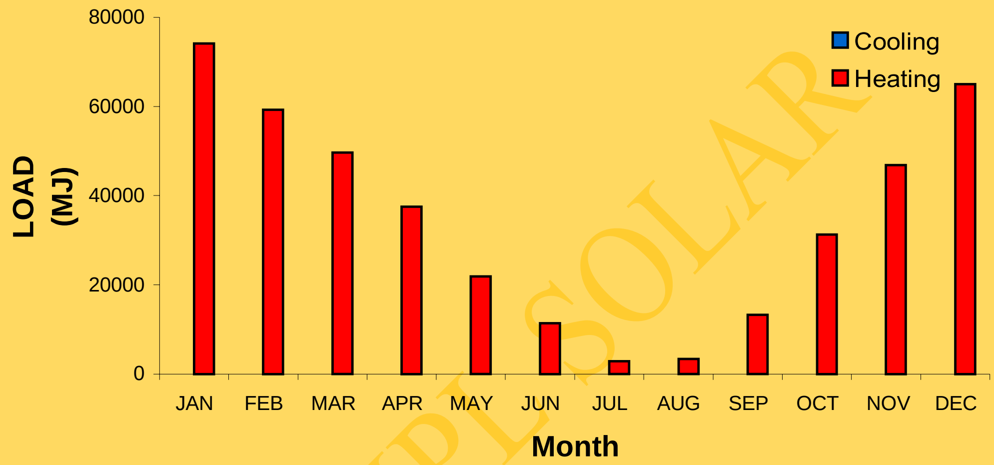
3.5.6.3 Residential Building (Bungalow)

(A)Conditioned building

Figure 5.81 shows the distribution of the annual and monthly heating and cooling loads of the conditioned building for the cold and sunny climate of Leh. On an annual basis, the heating load is predominant, heating being required throughout the year. The load profiles generally follow the climatic conditions. For example, the highest heating load occurs in January, which is the peak winter month. The load in December is also significantly high. The months from June to September display relatively lower heating loads.

The monthly variation of the percentage of loads through various building components is presented in Fig. 5.82. It shows that the heating requirement is primarily due to surface losses. The heat loss through surfaces and air exchanges are higher than the heat gain due to people and equipment throughout the year. Therefore, insulation of surfaces and control of air exchanges could lower the heating loads. In July and August, which represents summer months, the heat gains and losses more or less balance each other and hence the loads are small.

gain due to people and equipment throughout the year. Therefore, insulation of surfaces and control of air exchanges could lower the heating loads. In July and August, which represents summer months, the heat gains and losses more or less balance each other and hence the loads are small.



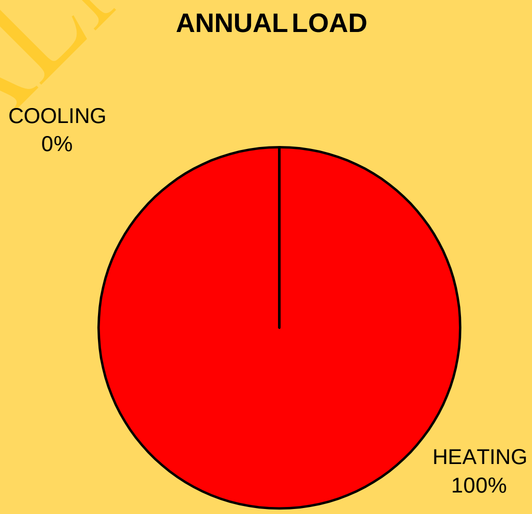


Fig. 5.81 Monthly and annual heating and cooling loads of the conditioned bungalow - Leh (cold and dry climate)

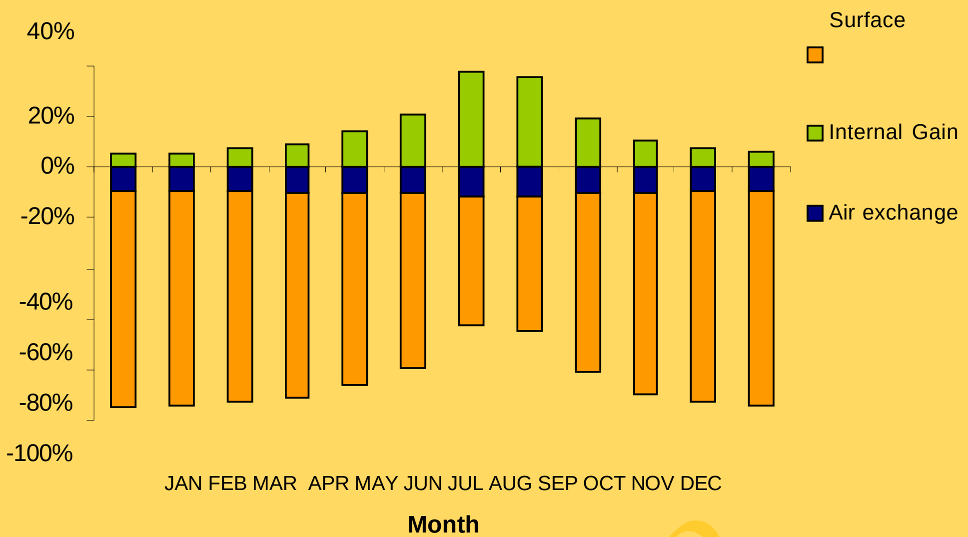


Fig. 5.82 Component-wise distribution of percentage heat gains and losses on a monthly basis of the conditioned bungalow- Leh (cold and dry climate)

Table 5.58 presents the room-wise annual loads for the conditioned bungalow. It is seen that the heating load of the living and dining room is significantly higher than that of other rooms. This is because of the fact that this room is very large and is also partly double storeyed. The heating load of the kitchen is the least due to internal gains from appliances (refrigerator and cooking range). The comparison of bedrooms shows that, the first floor bedroom on the north (Bed3) is the warmest in the house.

The bedroom located in the north-west corner (Bed3) on the same floor is the coolest. This is primarily due to heat losses from larger exposed surfaces and glazed windows.

The effects of building parameters on the annual load are presented in Table 5.59. The consequent percentage load reductions due to these parameters compared to the base case are also shown in the table. Based on the data, the following recommendations are made for increasing the performance of the conditioned bungalow at Leh:

(a) **Design Parameters**

(i) **Building orientation**

The east-west orientation (base case) is better than a north-south orientation.

(ii) **Glazing type**

Double-glazing with clear glass gives the best performance. It reduces the load by 20.9% in comparison with plain glass (base case). Double-glazing with low-E glass and reflective coated glass can also be used to reduce the loads by 20.2 and 15.5% respectively.

(iii) **Shading**

Shading of windows is not recommended for this climate. If 50% of the window areas are shaded throughout the year, the annual load increases by 9.0%.

Table 5.58 Room-wise distribution of the monthly and annual loads of the conditioned bungalow - Leh (cold and dry climate)

Month	Cooling load (MJ)							
	BED1	LIVDIN	KIT	BED2	BED3	BED4	BED5	Total
JAN	0	0	0	0	0	0	0	0
FEB	0	0	0	0	0	0	0	0
MAR	0	0	0	0	0	0	0	0
APR	0	0	0	0	0	0	0	0
MAY	0	0	0	0	0	0	0	0
JUN	0	0	0	0	0	0	0	0
JUL	0	0	0	0	0	0	0	0
AUG	0	0	0	0	0	0	0	0
SEP	0	0	0	0	0	0	0	0
OCT	0	0	0	0	0	0	0	0
NOV	0	0	0	0	0	0	0	0
DEC	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0

Month	Heating load (MJ)							
	BED1	LIVDIN	KIT	BED2	BED3	BED4	BED5	Total
JAN	6531	31004	4961	9093	6482	8160	7914	74145
FEB	5294	24627	3953	7299	5178	6567	6344	59262
MAR	4484	20923	3255	6035	4232	5455	5286	49669
APR	3474	15839	2412	4525	3114	4106	4006	37476
MAY	2116	9706	1291	2516	1643	2335	2293	21899
JUN	1215	5312	676	1210	686	1157	1141	11398
JUL	356	1719	264	158	31	160	159	2847
AUG	438	1939	282	252	32	251	209	3403
SEP	1476	5411	722	1717	1028	1572	1339	13264
OCT	3017	12640	1886	4037	2732	3653	3289	31254
NOV	4349	18898	2991	6023	4190	5395	4957	46803
DEC	5849	26845	4241	8115	5737	7256	6952	64995
Total	38599	174863	26934	50979	35083	46066	43889	416414

BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5

Table 5.59 Annual savings due to building design and operational parameters for the conditioned bungalow - Leh (cold and dry climate)

Parameter	Annual load (MJ)			Energy saving	
	Cooling	Heating	Total	(MJ)	(%)
Base case	0	416414	416414	- -	--
Orientation (longer axis)					
North-south	11	421989	421999	-5585	-1.3
Glazing type					
Double clear	7	329279	329286	87128	20.9
Single reflective coated	0	444371	444371	-27957	-6.7
Double reflective coated	0	351721	351721	64693	15.5
Double low-E	0	332115	332115	84299	20.2
Shading					
10%	0	423797	423797	-7383	-1.8
20%	0	431212	431212	-14798	-3.6
50%	0	454003	454003	-37589	-9.0
Wall type					
Thermocol (EPS) insulated brick wall	197	299289	299487	116927	28.1
Concrete block wall	14	513533	513547	-97133	-23.3
Autoclaved cellular concrete block	122	308259	308381	108033	25.9
Roof type					
Uninsulated RCC roof	0	442260	442260	-25846	-6.2
PUF insulated RCC roof	0	369257	369257	47157	11.3
Colour of external surface					
White	0	431877	431877	-15463	-3.7
Cream	0	426690	426690	-10276	-2.5
Dark grey	36	401241	401277	15137	3.6
Air exchanges					
1.0 ach	0	451872	451872	-35458	-8.5
1.5 ach	0	486393	486393	-69979	-16.8
Internal gain					
50%	0	438643	438643	-22229	-5.3
No internal gain	0	462050	462050	-45636	-11.0
Set point - cooling: 26 °C - heating: 19 °C	0	391280	391280	25134	6.0
Scheduling of air exchanges	0	416414	416414	0	0.0

(iv) **Wall type**

Insulation of walls helps to improve the performance significantly. Thermocol insulation can save annual loads by 28.1% and autoclaved cellular concrete block walls (e.g., Siporex) can save annual loads by 25.9% as compared to a brick wall (base case). Plain concrete block wall increases the load by 23.3% and hence should be avoided.

(v) **Roof type**

Insulation of the roof improves the performance of the building. Polyurethane foam (PUF) insulation brings down the loads by 11.3%. In contrast, a plain uninsulated RCC roof increases the load by 6.2%.

(vi) **Colour of the external surface**

Dark grey is suitable due to its higher absorptivity, it improves performance by 3.6%.

(vii) **Air exchanges**

A lower air change rate of 0.5 ach is desirable for reducing loads.

(b) **Operational Parameters**

The operational parameters such as internal gain, set point and scheduling of air changes can help in reducing the annual load of the building. The effects are summarised as follows.

(i) Internal gain

In cold climates, internal gains help to keep the building warm and hence are desirable.

(ii) Set point

Lowering the operating parameters for comfort cooling and heating can reduce the cooling loads by 6.0%. Thus a change in the expectation of comfort can lead to significant savings.

(iii) Scheduling of air exchanges

The scheduling of air changes is not desirable in this cold climate.

The combination of all design and operational parameters discussed (excluding building orientation and internal gain), results an appreciable load reduction of 73.0% for a conditioned bungalow at Leh.

(B) Non-conditioned building

Table 5.60 presents the yearly minimum, maximum and average temperatures, and the number of comfortable hours in a year for all the rooms of the non-conditioned bungalow for Leh. It is seen that the yearly minimum values of room temperatures are below freezing point, indicating acute discomfort in winters.

The room attaining the lowest temperature of -7.2 °C is the bedroom on the first floor (Bed2) in the northwest corner of the house. The maximum temperatures are quite comfortable ranging from 20.1 to 22.2 °C. The warmest room is the kitchen, which attains a maximum temperature of 22.2 °C and has an average temperature of 9.2 °C in a year. Therefore, summers are comfortable whereas winters are extremely uncomfortable. In terms of the number of hours in a year, all rooms are comfortable in a range of 42 to 47% of the year only. In other words, all rooms are uncomfortable for more than 53% of the year.

Thus, a change in design is indicated to reduce discomfort. Table 5.61 presents the performance of the building on a monthly basis in terms of the comfort fraction (CF). The rooms are very uncomfortable from October to May, as shown by negative CF values, which

Table 5.60 Performance of the non-conditioned bungalow on an annual basis - Leh (cold and dry climate)

Room	Yearly room temperature(°C)			Comfortable hours in a year(h)	Percentage of yearly comfortable hours
	MIN	MAX	AVG		
BED1	-6.0	20.1	7.8	3676	42
LIVDIN	-6.0	21	8.4	3963	45
KIT	-4.7	22.2	9.2	4097	47
BED2	-7.2	21.3	7.8	3686	42
BED3	-6.3	21.4	8.1	3708	42
BED4	-6.4	21.0	8.1	3691	42
BED5	-6.0	21.1	8.7	4014	46
Ambient	-13.9	24.5	4.5	2839	32

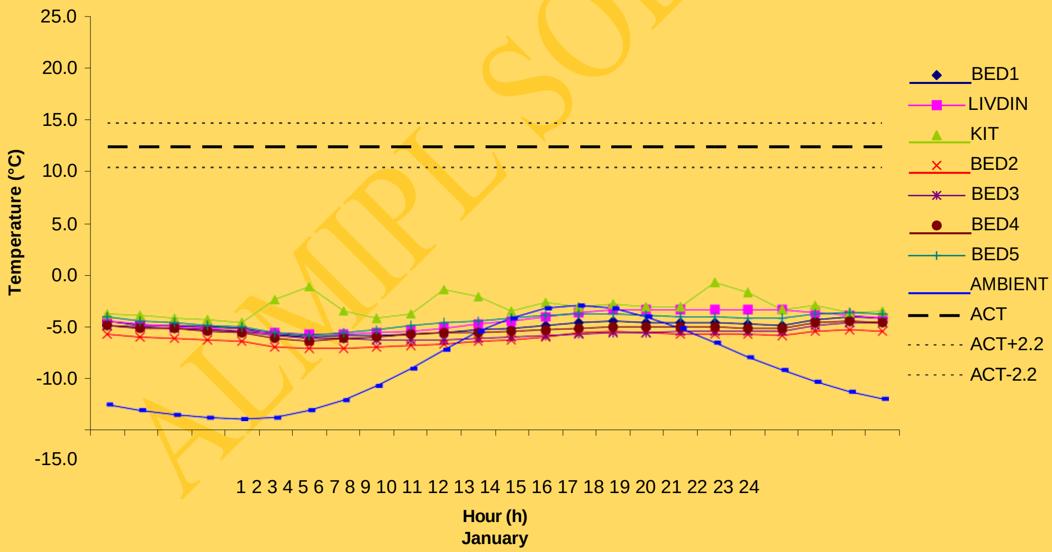
MIN = Minimum, MAX = Maximum, AVG = Average
BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5

Table 5.61 Performance of the non-conditioned bungalow on a monthly basis - Leh (cold and dry climate)

Comfort index	Month	Room						
		BED1	LIVDIN	KIT	BED2	BED3	BED4	BED5
Comfort fraction	JAN	-2.47	-2.35	-2.03	-2.72	-2.6	-2.55	-2.35
	FEB	-2.03	-1.91	-1.64	-2.23	-2.12	-2.09	-1.89
	MAR	-1.37	-1.27	-1.03	-1.45	-1.37	-1.35	-1.22
	APR	-0.85	-0.81	-0.61	-0.85	-0.79	-0.78	-0.70
	MAY	-0.23	-0.19	-0.01	-0.11	-0.08	-0.10	-0.07
	JUN	0.15	0.18	0.33	0.33	0.35	0.33	0.33
	JUL	0.57	0.64	0.73	0.80	0.82	0.78	0.79
	AUG	0.51	0.60	0.69	0.71	0.74	0.69	0.74
	SEP	-0.05	0.13	0.25	0.05	0.10	0.07	0.23
	OCT	-0.76	-0.52	-0.39	-0.81	-0.71	-0.74	-0.49
	NOV	-1.46	-1.17	-1.01	-1.63	-1.5	-1.51	-1.18
	DEC	-2.09	-1.92	-1.64	-2.31	-2.18	-2.15	-1.91

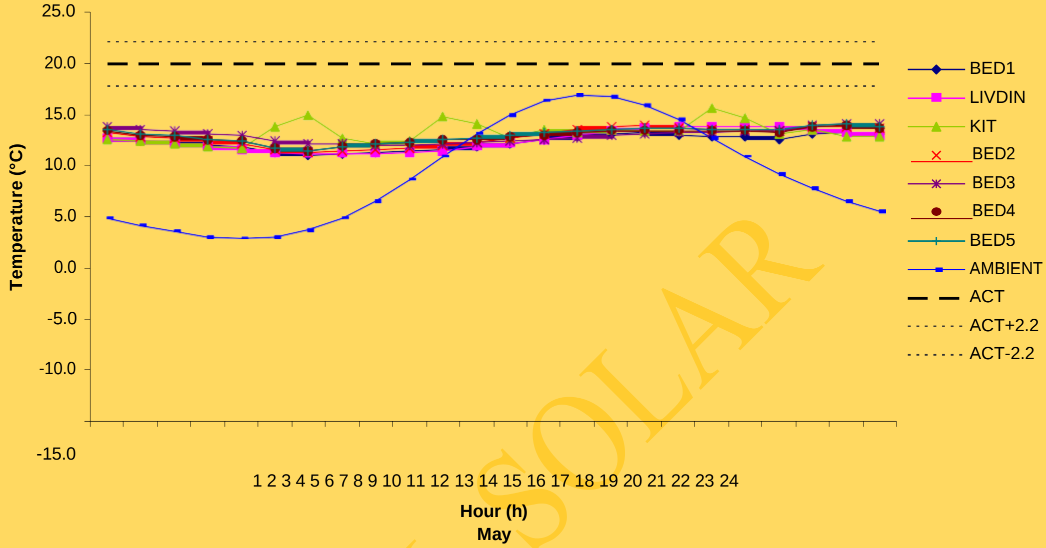
BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5

indicate acute discomfort. January is the most uncomfortable month with CF values ranging from -2.03 to -2.72. Hence, heating is a prime requirement from the design point of view. The house is relatively comfortable in July (CF values ranging from 0.57 to 0.82), and August (CF values ranging from 0.51 to 0.74). The hourly variation of room temperatures for a typical winter day of January and summer day of May are plotted in Figs. 5.83 and 5.84 respectively. It is seen that in January, all rooms are below the freezing line. In fact, the temperatures are below the comfort zone in the month of May as well. Hence, heating is essential not just in winter but also in the month of May.



BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5

Fig. 5.83 Hourly variation of room temperatures of the non-conditioned bungalow in January - Leh (cold and dry climate)



BED1=Bed room1, LIVDIN= Living and dining room, KIT=Kitchen, BED2=Bed room2, BED3=Bed room3, BED4=Bed room4, BED5=Bed room5

Fig. 5.84 Hourly variation of room temperatures of the non-conditioned bungalow in May - Leh (cold and dry climate)

Table 5.62 Improvement of the non-conditioned bungalow performance due to building design and operational parameters - Leh (cold and dry climate)

Parameter	Comfortable hours in a year(h)	Percentage increase in comfortable hours (%)
Base case	3686	-
Orientation (longer axis)		
North-south	3698	0.3
Glazing type		
Double clear	3824	3.7
Double low-E	3722	1.0
Single reflective coated	3654	-0.9
Double reflective coated	3693	0.2
Shading		
10%	3674	-0.3
20%	3665	-0.6
50%	3641	-1.2
Wall type		
Concrete block wall	3614	-2.0
Thermocol (EPS) insulated brick wall	3937	6.8
Autoclaved cellular concrete block	3911	6.1
Roof type		
Uninsulated RCC roof	3681	-0.1
PUF insulated RCC roof	3702	0.4
Colour of external surface		
Cream	3674	-0.3
Dark grey	3700	0.4
White	3669	-0.5
Air exchanges		
1.0 ach	3679	-0.2
1.5 ach	3671	-0.4
Internal gain		
No internal gain	3653	-0.9
50%	3669	-0.5

Table 5.62 presents the change in the number of comfortable hours in a year due to various parameters for a bedroom (Bed 2). The corresponding percentage increase or decrease (-) in comfortable hours compared to the base case is shown in the table.

(a) Design Parameters

(i) Building orientation

Changing the orientation of the building with respect to the base case (east-west) does not affect its thermal performance.

(ii) Glazing type

Double-glazing with clear glass gives the best performance. It increases the yearly comfortable hours by 3.0%. compared to plain glass (base case). Double-glazing with low-E glass shows a marginal improvement.

(iii) Shading

Shading of windows is not desirable in this climate.

(iv) Wall type

Insulation of walls helps to improve the performance significantly. Thermocol insulation and autoclaved cellular concrete block walls increase the yearly comfortable hours by 6.8 and 6.1% respectively.

(v) Roof type

Insulating the roof using polyurethane foam (PUF) insulation increases the performance marginally (0.4%) compared to a roof with brick-bat-coba waterproofing.

(vi) Colour of the external surface

Dark grey colour shows an improvement in the building's performance, but the effect is not very significant over other colours.

(vii) Air exchanges

A lower air change is desirable in this climate.

(b) Operational Parameters

(i) Internal gain

In cold climates, internal gains help to keep the building warm and hence are preferable.

(ii) Scheduling of air exchanges

The scheduling of air changes is not desirable in this climate.

The combination of all design and operational parameters (excluding building orientation and internal gain) significantly improves the building's thermal performance, resulting in an increase in the yearly comfortable hours by 41.5% in the cold and sunny climate of Leh. .

5.6 SUMMARY

In this chapter we have seen how adopting energy efficient practices in architectural design can appreciably reduce the annual loads of buildings. While the first part this chapter (section 5.4) has dealt with general recommendations for designing of buildings in different climates, the major part has been devoted to the detailed analysis of design and operational parameters for three building types (commercial, industrial and residential bungalow) for each of the six climatic zones of India.

For quick and easy reference, the information has been summarised in a set of tables and presented in this section. Table 5.63 summarises the comfort requirements for each climatic zone based on the characteristics of the climate. The corresponding physical manifestations are also given alongside the comfort requirements. Table 5.64 presents the passive techniques that can be used in different climates. The specific guidelines and recommendations for each of the three building types that were elaborated in section 5.5 are summarised in the Tables 5.65 through 5.68.

Passive solar aspects should become an integral part of the overall process of architectural design. Figure 5.85 elucidates such integration process of design step by step.

The upper layer shows the normal sequence that an architect follows, whereas the lower layer shows additional considerations for incorporating the passive solar aspects. While the process of design is essentially iterative, the given diagram is shown to be linear for the sake of simplicity.

The importance of evaluating the thermal performance of the building being designed using simulation techniques, to understand the effectiveness of the design in achieving energy efficiency, cannot be overemphasised. The ultimate benefits of incorporating passive principles far outweigh any apprehensions that an architect may have of the additional work involved.

Table 5.63 Comfort requirements and physical manifestation

1)Hot and Dry Region

OBJECTIVES	PHYSICAL MANIFESTATION
1) <u>Resist heat gain</u>	
a) Decrease exposed surface area	Orientation and shape of building
b) Increase thermal resistance	Insulation of building envelope
c) Increase thermal capacity (Time lag)	Massive structure
d) Increase buffer spaces	Air locks/ lobbies/balconies/verandahs
e) Decrease air exchange rate (Ventilation during day-time)	Weather stripping and scheduling air changes
f) Increase shading	External surfaces protected by overhangs, fins and trees
g) Increase surface reflectivity	Pale colour, glazed china mosaic tiles etc.
2) <u>Promote heat loss</u>	
a) Ventilation of appliances	Provide windows/ exhausts
b) Increase air exchange rate (Ventilation during night-time)	Courtyards/ wind towers/ arrangement of openings
c) Increase humidity levels	Trees, water ponds, evaporative cooling

2)Warm and Humid Region

OBJECTIVES	PHYSICAL MANIFESTATION
1) <u>Resist heat gain</u>	
a) Decrease exposed surface area	Orientation and shape of building
b) Increase thermal resistance	Roof insulation and wall insulation. Reflective surface of roof
c) Increase buffer spaces	Balconies and verandahs
d) Increase shading	Walls, glass surfaces protected by overhangs, fins and trees
e) Increase surface reflectivity	Pale colour, glazed china mosaic tiles, etc.
2) <u>Promote heat loss</u>	
a) Ventilation of appliances	Provide windows/ exhausts
b) Increase air exchange rate (Ventilation throughout the day)	Ventilated roof construction. Courtyards, wind towers and arrangement of openings
c) Decrease humidity levels	Dehumidifiers/ desiccant cooling

3) Moderate Region

OBJECTIVES	PHYSICAL MANIFESTATION
1) <u>Resist heat gain</u>	
a) Decrease exposed surface area	Orientation and shape of building
b) Increase thermal resistance	Roof insulation, and east and west wall insulation
c) Increase shading	East and west walls, glass surfaces protected by overhangs, fins and trees
d) Increase surface reflectivity	Pale colour, glazed china mosaic tiles, etc.
2) <u>Promote heat loss</u>	
a) Ventilation of appliances	Provide windows/ exhausts
b) Increase air exchange rate (Ventilation)	Courtyards and arrangement of openings

4)Cold and Cloudy Region/Cold and Sunny Region

OBJECTIVES	PHYSICAL MANIFESTATION
<u>1) Resist heat loss</u>	
a) Decrease exposed surface area	Orientation and shape of building. Use of trees as wind barriers
b) Increase thermal resistance	Roof insulation, wall insulation and double glazing
c)Increase thermal capacity (Time lag)	Thicker walls
d) Increase buffer spaces	Air locks/ Lobbies
e) Decrease air exchange rate	Weather stripping
f) Increase surface absorptivity	Darker colours
<u>2) Promote heat gain</u>	
a) Reduce shading	Walls and glass surfaces
b) Utilise heat from appliances	
c) Trapping heat	Sun spaces/ green houses/ Trombe walls etc.

5)Composite Region

OBJECTIVES	PHYSICAL MANIFESTATION
<u>1) Resist heat gain in summer and Resist heat loss in winter</u>	
a) Decrease exposed surface area	Orientation and shape of building. Use of trees as wind barriers.
b) Increase thermal resistance	Roof insulation and wall insulation
c) Increase thermal capacity (Time lag)	Thicker walls
d) Increase buffer spaces	Air locks/ Balconies
e) Decrease air exchange rate	Weather stripping
f) Increase shading	Walls, glass surfaces protected by overhangs, fins and trees.
g) Increase surface reflectivity	Pale colour, glazed china mosaic tiles, etc.
<u>2) Promote heat loss in summer/ monsoon</u>	
a) Ventilation of appliances	Provide exhausts
b) Increase air exchange rate (Ventilation)	Courtyards/ wind towers/ arrangement of openings
c) Increase humidity levels in dry summer	Trees and water ponds for evaporative cooling
d) Decrease humidity in monsoon	Dehumidifiers/ desiccant cooling

Table 5.64 Advanced techniques in different climates

CLIMATE	TECHNIQUES																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Hot and dry				✓		✓	✓		✓	✓			✓	✓	✓	✓			✓
Warm and humid											✓	✓							✓
Moderate	No advanced techniques required																		✓
Cold and cloudy Cold and sunny	✓	✓	✓	✓	✓	✓	✓	✓					✓				✓		✓
Composite*																		✓	✓

* If cooling is the major requirement, the techniques listed under hot and dry climate may be adopted. In case of heating requirement, the techniques for cold climates may be used. Techniques such as roof pond, roof radiation trap, solar chimney, earth berming, etc. which find dual usage can also be incorporated.

1. Direct gain
2. Trombe wall
3. Water wall
4. Solar chimney
5. Transwall
6. Roof pond
7. Roof radiation trap
8. Solarium
9. Evaporative cooling
10. Nocturnal radiation cooling
11. Desiccant cooling
12. Induced ventilation
13. Earth berm
14. Wind tower
15. Earth-air tunnel
16. Curved roof / air vents
17. Cavity wall / insulation
18. Varytherm wall
19. Daylighting

Table 5.65 Design recommendations for the commercial building

Parameter	Jodhpur (Hot & Dry Climate)	Mumbai (Warm & Humid Climate)	Pune (Moderate Climate)	New Delhi (Composite Climate)	Srinagar (Cold & Cloudy Climate)	Leh (Cold & Sunny Climate)
Building Orientation (Due direction of the glazed curtain wall)	NE-SW (south east)	NE-SW (south east)	NE-SW (south east)	NE-SW (south east)	NW-SE (south west)	NW-SE (south west)
Glazing Type	Reflective coated glass (double pane)	Reflective coated glass (double pane)	Reflective coated glass (single pane)	Reflective coated glass (double pane)	Low-E glass (double pane)	Low-E glass (double pane)
Shading of glazing (percent of the total area)	50	50	50	50	0	0
Wall Type	Autoclaved cellular concrete block	Autoclaved cellular concrete block	Concrete block	Concrete block	Autoclaved cellular concrete block	Autoclaved cellular concrete block
Surface Colour (External)	White	White	White	White	Dark grey	Dark grey
Air exchanges (ach)	0.5	0.5	0.5	0.5	0.5	0.5

NE-SW: Northeast-southwest; NW-SE: Northwest-southeast

Table 5.66 Design recommendations for the industrial building

Parameter	Jodhpur (Hot & Dry Climate)	Mumbai (Warm & Humid Climate)	Pune (Moderate Climate)	New Delhi (Composite Climate)	Srinagar (Cold & Cloudy Climate)	Leh (Cold & Sunny Climate)
Building Orientation	NE-SW	NE-SW	NW-SE	E-W	E-W	E-W
Glazing Type	Reflective coated glass (single pane)	Reflective coated glass (single pane)	Reflective coated glass (single pane)	Reflective coated glass (double pane)	Reflective coated glass (single pane)	Clear glass (double pane)
Shading	20	20	20	10	20	0
Wall Type	Concrete block	Concrete block	Concrete block	Brick	Concrete block	Brick wall with thermocol insulation
Roof Type	RCC with bitumen felt waterproofing	RCC with bitumen felt waterproofing	RCC with bitumen felt waterproofing	RCC with brick-bat-coba waterproofing	RCC with PUF insulation	RCC with PUF insulation
Surface Colour (External)	White	White	White	Cream	White	Grey
Air exchanges (ach)	12	12	12	12	12	3

NE-SW: Northeast-southwest; NW-SE: Northwest-southeast; E-W: east-west

Table 5.67 Design recommendations for the bungalow (conditioned)

Parameter	Jodhpur (Hot & Dry Climate)	Mumbai (Warm & Humid Climate)	Pune (Moderate Climate)	New Delhi (Composite Climate)	Srinagar (Cold & Cloudy Climate)	Leh (Cold & Sunny Climate)
Building Orientation	NE-SW (south east)	NE-SW (south east)	NE-SW (south east)	NE-SW (south east)	NW-SE (south west)	NW-SE (south west)
Glazing Type	Reflective coated glass (double pane)	Reflective coated glass (double pane)	Reflective coated glass (single pane)	Reflective coated glass (double pane)	Low-E glass (double pane)	Clear glass (double pane)
Shading	50	50	50	50	0	0
Wall Type	Brick wall with thermocol insulation	Brick wall with thermocol insulation	Brick wall with thermocol insulation	Brick wall with thermocol insulation	Brick wall with thermocol insulation	Brick wall with thermocol insulation
Roof Type	RCC with PUF insulation	RCC with PUF insulation	RCC with PUF insulation	RCC with PUF insulation	RCC with PUF insulation	RCC with PUF insulation
Surface Colour (External)	White	White	White	White	Dark grey	Dark grey
Air exchanges (ach)	0.5	0.5	1.5	0.5	0.5	0.5

NE-SW: Northeast-southwest; NW-SE: Northwest-southeast

Table 5.68 Design recommendations for the bungalow (non-conditioned)

Parameter	Jodhpur (Hot & Dry Climate)	Mumbai (Warm & Humid Climate)	Pune (Moderate Climate)	New Delhi (Composite Climate)	Srinagar (Cold & Cloudy Climate)	Leh (Cold & Sunny Climate)
Building Orientation	Base case (East-west)	Base case (East-west)	Base case (East-west)	Base case (East-west)	Base case (East-west)	North-south
Glazing Type	Reflective coated glass (single pane)	Reflective coated glass (single pane)	Reflective coated glass (single pane)	Reflective coated glass (single pane)	Reflective coated glass (double pane)	Clear glass (double pane)
Shading	50	50	50	50	20	0
Wall Type	Concrete block	Concrete block	Brick	Brick	Brick	Brick wall with thermocol insulation
Roof Type	RCC with PUF insulation	RCC with PUF insulation	RCC with PUF insulation	RCC with PUF insulation	RCC with PUF insulation	RCC with PUF insulation
Surface Colour (External)	White	White	White	White	White	Grey
Air exchanges (ach)	9	9	9	9	1.5	0.5

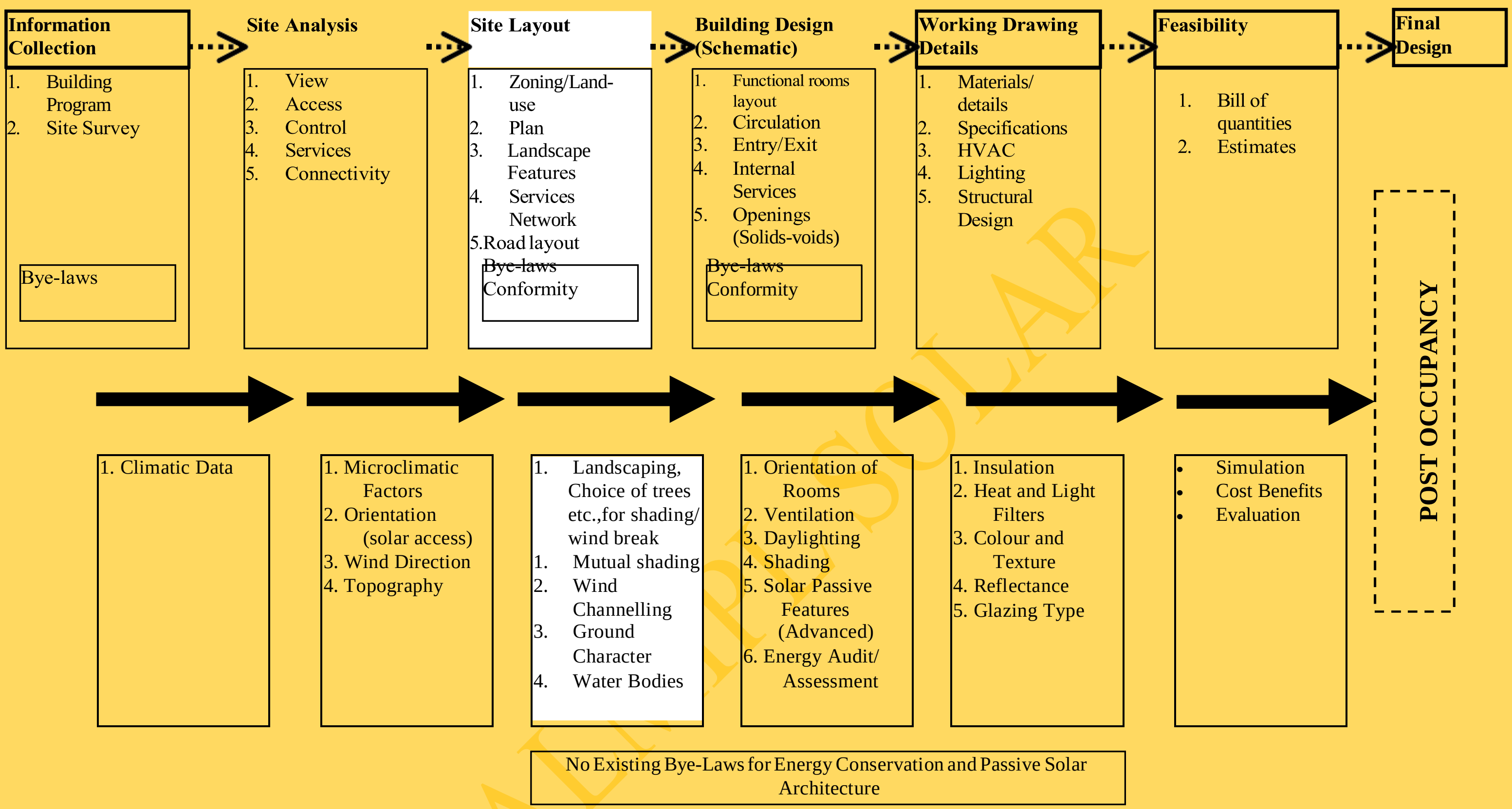


Fig. 5.85 Integrated design process

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APPENDIX V.1

ROOF SURFACE EVAPORATIVE COOLING (RSEC)

Roof surface evaporative cooling (RSEC) can reduce the ceiling surface temperature, consequently leading to a drop in indoor temperatures and cooling loads. This technique is generally adopted in warm climates. We have examined the effect of RSEC for an industrial shed and a residential bungalow (Fig. 5.3 and 5.5). The performance studies of these buildings have been carried out for Jodhpur, Mumbai, Pune and New Delhi which represent hot and dry, warm and humid, moderate and composite climates respectively. Further, the effect of the U-value of the roof on the indoor temperatures of the bungalow and industrial shed has been studied for the climate of Jodhpur. (The U-value of the roof for the base case is taken as 2.07 W/m^2K). The effect of the set point on the cooling loads of the bungalow incorporating RSEC has also been found. We have used the bio-climatic chart to identify the months during which cooling is required in the cities mentioned, and the calculations for RSEC have been done for these months.

Table V.1 presents the effect of RSEC on the maximum indoor temperature of the industrial shed as compared to a shed without RSEC in the month of May for Jodhpur, Mumbai, Pune and New Delhi. It is seen that RSEC is effective in Jodhpur, Pune and New Delhi; the temperature drops are about 2.3, 2.2 and 2.0ºC respectively in comparison with a shed without RSEC. In humid climate of Mumbai, the RSEC is not very effective with a drop in temperature of 1.1 °C only.

Table V.1 Performance of roof surface evaporative cooling on the room temperature of the industrial building in May in four cities representing warm climates

Place	Month	Maximum temperature of room(°C)		Difference in temperature (°C)
		Without RSEC	With RSEC	
Jodhpur	May	45.6	43.2	2.4
Mumbai	May	39.8	38.7	1.1
Pune	May	40.7	39.4	1.3
New Delhi	May	43.9	41.9	2.0

RSEC= Roof surface evaporative cooling

The effect of the U-value of the roof on the performance of RSEC in Jodhpur has also been studied. In this case, a higher U-value of 3.48 W/m^2-K has been considered compared with the base case U- value of 2.07 W/m^2-K. The results for the industrial shed are presented in Tables V.2. It is seen from these tables that the RSEC system is more effective when the U-value of the roof is high; the difference in temperature between indoors and outdoors can be as high as 5.1 °C in May. The table also shows the maximum room temperatures for various months. The RSEC is most effective in the months of May and June and least effective in the month of August (when the humidity is high due to monsoons).

The effect of RSEC on the maximum room temperature of Bedroom 2 of the bungalow in various months has been studied for all the four cities. It is seen from Table V.3 that in Jodhpur, RSEC is most effective in May with a difference in room temperature of about 2.7 °C. In Mumbai, there is hardly any difference in the performance during various months, the temperature difference ranging from 1.2 to 1.3 °C only. In Pune, the RSEC system is most effective in April with a difference in temperature of 1.9 °C. In New Delhi, the system is effective in May and June; the temperature difference being 2.3 °C.

The effect of the RSEC system on the cooling load of the conditioned bungalow has also been studied in order to determine how much load can be saved in the cooling season. In this case, the cooling load in kitchen has been ignored. The set point for cooling has been considered as 25 °C. The results of the study are presented in Table V.4. It is seen from the table that the savings effected are quite high, ranging from 15.5 % in New Delhi to 22.7% in Pune.

Table V.5 presents the effect of set points on the cooling loads of the conditioned bungalow incorporating the RSEC system. The set points considered for cooling were 24, 25, 26 and 27 °C. The table shows that for all cities, the higher the set point, the better is the performance in reducing cooling loads.
For example in Jodhpur, the savings achieved can be up to 22.4 % for a set point of 27 °C as compared to 17.4% for the base case (25 °C).

Table V.2 Effect of U-value of roof on RSEC (Place: Jodhpur; Building : Industrial shed)

Month	U = 2.07 W/m²-K			U = 3.14 W/m²-K		
	Maximum temperature of room (°C)		Difference in temperature (°C)	Maximum temperature of room (°C)		Difference in temperature (°C)
	without RSEC	**with RSEC**		**without RSEC**	**with RSEC**	
March	**37.9**	**36.5**	**1.6**	**39.0**	**35.5**	**3.5**
April	**42.7**	**40.6**	**2.1**	**44.0**	**39.3**	**4.7**
May	**45.6**	**43.2**	**2.4**	**46.9**	**41.8**	**5.1**
June	**44.8**	**42.9**	**1.9**	**45.9**	**41.7**	**4.2**
July	**41.3**	**40.1**	**1.2**	**42.1**	**39.3**	**2.8**
August	**39.9**	**38.9**	**1.0**	**40.7**	**38.1**	**2.6**
September	**39.8**	**38.8**	**1.0**	**40.7**	**38.0**	**2.7**
October	**39.5**	**38.1**	**1.4**	**40.4**	**37.1**	**3.3**

RSEC= Roof surface evaporative cooling

Table V.3 Performance of roof surface evaporative cooling on the temperature of bedroom2 of the residential bungalow

Place	Month	Maximum temperature of room (°C)		Difference in temperature (°C)
		Without RSEC	With RSEC	
Jodhpur	March	30.8	29.0	1.8
	April	35.9	33.5	2.4
	May	39.1	36.4	2.7
	June	38.8	36.6	2.2
	July	35.6	34.1	1.5
	August	34.2	32.9	1.3
	September	33.4	32.2	1.2
	October	32.3	30.5	1.8
Mumbai	March	31.0	29.7	1.3
	April	32.9	31.7	1.2
	May	34.5	33.2	1.3
Pune	March	31.6	29.9	1.7
	April	34.1	32.2	1.9
	May	34.1	32.5	1.6
	June	31.6	30.3	1.3
	July	28.6	27.8	0.8
	August	28.2	27.4	0.8
	September	28.5	27.7	0.8
	October	29.5	28.4	1.1
New Delhi	April	33.7	31.8	1.9
	May	37.4	35.1	2.3
	June	38.8	36.5	2.3
	July	35.1	33.8	1.3
	August	33.2	32.1	1.1
	September	32.8	31.7	1.1

RSEC= Roof surface evaporative cooling

Table V.4 Effect of roof surface evaporative cooling on the cooling loads of the conditioned residential bungalow

Place (Period)	Set point (°C)	Cooling Load (GJ)		Difference	
		Without RSEC	With RSEC	GJ	%
Jodhpur (March to October)	25	366.7	302.8	63.9	17.4
Mumbai (March to May)	25	102.5	86.4	16.1	15.7
Pune (March to October)	25	189.3	146.3	43.0	22.7
New Delhi (April to September)	25	281.8	238.0	43.8	15.5

Table V.5 Effect of cooling set points on the loads of the conditioned bungalow with RSEC system

Place (Period)	Set point (°C)	Cooling Load (GJ)		Difference	
		Without RSEC	With RSEC	GJ	%
Jodhpur (March to October)	24	410.3	346.1	64.2	15.6
	25	366.7	302.8	63.9	17.4
	26	322.8	259.3	63.5	19.7
	27	280.1	217.4	62.7	22.4
Mumbai (March to May)	24	118.9	102.8	16.1	13.5
	25	102.5	86.4	16.1	15.7
	26	86.1	70.1	16.0	18.6
	27	70.1	54.4	15.7	22.4
Pune (March to October)	24	232.2	188.4	43.8	18.9
	25	189.3	146.3	43.0	22.7
	26	148.1	106.9	41.2	27.8
	27	109.6	72.1	37.5	34.2
New Delhi (April to September)	24	314.5	270.9	43.6	13.9
	25	281.8	238.0	43.8	15.5
	26	249.0	204.6	44.4	17.8
	27	215.9	172.1	43.8	20.3

To summarise, the RSEC system works well in hot and dry weather with low humidity levels. If installed over a roof having a high U-value, indoor temperatures appreciably reduced compared to that of a roof with low U-value. From the point of view of conserving energy, the set points for cooling may be raised to 27 °C (as recommended by Indian Standard).

APPENDIX V.2

PERFORMANCE OF A COMMERCIAL BUILDING WITH ZERO INTERNAL GAIN IN A COMPOSITE CLIMATE - (NEW DELHI).

The effects of building parameters on the annual loads of a conditioned commercial building with zero internal gain are discussed in this Appendix. The results of these studies are presented in Table V.6. The possible percentage of savings that could be achieved compared to the base case is also presented in the table. Table 5.1 lists the various parameters investigated. The following conclusions are drawn:

(i) Restricting the glazing size to a height of 1.2m instead of a fully glazed curtain wall can reduce the annual load by 14.7%. Thus, reduction in the penetration of direct solar radiation can cause significant savings. It can also be surmised that larger expanses of glass in a building can lead to higher cooling loads.

(ii) Double-glazing with reflective coated glass is most effective, being better than the base case (single reflective coated glass) by 14.9%. Double low-E glass also improves the performance by 11.8%. Double clear glass shows the same performance as the base case. Plain glass should be avoided as it increases the loads by 12.9%. It may be noted that double-glazing per se is better than single glazing.

(iii) Appropriate orientation can reduce cooling loads by upto 2.8%. In general, a building with its glass wall facing north-west shows better performance than one facing west, north or southwest (base case).

(iv) Lowering the operating parameters for comfort cooling and heating can reduce the cooling loads by 13.7%. Thus, a change in the expectation of comfort can lead to significant savings.

(v) Reduction in solar radiation by shading windows causes a decrease in the heat gains, and consequently the cooling loads are reduced. The shading of windows by 50% throughout the year can improve the performance by upto 8.8%.

(vi) Dark colours on walls should be avoided. If dark grey is used in place of white, the cooling load can increase by 4.7%.

(vii) A wall type having low U-value (i.e. insulating property) improves the performance significantly as compared to the base case (concrete block wall). The loads are reduced by 8.8%.

Table V.6 Annual savings due to building design and operational parameters for Commercial building with zero internal gains (New Delhi)

PARAMETER	ANNUAL LOAD (GJ)			ENERGY SAVING	
	COOLING	HEATING	TOTAL	(GJ)	(%)
BASECASE	2552.19	300.22	2852.41	N.A.	N.A.
GLAZING SIZE (restricted to 1. 2m height)	2142.88	290.18	2433.05	419.36	14. 7
GLAZING TYPE					
Single clear	3011.32	208.49	3219.80	-367.39	-12.9
Double clear	2743.27	109.07	2852.34	0.07	0.0
Double low-E	2389.09	127.84	2516.93	335.48	11. 8
Double reflective coated	2261.73	166.42	2428.15	424.26	14. 9
ORIENTATION (longer axis)					
North-south	2345.12	489.62	2834.74	17.67	0.6
Northeast-southwest	2270.46	501.33	2771.79	80.62	2.8
East-west	2469.92	384.48	2854.41	-2.00	-0. 1
SETPOINT - cooling: 25 °C - heating: 20 °C	2236.83	224.54	2461.37	391.04	13. 7
SHADING					
10%	2473.42	321.99	2795.41	57.00	2.0
20%	2395.52	345.80	2741.32	111.09	3.9
50%	2172.30	428.37	2600.67	251.74	8.8
WALL COLOUR - dark grey	2735.70	251.52	2987.21	-134.80	-4. 7
WALL TYPE - Autoclaved cellular concrete block (e.g. Siporex)	2343.97	257.91	2601.87	250.53	8.8