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Ventilation Survey of Typical Airy Buildings—A Few Case Studies in Hot Dry and Hot Humid Zones of India

ISHWAR CHAND*
V. K. SHARMA*
N. L. V. KRISHAK*

This paper describes findings of a ventilation survey carried out in a few typical airy buildings located in hot dry and hot humid zones of India. The design details of ventilation systems in use have been discussed and design features conducive to air motion indoors identified. It is observed that the airy environment in buildings is attributable to the design parameters, like proper orientation, elevated location, large facade area, proper plan form, centrally located wind shaft, and series connection of openings in different rooms located in parallel rows. Necessity for optimization of these parameters has also been emphasized.

INTRODUCTION

PROVISION of adequate natural ventilation in buildings had always been an important consideration in the design of buildings in the tropics. Hence design guidelines and standards for designing buildings conducive to natural air motion indoors have been a genuine demand of the architects and designers. To this end, several investigations on wind induced air motion in buildings have been carried out in India [1–4] as also abroad [5–7]. The outcome of these studies was evolution of design solutions and formation of standards for optimum utilization of outdoor wind indoors for minimizing the thermal stress on the occupants. The findings are based mostly on the experimental studies carried out in the laboratory, hence it is of interest to examine the implications of their application in actual buildings. Therefore, a ventilation survey was carried out in a few typical airy buildings, and parameters which contribute significantly to indoor air motion, and which need specific attention in the ventilation design have been brought out.

The buildings covered during the survey are grouped into two categories, *viz*: (i) old buildings known for their airy character and (ii) modern buildings adorned with variety of design features employed for augmentation of natural ventilation therein. Buildings belonging to category (i) were chosen to explore the design features, developed and advantageously made use of by the contemporary designers through their personal skill and long experience; whereas buildings falling in category (ii) were chosen to examine the efficacy of the modern designs evolved with advanced knowledge of passive design of buildings in hand. For convenience of work and economic considerations it was decided to select sites where the large number of desired type of buildings are located at a single place. Jaipur and Jodhpur are the places where several old buildings with famous airy character are located. Likewise, Auroville is a place where buildings with a variety of designs have been put up with a variety of ideas by multinational brains. Hence the major part of the present study was limited to the buildings located at these three places only. However, a building with typical passive design at Delhi was also surveyed. To examine the performance of ventilation systems in use, wind speeds were measured in the interior of buildings at several points. Simultaneously, speed and direction of outdoor wind were also determined. The design details of ventilation system were noted and parameters responsible for augmentation of air flow through buildings were identified. The salient features covering observations and inferences of the study are discussed below.

UMAID BHAWAN PALACE, JODHPUR

This is a huge building with broad outlines depicted in Fig. 1. The various enclosures are located in parallel rows with longer axis facing nearly East and West directions. Tall verandahs and courtyards have been provided on the exposed sides of the enclosures. With its covered area about 13,765 m^2 the building is located at a height of about 315 m above sea level, and there is no obstruction in the neighbourhood. The enclosures are provided with large size fenestration on the opposite walls. Thus, enclosures in different rows are connected in series and cross flow of wind through them is ensured. A survey of the building revealed that no forced draft ventilation system or air conditioning appliances were in use. Strawpads with water trickling thereon were mounted on the wind facing openings to cool the incoming air. Only at a few locations were table fans used for inducing local air circulation. As such, the building was ventilated primarily

* Central Building Research Institute, Roorkee, India.

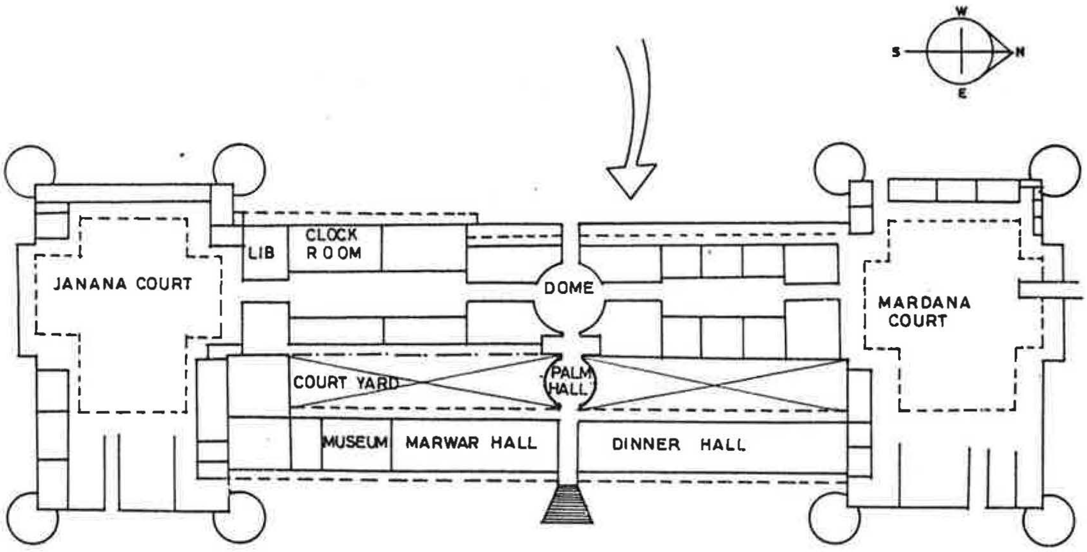


Fig. 1. Umaid Bhawan Palace, Jodhpur.

by natural force of wind. Dry bulb temperature, wet bulb temperature and wind speed were measured in different enclosures and passages as well. Based on the studies on thermal comfort of Indian subjects carried out in this institute earlier [8], the desired wind speeds for comfort were also calculated. The data pertaining to a few typical locations are presented in Figs 2a and b. It is seen that in passages (point D in Fig. 2a, and points G and H in Fig. 2b), the wind speeds are generally higher than those inside the rooms. Just behind the inlets (point B in Figs 2a and b), the speeds exceed the free wind speed also. It is noted that the available indoor wind speeds are generally higher than the minimum desired wind speed for comfort. Subjective observations also indicated that the indoor environment was quite comfortable. Thus the building was devoid of stagnant pockets and wind speeds at most of the places satisfied the required standards of comfort. It was also noted that the airy character of the building is attributable to the following design parameters.

High location

The palace is located at a height of 315 m above sea level whereas the city is located at about 224 m. As a result, free wind at the level of palace possesses a speed about 1.37 times the speed recorded by IMD at a height of 10 m above the ground. Further, the hilly terrain also accelerates the windflow thereon. Thus the velocity gradient in natural wind, and topographical influence of the hilly terrain on windflow patterns jointly contribute towards the enhancement in the speed of the wind incident on the inlet openings. Consequently, air motion indoors also gets increased.

Absence of obstruction in the neighbourhood

Obstructions like trees or structure particularly those projecting above the height of sill, while located on upstream side of a building, cause shielding effect and reduce air motion indoors. As the palace has no such obstructions in its neighbourhood, the full advantage from aeromotive force is derived for inducing air motion in the interior of the palace.

Large size openings connected in series

All the enclosures are provided with large size openings on opposite walls and enclosures in different rows are connected in series. Such an arrangement forms a system of ventilation with low resistance, and helps augment air flow inside the building.

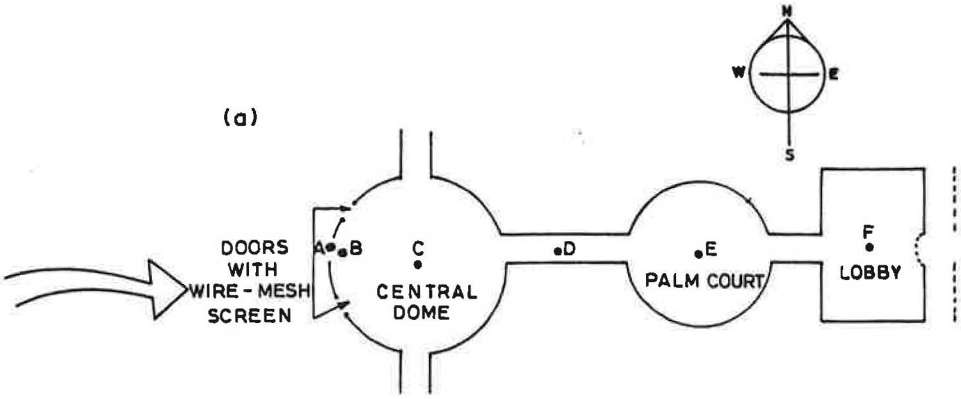
Provision of verandah and courtyards

After passing over the windward row of rooms the wind is deflected downwards in the courtyards, and gets trapped therein. As a result of this, the wind is forced to move through the various available openings around the courtyard. This causes flow of wind through the leeward row of rooms, and also through the openings located tangential to the free wind direction. Thus high rates of air flow take place through the passages. Further, large facade area of the building with tall verandah obstructs the flow of large amount of wind, which is subsequently forced to flow through the windward openings. As the size of the later is much smaller than the facade area, the wind speed through the openings is enhanced, and high air speeds are induced indoors. Thus provision of courtyards and verandahs contribute significantly towards the inducement of high air motion indoors.

CHOPASANI SCHOOL, JODHPUR

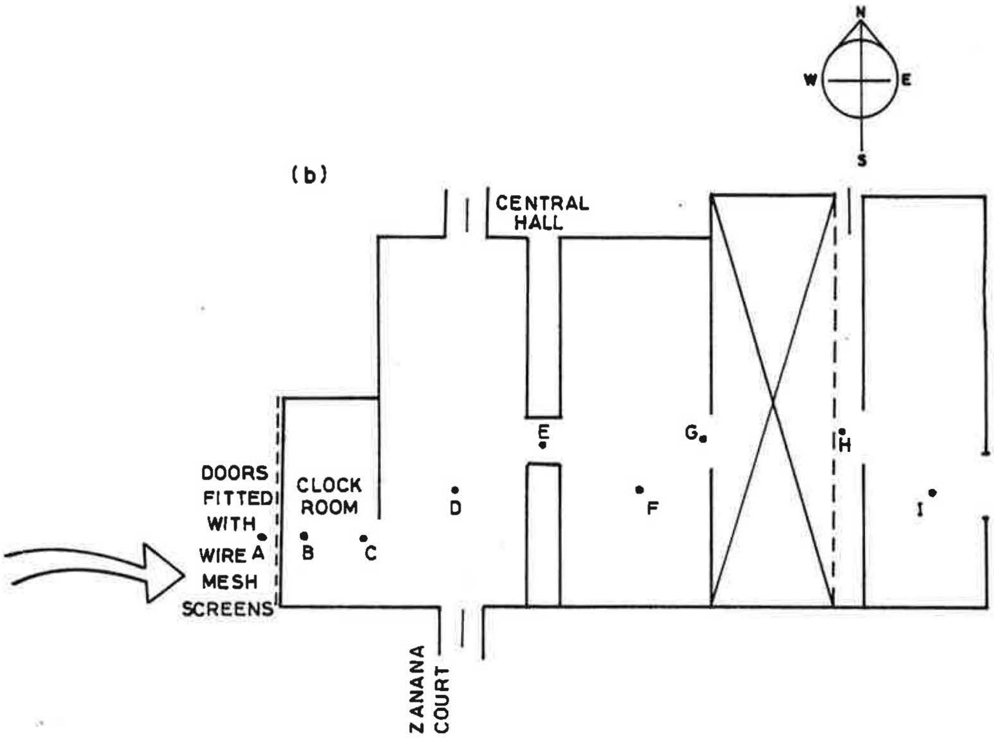
The school with broad outline depicted in Fig. 3 is oriented with longer axis in an E–W direction. It consists of two parallel rows of class rooms with two central passages running at right angle to each other. The rooms are about $6.7 \times 6.7\ m^2$ in size and with doors covering about 0.45 of the wall width on each of the two opposite sides. A verandah has been provided all around the building. The plinth level is at about 1 m above the surrounding terrain and there is no neighbouring obstruction in front of the exposed openings. For an outdoor speed equal to $1.5\ m\ s^{-1}$, the average wind speed in the interior of the rooms on ground floor was about $0.25\ m\ s^{-1}$. The speed was much higher in the passages as also in the rooms on 1st floor. The airy environment indoors

(a)



LOCATION / FACTORS	A	B	C	D	E	F
D. B (°C)	30	28	29	29.5	29.5	30.5
W·B (°C)	24	24	24	25.0	25.5	25.0
WIND SPEED (m/sec)	0·9 - 1.2	1.5	0·06	0·8	0·35	0·05
R.H. (%)	59	70	64	67.5	71	63
DESIRED WIND SPEED	0·06	—	—	0·044	0·08	0·33

(b)



LOCATION →	A	B	C	D	E	F	G	H	I
WIND SPEED (m/sec)	1.1	2.7	0·35	0·35	0·15	0·15	0·4	1.3	0·25

Fig. 2. (a) Wind data are different locations in Umaid Bhawan Palace; (b) distribution of wind speed at various locations in Umaid Bhawan Palace.

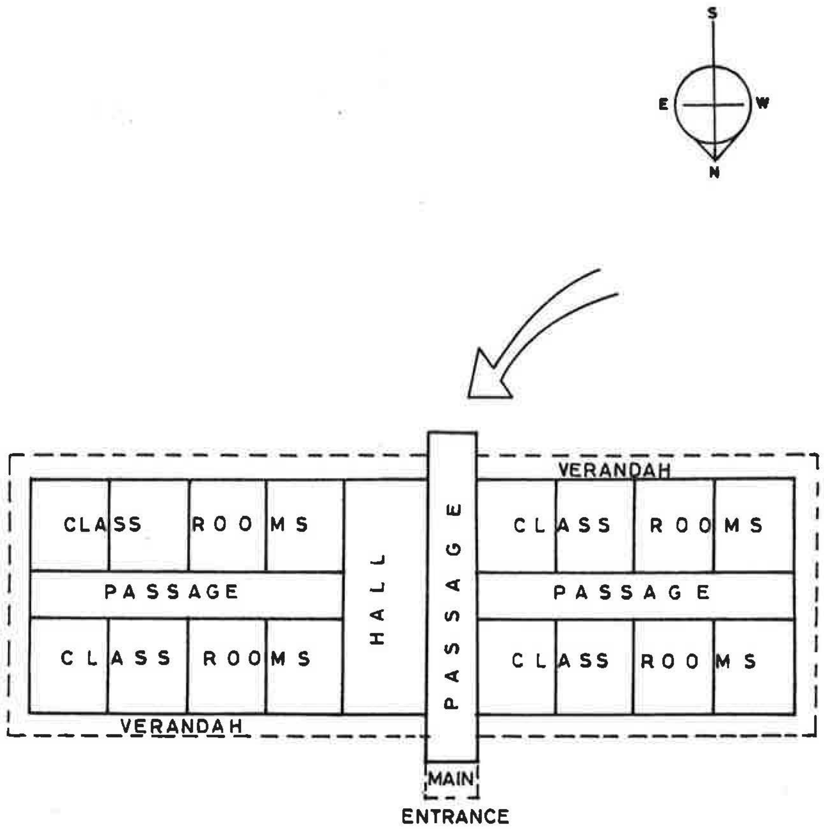


Fig. 3. Broad outline of Chopasani School, Jodhpur.

Fig. 4. Shape of the facade (carvation) of Hawa Mahal.

is attributed to the fact that large size openings connected in series facilitate cross ventilation through the building. This causes enhanced air movement indoors and helps reduce thermal stress on the children.

HAWA MAHAL, JAIPUR

The building located at Jaipur is constructed at an elevated location as compared to its neighbouring buildings. Courtyards at various levels have a single storey construction on west and double storey on east side. The other two sides have tall walls forming the shape of a valley. These features help trap the westerly wind, and deflect it downwards. This process augments flow of wind through the openings on eastern side of the courtyard. The speed at the openings was about 1 m s^{-1} when the free wind speed at the roof was about 1.2 m s^{-1}. The facade was not plane; it was fitted with stone jali (carvation) forming the shape shown in Fig. 4. The typical shape produces a venturi effect for normally incident wind and also creates enhanced positive pressure on the wind-facing side when wind strikes obliquely on the facade. This results in the enhanced air flow for a wide range of wind directions. An interesting design feature was observed in the windows provided in the ramp enclosure leading to the top of the building. The openings were fitted with brick jali (Fig. 5) inclined downward outdoors. The wind speed available in front of the jali was about 2.3 m s^{-1}, which is high enough for comfort considerations. Hence, the system, apart from providing visual privacy, functions as a good air flow device also.

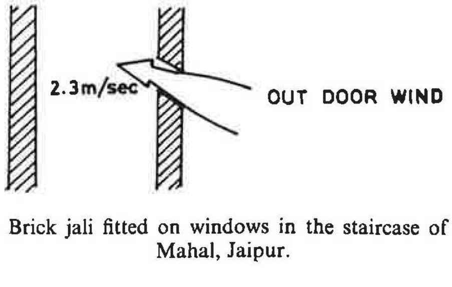


Fig. 5. Brick jali fitted on windows in the staircase of Hawa Mahal, Jaipur.

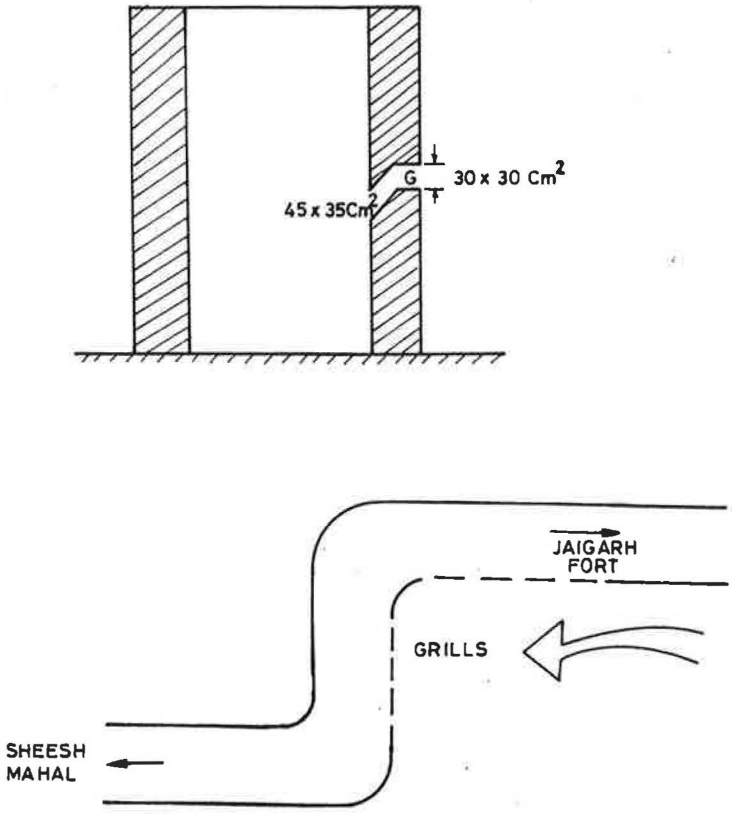


Fig. 6. Location and shape of openings in the passage of Amer Palace, Jaipur.

AMER PALACE, JAIPUR

The palace is located at the top of a hill. The ventilation system with typical features is the one employed in the passage connecting Sheesh Mahal to Jaigarh Fort. For security considerations, the passage is provided with doors at the two ends leading to the two buildings. Openings with typical shape sketched in Fig. 6 are provided on the two adjacent sides of the gallery. The openings provides visual privacy and are inclined downwards inside the passage. As the size of openings is only a small fraction of the size of the wall, wind flows with enhanced speed through them. The wind speed in front of the openings was about 1.2 m s^{-1} when the speed outdoors was about 0.9 m s^{-1}. Further, the obstruction to wind flow created by the wall normal to the incident wind creates pressure on opening on the wall tangential to the incident winds as well. This causes wind to enter in the passage through all the openings. Thus the design functions effectively for a wide range of wind directions.

CSIR SCIENTIST APARTMENTS, NEW DELHI

The apartments forming a multistorey complex with typical ventilating system are located a Maharani Bagh, New Delhi. The complex is intended to have two buildings identified as No. 1 and No. 2. At the time of survey, construction was going on and building No. 1 consisting of five wings was nearing completion. Wings No. 1 and No. 2 have eight storeys and Nos 3–5 are seven, six and five storeyed, respectively. Each of the wings has been provided with a wind shaft located centrally with respect to the different rooms of the wing (Fig. 7). As per the original proposal, the wind shaft was to be constructed up to a height of 9.0 m above the roof, and a water tank was to be provided atop the shaft. Openings were to be provided on the two opposite sides just below the tank at the terminating end of the shaft. The latter was to be connected to various rooms by means of branch ducts with supply openings above the doors in the rooms. It was envisaged that the air coming downwards through the shaft will be cooled by the water trickling from the tank, and will be subsequently supplied to various rooms for space cooling. However, because of the constraints posed by local by-laws, the proposed method of cooling had to be dropped. Until the time of the survey, the shafts were constructed up to the height of parapet walls, and a move was on to close the openings already provided in the circumference of the shaft. As such, it could not be possible to study the performance of a complete system. But, there was an opportunity to study the flow of wind through a shaft without the wind catcher thereon. Wind speeds were measured at the openings provided in the shaft as also in the centre of the shaft at mid height level of each of the openings. Direction of wind flow at the openings was also observed by introducing in the shaft the smoke produced by an ignited piece of gunny bag. Such measurements were taken at all the floors in all the five wings of the building. A typical set of observations is depicted in Fig. 8. Since the shaft was not connected

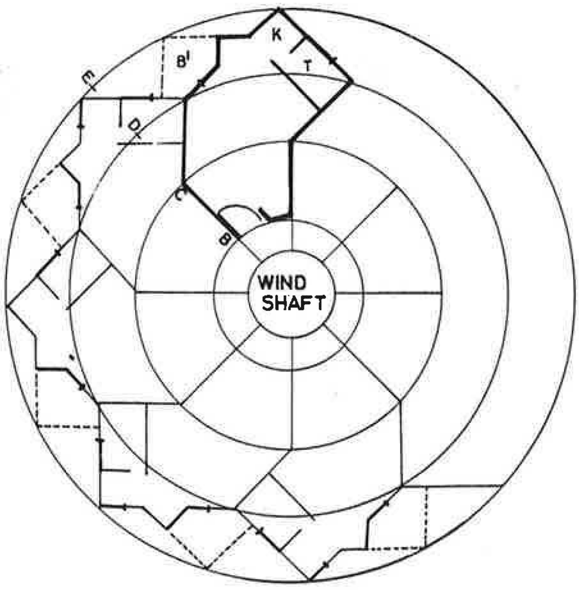


Fig. 7. Plan of CSIR Scientist Apartments, New Delhi.

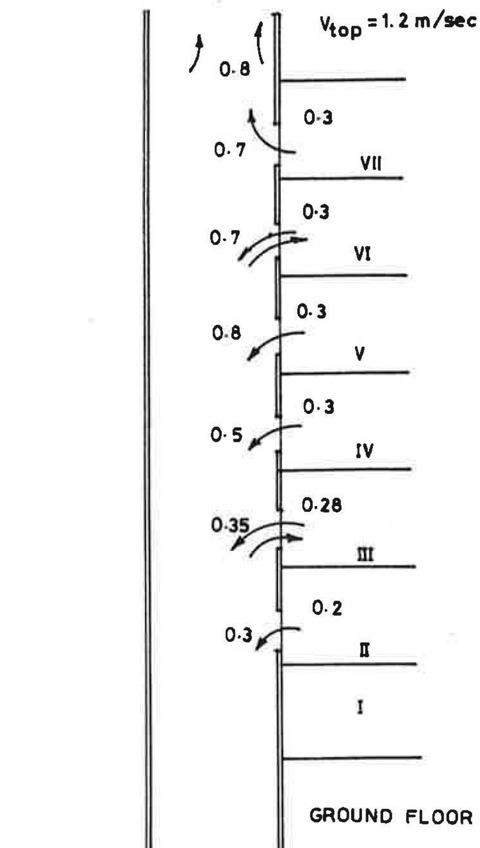


Fig. 8. Distribution of wind speeds at various floors and in the central duct.

to the rooms, and there was no scooping device atop the shaft, hence the observations do not show any systematic trend and no definite conclusion can be derived from them. However, there is a clear indication of the usefulness of the system for probable augmentation of air flow in rooms at different floors.

GOLCONDE, PONDICHERRY

The building is located in Pondicherry and is used for living. As shown in Fig. 9, the building has a finger type plan comprising of two parallel wings of rooms located in end on position. A verandah has been provided in front of the rooms, and building is oriented with its longer axis nearly in an E–W direction. The exposed walls of the rooms have been provided with windows covering the entire wall width. The height of windows and height of sill are about 2.7 m and 0.46 m, respectively. Windows are fitted with horizontal sashes (Fig. 10), each of length about 1/4 of wall width and width of about 0.38 m. Six sashes are coupled to a single operating system (Fig. 10) consisting of a vertical iron rod attached to each of the six clamps mounted on the three pairs of sashes. The latter are pivoted on horizontal axles. Thus by the movement of the vertical rod, the inclination of sashes with horizontal can be adjusted in any desired position. Further, in the closed position of windows, a leakage area of about 0.46 m^2 is always there in between the sashes. The doors provided on the verandah facing wall, cover about 3/7 of wall width. The door shutters are sliding type with a typical design providing an area of opening equal to about 0.74 m^2 in the closed position. Thus the design of the building is peculiar in the sense that the area of openings can be easily varied upto a large proportion of wall area, and the flow of wind in section can be adjusted by simple operation of the sashes. Further, an area of opening is always available on opposite walls when doors and windows are closed. The exposed side of the verandah is provided with horizontally pivoted sashes with adjustable inclination. Thus, apart from providing easy control on wind flow indoors, the design has provision for providing visual privacy without sacrificing the cross flow of wind through the building. The distribution of wind speeds at a work plane about 0.4 m above the floor was studied in two different rooms, one located at the end of the wing and the other near the centre of the wing. At the time of observations, the wind was incident obliquely on the exposed side of the rooms. The average indoor wind speeds in the middle room were 32 and 17% of the free wind speed for fully open louvers and for louvers inclined at 45° downwards respectively. However, the speeds were a little less in the room located on downstream corner. Wind speed measurements were also taken right at the window for various inclination of the louvers. The summarized results depicted in Table 1 show that wind speed in the channel formed between a pair of adjacent louvers is minimum when louvers are fully open. The velocity gets enhanced at 45° and is not affected by an increase in the inclination of the louvers. In their inclined position, louvers cover a portion of window and clear area of opening is reduced. Further, in-section wind follows the plane of inclined louvers, and because of its inertia, wind

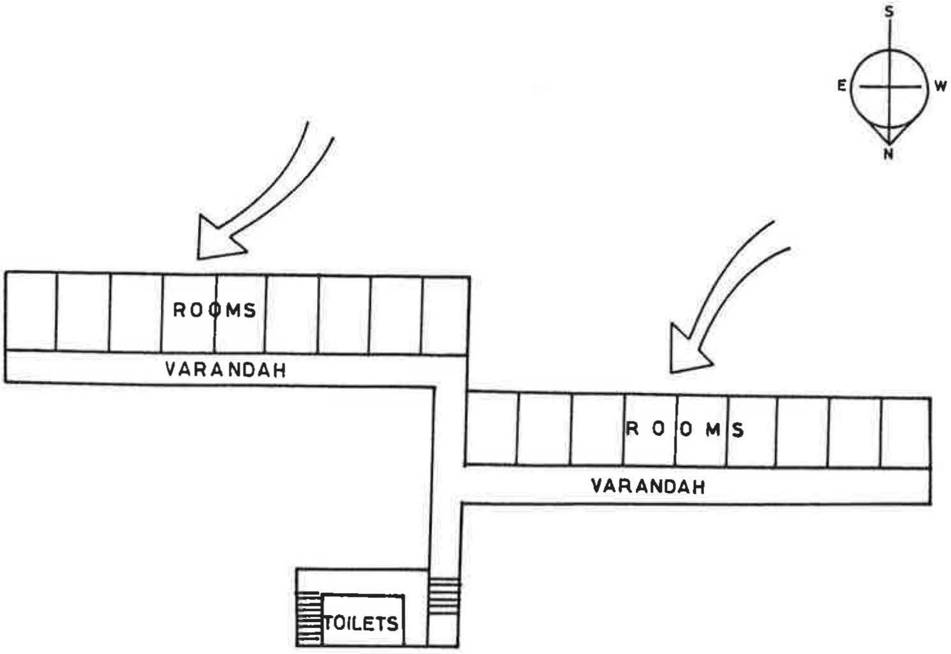


Fig. 9. Plan of Golconde, Pondicherry.

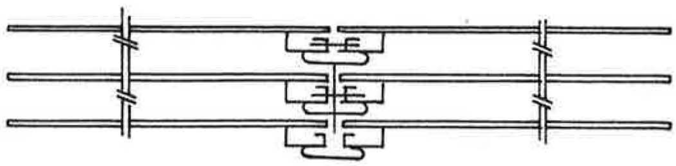


Fig. 10. Sketch of sashes fitted on windows in the rooms of Golconde.

tends to travel downward towards the floor. These two factors jointly lead to the reduction in indoor air motion at levels about 0.4 m above the floor level when louvers are inclined downwards.

TRADITIONAL TAMIL HOUSE, PONDICHERRY

Provision of a central courtyard is quite common in old Tamil houses. The prime objective of providing courtyards is to trap the cool air during night and to keep the walls of the surrounding rooms cool during the day time. Further, courtyards also facilitate provision of windows on opposite walls of rooms for achieving cross-ventilation through them. Wind speeds were measured in a typical Tamil house at the points marked in Fig. 11. It was found that the maximum available wind speed was about 20% of the outdoor wind speed. This amply indicates that courtyard contributes little to the wind induced air motion in the interior of buildings. This is also coroborated by the laboratory studies carried out earlier in the Central Building Research Institute [4].

Table 1. Wind speed right at the windows for various inclination of sashes

Inclination of the sashes with horizontal (degrees)	V (m s^{-1})
0°	1.8
45°	3.0
70°	3.0
80°	3.0

MODERN TAMIL FLAT, PONDICHERRY

The distinctive feature of a modern Tamil flat with plan broadly sketched in Fig. 12, is the open space between the adjacent flats. The space forms a vertical duct of about 5 m^2 projected upto about 2 m above the roof of the building. At its terminating end atop the flats, the duct is open to sky, and has encompassing walls (2 m height) on the three sides. Windows of the sitting rooms of different flats open into the duct and facilitate flow of wind from rooms to duct and vice versa. The sitting room has a door on the wall opposite to the duct. This ensures cross ventilation in the rooms and induces adequate air motion indoors. Depending on the direction of outdoor wind, the window on the wall common to the duct and the room, functions sometime as inlet and at the other time at outlet. Thus the provision of a vertical duct connected to rooms helps make the house quite airy.

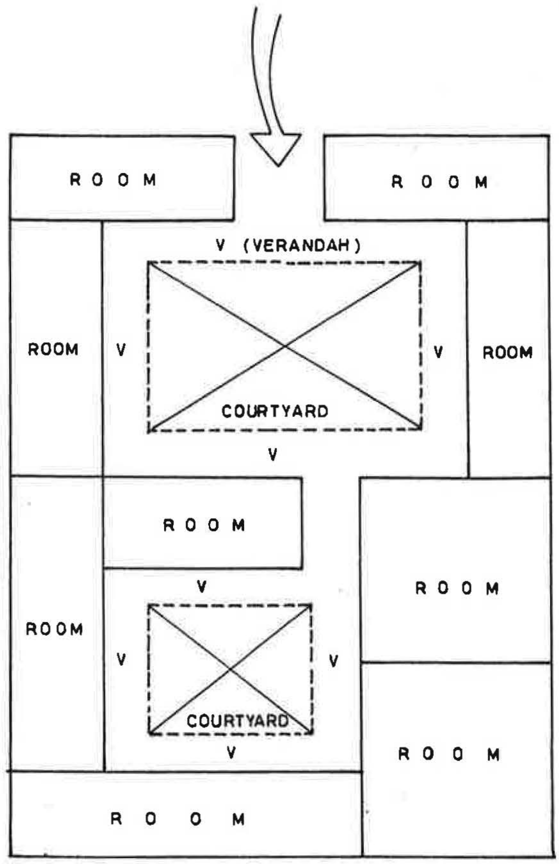


Fig. 11. Plan of a traditional Tamil house, Pondicherry.

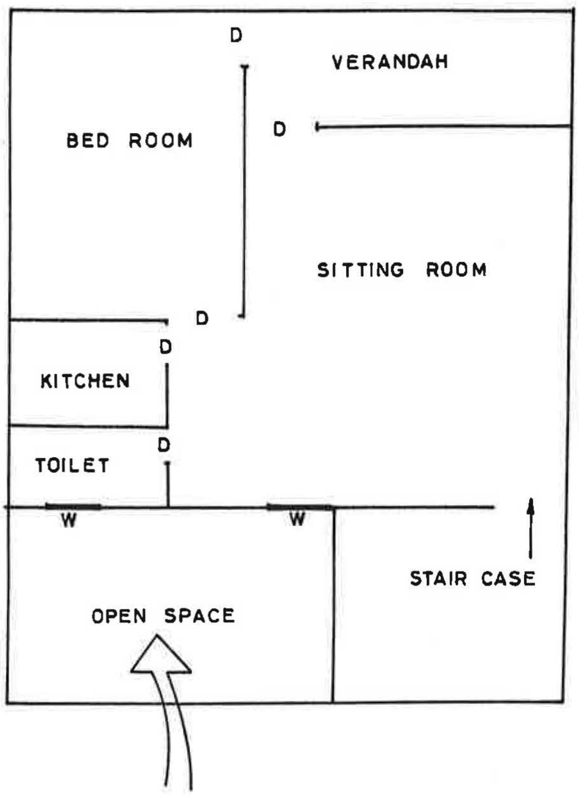


Fig. 12. Plan of a modern Tamil house, Pondicherry.

ANGAD BHAWAN, AUROVILLE

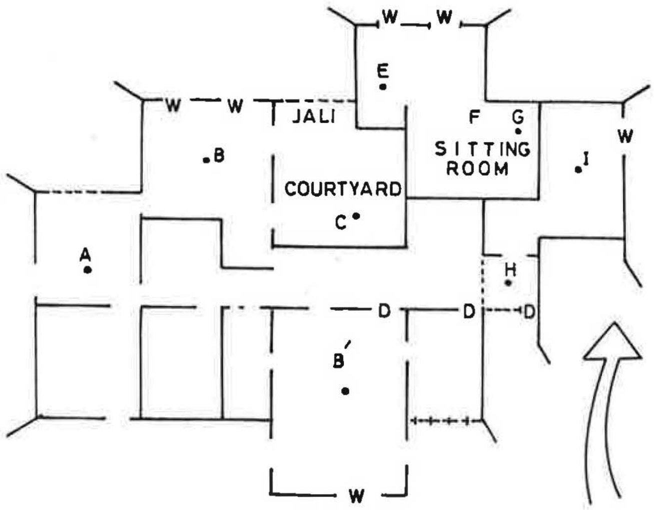
This is a residential building with the plan broadly shown in Fig. 13. The 1.35 m long projections at various points on the outer walls form one of the design features typical to this house. The projections being located on the two sides of the openings (door or a window) channelize the incident wind and help augment air motion in the interior of rooms. The experimentally observed values of wind speeds in various rooms are shown in Fig. 13. It is seen that the wind speed in one of the rooms facing the outdoor wind is about 1.4 times the speed of outdoor wind. However, in leeward rooms the wind speeds vary from 5 to 35% of the free wind speeds. This amply indicates the usefulness of long projections on the walls in respect of enhancement of air flow indoors. The other typical feature of the house is the system of ventilation through the roof. In one of the rooms, the roof is curved, and three pieces of pipes each with 5 cm diameter were embedded in the roof. The pipes being open at the two ends provide a link between indoors and outdoor environment, and help remove hot stagnant air from beneath the ceiling. The operation of the system is based on the fact that the velocity of wind at the apex of the curved roof gets accelerated, and consequently the pressure thereon decreased. This causes the air from below the ceiling to flow out through the pipes embedded in the roof. In the present case total area of roof openings being only 0.006 m^2, is too small to be of significant usefulness in respect of inducement of air motion for reducing thermal stress on occupants. However, the roof vents help induce air changes in the room.

RESIDENTIAL BUILDING WITH AN AIR SUCKING CHIMNEY

A house located at Arya, Auroville has a typical ventilation system for its living room. The house is a small unit consisting of a room, kitchen, bath and verandah as per plan depicted in Fig. 14. A wooden spiral shape stair case has a door opening in the living room and another door leading to the terrace. Thus the stair case forms a passage for the flow of wind through the living room. A blackened chimney type structure projecting about 3.00 m above the roof is constructed atop the stair case. The system is intended to suck the vitiated air from the living space for its subsequent ejection to outdoors. At the time of conducting the survey, all the doors and windows were closed, and hence the functioning of the system could not be evaluated quantitatively.

DISCUSSION

Findings of ventilation survey carried out in a few historical buildings with airy environment as also in buildings provided with newly conceived non conventional ventilation systems have been presented. Since two identical buildings differing only in one particular design parameter were no where available, it was practically impossible to assess quantitatively the contribution of an individual design parameter towards inducement of air motion indoors. However, an attempt



LOCATIONS / WIND SPEED (m/sec)	A	B	B'	C	E	F	G	H	I
GROUND FLOOR	0.3	—	—	0.05	0.1	0.15	0.3	0.5	0.2
FIRST FLOOR	—	0.08 TO 1.4	2.2	—	—	—	—	—	—

Fig. 13. Wind speeds at various points in Angad Bhawan, Auroville.

was made to study the peculiarities in the design of each of the buildings. As the study was concerned with the ventilation performance only, hence those design features which could have a bearing on air flow indoors were examined. Further, because of the non-availability of the drawings and photographs of the buildings, broad layouts depicting the points of observation have been presented in this paper. In situation where several rooms were located in identical positions, only a few rooms representing the functioning of all the rooms were covered for the measurements. Based on the analysis of the data, parameters conducive to air motion indoors have been identified. A judicious integration of these parameters would lead to best utilisation of outdoor wind for amelioration of ventilation conditions indoors. Hence, optimization of these parameters is of vital importance from view point of saving energy used in operating the mechanical ventilation appliances in buildings. It would be worth mentioning that neither the designers nor the users of various buildings were available to explain the aim of the relevant typical designs. Hence, it was not possible to ascertain the extent to which the design could meet the inherent objective. As a matter of fact, evaluation of the efficacy of the various ventilation systems, particularly of the non conventional ones, needs long term monitoring, and many more studies are desirable in order to make definite recommendations for their mass scale adoption.

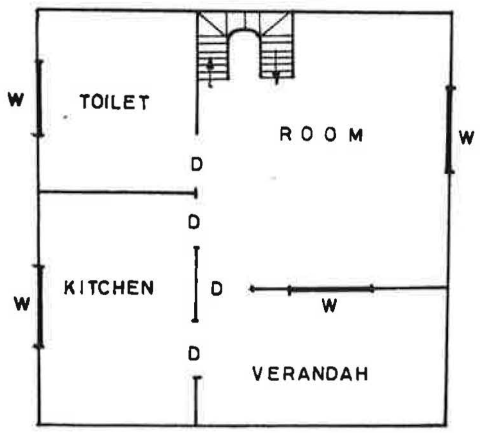


Fig. 14. Plan of a house with air sucking chimney, Auroville.

CONCLUSION

(1) Though a lot of advancement has been made in the technology of mechanical systems of ventilation, the tendency among building designers to give prime importance to the provision of natural ventilation in the design of buildings still persists.

(2) Non conventional system of natural ventilation based on the newly conceived ideas are adopted by designers and users without any reservations.

(3) The airy environment in the interior of buildings is attributable to the following design parameters.

- Proper orientation with respect to the prevailing winds.
- Elevated location as compared to the surrounding buildings.
- Provision of ample cross ventilation through series connected openings.
- Large facade area on windward wall to facilitate venturi effect.
- Proper plan form to provide blockade to wind flow across the openings tangential to the on blowing wind.
- High location of wind scoops at the top of the buildings.

REFERENCES

1. I. Chand and N. L. V. Krishak, Window design for natural ventilation in tropics. Building Research Note 62, Central Building Research Institute, India (1986).
2. I. Chand and P. K. Bhargava, Guidelines for designing airy buildings. Building Digest No. 121, Central Building Research Institute, India (1976).
3. Code of Practice for Natural Ventilation for Residential Buildings. Indian Standards Institution (1977).
4. I. Chand, Ventilation of wide-span schools in the hot, humid tropics. Educational Building Report 6, UNESCO Regional Office for Education in Asia Bangkok, Thailand (1977).
5. B. Givoni, Basic study of ventilation problems in housing in hot countries. Research Report to the Ford Foundation, BRS, Technion Haifa (1962).
6. E. G. Smith, The feasibility of using models for predetermining natural ventilation. Texas Engineering Research Station, Texas, Research Report No. 26 (1951).
7. J. F. Van Straaten, S. J. Richards, F. J. Lotz and E. N. Van Deventer, Ventilation and thermal consideration in school building design. South African Council for SIR Pretoria (1965).
8. M. R. Sharma and S. Ali, Tropical summer index—a study of thermal confort of Indian subjects. *Bldg Envir.* **21,** 11–24 (1986).