NATURAL VENTILATION IN THE MODERN HOSPITAL

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This paper asseses the role of natural ventilation in a modern hospital within the limits of current knowledge. It considers optimum standards of air change rates for winter and summer conditions and reviews factors within the hospital context that are likely to affect the realisation of natural ventilation. Reference is made to actual measurements in a new hospital and to other theoretical work. There is also some comment on future trends and the influence of energy consumption on the use of natural ventilation.

INTRODUCTION

"The very first rule of nursing is to keep the air the patient breathes as pure as the external air without chilling him. The question is often asked - when ought windows to be opened? The answer is - when ought they to be shut?" These extracts from "Notes on Nursing" 1859 are attributed to Florence Nightingale and express her sentiments on the therapeutic effects of fresh air and by inference natural ventilation.[1] Today this concept still holds good for hospitals in the United Kingdom albeit to a lesser degree. Whereas the general level of pollution has increased during the intervening years various Acts of Parliament have safeguarded the purity of the atmosphere and limited contamination. Ambient air is still suitable, with few exceptions, to naturally ventilate large areas of the modern hospital although the conditions under which it is now used have also changed significantly due to advances in medicine.

Over the past few years there has been some rethinking on the likely size and functional content of the District General Hospital (DGH) most appropriate for tomorrow's needs. This reassessment has come about by an awareness of the disadvantages of large size and changes in administering health care. A greater emphasis is now placed on the role of the primary health care team and the practice of preventive medicine. This is leading to an increase in provision for Out Patient and Day Care treatment facilities and a reduction in the overall number of beds provided. A future DGH is likely to cater for a population of some 200 000 with approximately 600 beds of in-patient accommodation comprising acute, geriatric, maternity, mental illness and children's nursing units. At current prices capital costs for the buildings and equipment will be about £35 million.

In past years the National Health Service has had problems with the construction of large hospitals. Practical experience gained from those already built has indicated that a large scale development should be avoided. There is also, quite understandably, a reluctance to commit limited resources to one specific project built in a single phase. Consequently there is a tendency for the hospital to be built in two or more phases with the first phase limited to about 300 beds. A typical first phase hospital is shown in Figure 1. It is in fact an example of a potential DGH based on the "Nucleus" designs developed by the Department of Health and Social Security (DHSS). This particular type of hospital is likely to constitute about 40% of all new projects planned for the next decade. The design relies on most perimeter areas being naturally ventilated throughout the year.

APPLICATION

Patients' wounds can become infected with micro organisms emanating either from the patient himself, or by cross infection from other patients and staff. Where cross infection occurs aerial-bourne contamination is often the first cause considered although there may be other

contributing factors such as the techniques employed for aseptic procedures. The use of centralised shared treatment facilities as compared with ward based treatment rooms has been claimed as one method of controlling cross infection.[2] In areas other than those needing special aseptic conditions natural ventilation may be acceptable if it can provide a suitable environment.

There are of course many areas (which are listed in DHSS departmental Building Notes[3]) that must have mechanical ventilation for functional and clinical reasons. It will also be provided to other parts of the hospital to satisfy specific operational policies or to maximise use of accommodation. Usually these special requirements are identified in conjunction with the Client Group at the project briefing stage. Mechanical ventilation and/or air conditioning is used in these spaces to maintain aseptic conditions - operating theatres; to maintain fixed temperature and relative humidity conditions - special care baby unit; to deal with processes - sterilizing and disinfecting; to cope with special needs such as acoustic isolation of an audiology room; to provide suitable environmental conditions within deep-planned rooms.

The remainder of the hospital generally relies on natural ventilation whenever and wherever the quality of the ambient air is suitable. This is usually acceptable although there will be times when air change rates are adversely affected by high wind speeds, low outside temperatures and other factors.

In the exemplar hospital 50% of the total area of 14112m^2 is naturally ventilated. Extract ventilation or assisted passive ventilation is provided to 30%. These areas usually include ablution zones as well as the internal corridors and circulation spaces through which they are ventilated. The remaining 20% is provided with conditioned air - 18% as of right for clinical or other needs and 2% due to internal planning. When the hospital is fully developed into a DGH these percentages may not change very much as more ward accommodation will be added in subsequent phases. It is more likely that a greater area will be naturally ventilated as less than a third of the area in a ward template is mechanically ventilated - supply or extract or both.

AIR CHANGE RATES

The minimum air change rate needed for various types of accommodation will be of different magnitude depending on the functional use of the space and these values will also vary throughout the year. The amount needed for life support and maintenance of a low level of CO_2 concentration[4] will readily be achieved without much attention - for example 0.3 air changes per hour will suffice within a 6-bed geriatric ward. Optimum rates will therefore vary from minimum required in winter for the dilution of body odours and background smells to a maximum in summer; the higher summer rate will reduce internal temperatures which would otherwise be intolerable.

In the early 1970's DHSS sponsored research on odours within an air conditioned hospital. The results indicated that source rooms with acute odours needed air change rates greater than 6 per hour.[5] Some confirmation of this particular work is witnessed at the totally air conditioned Greenwich DGH, one of the Department's early development projects. Here odour within the Geriatric ward is effectively suppressed by an air change rate of approximately 8 per hour. Such a rate would have to be maintained throughout the 24 hour period but it could not be sustained naturally and would cause draughts and other problems. It is therefore unlikely that within the present limits of existing technology natural ventilation can effectively cope with acute odours. Further research is continuing in this field and will include examination and field trials of other techniques of odour control. If they are successful and acute odours can be reduced to an acceptable level of tolerance for patients, staff and visitors then it will be possible to rely on natural ventilation in the affected spaces.

The early studies also demonstrated that within general surgical wards and similar accommodation 3 air changes per hour would dilute intermittent background odours to an acceptable level of tolerance. Today improved nursing techniques, the adoption of Central Treatment Suites and better standards of mechanical ventilation where it is needed have all contributed towards better conditions. Against this background it seems likely that natural ventilation with less than 3 air changes per hour can provide an acceptable environment within nursing units and other like areas.

The higher rate needed in summer will be influenced by several factors but the underlying requirement is to ensure that internal temperatures do not rise to unacceptable levels. There are many authoritative publications on summer-time temperatures and the CIBS Guide[6] is as good a reference point. It recommends that 27°C should not be exceeded often in non-air conditioned buildings. Some patients will undoubtedly be less able to cope with high space temperatures because of their weakened physical state. However the wearing of light clothing

within the hospital environment will help to alleviate the level of discomfort.[7] In practice peak conditions do not happen often and do not last very long. They normally occur when wind speed is low and this coincides with high external temperatures. During these times natural ventilation can only materialise through temperature differences between inside and outside and the air change rate is likely to be lower than that produced by the wind. The last hot summer of 1976 was indeed an exception and weather data for Kew 1967 is regarded as being more typical of ambient conditions. In that year there were only 6 days when an external temperature of 25°C was exceeded and for a total time of 24 hours.

Figure 2 gives an indication of internal air temperatures that are likely to prevail within the shaded top floor 6-bed ward in Figure 1. It is based on computer simulations of the space for July 16 using the Kew '67 weather data. The room has two roof lights each 900mm square and 23% of the south facing external wall is glazed and provided with internal venetian blinds. Air change rates are assumed to be constant throughout the 24 hour period. These graphs show the marginal reduction in room temperature when the air change rate is increased beyond 6 per hour. In fact an increase from 6 to 10 lowers the temperature by only 0.5°C. Similar patterns were noted for 17 July when the external temperature rose to 28°C for 2½ hours. The results demonstrate that between 5-6 air changes per hour would provide tolerable temperatures within this particular room during peak conditions. Since this space is not unrepresentative of other naturally ventilated parts of the hospital the data can be applied elsewhere with some degree of confidence. In a live project it may be judicious to categorise the accommodation into various space types and simulate each type for a more accurate assessment.

Recent tests to which reference is made later on have indicated that a wind speed of 2m/s would generate an air change rate of 6 per hour in the case of the exemplar ward. It would therefore have achieved adequate ventilation as wind speed recorded in the Kew 1967 file averaged 2.2 m/s and exceeded 4 m/s most of the afternoon. However the same room in a closed courtyard location, without the effect of wind, would not have fared as well. If the space temperature must not exceed 27°C when the ambient is at 25°C then the driving force for natural ventilation is limited to that caused by a temperature difference of 2°C. Such situations would need special attention particularly with regard to the type and size of windows that minimise solar gain and readily support natural ventilation by this method.

PLANNING

Quite apart from external influences, several characteristics of the hospital itself will help to determine the manner in which and the degree of natural ventilation that will be achieved. The building shape and form for example will influence the extent of naturally ventilated accommodation. In normal situations the hospital is not likely to be more than 4 storeys and as windows can be opened at this height any accommodation on the perimeter is a potential candidate for natural ventilation.

Since an element of deep planning can seldom be avoided it makes sense to locate within the core, whenever possible, those rooms that must be mechanically ventilated for functional reasons. This position will also suit rooms which have a transient occupancy.

The introduction of internal and external courtyards will open up greater areas to natural lighting and ventilation albeit at a higher capital building cost. The wall to floor ratio will increase as will the winter heating load. Nevertheless, there will be a significant reduction in overall energy usage for environmental services. Current studies into the design of a low energy hospital sponsored by DHSS have indicated that the annual energy consumption for core rooms is about five times that for perimeter spaces. The performance of closed courtyards as ventilators is outside the scope of this paper, but it is obvious that internal dimensions will have to be sufficient to permit continuous air exchange with the outside and avoid stagnation at ground level.

Subdivisions within the hospital play a major role in determining the ease with which air can migrate throughout the accommodation. Individual departments tend to operate within closed compartments for a variety of reasons. This effectively reduces the contribution made by crossflow and prevents the realisation of any driving force due to "stack effect" between floors. It is likely too that the effectiveness of cross ventilation which was very much a feature of Nightingale Wards will also be seriously reduced by internal partitioning. In recent times health care practices have necessitated direct supervision of a larger number of more acutely ill patients as well as greater flexibility in the use of accommodation to nurse mixed sexes. In order to achieve these and other aims nursing units have become compartmentalised into single and multi-bed wards which suppress cross ventilation. Open doorways do help but this cannot always be tolerated in operational terms.

The quality and extent of internal barriers, above and below any false ceilings, that are needed to satisfy modern standards of fire separation and smoke stopping are other negative factors. Their effect could be lessened by the installation of louvres that close on initiation of some automatic sensing device. However such systems can have only limited application since any failure will undoubtedly compromise the integrity of the barrier and the compartment. Internal partitions within the exemplar 56 bed acute nursing unit are shown in Figure 3. Sub-compartments are formed within the overall 1 hour fire resistant compartment to assist staged horizontal evacuation in the event of a fire.

WINDOWS

Windows make a major contribution towards enhancement of the internal environment. They benefit the well being of both patients and staff in maintaining their visual and aural contact with the outside world. They are also the means by which perimeter accommodation is naturally ventilated and lit and benefit from solar gain in winter. Yet notwithstanding its many virtues the window is often cast in the role of villain; a role that has been acquired over the past few years through the indiscriminate use of glass as a cladding material. This has caused draughts in winter, glare and high internal temperatures in summer and even spring and autumn. Now, there is a better appreciation of such factors and an awareness of the need to optimise glazing ratios throughout the hospital and especially in continuously occupied spaces. In the exemplar hospital the recommended overall glazing ratio has been fixed at 26% although this would be varied to suit particular needs within each room. If rooms are to be naturally ventilated the types of windows forming these smaller glazed areas must not restrict or prevent this process.

Historically bottom openings of windows have usually been limited to 100mm (although a few recently built hospitals have opted for 225mm) but this restriction does not seem to have been applied to the top as well. Past practice can no longer remain sacrosanct and in the current climate more effort will be directed to the search for other means of obtaining maximum openings consistent with acceptable standards of patient safety and security.

Louvre windows that are air tight when shut may be acceptable. An alternative could be the vertical sliding window which can provide 50% opening with maximum separation between top and bottom; a profile most likely to promote natural ventilation. Window shading will also need special consideration. Such devices must not impede air flow neither must frequent adjustment, be necessary or a burden to nursing staff.

In exceptional cases openable roof lights could be used at top floor level to increase day lighting and natural ventilation. However, their installation needs to be evaluated against such factors as cost, control, ease of maintenance and the like.

SITE MEASUREMENTS

During summer 1978 tests on natural ventilation were carried out at Southlands Hospital, Shoreham-by-Sea while it was being fitted out. They were conducted by personnel from West Midlands Regional Health Authority under the aegis of the DHSS. This hospital, see Figure 4, is similar in profile to the Nucleus shape and has four storeys of ward accommodation totalling 294 beds. The average glazing ratio is 55%, part of which is fixed. Openable areas have vertical sliding windows 1.5m high x 1m wide with restrictions which limit top and bottom movement to 225mm. This represents 7% of the room elevation at maximum opening. Internal blinds are installed throughout the wards and consist of individual vertical blades which can be drawn across the glazing and set at any angle.

Natural ventilation rates using the tracer gas Krypton were measured in a courtyard facing 5m deep 3 bed ward on the ground floor, 7.5m deep 5 bed wards with external elevation on the ground and 4th floors and a specially formed courtyard facing room 7.5m deep within the catering department on the 2nd floor. In all but 2 of the tests these rooms were sealed with polythene sheet to simulate conditions for single sided ventilation.

The range of wind speeds recorded was between 0.5 m/s to 10 m/s with a maximum of about 6 m/s occurring more often and from a south westerly direction. In the courtyard facing the catering room air movement was turbulent and air speeds in excess of 4 m/s were logged. Recordings were also taken of wind speeds at window openings and these confirmed that whenever wind causes ventilation air can flow through both top and bottom openings simultaneously. During the test programme the temperature within the catering room remained fairly constant at 21°C whilst the external ambient varied cyclically between 14.5°C and 20°C. An inside peak of 23°C was charted at the weekend when the building was closed and the outside a maximum of 19°C.

Measurements from this pilot study on natural ventilation were not sufficiently exhaustive to advance positive conclusions. Yet the results did yield valuable data which can influence building design. The realisation of single sided ventilation was confirmed as was its effectiveness in deep planned courtyard facing rooms. Five air changes per hour were measured at back of the catering room when the inside/outside temperature difference was 2.6°C and wind speed 9 m/s. The same temperature difference produced a rate of just under 4 with a wind speed of 4 m/s. It was to be expected that identical window openings in the 3 bed ward would foster greater air change rates. Indeed a rate of 11 per hour prevailed when the wind speed was 9 m/s and the temperature difference 2°C. Within the 5 bed ward a gentle breeze (4 m/s) caused 11.5 air changes per hour.

Computed air change rates based on a theoretical formula for air transferred by temperature difference[8] were partially supported by field results for courtyard facing rooms. Measured values were marginally greater except for the 3 bed ward where they were three times as much. These indicate the likelihood of wind having a greater affect on natural ventilation in these areas then temperature differences. In the 5 bed ward the enhancement from cross ventilation was found to be less than one air change per hour.

The work also provided crude yardsticks on the characteristics of internal blinds. Roller types reduce natural ventilation by 80% when fully closed. The performance of venetian blinds is better with 20% to 40% reduction depending on blade angle. Vertical blinds with individual slats do not impede air flow providing blades are less than 50% closed. Beyond this setting the reduction varies from 35% to 60% depending on the rate of air exchange with the outside.

SUMMARY

Present health care practices acknowledge that a significant part of the modern hospital can be naturally ventilated throughout the year by the introduction of untreated fresh air. The ventilation rate needed varies and is usually adjusted by manually opening windows. There are no specific winter design parameters although 1.5 air changes per hour is usually assumed for heat loss calculations and the avoidance of draughts is an obvious pre-requisite. Undoubtedly there are instances when an enhanced rate of 3 per hour for short periods would be beneficial but this should not influence the design of the heating system. In peak summer conditions a minimum rate of 6 air changes per hour is needed to off set heat gain.

Cross ventilation is unlikely to be achieved and designs should be based on single sided ventilation. Although wind will be the driving force for both courtyard and perimeter locations, the force created by temperature difference will predominate in light air conditions. Windows play a vital role and before a selection is made their performance as ventilators should also be evaluated. The choice should be for a type that permits maximum opening without endangering patients' safety and security. Computer simulation techniques are powerful tools that can be used to help this design process.

FUTURE TRENDS

Natural ventilation has many virtues not least of which are its availability and free cost. However there are drawbacks which although not particularly important in past years will cause greater concern in the future.

It is not uncommon for optimum ventilation rates needed to vary during the course of the day. Yet the rate that actually occurs defies instantaneous measurement. Effective control over air flow is also elusive as contributing forces change over short periods. This effect is more pronounced because of variations in wind direction and speed; the latter over a range of zero to in excess of 11 m/s. In practice higher air change rates than those actually needed are often realised. During summer this can benefit the internal environment without incurring cost; not so in winter when consumption of fuel used for space heating is increased.

Extra revenue cost is incurred by wasteful heat loss from an overprovision of ventilation in winter. This is only a small proportion of the total fuel bills and is moderated by the temperate climate in the United Kingdom. In the exemplar hospital for example, the annual revenue cost of fuel to provide one air change per hour in the Clinical Block is £1,500. However, as fuel prices rise in real terms individual elements of overall fuel consumption will become more significant and will be identified as such. This is likely to establish the need for better management of ventilation during winter. Installations which satisfy this objective will also have added advantages of guaranteeing specific air change rates throughout the day and at nights and relieving nursing and other staff of any control function. Perhaps central air handling and heat reclaim plant providing 3 air changes per hour for both space heating and ventilation would be economically worthwhile.

The building would need to be sealed in winter but windows could be used in summer to enhance ventilation. These benefits will have to be balanced against an inevitable increase in capital costs and the response of manufacturing industry in meeting the need for better equipment. The DHSS low energy hospital studies are paying particular attention to these and other issues.

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REFERENCES

1. Lord Taylor, The natural history of windows. British Medical Journal 1979 page 870-875.

2. R J Brigden, Shared Treatment Facilities. DHSS May 1980.

3. DHSS Hospital Building Notes.

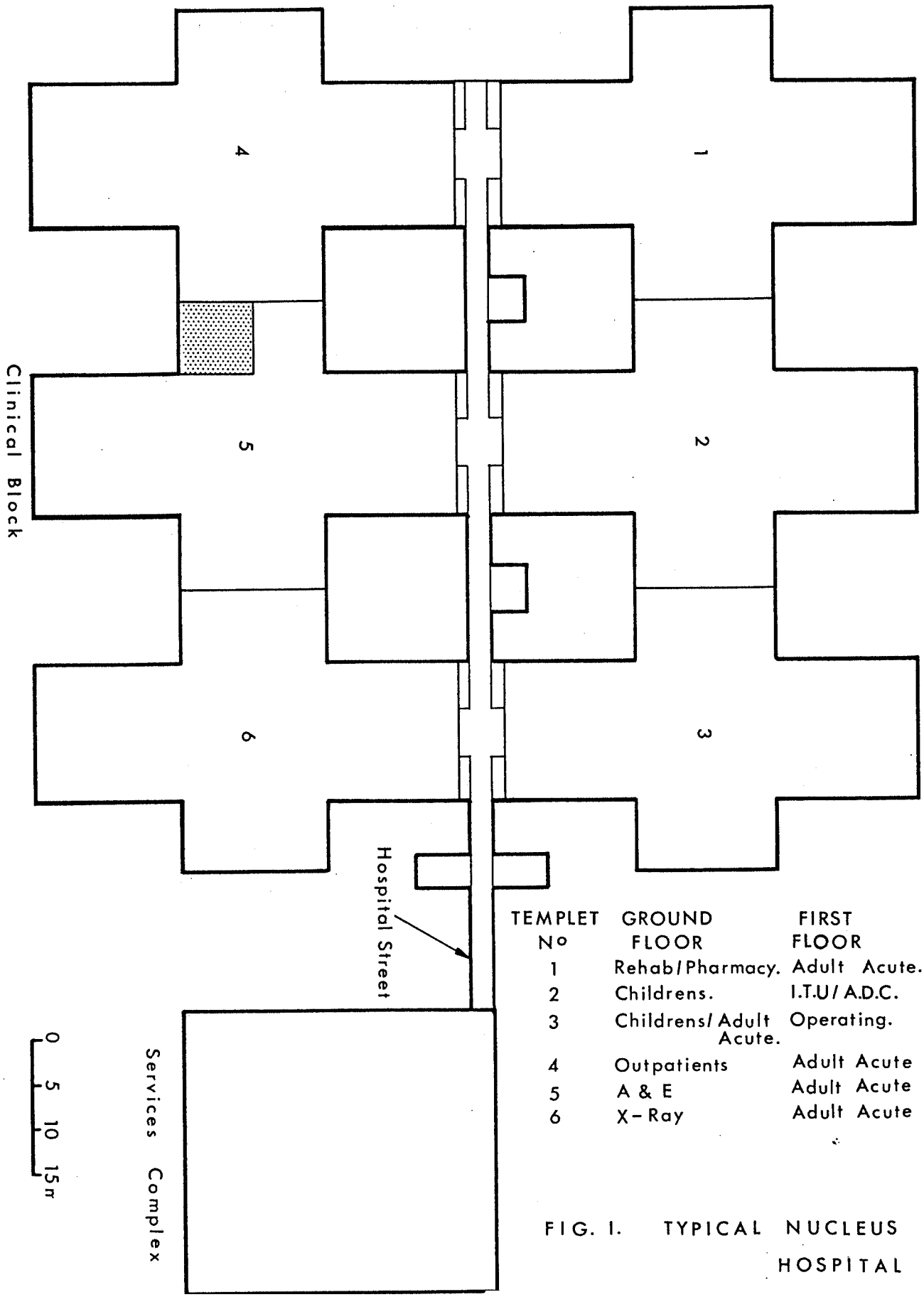
4. Ventilation Requirements. Building Research Establishment Digest 206, October 1977.

5. A Rae and R M Smith, Subjective Odour Levels in an Air Conditioned Ward. Building Services Research Unit, University of Glasgow.

6. CIBS Guide Book 1970 Section A8.

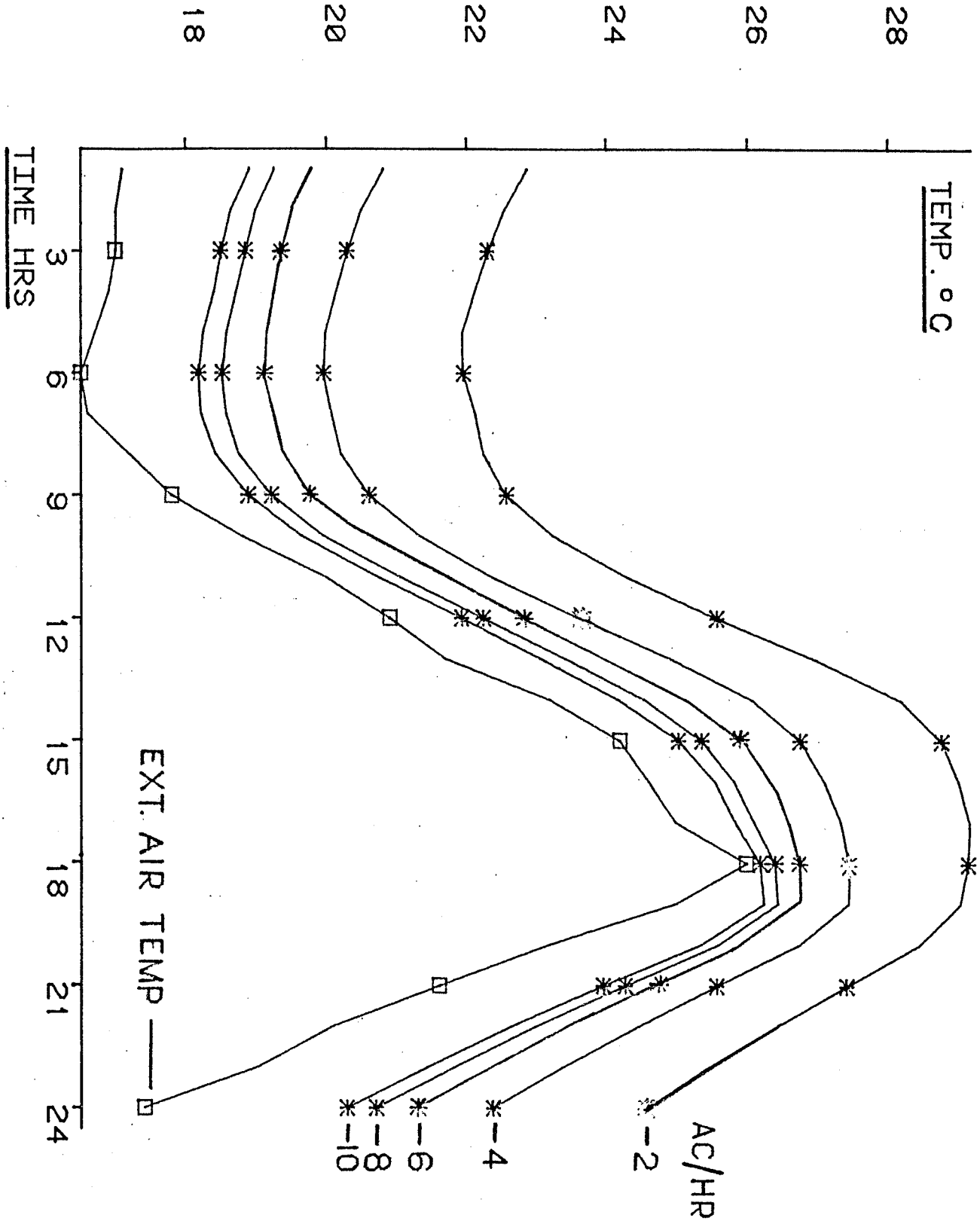
7. M A Humphreys and J F Nicol, Theoretical and Practical Aspects of Thermal Comfort. Building Research Station, CP 14/71.

8. Principles of natural ventilation. Building Research Establishment Digest 210, February 1978.



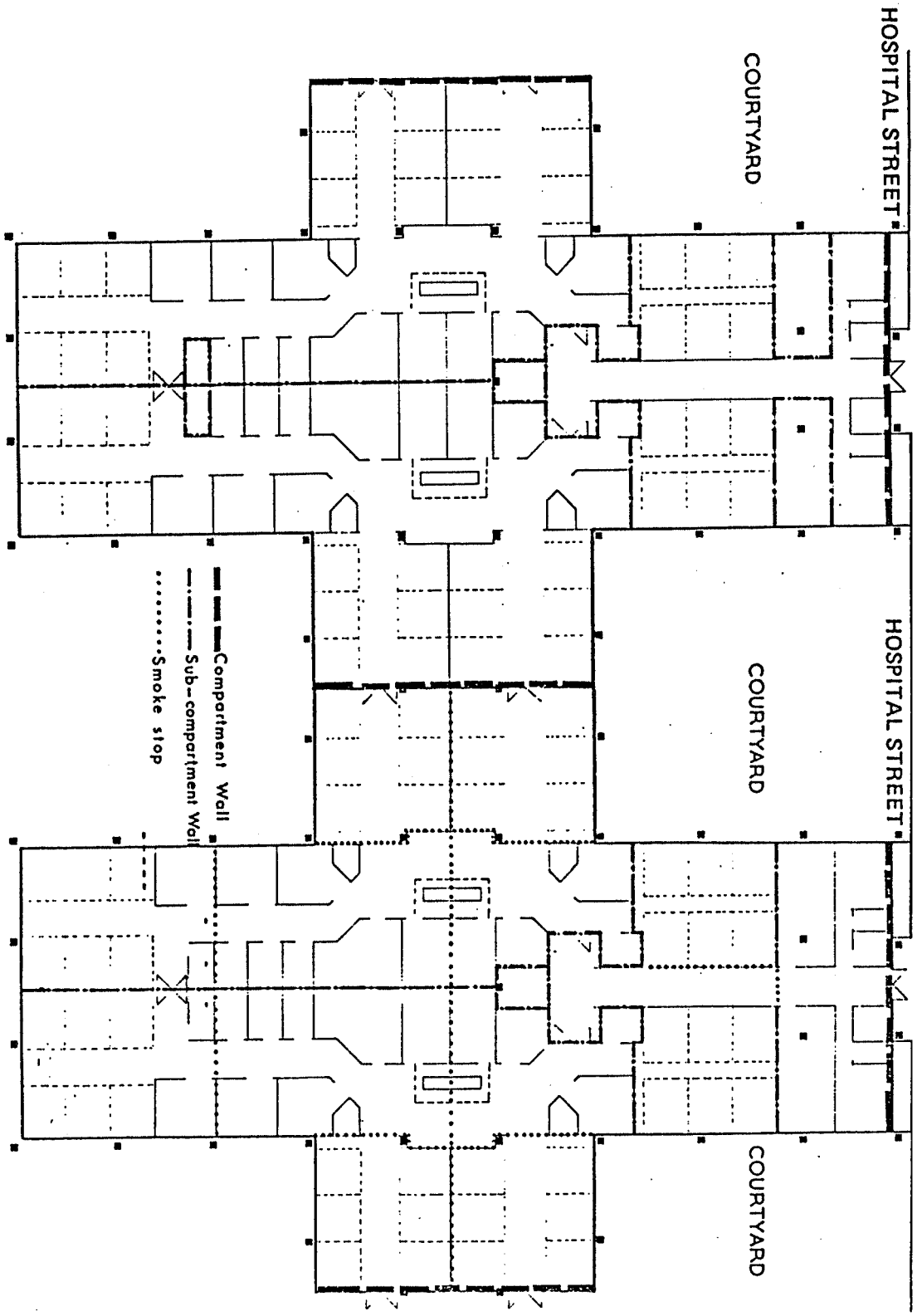
TEMPLET No	GROUND FLOOR	FIRST FLOOR
1	Rehab/Pharmacy.	Adult Acute.
2	Childrens.	I.T.U/ A.D.C.
3	Childrens/ Adult Acute.	Operating.
4	Outpatients	Adult Acute
5	A & E	Adult Acute
6	X-Ray	Adult Acute

FIG. 1. TYPICAL NUCLEUS HOSPITAL



SIMULATION NO. 1 OUTPUT PERIOD FROM 16, 7, 1 TO 16, 7,24

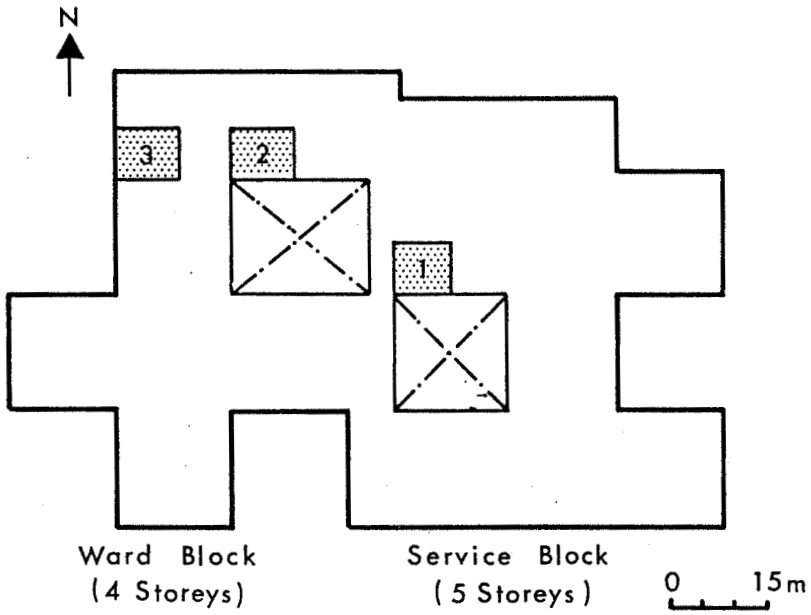
FIG.2 SIX BED WARD INTERNAL AIR TEMPERATURE



FLOOR PLAN

CEILING VOID

FIG.3 FIRE/SMOKE BARRIERS- ADULT ACUTE WARD



Key

1. Catering. 2. 3 Bed Ward. 3. 5 Bed Ward.

FIG.4 SOUTHLANDS HOSPITAL