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Natural
Ventilation
Of School Buildings
Workshop 20 October 1987

REPORT

SECOND CONSORTIUM OF LOCAL AUTHORITIES

NATURAL VENTILATION OF SCHOOL BUILDINGS

CONTENTS

SECOND CONSORTIUM OF LOCAL AUTHORITIES

DEPARTMENT OF EDUCATION AND SCIENCE

SUMMARY OF DISCUSSION GROUPS

NATURAL VENTILATION OF NEW SCHOOLS

It was generally recognised that because of occupants' behaviour, natural ventilation rates were usually much lower than the accepted criteria for calculation. A great deal of anecdotal data existed which showed that frequency of opening windows bore a direct relation to external temperature and that the greater the volume the less the frequency of opening. The recent BRE survey also shows that very low ventilation rates, below 4 cubic metres/ person/hr have been found to be acceptable. Recent work by Portsmouth Polytechnic on schools in England and New Zealand also confirms this.* Appendix 2 summarises calculations and measurements in a range of new school buildings, mostly large volumes.

Both discussion groups considered that satisfactory design for natural ventilation was only achieved if the design team accepted this as a priority from the beginning. As windows are the usual vehicle for natural ventilation, daylighting also becomes a consideration balanced against heating and comfort requirements. Without doubt the BRE Design Aids would be an invaluable help at this stage. Graphical aids and computer programmes would both be useful.

Users of buildings need to be fully informed of how their building is meant to work. Many users' complaints could be reduced if they 'understood' their buildings better, but designers had to bear in mind that the occupants are in the building to do a particular job, and running the building is not necessarily their concern. Their involvement can only be for simple and commonsense operations. Clear instructions are essential, even if the mechanisms are obvious, such as windows, but more so if ventilation grilles, fans or ducts are incorporated.

Feedback from building users is seen as an important part of the design process, not only to find out what can be improved, but also what is successful; this information can be applied to future designs.

* Refer to Epilogue for recent publication

REFURBISHMENT OF EXISTING SCHOOLS

Discussion centred on four subject areas for which the major points were as follows:

Buildings built pre-1945

The type of building determined much of the potential control of ventilation. The older schools, of massive construction with high ceilings, perform very differently from the largely glazed medium height structures of the 1950's and 60's.

The Hither Green School is a Victorian multi-storey primary school in central London which had received very close monitoring of conditions before and after refurbishment. In the original state, the school had an average infiltration rate of 1.7 air changes/hour. This was halved by draught-stripping, but it was acknowledged that draught-proofing should not be overdone.

The older buildings are good climatic modifiers: both winter and summer peaks are evened out. In such buildings the rule of thumb of "opening window area should be at least 1/20th of floor area" is usually satisfactory. High ceilings in such buildings are not necessarily wasteful of energy but the top floor roof void should be well insulated to even out temperature gradients.

Buildings built post-1945

Generally buildings of light weight construction, flat roofed with low ceilings and large glazed wall areas predominate. In such buildings, overheating is likely to occur in summer due to solar penetration. This of course penetrates through the roof as well as the glazed facades, although its effect in comparison with large areas of glazing is not significant. Before trying to manage ventilation, such solar overheating needs to be screened out, but this is likely to affect day-lighting levels.

Window Design

Provided the window design is well done, it is possible to maintain comfort conditions in most cases by natural ventilation. The following criteria were identified as necessary to achieve a successful solution:

- high and low level openable windows (at least 1000 mm apart vertically)
- screening from direct draughts
- openings distributed over more than one face of the room or good cross ventilation must be achieved by other means.
- reliable means of opening and closing windows, simple to operate and easily accessible to the operator
- openable window area equal to at least 1/20th of the floor area
- maximum depth of single side ventilated rooms should not exceed 6 m.

Limitations for these criteria include:

- possible clashes with safety requirements on upper floors and security at ground floor
- fire separation may limit ability to achieve effective cross ventilation
- sliding windows can only open 50% of their face area: both these and other windows, including pivot windows, may not be fully openable due to safety limitations.

Occupant Behaviour

It is important to observe how the occupiers use the existing ventilation. Adverse comments by users may be influenced by shortcomings in other features of the building. These need to be clearly identified by the designer.

There are two levels of air movement rate: the at rest infiltration rate and the working ventilation level due to movement through the building by occupants and the personal choice of ventilation levels by particular room occupiers. The designer needs to observe the school in action, possibly on several different occasions, in order to be able to assess the best means of providing a satisfactory environment.

Summary

The design of ventilation in a refurbished building therefore requires a good study of the performance of the existing building before any design is started.

It then needs to provide a sufficiency of openable windows at high and low level to give the users reasonable control of their environment. These should be well sealed when closed and easy to operate reliably and safely.

Location of openable windows should maximise the potential for cross flow in the spaces. This has to be balanced with any requirement for fire separation.

The effects of ventilation on energy conservation must be considered, together with possible conflicts with Health and Safety Legislation, security, fire protection and means of escape.

The location of glazing for efficient daylighting may not always accord with the ventilation needs. Solar overheating from southward facing windows can overload ventilation unless shade control is considered.

WINDOW DESIGN

Discussion centred on three subject areas for which the major points were as follows:

Provision of Daylight

Normally the provision of daylighting is the primary function of windows. Generally the group felt that architects were aware of existing guidelines intended to assist the specification and placing of windows to provide daylighting. However, some members thought that these guidelines, whilst adequate for simple building geometries, did not fully meet the complexities of modern design.

Factors responsible for this included more complex plan layouts and increasing use of pitched roofs, especially with low, overhanging eaves. At the same time the proportion of window to solid wall was decreasing, making the location of windows more critical.

Rooflights were being used increasingly, partly to help produce interesting interiors, but also becuase of the good quality of daylight admitted. This makes placement less critical than with ordinary windows, although increasing the possibility of sky glare and of solar gains. Resurrection of Protractors and Waldram diagrams, Dot field diagrams etc is the only way to solve complex designs. Attention was also drawn to the advantages of simple transparent slide graphs which could be of considerable assistance in window sizing, and computer packages based on rectangular room configurations.*

It was felt that the Department of Education and Science Design Note 17 recommendation, of 150 lux as a minimum acceptable level for working plane illumination in primary schools, was not generally being achieved by natural means. This was principally through over-optimistic expectations by architects and their desire to achieve more interesting forms.

* Refer to Epilogue for recent publications.

Ventilation

Existing rules of thumb relevant to ventilation were said to be harder to apply and less certain in outcome than those regarding daylighting. Neither could the situation always be remedied by providing fans, because these did not always ensure adequate distribution of internal air. It was however said that air would in general be well mixed under natural ventilation conditions. Openable roof lights, it was agreed, ought to work well in conjunction with openable windows to maximise buoyancy-driven flow on summer days when stack effect ventilation had to be relied on to moderate overheating. The group discussed how a simplified microcomputer thermal response model could assist with sizing and placement of windows to achieve adequate ventilation under buoyancy-driven flow.*

Windows were necessary to provide controllable ventilation all year round, together with the possibility of opening a larger area in the summer should conditions require it. Top hung, horizontal pivotted and vertical sliders were mentioned as particuarly suitable window types for school use. Louvres were also mentioned as a type combining the possibility for fine adjustment with the potential for large open areas, but a higher infiltration rate has to be accepted. It was emphasised that for louvres to give satisfactory performance, good design had to be combined with geometrically true installation, but infiltration rate increases with age and they are difficult to make burglar-proof. The three window types mentioned share the virtue of not projecting outwards at low level when open. This is particularly important for safety reasons in schools which tend to militate against the use of side hung casements, despite the fact that per window they offer a greater openable area than do sliders.

Rotary ventilators were mentioned as another way to provide both trickle ventilation and large volumes of air when necessary.

* Refer to Appendix 3 for notes on a dynamic response model for sizing windows which was tabled at the meeting.

Thermal Control

Turning briefly to thermal aspects of window design, the group identified a possible conflict in that overhanging eaves, used to control summertime solar gain in buildings with an element of passive solar design, would also reduce the amount of daylight admitted by the window when the external illumination was low. A somewhat similar dilemma is that solar films designed to reduce excessive solar gain, also operate when the solar gain is desirable to offset space heating requirements. This encourages the use of retractable blinds, but these have their own problems. Northlights were mentioned as a way to provide illumination in schools without the risk of excessive solar heat gains, but consideration then had to be given to the increased need for double glazing and that control of ventilation may be difficult or more expensive. Interest was also expressed in the possible use of shutters, which might be desirable for security reasons as well as having a beneficial impact on space heating requirements. Continental experience with shutters should be reviewed. A technical innovation which could lead to a resolution of this problem, said to be in prospect, would be a type of glass which darkened, either in response to light, or to electrical stimulus (but at what cost?).

In all areas discussed by the group a need was identified for design guidelines or rules of thumb coupled to particular classroom or building forms, orientations, and thermal characteristics. Once eststablished, these typologically based indicators could be applied to specific cases. However, the group felt that whatever methods of assistance were developed, the intuition and experience of the designer would still play a crucial role. This belief highlighted a second desideratum; that there should be more sharing of experience, both within an individual design office, and between offices.

Despite the changes in education currently foreshadowed, the group felt that the basic requirements for lighting and ventilation from windows would not change a great deal. The use of computers in schools would have to grow considerably before there was a significant impact on ventilation requirements. The problem of lighting glare on computer screens had to be recognised however.

The group identified a need for further study of user reactions in educational buildings (the Hopkinson study is now fifteen years old).*

* Refer to Epilogue for recent publications, particularly report for SERC.

CONDENSATION

It was generally agreed that condensation is not a significant problem in schools (excluding special cases of swimming pools, kitchens etc). Major areas of concern are flat roofs and surface condensation on floors, some refurbishment work, and possibly small volume schools.

The designer must consider the possibility of condensation in the context of ventilation rates, humidity conditions, heat loss and thermal response of building, occupancy levels, heating system and heating levels. He must calculate the risk of condensation; the only satisfactory way is by the use of a computer programme. Single condition calculations will be misleading as it is not possible to cover the number of variations. There are several such programmes available and a brief demonstration of Peter Burberry's was given following the discussion.

However, current data is contradictory and in a multiplicity of units, and calculation methods are various (compare BS 5250: 1974 vs BS 6229: 1982 vs CIBSE Guide vs BRE Digest 110: 1972 etc). Hopefully there is light at the end of the tunnel with a new draft of BS 5250 due for publication at the end of the year. This is intended to be the 'head code' for condensation prediction, condensate quantity and data base of vapour properties for building materials. A computer programme based on the new BS 5250 when published would therefore be ideal.

A suitable design concept could be based on specifying an air moisture figure not to be exceeded, with ventilation rate, heat load, insulation, occupancy etc to be analysed to check if the specified figure will be achieved.

Some energy saving methods may create/exacerbate condensation problems and increase the risk of building failure. The material to be used is important, e.g. organic, fibrous, and sheet plastic/metal materials will behave differently under condensation conditions. It was generally accepted that vapour barriers were probably unreliable.

The subject of cold bridges was well documented.* Whilst some standard solutions to cold briding problems may well be appreciated, it still appeared to be overlooked by designers, most probably because insufficient consideration and time is allocated to this aspect. Here again the application of the computer to check out solutions was important.

There was a difference of opinion on the best means of tackling condensation. It was disputed whether a set of ground rules, including 'no-risk' solutions, pitfalls to be avoided, etc are desirable or not: 'too busy to do a proper analysis' school versus 'think of the problem, understand the principles' school.

* refer: Cold bridges: construction calculation by Peter Burberry, Architects Journal, 27th January, 1988.

IN CONCLUSION - CHAIRMAN'S LAST WORD

If one starts to consider natural ventilation, linked as it is with windows and daylighting, one very rapidly enters the whole complex field of environmental design and comfort conditions, and the this is confirmed in the reports of the discussions by the study groups.

At the present moment, with fuel prices low and market forces ruling most aspects of our lives, there is very little interest in energy conservation or efficiency and the present trend in architectural thought seems to be more towards art and visual expression than to produce a well balanced and integrated building, towards sculpture rather than architecture.

It is easy for architects to follow this course; engineers of all types are adept at making the most difficult problems go away. There are dangers in this approach, in that with so much remedial engineering, controls technology becomes an end in itself and the occupants of the buildings are forgotten, left to the whim of a fully mechanised environment and processed through their lives rather than savouring the variabilities and inconsistencies of a more naturally linked environment. However, with natural ventilation and daylighting it is the architecture that solves the problem. Few seem to still understand this.

Is this a consequence of inadequate teaching and training? Designers and design teams used to know, didn't they? Or is this personal view, of one who has practised as both an engineer and architect, somewhat jaundiced?

What has been revealed by the Workshop is that many of the old design rules and simple aids have been forgotten or discarded as of no value in resolving present-day problems. The 1/20th of floor area and 6 m maximum depth rules of thumb do not get you very far in many modern designs. But the problems remain and in every study group the need for improved design aids has been identified. It is also clear that whether these are in table top or computer form they must be highly visual and articulated as a series covering climate and exposure, provision of daylight and control of insulation, ventilation and thermal design.

Work on measuring ventilation and occupants' behaviour is sparce since Yaglou's efforts in the Twenties, and publication of the work by the International Energy Agency on 'Inhabitant Behaviour and Ventilation' and 'Demand Controlled Ventilation Systems' must be eagerly awaited by all.

Having said all this, and hoping that those researchers amongst us will take to heart these pleas for aid and come along with it soon, I am reminded by a quotation made by Jim Powell in his inaugural lecture a while back, which I append.

Derek Poole

The time needed to acquire information, to understand it and exploit it must be kept to a minimum. Design valuable information will enable architects to readily gain a 'feel' for what they are doing so that they eventually have complete confidence in their proposed solution. However, the following poem sent to us by one of our architectural interviewees summarises extremely succinctly, and far more eloquently than I, the paradox that will always exist between architects and information.

There is something I don't know
that I'm supposed to know.
I don't know what it is I don't know
and yet am supposed to know.
And I feel I look stupid
if I seem both to know it
and not to know what it is I don't know.
Therefore, I pretend I know it.

This is nerve-wracking
since I don't know
what I must pretend to know.
Therefore, I pretend to know everything.

I feel you know
what I am supposed to know
but you can't tell me what it is
because you don't know
that I don't know what it is.

You may know what I don't know,
but not that I don't know it,
and I can't tell you.

So you will have to tell me everything ....
........but in no more than 5 minutes per day.

EPILOGUE

Since the Workshop, five documents have been published which are relevant to the subjects discussed:

- SERC: "Assessment by teachers of the environmental conditions and control of energy consumption in British, New Zealand and Australian Primary Schools" by J. D. Sime and J. A. Powell, School of Architecture, Portsmouth Polytechnic, published in November 1987. This is a report of the results of several surveys of teachers' assessments, carried out on behalf of the Scientific and Engineering Research Council, The British Council and the New Zealand Ministry of Works. Quoting from the final statement of the Summary to the Report: The research suggests that introduction of energy saving policies by local authorities through technical means or co-operation of users will be problematic

  (a) if the environmental conditions in each classroom/teaching space cannot be controlled by the teacher responsible for children using that area,
  (b) an energy management system is introduced without consultation and negotiation with the teachers in each school, and
  (c) there are existing dissatisfactions with the design and maintenance of the school building and its environmental performance (heating, ventilation, lighting and acoustics).

- CIBSE: Window Design Applications Manual. This concentrates on the lighting and insulation aspects of window design.

- DES: Research Report 1; Energy Conservation and Maintenance through retrofit measures. This covers three case studies in coal fired schools.

- The Martin Centre: "The atrium environment". This report is published in the Building Technical File No. 21, April 1988. It consists of eleven pages on the benefits of atria in commercial development but has much of relevance in terms of lighting and thermal performance, acoustics and subjective factors.

- BRE Report: "Environmental design manual; summer conditions in naturally ventilated offices". This provides the means of locating and sizing windows using a series of graphical aids for daylighting, ventilation and thermal design. This manual is clear and concise and it is possible to carry out both feasibility studies and actual design appraisals very quickly. It is limited to offices having one external wall. Notwithstanding this limitation, it provides a designer with a new 'set of rules' covering an extremely wide range of possibilities. It would appear to be exactly the type of design aid required for schools.

APPENDIX 1

DISCUSSION GROUPS AND PARTICIPANTS

VENTILATION OF NEW SCHOOLS (1)

Derek Poole	Architect, Hampshire CC
Mike Burnett-Smith	Architect, Department of Education and Science
Lionel Lambert	Architect, Bedfordshire CC
Martin Liddament	Head of Air Infiltration and Ventilation Centre, BSRIA
Dave O'Bryan	Engineer, Gloucestershire CC
Earl Perera	Engineer, Building Research Establishment
Greg Young	Engineer, Shropshire CC

VENTILATION OF NEW SCHOOLS (2)

Ken Viney	Engineer, Oxfordshire CC
John Bennett	Architect, Inner London Education Authority
Ian Carswell	Engineer, Cleveland CC
Tony Hoskins	Architect, Shropshire CC
Mukund Patel	Engineer, Department of Education and Science
Josephine Prior	Chemist, Building Research Establishment
Robert Thompson	Architect, CLASP
John Williams	Engineer, Somerset CC

REFURBISHMENT OF EXISTING SCHOOLS

Mike Woods	Engineer, Gwent CC
Mark Guthrie	Architect, Norfolk CC
Mike Hohmann	Architectural Consultant, formerly Greater London Council
John Palmer	Engineer, Data Build
Eric Rowe	Architect, Essex CC
Richard Walker	Physicist, Building Research Establishment
Sue Wood	Architect, SCOLA

WINDOW DESIGN

Peter Kirkham	Architect, Consortium for Method Building
Ian Cook	Architect, SCOLA
Jeff Davey	Architect, Somerset CC
Gordon Nelson	Engineer, Lecturer, Oxford Polytechnic
Graham Parr	South West Energy Unit
Jim Penman	Head of Energy Study Unit, University of Exeter
Richard Stuart	Architect, Derbyshire CC
Alan Wood	Architect, CLASP

CONDENSATION

Peter Burberry	Head of Department of Building, UMIST
David Curtis	Engineer, Essex CC
Peter Crean	Engineer, Shropshire CC
Ray Freemantle	Architect, SCOLA
Ralph Fuller	Architect, Shropshire CC
Ken Tythacott	Engineer, Surrey CC

NATURAL VENTILATION IN RECENT SCHOOLS IN HAMPSHIRE

BUILDING SHAPE AND ENERGY EFFICIENCY

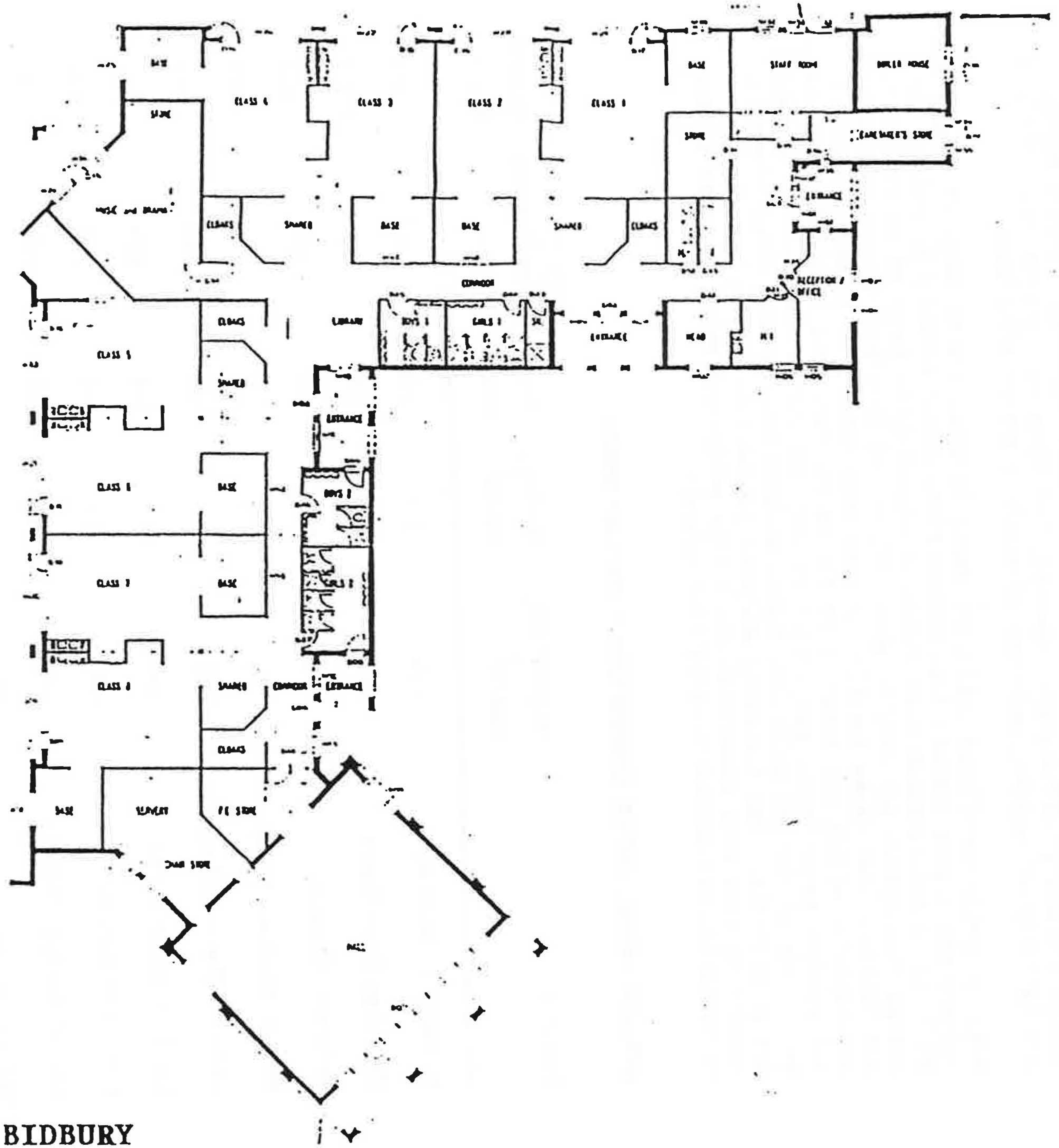
There has been a great deal of theoretical work regarding building shape, volume and energy efficiency. However, buildings are designed to satisfy a multiplicity of demands, only one of which is energy efficiency.

With naturally ventilated buildings there is quite a wide range of shapes and volumes which give overall fuel consumptions within acceptable limits. In DN17, it is demonstrated that within an aspect ratio range of up to 12:1 the energy consumption can vary by about 7%, beyond this both energy consumption and building cost rises rapidly. A very wide variety of shapes are easily accommodated within the range up to 8:1 which, with good insulation and design for passive solar input, can result in very low energy consumptions of half to two thirds of the DES guideline figure without compromising other essential design criteria. The following examples demonstrate this whilst the concluding note also summarises the design philosophy which has been adopted in Hampshire for naturally ventilated schools.

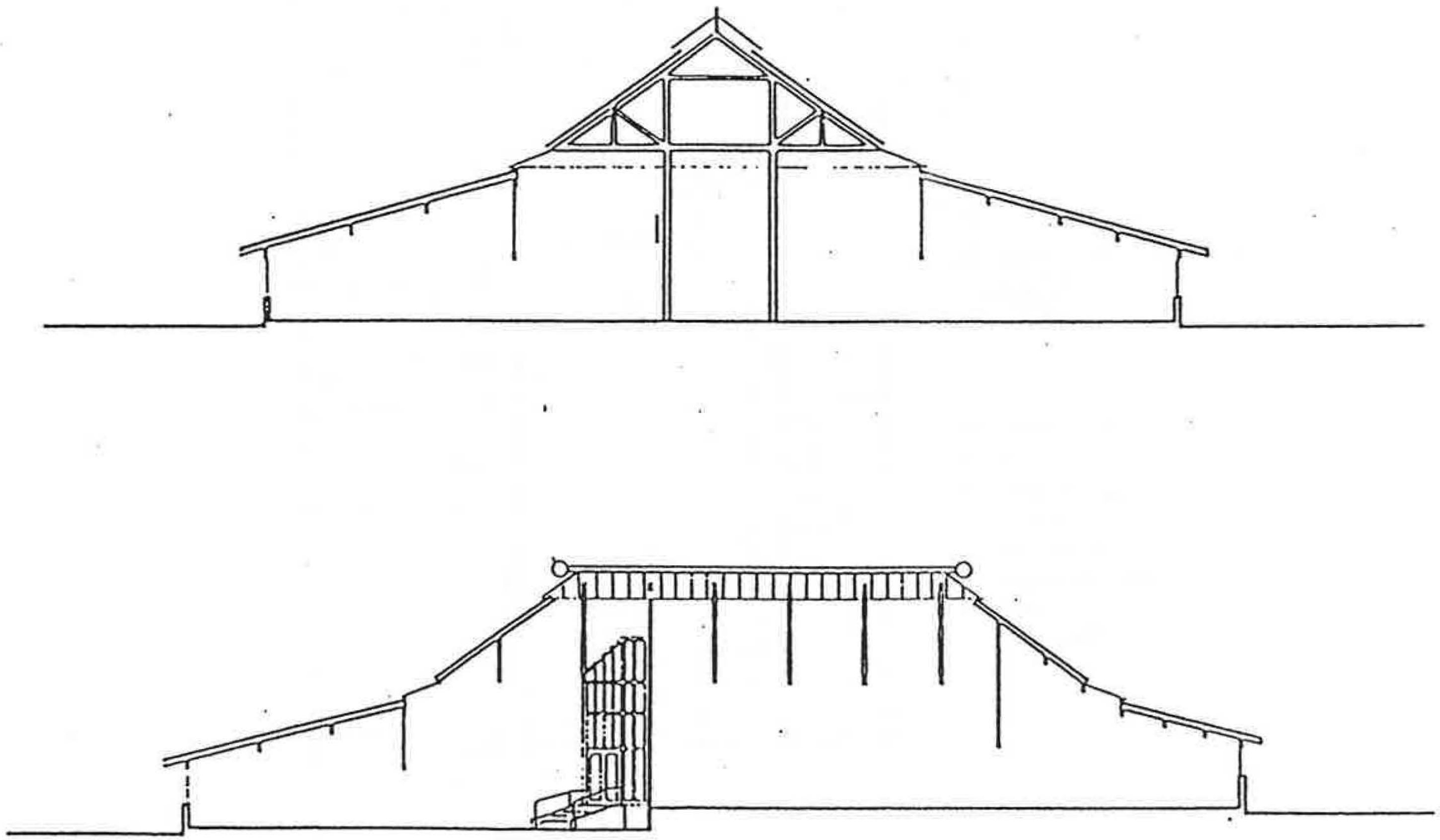
AVERAGE ANNUAL ENERGY CONSUMPTION - PRIMARY ENERGY

Project	Electricity kWh/m^2	Heating kWh/m^2	Total kWh/m^2	DN 17 Prediction kWh/m^2	Aspect Ratio
Bedhampton Bidbury	114	204	318	247	7:1
Chineham Four Lanes	127	153	280	231	5.5:1
Rookwood Infants	94	173	267	277	4:1
Tadley Burnham Copse	76	178	254	256	5:1
Gosport Elson Infants	122	126	248	266	6:1
Hardley Manor First	49	197	246	244	5:1
Hook with Warsash	148	95	243	258	6:1
Havant Bosmere Middle	47	150	197	191	7.5:1
Netley Infants (passive solar)	53	79	132*	80	8:1

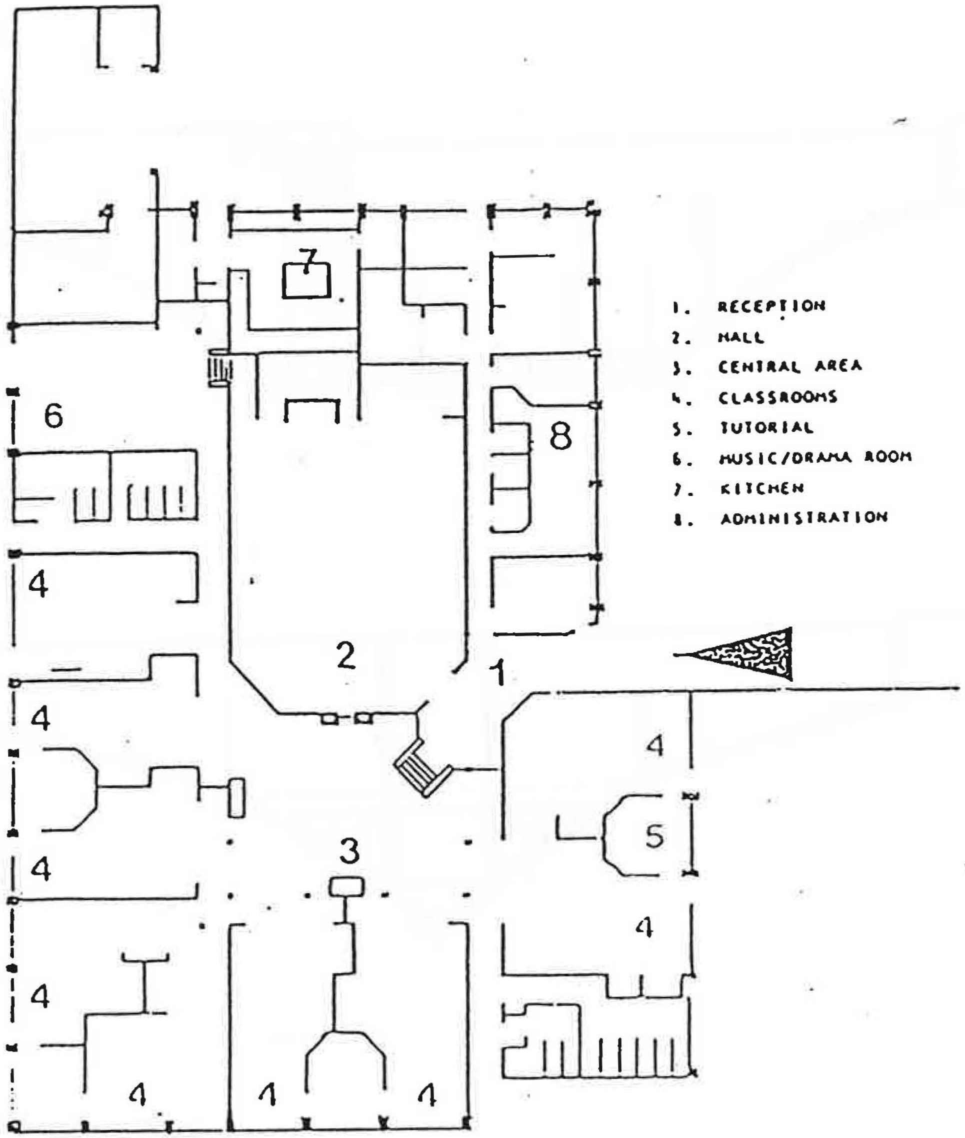
* Monitoring over the last heating season indicates a 39% solar contribution to heating load.



BEDHAMPTON BIDBURY



CHINEHAM FOUR LANES



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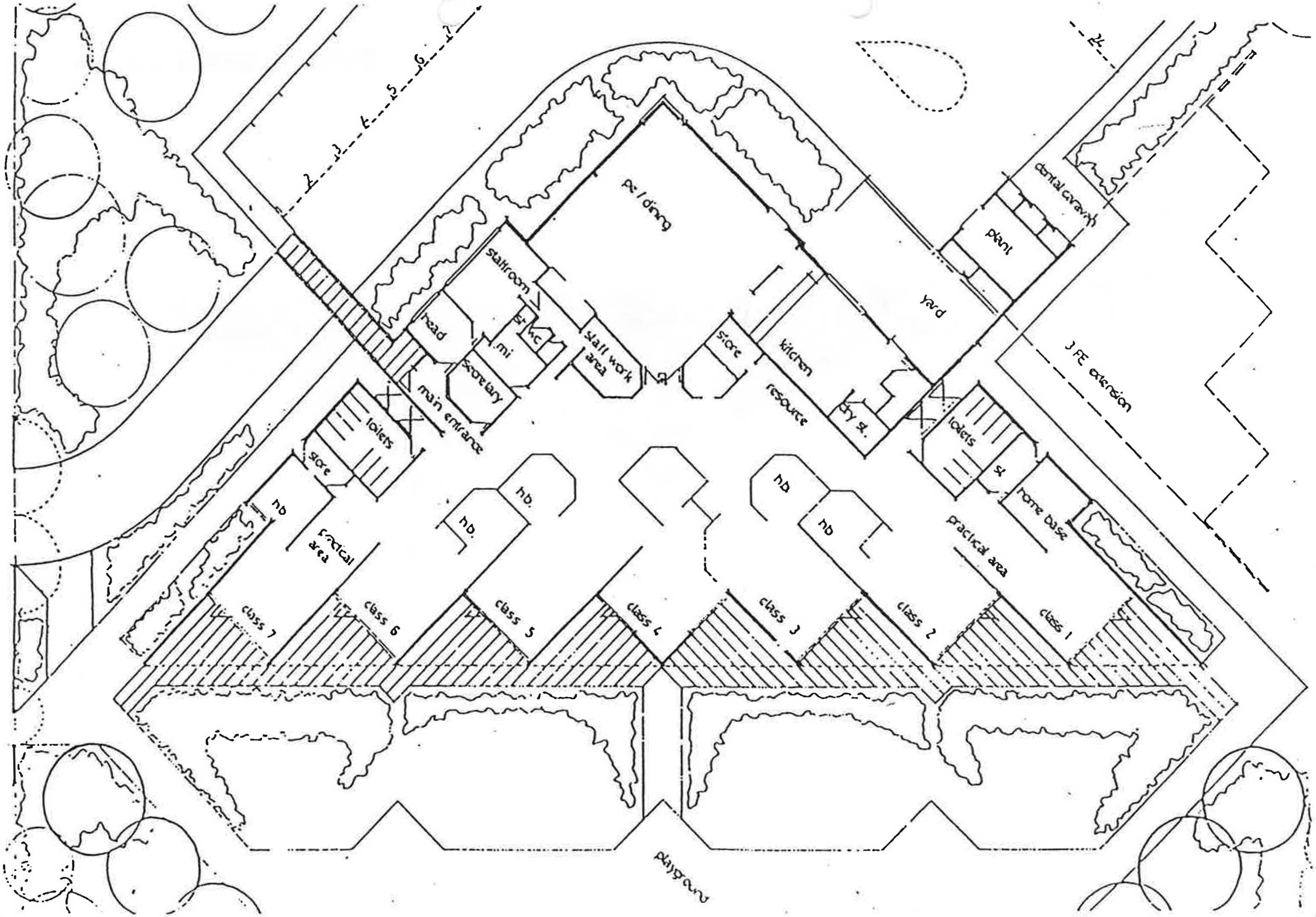

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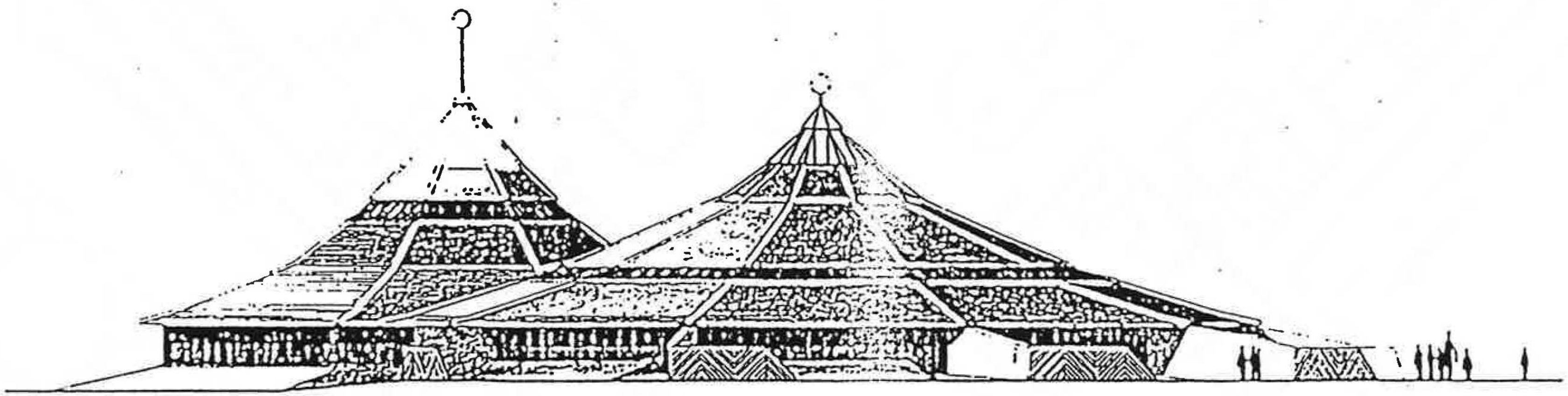
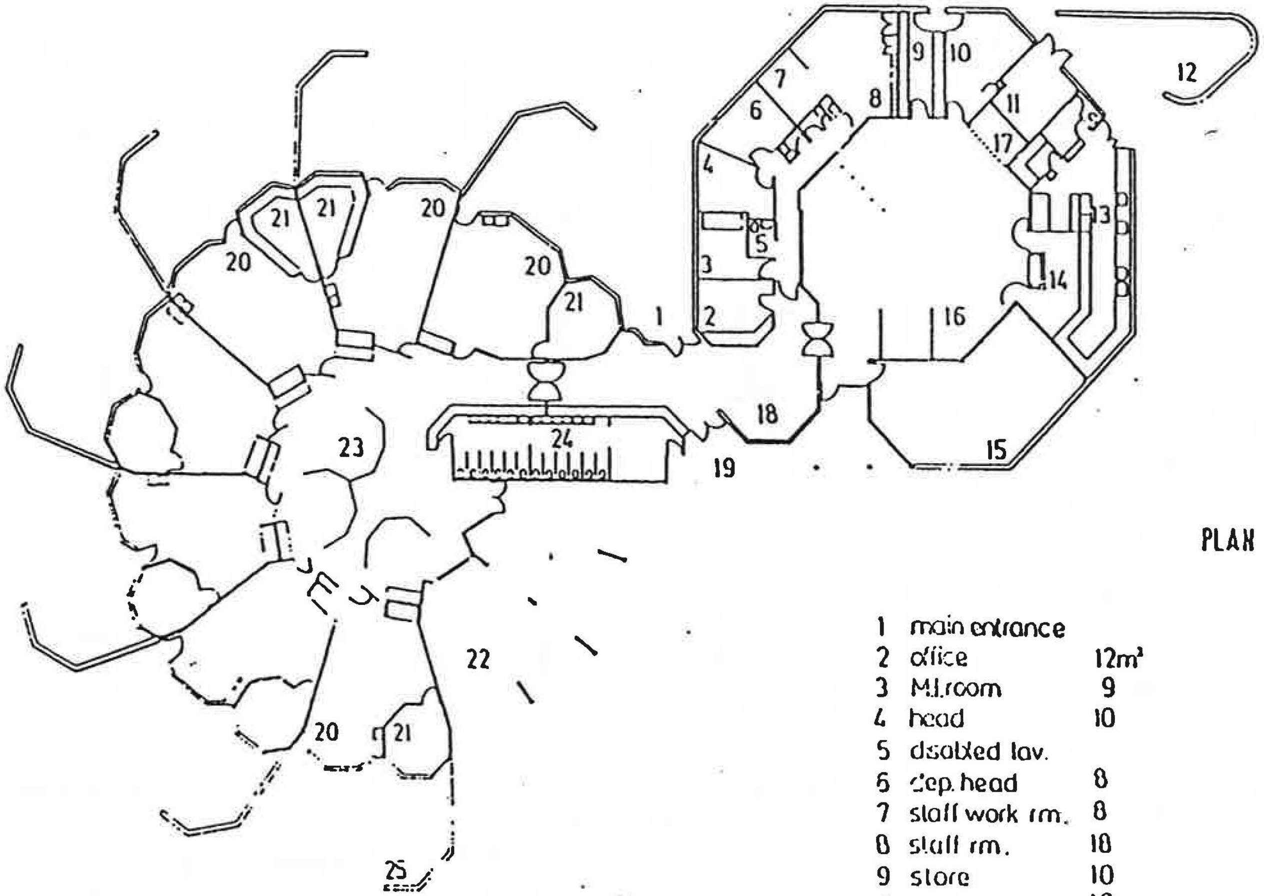
ROOKWOOD INFANTS



TADLEY BURNHAM COPSE



PLAN 1:200

1	main entrance	
2	office	12m²
3	M.I.room	9
4	head	10
5	disabled lav.	
6	dep.head	8
7	staff work rm.	8
8	staff rm.	18
9	store	10
10	caretaker	15
11	plant	
12	yard	
13	kitchen	53
14	servery	10
15	music/drama	55

16	hall	125
17	P.E.store	4·5
18	library recess	
19	childrens entrance	
20	classroom	[illegible]
21	class base	[illegible]
22	covered play/future classrooms	
23	shared area	3[illegible]+
24	loos	
25	outdoor areas	

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TADLEY BURNHAM COPSE

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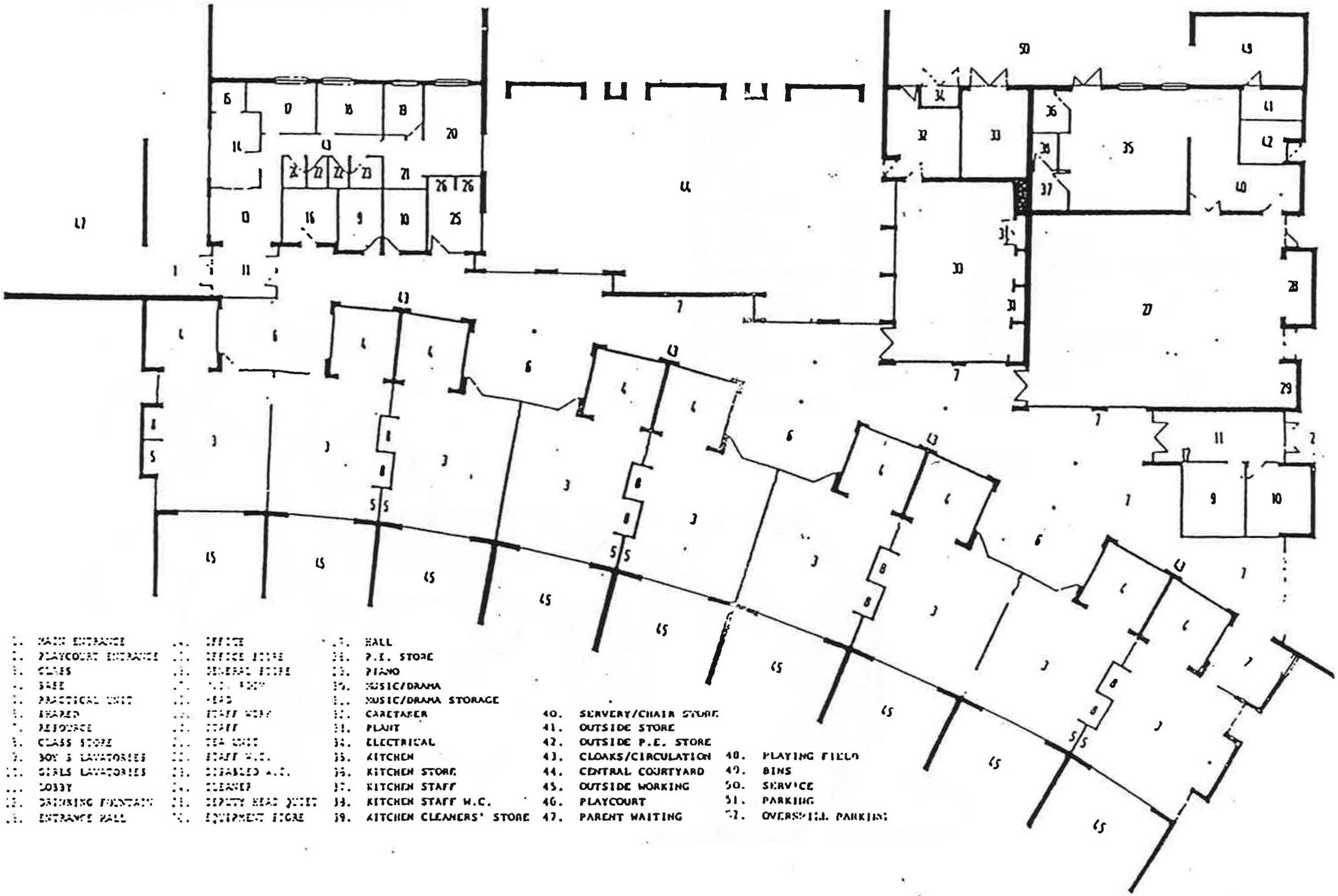
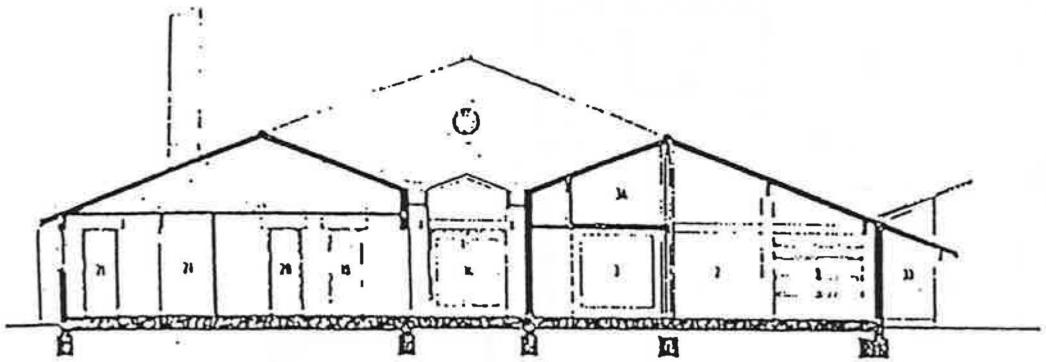
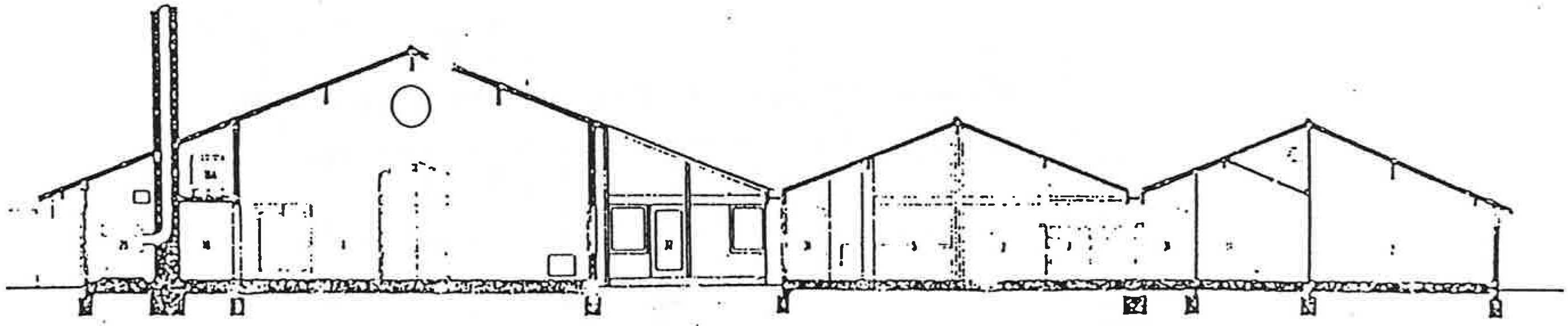


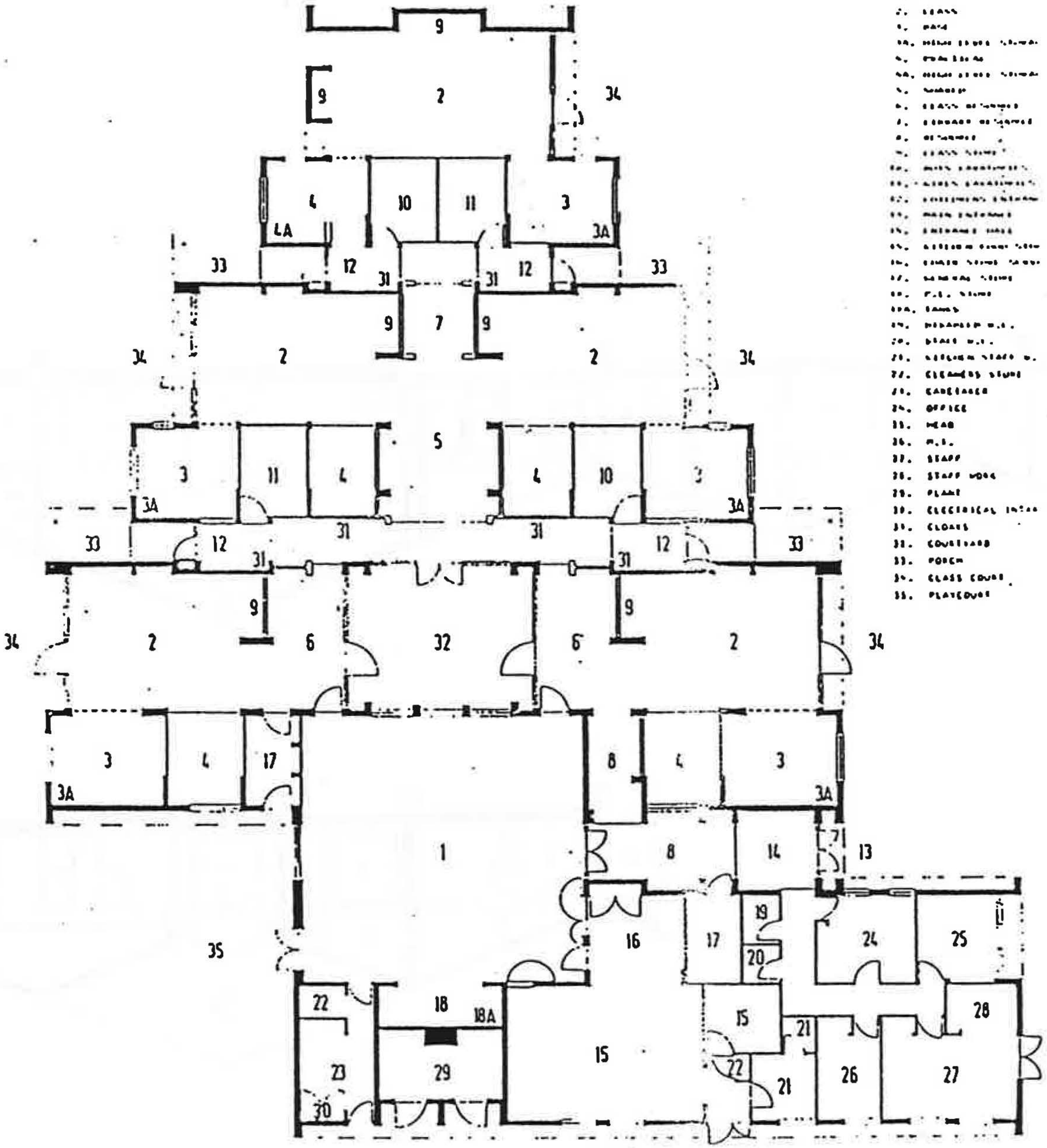
1. MAIN ENTRANCE
2. PLAYCOURT ENTRANCE
3. CLASS
4. BASE
5. PRACTICAL UNIT
6. SHARED
7. RESOURCE
8. CLASS STORE
9. BOY'S LAVATORIES
10. GIRLS LAVATORIES
11. LOBBY
12. DRINKING FOUNTAIN
13. ENTRANCE HALL
14. OFFICE
15. OFFICE STORE
16. GENERAL STORE
17. M.I. ROOM
18. HEAD
19. STAFF WORK
20. STAFF
21. TEA UNIT
22. STAFF W.C.
23. DISABLED W.C.
24. CLEANER
25. DEPUTY HEAD QUIET
26. EQUIPMENT STORE
27. HALL
28. P.E. STORE
29. PIANO
30. MUSIC/DRAMA
31. MUSIC/DRAMA STORAGE
32. CARETAKER
33. PLANT
34. ELECTRICAL
35. KITCHEN
36. KITCHEN STORE
37. KITCHEN STAFF
38. KITCHEN STAFF W.C.
39. KITCHEN CLEANERS' STORE
40. SERVERY/CHAIR STORE
41. OUTSIDE STORE
42. OUTSIDE P.E. STORE
43. CLOAKS/CIRCULATION
44. CENTRAL COURTYARD
45. OUTSIDE WORKING
46. PLAYCOURT
47. PARENT WAITING
48. PLAYING FIELD
49. BINS
50. SERVICE
51. PARKING
52. OVERSPILL PARKING

GOSPORT ELSON INFANTS





A2/9 **HARDLEY MANOR FIRST**



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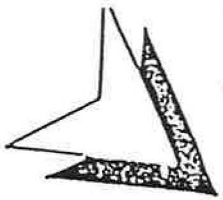

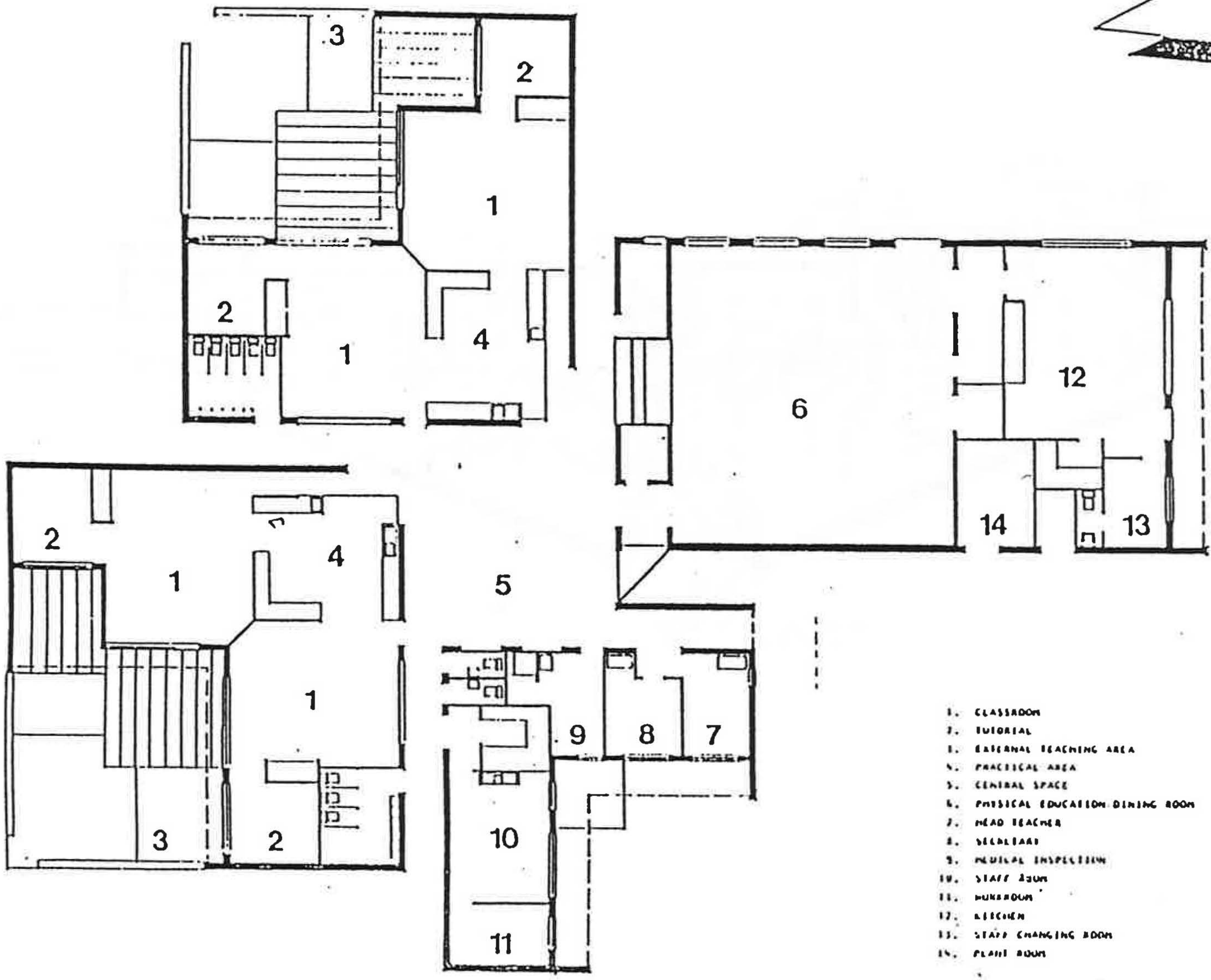

1. CLASSROOM
2. TUTORIAL
3. EXTERNAL TEACHING AREA
4. PRACTICAL AREA
5. CENTRAL SPACE
6. PHYSICAL EDUCATION DINING ROOM
7. HEAD TEACHER
8. SECRETARY
9. MEDICAL INSPECTION
10. STAFF ROOM
11. WORKROOM
12. KITCHEN
13. STAFF CHANGING ROOM
14. PLANT ROOM

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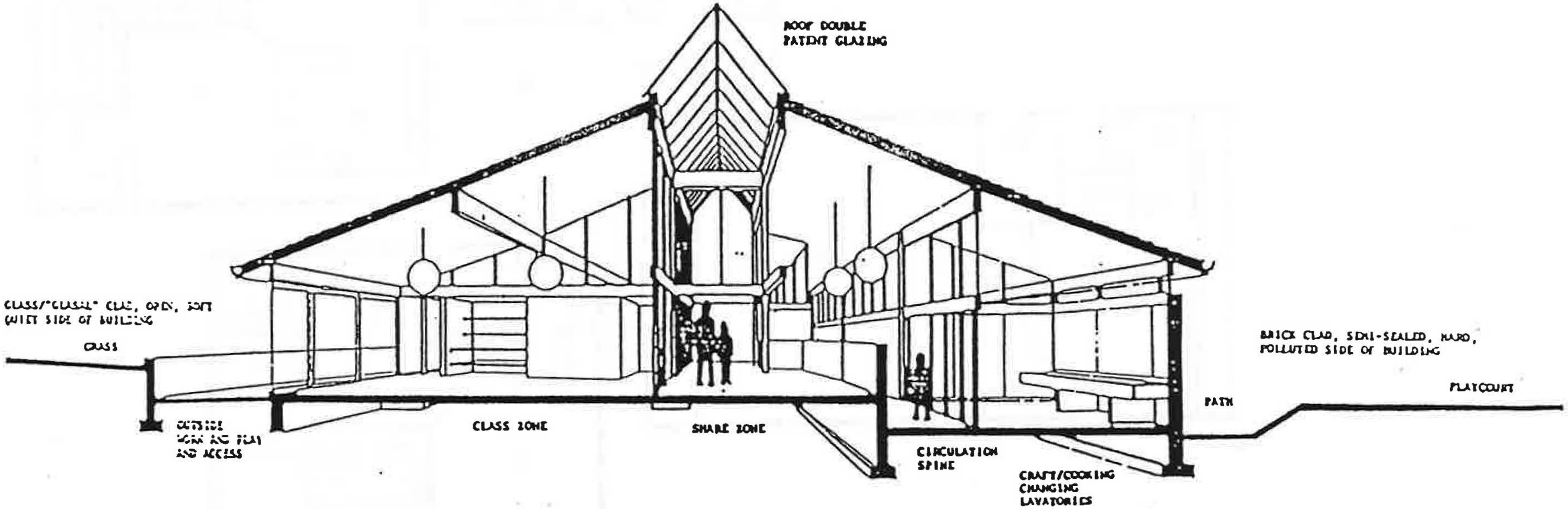
HOOK WITH WARSASH



HAVANT BOSMERE MIDDLE

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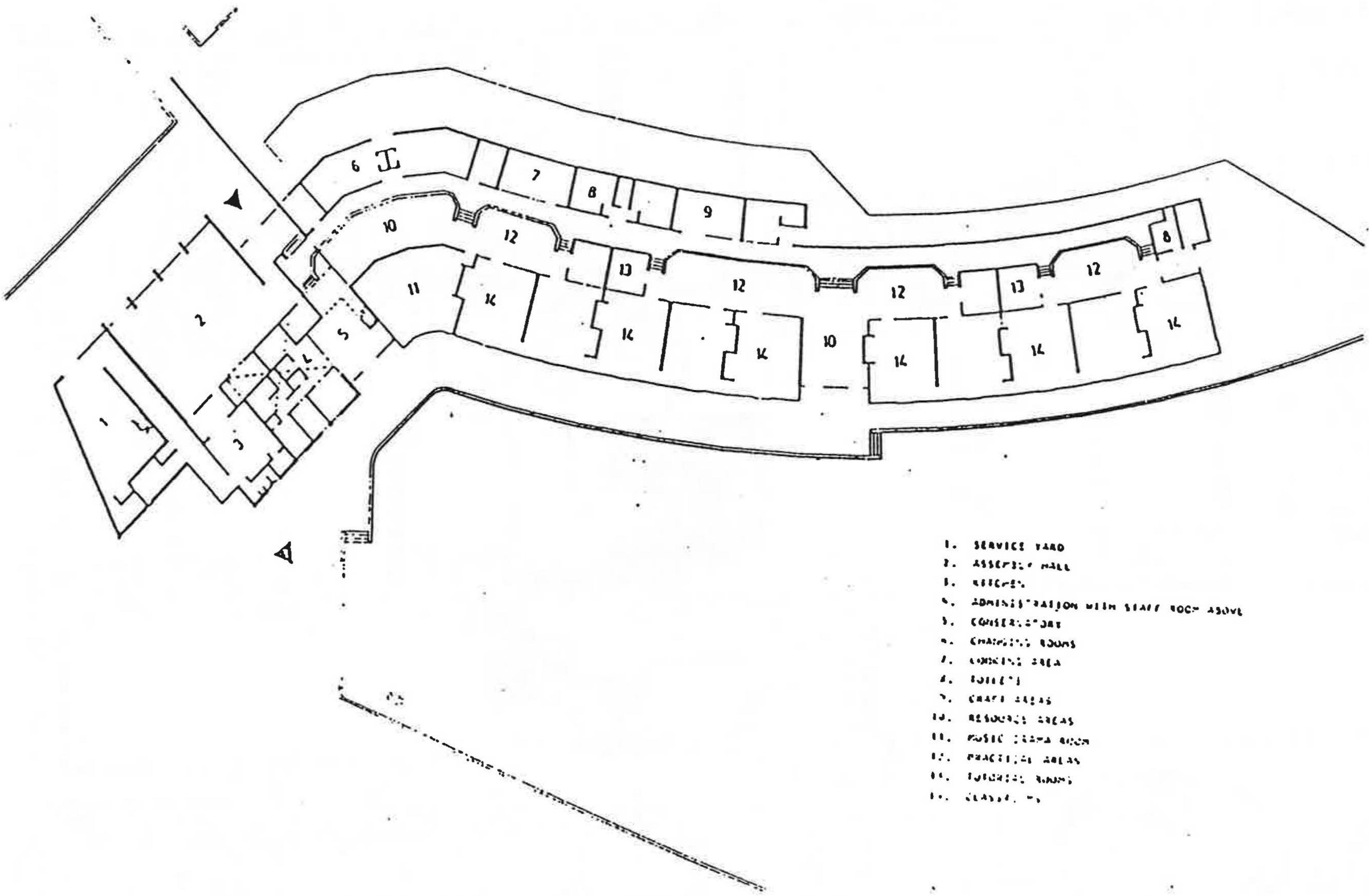
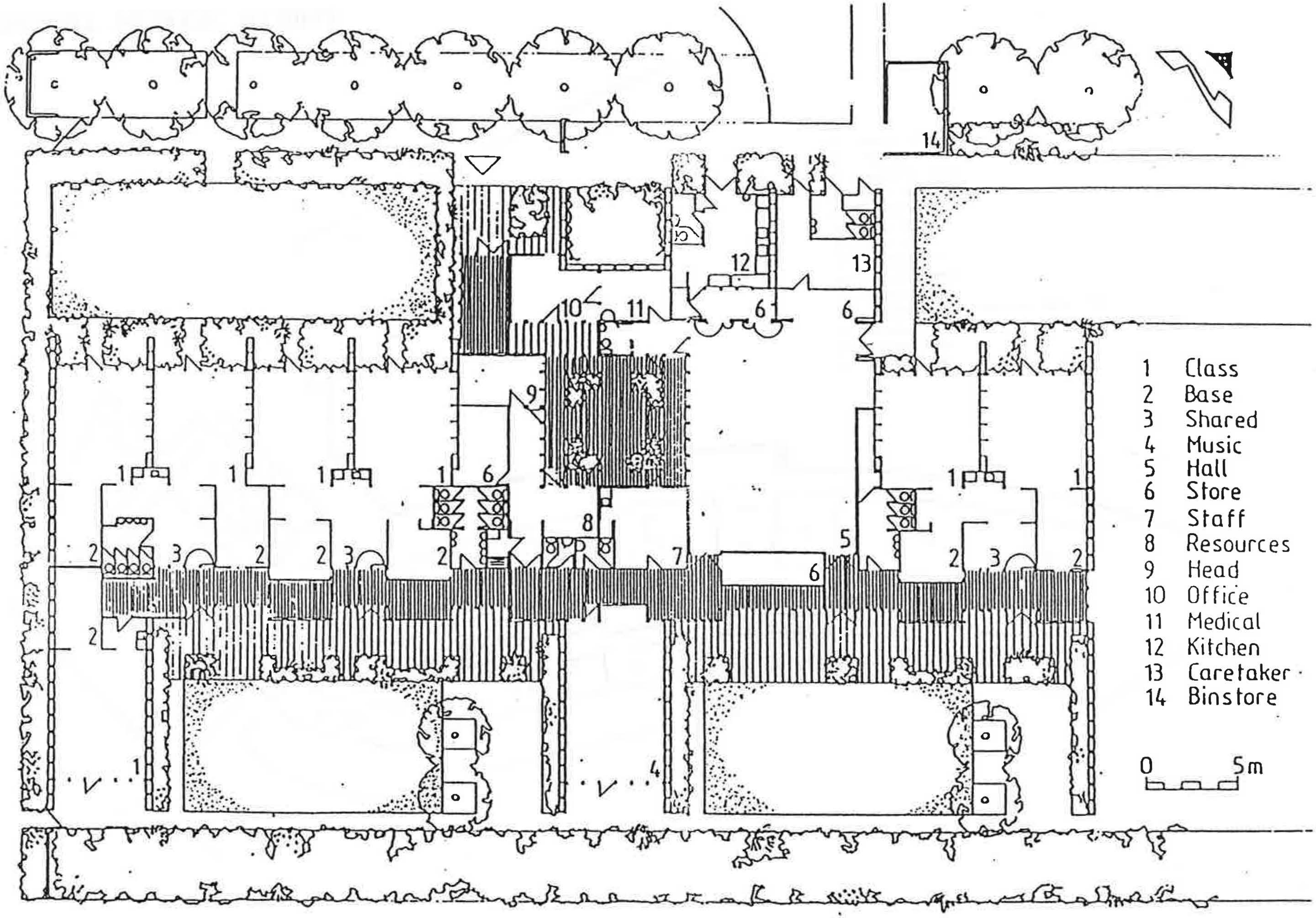


HAVANT BOSMERE MIDDLE



NETLEY INFANTS

VENTILATION AND BUILDING VOLUME

There is still a great deal of confusion regarding ways, means and needs of ventilation within a building and its volume. Most of this arises from a poor understanding of the mechanisms of ventilation and the various criteria that have been established over the years.

In the past it was common practice to specify a ventilation need in terms of 'air changes per hour', that is, the number of times the whole room volume of air was to be changed during the hour. Although this was well tied in to occupancy and a range of volumes, this was frequently forgotten and in days of cheap energy it was of little consequence.

The second factor is the way in which ventilation is achieved. The only way in which any particular rate of ventilation can be guaranteed is by mechanical means. Natural ventilation is dependent on a very wide range of parameters, not least of which is the action and the activities of the occupants. Temperature gradients and wind direction combine with the number and position of openings and the disposition of partitions and doors within the building to make natural ventilation a very haphazard process, and very difficult to predict with any certainty.

Although a great deal of research and observation has taken place, there is still not enough work done, but our understanding to date does lead us to draw certain conclusions and note some factors for good practice.

Since the early Seventies it has become practice to specify ventilation needs in relation to occupancy rather than room volume. This relates directly to the need and so will vary with activity also. Thus in 1972 the DES Environmental Guidelines on advice from BRS, specified a basic ventilation rate of 30 m^2 per hour per person. Half of this was reckoned to be heated by the plant and the rest made up by metabolic and other gains.

Although a range of research work and practice has indicated that 10-15 m^2 per hour per person is adequate, at the time there was little evidence to show that school children washed any more than they did in the Thirties when Yaglou did the original work. So it has remained at 30 m^2 when half that has proved adequate in practice.

This has a direct effect in buildings with mechanical ventilation, in that the introduced ventilation rates are dependent only on occupancy and are entirely independent of room volume. This however only applies to a minority of buildings.

Anecdote and observation combined with some research serve to provide a basis for understanding and some design guidance for naturally ventilated buildings.

The main facts that came together were as follows:

1. Investigations by BRE and CEGB amongst others established that the external temperature below which few people open windows is $7^{o}C$ ($45^{o}F$). In other words it is established that natural ventilation is considerably reduced below this temperature.

2. Work by Oxford Polytechnic, DES and Oxford County plus later work by Professor Hardy at Newcastle and Burberry at UWIST, established that, when a "lay in grid" or similarly jointed acoustic ceiling is used, such as those found frequently in schools, the possibility is such that conditions above the ceiling reflect accurately those below. It was further verified that this was independent of the amount of thermal insulation above the ceiling.

   Thus the practice of putting ceilings in Victorian schools, whether or not they were also insulated, has little effect on the heating. It does, however, have a great effect on the ventilation due to the third factor.

3. The need for ventilation is perceived by the occupants on the basis of the build up of odours and the outside and inside temperatures. There is plenty of anecdotal evidence allied with work by Hardy, BRS and DES which shows that windows are opened more often in rooms with small volumes than in those with large volumes.

   The reasons are very simple. In the first place a larger volume per person means that a greater volume of air has to become vitiated before it is noticed and action taken. Secondly, in a large volume, the vitiated air rises and thus delays the point where the need is felt for ventilation. Other observations follow from this of course. Because of the greater temperature gradients in the volume the higher temperature difference across the structure must be counteracted by a greater degree of thermal insulation.

   There is also, of course, the possibility of reducing the gradient by using fans to bring the warm air down but this, of course, can be counter productive in a densely occupied space.

   An additional bonus from a high space can be the improved summer ventilation provided by an effective bouyancy, thus giving air movement within the building on a hot still day, when there is no wind outside.

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2nd March 1987

APPENDIX 3

USE OF A DYNAMIC THERMAL RESPONSE MODEL IN SIZING WINDOWS FOR NATURAL VENTILATION

Notes prepared for SCOLA Workshop on Natural Ventilation of School Buildings, Cheltenham, 20 October 1987.

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These notes are based on a study of overheating in lightweight temporary school buildings, undertaken with EXCALIBUR, the Energy Studies Unit's simplified building thermal response model (1). The results are for particular configuration of Elliott-Medway building (EMB) owned by Cornwall County Council, but the methodology should be more generally applicable.

Look at figure 1. This shows, as a function of assumed ventilation rate, EXCALIBUR'S estimate of the degree of overheating in the EMB. The degree of overheating is measured by the percentage of occupied hours in the summer term with inside temperature $T_i \geq 27^{o}C$. This percentage is shown along the vertical axis. Overheating will be called 'acceptable' if fewer than 5% of occupied hours have $T_i \geq 27^{o}C$. This criterion is loosely based on CIBS recommendations (2). According to the EXCALIBUR results shown in figure 1, this means that we need a ventilation rate of at least 13 ac/h during occupation.

Let us assume that overheating occurs primarily on anticyclonic days, which in summer tend to combine sunshine with low wind speed. This implies that we are looking to buoyancy-driven flow to provide 13 ac/h.

Making further use of EXCALIBUR results, the inside-outside temperature difference T for $T_i \geq 27^{o}C$ (ie the T typical of overheating conditions) has been found as a function of assumed ventilation rate. This relationship is shown by the solid curve in figure 2. It is this T which will produce the buoyancy-driven flow.

The EMB considered has sash windows which can provide about 8 m^2 of open area, arbitrarily distributable between bottom and top sashes when open. The maximum pressure head for driving the flow of air will be provided if the open area is equally distributed between top and bottom. The minimum pressure head (with the windows open) will occur if all bottom (or top) sashes are open. These two conditions provide natural limiting cases for consideration.

The buoyancy-driven flow equation for what is effectively single-sided ventilation through rectangular openings can be written

$$V = k\,\Delta T^{1/2} \qquad (1)$$

where V is the ventilation rate in ac/h, and k a constant depending on the geometry (3). In our case if all bottom (top) sashes are open

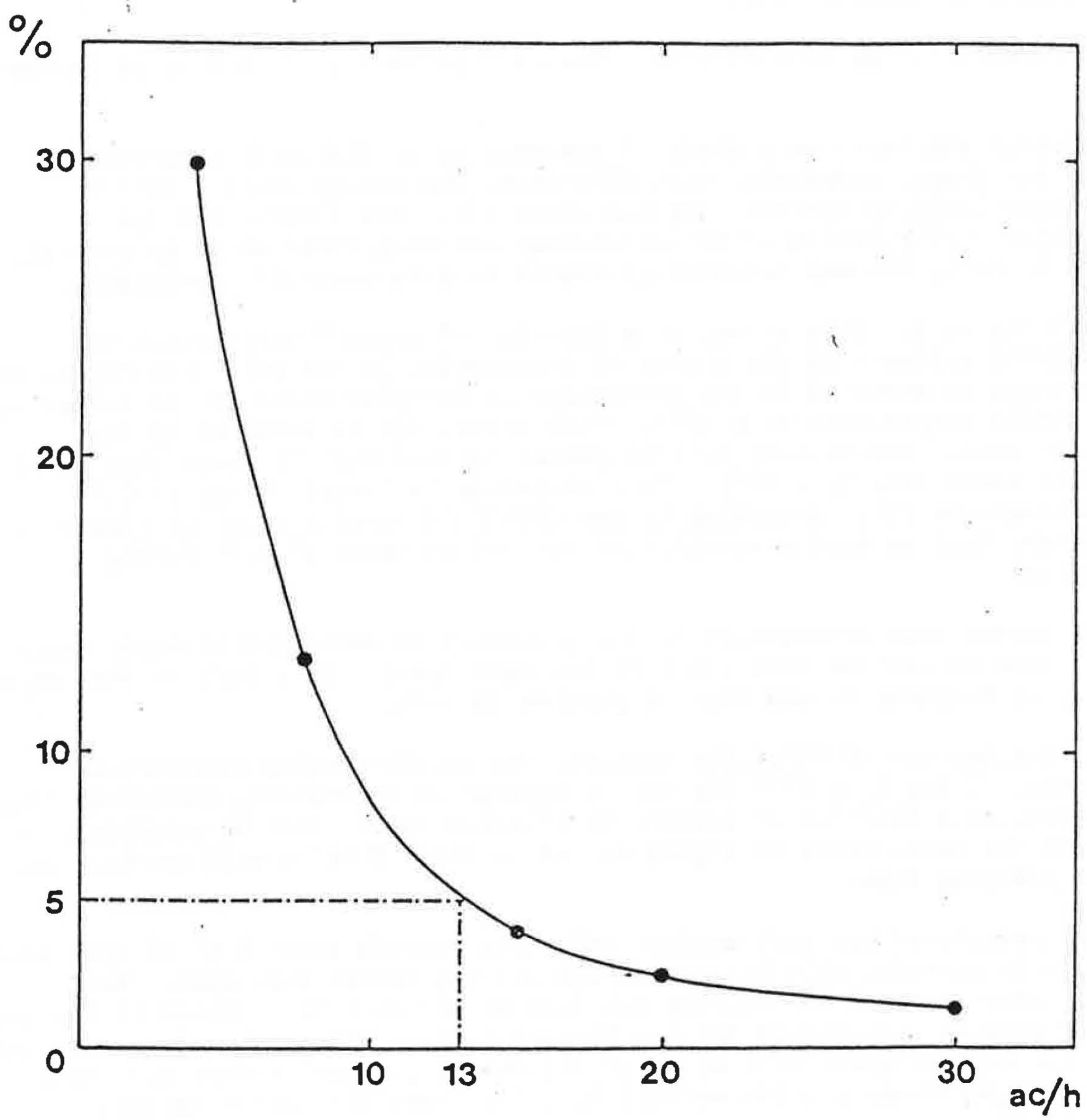
$$k = 2.4\ (ac/h)\ {}^{o}C^{-1/2} \quad (a)$$

If the opening is equally distributed between bottom and top sashes,

$$k = 3.39 \quad (b)$$

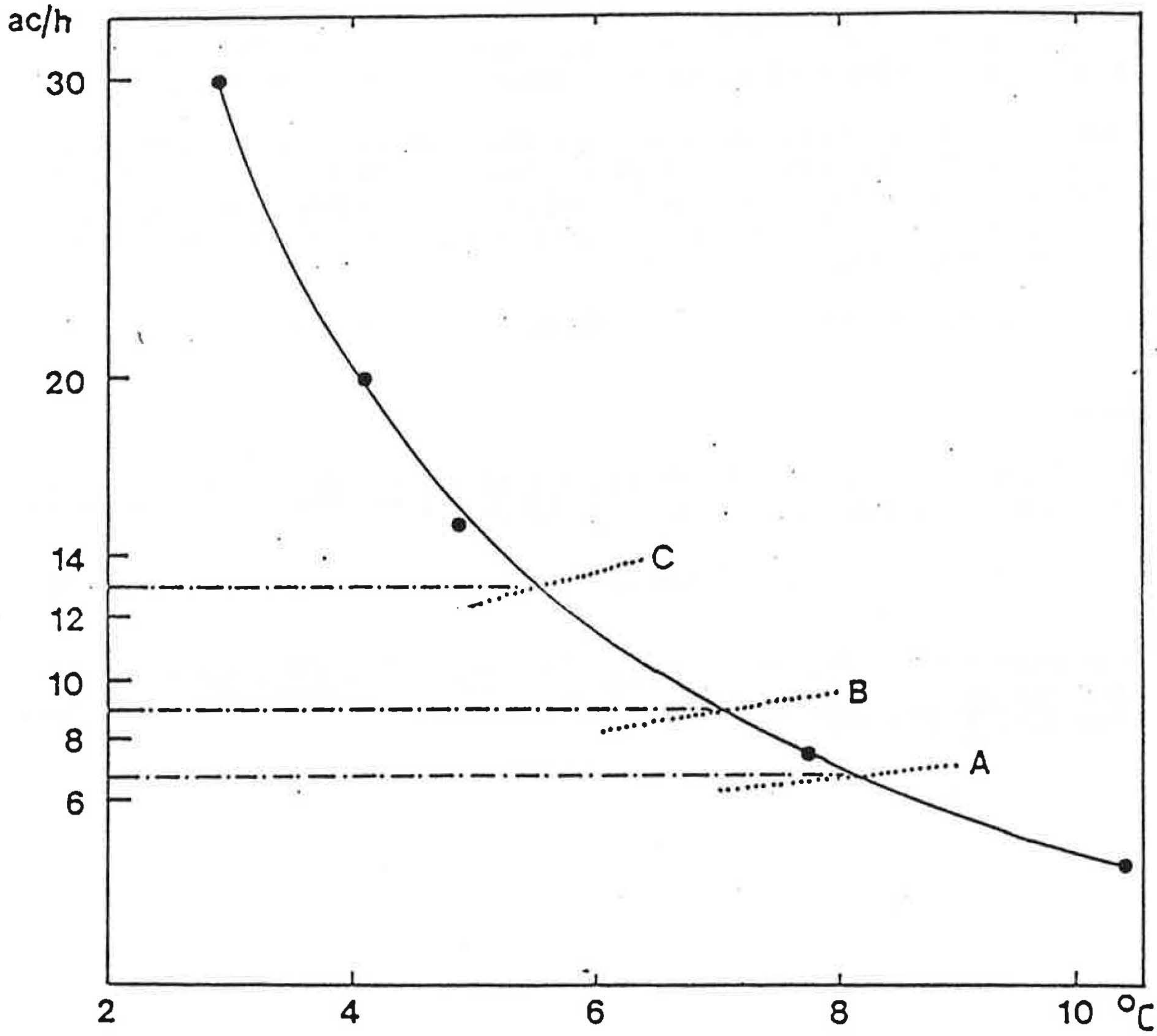
These two cases are plotted as the dotted curves A and B on figure 2.

Figure 1. Overheating as a function of ventilation rate.



The horizontal axis shows the ventilation rate in air-changes per hour. The vertical axis shows the percentage of occupied hours with the inside temperature equal or in excess of 27^{o}C.

Figure 2. Graphical solution of equations determining ventilation rate under buoyancy driven flow.



The horizontal axis shows the inside-outside temperature difference in degrees Celsius. The vertical axis shows the ventilation rate in air changes per hour. The solid curve is the relationship from the entries underlined in column J of Table 2 (EXCALIBUR results). Dotted lines, A, B and C are the buoyancy driven flow relationships given by equations (a), (b) and (c) in the text. These correspond respectively to all the bottom sashes open, half bottom and half top sashes open, and bottom sashes open plus sufficient roof level ventilation so that the building is estimated just to meet the overheating acceptability criterion described in the text.

The operating point of the building as it is under buoyancy-driven flow will be determined by the intersection of the solid curve and some curve between A and B depending on how the 8 m^2 of open area is distributed. Evidently the ventilation rate will lie between 7 and 9 ac/h, and will be insufficient to meet overheating acceptability criterion, because referring back to figure 1 we see that ventilation rates in this range imply well in excess of 10% of occupied hours with $T_i \geq 27^{o}C$ during the summer term.

Line C on figure 2 has k = 5.5 (c). This line gives a building operating point of 13 ac/h under typical summer term overheating conditions.

The window sizing question now reduces to choosing openable areas to give k = 5.5. This can be done in many ways. However, the theory of single-sided ventilation suggests that, for the EMB under consideration, introduction of an openable area of about 3.3 m^2 at roof level would, in combination with the existing windows, suffice.

A research paper describing this work in full is currently in preparation.

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