INTEGRATED ENVIRONMENTAL DESIGN OF BUILDINGS

Professor P E. O'Sullivan

The Welsh School of Architecture, University of Wales Institute of Science and Technology

Introduction

Historically, the concept of buildings as a means of protection against the more inimical natural elements, predators and the like has gradually given way, with social and cultural development, to increasingly sophisticated control and modification of the natural climate in the interests of more efficient and comfortable participation in more and more complex human activities. At any given time the degree of success has been related to the state of scientific and technological development. The former has made possible increasingly accurate specification of psychophysical conditions for optimum efficiency and comfort, the latter the means of achieving them with greater certainty. Though relationships between cause and effect are far from simple, theoretical knowledge has usually been in advance of applicable techniques, and fragmentation in the interests of deeper specialised knowledge (as in the medical sciences, for example) has tended to produce isolated techniques for the better achievement of specifications - whether visual (eg the glare indexes of the IES Code) [1] thermal (eg Webb's work on effective temperature) [2] or aural (eg the Dutch work on the sound insulating properties of glass) [3] - to accord with the individual criteria emerging from specialist studies in depth of each aspect. It is only recently that efforts have been made to bring together a number of environmental and building design factors. It is the intention of this paper to trace the brief but important history of these efforts in Great Britain and the effects they have had on building design.

Integrated Design

The concept of integrated design adopted in this paper recognises that the building itself, its fabric, shape and relation to local climatic conditions, its effect on those conditions and its internal organisation of space, are no less important than installed services in effecting a close relationship between internal environment and known physical optima for human comfort and convenience, with economy and efficiency of means; in short, in designing an effective filter between man and his natural environment. On occasions, environmental effects resulting from decisions about the building itself through the subsequent installation of services. Such a concept demands a new rationale of collaboration in the design process. The participants, building owner or client, the design and building teams all contribute toward a common and comprehensive view of long and short term aims. All share the decision at the inception of a project to integrate design factors for which they are normally individually responsible. Furthermore, decision making thereafter becomes a concurrent process in all the disciplines involved in and not sequential (and, therefore, logically isolated) as in the normal case of building design.

The Environmental 'Era'

It is important to note, yet not generally recognised, how new the current approach to environmental design is, for it can well be argued that the environmental era began 'officially' in November 1967, when the Institution of Mechanical Engineers held their Conference on 'Heating and Ventilating for a Human Environment'. For this reason the results, although fully documented are worth summarising here.

Billington [4] and Crenko [5] in the separate ways, reviewed the work on discomfort. They indicated that under 'stress' conditions, increasing the air temperature, varying the humidity and rate of air airflow, and increasing the Effective Temperature, could and indeed had been correlated with a fall off in productivity and Health, and an increase in industrial accidents. However, when 'stress' conditions did not apply, for example, in air temperatures of 20°C or less, comfort conditions were assumed to occur. In this 'region' no optimum standards had been determined, nor indeed what tolerances existed. What was true in the Thermal Environment appeared also to be true in the Acoustic Environment [6].

The state of the Art of Heating and Ventilating[7,8] was widely discussed, mainly in terms of 'hardware'. The control of the thermal environment, however, appeared to be easily 'dismissed' with such statements as .... if 'normal' heating and ventilating is unable to cope with the internal conditions, and in some cases this happens, then Air Conditioning can and must be provided ..... either by traditional or by packaged units [9]. The implication being that Heating and Ventilating plant sometimes in the form of air conditioning, can and will solve the environmental problems created by the building, albeit at a cost. Further, that the key to this problem solution was through Controls and Control Theory. New and better controls, with increased rates of response, for example, would make up for the deficiencies of plant and buildings.

The cost of building services, both as a total and as a percentage was increasing rapidly. The suggestion was that this cost could be offset to some extent by 'standardisation' always allowing that 'flexibility' was maintained.

So the 'traditional' service arguments were restated as they had been done so clearly for many years. The picture which emerged was that of a technology, highly developed but with no theoretical base to relate it to 'buildings'.

However, at this same Conference where the traditional view was so powerfully put, the beginnings of a new Concept emerged.

The Concept of Climatic Modification [10] in which the building is considered as a filter between man and his environment, a filter between the meteorological climate on the one hand and the required private climate on the other 'appeared'. This filter was considered to have three sections. Namely:

a. The conversion of the meteorological climate of the region, to the correct microclimate around the building.

b. The modification of this microclimate by the properties of the Building Envelope itself, ie, by the properties of the materials in construction.

Further, that it was these first two stages combined, which should act as the course control on the environment to produce the (basically) correct internal climate. That mistakes made in (a) and (b) could not be rectified in stage (c) which consisted of the 'fine tuning' of the environment so produced, by the thermal plant, the lighting etc.

Inherent, in this concept was a numerate based probabilistic view of design, which can be summarised as .... 'you can never be absolutely right, so how wrong do you want to be?'

Stage (a) above was further set on a firm 'climatic' basis by Lamb [11] in his discussion on Heat Islands.

Force was added to the argument in Stage (c) by Eccleston [12] who showed how the performance of thermal plant was dependent on the building envelope. Finally, Scott [13] demonstrated that these new ideas, required a new role, that he and other people were already beginning to define.

Window Function

This concept of Climatic Modification, with the emphasis on the building as the prime control, was seen by some Architects and indeed some Heating and Ventilating Engineers, as a means of establishing a new route through the problem of environmentally uncontrollable buildings and the attendant blame that attached to them. An analysis of this problem was, attempted under the heading of 'window function' [14].

Window function may be regarded as three fold: to provide planar illumination (the specified level determines the area of glass required); to provide a directional component in the lighting (which varies with shape and position of windows); and to provide a view out (which may determine the number, the size, and to some extent the position of windows). A basic environmental design decision is how to allocate priorities to these three functions, and how to combine them in such a way as to achieve a specified integrated environment. The relationships of window function to the principal aspects of the physical environment are dealt with separately and collectively below.

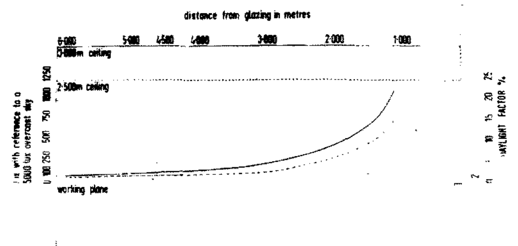
The Visual Environment

A fixed quantitative standard for natural lighting has three 'effects' on building design:

a. For a given floor to ceiling height it limits room depth (Fig 1) or restricts the buildings to a single storey, unless clerestory windows or roof lights are used to augment the unidirectional lighting.

b. It produces designs with a high ratio of external wall area to internal volume.

c. It produces designs with a high proportion of glazed to unglazed external wall.



distribution of daylight on the horizontal working plane within a room 3·000m wide and 6·000m deep with 2·500m and 3·000m ceiling heights, the glazing is from cill to ceiling and wall to wall with an unobstructed sky

——— 3·000m ceiling - - - - 2·500m ceiling

DIAGRAM ILLUSTRATING HOW DAYLIGHTING REQUIREMENTS CAN LIMIT ROOM DEPTH

For example, a 2% Daylight Factor (DF)[15] related to the standard overcast CIE sky of 5000 lux produces minimum internal illumination of 100 lux, but of course sky brightness varies. In the United Kingdom this variation is such that, during an average year, 100 lux is achieved or exceeded for 84% of the periods during which offices are occupied (0900-1730)[16].

Recommended levels of planar illumination have risen progressively with rising standards of living. The IES standards[17] reflect this. Clearly, if these recommendations are met for only about 50% of normal working hours, the point has been reached at which it is impossible to meet them in rooms of economic ceiling height merely by increasing the area of window. (Many offices built to the 2% DF already have cill to ceiling and wall to wall glazing, and any increase in window area would necessitate an increase in ceiling height). Furthermore, large areas of glazing produce 'sky glare' discomfort under certain conditions of sky luminance, irrespective of orientation[17]. High brightness sky may be the area of greatest luminance visible from inside the room, causing serious visual distraction and a serious reduction in visual acuity. If, in addition, the windows admit direct sunlight, excessive luminous contrasts can result, reducing visual acuity still further, and possibly producing reflected glare from specular surfaces, and so still greater visual discomfort.

The distribution of daylight within a sidelit room (Fig 1) is such that the illumination levels close to the windows are very high compared with the levels at the back of the room, particularly, if it is more than 4·8m deep. For example, in an office with no rooflights and designed to give a minimum of 2% DF at points most distant from the window, there could well be a 20% DF near the window wall. Though the quantity of daylight reaching the rear of the room is 'adequate' in terms of the recommendations, it appears gloomy by comparison, and artificial light is used for subjective, as apposed to funcational, reasons. It can be seen, therefore, that in buildings with windows designed for planar illumination, artificial lighting is often used and/or blinds may be drawn[18] to reduce visually uncomfortable luminous contrasts between the sky and room interior or within the room between the working areas near to and distant from the window, to prevent excessive brightness contrasts due to direct sunlight, or simply to augment 'inadequate' illumination levels. Blinds reduce sky and sun glare. Artificial lighting improves the luminance distribution over the room area and increases planar illumination when necessary. Both are needed where windows are designed in terms of planar illumination only. They do, however, provide also a directional component, necessary for clear visual resolution of solid or modelled objects[19] and for the psychological desirable outward view. It would seem, therefore, that since planar illumination can be artificially augmented, it should no longer be paramount, and that the latter functions should be given greater priority in window design.

Thermal Environment

The application of 'climatic modification' to the thermal environment, resulted in the emergence of the idea of a 'Balance Point'[20] which may be described as follows.

It is possible to plot on a graph of axes external air temperature v heat input, both the heat losses from a building which increase approximately linearly with decrease in external temperature, and the heat gains to a building which increase with increase in air temperature, but not linearly. An example is given in Fig 2.

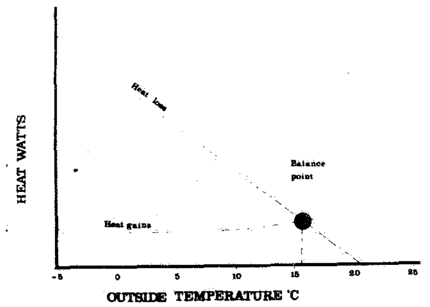


Figure 2

The point where the two curves **cross is** known as the 'balance point'. At all external air temperatures above the 'balance point' the building is self-sufficient in heat, albeit in some conditions uncontrollably as the upward swinging heat gains curve shows. The balance point shown is that for a 15m wide, 2% DF building with 70% of the external wall glazed and balances at 16°C. It, therefore, requires heating whenever the external air temperature falls below this value and conversely it may require cooling and that of a large **order** when the external air temperature rises.

The effects of the various design steps that might be taken to improve this thermal 'state' of affairs are shown in Fig 3. For example, the effect of reducing the U-value of the opaque parts of the wall from 0·7 to 0·57 W/m^2 deg C is quite small: the heat loss curve moves from 1 to 2. Reducing the area of glass from 70% to 20% reduces the heat loss from 1 to 3 and increases the heat gains from B to A. In other words, it is possible to draw a diagram of the effects on the thermal properties of the building, and therefore, on its thermal performance, of design decisions concerning, windows, materials and so on.

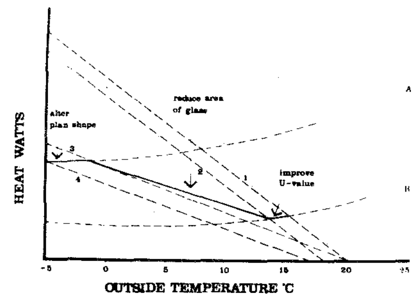


Figure 3

The idea of 'controllable' building, ie, one which acts not only as a control on the external climate but also as a control on both the total heating/cooling requirement and the time for which that applies had emerged, and what is more, emerged as design based.

During the same period further work on the external climate, [21,22] defined more clearly the existence and potential of heat islands, that is, the increased air temperatures found in cities, which can be correlated with urban density. This work when linked to the new 'probabilistic' view mentioned earlier, produce, and is still producing from the results of a computer analysis of all the British Meteorological Data of Dry Bulb Air Temperatures, temperature curves such as Fig 4 [23] which give the probability of any external air temperature occurring at any time. It is this work which enabled the theoretical concept of a Balance Point to be put onto a predictive design basis.

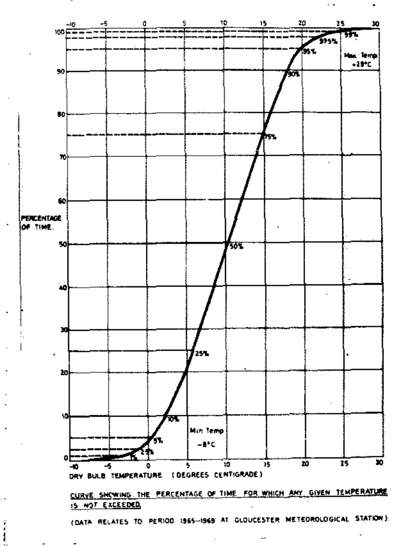


Figure 4

The concept of climatic modification and the attendant balance point theory have centred a great deal of research interest on the building envelope in the last five years (eg [24,25,26,27]). From this work it can be concluded that the better the climatic modification characteristics, the lower the heat losses and hence the easier and 'cheaper' it is to control the internal thermal environment. Taking window function again in this context, the larger the 'proportion' of glass in external walls the greater will be the effects of solar overheating and radiation and/or convective cooling, producing greater heat losses through the fabric by conduction and radiation, greater heat gains due to radiation, larger building air temperature swings, greater difficulties in thermal control, and more complaints of unsatisfactory thermal environment. These problems, directly related to glass area cannot be overcome merely by air conditioning [28,29,30] or my manipulating the thermal properties of the opaque parts of the building enclosure.

The case, therefore, for reducing areas of glass was made and resulted in conclusions such as those shown in Table 1 [27].

Table 1: Limits of glass areas as a percentage of total area of southfacing facade (no external screening)

		Thermal environment is uncontrollable even with current standards of air conditioning	Thermal environment is controllable with current standards of air conditioning	Thermal environment may be controllable with mechanical ventilation only
lightweight	single glazing	greater than 60 per cent	60 per cent or less	20 per cent or less
construction	double glazing	greater than 50 per cent	50 per cent or less	20 per cent or less
heavyweight	single glazing	greater than 75 per cent	75 per cent or less	20 per cent or less
construction	double glazing	geater than 65 per cent	65 per cent or less	40 per cent or less

The Acoustic Environment

The continual increase in external noise levels (eg, urban traffic noise) had made urgent the problem of preventing penetration of noise into buildings. Recent fieldwork on the sound insulation characteristics of windows demonstrates that, of the external noise penetrating a window wall, approximately, 90% comes through the windows, and more than half of this through cracks around the edges of the windows - ie, it is not a simple area effect as in the case of solar overheating [23]. Unless windows are sealed (with all this implies in terms of artificial ventilation) and made more acoustically efficient, there is, once again, the conclusion that window size should be reduced.

The Total Environment

In 1968 these 'sets' of results began to come together. As a result of 'climatic modification', buildings which were both thermally efficient and comfortable were wanted, and for perhaps the first time designers clearly understood how to produce them. There was also a desire to design and produce thermal plant, matched to these buildings, which would be economic and efficient.

As it is not possible (except for very specialised purposes) to design a building in the United Kingdom that will require heating all the time, the decision was taken to produce buildings that required no heating overall, ie, were self-sufficient in heat. However, a building balancing at, for example, 0°C poses several problems in practice. For self-sufficiency in heat overall does not necessarily mean the right amount of heat at the right time in the right areas, since some areas tend to produce too much heat some too little. Traditionally the excess heat would be thrown away and new heat generated for the heat starved areas. Could not the excess heat produced (which had already been paid for) be collected and transferred to parts of the building that need it? The answer was 'yes' as a result of a new idea in air conditioning, namely, 'heat recovery'. [33]

The idea is as follows. The heat producing areas (people and light in offices; people, light and machinery in production spaces) have their excess heat removed by a cooling air load. This load is designed to be as stable as possible as a result of the thermal properties of the building enclosure. The heat now in the air is then recovered by a heat recovery coil instead of being thrown away and redistributed to other parts of the building. Finally, any excess heat is thrown away.

In fact, if the buildings were thermally efficient and the heat loss was low, a large proportion of the heat would be continually thrown away during working hours, so that a further development to enable that heat recovered to be stored during the day and then used to preheat the building next morning, could occur.

Consequently, the following decisions were made: for lighting purposes, windows would be designed to produce a directional component of light and view out only; planar illumination would be provided by electric lighting; window area would be reduced to approximately 20% of the external facade, and the general thermal and acoustic properties of the fabric would be designed to give the best possible combined performance in terms of heat loss, heat gain, temperature swing, and human 'comfort'.

These decisions have now been applied to a number of building types [34] of which the most significant are, the Wallsend Building [35,36] the Eastergate School [37], the Liverpool Daily Post and Echo Building, [38] the Simon Building, Stockport [39], and the Bentalls Store, Bracknell [40].

It is important to remember that these buildings, perhaps, more properly described as 'controlled experiments', built through the process of Integrated Design, have only recently come into use. So that although these buildings were instrumented in order to record the energy balance and the resulting physical environment, results have to date been scarce and are only now available for analysis. Similarly, the way people use these buildings, the 'human end' evaluation, and to ensure that, for example, the visual environment has not deteriorated as a result of improving thermal and acoustic performance has just begun. Hence, conclusions drawn from them can only be tentative. However, the indications are:

(i) The ability of these buildings to produce and control the desired internal thermal environment is established.

(ii) User reaction to the Environments so produced appears to be favourable (see 'filmed' evidence).

(iii) Predicted economics of capital and running costs have been realised.

(iv) The balance point concept, although necessary to the design of a 'controllable' building, and to explain to the design team how the thermal parameters interact, where the economic break points are, and therefore, what heating and/or cooling system should be used is unfortunately of no great help in designing the actual system itself.

(v) Furthermore, the balance point tends to lead to over optimistic assumptions of how much heat can be recovered, is worth recovering, and what can be done with it. For example, it can lead one into designing complex controls to operate basically simple plant, in order to recover that extra 2% of heat.

(vi) Integrated Design can lead to the establishment of a method which can be described as the 'mesh'. This occurs when a set of building performance parameters are first established and 'meshed' against a set of 'human' parameters to produce the required internal environment, and appears to suffer from two disadvantages. Firstly, because of the very way that thermal plant operates, it tends to produce regular environmental conditions, and secondly, because the human parameters have been based on 'comfort' conditions (established by 'lack of complaint' and personal opinion), the results are not as universally satisfactory as was originally hoped.

Further as the building parameters were the only ones that were based on actual evidence, the evidence, two parallel research programmes must also be considered:

(a) As 'comfort' conditions were not defined and appeared to span a wide range of which no one knew what the tolerances were, the idea of a 'swing' of internal building temperatures emerged as a means of reducing plant costs and size, [41] and attempts to define acceptable swings began. The author's own current research work leads him to believe there is in fact no such thing as 'comfort', but that there are three zones, namely, discomfort; lack of discomfort; and pleasure. Current knowledge enables one to design in the 'lack of discomfort' zone, but there is no information, but plenty of opinion, on how to design for pleasure.

(b) Currently, many research workers have and are taking part in a research programme to measure the performance of thermal plant. Yet apart from re-affiring that hot air still rises, the most important factor discovered to date is that 'non assessibility' appears to be the fundamental criteria in plant design. The fact is that how heating and/or cooling systems work is not known in anything but the crudest detail. There are too many partial measurements, too many approximations, and too many unmeasurable systems. Furthermore, the indications are that systems which are designed to work at optimum efficiency at the design conditions are for the majority of their life when design conditions are very seldom met, operating at anything up to 40% inefficiently.

This then is the situation that has been reached as the result of the first Research and Development Cycle.

Current Research

In December 1970 it was concluded that the previous work was 'definitive' enough to encourage further detailed research and application of the principles [14] outlined above. For the feedback results had suggested that there were two ideas that could be developed, for the Designer, namely:

(a) Variety reducing constraints - the law of diminishing returns.

(b) 'Positive' degrees of freedom.

To this end, a range of standard structural panels of different combinations of materials in construction was first investigated by computer simulation to demonstrate the effect of choice of materials and differing glass and solid ratios. An example of the results, is given in Fig 5, translated into terms of 'heat loss' in Fig 6. From this study a limited number of materials in construction, economic in thermal, acoustic and constructional terms emerged, for example, a heavyweight panel of U-value $0 \cdot 5 W/m^2$ deg C containing 20% 6mm glass in a cedar wooden frame. In addition, economic 'break points' at which the environmental performance of the roof and floor rather than that of the walls should be considered were examined.

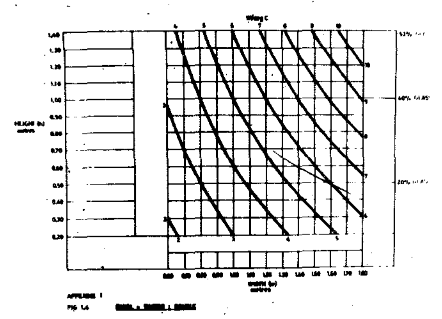


Figure 5

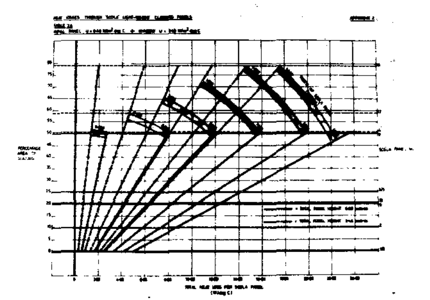


Figure 6

Using these results a series of complete buildings of simple rectangular plane form were next analysed. The following parameters were varied: width/length ratio; number of storeys; total floor area; floor to floor height; heat transfer coefficient of roof and floor; window wall ratio. An analysis showing the effect of these variables on heat loss, capital, and running costs was derived. Fig 7 gives an example of the results.

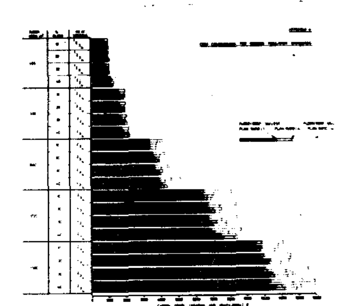


Figure 7

The similarity of sections of these results, and, therefore, perhaps the freedom of designing for the scene thermal consequences, for example, over a range of storey heights, plan shapes, areas of glass etc should be considered. The suggestion that a number of spaces of differing shapes and sizes, have the same 'thermal capability' present itself. Comparisons with Musgrove's work [42] on space classifications are irresistible.

Using this process a 2 Form Entry Junior School has been designed (Fig 8) and is in the process of being built [43].

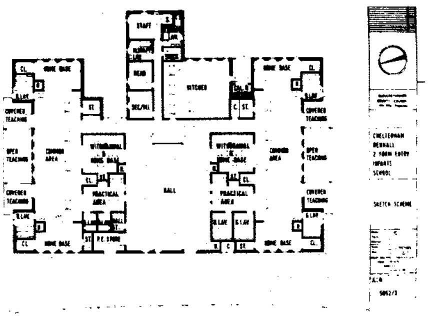


Figure 8

The Research and Development Cycle is into its second time around.

What then for the future? The plea, therefore, must be for simplicity in design and control. For Design based on the simple principles which are often forgotten. For Design based on the probabilistic view. Finally, for Design that is measurable. Then we must build more, monitor and wait.

References

1 'IES Code: Recommendations for good interior lighting'. Illuminating Engineering Society, London 1969.

2 Webb, C.G. 'Thermal comforts and effective temperature'. CIE Conference on sunlighting in buildings. Newcastle Upon Tyne, 1965.

3 Oosting, W.A. 'Onderzoek Naar de Geluidisolatie van Vkakglas'. Report 706, 007, Technical Physics Service, TNOTH, Delft, Holland, 1967.

4 Billington, N.S. 'The Working Environment' Heating and Ventilating for a human environment. Institute of Mechanical Engineers, London 1967. Paper No 14.

5 Chrenko, F.A. 'Thermal Comfort' Heating and ventilating for a human environment. Institute of Mechanical Engineers. London 1967 Paper No 8.

6 Allaway, P.H. 'Annoyance Factors in Ventilation Noise and Practical Control Problems'. Heating and ventilating for a human environment. Institute of Mechanical Engineers. London 1967. Paper No 9.

7 Doherty, C.H. 'Practices in the Domestic Field'. Heating and ventilating for a human environment. Institute of Mechanical Engineers. London 1967 Paper No 1.

8 Dale, K.W. 'Practices in the Commercial Field'. Heating and ventilating for a human environment. Institute of Mechanical Engineers. London 1967. Paper No 15.

9 Taylor, F.M H. 'Applications of Factory-made Air-Conditioning Units'. Heating and ventilating for a human environment. Institute of Mechanical Engineers. London 1967. Paper No 3.

10 Hardy, A.C. O'Sullivan, P.E. 'The building as a Climatic Modifier'. Heating and ventilating for a human environment. Institute of Mechanical Engineers. London. 1967 Paper No 13.

11 Lamb, H.H 'Britain's climate, its variability and some of its extremes'. Heating and ventilating for a human environment. Institute of Mechanical Engineers. London 1967. Session 3. Paper No 7.

12 Eccleston, W.H. 'Some basic considerations in the practice of heating, ventilating, and air conditioning'. Heating and ventilating for a human environment. Institute of Mechanical Engineers. London. 1967. Paper No 6.

13 Scott, D.R. 'Education in Architectural Environmental Engineering and Design'. Heating and ventilating for a human environment. Institute of Mechanical Engineers. London 1967. Paper No 16.

14 'Research in Action : An Integrated Design Study Applied to Schools Development'. Architectural Research and Teaching. Vol 1. No 2. November 1970.

15 Statutory Instrument. No 890. HMSO 1959.

16 Hopkinson, R.G. Longmore, J. Petherbridge, P. 'Daylighting'. Arnold Press, London.

17 Hardy, A.C. O'Sullivan, P.E. 'Insolation and Fenestration. Oriel Press, 1967

18 Markus, J. 'The function of windows : a reappraisal'. Building Science Vol 2, pp 97-121. London 1967.

19 Lynes, J.A. Burt, W. Jackson, G.K., Cuttle, C. 'The flow of light into buildings'. Illuminating Engineering Society Journal. Vol 31, No 3 London 1966.

20 O'Sullivan, P.E. 'Air Conditioning 1'. RIBA Journal, August 1970.

21 Chandler, T.J. 'The climate of London'. (University College London). Hutchinson 1965.

22 O'Sullivan, P.E. 'Heat Islands in Cities'. Architectural Research and Teaching. May 1970. Vol 1 No 1.

23 Greenwood, P.G. 'The Interpretation of meteorological data for environmental design'. PhD Thesis. September 1971.

24 Petherbridge, P. 'Sunpath diagrams and overlays for solar heat gain calculations'. Building Research Current Paper, Series 39. Building Research Station. 1965.

25 Loudon, A.G. 'Window design criteria to avoid overheating by excessive solar heat gains'. CIE Conference on sunlighting in buildings. Newcastle Upon Tyne. 1965.

26 Langdon, F.J. 'Modern offices : a user survey' National Building Studies Research Paper 41. HMSO, London 1966.

27 Turner, D.P. 'Windows and environment'. Pilkington Advisory Service (McCorquodale and Co Ltd) St Helens 1969.

28 Daws, L F. Penwarden, A.D. Walter, G.T. 'The visualisation technique for the study of air movement in Rooms'. Journal of the Institute of Heating and ventilating Engineers Vol 33. April 1965. pp 24-28.

29 Black, F A. Milroy, F.A. 'Experience of air conditioning in Offices'. Building Research Current Paper, Series 51. Building Research Station, Garston 1966.

30 Milbank, N.O 'An investigation of energy consumption and cost in large air conditioned buildings: an interim report'. IHVE/BRS Symposium on 'Thermal Environment in Modern buildings: aspects affecting the design team'. February 1968.

31 Hardy, A.C. O'Sullivan, P.E. 'Building a Climate'. Electricity Council. London 1967.

32 Lewis, P.T. 'Real Windows'. Paper 2 Conference on Building Acoustics, University of Newcastle Upon Tyne. April 1970. Oriel Press October 1971.

33 Mitchell, H.G. 'Use of Heat Pumps in air conditioning'. Electricity Council 1969.

34 Page, J.K. 'Review of practice in the UK in environmental design'. Illuminating Engineering Society Conference, York. 1970. Vol 153 (1962) Transactions.

35 'Integrated Design : a Case History'. The Electricity Council, London 1969.

36 Hardy, A.C. Mitchell, H.G. 'Building a Climate : The Wallsend Project'. Elecricity Council 1969.

37 'Eastergate Primary School' Chichester, Sussex. Building Specification. June 1971.

38 Cadwaladr, R.O. 'The Liverpool Daily Post and Echo Building'. RIBA conference 'Architecture and the Internal Environment' London September 1971.

39 Gaytten, J. 'Simon Building - Stockport'. RIBA Conference ' Architecture and the Internal Environment'. London September 1971.

40 Harris, R.G. 'Bentall's Store - Bracknell'. RIBA Conference 'Architecture and the Internal Environment'. London September 1971.

41 Sherratt, A.F.C. 'Air conditioning system design for buildings'. Proceedings of the Joint Conference held at University of Nottingham, March 1969. Elsevier Publications Ltd 1969.

42 Musgrove, J. Doidge, G. 'Room Classification'. Architectural Research and Teaching. Vol 1 No 1 May 1970.

43 'Integrated Environmental Design : a feasibility study for School Buildings' Gloucestershire County Council Architects Department.