The Environmental Evaluation of Buildings: A Worked Example and Technical Specification

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Abstract

This paper describes work at the centre for Land Use and Built Form Studies (LUBFS) in the University of Cambridge, England, on the construction and application of a computer model to perform room-by-room environmental evaluations of building designs. In this context the definition of the "environment" is limited to the quantifiable components of the visual, thermal and acoustical conditions within buildings.

One of the principle attributes of the model is that its application is not restricted to any particular building type or form. In addition, the data collection and input effort required is not excessive and, within the Cambridge TITAN/ATLAS computer system which it uses, it is possible to make substantial and useful changes to any design by means of the on-line editing facilities.

The process of translating a conventional architectural description of a building into the required data is described and the output produced by the computer is illustrated.

The paper concludes with a brief outline of the logical processes carried out within the model. These are described in full in LUBFS Working Papers Nos. 15 and 29 (1 and 2).

Data collection and input

The input method employed in this model is to present entirely numerical data to the computer by means of punched paper tape or directly through an on-line teletype. Prior to the physical process of input it is therefore necessary to collect the required data. To aid this a series of standard data forms is used upon which the architect is required to describe certain dimensional and physical properties of the proposed design.

Clearly it is important in designing a computer system of this kind to minimize the effort required in data collection. To help in this respect the concept of Standard Room Types has been devised. This evolved from the realization that, in many modern buildings, large numbers of rooms are similar in many respects. For example, floor and wall finishes are frequently identical and a single type of light fitting might be specified for use throughout the building. To input this repetitive data for each room in a building would be both time consuming and tedious. The Standard Room Type system allows the designer to group together all those rooms which he considers to have sufficient communality of specification and then to input the common data as a single block. For each individual room it is then necessary to collect only that data which is unique. Before the model is run a pre-processing program is used to macro-generate all the data for each room from the raw data. This program also produces a fully annotated output of the data as an aid to data verification.

The process of translating a conventional description of a building into the data required by the model is illustrated in the following example.

Figures 1 and 2 illustrate by means of conventional architectural drawings the simple building which is to be evaluated in this example and show its relationship to adjacent buildings. Table 1 sets out a specification of the properties of surfaces which cannot be communicated directly by drawings and which are required f or the evaluation process.

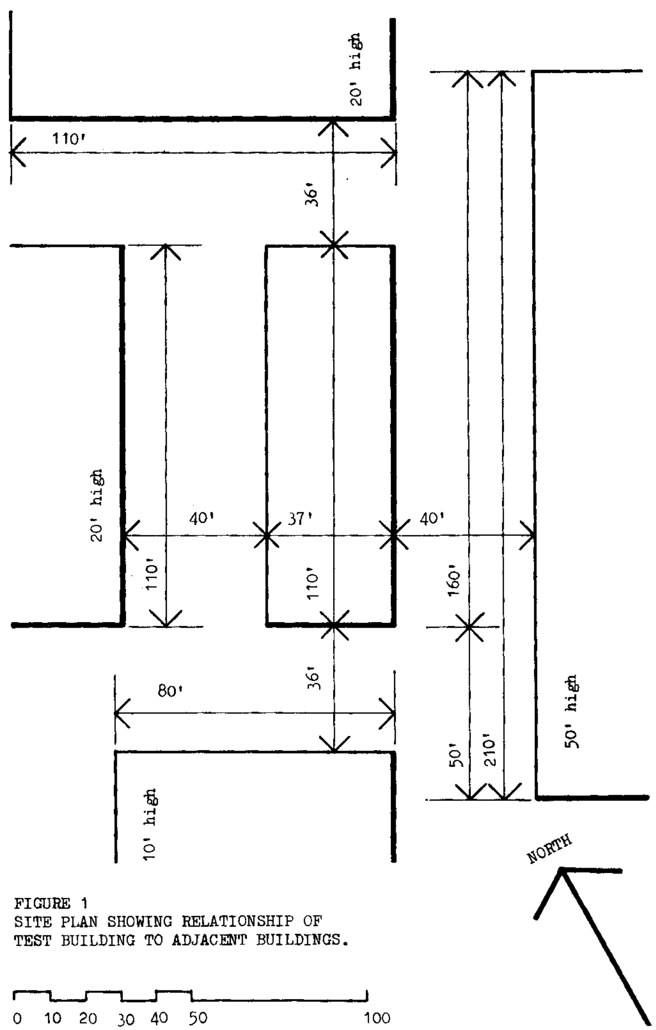


FIGURE 1
SITE PLAN SHOWING RELATIONSHIP OF
TEST BUILDING TO ADJACENT BUILDINGS.

0 10 20 30 40 50 100
Scale of feet

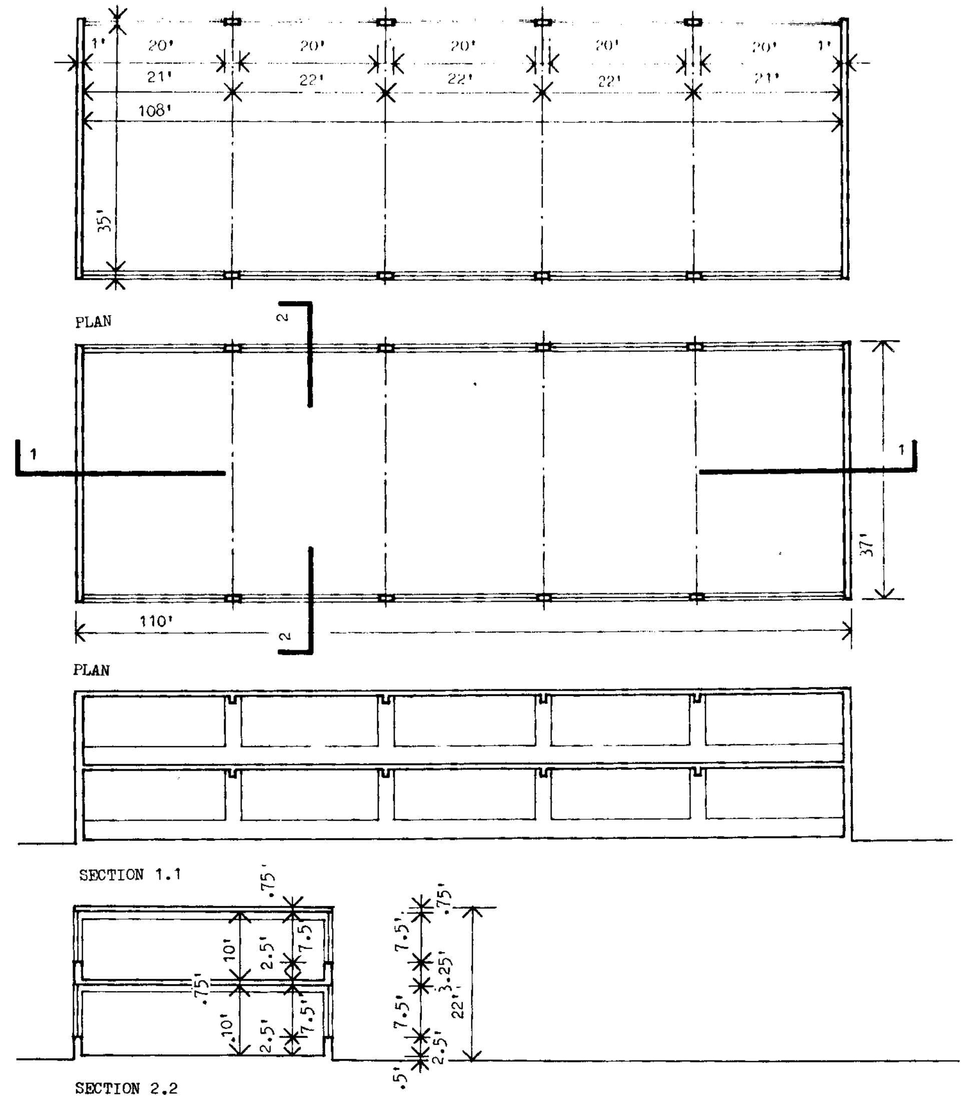


FIGURE 2
PLANS AND SECTIONS OF TEST BUILDING

0 5 10 20 30 40 50 100
Scale of feet

Table 1

Specification of properties of surfaces

Note: Both rooms in this building are similar in their finishes, therefore the following data are common:

1. Finish of outside surfaces of buildings when clean

   a. walls: medium

   b. roof: dark

2. Structural class of building: light construction

3. Depth of window reveal to glass line: 6"

4. Type of glazing: 32 oz., single

5. U values

   a. walls: 0.2

   b. windows: 0.7

   c. roof: 0.2

6. Average reflection factors

   window walls: 0.7

   solid walls: 0.5

   ceiling: 0.8

   floor: 0.15

7. Sound reduction indices

   window walls: 22 dB

   solid walls: 45 dB

   ceiling: 45 dB

   floor: 45 dB

8. Loudness reduction coefficients

   window walls: 0.1

   solid walls: 0.3

   ceiling: 0.7

   floor: 0.05

9. Density

   external walls: $90^{lb}/ft^3$

   roof: $90^{lb}/ft^3$

10. window frame type: 1

In addition to this information it is necessary to have the data which is collected together at Table 2.

Table 2

1. Height of working plane: 2'6"

2. Location of daylight factor reference points

1	X1	0.0	.Y1	10.0
2	X1	0.0	.Y1	17.5
3	X1	----	.Y1	----

3. Artificial lighting installation data

   Required design level of illumination: 40 lumens/ft^2

   Fittings data:

   B2 classification: 6

   Downward L.O.R. 48% Upward L.O.R. 22%

   Total flux output: 4400 lumens.
   Efficiency of source: 52.9 lumens/watt

   Suspension length: 0
   Maintenance factor: 0.8

4. Thermal performance data:

   Design air temperature

   For the purposes of this example it is assumed that during the winter months the air temperature within the building between the hours of 08.00 and 18.00 inclusive - i.e. when the building is occupied - will be 68°F, and for the remainder of the 24 hour period the temperature will not be allowed to fall below 55°F. During the summer it is assumed that the inside air temperature is equal to that outside except that an upper limit of 75°F is imposed

   Note: We would stress that these data have been arbitrarily selected and that any thermal performance data appropriate to a particular building could be incorporated.

   Design rate of air change: 0 3 ft^3/min/sq ft floor

5. Acoustic performance data

   Noise criterion curve: NC 35

From these data we are able to complete a series of standard data forms. There are three of these:

a. Site and general building data
b. Standard room data
c. Individual room data

We shall now go through these forms step by step describing the transcription of the data from the drawings and written specification.

The first form is that for the collection of Site and General Building Data The information about the location is irrelevant in the present example, but in practice this would be important to enable the appropriate meteorological data to be selected.

Figure 3 shows the site plan from Figure 1 with the basic co-ordinates and the north point superimposed. The co-ordinates are located upon the plan by ensuring that the north point is contained between X and Y. The required orientation data is then simply found by specifying the displacement of north from Y.

Figures 1 and 3 also provide the information which allows us to fill in the location of adjacent buildings data. The procedure here is to specify the locations of the edges of each neighboring building in terms of X, Y and Z.

The determination of the overall dimensions of the building is obvious.

In this case, where we are concerned with a building whose plan is a simple rectangle, there are no subtracted areas to be taken into account

The surface finish of external finishing materials is found from tabulated data where the position of the appropriate material in the table is entered in the data form, a light surface being No. 1, medium No. 2 and dark No. 3. The insertion of the appropriate coefficient is done within the model.

The structural class of the building is again found by reference to tabulated data. Since this is a simple building with only two rooms which belong to the same type we have pnly one standard room to consider.

The first requirement on the standard room data form is to identify the data. In this case the room type is No.1.

The compilation of the next set of information is self-explanatory, the thicknesses of enclosing surfaces being directly derived from the drawings (Figure 4).

"Glazing type" refers to the four glass types defined in tabulated form.

The U-values of the surfaces may be obtained from a number of sources such as the current IHVE Guide (3) and any correction for exposure must be performed prior to the input stage.

The average reflection factors, sound reduction indices and loudness reduction coefficients are all data which are readily obtainable from manufacturers' technical information sheets and popular textbooks.

The densities of walls and roofs are also easily found.

The best source of design levels of illumination is the IES Code (4). This document specifies levels in the newly adopted metric unit (LUX) and until the model is converted to metric it is necessary to perform the conversion by hand before input.

All the fittings data are readily obtainable from manufacturers' technical literature.

The compilation of the thermal performance data is simply a question of determining the temperature range for the activity to be housed. The rate of air change data relating rates of change to activities is published in the IHVE Guide.

The appropriate Noise Criterion curve may be selected by reference to Beranek's work (5).

The procedure for selecting the window frame type is to calculate the approximate portion of the clear, structural window opening which is obstructed by window frame and then again to refer to tabulated data and quote the glazing bar type whose correction factor most closely corresponds to the proportion calculated. It is difficult to be more explicit than this since the factor is a function of both the geometry and the construction of the window frame.

Policies on the utilization of daylight in a building are clearly a matter which should be discussed between architect and client. It is possible by making use of the model at the design stage to investigate the effects of the alternate policies upon heat loss and gain.

We now turn to the Individual Room Data forms. On these we have to describe those properties of each room which are unique and also those which differ from the properties on the Standard Room Data form.

In the first place it is necessary to specify to which standard type the particular room belongs. Then the floor upon which it is situated and the number given to the room are specified These are required solely to aid identification of output.

The primary location of a room is the point in it where the values of the co-ordinate dimensions X, Y and Z are the lowest possible. Actual room dimensions are easily derived from the drawings.

Moving past the subtracted area data which is not applicable in this example, we define certain surface characteristics. The

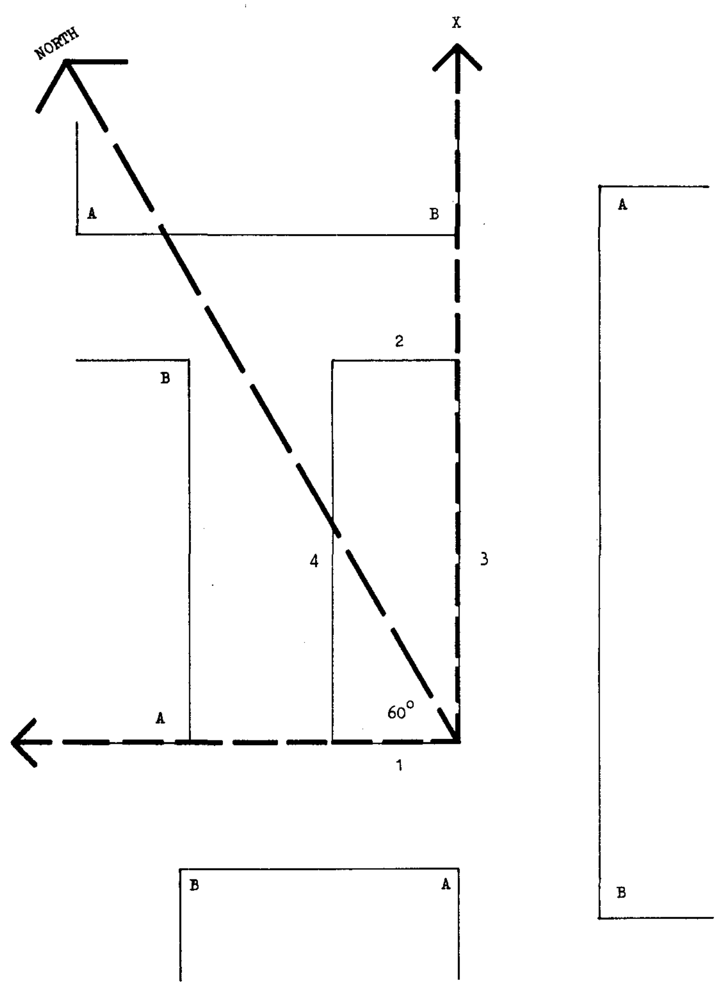


FIGURE 3
SITE PLAN WITH PRIMARY CO.ORDINATES
SUPERIMPOSED

0 10 20 30 40 50 100
Scale of feet

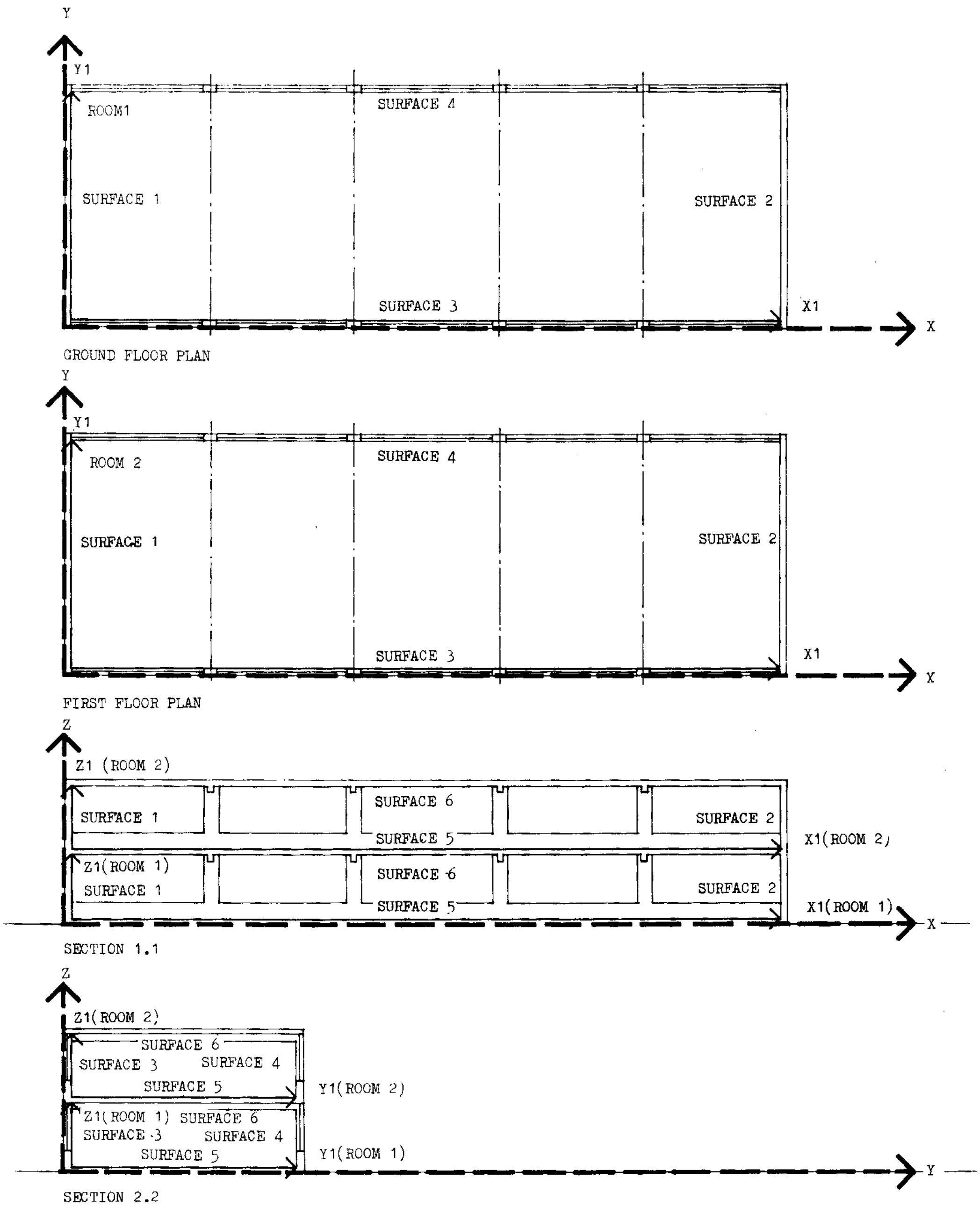
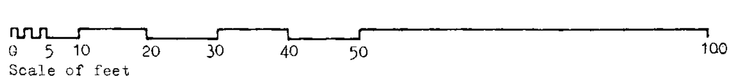


FIGURE 4
PLANS AND SECTIONS OF TEST BUILDING
WITH CO.ORDINATES SUPERIMPOSED

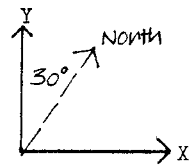


ENVIRONMENTAL PERFORMANCE EVALUATION

SITE AND GENERAL BUILDING DATA

LOCATION CAMBRIDGE

ORIENTATION
Indicate orientation relative to X/Y co-ordinates



LOCATION OF ADJACENT BUILDINGS

Opposite wall number	Building edge	X	Y	Z
1	A	-36	0	10
	B	--36	80	10
2	A	146	110	20
	B	146	0	20
3	A	160	-40	50
	B	-50	-40	50
4	A	0	77	10
	B	110	77	10

SOUND PRESSURE LEVELS IN ADJACENT OPEN SPACES

Space location	Noise rating
1	70 dB
2	60 dB
3	80 dB
4	60 dB

OVERALL DIMENSIONS OF BUILDING

X 110 :Y 37 : Z 22

DIMENSIONS AND LOCATIONS OF SUBTRACTED AREAS

Location			Dimension		
X	Y	Z	X	Y	Z

DESCRIPTION OF SURFACE OF EXTERNAL FINISHING MATERIALS

Surface number	Finish
1	Medium
2	ditto
3	ditto
4	ditto
5	—
6	dark

STRUCTURAL CLASS OF BUILDING 2

ENVIRONMENTAL PERFORMANCE EVALUATION

STANDARD ROOM DATA

ROOM TYPE: 1

Thickness of window wall: 1' 0"
Depth of window reveal to glass line: 6"
Thickness of other external walls: 1' 0"
Thickness of roof: 9"

GLAZING TYPE: 1

U-VALUES:
Walls: 0.2
Roof: 0.2
Floor: –
Window openings: 0.7

SURFACE PROPERTIES	Average Reflection Factors	Sound Reduction Indices	Loudness Reduction Coefficients
Window walls	0.7	22 dB	0.1
Solid external walls	0.5	45 dB	0.3
Internal walls	—	—	—
Ceiling	0.8	45 dB	0.7
Floor	0.15	45 dB	0.05

DENSITY:
External walls: 90 lb/ft^3. Roof: 90 lb/ft^3

ARTIFICIAL LIGHTING INSTALLATION DATA:

Required design level of illumination: 40 lumens/ft^2

FITTINGS DATA:
BZ classification: 6
Downward L.O.R. 48% Upward L.O.R. 22%
Total flux output: 4400 Efficiency of source: 52.9 lumens/watt
Suspension length: 0 Maintenance factor: 0.8

THERMAL PERFORMANCE DATA:	Winter Max	Min	Summer Max	Min
Design air temperature	68°F	55°F	75°F	Minimum outside temp.

Design rate of air change/movement 0.3 ft^3/min./sq ft floor

ACOUSTIC PERFORMANCE DATA:
Noise Criterion curve: 35

Window frame type: 1

Is room to be considered daylit? YES

ENVIRONMENTAL PERFORMANCE DATA

INDIVIDUAL ROOM DATA

ROOM TYPE: 1

Floor: 1 (Ground) Room number: 1

Primary location: X 1' Y 1' Z 0.5'

Room dimensions: X1 108' Y1 35' Z1 10'

DIMENSIONS AND LOCATIONS OF SUBTRACTED AREAS

Location X1	Y1	Z1	Dimension X1	Y1	Z1

CHARACTERISTICS OF ROOM SURFACES

	Surface 1	2	3	4	5	6	7	8	9	10
Outside surfaces	✓	✓	✓	✓						
Window location			✓	✓						
Sill height			2.5'	2.5'						
Head height			10'0"	10'0"						
Location of opening jambs	Y1	Y1	X1 0 x22 88	X1 0 x22 88						
Number of windows in wall			5	5						
Location of closing jambs	Y1	Y1	X1 20 x22 108	X1 20 x22 108						
Blinds, etc.										
Shade factor of blinds										
Transmission factor of blinds										
Glazing type										
Thickness of surface										

ENVIRONMENTAL PERFORMANCE DATA

INDIVIDUAL ROOM DATA CONTINUED

	Surface 1	2	3	4	5	6	7	8	9	10
Depth of reveal to glass line										
U-VALUES Walls, etc.										
Window openings										
Average R.F.										
Sound reduction indices										
Loudness reduction coefficients										
Density										
Sound pressure levels in adjacent rooms					44.4					

Height of working plane: 2' 6"

Location of Daylight Factor reference points:
No.1 X1 0' ;Y1 10' :No.2 0' X1 0' ;Y1 17.5': No.3 X1 ; Y1

Number of refernce points: 2

Window frame type:

Is room to be considered daylit?

ARTIFICIAL LIGHTING INSTALLATION DATA

Required design level of illumination:

FITTINGS DATA:
BZ Classification:
Downward L.O.R.
Upward L.O.R.
Total flux output:
Efficiency of source:
Suspension length:
Maintenance factor:

THERMAL PERFORMANCE DATA:	Winter Max	Min	Summer Max	Min
Design air temperature:				

Design rate of air change/movement ft^3/min./sq ft floor

Number of occupants: 15 Activity group of occupants: 2

indication of the outside surfaces is straightforward as is the location of walls containing windows.

If the windows in the room are to be fitted with blinds, and their effect upon the thermal transmittance and daylight illumination is to be evaluated, it is necessary to input the data for shade factor and transmission factor. In this example these are ignored and therefore the form is left blank.

All the data in the following sections of the form, up to the sound pressure levels for adjacent rooms, are as the standard room.

The next three items on the data form are concerned with the location and number of the Daylight Factor reference points Firstly, the height of the working plane is established. This is, of course, dependent upon the nature of the activities within the room, but as yet we are only able to handle conventional, horizontal working planes. Selection of the location, in plan, of the reference points requires some care. Beyond this it is simply a matter of describing their position in terms of X1 and Y1 co-ordinates.

It is necessary to specify the number of occupants in each room in order to calculate the heat gain due to their presence. Often it will be possible for the designer to give this information with precision, but in some cases it may be necessary to arrive at a figure via a typical floor space standard for a room of the kind under consideration. In addition to these simple numerical data we have some idea of the kind of activity which the occupants of a room will perform. Figures for these may be found in the IHVE Guide. Finally in this section the time of arrival and departure of the occupants must be specified.

If there are any machines in the room which are likely to prove to be major heat sources their total combined horse-power should be specified. We also include a facility for the inclusion of any other particular heat source which might occur.

Upon completion of this form the next room within the same standard type should be described and so on until that class is completed. Then the next standard type should be selected, if one exists, and so forth until the entire building is described in this form. It should be noted that any single rooms which do not belong to a standard may be input in their entirety on the Individual Room Data forms.

The Output

The model produces a comprehensive analysis of a building on a room-by-room basis. In addition it is possible to request whole building totals, but in general use these have so far been restricted to total heating and cooling loads. The complete list of outputs is given below.

Room Outputs

1. General
   - A. Areas of individual enclosing surfaces
   - B. Total surface area
   - C. Areas of window opening per wall
   - D. Total window area
2. Daylight Evaluation

   Calculated values at each reference point of:
   - A. Sky component
   - B. External reflected component
   - C. Internal reflected component
   - D. Total daylight factor
   - E. Daylight factor corrected for glazing and glazing bar losses
3. Artificial Lighting
   - A. Total flux required to provide illumination level specified
   - B. Number of specified fittings required
   - C. Total wattage of installation
4. Thermal Performance Evaluation
   - A. Total heat flows through all external surfaces of space per hour of day selected
   - B. Analysis of flows by surface
   - C. Analysis of flows through solid and window openings - for window walls only
   - D. Hourly total incidental heat gains - occupants, machines, etc.
   - E. Hourly gains due to artificial lighting - winter and summer
   - F. Losses due to ventilation
   - G. Hourly total ventilation requirement
   - H. Curves of total heating and cooling load per room

F. Acoustic Evaluation

A. Maximum acceptable noise level

B. Actual, calculated noise level

C. Difference between acceptable and actual

Whole Building Outputs

A. Total heating and cooling load for whole building

The whole of the output for each room is extensive. A typical first page, as produced by the computer for the building described above, is illustrated below (Figure 5). The whole of this output has been published in LUBFS Working Paper 28 (6).

Technical specification of the model

As mentioned above the logical processes which are performed by the model are described in detail in LUBFS publications. For present purposes it is sufficient to state that the actual design calculations which are performed are all well established and accepted methods.

The bulk of the daylighting calculations are based upon the work of Hopkinson and his colleagues at the Building Research Station (7), with the principal exception of part of the rooflight calculation which makes use of the equation proposed by Arndt (8) for the calculation of the internal reflected component.

The artificial lighting calculations follow the British Zonal Method (9) and the thermal stage of the model uses the methods recommended by the Institution of Heating and Ventilating Engineers (10). Finally, the acoustical calculations are based upon equations published by Parkin and Humphries (11).

In broad outline the process performed by the model for each room in a building is linear. Within individual sub-routines there are often tests and loops which offer the ability to handle complex situations, but the basic process is simple (Figure 6). When each room has been analysed the model returns to the beginning and automatically selects the data for the next room. This process is repeated until the data is exhausted.

Hardware and Software Background

The system is currently run on the Titan computer which is situated at The Mathematical Laboratory, University of Cambridge. Titan is a prototype Atlas II with 128K of 48 bit core store and random access backing store provided by a large fixed disk of capacity 16 million words. Titan provides a job-shop facility capable of running 1000 jobs per day and simultaneously services the Cambridge Multi-Access system. The system allows up to 20 simultaneous users remote access from teletypes throughout the University.

The subsystems available under this system include a complex file-handling system and advanced editing features. There is also a wide range of compilers and assemblers. In particular the standard high level programming language is USASI Fortran. In fact the Titan Fortran system has a number of extensions of USASI Fortran but (it is hoped) no inconsistencies.

The main virtue of the use of Fortran for this sort of major package is the ease with which new subprograms can be independently tested and then integrated into the system. The other advantage is that Fortran is the scientific language to have achieved world wide use (with Algol a poor second) and so allows transfer of the package to other machines.

These advantages seemed to outweigh the lack of flexibility inherent in Fortran such as its lack of list processing facilities.

Data Structure

The backbone of a suite of programs of this type is the data structure used to store the initial data and to transfer intermediate results between programs. The main criteria for a good data structure are ease of creation, ease of access and efficiency in the use of storage space and ease of extension for new programs. Data structures tend to model the physical or conceptual structure of the object under study and so one would expect that an object as complex as a building would lead to a complex data structure.

The fact that this is not so is due to several factors; the most important of these is the absence of inter-room calculations. We are concerned with the effect of the external environment of a room, and so ignore inter-room heat flows. Also the acoustic evaluation assumes that there are maximum permissible noise sources in adjacent rooms. All this means that at any point in the evaluation we need two separate blocks of data.

Firstly there is a block which is 'common' to all the rooms. This consists of the site, orientation and adjacent building data and the various tables including the meteorological data and so forth. The second block is that specific to the room. This includes the various overall and window dimensions and the properties of the surfaces as well as the lists of the activity and machine

ENVIRONMENTAL ANALYSIS

FLOOR NUMBER 1. ROOM NUMBER 1.0

ROOM DIMENSIONS

PLAN	108.0 X 35.0 FT
HEIGHT	10.0 FT
WALLS 1 & 2	350.0 SQ FT
WALLS 3 & 4	1080.0 SQ FT
FLOOR & CEILING	3780.0 SQ FT
WALLS 7 & 8	0. SQ FT
WALLS 9 & 10	0. SQ FT
TOTAL SURFACE AREA OF ROOM	10420.0 SQ FT

WINDOW AREAS OF ROOM

WALL NUMBER	
1	0. SQ FT
2	0. SQ FT
3	750.0 SQ FT
4	750.0 SQ FT
TOTAL AREA OF ALL GLAZING	1500.0 SQ FT

WINDOW CILL HEIGHT 2.5 FT.
WINDOW HEAD HEIGHT 10.0 FT.

DAYLIGHT EVALUATION

REFERENCE POINT	SKY COMPONENT	INTERNAL REFLECTED COMPONENT	EXTERNAL REFLECTED COMPONENT	DAYLIGHT FACTORS	CORRECTED
1	0.40%	2.30%	0.30%	3.00%	2.40%
2	0.89%	2.30%	0.10%	3.29%	2.63%

ARTIFICIAL LIGHTING INSTALLATION

TOTAL FLUX REQUIRED	337607.3 LUMENS
NUMBER OF FITTINGS REQUIRED	77
TOTAL WATTAGE OF INSTALLATION	6381

TOTAL FLOW THROUGH SURFACES OF SPACE.BTU/H

TIME OF DAY	WINTER CLOUDY	WINTER CLEAR	SUMMER CLOUDY	SUMMER CLEAR
1	-17458.	-28040.	0.	5191.
2	-17458.	-29703.	0.	6130.
3	-17458.	-29822.	0.	6246.
4	-17458.	-28640.	0.	6904.
5	-19952.	-28438.	0.	6576.
6	-19952.	-28438.	0.	5699.
7	-19952.	-26607.	0.	6599.
8	-36163.	-42818.	0.	30553.
9	-38657.	-42699.	0.	36636.
10	-33669.	-42579.	0.	69289.
11	-33669.	-38829.	0.	103827.
12	-31175.	-33699.	0.	122807.
13	-28681.	-29318.	0.	131783.
14	-28681.	-25718.	0.	128733.
15	-28681.	-24699.	0.	108145.
16	-28681.	-1517.	0.	78472.
17	-28681.	8517.	0.	55294.
18	-28681.	-12751.	0.	47058.
19	-12470.	-24036.	0.	69957.
20	-12470.	-30421.	0.	95682.
21	-12470.	-30310.	0.	107056.
22	-12470.	-28327.	0.	88867.
23	-14964.	-26468.	0.	16236.
24	-17458.	-26461.	0.	4880.

FIGURE 5
Typical output

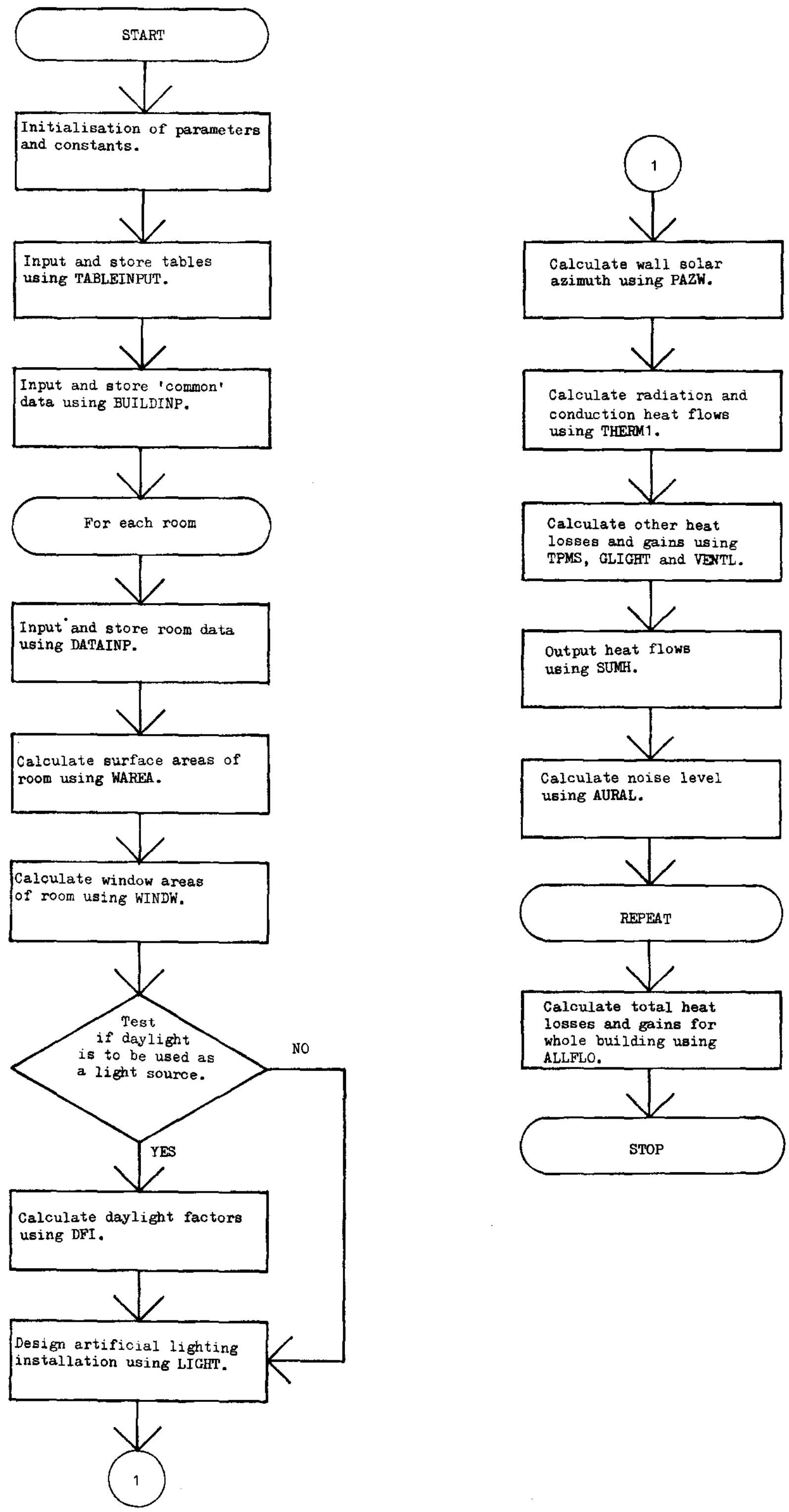


FIGURE 6
Flow chart of
control program

factors. So the common data are stored for the whole evaluation of the building while the specific data for each room are overlaid on those of the previous room.

The next point of importance to discuss is the actual form of the data structure. As pointed out above, the complexity of the data structure is a reflection of the complexity of the object but there is another important factor. This is the type of access needed. For an information retrieval package or a quantity surveying package one needs many cross links in the data and a strong hierarchy. In contrast we do no aggregation or classification of the data apart from simple totals and only need to access a specific list of data in a unique way. For example we never ask the type of question 'Which walls are more than nine inches thick?' but always 'How thick is wall 3 of room 4.2'.

This means that we can use the most basic type of data structure which is a series of simple lists. Of course there are some properties which need variable amounts of space for different rooms, for example the number of windows will change; but this sort of problem is dealt with by lists with the first element giving the number of data items following.

This sort of structure is implemented using the 'named common' feature of USASI Fortran. This allows us to group data which is likely to be needed together into distinct blocks. For example the artificial lighting variables are stored together in a common block named LIGHTFIT. Named common blocks are used also to transfer intermediate results. One has only to mention in each subprogram those common blocks needed.

Techniques in the Evaluation Programs

We make extensive use of tables in the evaluative programs, especially for meteorological and artificial lighting data. This means that we frequently use interpolative routines in many of the programs. A careful study of the tables and evaluative routines convinced us that linear interpolation was quite accurate enough considering the accuracy of the other data involved. The modularity of the evaluation makes it very easy to update or extend the programs.

Run Time Parameters

The preprocessing program needs 8K of store altogether and takes 1.4 secs CPU time to run per room. The evaluative programs if all loaded take 24K of core and take 10 secs CPU time to run for an average room in a building. Unfortunately there is no overlay loader on Titan so we have to load everything we need simultaneously. If an overlay loader were available the suite would run in 12K but with a consequent increase of CPU time. We keep various of the programs compiled into relocatable binary on magnetic tape to save compilation time.

The Application of the Model

The model has been used extensively as a research tool to study in detail the relationships between the form and detail of buildings and the environment within them. The outcome of the first stage of this work has been published as a LUBFS Working Paper (12).

In order to bring practising architects into contact with research work of this kind we have carried out a series of case studies in which a number of architects saw their current design projects input into the computer and analysed by the model. They were then able to study the output and to make changes to their designs through the on-line editor and then re-run the model. A wide range of building types was studied, demonstrating the model's flexibility.

The exercise produced valuable reactions to the system which were collected through a short questionnaire. As a result the validity of the approach which has been adopted was confirmed and indications were gathered about the directions in which future work should move. A paper has been prepared describing the whole exercise (15).

References

1. Hawkes, D. and Stibbs R. The Environmental Evaluation of Buildings, 1 A mathematical model. Working Paper 15, LUBFS, Cambridge, 1969

2. Hawkes, D. and Stibbs R. The Environmental Evaluation of Buildings, 4 The description and evaluation of rooflights. Working Paper 29, LUBFS, Cambridge, 1970

3. Institution of Heating and Ventilating Engineers, IHVE Guide, The Institution, London, 1965.

4. Illuminating Engineering Society, IES Code, The Society, London, 1968

5. Beranek, L.L. Revised Criteria for Noise in Buildings in Noise Control, January, 1957

6. Hawkes, D. and Stibbs R. The Environmental Evaluation of Buildings, 3 A worked example. Working Paper 28, LUBFS, Cambridge, 1970

7. Hopkinson, R. Petherbridge, P. and Longmore, J. Daylighting, Heinemann, London, 1966

8. Arndt, W. The Calculation of Reflected Daylight in Compte Rendu, Commission Internationale de l'Eclairage, 13th Session, Vol 2, The Commission, Paris, 1955.

9. Illuminating Engineering Society. The Calculation of Coefficients of Utilization. The British Zonal Method. IES Technical Report No. 2, The Society, London, 1961

10. Institution of Heating and Ventilating Engineers, op cit.

11. Parkin, P.H. and Humphries, H.R. Acoustics, Noise and Buildings, Faber, London, 1958

12. Hawkes, D. The Environmental Evaluation of Buildings 5. Explorations. Working Paper 30, LUBFS, Cambridge, 1970

13. Hawkes, D. The Use of an Evaluative Model in Architectural Design. Case Studies. Working Paper 31, LUBFS, Cambridge, 1970