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HEATING LOW HEAT LOSS BUILDINGS - DO THE OLD RULES STILL APPLY?

A. Hildon, MA, PhD, CEng, MInstE, MCIBSE, J. Palmer, MSc, MSc, CEng, MInstE

This paper draws upon the authors' experience of the design and evaluation of low energy buildings to suggest that currently recommended standards of insulation, taken together with increased utilisation of electricity and of solar gain, are sufficient to question traditional simple approaches to the design and control of heating systems for naturally ventilated buildings. The paper is intended as a stimulus for debate and further research and is a reflective rather than a definitive contribution to the discipline. The numerical analysis is unsophisticated but, based as it is on measured data, it serves to illustrate the main parameters of the arguments.

BACKGROUND

A substantial majority of non-domestic buildings in the UK are naturally ventilated and of modest proportions. Their thermal performance is largely determined by the properties of the external fabric, and the design of the space heating services, together with fuel used for space heating, will be envelope and not plant dependent.

Current good practice (assisted by product developments such as low emissivity glazing) is leading to better insulated building fabrics with a consequent reduction in envelope heat loss. Concurrent with this trend has been the steady increase in the use of electrical equipment within the workplace and hence increased internal heat gains. Additionally, the utilisation of passive solar heating further increases the heat gains to be set against the reduced heat losses.

With heat loss rates significantly greater than heat gain rates then the traditional approach to the design of heating services has been to ignore the gains and to provide a system which can meet the heat demand in the absence of any gains (equivalent to an unoccupied building before sunrise). Gains at other times would be dealt with by a mixture of thermostatic controls, increased temperatures, and increased ventilation (i.e. increased heat loss). This is acceptable when gains are small relative to losses.

This paper addresses those naturally ventilated buildings where heat losses and incidental heat gains are, under average conditions, of comparable magnitude. The effects of this are compounded by the dynamic nature of climate and building use which means that at some times and in some parts of the building the incidental gains will exceed the comfort heating requirements. In these buildings, whilst the need for a heating system to deal with the low or zero heat gain condition is still present (e.g. preheating) the argument that it can, by default, also deal with the high heat gain condition may well be invalid. Data from 3 well known low energy buildings are used to illustrate the key principles, they are:-

* Walmley Schools, Birmingham
* JEL Factory, Stockport
* South Staffordshire Water Company, Head Office, Walsall.

THREE BUILDINGS

Of the 3 examples, full and measured data are available for the Walmley Schools by virtue of a 2 year 200 channel monitoring exercise. For the other 2 buildings only limited measured data is available from meter readings and from their energy management systems together with some early monitoring results under the Dept. of Energy's Energy Performance Assessment project - EPA (10, 11).

Walmley Schools (Figure 1)

Two linked schools for 500 children aged 5 to 13, this 2200m^2 building was occupied in 1981 and intensively monitored under the Dept. of Energy's Energy Efficiency Demonstration Scheme. The project has been widely reported (1, 2, 3, 4, 5, 6) and is a case study in the Design Guide to BS 8207 - Code of Practice for Energy Efficiency in Buildings (7). The fabric is highly insulated with U-values of 0.26 to 0.35/W/m^2/°C for opaque elements, the small windows are double glazed. The building has a high thermal capacity - greatly assisted by the heat sink effect of the ground floor in this single storey school. Heating is by gas fired boiler plant and LPHW distribution to radiators.

Monitoring confirmed that the schools cost no more than contemporaries but used half as much gas although electric lighting use was higher than average. The pay back on the additional fabric insulation was computed as less than 8 years, by comparing the measured cost of the insulation measures with the estimated increase in measured heat loss that would have resulted from their omission.

JEL Factory (Figure 2)

An office facility and manufacturing base of 2050m^2, this 2 storey simple box form includes a double height production space. The opaque elements are insulated to 0.3W/m^2/°C and double glazing is used. The south facade is 100% glazed with a centrally placed boiler room in this elevation. Solar gain is redistributed by a forced ventilation system from south facing rooms via the boiler atrium and to the production space through its warm air heating system. Spaces other than the production area are heated with LPHW radiators from the gas boilers. The south facade is fitted with internal and external automated solar control blinds. The building is a BS 8207 case study (7) and has been reported elsewhere (8, 9).

The building was monitored by JEL themselves in the first year using their own energy management systems. Currently, it is being evaluated under the EPA Project (10, 11). Heating energy use is low (similar to that for the Walmley Schools) and the building cost was described as 'cheap for an office, expensive for a factory, but very good value'.

South Staffordshire Water Company, Head Quarters, (Figure 3)

A new HQ office on an existing company site, this 3,500m^2 building was occupied in 1985 and was the overall winner of the 1986 Building Services Energy Award (12). The opaque fabric is insulated to 0.3 W/m^2/°C. The windows are about 60% of the perimeter wall and use argon filled low emissivity glass in an insulated frame (both glass and frame have a U-value of 1.6 W/m^2/°C). The window/wall incorporates internal and external 'shelves' to provide protection against summer solar gains and to 'bounce' daylight to the rear of the rooms. This redistribution of daylight, in conjunction with the light level controlled automated control of electric lighting, is intended to reduce electricity consumption. Heating is by gas boilers supplying heat to radiators via a LPHW system.

The building has been described elsewhere (12, 13) and is to be monitored under the EPA Project (10, 11). Some initial data has been provided by the owner from sub-meter readings and from the energy management system. Whilst energy use is a little higher than expected, it is still low and this may well be a reflection of the inevitably atypical first year when energy management procedures are still evolving. The building cost is typical for this standard of office accommodation and the consultants' analysis suggests that costs attributable to extra fabric insulation should be recovered within 10 years.

Overview

Each of the 3 buildings is similar in scale and with an envelope heat loss of about half that commensurate with insulation to minimum standards (i.e. building regulations) each building was built within its own cost limits and as such the higher performance did not add to the overall cost. The evidence is that the heat savings will pay for the costs attributable to the extra insulation within 5 to 10 years. These and other similar examples seem to confirm that U values of about 0.3 $W/m^2/°C$ and double glazing should be affordable and cost effective in new buildings of this scale and nature.

DATA

Table 1 presents the data expressed per unit floor area, from which the similarities are apparent. However, the buildings differ in function and form and this is reflected in the data. For example:-

* Walmley Schools are single storey with a relatively high surface area but with small windows. Occupancy gains are high but solar gains are small. The occupied period is short. The building has a very long time constant by virtue of the ground floor slab, as well as the dense concrete block partitions.

* JEL factory is a compact 2 storeys but with a lightweight roof and passive solar south facade. It has a double height production space, and occupancy gains are small. It has a heat redistribution mechanism within its heating system. Lighting energy is low by design but other electrical use is high.

* SSWC, HQ is almost cubicle in form extending to 4 levels. It has a high glazing area and is deliberately designed for high daylight levels but with minimum impact on heat loss and summer heat gain. The thermal mass in concrete floors and concrete block partitions is high. The use of office machines - VDU's, etc., is substantial. It has an 8m x 8m core providing for emergency escape, services ducts, toilets, etc., which adds to its depth and reduces the surface to volume ratio.

Nevertheless, as the data reveals, there are sufficient parallels to reveal the key, consistent principles which underpin the conclusions. The main comments are summarised below.

Heat Losses

The convention for naturally ventilated buildings is to take a figure for ventilation of about 1 ac/hr. Measurement at Walmley shows that despite its high surface area, the heating season average ventilation was only about 0.4 ac/hr. This equated to 0.3 ac/hr during unoccupied periods and 0.9 ac/hr during occupied periods. In classrooms the ventilation rate was typically about 1.3 ac/hr during occupied periods. Reference to measurements on more typical buildings suggested that at Walmley a conventional envelope would have had an average ventilation rate of about 0.7 ac/hr. Consequently, for the purpose of calculation in table 1 0.5 ac/hr has been taken as the average ventilation rate with 1.0 ac/hr during occupied periods. For calculating the building regulation equivalent 0.7 ac/hr has been used.

The data show that heat loss is reduced by about 40% relative to the minimum standards.

Heat Inputs

These are computed for a heating season of October to May and consist only of 'useful' heat into spaces as distinct from fuel supplied to plant. This is classified as:-

* heating services - the fuel consuming heating system

* light and power - lighting and electrical equipment releasing heat into space

* people and sun - essentially free heat.

(Note: heating and electrical inputs are derived from measurements; people and solar gain are estimated from measured occupancy, building geometry and climate.)

The data show that about 40-50% of the total heat input into the building is met from sources other than the heating system. Walmley and JEL have high free heat, due to large numbers of occupants for the former, and a passive solar system for the latter.

Heat Balance

Figure 4 illustrates an average heat balance for the 3 buildings from which the effect of the increased insulation (reduced heat loss) eating into the heating system contribution can be seen. This is, after all, the purpose of the insulation, but the dramatic effect on the make up of the heat inputs is not usually considered at the design stage.

Balance Temperatures

Applying the conventional steady state analysis to the heat balance suggests that, on average, the heat gains are worth about 4 to 7°C temperature rise. This does not appear problematical with a winter average temperature of about 7°C and design external temperature of -1°C.

However, if we apply the same calculation to occupied periods when admittedly, the building's heat loss is slightly higher but when most gains are squeezed into a short period of time, then we see that the heat gains are now worth 12 to 14°C.

Since the external temperatures are higher during occupied periods and since these figures are based on average and not sunny data, then it becomes clear that for much of the winter these buildings, theoretically at least, require little or no heating during the occupied periods. Indeed there appears to be a risk of overheating as illustrated by the balance temperatures calculated for the main occupied or sunny spaces where the heat gains are worth 19 to 27°C! In these cases, there is a need for heat dumping and/or redistribution to other spaces.

Thermal Mass

So why is it that for these buildings the heating system operates during the occupied periods?

The data for the Walmley Schools can be split between occupied and unoccupied periods - Table 2 - from which it is clear that the thermal mass of the building is the effective heat sink for the excess heat fed into the building during occupied periods. It also acts as the thermostatic control preventing the over-heating suggested by simple steady state analysis. Figure 5 illustrates the average heating system load profile and internal temperatures for the building. It is clear that the mass is smoothing any obvious effect of heat inputs (from the heating system and other sources) on the internal temperature conditions. Perhaps this is forunate (?).

Almost half the heating input and hence fuel is used for preheating at Walmley and the illustrative data for SSWC is similar (Figure 6). In the case of Walmley the oversizing factor of 1.5 seems to have been insufficient to provide for a short preheat period and a similar finding has been reported by the consultants for the JEL building. It appears that whilst insulation can reduce the heat load by almost half, it is unwise to reduce the heating system size pro-rata if intermittent heating and short preheat periods are required.

Heat Redistribution

The JEL building has a potential and a need to redistribute heat from the passive solar south facade. Figure 7 shows that for a typical day in May, the building requires preheating but during the occupied period solar and other gains are sufficient to maintain and increase internal temperatures without the heating system. Notwithstanding this there is evidence of relatively high internal temperatures which to some extent may increase heat stored in the building's mass.

CONCLUSIONS

The examples as outlined above, together with published and unpublished data, suggest that the levels of insulation which they incorporate are affordable, desirable and cost effective in new naturally ventilated buildings of this scale and type. What is less clear is what is the correct response of the heating system designer when faced with such a low heat loss building. Similarly, it is not clear what is the optimum role for thermal mass.

Clearly the heating system needs to be able to preheat in the absence of heat gains and here the design principles remain unaltered, except that proportionally a larger boost factor may be needed since although heat loss may be halved, thermal capacity or admittance is unlikely to be so reduced. However, this will generate a heating system of substantial overcapacity for the occupied periods when the need seems to be for small amounts of localised heating with, ideally a facility to redistribute heat.

At the moment, it is unlikely that these 2 distinct regimes for, and requirements of, the heating system receive more than passing attention. Several possible responses occur but which is better, and under what circumstances, will need more research.

For example, it would appear that a warm air heating system operating on recirculated air could provide rapid preheating from larger heater batteries, and could operate at zero or low heat input during the day acting mainly as a heat redistribution system. However, the ductwork can be space and cost consuming and the electrical power to move the air is not insignificant. Perhaps a LPHW system with local fan assisted convectors could overcome some of these difficulties? In any event, if warm air is to be the heating medium then should thermal mass be shunned for fast response or is it required as a form of temperature stabiliser and thermostatic control? (i.e. a safety mechanism.)

An alternative strategy which requires a life cycle cost approach would be to opt for thermal mass and electric heating. The temperature bahaviour of these buildings shows that they hardly cool at night and that the day time heat input is actually being used 'over' several days. It may be just as effective to input this heat at night using off-peak electricity, relying on local on-peak electric heaters to provide the fine tuning required to top up the internal gains. The higher running costs relative to cheaper fuels can be offset by the lower installation costs. This design strategy was illustrated in a previous CIBSE technical conference (14) (if the concept appears ludicrous reflect on how widely accepted de-centralisation of hot water supply has become using local electric water heaters once the facts about actual use, standing losses, etc., became more widely established through monitoring).

Similarly, an analysis based on Response Factor (the building's admittance divided by its heat loss, including ventilation in both cases) (15) might lead a designer to question whether the cost of oversizing, and suitable controls to achieve intermittent heating, was cost effective. An attractive option could well be to design and control for continuous heating. This point was theoretically illustrated as long ago as 1977 (16), but it is in the more recent examples of high response factor buildings such as those illustrated here that the theory takes on a practical immediacy.

Whichever of these or other strategies is adopted, it seems clear that the levels of insulation suggested by these 3 and other similar buildings is as low as can be justified when used in conjunction with conventional LPHW central heating systems. It may well be that if the higher running cost/lower capital cost strategies of electric storage or continuous heating are pursued, then lower heat loss rates could be justified. However, until some of the problems caused by the interaction of gains and losses highlighted in this paper are more thoroughly understood in practice and embodied in appropriate design guidance, then it would seem unwarranted to seek lower levels of envelope heat loss. Heating system design and designers need to respond to the challenge presented by these types of buildings.

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SSEC, HQ: Client - South Staffordshire Water Company
Architect - Harry Bloomer Partnership

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TABLE 1 - COMPARATIVE DATA

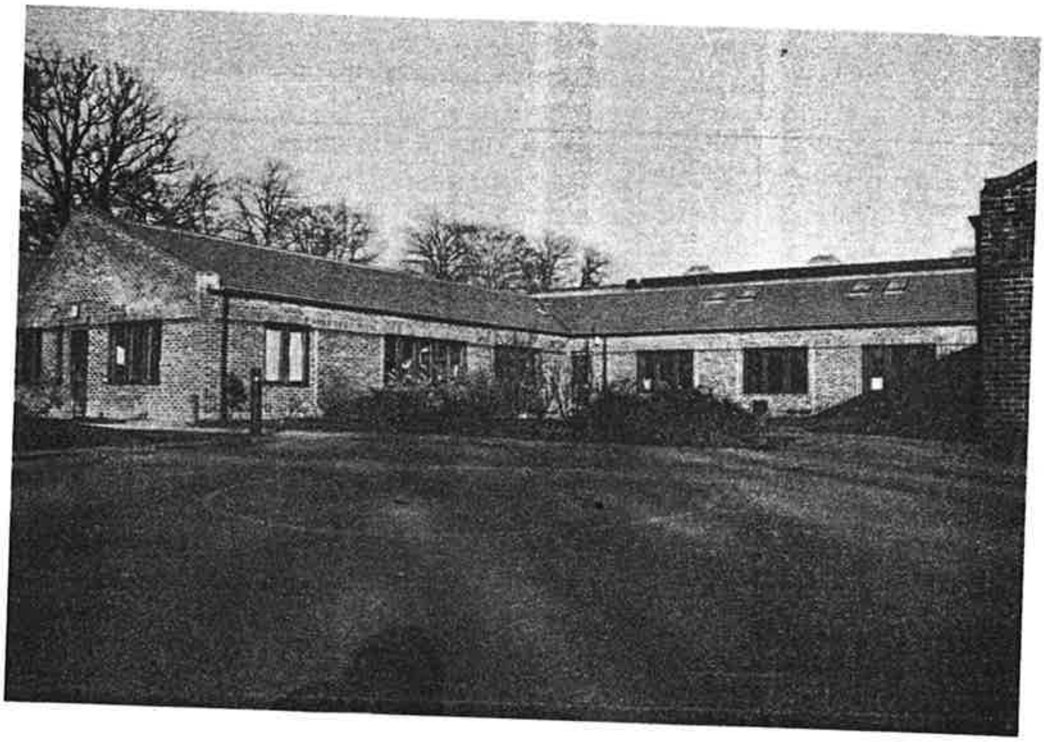
(All Energy data are expressed per unit of gross floor area)

	WALMLEY	JEL	SSWC
*Envelope			
-Floor Area m^2	2200	2050	3500
-Volume m^3	7700	7500	11000
-Surface area (inc g.f) m^2	6000	3500	4500
-Average U Value $W/m^2/°C$	0.4	0.6	0.6
*Heat Loss Per m^2 floor area: W/°C Temp. diff.			
-Average all times @0.5ac/h	1.6	1.6	1.2
-Average occupied @1.0ac/h	2.3	2.3	1.7
-B'g regs standard @0.7ac/h	2.7	3.0	2.3
*Annual Delivered Fuel kwh/m^2 floor area pa			
-Gas (space and water heating)	100	85	49
-Electricity (light & other)	31	48	60
*Nett Heat to Spaces kwh/m^2 floor area per heating season			
-Heating System	61	61	49
-Electrical equipment	21	31	43
-People and Sun	21	20	9
- Total	103	112	101
*Balance Temperatures			
*average, all times, whole B'g			
-heat loss W/°C per m^2	1.6	1.6	1.2
-heat gain watts per m^2	6.8	8.4	8.6
-temp rise from gains °C	4.3	4.0	7.2
-balance T_e (t_i = 16°C)	12	12	9
*Average, occupied, whole B'g			
-heat loss W/°C per m^2	2.3	2.3	1.7
-heat gain watts per m^2	33.0	30.00	21.0
-temp rise from gains °C	14	13	12
-balance T_e (t_i = 20°C)	6	7	8
*Average, occupied, part B'g-	Classroom	S. Office	S. Office
-heat loss W/°C per m^2	2.5	2.9	1.5
-heat gain watts per m^2	47.0	70.0	40.0
-temp rise from gains °C	19	24	27
-balance T_e (T_i = 20°C)	1	-4	-7

Table 2 - Occupied v Unoccupied Periods

Walmley Schools 82/83 Heating Season

	All Times	Occupied Periods	Unocc. Periods
	6050hrs	1120hrs	4930hrs
Nett Heat to Spaces kWh/m^2			
-heating system	62	25	36
-elect equip	21	18	3
-people + Sun	21	18	3
Total	103	61	42
-equivalent watts/m^2	17	55	8
Measured Heat Loss - Watts/m^2	17	22	15
-T_i °C	17.5	19.7	16.9
-T_e °C	6.2	8.1	5.9
-heat loss W/°C per m^2	1.5	2.1	1.4



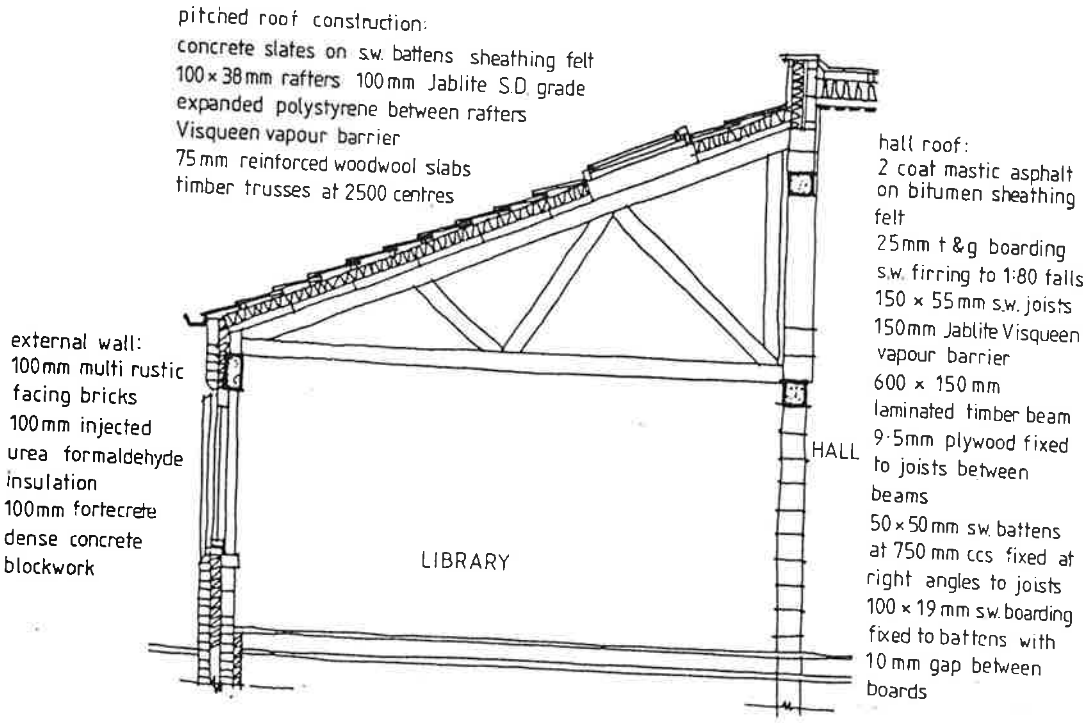
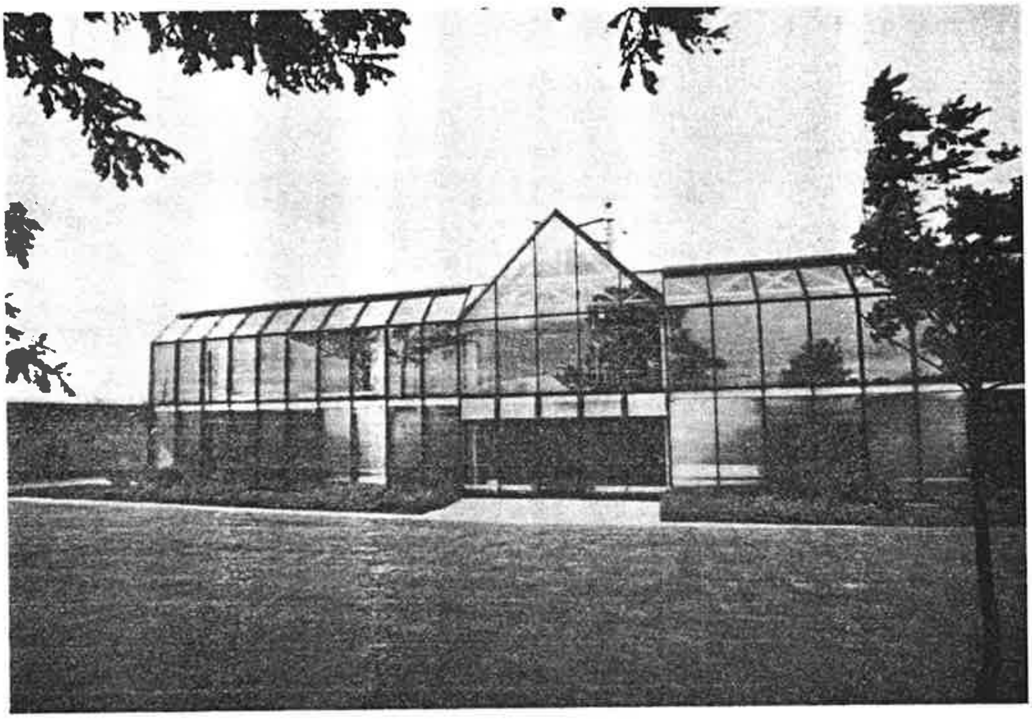


FIG. 1

DEANERY FIRST AND MIDDLE SCHOOLS – WALMLEY BIRMINGHAM



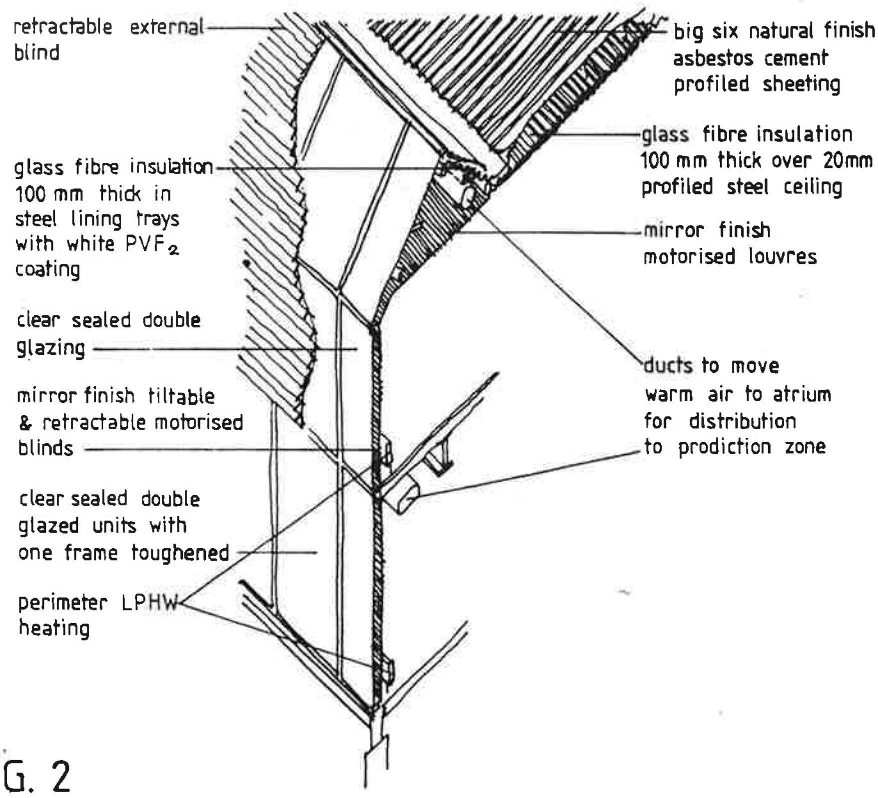
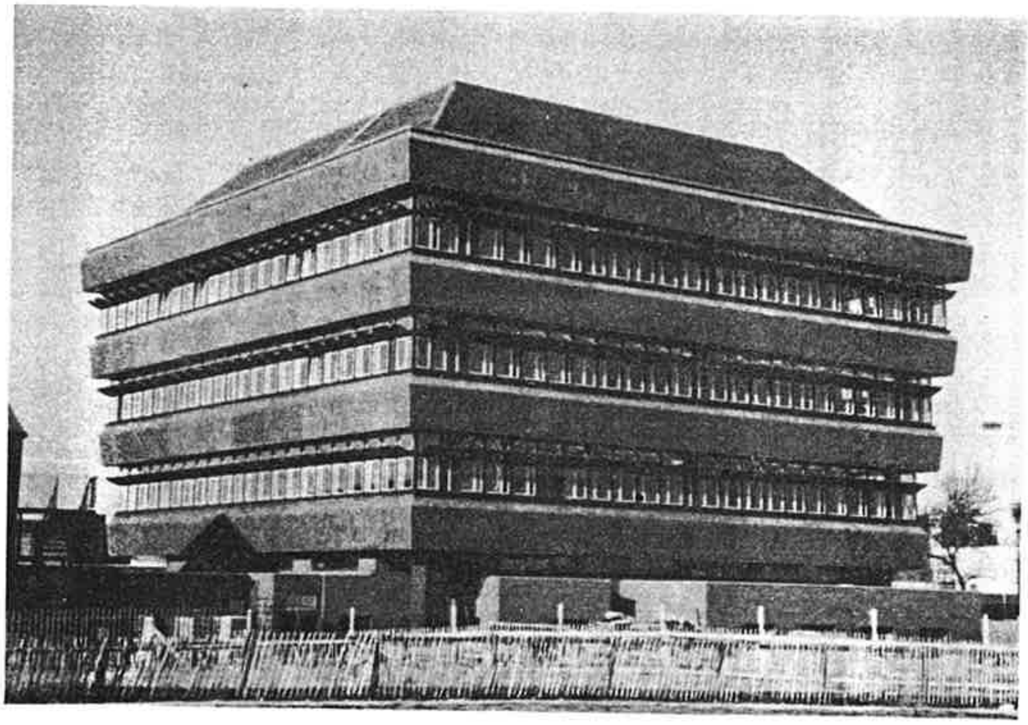


FIG. 2
J.E.L. FACTORY - STOCKPORT



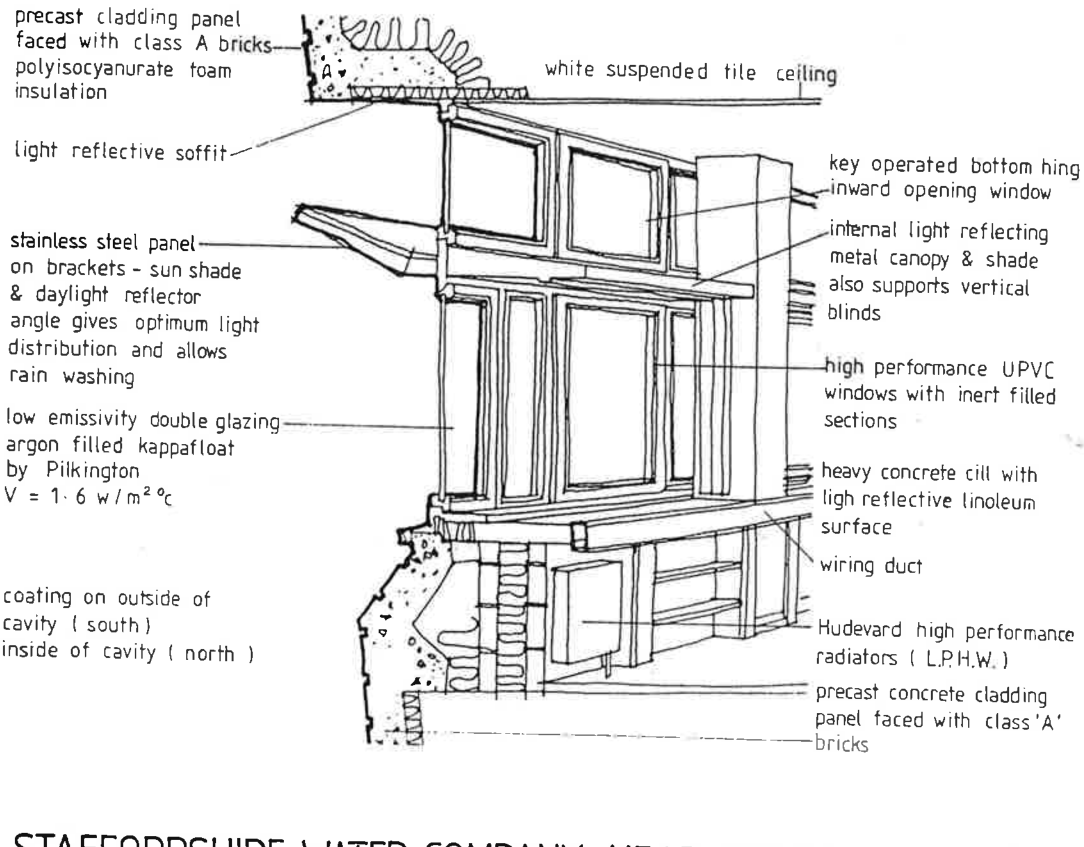


FIG. 3

SOUTH STAFFORDSHIRE WATER COMPANY HEAD OFFICE - WALSALL

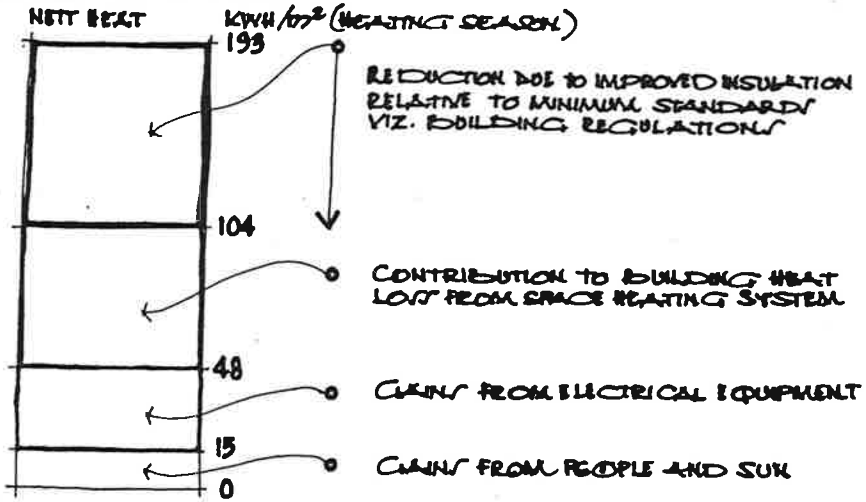


FIGURE 4 :- AVERAGE HEAT BALANCE FOR THREE BUILDINGS IN TABLE 1

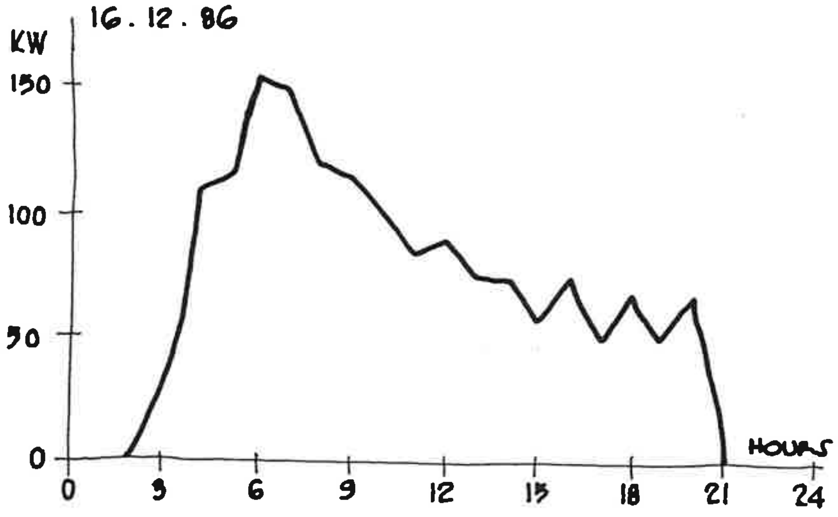


FIGURE 5 :- GAS SUPPLY FOR SPACE HEATING (S.S.W.C.)

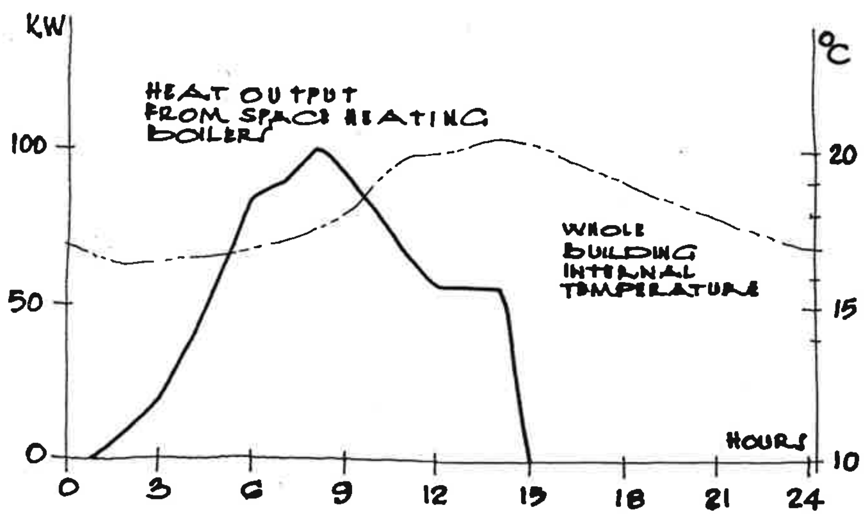


FIGURE 6 :- AVERAGE HEATING SEASON (81-82) HEAT & INTERNAL TEMPERATURE (WALMLEY)

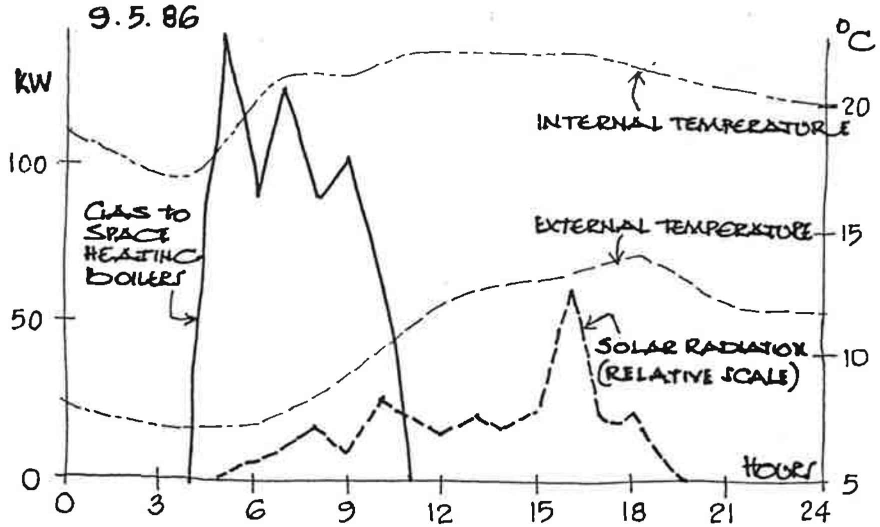


FIGURE 7: B GAS TEMPERATURE & SOLAR GAIN PROFILES (JEL)