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AUTHOR	Milbank, N. O.
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ABSTRACT

Two similarly large buildings and air conditioning systems are comparatively analyzed as to energy consumption, costs, and inefficiency during certain measured periods of time. Building design and velocity systems are compared to heating, cooling, lighting and distribution capabilities. Energy requirements for pumps, fans and lighting are found to be the major contributors to operating costs. This analysis suggests a method of obtaining reliable estimates of energy consumption and costs so architects and clients may become aware of the implications of their environmental control and design decisions. Charts and graphs are used to analyze the problem; a reference list is supplied. (TG)

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Energy consumption and cost in two large air-conditioned buildings

N O Milbank

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AN INVESTIGATION OF ENERGY CONSUMPTION AND COST IN LARGE AIR-CONDITIONED BUILDINGS - AN INTERIM REPORT

N.O. Milbank, MSc, Grad I Mech E

Paper presented at the IHVE/BRS Symposium 'Thermal environment in modern buildings - aspects affecting the design team', February 29, 1968

The Building Research Station is investigating annual energy consumption in several air-conditioned buildings, and in this first paper on the work in progress, results of measurements are analysed for two office buildings, one with a traditional low-velocity system, and the other with a high-velocity induction system. These results show the relative importance of lighting, fans, pumps, refrigerators and boilers, and energy balances are drawn for periods of half an hour and 12 hours, and also for weekly intervals over one year. The cost of energy is considered under the groupings heating, cooling, distribution and lighting, and it is seen that, of these, lighting is the most important.

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BUILDING RESEARCH STATION
Ministry of Public Building and Works

AN INVESTIGATION OF ENERGY CONSUMPTION AND COST IN LARGE AIR-CONDITIONED BUILDINGS - AN INTERIM REPORT

N.O. Milbank

INTRODUCTION

Interest in energy consumption stems from the desire to make better assessments of the costs-in-use for new building developments. Whereas in non-conditioned buildings the cost of fuel for heating may be quite small, in air-conditioned buildings the additional power needed to operate pumps, fans and refrigeration increases electricity consumption, and consequently increases the operating costs to be set against the provision of a more controlled thermal environment.

The current research programme at the Building Research Station includes a study of the services in air-conditioned office buildings and how they are controlled by the design of the building, its usage and the environment provided. Effort at present is concentrated on the use of energy and the cost of maintenance, whether by contract or direct-labour. The present paper forms an interim report on this work, providing information on the quantity and cost of energy consumption in two office buildings for a period of twelve months. Energy balances are presented which show how the use of oil and electricity is related to the design and use of the buildings and the prevailing weather conditions. The cost of energy is shown to have four significant parts, that for heating, cooling, distribution and lighting. For each of these, a further division is made to show the proportion of cost which arises from energy used and that which is determined by the capacity of the plant (i.e. maximum demand and connected load charges), a breakdown which is useful when considering the savings which may be possible by changes in design.

Work is continuing in four other buildings with different architectural forms and air-conditioning systems, whilst improved methods of analysis are also being introduced drawing on the work reported by Loudon elsewhere in the symposium (1). It is expected ultimately to provide information in a form suitable for use in the early design stages of new buildings.

The buildings and their environment

The two buildings, which are in normal commercial use, differ considerably in shape and methods of lighting and air conditioning, but have similar thermal response characteristics to energy input, as each is fitted with internal venetian blinds, demountable office partitioning and a suspended ceiling. The principal features of the two buildings are given in Table 1 whilst Table 2 contains details of the major items of plant which concern this report. Since the principles and methods of air conditioning are already well formulated (2, 3, 4) this paper only contains a brief description of the air-conditioning systems used, which are conventional for their type.

Building A consists of tower and podium with overall height 225 ft (68 m) and a façade which is predominantly glass. It was designed in 1957 and has a system which provides convector heating to meet fabric losses whilst the energy gains from occupants, lighting, office power and the sun are dealt with in a conventional manner on the air side. The separate zones for convector heating and air systems do not cover the same areas and are not strictly according to aspect. The control system is designed to schedule room temperature with outside air temperature; the internal design temperature is 69°F (20.5°C) but this is allowed to rise whenever the outside air exceeds this value: for every 3 deg F (1.7 deg C) rise in outside temperature the temperature in the podium should rise by 1 deg F (0.6 deg C) and in the tower by 2 deg F (1.1 deg C). In practice temperatures are 2-3 deg F (1-1.5 deg C) above the design values. Measurements show that temperatures in the podium are quite stable with temperature swings of ± 2 deg F (± 1.1 deg C) in the course of the working week; in the tower swings of ± 5 deg F (± 2.8 deg C) have been found.

Building B is a 3-storey structure, rectangular in form, with two light wells. The air-conditioning system is of the two-pipe, change-over induction type, zoned according to aspect with the faces of the light wells allocated to the appropriate zones. The design internal temperature is 70°F (21.1°C) unless the outside temperature exceeds 80°F (26.7°C), when a differential of 10 deg F (5.6 deg C) is provided. In practice, for normal working hours, mean temperatures of about 72°F (22.2°C) with swings of about ± 3 deg F (± 1.7 deg C) have been recorded.

Major differences between the buildings are low pressure and high pressure air distribution, reciprocating and centrifugal refrigeration, tungsten and fluorescent lighting and high rise and low rise lifts.

TABLE 1

Description of buildings

	A				B			
No. of floors	19				3			
Floor areas - ft^2								
Total floor area (excluding garage space and plant rooms)	169 607				118 408			
Stairs	6 645				1 871			
Lifts	7 933				850			
Cloakrooms and toilets	5 502				8 404			
Corridors	18 329				14 347			
Service ducts	5 999				2 800			
Plant room area	23 380				9 400 (excludes cooling tower)			
Conditioned area (offices, corridors and toilets)	149 030				112 887			
Vertical glazed areas - ft^2								
Orientation facing	30° N of E	30° E of S	30° S of W	30° W of N	NE	SE	SW	NW
Area of single glazing with internal white venetian blind	9229	6499	8819	6045	6092	7745	6733	9596
Area of double glazing with venetian blind between glass	6361	4987	3932	2122	-	-	-	-
Total glazed area	Single 30 592 Double 17 402				Single 30 976			
Average number of occupants	250				250			
Fresh air ventilation rate - c.f.m.	measured: 46 500				60 300			
Fabric loss - Btu/h deg F	56 061				49 260			
Ventilation loss - Btu/h deg F	50 196				66 204			

NOTE: The following conversion values may be used to derive SI units:

$$1 \text{ ft}^2 = 9.29 \times 10^{-2} \text{ m}^2$$

$$1 \text{ c.f.m.} = 4.72 \times 10^{-4} \text{ m}^3/\text{s}$$

$$1 \text{ Btu/h deg F} = 5.25 \times 10^{-1} \text{ W/deg C.}$$

TABLE 2

Installed plant capacity

<table>
<tr><th></th><th colspan="2">A</th><th colspan="2">B</th></tr>
<tr><td>Type of air-conditioning</td><td colspan="2">Low velocity air, and convector heating</td><td colspan="2">High velocity, two-pipe changeover induction</td></tr>
<tr><td>Boilers</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Fuel (Viscosity - Redwood 1 at 100°F)</td><td colspan="2">Oil - 960 sec.</td><td colspan="2">Oil - 960 sec.</td></tr>
<tr><td>Rated output - Btu/h</td><td colspan="2">13.25×10^6</td><td colspan="2">12×10^6</td></tr>
<tr><td>Refrigeration</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Type</td><td colspan="2">Reciprocating</td><td colspan="2">Centrifugal</td></tr>
<tr><td>Working fluid</td><td colspan="2">Refrigerant 22</td><td colspan="2">Refrigerant 11</td></tr>
<tr><td>Capacity - tons R.</td><td colspan="2">320</td><td colspan="2">360</td></tr>
<tr><td>Shaft horse power</td><td colspan="2">350</td><td colspan="2">287</td></tr>
<tr><td>Air handling plant</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Total supply rate - c.f.m.</td><td>15 1500</td><td>90 000</td><td>45 257</td><td>16 043</td></tr>
<tr><td>Overall pressure difference - in w.g.</td><td>2.5</td><td>2.0</td><td>7.7</td><td></td></tr>
<tr><td>Normal hours operation per week</td><td colspan="2">66</td><td colspan="2">60</td></tr>
<tr><td>Artificial lighting</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Type</td><td colspan="2">Tungsten</td><td colspan="2">Fluorescent</td></tr>
<tr><td>Approx. number of fittings</td><td colspan="2">3540</td><td colspan="2">4059</td></tr>
<tr><td>Installed load - watts</td><td colspan="2">493 700</td><td colspan="2">303 360 (includes ballasts)</td></tr>
<tr><td>Av. illumination - lum/ft^2</td><td colspan="2">17</td><td colspan="2">53</td></tr>
</table>

NOTE: The following conversion values may be used to derive SI units:

1 Btu/h = 2.931×10^{-1} W

1 ton R. = 3.516×10^{3} W

1 h.p. = 7.457×10^{2} W

1 c.f.m. = 4.72×10^{-4} m^3/s

1 in.w.g. = 2.492×10^{2} N/m^2

1 lum/ft^2 = 1.076×10^{1} lx

Instrumentation and measurement

Electricity sub-meters were fitted to measure the individual consumption of electricity on lighting, refrigeration, lifts, pumps, cooling towers, and air handling plant. Oil meters were already installed. In building A only, water meters were added to monitor water supplies for domestic hot water and the cooling towers. Log sheets were provided for the resident maintenance staff to take readings of all these meters at weekly intervals.

Detailed performance tests were made for several 12-hour periods at different times of the year. Organisation of these studies required that the day for the test should be selected a fortnight in advance and so, apart from season, there was no choice of prevailing weather. The tests established the flow of energy through the building and plant for $\frac{1}{2}$-hour periods. Each element of energy flow was obtained either by direct measurement, as for oil consumption and electrical power, or otherwise as the product of the appropriate temperature difference and a flow parameter. The derivation of the fluid and heat flow parameters varied: surface areas and 'U' values were taken from information supplied by the architects: water flows were established from characteristics supplied by the pump manufacturers and on-site measurement of pump head and speed. Air flow rates were obtained from fan characteristics and checked by Pitot traverses across the appropriate duct sections.

The use of venetian blinds was noted for each test period and a count was made of the people entering and leaving in the course of one day. The resultant occupancy values were taken as typical for the year, but, as is shown later, energy release from occupants has only a slight effect on the energy balance for the buildings.

Hourly values of dry-bulb temperature, total and diffuse solar radiation, and 3-hourly readings of wet-bulb temperature were provided by the Meteorological Office. Although building A was 1 mile (1.6 km) from the weather site and B was 16 miles (25 km), occasional checks over 12 hours showed no significant variation in weather between the three positions.

Method of analysis

At this stage of the work only simple theoretical models have been used to calculate fabric and ventilation losses and solar gains. Whilst this introduces limitations it does give a check that the measurements are self-consistent and that energy balances are of the correct magnitude. The major restriction is that no allowance is made for internal temperature swing; whilst this is most important for winter and summer design days, these do not occur very often in the British Isles and for energy consumption more importance is attached to average days when swings are less marked. A digital computer program is in preparation which includes a more sophisticated theory to allow for these effects.

For the $\frac{1}{2}$-hour and 12-hour balances discussed later, fabric and ventilation losses are based on measured room temperatures. The average values derived from these short-period tests have been used for the analysis of weekly results. Solar gains have been calculated from the data given for buildings of lightweight construction in the IHVE Guide (5) and the Carrier 'Handbook of Air Conditioning System Design' (6). These sources make some allowance for the fact that at any particular instant energy may be entering or leaving the structural mass of the building and as a consequence the instantaneous cooling load does not equal the instantaneous solar gain. To allow for the annual variation of sun position the design data are given for 12 days, usually 21st day of each month, and these monthly values have been applied to the fortnightly periods, both prior to, and following the reference day. Since the data relate to design days rather than real weather conditions, scaling has been applied in the following way. For any given time in the design day the proportion of solar gain from direct and diffuse radiation can be determined by inspection. These values have been scaled by the ratio of actual direct to design direct radiation and actual diffuse radiation respectively. In the calculations it is assumed that the venetian blinds are lowered only on the faces of the building exposed to direct sunshine.

Shadows cast from surrounding buildings also vary with time of day and year and calculations of solar gain by direct radiation must allow for this effect. Stereographic photographs similar to that shown in Figure 1 were taken at the corners and the centre of each face of the buildings. The overlay showing sun positions indicates when each point can be shaded, and in this way the degree of shading is established for 5 points on each face. This gives an estimate of the proportion of glazing exposed to full sunshine at each hour of the day.

Results and discussion

The analysis of energy gains and losses has been made in three stages. Half-hour balances have been used to study the interaction of building and plant, and also to establish the validity of the theory used for analysis.

Consecutive half-hour results have been brought together for 12 hour periods, which is the usual daily plant operating time. The same method has then been applied to the weekly results for a complete year.

(1) The half-hour energy balance

It has already been noted that detailed measurements of energy flow were made at different times of the year. These measurements lead to the preparation of energy flow diagrams for half-hour periods and, as an example, Figs.2(a)(b) and (c) illustrate an energy balance for building B. This particular figure covers the period 10.30-11.00 am on a dull July day and is a good example of plant performance in such conditions.

The left hand column of Fig. 2(a) shows all the energy imputs to the conditioned area, including air heating to the perimeter zones, water pump and fan energies, artificial lighting and power and solar and occupancy heat gains. Energy losses from the same area relate to cooling air to the internal zones, chilled water to the perimeter induction units and fabric losses. The two columns are not equal and, apart from inaccuracies in measurement, the difference probably arises from the treatment of lighting energy for which (unlike solar gain) no allowance has been made for storage in the building structure. The diagram applies to the total conditioned area: individual zones have not been considered because the subdivision of lighting power, which forms one-third of the energy input, does not follow that of the air conditioning.

The air handling plant in this building is basically a zoned reheat system and Fig. 2(b) shows the flows of energy in the conditioning process. Starting from the left of the diagram, outside air, which is below room temperature, is cooled by the chilled water in the air cooler battery and then divided into five streams, one passing directly to the internal areas and the other four to the individual reheat batteries on each perimeter zone.

For purposes of illustration the four perimeter zones have been grouped together. Hot water from the boilers is supplied to each zone air heater battery to make up the ventilation loss and the subsequent cooling in the air cooler battery, also to heat the perimeter air above room temperature and so make up the fabric loss.

If Fig. 2(b) is reversed it can be combined with Fig. 2(a) and the addition of balances for the boiler and refrigeration plant then gives the total balance for the plant and building as shown in Fig. 2(c). Each column is a rearrangement of the preceding column and illustrates the flow of energy from left to right. If all the measurements were correct and the analytical method perfect, then each column would be the same height. In fact this does not happen and the sloping dotted lines between columns indicate mismatches. The mismatch for the conditioned area has already been mentioned, whilst the other, on the refrigeration plant, is associated with the estimate of condenser water flow rate. As already noted, water flows are calculated from the pump characteristics and measurements of pump head and speed. In this particular case the measured head exceeded that given on the pump characteristic, so the original design flow of 900 gal/min. (6.8×10^{-2} m^3/s) was used in the calculations. Subsequent energy balances all show this value to be about 10% high.

This type of diagram is invaluable for assessing the accuracy of measurements and calculations since it gives checks from the columns on both sides of the measurement under examination. The visual presentation clearly demonstrates the relative importance of individual items of plant and the influence of the control system and in this context it is worth examining the balance for the conditioned area in more detail. Figure 2(a) shows air heating in the gains column and water cooling amongst the losses and implies that the boiler and refrigerator are in opposition. Because the illustration deals with all zones, some of which are predominantly heating and others which are cooling, it over-emphasises the situation, but even so there is a considerable overlap of heating and cooling within each zone. This is inevitable in this type of installation where the fabric losses are met either by warm air or warm water which is under separate control from the cooling system.

Perhaps of more significance is the philosophy of varying the air temperature on the intermediate cycle of an induction system. When outside air temperatures are about 70°F (21.1°C), this gives better control than a system of varying water temperature but since in any case the air supply is cooled to give humidity control it is inefficient not to use the cold air for cooling the conditioned space. Reheating the air and supplying chilled water to the induction units is equivalent to supplying boiler heat straight to the refrigeration machine. This point is emphasised in Fig. 2(c) where the proportion of energy flow in the conditioned space is only two-thirds of the total energy flow.

It is fair to say that such inefficiencies cannot be avoided in either building, for in A the zoning of air and water is entirely different and in B the perimeter zones include the façades of the light wells. The shading patterns for this area are such that in cold sunny weather the shaded regions of a zone may still need heating to meet fabric losses whilst the remainder need cooling because of solar gain. When the siting and design of a building eliminate shadow patterns within the zones, energy can be saved by reducing boiler heat input to allow for solar gain and electrical power-consumption. For example, a detailed analysis suggests that for one week in July oil consumption could have been halved and total electricity consumption reduced by 10%. On a year round basis a cost saving of about £900 for building A and £750 for B might be possible. Whether this saving is sufficient incentive for more complex controls is another matter.

(2) 12 hour balances

The energy exchanges in $\frac{1}{2}$-hour periods can be brought together to show the pattern for the day. The three parts of Figure 3 show the variations in energy flow in building A on a cold but sunny day in March. Figure 3(a) contains the measured inputs of energy and, with the exception of solar gain, the values remain sensibly constant through the day. It is worth noting that the lights and office power provide one-quarter of the total energy input. The ventilation and fabric losses shown in Fig. 3(b) decrease with the rise in outside air temperature. The step change in ventilation loss at 16.00 hours is caused by changing to 100% fresh air supply (instead of the normal 15%), a change stemming from the need to shut down the refrigeration plant for maintenance purposes.

In Fig. 3(c) the losses and gains are compared with the building air temperature. In the morning the rise in temperature is associated with the excess energy input whilst for the rest of the day temperatures are fairly stable, and this is reflected in the closer balance between the total gains and losses.

(3) The balance for 12 months

The results already presented gave sufficient encouragement to extend the calculations to cover weekly periods. For this purpose ventilation and fabric losses have been based on degree-days relative to room temperature and, because the refrigeration plant is not used in either building at weekends, solar gains are for the days Monday to Friday only. The weekly readings of electricity and oil consumption have been used with the values of boiler efficiency and refrigerator performance obtained on the short-term tests to give the equivalent gains and losses for the installation.

The calculated energy losses for building B are shown in Fig. 4(a) and the corresponding gains are presented in Fig. 4(b). The electrical consumptions for lighting and small power are of the same order as those for pumps and fans and, although there is a slight reduction in summer, electricity is the source of nearly one-half of the total energy flow. Solar gains are not very important in this balance, which is concerned with average weather, but of course they are very significant during the peak hours of design days. The heat output from the boilers dominates the picture since it provides the other half of the total energy usage.

For convenience the total losses are superimposed on Figure 4(b) and it will be seen that an acceptable balance is obtained for most weeks. The largest error occurs in the middle of April. This is thought to arise from a misreading of oil consumption which appears to be 1000 gal. (4.5 m^3) too low when compared with values for other periods with a similar outside air temperature.

Crude comparisons in both buildings show that the boiler energy output approximates to the fabric losses, whilst solar and electrical gains in the conditioned space are together approximately constant week by week, and are balanced by the ventilation loss and the chilled water supply. This comparison is not valid for short periods of analysis and is unlikely to apply to buildings in which ventilation and artificial lighting loads differ from these two examples. It is worth noting that in building B the fresh air supply is sufficient to meet the cooling needs in the winter season, but in A it is necessary to use the refrigeration plant to maintain conditions in all but the very coldest weather.

Annual quantities and cost of energy

Ultimately interest centres on the quantities of fuel and electricity which the user of the building must purchase. Table 3(a) sets out these measured consumptions for each section of plant and in Table 3(b) the cost of energy is given with a breakdown of the individual parts of the electricity tariff. Gas and water charges are included for comparison. Of the two the water charge is the larger and for both buildings this charge is based on rateable value of the property and not on water consumption.

(1) Fuel oil

It has already been shown that the heat output from the boilers is of the same order of magnitude as the building fabric losses and in Fig. 5 the weekly values of fabric loss are plotted against the total heat equivalent of the fuel consumed. When allowance is made for boiler efficiency the consumptions of oil correlate well. In both cases fuel costs are £2500 and represent about 10% of the total expenditure on energy.

(2) Electricity

In both buildings the greatest energy charge is that for electricity. Figure 6 is included to show the weekly variation in electrical consumption and maximum demand in building A. This maximum demand is taken from meters which are only reset at monthly intervals, so when the peak occurs early in the month the subsequent readings remain at the highest level until the meter is reset.

The pattern of lighting consumption is very similar in both buildings and analysis of the power consumption and installed load capacity show that the use of equivalent to 3500 hours/annum if office power consumption is neglected. As is seen in Figure 6, the power consumption on the lighting circuits cycles slightly, from peak usage in winter to a minimum in summer. This presumably results from variations in natural lighting intensity but, since such readings are not available, diffuse solar radiation has been taken as an index for comparison, and in Figure 7 weekly lighting power consumptions are plotted against the aggregate diffuse radiation onto the horizontal plane for Monday to Friday each week. Although this shows a general trend of reduced power consumption as the radiation increases, for practical purposes the results can be considered in two groups, the lower for summer and the upper for winter. The points linking the groups occur in spring and autumn and their scarcity shows that the change from summer to winter and back is quite rapid.

The figures in Table 3 stress the significant differences between tungsten and fluorescent lighting systems. Building A with tungsten fittings, used 11.6 kWh/ft^2 floor in comparison with B, with fluorescent fittings, consuming 9.6 kWh/ft^2 floor for the year (i.e. 450×10^6 J/m^2 compared with 370 J/m^2). Thus for 20% more power the average lighting of 17 lumens ft^2 (180 lx) in A was only one-third that measured in B (53 $lumens/ft^2$ or 570 lx).

Consumption of electricity on the refrigeration machine and the cooling tower is influenced by many features of the building and plant, including the window/floor area ratio, power for lighting, fans and pumps, ventilation rate and the method of control. It is rather surprising therefore to find that the quantities of cooling for the two buildings are similar; that for A is 3.1 ton $hours/ft^2$ (425×10^6 J/m^2) and for B the corresponding figure is 3.3 ton hours/ft^2 (450×10^6 J/m^2) for the 12-month period.

The analysis so far made shows that the two refrigeration machines do not have the same influence on maximum power demand (MD). In both cases figures for the winter period establish those MD levels to be attributed to lights, fans and pumps. The peak MD occurs in summer with the refrigeration at full load but at this time not all the lights will be in use, and figures for building A show that the summer MD increases by only 190 kW for a combined capacity of 305 kW on refrigerator and cooling tower. For building B the increase is 280 kW but the load of the cooling system is only 240 kW. It is unfortunate that in building B about 10% of the total power consumption is not directly associated with the air conditioned building and it may well be this portion which is raising the MD reading.

TABLE 3

a. Consumption of energy

12 month period Nov. 65 - Nov. 66

	Building	
	A	B
Fuel Oil Consumption gal	74 203	79 546
Heat output at stated efficiency - kW	2 838 000 (75%)	2 440 000 (60%)
Electricity kWh		
Boiler plant and water circulating pumps	136 445	418 180
Refrigeration machines	373 324	222 765
Cooling tower	156 338	35 116
Air handling plant	343 235	425 458
Lifts	97 821	9 734
Lights and office power	1 737 896	1 062 720
Total	2 845 059	2 280 916
Main meter readings kWh	2 864 206	2 522 070
Max. demand kW	840	830

b. Cost of energy

Fuel Oil	Quantity	71 940 gal	81 000 gal
	Charge	£2457	£2545
Electricity	Units	2 863 273 kWh	2 531 680 kWh
	Unit charge	£14 633	£10 143
	Maximum demand	840 kW	530 kW
	MD charge	£7975	£4713
	Connected load	-	1 000 kVA
	Connected load charge	-	£1375
	Total charge	£22 608	£16 231
Water		£2485	£1249
Gas		£433	£45

NOTE: The following conversion values may be used to derive SI units:

1 gal = 4.546×10^{-3} m^3
1 kWh = 3.6×10^6 J

(3) Electricity tariffs

It was fortuitous that the buildings are supplied by different Electricity Boards. In the event both buildings have similar MD readings but building B uses 12% less electricity with a 28% reduction in the bill. This is because the tariff structures and charges differ for the two areas and the plant in the two buildings is operated in different ways. For building A the tariff has three sections:

a) an MD charge assessed on the worst half-hour for the year;

b) a charge for units consumed;

c) a fuel cost adjustment for variations in the cost of fuel used to generate the electricity.

For B the tariff is in four parts:

a) a service charge based on transformer capacity;

b) an MD charge assessed for the worst half-hour in the hours 7-10 am, 4-7 pm, Monday to Friday, for the months of November to March inclusive;

c) a charge for units consumed, including reduced charges for night units;

d) a fuel cost adjustment.

The important difference between the tariffs is that for B there is no MD penalty for using refrigeration plant in the summer period. Since this building operates on a change-over system to use air cooling in winter, the use of refrigeration in the winter MD period has been avoided. In addition since there is a cheap night rate, the portion of lighting energy used in the evenings, when the offices are cleaned, is obtained at a lower rate. If it were possible to have such a tariff for building A, then the full benefit would only be obtained by increasing the supply of fresh air for cooling in winter so that refrigeration was no longer necessary at the critical times for MD levies.

The scope for economy

As a guide, the energy costs for the two buildings have been divided into four parts, the cost of providing heating and cooling, the cost of distributing this energy around the building (i. e. the energy for pumps and fans) and the cost of lighting. These values are presented in Table 4 in which the charges are subdivided to show the effect of quantity of energy as well as MD and connected load charges. It is quite clear that the charges for heating and cooling are the lesser parts of the bill and in the case of refrigeration the charge is strongly dependent on the tariff charges for maximum demand. Distribution costs are at least as important as those for heating and cooling and the cost penalty of the high-velocity air supply system in building B raises the charge to a similar level to that for lighting. It should be noted that in both buildings large areas of lighting are controlled from one switch; a comparison with individual room switching will be possible at a later date.

TABLE 4 Partitioned energy costs for the environment - £/ann.

	Building A				Building B			
	Heating	Cooling	Distribution	Lights	Heating	Cooling	Distribution	Lights
Unit charge	2550	2300	2850	8900	2500	1030	3400	4250
MD charge	-	2060	1220	4700	-	-	2130	2580
Connected load charge	-	-	-	-	-	450	460	560
TOTAL	2550	4360	4070	13600	2500	1480	5990	7390

Conclusion

The two systems of air conditioning examined in this paper operate inefficiently at certain periods of the year. This could be improved by installing a more sophisticated control system but the possible savings in energy and cost may not justify the change. Greater savings may be expected from an electricity tariff which assesses the maximum demand charges on the basis of winter use only. The energy requirements for pumps, fans and lighting make the major contribution to operating costs.

The results show that energy balances can be established for air-conditioned buildings of the type shown. Work in progress on additional buildings covers a double-duct system, a ventilating ceiling and a building fitted with external blinds. The analysis is expected to lead to a method of obtaining reliable estimates for energy consumption and cost so that the architect and the building owner may become more aware of the implications of their design decisions.

ACKNOWLEDGEMENTS

The author would like to thank his colleagues, Mr. A. Slater, Mr. J. Harrington-Lynn and Mr. J.P. Dowdall and also the architects, services consultants and contractors and, in particular, the owners and maintenance engineers of the buildings concerned, for their willing co-operation. Electricity submetering was provided by the Electricity Council.

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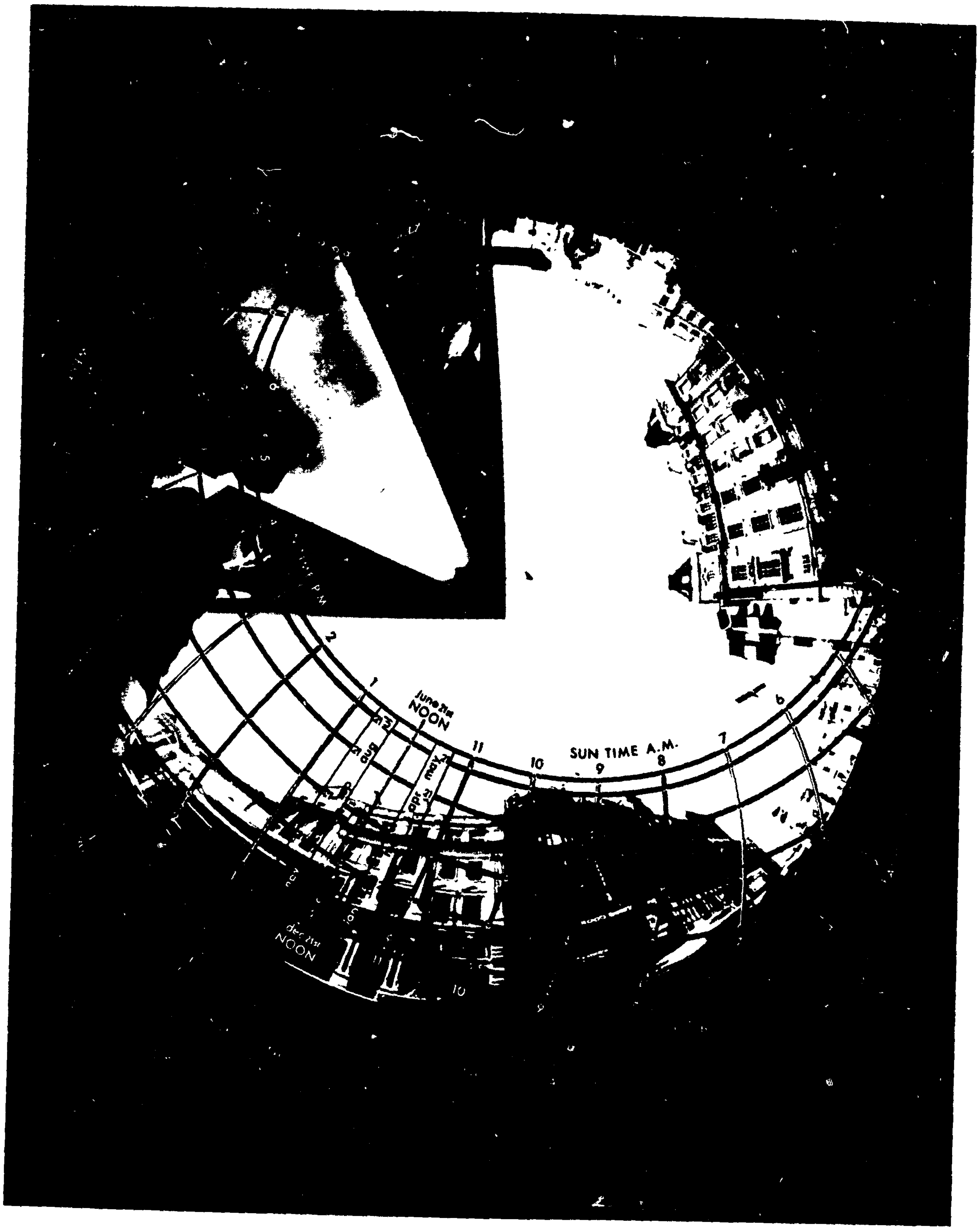

Fig. 1 The use of stereographic photographs and sunpath diagrams to establish the incidence of sunshine at the corner of a building.

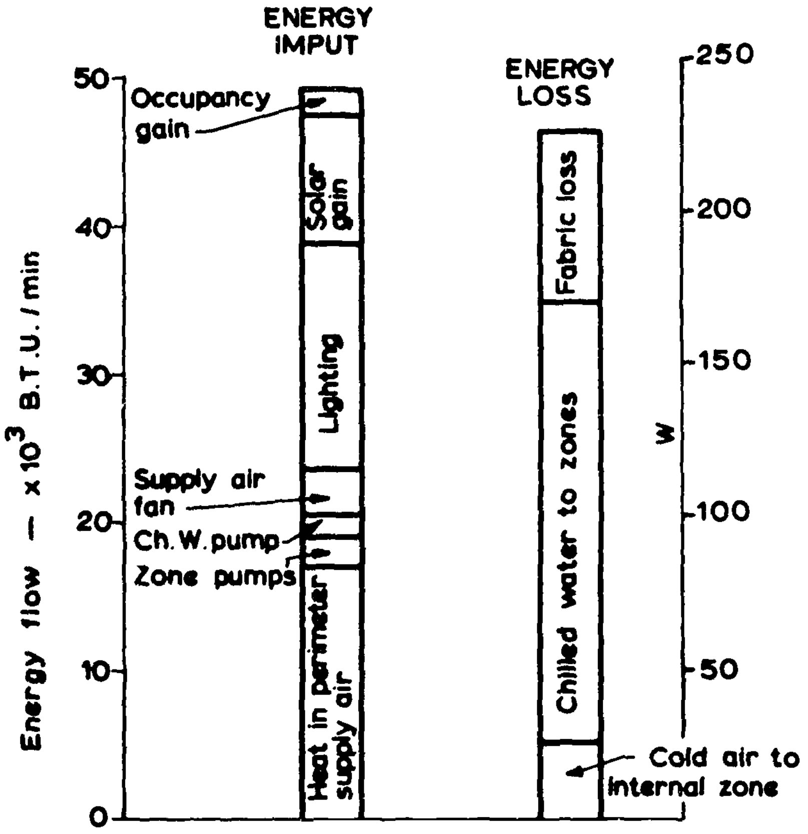

Fig.2a. Energy balance for the conditioned space.

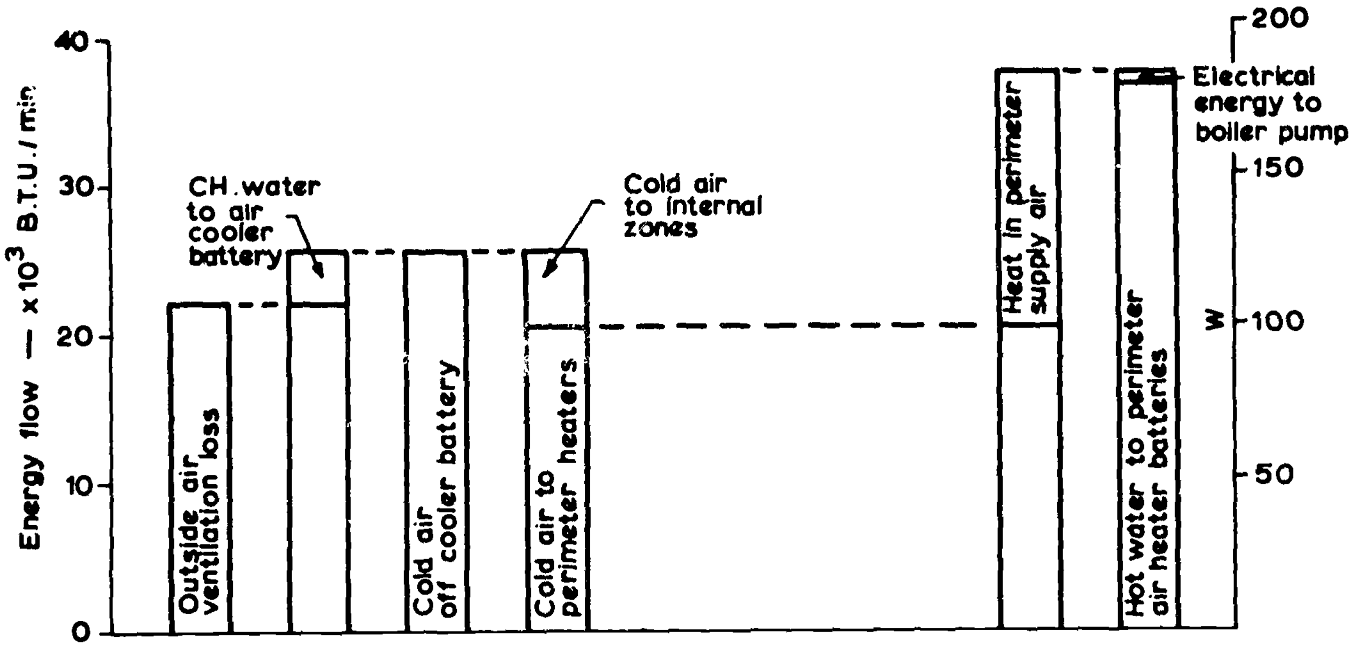

Fig.2b. Energy balance for the air handling plant.

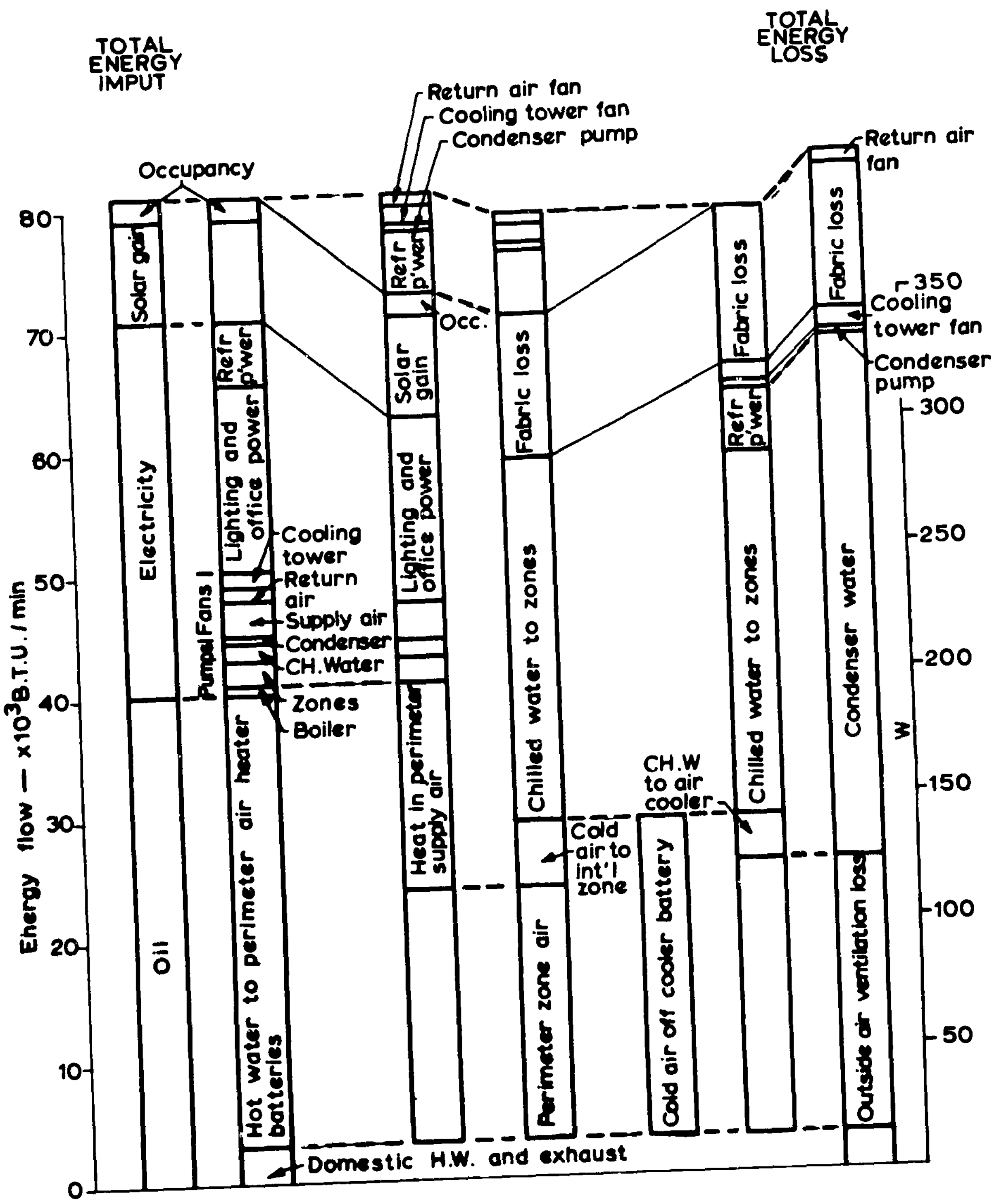

Fig. 2c. The complete energy balance for ½ period.
(Building B 10.30 - 11.00 a.m. 27.7.66)

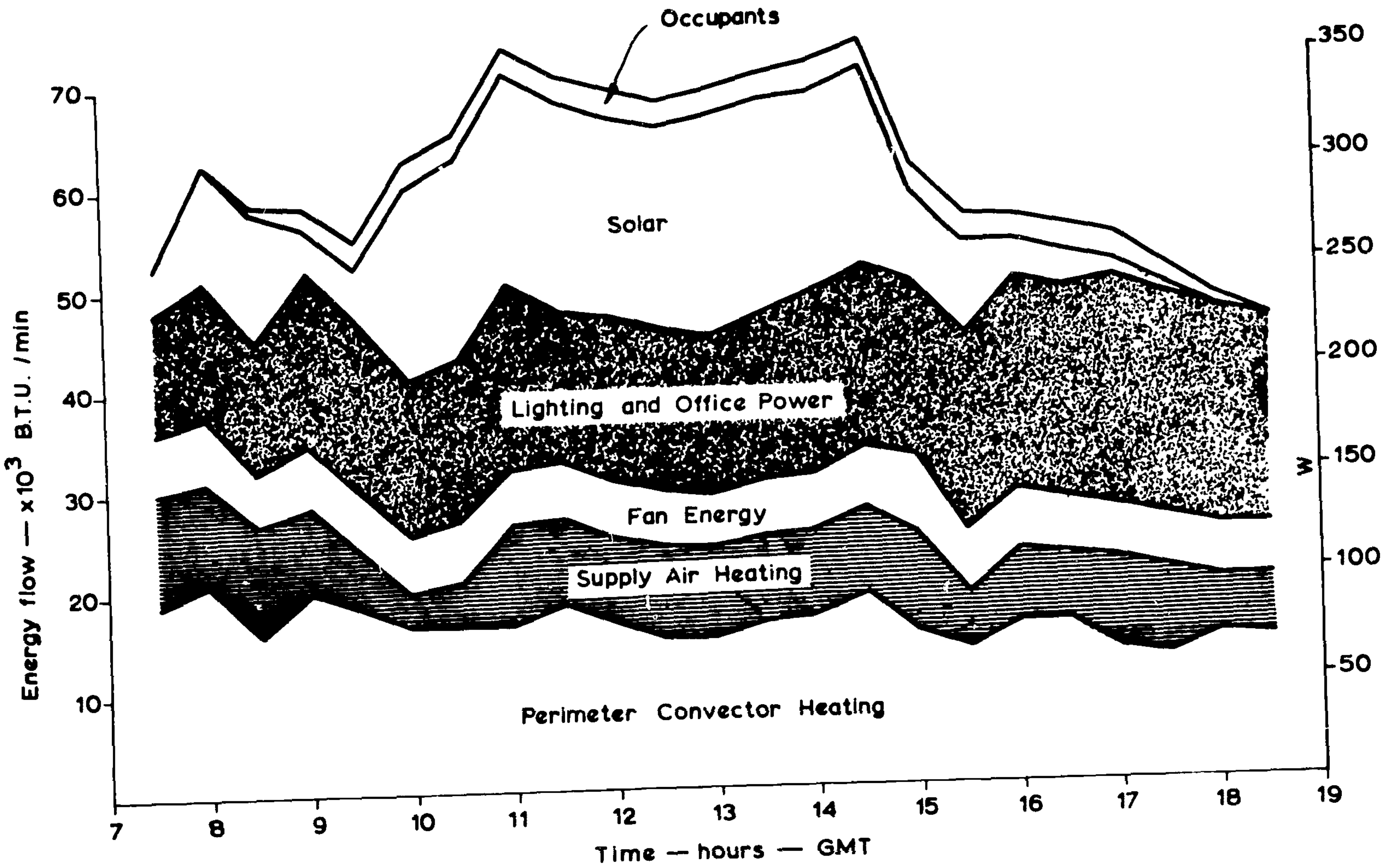

Fig. 3a. Cumulative energy gains to the conditioned space.

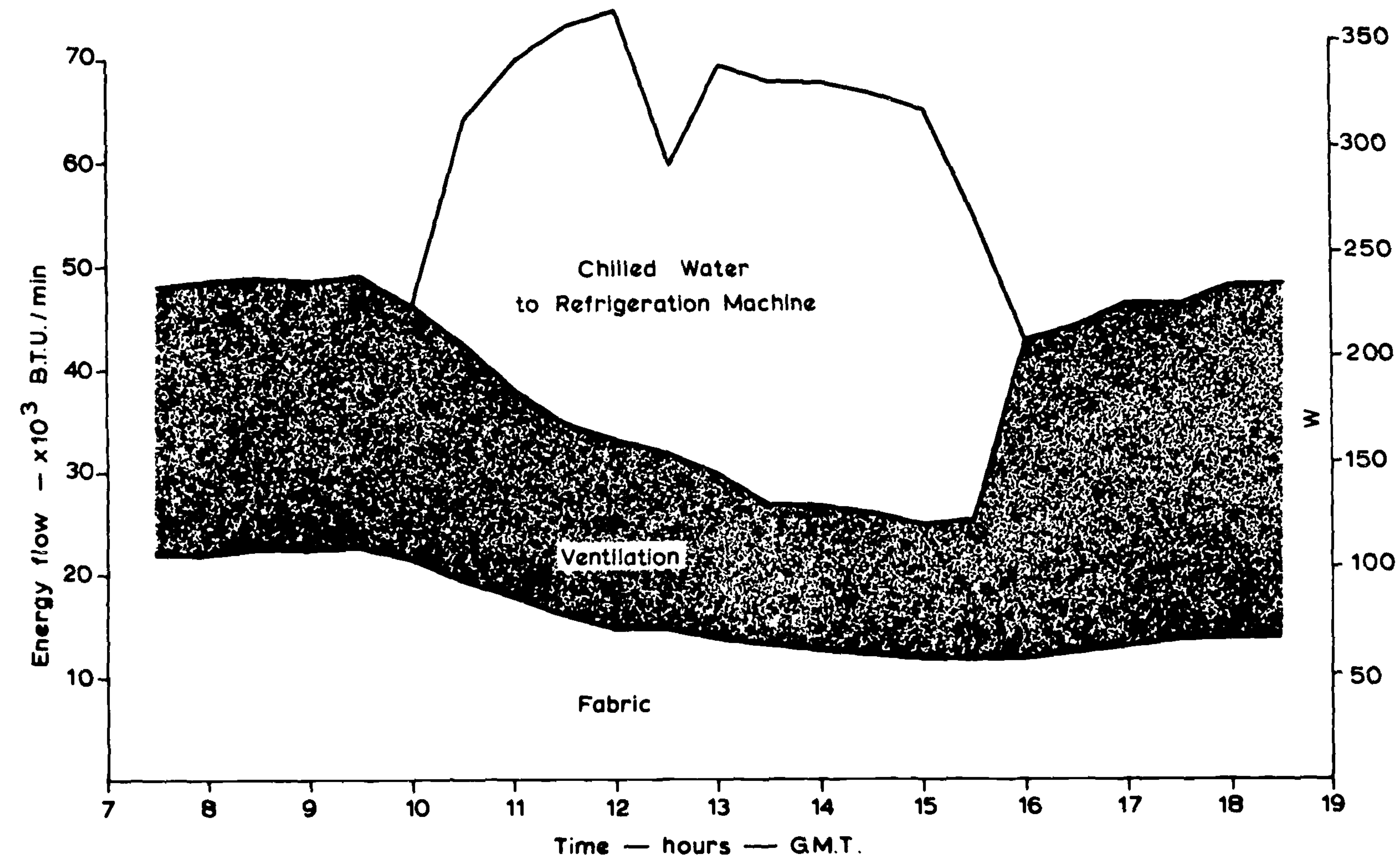

Fig. 3b. Cumulative energy losses from the conditioned space.

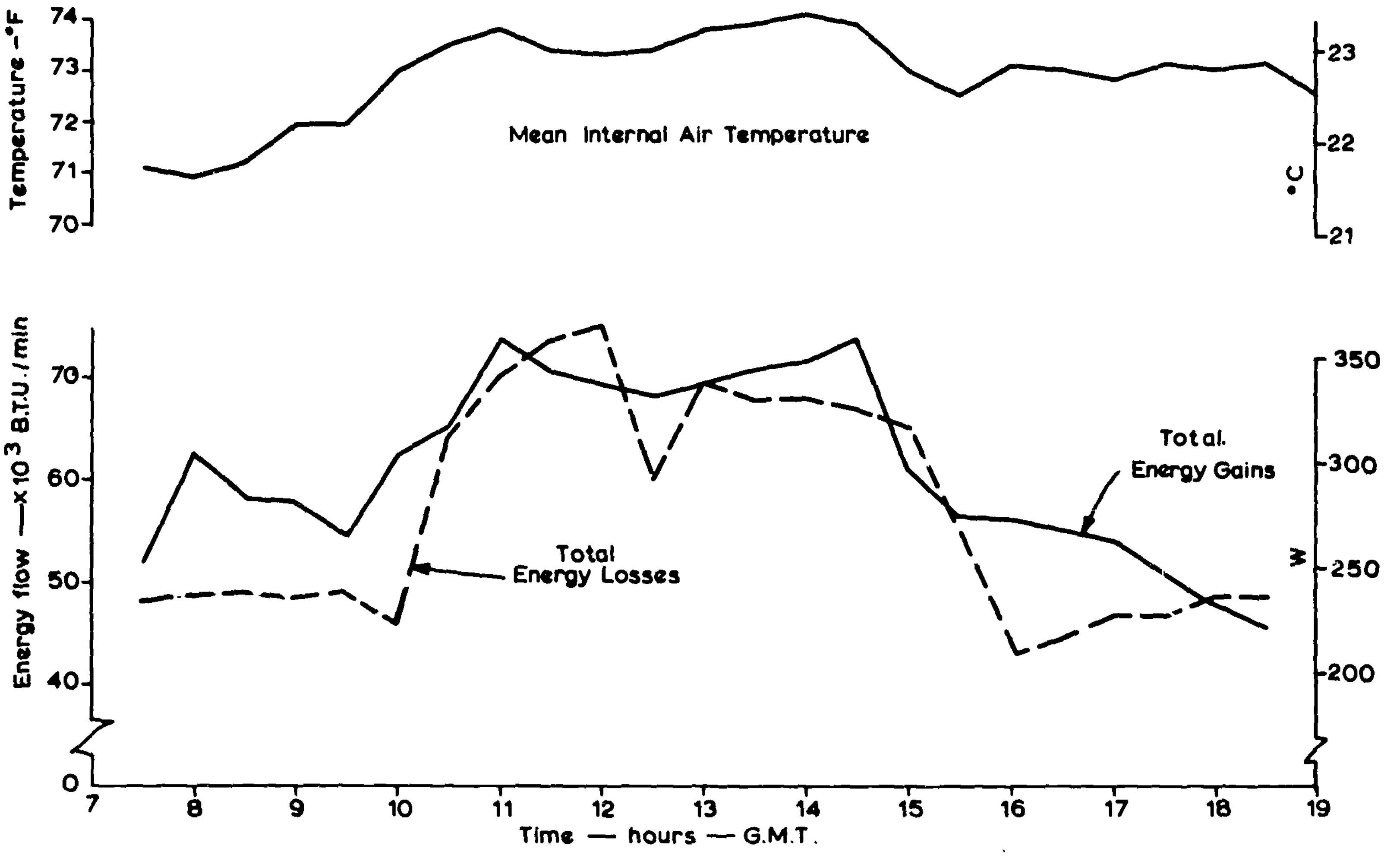

Fig. 3c. Comparison of total energy losses and gains with air temperature
for 12 hour period. (Building A - 8.3.66)

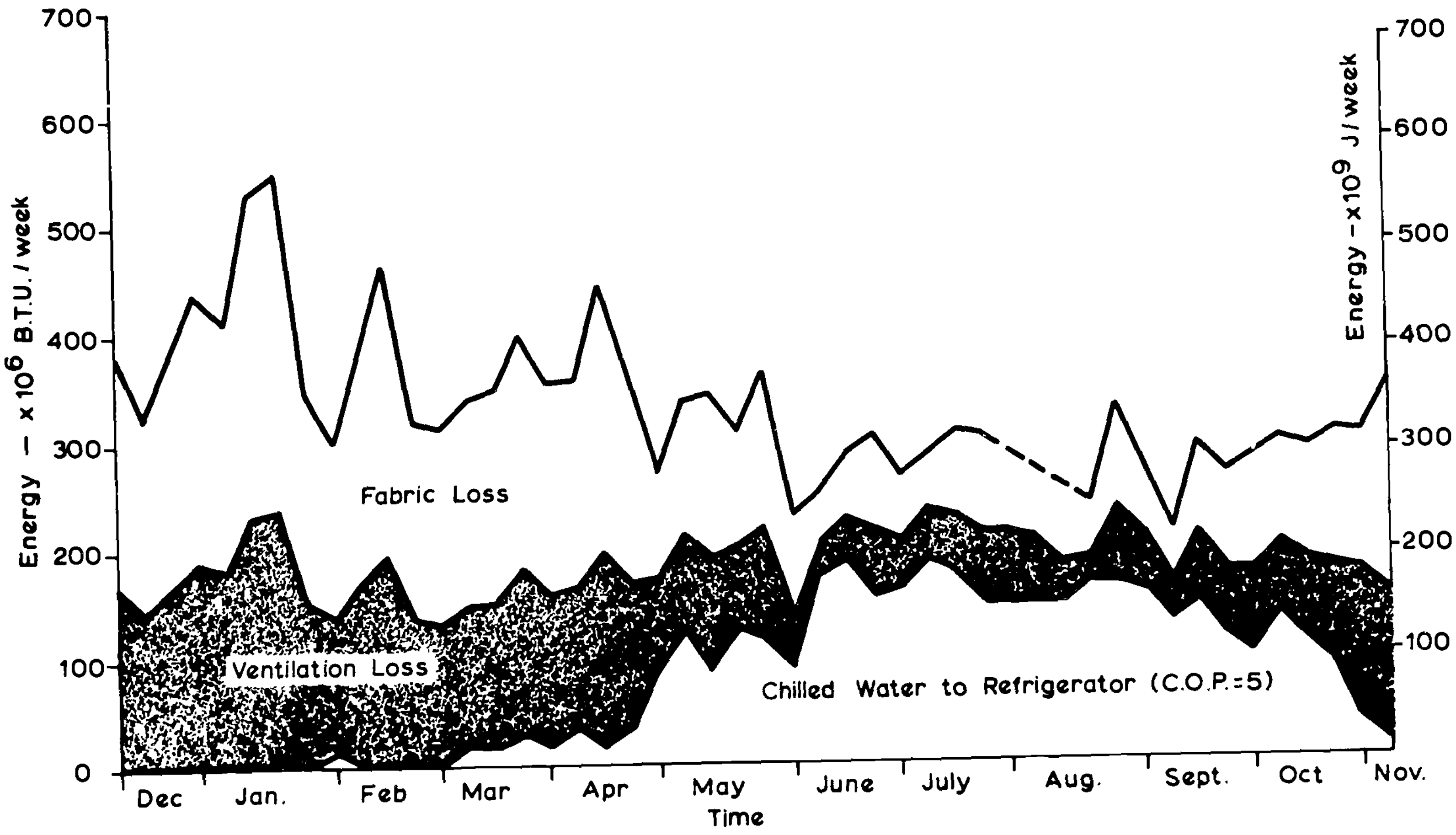

Fig. 4a. Cumulative energy losses for weekly periods. (Building B - 1965-66)

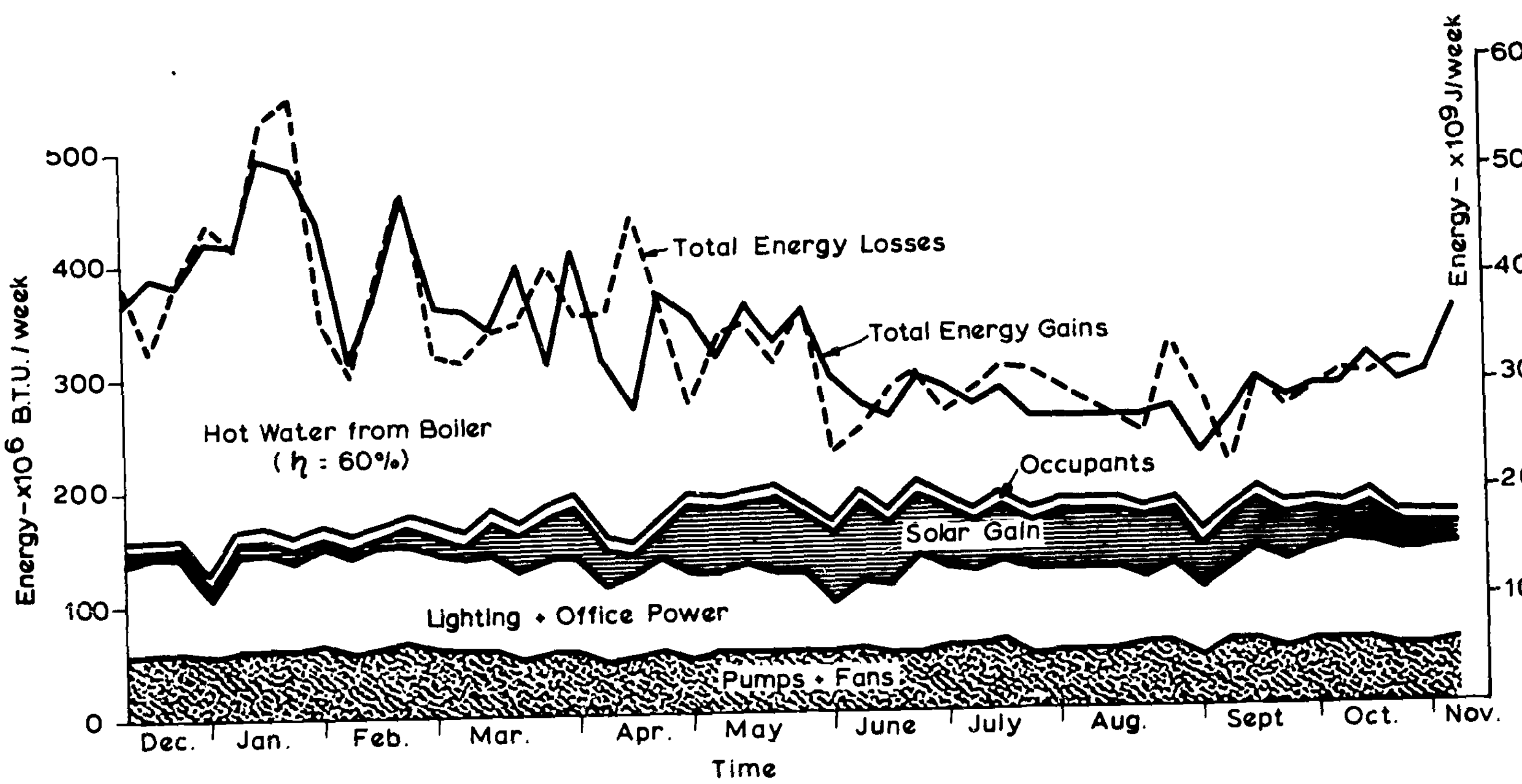

Fig. 4b. Cumulative energy gains with total losses superimposed for weekly intervals. (Building B - 1965-66)

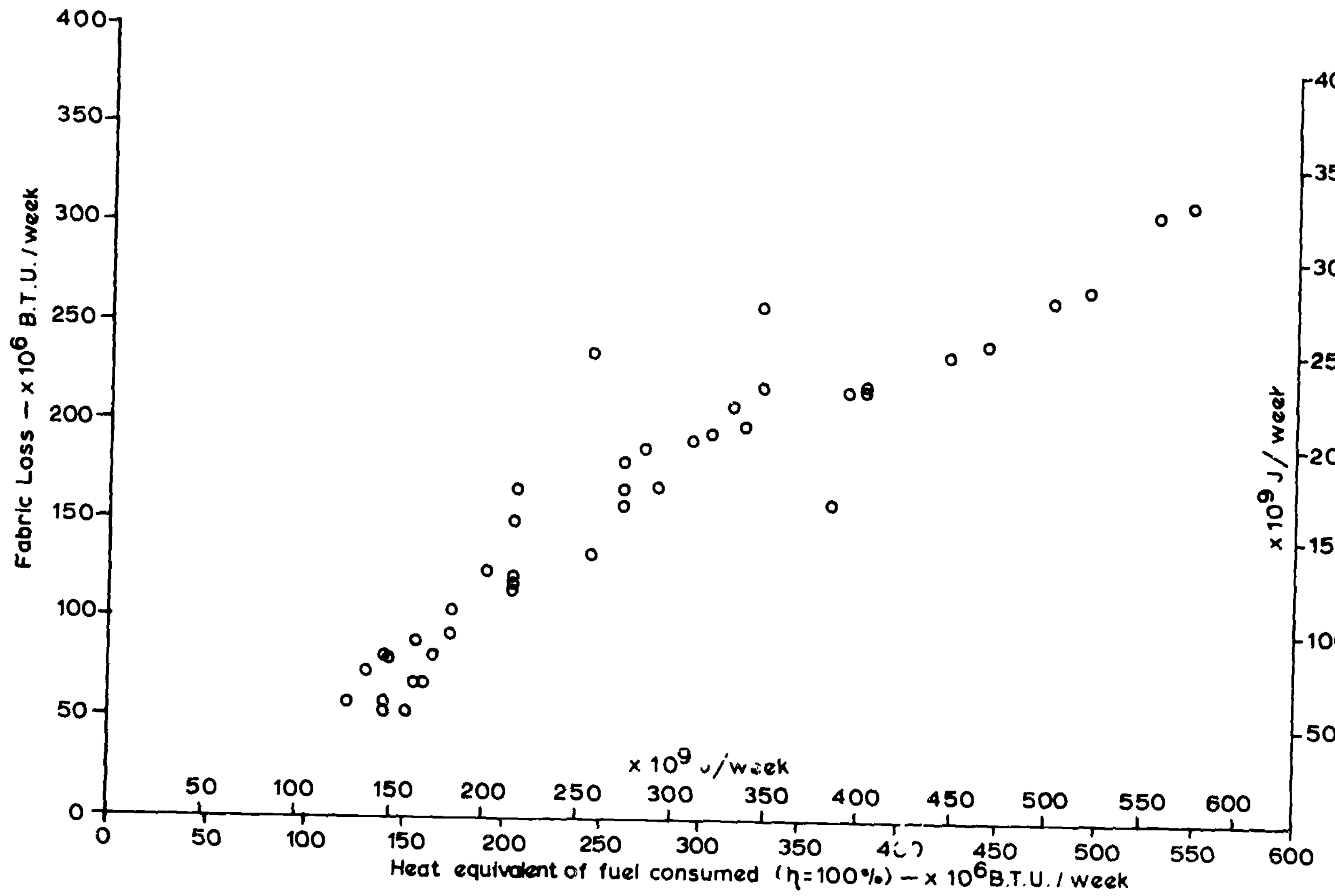

Fig. 5. Weekly values of fabric loss compared with oil fuel consumption. (Building B.)

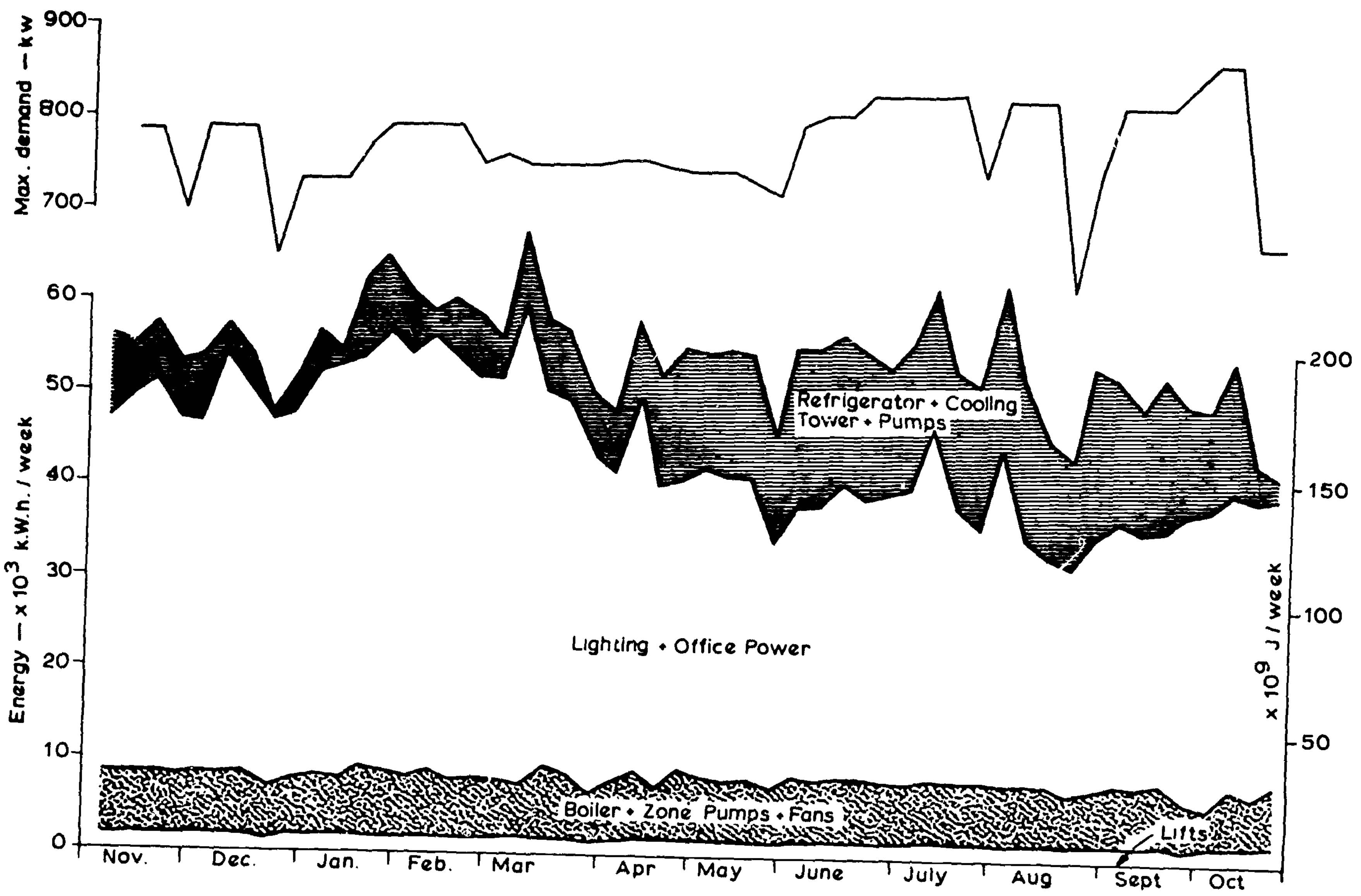

Fig. 6. Cumulative electrical power consumption and maximum demand. (Building A - 1965-66)

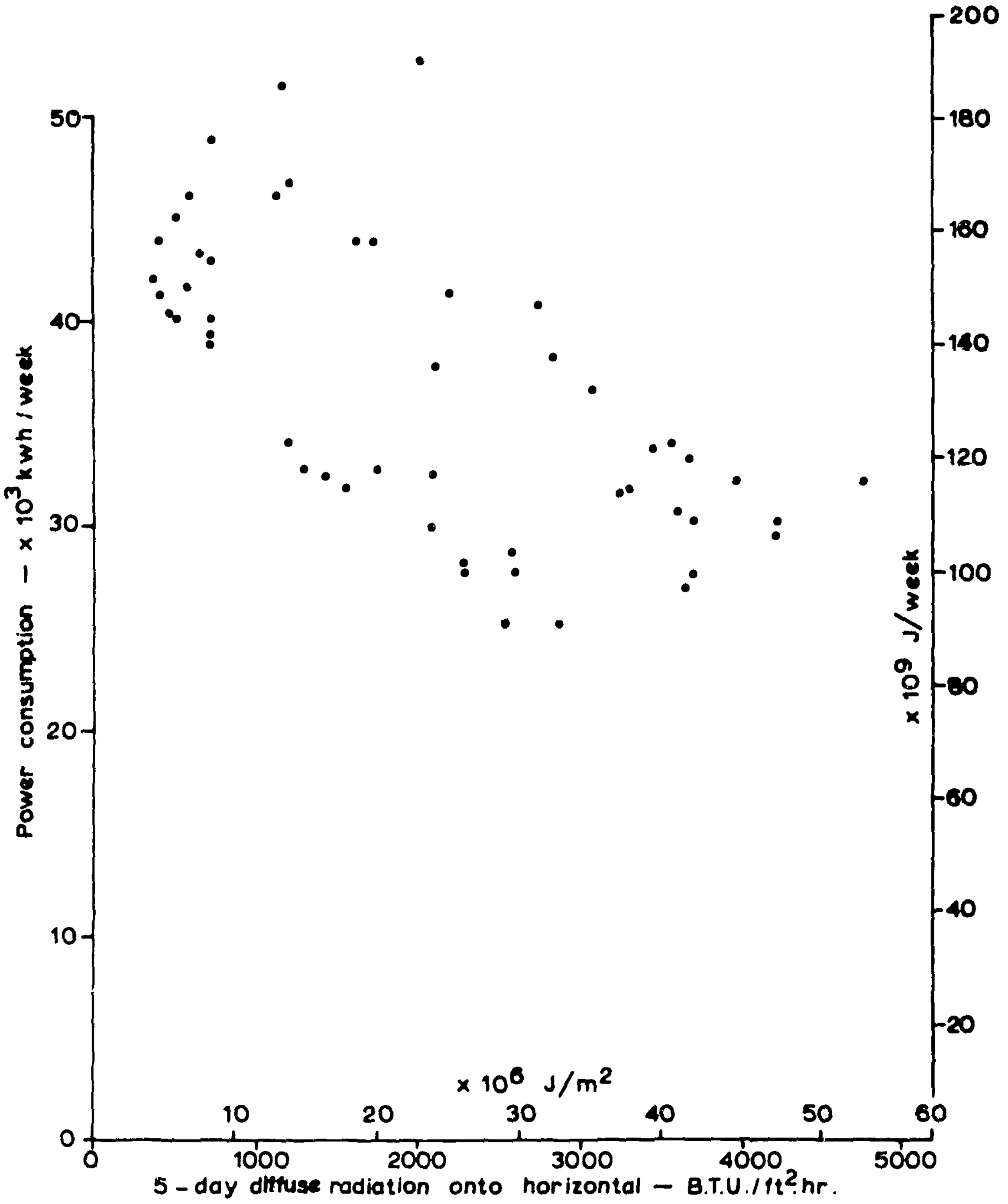

Fig. 7. The correlation between weekly lighting power and diffuse solar radiation onto the horizontal. (Diffuse radiation is summed for hourly intervals for Monday to Friday each week - Building A)

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