U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
PB-276 752

Designs for Low Energy Houses

Electricity Council Research Centre, Capenhurst (England)

Mar 76

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. ECRC/M-922	2.	3. Recipient's Accession No. PB-276 752

4. Title and Subtitle

Designs for Low Energy Houses.

5. Report Date

March 1976

6.

7. Author(s)

J. B. Siviour.

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

Electricity Council Research Centre
Capenhurst (England)

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.

(C)

(G)

12. Sponsoring Organization Name and Address

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

Space heating requirements have been calculated and compared for typical British family housing with insulation levels (a) meeting the 1975 Building Regulations and (b) U-values of 0.3 (W/(m squared)K) for the walls, roof and floor and 2.5 (W/(m squared)K) for windows. The contribution of free heat to space heating is estimated together with the possible contribution of a ventilation heat recovery system. Some designs and performance requirements of well insulated houses and heating equipment are discussed.

17. Document Analysis a. Descriptors

*Energy conservation
*Houses
*Residential buildings
Space heating
Heat loss
Thermal insulation
Ventilation
Energy requirements
Design
Great Britain

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group 13A, 10A

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
National Technical Information Service Springfield, VA 22161	unclassified	
	20. Security Class (This Page) unclassified	22. Price (PC A02/MF A01)

(See ANSI–Z39.18) *See Instructions on Reverse* OPTIONAL FORM 272 (4–77) (Formerly NTIS–35) Department of Commerce

NOTICE

THIS DOCUMENT HAS BEEN REPRODUCED FROM THE BEST COPY FURNISHED US BY THE SPONSORING AGENCY. ALTHOUGH IT IS RECOGNIZED THAT CERTAIN PORTIONS ARE ILLEGIBLE, IT IS BEING RELEASED IN THE INTEREST OF MAKING AVAILABLE AS MUCH INFORMATION AS POSSIBLE.

THE ELECTRICITY COUNCIL RESEARCH CENTRE ECRC/M922

DESIGNS FOR LOW ENERGY HOUSES

by

J. B. Siviour

This paper will be delivered at the CIB meeting at BRE Watford in April 1976

March, 1976.

CONTENTS

DESIGNS FOR LOW ENERGY HOUSES

DESSINS POUR MAISONS A BAS ENERGIE

J B SIVIOUR

SUMMARY

Space heating requirements have been calculated and compared for typical British family housing with insulation levels (a) meeting the 1975 Building Regulations and (b) U-values of 0.3 W/m^{2}K for the walls, roof and floor and 2.5 W/m^{2}K for windows. The contribution of free heat to space heating is estimated together with the possible contribution of a ventilation heat recovery system. Some designs and performance requirements of well insulated houses and heating equipment are given and discussed.

SOMMAIRE

Les besoins de chaleur de l'espace pour une habitation Brittanique typique avec des niveaux d'isolation (a) qui conviennent aux Régles de Batiment 1975 et (b) conductances thermiques de 0,3 W/m^{2}K pour les murs, plancher et toiture et 2.5 W/m^{2}K pour les fenêtres ont été calculés et comparés. La contribution du chaleur gratuite à l-enchauffement de l'espace est évaluée avec la contribution éventuelle d'une système de recoupment de chaleur du ventilation. Nous donnons et discutons des exigences de rendement des maisons bien isolés et de l'installation de chauffage.

1. INTRODUCTION

The use of insulation reduces the gross space heating requirements of houses. Free heat from such sources as lighting, cooking and solar radiation can provide a large proportion of the gross heating requirement in well insulated houses. An outline is given of design features to make maximum use of free heat for space heating. Ventilation control is discussed, and the possible contribution to space heating of ventilation heat recovery is estimated. It is shown that in a well insulated house normal sizing procedures would result in very oversized heating equipment.

2. HOUSE DESIGNS FOR REDUCING GROSS SPACE HEATING REQUIREMENTS

A semi-detached house of the size given in table 1 is used in this paper to illustrate some features of low energy housing. It represents typical 5 person, 3 bedroom houses, has a total floor area of 85m^2 and a combined kitchen/dining room. The semi-detached house was chosen based on the assumption that most new dwellings will be houses rather than flats, and that it will be more common than either terraced or detached houses. Although a square in plan for the pair of houses would have a shorter perimeter of external walling than the dimensions given, the saving would only be 1%. A cube would be an impractical shape for a semi-detached pair of houses because the height would be far greater than necessary.

Table 1 House Dimensions

Total floor area (2 floors)		85 m^2
Internal dimensions	depth	8 m
	width	5.31 m
	floor to ceiling height	2.3 m
Volume		200 m^3

Heat losses have been calculated for two levels of thermal insulation, one just meeting the 1975 Building Regulations, and two a proposed level of thermal transmittance values of 0.3 W/m^2K for the walls, roof and floor, and 2.5 W/m^2K for windows and glazed doors. The calculated results for a design day temperature difference of 18 K are given in table 2. The total fabric loss is only 1.6 kW with the proposed level of insulation compared with 4.0 kW for the Building Regulations level. The ventilation heat loss is 1.15 kW in both cases for the same ventilation rate of one air change per hour.

The U-value of 2.5 W/m^2K for windows can be achieved using double glazing in wooden frames. Examples of constructions having a U-value of 0.3 W/m^2K are shown in figure 1. In the walls and roof a thickness of 130-140 mm of mineral fibre insulation is required, assuming that heat bridging through the insulation increases the effective thermal conductivity to 0.048 W/mK from 0.036 W/mK for the insulation alone. In the case of a concrete floor only edge insulation is needed.

The examples for roof and floor are normal constructions but with extra insulation. The wall construction however is not common in the U.K. The principle on which it is based is to provide by separate components the main requirements of a wall which are structural strength, thermal insulation, and weather and impact protection externally. The structural component of brick or concrete would be sufficiently impermeable to act as a vapour barrier on the warm side of the insulation to prevent interstitial condensation. An array of battens or pins could be used to support the cladding and leave space for the insulation. Many cladding materials are available based on wood, cement and concrete, and metal. Wood is extensively used in timber framed housing. Cement rendering on wire reinforcement is suitable because it can be easily shaped around windows and other openings.

A design ventilation rate of one air change per hour has been assumed in the heat loss calculations. To achieve a value as low as this in practice will require a well sealed house to minimize uncontrolled infiltration plus a simple and effective means of providing controlled ventilation in each room. Uncontrolled infiltration occurs through gaps around openable windows and doors when they are closed and through gaps in the structure, for example around window and door frames. Measurements yet to be reported (ref. 1) show that

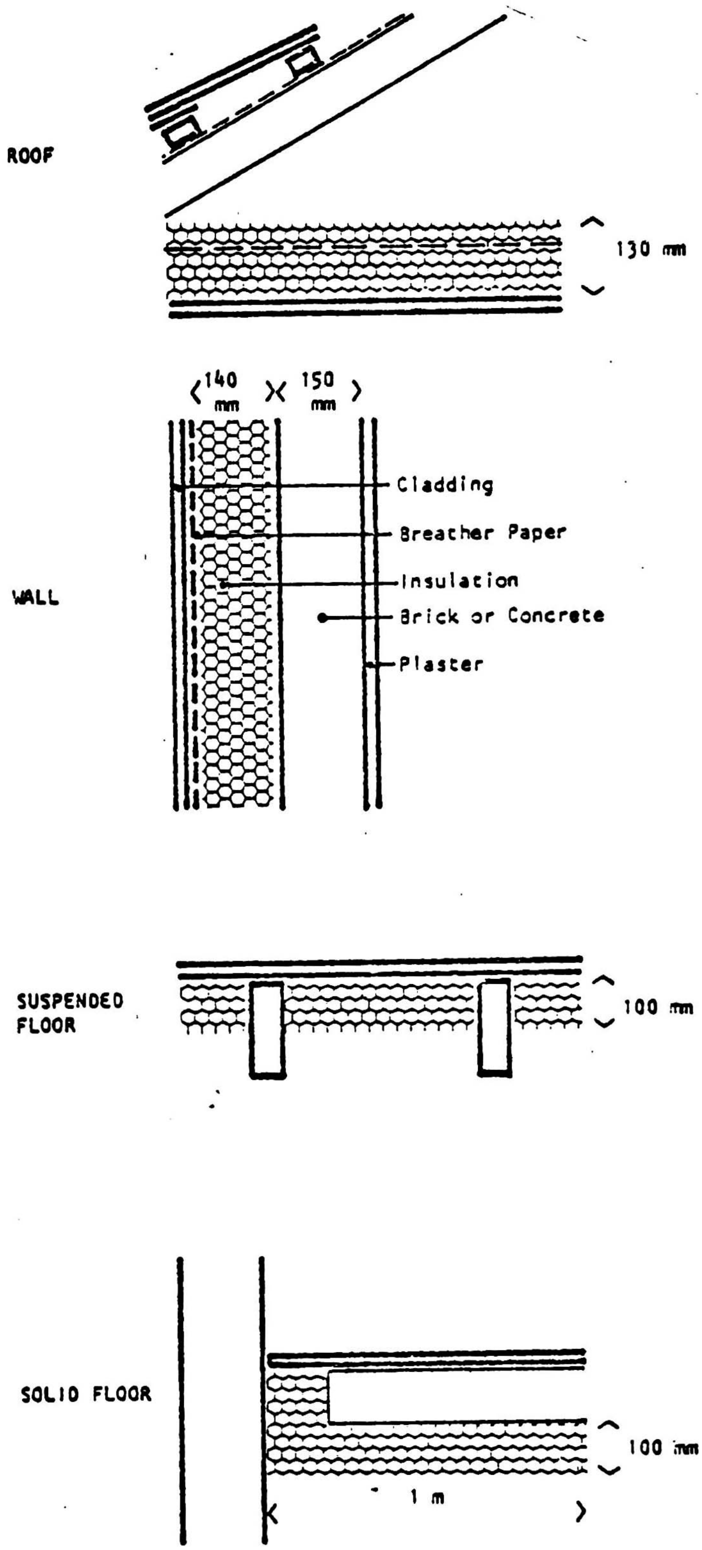


Figure 1 Insulation thicknesses to achieve U-values of 0.3 W/m^2K

weatherstripping the windows and doors of existing houses and sealing obvious gaps in the structure can reduce uncontrolled infiltration to 0.35-0.5 air changes per hour. New designs must reduce gaps in the structure to reduce uncontrolled infiltration to around 0.2 air changes per hour.

Table 2 Calculated Design Day Heat Losses

Design day temperatures Internal 18°C
External 0°C

Component	Area m^2	U-value W/m^2K	ΔT K	Q W	Q %	H kWh/day	E kWh/K day
(A) Proposed level							
Windows	17.0	2.5	18	765	27.8		
Walls	68.5	0.3	18	370	13.4		
Floor	42.5	0.3	18	230	8.4		
Roof	42.5	0.3	18	230	8.4		
Total fabric				1595	58.0	38.3	2.13
Ventilation 1 ac/hr, 200 m^3/hr				1150	42.0	27.6	1.53
Total				2745		66.0	3.66
(B) 1975 Building Regulations Standard							
Windows + walls	85.5	1.8	18	2770	53.8		
Floor	42.5	1.0	18	765	14.9		
Roof	42.5	0.6	18	460	8.9		
Total fabric				3995	77.6	95.9	5.33
Ventilation 1 ac/hr, 200 m^3/Hr				1150	22.4	27.6	1.53
Total				5145		123.5	6.86

Higher ventilation rates could be obtained when required by opening windows or by mechanical ventilation. Opening windows is simple, provides some degree of room control and is operated by the occupants. However windows can be left open unnecessarily and the ventilation rate varies with windspeed and direction. An infinitely variable device is required to control the size of opening, from closed to a gap width of about 15mm. No control of ventilation routes is obtained so that in Britain a kitchen with a westerly facing open window would be ventilated usually (and undesirably) from the outside to the rest of the house, whereas an upstairs bathroom with an easterly facing open window would be ventilated usually (and desirably) from the rest of the house to the outside.

Mechanical ventilation could control routes as well as rates. However suitable systems have yet to be developed which can give room by room control, and provide the very changeable rates required in the kitchen and bathroom. It does however introduce the possibility of having ventilation heat recovery as discussed later.

3. ANNUAL GROSS SPACE HEATING REQUIREMENTS AND FREE HEAT

Estimates of the gross space heating requirements through the year are shown in figure 2 and table 3. An average internal air temperature of 18°C was used and the monthly average external air temperature for Capenhurst. The total of 20,900 kWh/year with insulation to the 1975 Building Regulations is nearly twice the 11,100 kWh/year required with the proposed level. Ventilation needs 4670 kWh/year.

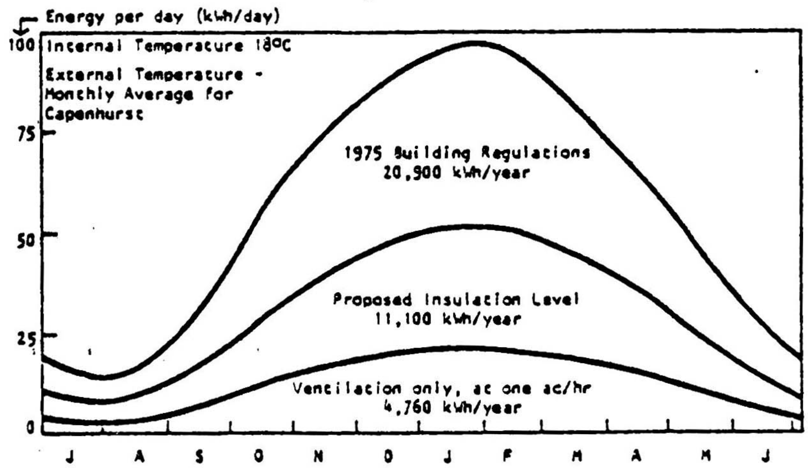


Figure 2 Calculated Gross Space Heating Requirements Through Year

The average internal temperature of 18°C allows for higher temperatures of 21-23°C in living rooms and bathrooms when occupied, and lower temperatures of 14-16°C in unoccupied rooms.

Table 3 Calculated Gross Space Heating Requirements
Average internal temperature = 18°C

Month	Average External Air Temperature °C	Temperature Difference K	Gross Heating Requirements		
			Ventilation kWh/day	Proposed level kWh/day	1975 Building Regulations kWh/day
January	4.0	14.0	21.4	51	96
February	4.2	13.8	21.1	50	95
March	6.0	12.0	18.4	44	82
April	8.3	9.7	14.8	36	67
May	11.3	6.7	10.3	25	46
June	14.1	3.9	6.0	14	27
July	15.7	2.3	3.5	8	16
August	15.6	2.4	3.7	9	17
September	13.7	4.3	6.6	16	30
October	10.3	7.7	11.8	28	53
November	7.2	10.8	16.5	40	74
December	5.3	12.7	19.4	47	87
Yearly total			4,670	11,100	20,900

Part of the gross space heating requirements would be provided by the so-called free heat arising from occupancy and solar radiation. Estimated values are shown in table 4 and figure 3 for a 4 person family. The solar heating has been calculated as described in reference (2) using average monthly solar measurements for Capenhurst. Eighty per cent occurs through the glazing and 20% is effective through the opaque parts of the structure. In dull weather solar heating would be about half the average values, and in bright weather twice the average.

Table 4 Free Heat and Ventilation Recovery in kWh/day

Month	Due to Occupants	From Domestic Hot Water	Solar Heating	Total Free Heat	50% Ventilation Recovery
January	19	5.0	5.0	29	11
February	19	5.0	7.0	31	11
March	18	4.5	12.5	35	9
April	16	4.0	19.0	39	7
May	14	3.5	25.0	43	5
June	12	3.0	29.0	44	3
July	12	3.0	27.0	43	2
August	14	3.5	21.5	39	2
September	16	4.0	14.0	34	3
October	18	4.5	8.5	31	6
November	19	5.0	5.0	29	8
December	19	5.0	5.0	29	10

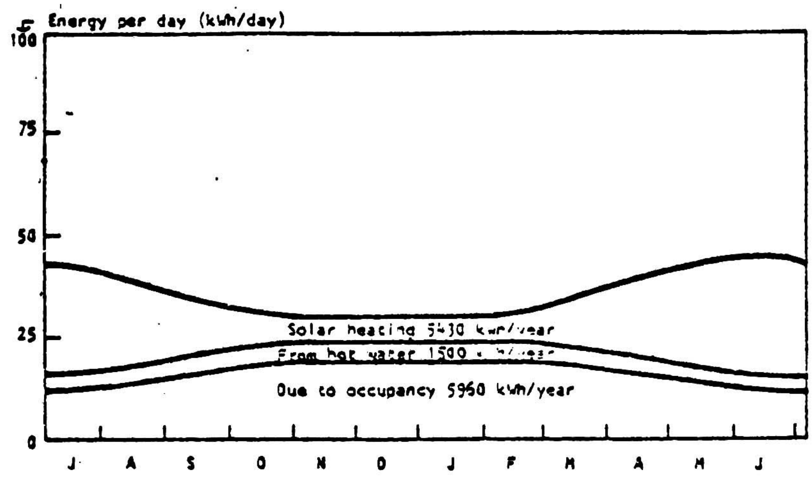


Figure 3 Estimated total free heat through the year

4. FREE HEAT CONTRIBUTION TO SPACE HEATING

Figure 4 shows the estimated free heat contribution to space heating if an average of 70% of it can be usefully used. With the proposed level of insulation the contribution is almost 7000 kWh/year, leaving 4140 kWh to be provided by other means. With insulation meeting the 1975 Building Regulations the additional heating requirement is about three times as much at 12,700 kWh/year.

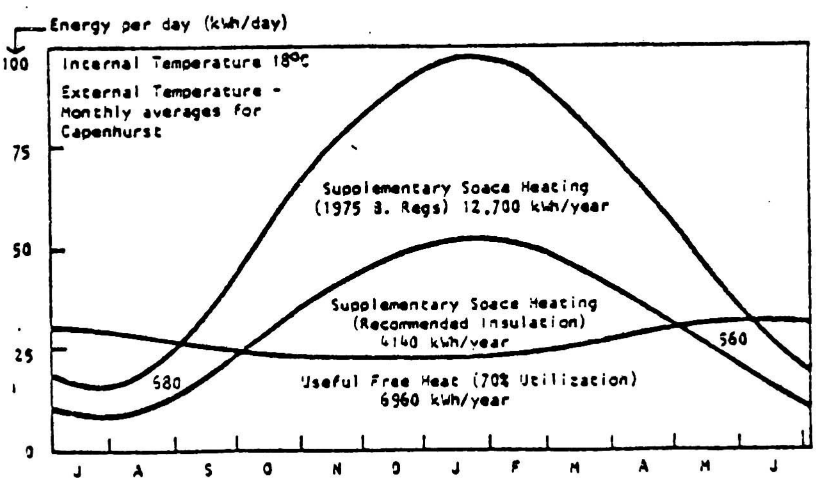


Figure 4 Space heating requirements allowing for useful free heat.

Problems in utilizing all the free heat for space heating arise because of the variability of its input and its association with steam and smells as the following list shows:

1. Due to occupancy

   (a) people - good - because heat from them is where it is required.
   (b) appliances - fair - heat is sometimes where required, e.g. television.
   (c) lights - good - heat is where it is required.
   (d) cooking - poor - concentrated in both time and space and is accompanied by steam and smells.
   (e) drawing curtains - good - heat saving can be throughout the house.

2. From domestic hot water

   (a) from storage vessel - fair - concentrated but continuous.
   (b) pipe losses - fair - dispersed but intermittent.
   (c) point of use - poor - concentrated and accompanied by moisture.

3. Solar heating - fair - varies from day to day, during the day from room to room.

The utilization could vary widely from 70% depending on the design features outlined below and on how the house is managed.

The kitchen/dining room and bathroom are the main problem areas because the free heat is accompanied by moisture and smells. The kitchen is the worst of the two, partly because an estimated 40% of the free heat would be generated there, and partly because the heat from cooking is at relatively high rates over short periods and can exceed the gross space heating power requirement for the room even in winter.

Departures from average weather conditions will cause variations in gross heating requirements, adding to the difficulties, especially in spring and autumn. In summer free heat exceeds gross heating requirements but it is not practical to store the excess for use in winter. The ECRC mathematical house model is being used to calculate in detail the effects of free heat on internal conditions and heating requirements. Early results appear in reference (3), and others will be reported.

5. DESIGNING FOR MAXIMUM UTILIZATION OF FREE HEAT

A well insulated house should have temperatures controlled separately in each room, and have room heaters which are responsive. Room temperatures can then be set by the occupants, and whenever the rate of free heat generation in any room exceeded its heating requirement, the heater would switch off and have little heat content to cause overheating.

The controls would enable rooms which are not in continual use to be maintained at lower than average temperatures, around 14-15^{o}C, and to be heated quickly to a comfortable temperature. The maintenance of lower temperatures in such rooms would also depend on their thermal isolation from the rest of the house. This would require insulation between floors and in internal walls and a reduction in casual air flow around the house. Unfortunately a high degree of thermal isolation of all rooms would reduce the amount of casual redistribution of heat, worsening overheating in rooms with high free heat gains.

The thermally massive interior which the proposed wall construction would give can contribute towards effective use of incidental heating in two ways. First the mean radiant temperature within a room with variable rates of free heating will remain relatively stable even when the air temperature changes significantly. Conditions will therefore be more comfortable internally and the incidence of opening windows should be lower. Second the walls will provide some heat storage through the day by absorbing heat whilst still maintaining a stable mean radiant temperature when heat gains are high, and using the heat later. It may not heat the interior, but instead provide some of the fabric losses through the walls. The thermally massive interior has a disadvantage in that considerable time and energy would be required to warm the walls if they cooled considerably, for example if the house was without heating for some days. Lack of heating overnight in the well insulated construction proposed here would not cause this problem because the walls would only cool a few degrees during that period (3).

Redistribution of free heat around the house from regions where it is in excess to other rooms would improve the overall utilization. If the heat gain arises from solar radiation, for example through south-facing windows, then direct transfer of the room's warm air may be sufficient. From the kitchen and bathroom where smells and steam are produced, such direct transfer would not be acceptable. Controlled supply and extract ventilation with heat recovery might be effective if each room had a supply and extract.

6. VENTILATION HEAT RECOVERY

An estimated contribution to space heating by ventilation heat recovery is shown in figure 5, assuming that half of the ventilation heating requirement for one air change per hour is recovered. With the proposed level of insulation the supplementary space heating required is reduced by 1700 kWh/year to approximately 2500 kWh/year. Fifty per cent recovery would be achieved if the recovery system was 70% efficient and handled 70% of the total ventilation (the other 30% occurring through open windows and doors).

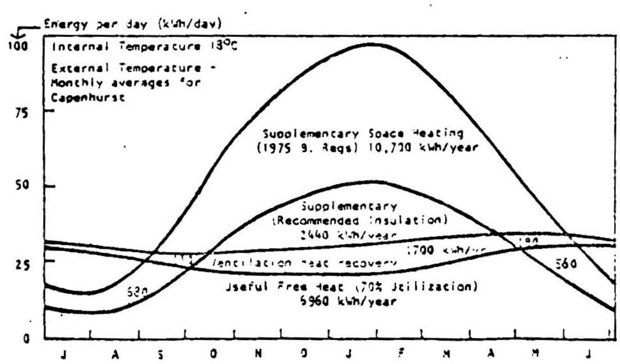


Figure 5 Space heating requirements allowing for useful free heat plus ventilation heat recovery

Each room could have a supply and extract, or alternatively fresh air could be supplied to living rooms, with extraction from the kitchen and bathroom. The latter scheme would to some extent control the flow of air through the house, and help to prevent the spread of smells and moisture.

The rate of airflow at 140 m^3/hour is quite small, less than one-fifth of the rate typical of warm air heating systems. Simple stubduct supply and extract networks should be adequate made from small uninsulated piping. Grilles could be mounted in internal walls at any convenient level.

7. HEATING EQUIPMENT AND SIZING

The basic requirement of the heating system is to provide temperature control in each room separately. In addition room heaters must be responsive. The occupants need to be able to adjust the control temperature, and automatic time control would be useful.

Existing heating systems generally do not meet these requirements. Warm air systems can be responsive but are somewhat difficult to control separately in each room. Conventional panel steel hot water radiators are too sluggish in response. Static and fan hot water convectors of existing designs could be satisfactory if they can be provided with suitable thermostatic control. Output from such a convector, if insulated so that its standing emission was very small, could be controlled by switching the fan. It has the advantage that it is much smaller than a static heater of the same rating.

Many sources of heat are available for central heating. Electrical sources include the heat pump, off-peak storage and direct acting. Direct acting room heaters can meet all the requirements stated above. Development work is in progress on air source heat pumps at ECRC (4). To achieve a coefficient of performance above about 2.5 in winter the supply temperature of air or water cannot be higher than about 35°C. This is an important factor in sizing room heaters and heat distribution systems. Off peak storage could conveniently be based on water systems. Operating the store over the range from 95°C to as low as 30°C would give a small store, but would require large room heaters. Fan storage radiators with low case emission would provide some background heating, and be responsive by switching the fan.

Distribution networks of pipes and ducts should be within the house. Heat losses from them will not then be lost. Even so insulation will be needed, especiall on ducts, otherwise the uncontrolled heat emission from them would make temperatur control in the house difficult.

Equipment is normally sized to meet the calculated design day power requirements plus 15 to 25%. It can supply far more energy per day than required under average conditions even in January especially when free heat is taken into account. Taking the proposed level of insulation as an example the power of the central heater would be 3.3 kW (2.75 kW + 20%), and the maximum daily energy output would be 79 kWh. The estimated average requirement in January allowing for free heat is only 33 kWh/day, or 52 kWh/day gross.

Clearly some new design procedures as well as equipment need to be developed taking into account free heat, the extent to which internal temperatures could be permitted to fall below design values in colder than average weather, and warm up times after periods of unoccupancy. Energy as well as power must be considered. The heating rate into a house can be larger over short periods than the continuous rating of the central heater if a heat store is provided.

The sizing of room heaters should consider response time as well as the above points, especially in rooms occupied intermittently. Houses which are thermally massive and well insulated cool slowly, but it may be desirable to maintain a minimum temperature of about 14°C to avoid long warm up times.

8. CONCLUSIONS

A typical British family house of 85m^2 floor area insulated to the 1975 Building Regulations Standard has a calculated gross space heating requirement of 21,000 kWh/year. The average net requirement, to be provided by a heating system, is estimated to be 12,700 kWh/year after allowing for the useful free heat contribution for a family of four and from solar radiation.

Insulating to a U-value of 0.3 W/m^{2}K for the walls, roof and floor and having double glazing reduces the calculated gross value to 11,000 kWh/year. The estimated net requirement is then 4,200 kWh/year after making the allowances for free heat. Ventilation heat recovery could provide a useful 1,700 kWh/year of this net requirement.

New sizing procedures are required for well insulated houses to avoid substantial oversizing of equipment.

9. ACKNOWLEDGEMENTS

I wish to thank Mr. A.E. Mould for his help in preparing this paper.

10. REFERENCES

1. Work carried out mainly by BRE in ECRC test houses.

2. Siviour, J.B. Solar Heating in Unoccupied Houses. ECRC/N840, 1975.

3. Basnett, P., Mould, A.E. and Siviour, J.B. Some effects of ventilation rate thermal insulation and mass on the thermal performance of houses in summer and winter. Energy and Housing Building Science Special Supplement, 1975.

4. Heap, R.H. Heat Pumps for British Houses? Energy Conservation for the Built Environment, CIB W67, 1976.

APPENDIX **Average Daily Free Heat due to Occupancy and from Hot Water in kWh/day**

Source	WINTER					SUMMER
	Siviour & Basnett (1)	Billington (2)	Wolf (EDH) (3)	Brundrett (4)	Heap (5)	Siviour & Basnett (6)
Occupants	5	4.8	5.4	6	4	4
Lighting	4)	1.8)	)	)	1.4)	1
Cooking	4) 12	8.0) 17.6	) 12	) 12	3.4) 8.2	4
Appliances	4)	7.8)	)	)	3.4)	3
Curtains	2	-	6.0	-	2.0	Nil
Total	19	22	23	18	14	12
From hot water	5	15	-	11	3.4	3

Occupants Two adults 100W each (daytime) 80W each (night-time)
Two children 60W each (daytime) 50W each (night-time)

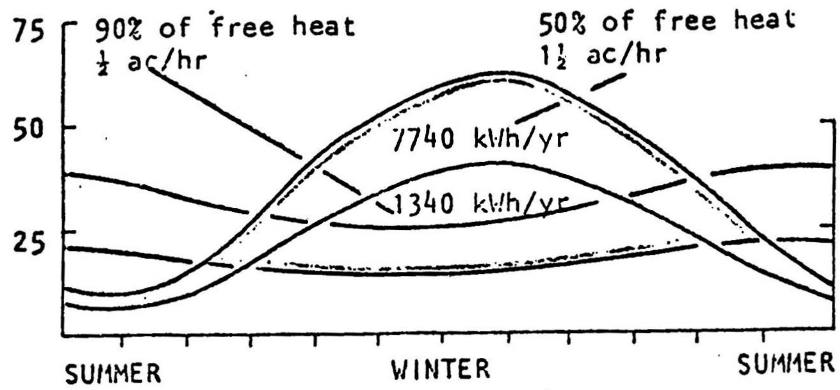
8 hours overnight	2 x 80 + 2 x 50	2.08 kWh
1 hour morning	2 x 100 + 2 x 60	0.32
6 hours day	1 x 100 + 2 x 60	1.32
2 hours afternoon	vacant	
5 hours evening	2 x 100 + 2 x 60	1.60
2 hours evening	vacant	
	Total	5.32 kWh/day
	say	5 kWh/day

Curtains Area 15m^2
U-value change from 2.6 to 1.8
Temperature difference 15K
Time drawn 12 hours
Saving 15 x (2.6 − 1.8) x 15 x 12 = 2.16 kWh/day
say 2 kWh/day

Hot Water

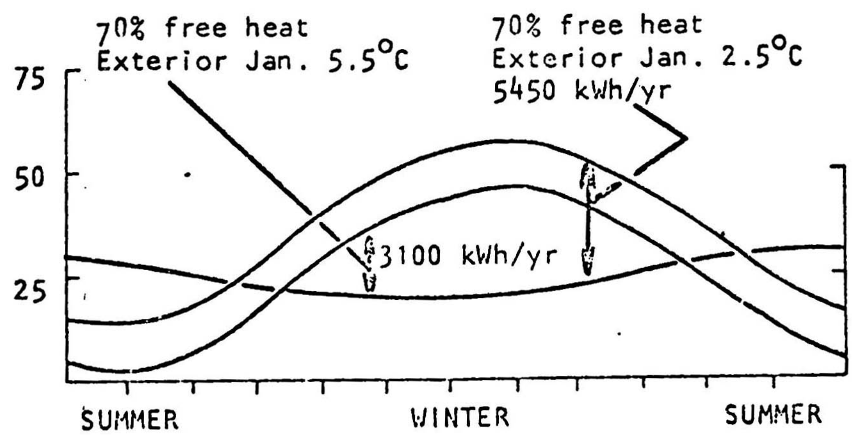
Tank loss		1.5 kWh/day
Pipe and in use losses,	kitchen	1.5 kWh/day
	bathroom	2.0 kWh/day
	Total	5 kWh/day

(1) and (6) are used in this report, and were assembled by J.B. Sivour & P. Basnett at ECRC.
(2) N.J. Billington. Thermal Insulation and Domestic Fuel Consumption. BSE April 1972 p. 23-24.
(3) R. Wolf. Chauffage et Conditionnement Electriques des Locaux. (Electric heating and air conditioning of dwellings) Eyrolles (Paris) 1974, p.63.
(4) G.W. Brundrett. Some effects of thermal insulation on design. Applied Energy. (1) 1975, 7-30.
(5) R.D. Heap. Assembled at ECRC from MR415 and Electricity Supply Industry Statistics.



Net space heating with ½, 1½ ac/hr and 50, 90% free heat utilization

Finally I would like to show the effects of different temperature differences between the inside and outside. The next slide shows changes of ±1.5 K on the average. With 1.5 K less the net requirement works out to be 3100 kWh/year, and with 1.5 K more the requirement is 5500 kWh/year. If these differences are due to different external temperatures then these two extremes can cover the country from Aberdeen to the Isle of Wight.



Net space heating with ΔT ±1.5K from Capenhurst average (Aberdeen, Isle of Weight)

Corrections to paper: page 10, last line, delete 23, replace by 33.
page 11, line 13, delete 14,000, replace by 12,700.

Date Due		
[illegible]		