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ECRC LOW ENERGY HOUSES: DATA COLLECTION
AND COMPUTER ANALYSIS

by D. A. McIntyre, J. B. Siviour and
J. P. Edwards

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CAPENHURST, CHESTER. CH1 6ES

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SUMMARY

ECRC Capenhurst was responsible for monitoring temperature and energy in four occupied low energy houses over a period of one year. Separate data loggers were used to record temperatures, energies and weather for each house. Data tapes were collected weekly, and processed to produce summary tables and graphs, and a comprehensive count of energy flows.

This Memorandum describes the data collection and computer analysis. The comprehensive data collection and rapid turn round was successful in its aims of providing early warning of any equipment malfunction, and in providing detailed summaries of information on which to base studies of system behaviour. The large amount of data available enabled detailed analysis to be made of energy flows. This computer based analysis did not show a significant increase in accuracy of energy estimation when compared with a more simple manual analysis which was based on weekly averages of the measured quantities. In other circumstances, particularly if the ventilation rate is variable, or where detailed solar analysis is important, it will be necessary to use an hourly analysis of energy flows.

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(i)

1. INTRODUCTION

ECRC Capenhurst promoted the construction of four low energy all-electric houses, which were built for sale by two national house builders. The houses were of conventional layout and appearance. The two designs were both three bedroom detached houses of about 80 metre² total floor area and were built of traditional brick/block wall construction. Insulation was of a high standard. The cavity width was increased to incorporate 100 mm of insulation, the floor was insulated and roof insulation increased to 150 mm. All windows and doors were double glazed and draughtstripped. A fully ducted mechanical ventilation system with heat recovery was installed, which extracted waste air from bathroom and kitchen, and delivered tempered fresh air to the living and bedrooms. Measurement of the heat loss of the houses under test conditions showed that a transmission loss of about 140 W/K was achieved, and that the combined natural and mechanical ventilation loss was about 30 W/K.

The bulk of the space heating was provided by a fan storage radiator in the living room, and a thermostatic storage radiator in the hall. Direct acting heaters were installed in the bedrooms, and a focal point heater in the lounge area. Domestic hot water is provided from a 225 litre insulated storage tank.

ECRC undertook to monitor the thermal performance of the houses during their first year of occupation. Since the houses were occupied by their new owners, monitoring had to be unobtrusive, and cause minimal disturbance to the occupants. Transducers were installed during construction to measure temperature, humidity and electrical energy consumption, and their output was recorded on data loggers installed in the garage of each house. In addition, window and door opening was monitored, using a commercial burglar alarm installation as a detector. A weather station was installed on each site, with its own data logger. Each house was visited weekly, to change data tapes; in addition several meter readings were noted, as a check against any instrument malfunction.

The logging had two major functions. It provided an indication of the operation of the equipment in the houses. This information was required routinely, and with the minimum of delay, so that any malfunction of the house equipment could be detected and rectified promptly. The second

function was to provide data which would be used to analyse the thermal performance of the houses in detail. This required measurements which would require the estimate of heat gains and losses of the house from all sources. This includes solar gains and incidental gains from the use of electrical equipment as well as from the heating system. Heat loss estimation requires a knowledge of inside and outside temperatures, together with the ventilation rate.

Data tapes were brought from the houses to Capenhurst each week, and read into the main Prime computer. The data was analysed to produce:

- a. a set of graph plots of all measurements against time.
- b. a set of summary tables, showing daily and weekly averages of the measured quantities.
- c. an analysis of energy inputs and outputs.

These were all produced automatically, using specially written programs. In addition, a manually produced table was maintained, which incorporated manual meter reading measurements as well as computer generated averages. The flow of data from logger to final summary table goes through several stages. This report describes the major computer programs. Details of other aspects of the data handling and analysis will be found in Siviour and Edwards (1985) Report.

2. MEASUREMENT

2.1 Data recording

The measurements may conveniently be described into three groups, by the code name of the data logger which reads them.

HOUSE Internal house temperatures, dew points and mechanical ventilation settings were recorded every 30 minutes on a Solartron data logger.

These measurements are referred to as HOUSE data, and coded prefix H.

ENERGY Electrical energy consumption on four channels was recorded every 10 minutes on a Cristie data logger, together with the durations of door and window opening. These measurements are referred to as ENERGY data, and coded prefix E.

WEATHER Wet and dry bulb temperatures, sunshine, wind speed and direction were recorded on a Cristie logger. These measurements are referred to as WEATHER data, and coded prefix W.

2.2 Temperature

Copper constantan thermocouples were used for temperature measurement throughout the house. Hot junctions were spot welded, and the wire run in a continuous length to the data logger. Checks on the thermocouples showed them to be of good consistency, generally within 0.2 K of each other. Cold junction compensation and thermocouple law correction was provided by the logger; the information was recorded by the logger directly as temperature, and did not require further processing. It was found that there was a drift in the cold junction compensation in the Solartron logger of up to 1 K, possibly caused by operation of the logger in low ambient temperatures. The error was additive, applying equally to all channels. The error was checked each week when changing tapes. For part of the time, a reference enclosure of known temperature was set up near the logger, and its temperature recorded using a thermocouple wired into a spare logger channel. This allowed the correction to be automatically provided by the computer program hour by hour. Otherwise, the average weekly correction was applied.

A most important consideration for temperature measurement is the choice of sensor position. Air temperature is by no means uniform over a room, particularly when a heating system is in operation. Our thermocouples were mounted some 150 mm below ceiling level next to a wall. Choice of position was dictated by the need to ensure that our instrumentation was as unobtrusive as possible. Additional thermocouples were mounted immediately over the doorway in the lounge, hall and kitchen, some 30 mm below ceiling level.

The warm air convected from the heaters produces a layer of warm air at ceiling level. This temperature stratification is greatest on cold days, when the heaters are at maximum output. Measurements taken about noon in midwinter found that, with the central room temperature 21°C, the ceiling air temperature over a heater was 28°C, and the ceiling air temperature remote from the heater was 23°C. Air temperature near the floor was 20°C. It is therefore difficult to choose a single temperature

measurement position which will give a representative room temperature under all conditions. The over door position proved to be a reasonable compromise.

External air temperatures adjacent to the house were measured using thermocouples connected to the HOUSE logger. Thermocouples were mounted on the northern side of the house, to shield them from solar radiation.

2.3 Humidity

Internal humidity was measured both in the ducts of the mechanical ventilation system and in the hall of each house, using lithium chloride "Dewcel" transducers. The lithium chloride cell is reputedly the most reliable of humidity sensors. However, we experienced several problems. The mode of operation of the cell is to pass an alternating current across a wick saturated with lithium chloride solution. The heat produced raises the temperature until the wick dries out, so reducing the current. An equilibrium temperature is attained, which is a function of atmospheric dew point. In practice, it is necessary to use the proper start up procedure, and then maintain the heater current continuously.

Interruption of the current allows the lithium chloride to cool and absorb moisture from the atmosphere. A subsequent wet restart produces high local currents, which may damage the probe. An additional problem is that the low resistance of the wet wick may not produce sufficient ohmic heating for a successful restart. The houses suffered some electrical supply interruptions, with consequent problems with the sensors.

Another problem was associated with measurements in the ventilation ducts. High air movement over the probe may result in excessive cooling and an erroneous measurement. We originally specified Yellow Springs YSI 9102 probes, which have a double bobbin for use in high air speeds. Manufacture of this dual probe was discontinued, and the replacement 9103 probes offered proved to be inaccurate at the air flow of 2.5 metres per second in the ducts. The probes were relocated in side pockets, and this cured the problem. A simple T-piece was constructed from copper pipe, and the stem inserted into the duct. The probe was mounted external to the duct out of the air flow, but able to communicate freely with it. A cooling correction was incorporated into the computer program for duct mounted probes, which was based on bench tests.

The probes require cleaning and recharging at intervals. Several probes were damaged during this operation, either by physical damage to the delicate wire, or by corrosion of the mounting pins by the salt solution. The probes in the hall generally worked well, but the severer environment in the ventilation ducts caused several failures.

Wet and dry bulb temperatures measured in the Stevenson screen of the weather stations provided a measure of external ambient humidity. The wet bulb used a simple wick arrangement and there was no aspiration. Temperatures were measured by platinum resistance thermometers. This arrangement worked well. In addition, a Lee Dickens HPP5 Hygropolymer sensor was installed in the Stevenson screen to measure relative humidity. This device incorporates a thin polymer film, which swells with increasing r.h.; the swelling is measured by change in the capacitance. These sensors proved unsatisfactory. They were delivered incorrectly calibrated, and two failed shortly after installation. The fundamental objection to their use for measuring out-door r.h. is that above 75% r.h. a slow drift occurs, causing readings of up to 115% r.h. to be recorded. The use of these sensors was discontinued.

2.4 Wind speed and direction

Wind speed and direction were measured at the weather station at a height of about 8 metres above ground level, using a Vector Instruments portable anemograph, type R500. Wind speed was measured by a rotating cup anemometer, and wind direction by a wind vane. The device shows wind speed and direction on panel meters, and incorporates its own miniature chart recorder, as well as providing output to the data logger. An averaging circuit is incorporated in the instrument and was set to give a time constant of about 5 minutes. The instrument worked satisfactorily.

2.5 Insolation

Insolation on a horizontal plane was measured by a solarimeter, mounted at a height of 8 metres. Insolation was integrated over 10 minute periods by a Time Electronics CJ20 integrator.

2.6 Window and door opening

During construction of the house, a burglar alarm was incorporated in the house by the local Area Board. Proximity switches were mounted on all

windows and external doors. Two separate circuits were used, one for all the windows, and the other for the external doors. The switches in each circuit were wired in series, so that the recording apparatus detected whether at least one window was open or at least one door. The energy Cristie logger recorded total open time every 10 minutes for the two circuits.

3. DATA HANDLING

3.1 Data flow

Figure 1 shows the flow diagram of the data collection and analysis. The first few steps are concerned with physical transportation of the magnetic tapes containing the data to ECRC, and its reading into the Prime computer and the preparation of data files edited to provide continuous data for one week, from 0000 Monday to 2400 the following Sunday. Program Chart (Sharman 1982) is then used to produce a graphical output from each tape. An example of this output is shown in Figure 2. These charts are used to provide an easily assimilated picture of the behaviour of all the systems, and are invaluable in providing early warning of any equipment malfunction. Program CHART provides some data checking and cleaning, and produces a fresh data array; the arrays are referred to as data files AH, AE and AW in Figure 1. Three programs, referred to as TABHOUSE, TABENERGY and TABWEATHER respectively, are used to produce weekly summary tables. Examples of the tables are shown in Tables 2-4. The three TAB programs also process the data to produce the information required by the final energy analysis program account.

The procedures for data handling are described in detail by Siviour and Edwards (1985). This report describes the TAB and ACCOUNT programs, paying particular attention to the physical assumptions involved in the energy analysis.

4. PROGRAM TABHOUSE

Program TABHOUSE performs simple averaging and tabulation of the quantities recorded by the Solartron logger. A large part of the program is taken up with file name handling and other input routines. During the year's monitoring, there were of course changes made to the logger wiring, channels recorded and instrumentation; towards the end of the season, Houses 8 and 9 Gairloch Close had a limited temperature selection recorded on one shared logger. The program TABHOUSE was continuously updated to handle all these changes. The program remained comprehensive, so that the current version of the program could handle all current and earlier data files. This meant that the program had to identify the data input when related to the contemporary experimental set-up. This meant that the program contained out of date routines, which would only be used if old data were to be run again. However, this arrangement had the considerable advantage that only one version of the program existed at any one time, which could be used without alteration to run any data file.

Table 2 shows an example of the output from TABHOUSE. Each measured and derived quantity is identified by a TAB number, which remains unchanged and is used internally in the program. A separate data file for each house records the logger channels on which each quantity is recorded; this may change from time to time if any reconnections are made. The logger channel is printed out in the table; derived quantities are given the dummy channel number 99.

5. TABENERGY

Program TABENERGY tabulates the data from the Cristie logger which is used to record energy consumption. The logger records energy every 10 minutes from four circuits: (1) total electricity to house, (2) energy to storage heater circuit, (3) energy to lounge radiant heater, (4) energy to cooker (later changed to immersion heater in house 31AG). Channels 5 and 6 record the duration in each 10 minute period that a door or a window has been open. The graph plot produced by a chart of the data from the energy Cristie is shown in Figure 3. Program TABENERGY performs a simple tabulation of the data, producing daily and weekly averages. Since the two storage heaters have different input ratings, which can be

deduced from the graphs, it is possible to sub-divide the total storage heating energy into the individual charges of the two heaters. The partition can be done uniquely if neither heater switches during the 10 minute observation period. If one of the heaters switches during the period, it is not possible to decide the partition exactly, and a simple pro rata division is used.

For most of the monitoring season, the charge taken by the immersion water heater was noted manually each week. Daily estimates were made by TABENERGY from the residual power during the low rate period. The residual power is the total input power to the house less storage heating, radiant heating, and cooking. If the residual power was greater than the rating of the immersion heater, it was assumed that the immersion heater was on. This method gives an average error of 1 kWh per switching. This method does not work during the day rate period; however, the manual readings confirmed that little water heating was taken at day rate. A sample output of program TABENERGY is shown in Table 3. The averages run from midnight to midnight. If the low rate starts before midnight, then the storage heating charge shown in row 3 will apply to two separate charge periods. To look at the charging behaviour of the storage heaters, it is needed to record the charge taken in a single low rate period; this is deduced and shown in rows 16 and 17. In the table shown, Channel 4, originally reading cooker usage, measures the immersion heater consumption directly.

6. TABWEATHER

This program produces a table of daily and weekly averages of quantities measured at the weather station; an example is shown in Table 4. Vapour pressure, relative humidity and dew point are deduced from air temperature and wet bulb temperature using standard relationships. A cross-tabulation of windspeed and direction is carried out, and the table shows the number of hours at given combinations of windspeed and direction.

7. ENERGY FLOW. PROGRAM ACCOUNT

Program ACCOUNT attempts to produce an itemised breakdown of all energy inputs and outputs to the house, as well as providing information useful for further calculation and analysis. Figure 5 summarises the flow of energy, and the calculation routes involved. The energy flow includes all sources of energy, and is not limited to the heating season. All heat liberated in the house should therefore be accounted for. In normal space heating calculations, incidental heat gains, such as solar heat or heat from electrical appliances, which raise the house temperature above the desired level are regarded as wasted heat, since it does not contribute to any reduction in the energy required for space heating. In the total model shown in Figure 5 all heat liberated in the house has to be accounted for in the heat balance. The only heat produced in the house which may be regarded as wasted is energy which is not liberated into the space, such as hot water down the drain. Solar heat rejected by the window glass does not reach the interior space and so plays no part in the heat balance. The model is unusually complete in that it includes latent as well as sensible heat. Since both internal and external humidities are known, together with the ventilation rate, it is straightforward to calculate the energy lost from the house in the form of latent heat of evaporation. Metabolic heat from the occupants produces a direct latent heat input. All other sources of water vapour, whether from clothes drying, or from drying out of the structure, are a charge on the heat input to the building. It will be noted for instance that the exhaust fan of the mechanical ventilation unit has to be considered in the heat balance, since it injects its heat upstream of the exhaust temperature measurement; the heat from the fan however makes no useful contribution to the heating of the house.

A detailed commentary on the organisation of program ACCOUNT and of the physical relationships assumed are given in the Appendix. An example of the output from ACCOUNT is given in Table 5 and a print-out of the house constants in Table 6.

The solar gains are worked out hour by hour. Estimates are made of vertical insolation from the horizontal measurement and give the window gain when combined with glass area and transmission factor. The transmission loss is worked out using the sol-air temperature concept.

The sol-air temperature was worked out for each vertical surface using average 24 hour insolation, and then the five sol-air increments averaged over the four walls and roof to give an overall sol-air increment to be applied to the outside air temperature. The sol-air temperature was then used in place of the outside air temperature when calculating house heat loss from the whole house heat loss coefficient. The application of sol-air temperature in the program over-estimates the effect of sunshine on the opaque surfaces. The glazed areas should have been eliminated from the calculation, since the sol-air concept applies only to opaque surfaces, and solar gain through the windows appears separately in the calculation. This caused the sol-air increment to be over-estimated by some 9%. No account was taken of shading of walls. This is more serious in the case of the sol-air temperature than for the solar gain through glass calculations, since the windows of the house are positioned so as to be little shaded. However, the two side walls of the house are substantially shaded by neighbouring houses. It would be reasonable to reduce the sol-air increment by some 20% to take this shading into account.

Another factor ignored in the calculation was the effect of radiation to cold skies. Sky temperature can be up to 25° K below air temperature; the value depends on cloud cover and is typically about 10 K. This reduces the effective air temperature experienced by the roof by about 2.5 K. However, the average effect on the whole house will be less than this since the roof has a much lower average U-value than the vertical surfaces. The effect for the whole house is an equivalent reduction in air temperature of between a quarter and half a degree K, when the sky temperature is 10 K below air temperature. Based on his experience in the detailed analysis of heat loss in the ECRC Test Houses, Siviour (1977) developed an effective working rule that the effective solar gain on the opaque surfaces of a typical house was equal to 1% of the total insolation received on the opaque surfaces. This is roughly one-third of the gain computed in program ACCOUNT using the sol-air method.

The quantities in the heat balance produced by ACCOUNT and in the manual table are shown without any errors or confidence limits. Table 7 lists the main quantities, and shows the possible errors and the consequential uncertainty in the daily energy balance. The error shown in the Table is

not necessarily an instrument error. Many of the measurement quantities vary over space and it is a difficult matter to choose a measurement position that will be representative of the spatial average at all times; this applies to both internal and external temperature, which are found to vary substantially from place to place. Some important quantities in the energy analysis are not measured directly, but estimated from published information; this applies to window transmission and solar reflectance of walls. Other errors are the consequence of unrecorded behaviour; the number of people in the house, their activity and duration of occupancy are unknown, and simply estimated as a likely average value. One of the largest errors in the Table is solar gain. Sunshine is measured directly as insolation on a horizontal plane. This figure is used to estimate insolation on the four vertical surfaces of the house, using Basnett's program (Basnett 1975), this conversion may have an error of up to 15%. External solar shading was not measured, nor the amount of internal shading by curtains.

Some errors are expected to be random and introduce little long term bias to the results. This would apply to the conversion error of the insolation and the effect of wind speed on the U-value of the walls. Other errors may introduce a permanent bias; an incorrect thermocouple position may read consistently too high or low, or a particular behaviour pattern of the occupants may again produce a permanent bias in the estimates.

The implication of Table 7 is that a worthwhile improvement in the accuracy of the heat balance can only come from simultaneously improving the accuracy of many measures; improving the accuracy of individual measurements while leaving others with a large error is not worthwhile.

It was stated above that the final energy analysis was performed weekly, using arithmetic means of temperature, and integrated energies over the period. However, this conceals the fact that some of the preliminary analysis on which this is based were performed at time intervals of one hour. Estimates of conduction heat flow through the fabric may be made using time averaged values of internal and external temperatures without any loss in accuracy; in fact estimates over longer periods will be more accurate, since the effect of heat storage is then minimised.

However, ventilation loss is proportional to the product of ventilation rate and internal-external temperature difference. Since these quantities may vary independently, it is not in general possible to work with their time averages. Strictly, one should compute the product at frequent intervals, and average that. Table 8 gives a brief summary of the effects of measurement and calculation frequency on the accuracy of energy flow estimates. It can be seen that in the case of the low energy houses weekly estimates produce no error for estimation of conduction loss, and in practice produce a very small error for the estimation of ventilation loss. Estimates of vertical insolation are improved if the calculations are performed hourly rather than daily or weekly. However, in this case, unlike that of ventilation, the error is random, and so becomes of less importance when considering the seasonal energy balance.

8. DISCUSSION

8.1 Operation

The monitoring achieved a high standard of reliability, with weekly visits to the houses, tape retrieval and data analysis obtained during the course of the experiment. The graphical and tabular summaries for all four houses were always made available before the next weekly visit. Any equipment malfunction could therefore be detected in time for provision to be made to rectify it. Tape retrieval and analysis required the full time efforts of two experienced technicians, plus back up during absence. Additional effort was needed to maintain the associated software, which required frequent updating as operational requirements changed.

Operation at remote sites emphasised the need for reliable equipment. Ideally, no equipment should be installed on site without its first having been used in the laboratory, to gain familiarity in use. Humidity measurements in particular were unreliable. The reliability could have been improved if the lithium chloride cells had been thoroughly tested before use.

8.2 Descriptive output

The weekly graphical and tabular summaries of house performance provided a fund of data, which has been used in the production of several reports

average internal temperatures at a particular time of day over a period of one week, thus getting the underlying diurnal temperature profile, with day to day irregularities smoothed out. Several reports are being written using the data provided.

8.3 Energy in the houses

The final energy analysis of the houses is described by Siviour. The energy analysis was basically simple, using daily average temperatures and an overall heat loss coefficient for the house. Computing power was exploited to estimate hourly vertical insolation figures from horizontal measurements; this was a complex calculation, and would not have been feasible without the use of a computer. Ventilation loss was computed hourly, and this leads in principle to an improvement in accuracy, since it takes into consideration the independent variation of air temperature and ventilation rate.

9. ACKNOWLEDGEMENTS

This Memorandum describes only one aspect of a large job. People who contributed to the successful instrumentation, data logging and analysis include: L. R. Dowdeswell, E. B. Edwards, A. R. Marchant and Mrs. C. Roberts.

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Table 1. Summary of equipment

Function	Model	Remarks
<u>Data loggers</u>		
50 channel logger	Solartron 3430	Cold junction drift
6 channel logger	Cristie CD6	Satisfactory
<u>Sensors</u>		
Thermocouples Pt resistance	Cu-con	Satisfactory
Lithium chloride dew point	Yellow Springs 9100 series	Maintenance problems
Hygropolymer RH	Lee Dickens HPP3	Unsatisfactory, abandoned
Anemometer and wind vane	Vector Instruments R500	Satisfactory
Solarimeter and integrator	Time Electronics CJ20	Satisfactory
Energy	GEC Integrating kWh meter C11 B2-TS	Satisfactory

TAB		UNITS	Logger Channel	MON	TUE	WED	THUR	FRI	SAT	SUN	Week	TAB
TEMPERATURES												
1	LOUNGE	DEGC	3	21.31	20.24	19.22	19.18	20.15	21.01	19.93	20.15	1
2	DOOR	DEGC	4	23.34	22.47	21.56	21.54	22.39	22.92	21.96	22.31	2
3	DINING ROOM	DEGC	5	21.73	20.71	19.87	19.73	20.64	21.24	20.22	20.59	3
4	KITCHEN	DEGC	1	18.47	18.32	17.35	16.42	17.14	17.90	17.66	17.61	4
5	DOOR	DEGC	2	18.39	18.14	17.22	16.29	17.00	17.79	17.45	17.47	5
6	HALL	DEGC	6	19.30	19.54	18.70	18.22	19.27	19.47	19.03	19.08	6
7	DOOR	DEGC	7	20.17	20.08	19.00	18.59	19.63	20.20	19.39	19.58	7
8	WC	DEGC	8	15.57	14.49	13.28	12.95	14.65	14.99	13.27	14.17	8
9	BEDROOM 1	DEGC	14	16.58	15.66	14.50	14.05	15.50	16.04	14.77	15.30	9
10	BEDROOM 2	DEGC	9	16.61	15.80	14.82	14.79	15.81	16.27	14.98	15.58	10
11	BEDROOM 3	DEGC	11	17.13	16.41	15.48	14.97	16.35	16.89	15.75	16.14	11
12	LANDING	DEGC	13	18.41	18.07	17.14	16.69	17.91	18.28	17.38	17.70	12
13	BATHROOM	DEGC	12	16.14	16.03	15.99	14.74	16.37	16.49	15.69	15.92	13
14	WHOLE HOUSE AVERAGE	DEGC	99	18.70	18.15	17.24	16.78	17.91	18.42	17.50	17.82	14
BAHCO UNIT TEMPERATURES												
15	INTAKE	DEGC	15	8.63	3.12	2.42	4.15	8.06	5.31	0.34	4.58	15
16	DISCHARGE	DEGC	16	12.74	9.17	8.43	9.11	11.84	10.51	7.77	9.94	16
17	SUPPLY	DEGC	17	13.81	10.55	9.80	10.14	12.64	11.62	9.16	11.10	17
18	EXTRACT	DEGC	18	15.72	14.69	13.62	13.29	15.09	15.31	13.70	14.49	18
19	OUTSIDE AIR (Canopy)	DEGC	29	8.66	3.30	2.45	3.96	7.79	6.04	1.51	4.82	19
39	LOFT	DEGC	0	9.30	4.92	4.10	4.72	8.86	7.79	3.76	6.21	39
DEWPOINTS												
20	HALL	DEGC	25	6.39	4.62	2.52	2.21	4.20	4.81	3.53	4.04	20
21	BAHCO INTAKE	DEGC	27	0.11	0.36	0.39	0.31	0.14	0.26	0.48	0.29	21
22	BAHCO DISCHARGE	DEGC	26	-0.07	0.09	0.12	0.09	-0.03	0.03	0.15	0.05	22
RELATIVE HUMIDITIES												
23	HALL	PC	99	42.98	37.54	34.09	34.26	36.94	38.07	35.87	37.11	23
24	BAHCO INTAKE	PC	99	55.12	82.38	84.86	74.83	55.65	64.74	45.29	66.12	24
25	BAHCO DISCHARGE	PC	99	40.38	50.30	53.59	52.05	37.59	29.18	57.51	45.80	25
BAHCO SETTINGS												
30	LOW	PC	35	0.00	0.06	0.72	0.78	0.94	0.60	0.84	0.56	30
31	NORMAL	PC	36	0.00	0.44	0.26	0.22	0.06	0.40	0.14	0.22	31
32	BOOST	PC	37	0.00	0.02	0.02	0.02	0.02	0.04	0.02	0.02	32
Number of scans				50	50	50	50	50	50	50		

Table 2. Weekly summary of house temperatures

Quantity	Units	Channel	Mon	Tues	Wed	Thur	Fri	Sat	Sun	Week
1 Total low rate	kWh	1	39.55	40.60	43.48	43.65	41.36	35.44	44.59	41.24
2 Total day rate	kWh	1	8.64	11.56	11.48	9.34	7.25	11.32	13.19	10.40
3 Storage heaters	kWh	2	27.77	33.41	34.15	34.81	33.44	29.79	33.02	32.34
4 >Lounge heater	kWh	2	17.34	18.01	17.96	18.61	18.31	17.74	17.80	17.97
5 >Hall heater	kWh	2	10.44	15.41	16.19	16.20	15.13	12.05	15.22	14.38
6 Radiant heater Low rate	kWh	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7 Radiant heater day rate	kWh	3	0.73	0.68	0.78	1.61	0.56	0.98	0.80	0.88
8 Cooker low rate	kWh	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9 Cooker day rate	kWh	4	1.65	3.25	3.47	0.49	0.60	2.05	4.92	2.35
10 Residual low rate	kWh		4.31	2.92	3.99	3.51	3.70	3.52	4.10	3.72
11 Residual day rate	kWh		6.26	7.63	7.22	7.24	6.09	8.29	7.46	7.17
12 Doors open	hrs	5	0.09	0.10	0.09	0.06	0.07	0.20	0.18	0.11
13 Windows open	hrs	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14 >Immersion heater	kWh		7.47	4.27	5.33	5.33	4.22	2.13	7.47	5.17
STORAGE HEATER CHARGE										
16 > lounge	kWh		17.34	18.01	17.96	18.61	18.31	17.74	17.80	17.97
17 > hall	kWh		10.44	15.41	16.19	16.20	15.13	12.05	15.22	14.38
Number of scans			144	144	144	144	144	144	144	0

Table 3. Weekly summary of energy consumption

CHANNEL	UNITS	MON	TUES	WED	THUR	FRI	SAT	SUN	WEEK
AIR TEMPERATURE	DEGC	7.86	1.91	0.78	2.50	6.78	4.20	-0.29	3.39
SCREEN WET BULB	DEGC	6.37	0.83	-0.59	1.62	5.16	3.01	-0.49	2.27
>VP	KPA	0.84	0.57	0.48	0.62	0.75	0.67	0.55	0.64
>RH	%	79.10	80.72	74.96	85.09	76.41	81.37	92.05	79.61
>Tdp	degC	4.45	-1.10	-3.30	0.20	2.92	1.22	-1.50	0.41
WINDSPEED	M/S	9.78	5.87	3.12	3.57	4.94	2.17	1.95	4.48
INSOLATION	WH/M2DAY	560.09	698.61	1148.77	582.69	1068.29	621.82	924.47	800.68
NUMBER OF SCANS		144	144	144	144	144	144	144	

TABLE OF WIND SPEED AND DIRECTION

SPEED		DIRECTIONS				TOTAL
		N	E	S	W	
<1	M/S	2.3	9.8	4.7	4.2	21.0
1-3	M/S	1.7	1.5	9.8	22.3	35.3
3-5	M/S	0.8	0.3	8.0	42.0	51.2
5-7	M/S	0.2	0.2	0.3	29.7	30.3
7-10	M/S	0.2	0.2	0.2	18.7	19.2
>10	M/S	0.0	0.0	0.0	11.0	11.0
	TOTAL	5.2	12.0	23.0	127.8	0.0

Table 4. Weekly summary of weather measurements

	Azimuth	Mon	Tue	Wed	Thur	Fri	Sat	Sun	Average
Window gain (kWh)									
1 Front	315	1.57	2.20	7.08	3.92	2.39	8.13	7.24	4.65
2 Side	45	0.14	0.19	0.52	0.24	0.21	0.44	0.39	0.30
3 Rear	135	2.50	3.45	12.63	4.25	5.04	9.06	8.54	6.50
4 Side	225	0.21	0.31	1.34	0.57	0.31	1.06	1.14	0.71
Total		4.42	6.15	21.57	8.99	7.95	18.69	17.31	12.15
Insolation (kWh/m ²)									
1 Front	315	0.59	0.84	2.74	1.48	0.90	3.03	2.73	1.76
2 Side	45	0.62	0.85	2.39	1.08	0.99	1.99	1.76	1.38
3 Rear	135	0.67	0.92	3.44	1.14	1.31	2.37	2.31	1.74
4 Side	225	0.61	0.92	3.93	1.63	0.93	3.06	3.30	2.05
Horizontal insolation (kWh/m ²)		0.92	1.34	5.63	2.00	1.66	3.85	4.17	2.79
TRANSMISSION LOSS (KWH)									
Whole house average		24.45	25.05	3.25	9.29	14.78	3.43	9.84	12.87
Room by room		22.48	23.45	11.52	12.60	15.25	12.06	13.88	15.89
Whole house, ignoring sun		29.40	30.42	21.26	19.37	21.00	22.41	22.00	23.69
Average internal temp									
Average external temp (screen)		20.93	19.52	19.54	19.83	20.77	21.35	21.87	20.55
Average solair temp		12.49	10.77	13.43	14.27	14.74	14.92	15.55	13.74
Average solair temp		13.91	12.32	18.61	17.16	16.53	20.37	19.04	16.85
VENTILATION									
Natural ventilation loss (kWh)		2.78	3.67	2.88	3.11	3.07	4.07	2.53	3.19
Bahco ventilation loss (kWh)		2.55	2.18	1.33	1.68	2.01	1.84	1.84	1.92
Natural ventilation rate (m ³ /h)									
Natural ventilation rate (m ³ /h)		40.75	57.71	51.67	65.50	73.33	90.06	51.32	61.48
Bahco ventilation rate (m ³ /h)		76.15	70.31	72.08	77.40	73.85	75.55	72.08	73.92
LATENT HEAT LOSS (kWh)									
		3.85	0.56	-0.16	-0.54	2.46	2.48	2.87	2.44
ELECTRICAL INPUTS (KWH)									
Useful heat inputs (estimated)									
Total electrical	0.69	16.06	18.72	15.52	13.04	23.84	13.84	15.08	16.59
Heaters	1.00	1.49	5.70	0.00	0.00	4.72	0.00	0.00	1.70
Cooker	0.50	2.14	1.89	1.60	1.87	1.76	2.44	2.48	2.03
Bahco	0.50	0.77	0.73	0.75	0.83	0.78	0.80	0.75	0.77
Water heating	0.50	1.75	2.25	3.50	2.00	1.99	1.75	2.75	2.28
Lights, power	0.80	9.90	8.14	9.66	8.34	14.59	8.85	9.10	9.80
METABOLIC INPUTS (estimated) kWh									
		5.56	5.56	5.56	5.56	5.56	5.56	5.56	5.56
HEAT BALANCE									
Inputs: Sun+metabolic+electric (kWh)		26.04	30.43	42.65	27.59	37.35	38.09	37.95	34.30
Losses: Transmission + vent+latent		33.63	31.65	7.30	13.54	22.32	11.82	17.08	20.42

Table 5. Summary of energy balance

Window data held on file HDWINBGC

	Front	Side	Rear	Side
Azimuth (degrees from N)	315.00	45.00	135.00	225.00
Glazed areas (m ²)	4.53	0.40	6.39	0.61
Normal transmission factors	0.65	0.62	0.65	0.62
Latitude (degrees)	53.10			
Ground reflectance	0.20			

Ventilation data held on file HDVENTBGC

Minimum natural ventilation rate	40.00	m ³ /h	
Natural ventilation constant (temperature)	2.70	m ³ /h per K	
Natural ventilation constant (wind)	5.40	m ³ /h per m/s	
Bahco constants	Slow	Normal	Boost
Flow (m ³ /h)	65.00	105.00	150.00
Power W	55.00	75.00	150.00

U value data held on file HDUVBGC

Room	WALLS							WINDOWS			
	Front	Side	Rear	Side	Ceiling	Floor	Front	Side	Rear	Side	
1 Lounge	0.00	4.50	2.25	0.00	0.00	6.10	0.00	0.00	8.20	0.00	
3 Dining	0.00	0.00	1.57	2.48	0.00	2.39	0.00	0.00	5.18	0.00	
4 Kitchen	1.68	0.00	0.00	3.02	0.00	3.60	5.22	0.00	0.00	5.43	
6 Hall	2.61	1.71	0.00	0.00	0.00	2.32	5.37	0.00	0.00	0.00	
8 WC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
9 Bedroom 1	0.00	0.00	1.83	3.67	3.00	0.00	0.00	0.00	6.15	0.00	
10 Bedroom 2	1.85	0.00	0.00	2.19	1.80	0.00	6.15	0.00	0.00	0.00	
11 Bedroom 3	0.00	2.32	1.91	0.00	1.96	0.00	0.00	0.00	6.12	0.00	
12 Landing	1.95	1.61	0.00	0.00	1.85	0.00	5.79	0.00	0.00	0.00	
13 Bathroom	0.00	1.67	0.00	0.00	1.19	0.00	0.00	1.92	0.00	0.00	

Whole house conduction coefficient (W/K)	145.00
Average solar reflectance of walls	0.50

Utilisation factor data held on file HDUFACTBGC

Heaters	1.00
Cooker	0.50
Bahco	0.50
Hot water	0.50
Residual	0.80

Occupancy details held on file HDCCBGC

Number of adults at home	2
Number of adults at work	2
Number of children at home	0
Heat production of adult at home (kWh/day)	1.46
Heat production of adult at work (kWh/day)	1.32
Heat production of child at home (kWh/day)	1.15

Table 6. Example of house constant data

Table 7. Consequences of Errors and Unknowns

Quantity	Error	Effect on energy balance (kWh/day)
Temperature (in or out)	0.5 K	2
Dew point	1 K	1
Wind speed	Still/average	2
Insolation	15% conversion error	5
Window transmission	0.1	
Cloud cover	0.5	1
Heat loss coefficient	10 W/K	4
Average U-value	0.05 W/m ² K	4
Window U-value	0.3 W/m ² K	1
Solar reflectance of walls	0.15	1
Ventilation rate	0.1 ac/h	2
Window opening	extra window for 1 hour	1
Bahco efficiency	0.1	1
Metabolism	1 person	2
Hot water utilisation	0.1	1
Curtains	all drawn at night	2

The table shows the effect on a daily average balance of an error in measurement or assumption. Figures were calculated for a typical winter's day: $T_o = 5^\circ\text{C}$, with moderate sunshine (2 kWh/m² on horizontal).

Table 8. Effect of frequency of analysis

Sunshine

Insolation on a vertical surface is estimated from measurements made on a horizontal plane (Basnett ECRC/N846). Maximum errors are likely to be as follows:

<u>Integrated insolation</u>	<u>Calculation frequency</u>	<u>Error</u>
Daily	Hourly	15%
Daily	Daily	30%
Weekly	Hourly	5%
Weekly	Daily	10%

Fabric Loss

Given a constant U-value, there is no loss in accuracy from using average rather instantaneous temperatures when estimating transmission loss through the wall. Heat storage in walls distorts short term measurements, and daily estimates are likely to be in error. 1 K temperature change in the wall over one week represents an average heat flow into the wall of 0.4 W/m^2 , which is over 10% of the normal heat flux in a well insulated wall.

Ventilation Loss

Ventilation heat loss is proportional to $N (T_i - T_o)$ where N is the ventilation rate. If either the ventilation rate or $(T_i - T_o)$ is constant, there is no error introduced by using average temperature difference and average ventilation rate. If the two quantities vary independently then the ventilation loss should be estimated each hour. In a house where ventilation rate changes from 1 to $\frac{1}{2}$ from day to night, coupled with a 5° fall in outside temperature, then there will be about a 5% error in ventilation loss estimated using averages. The error will be much greater in a situation where high ventilation rate is associated with high temperature difference.

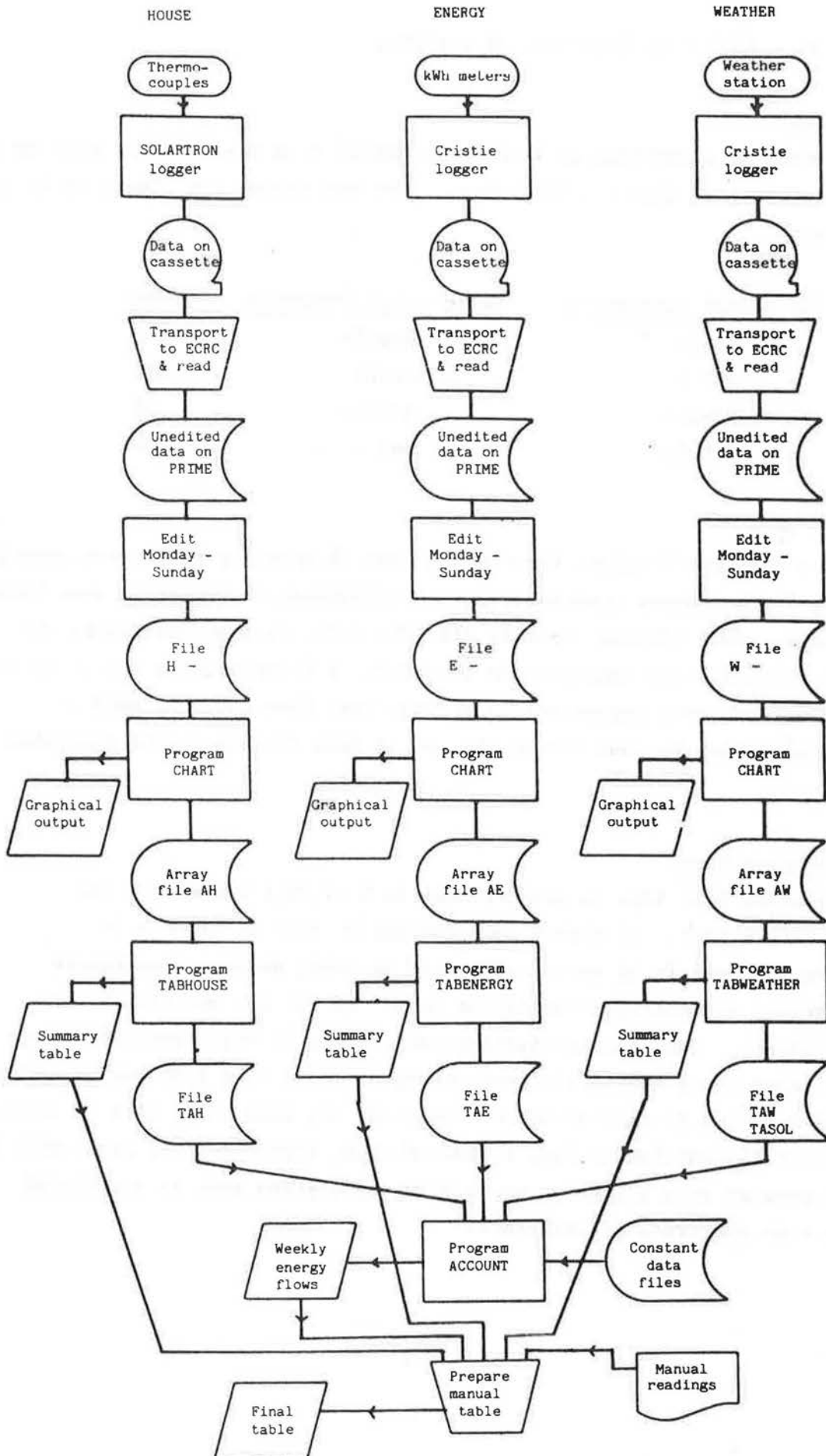


Figure 1. Flow of data, from logger to final analysis table

H22AG17-23JAN83 UNLOADED HOUSE DATA DAYS 17-23 FROM 0000 MONDAY 17JAN83 TO 2400 SUNDAY 23JAN83

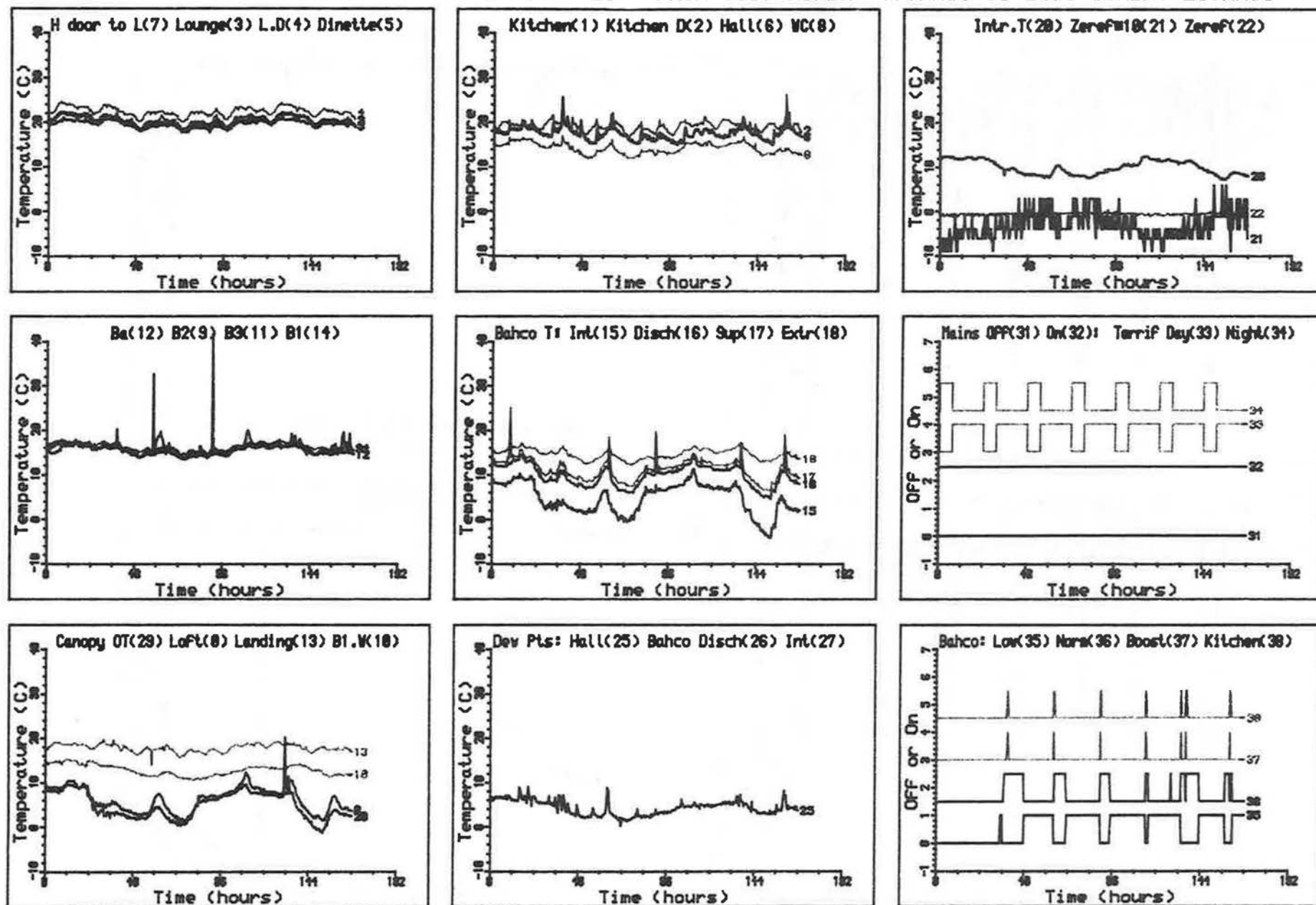


Figure 2. Graphical output from HOUSE data tape.

E22AG17-23JAN83 UNLOADED ENERGY DATA DAYS 17-23

FROM 0000 MONDAY 17JAN83 TO 2400 SUNDAY 23JAN83

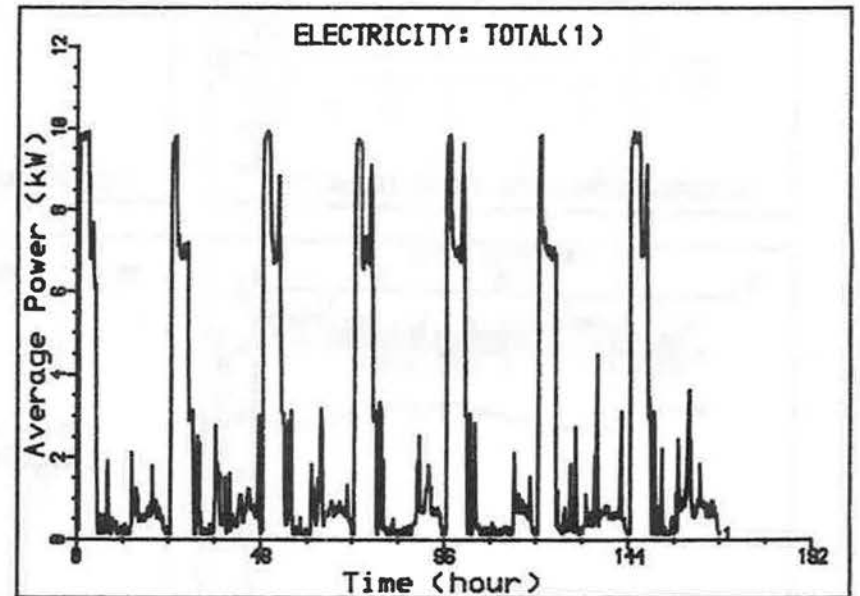
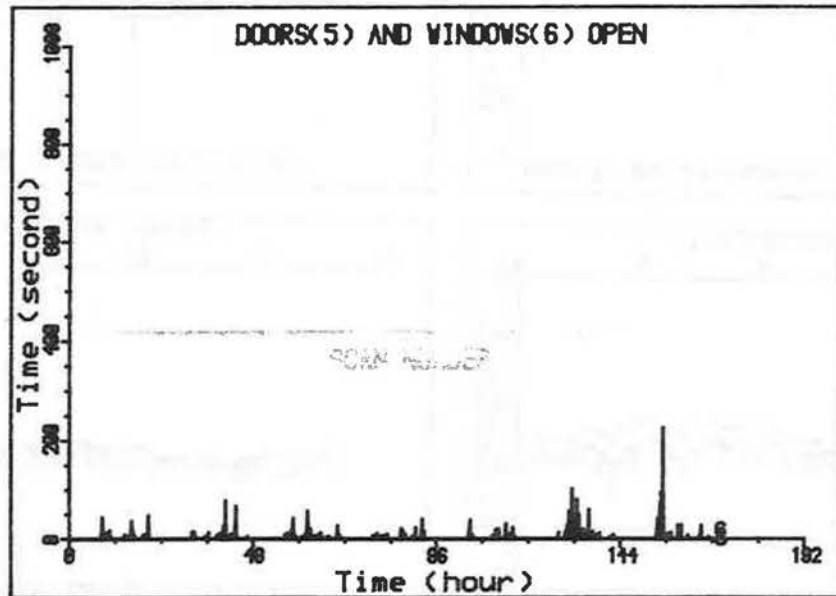
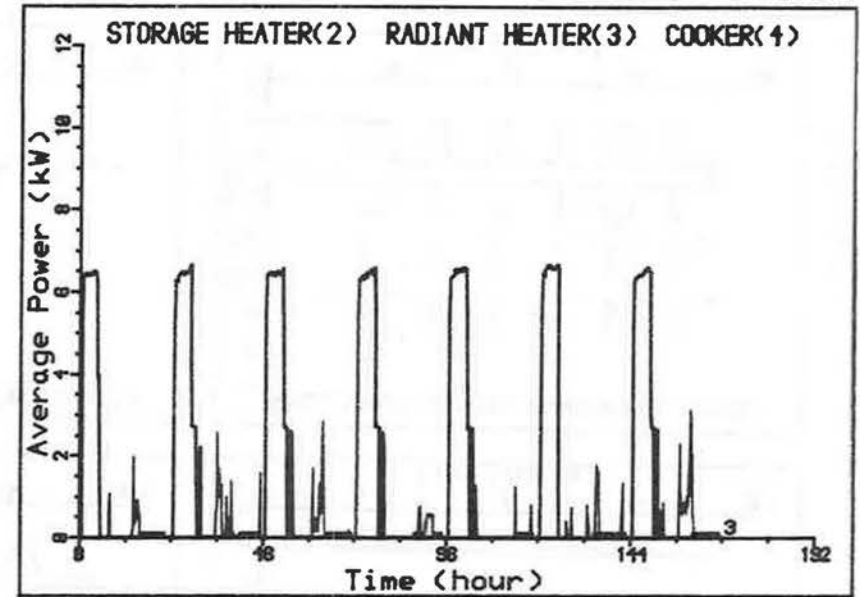
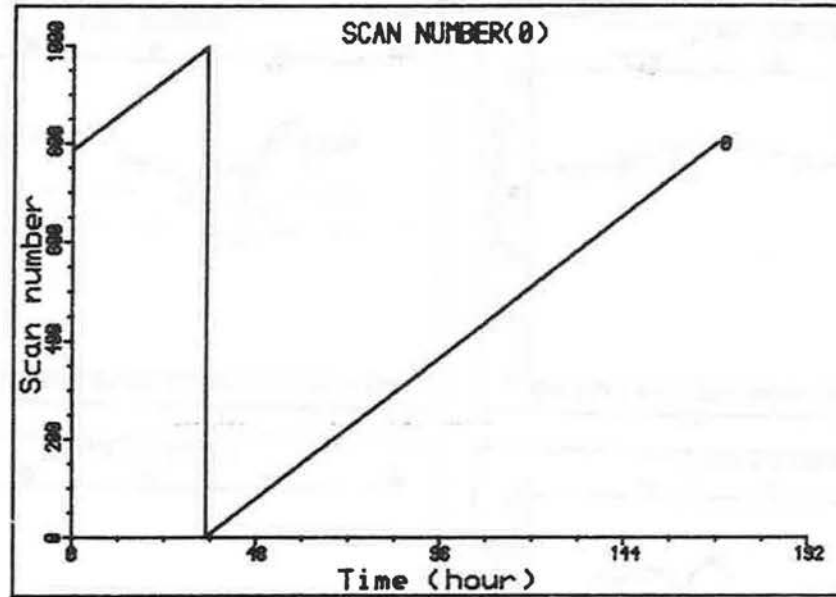


Figure 3. Graphical output from ENERGY data tape.

WAG17-23JAN83 UNLOADED WEATHER DATA DAYS 17-23

FROM 0000 MONDAY 17JAN83 TO 2400 SUNDAY 23JAN83

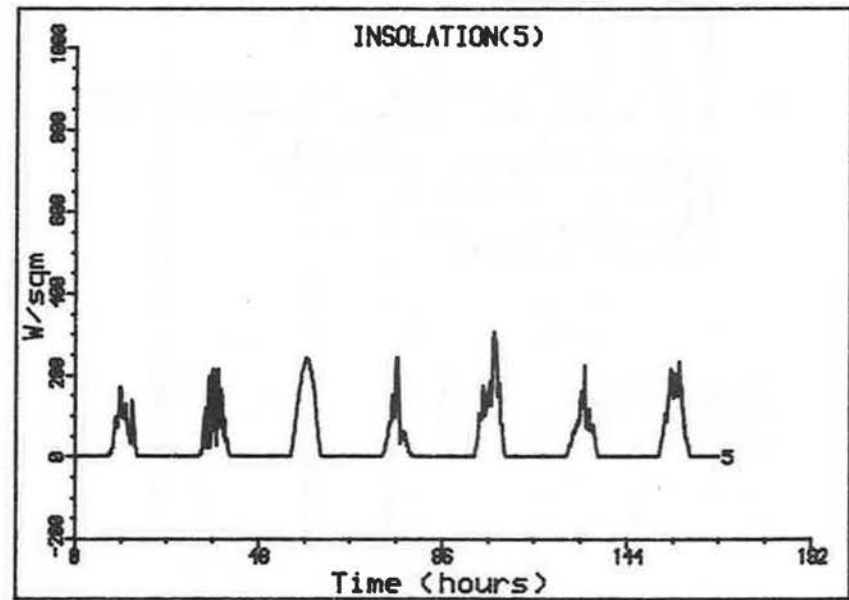
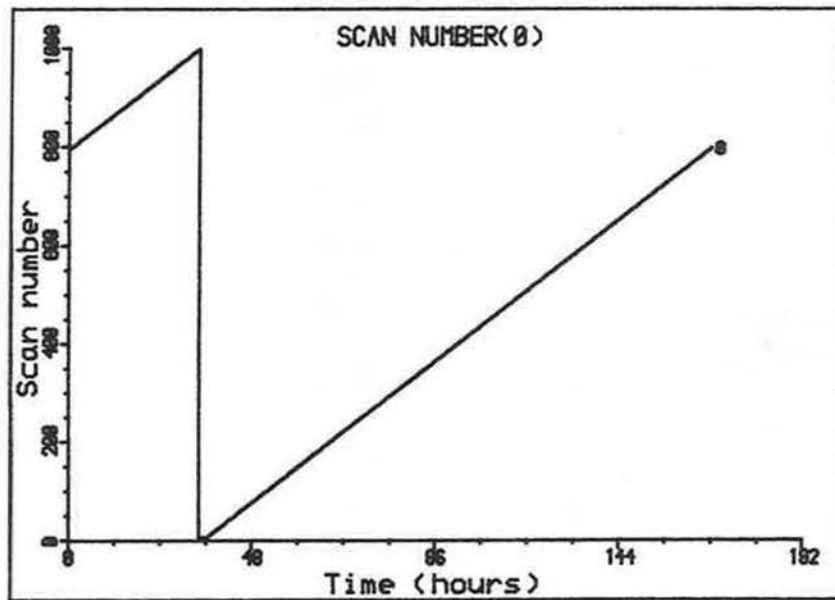
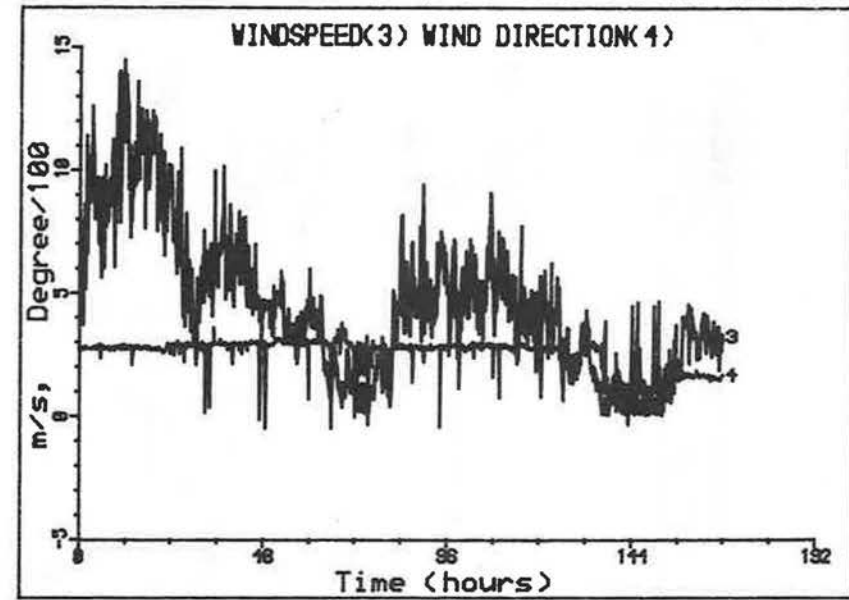
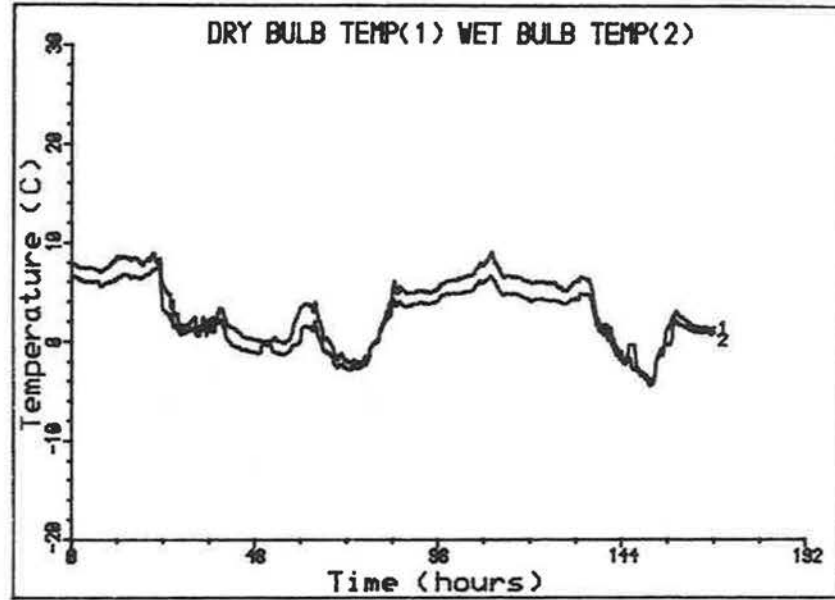


Figure 4. Graphical output from WEATHER data tape.

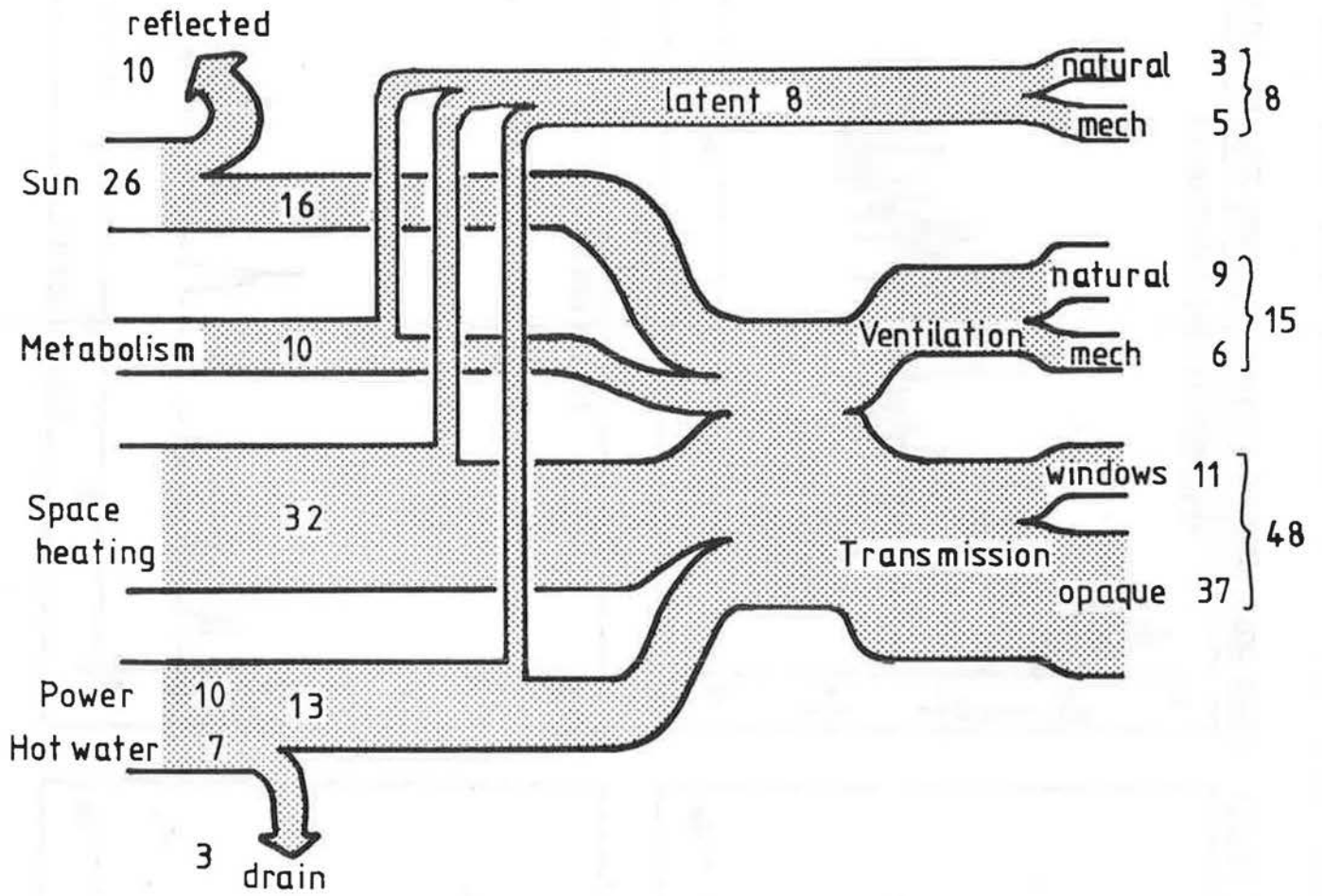


Figure 5. Energy flows in ECRC low energy house, shown as percentages of the total.

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WEEKLY ENERGY ACCOUNT FOR LOW ENERGY HOUSE

1. Description of Program ACCOUNT

Introduction. The low energy houses built in association with ECRC Capenhurst are being intensively monitored, to check whether their performance accords with expectation. Some 40 variables are recorded every 10 or 30 minutes on 3 data loggers. The data includes inside temperatures, outside weather and electrical energy inputs. Such a large amount of data has to be handled by computer.

Each week, the three magnetic tape cassettes from the data loggers are brought to Capenhurst. The first step is to read the cassettes into the main Prime computer, after which they are analysed to give a graph of each measured variable against time. The next step is to analyse each of the three sets of data to produce a summary of the week's data in the form of a printed table of daily and weekly averages. The final step is to analyse all the data together to produce a table of estimates of the energy inputs and outputs of the house. This final analysis is carried out by program ACCOUNT.

The analysis may be broken down into separate parts.

Solar gains.

Hourly insulations on the vertical surfaces of the house are estimated from the measured hourly horizontal insulations, using Basnett's algorithm. These are multiplied by the measured glass areas and estimated solar transmissions of the windows to give the total solar gains. No allowances are made for any shading of the windows by external obstructions.

Conduction losses.

The external conduction loss from each room is estimated from the daily average internal and external temperatures. The temperature difference is multiplied by the area*U-value of the surface element involved. The areas are measured or estimated from the builder's drawings. The U-values are estimated from knowledge of the structure and material thermal constants. An allowance for sunshine on the outer wall surface is made using the sol-air technique. The daily conduction loss is also estimated using the measured whole house heat loss coefficient and the inside average temperature.

Ventilation loss.

The natural and mechanical ventilation rates are treated separately. The natural ventilation rate is estimated every hour using the measured wind speed and recorded information on window and door opening. The hourly heat loss is calculated using the measured average internal temperature and the outside air temperature. The mechanical ventilation rate is estimated using the recorded speed settings of the Bahco system to give the air flow rates, which were measured before occupation. The corresponding heat loss is estimated each hour, using the measured Bahco intake and discharge air temperatures.

Electrical heat inputs.

The measured electrical energy used each day is classified into five categories, and the appropriate heat input found by multiplying the electrical energy by a utilisation factor, which expresses the fraction of the electrical energy input which appears as heat in the house. These utilisation factors are estimated from experience gained in field work

Metabolic heat inputs.

The heat input to the house from the metabolic activity of the occupants can only be estimated approximately. Average values of total heat inputs from adults and children are used. It is assumed that the occupants are absent on days when no door opening is recorded.

2. ORGANISATION OF UFD'S

The large amount of data to be handled each week necessitates organisation of the files into sub ufd's. The text of program ACCOUNT is held in ufd DAM. The compiled and loaded file is held in ufd CR, in which all the analysis is carried out.

MAIN UFD: CR HOUSE

SUB UFD'S PR Program sub ufd
Contains loaded files: TABENERGY, TABWEATHER,
TABHOUSE and ACCOUNT

A(address) e.g. A22AG. ACCOUNT sub ufd
ACCOUNT is called and run from this sub ufd.
The sub ufd contains a set of house constant
data files: HDUV, HDVENT, HDWIN, HDUFACT.

H(address) e.g. H22AG. House sub ufd.
Contains the data array AH(address)(date)
produced by CHART, and the logger wiring file
HDLOG(address). TABHOUSE is run from this sub ufd,
and the program writes the output summary file
TAH(address)(date) into this sub ufd.

E(address) e.g. E22AG. Energy sub ufd
Contains the data array EH(address)(date) produced by
CHART. TABENERGY is run from this sub ufd. Output
summary TAE(address)(date) is written into this sub
ufd. Contains the file of storage heater constants HDSTOR.

W(site address) e.g. WAG. Weather sub ufd
Contains the data array AW(site)(date) produced by CHART.
TABWEATHER is run from this sub ufd. Output summaries
TAW(site)(date) and TASOL(site)(date) are written into
this sub ufd.

3. FILE NAME PROTOCOL

Files used in the weekly analysis of the low energy houses are named methodically, to provide unambiguous identification. Common elements of the names are:

(address) e.g. 22AG
(date) e.g. 6-12SEP81

The site address on weather tapes is truncated e.g. AG

House constant data files HD

The permanent data for each house is stored in a series of files, which are rarely altered. The form of the filename is HD(type)(address).

(type) specifies the type of data:

LOG	logger connections. Suffix .SL indicates shared logger.
UV	U values
WIN	Window areas, orientations and transmissions
VENT	Ventilation constants
UFACT	Utilisation factors
STOR	Storage & low rate immersion ratings and off peak times
OCC	Occupancy pattern and metabolic heats

Thus HDUV22AG contains the U-values of 22 Ash Grove.

Weekly data arrays.

The data arrays produced by CHART from the logger tapes are subsequently used by the TAB programs. The data arrays are stored in files with names of the form:

(type)(address)(date)

(type) specifies:

AH	array of house data, derived from Solartron
AW	array of weather data, from Cristie in weather station
AE	array of energy data, derived from Cristie logger in house

(address) is truncated for weather data.

e.g. AE22AG10-16JUL81
or AWAG10-16JUL81

From Sep 82, 8&9 Gairloch Close share a single Solartron logger.
The address on the H file is coded 8/9GC

(date) refers to the week being analysed. The dates should always cover a full seven day period, starting on Monday and finishing on Sunday, even if the file contains less than seven full days data. This is necessary so that the sets of data produced by the three TAB programs have matching names when they are analysed by ACCOUNT. Information on the actual start and finish times of the data is contained in the file headings. While in current use, the file name should not contain any extra symbols (such as £).

The preferred form of the month name is the first three letters.

FILE HEADINGS

Each of the data arrays starts with three lines of heading, in standard form. The headings identify the data to the operator, and contain information which is read and used by the TAB programs.

APPENDIX Description of Program ACCOUNT

First line refers to the unloaded file used by CHART e.g.
E22AG21-27DEC81 UNLOADED ENERGY DATA DAYS 355-361

This line is read by TABWEATHER to establish the day number.

Second line gives the start and finish of the data e.g.
FROM 1030 TUESDAY 22DEC81 TO 1730 SATURDAY 26DEC81

This line contains the actual start and finish times of the data contained in the file. It will be read by the TAB programs. Month name should be initial three letters, weekday names in full.

Third line gives the amount of data contained in the file e.g.
THERE ARE 7 COLUMNS AND 1009 ROWS OF DATA

This line is written automatically by CHART, and read by the TAB programs.

4. VARIABLE DATA FILES

Each of the family of TAB programs produces a summary of data, which is stored on file for subsequent use by the ACCOUNT program. The filenames are created automatically by the TAB programs, and opened from within the program.

House data. File TAH(address)(date) produced by TABHOUSE

((ATABH(I,J),I=1,50),J=1,8)	array of daily averages
((ATIMP(I,J),I=1,24),J=1,7)	hourly internal average temperatures
((ATOMP(I,J),I=1,24),J=1,7)	hourly external temperatures
((ABINT(I,J),I=1,24),J=1,7)	hourly Bahco intake temperatures
((ABDIS(I,J),I=1,24),J=1,7)	hourly Bahco discharge temperatures
((LABSET(I,J,K),I=1,24),J=1,7),K=1,3)	logical Bahco settings

Weather data. File TAW(site)(date) produced by TABWEATHER

((ATABW(I,J),I=1,10),J=1,8)	array of daily averages
((AWIND(I,J),I=1,24),J=1,7)	hourly wind speeds (m/s)

File TASOL(site)(date) produced by TABWEATHER

((ASOL(I,J),I=1,24),J=1,7)	hourly horizontal insolation (Wh/m ²)
IDNUM	day number of first day

Energy data. File TAE(address)(date) produced by TABENERGY

((ATABE(I,J),I=1,15),J=1,8)	array of daily averages
((ADRS(I,J),I=1,24),J=1,7)	hourly door opening
((AWDWS(I,J),I=1,24),J=1,7)	hourly window opening

5. HOUSE CONSTANT DATA FILES

The constant data for each house is held in four data files. Data may be entered into these files if desired during the execution of ACCOUNT. A summary of the contents of the files may be optionally printed out at the end of the execution of ACCOUNT.

File HDUV(address). U-value data

File HDUV contains the array AUVAL, stored in order
 ((AUVAL(I,J),I=1,14),J=1,10)

Each row of the array contains the 10 AU values of one room of the house. Since only external heat flows are calculated, all internal surfaces, bounding another room of the house, are given AU values of 0. An AU value is the product of area and U-value for one room surface. Each room is divided into opaque and window subdivisions. This is because the solar gains of the two types of surface are treated separately. The 10 values are listed in the order:

4 walls (clockwise from front of house), ceiling, floor,
 then four windows in the same order.

The numbering of the rows of the array follows the standard numbering used in program TABHOUSE. Thus not all rows are full:

1	Lounge
3	Dining room
4	Kitchen
6	Hall
8	W.C.
9	Bedroom 1
10	Bedroom 2
11	Bedroom 3
12	Landing
13	Bathroom

Last row contains: AUVAL(14,1) whole house transmission coefficient W/K
 AUVAL(14,2) average solar reflectance of walls

File HDUFACT(address) Utilisation factors.

File HDUFACT contains the estimated proportions of the electrical energy input to the house that appears as heat within the house. The factors are contained in the array AQFACT(10).

AQFACT(1)	overall utilisation factor. (no data:computed)
AQFACT(2)	heater utilisation (unity)
AQFACT(3)	cooker utilisation
AQFACT(4)	Bahco utilisation
AQFACT(5)	residual utilisation

Residual energy includes water heating, lighting power, and the bedroom heaters.

File HDVENT(address). Ventilation data.

File HDVENT contains the ventilation constants for a house. They are, in order.

VCMIN,VCT,VCW	natural ventilation constants
VSL,VMED,VBST	Bahco flow rates (m ³ /h)
WSL,WMED,WBST	Bahco power consumptions

File HDWIN(address). Window data.

File HDWIN contains data on the windows. The windows on each of the four sides of the house are lumped together, and the four sides are always referred to in the same order: front of house first, then the other sides in clockwise order.

AREA(4)	m ²	area of glass (not including frame)
AGZ(4)		solar heat transmission at normal incidence
ANGLR(4)	radians	azimuth from N
DLAT		latitude
GR		ground reflectance

Note that the azimuth angles of the windows are stored in radians. When entering data via subroutine DWINDOW, or when the data is output by WRCONST, the angles are given in degrees. The solar heat transmissions are for the sun's rays normal to the plane of the window. Adjustments are made within the program for off-axis transmission.

File HDOCC(address) Occupancy data

File HDOCC contains data on the occupancy of the house, and on the expected metabolic heat contribution of the occupants to the heat balance of the house. The data contained in the file is, in order:

NAH	integer	number of adults at home
NAW	integer	number of adults at work
NCH	integer	number of children at home
HAH	kWh/day	heat production per adult at home
HAW	kWh/day	heat production per adult at work
HCH	kWh/day	heat production per child at home

6. PROGRAM ACCOUNT. List of subroutines. All subroutines are filed under their own name.

ACCOUNT	Main program
TITLE	Identifies program version on screen
INFILES	Opens variable data files and reads data
INCONST	Opens constant data files and reads data
DUHOUSE	Updates HDUV U-value file
DUFACTOR	Updates HDUFACT utilisation factor file
DVENT	Updates HDVENT ventilation data file
DWINDOW	Updates HDWIN glazing factor file
DOCC	Updates HDOCC occupancy factors
SETLA	Sets logical arrays of known faults
CHECKH	Checks house data
CHECKW	Checks weather data
CHECKE	Checks weather data
SOLAR	Calculates and writes weekly solar gains
SUN	Calculates daily sunshine
CONDUCT	Calculates and writes conduction losses
ULOSS	Calculates one day's conduction losses
VENTIL	Calculates and writes ventilation losses
LATENT	Calculates and writes latent losses
POWERIN	Calculates and writes electrical heat inputs
METAB	Estimates and prints metabolic heat inputs
BALANCE	Summarises and prints heat inputs and outputs
WRCONST	Writes table of constant data

Library subroutines: RDYSNO, OPENR, OPENW, RDREAL, RDINT2

7 . VARIABLE DATA INPUT.Subroutine INFILES

Subroutine INFILES asks the operator to supply the address of the house and the dates of the week analysed. The routine then constructs the appropriate file names:

```
TAH(address)(date)
TAE(address)(date)
TAW(site)(date)
TASOL(site)(date)
```

The routine then asks if the files are held in another ufd. If the answer is negative, it is assumed that the files are in the same ufd as the program is being run in. Normally, the data files are held in separate ufds. The routine asks the operator to provide the main ufd heading e.g. CR. The routine then constructs the following tree names:

```
CR>H(address)>TAH(address)(date)
CR>E(address)>TAE(address)(date)
CR>W(site)>TAW(site)(date)
CR>W(site)>TASOL(site)(date)
```

The existence of the files is checked. If OK, the following data is read:

```
ATABH
ATIMP, ATOMP
ABINT, ABDIS
LABSET
ASOL, IDNUM
ATABW, AWIND
ATABE
ADRS, AWDWS
```


8. CONSTANT DATA INPUT. Subroutine INCONST

The routine constructs the following file names:

HDUV(address)	contains U values
HDUFACT(address)	contains utilisation factors
HDVENT(address)	contains ventilation constants
HDWIN(address)	contains window data

The operator is asked if the files are complete and up to date. If yes, the following data is read in:

AUVAL
AQFACT
VCMIN,VCT,VCW,VSL,VMED,VBST,WSL,WMED,WBST
AREA,AGZ,ANGLR,DLAT,GR

If the operator wishes to alter the files of constant data, the routine calls the four data entry routines:

DUHOUSE
DUFACTOR
DVENT
DWINDOW

9. DATA CHECKING. Subroutines CHECKH,CHECKW,CHECKE

These routines carry out simple checking of the variable data input to ACCOUNT. Data is checked against upper and lower bounds, and where appropriate for missing data. If apparently faulty data is found, it is identified on the VDU screen. At the end of the routine, a warning message is written onto the results file, and the operator asked if he wishes to continue execution.No other action is taken by the program.

The operation of the routines is fully described in the program listings.

C

C Upper and lower bounds for checking file TAH

Channel	Variable	units	Lower	Upper
Array ATABH				
1-14	Internal house (24h)	degC	5	35
20&22	Internal dewpoints (24h)	degC	4	25
21	Intake dewpoint (24h)	degC	-10	25
15&19	Outside (24h)	degC	-10	30
Plus: Bahco intake (15)<discharge(16) supply(17) <extract(18)				
Array ATIMP	(hourly internal average temp)		5	30
Array ATOMP	(hourly external average temp)		-10	30
Plus: Check if all values =0				
Array ABINT	(hourly Bahco temps)		-10	30
Array ABDIS	(hourly Bahco discharge)		5	30
Array LABSET	Check for all identical			

C

C Upper and lower bounds for checking ATABE

Channel	Variable	Units	Lower	Upper
1	Total low rate	kWh	1	100
2	Total day rate	kWh	1	100
3	Storage heaters	kWh	1	50
4	>lounge	kWh	0	28
5	>hall	kWh	0	21
6	Radiant heater low	kWh	0	10
7	Radiant heater day	kWh	0	32
8	Cooker low rate	kWh	0	10
9	Cooker day rate	kWh	0	30
10	Residual low rate	kWh	0	30
11	Residual day rate	kWh	0	50
12	Doors open	hours	0	12
13	Windows open	hours	0	24
14	Water, low rate	kWh	0	20

Upper and lower bounds for checking ATABW

Variable	Units	Low	High
1 Air temperature DB	deg C	-10	30
2 Screen wet bulb	deg C	-10	25
3 Windspeed	m/s	0.001	50
4 Wind direction	deg from N	0	360
5 Horiz. insolation	Wh/m2day	1.0	SMAx
6 RH sensor	per cent	20	100
7 V.press from 1&2	kPa	0.3	4.0
8 RH from 1&2	per cent	20	100
9 V.press from 1&6	kPa	0.3	4.0
10 Time	hours	0	999

SMAx=5000+3890*sin((IDNUM-90)*PI/180) IDNUM is day of year

10. SOLAR GAINS. Subroutines SOLAR and SUN

MEASUREMENT

Variables

Sunshine	solarimeter & integrator
----------	--------------------------

Constants

Window area	glass area measured
Window orientation	magnetic compass
Glass transmission	published data
Ground reflectance	published data

RECORDING

Horizontal insolation Channel £5 on weather Christie

ANTECEDENT ANALYSIS

The weather logger tape is processed by CHART to give a graphical output, and a cleaned up data array. This array is analysed by TABWEATHER to produce a weekly summary table, plus an array of hourly horizontal insulations ASOL(24,7) Wh/m²

SUMMARY OF ANALYSIS

The analysis is based on the program developed by Basnett (ECRC M846). From the horizontal insolation, time of day and latitude, Basnett's procedure produces, for each hour of the day, estimates of

DIR	direct component of insolation(Wh/m ²), normal to sun
DIF	diffuse component on vertical surface

The solar gain through unit area of window is given by

DIR*COS(THETA)*T	direct component
+ DIF*TDIF	diffuse component
+ HOR*GR*TDIF	ground reflected component

where:

THETA	angle between normal to window and sun
GR	ground reflectance
HOR	horizontal insolation Wh/m ²
To	normal solar heat transmission
T	direct solar transmission
	T=To if THETA < 1.0 radians
	T=To*(1.57-THETA)/0.57 if THETA > 1.0 radians
TDIF	diffuse transmission=0.9*To

11. CONDUCTION LOSS. Subroutines CONDUCT and ULOSS.

MEASUREMENT

Variables

Room temperatures	thermocouples at high level
Outside air temp.	PRT in weather station
Sunshine	solarimeter at weather station
Wind speed	anemometer at weather station

Constants

Areas	measured or estimated from plan
U-values	estimated from construction details
Whole house loss	measured during house calibration
Solar reflectance of walls	Published data

RECORDING

Room temperatures	Channels #1-13 on Solartron
Outside air temp.	Channel #1 on weather Cristie
Insolation	Channel #5 on weather Cristie
Wind speed	Channel #3 on weather Cristie

ANTECEDENT ANALYSIS

The logger tapes are separately processed by CHART, giving a graphical output and cleaned up data arrays. The arrays are processed by TABHOUSE and TABWEATHER to produce weekly summary tables, and arrays of data which will be used by the conduction subroutine. During the execution of ACCOUNT the sunshine data is analysed by subroutine SOLAR to produce an array of insulations on vertical surfaces.

ATABH(50,8)	daily average house temperatures
ATABW(10,8)	daily average weather data
ASWLWK(5,8)	daily insolation on vertical surfaces

DATA

In addition to the above arrays, CONDUCT requires constant data held in AUVAL(14,10). For each room, the AU value(W/K) is recorded for six opaque surfaces and four vertical glazed surfaces. Only external surfaces are recorded. The array also holds the whole house heat loss coefficient (W/K) and the average solar reflectance of the surfaces.

SUMMARY OF ANALYSIS

The analysis is based on daily averages.

First the 24h average solair temperature is estimated for each surface.

$TSOLAIR = TO + (1-R)*E/HO$	E is mean 24h irradiance (W/m ²)
$HO = HC + HR$	
$HC = 5.8 + 4.1*V$	10<HC<50 (CIBS A3 formula)
$HR = 5$	V is wind speed (m/s)
	HC is external transfer coefficient (W/m ² K)
	R is average solar reflectance

For each room, average temperature TA, evaluate:

$AU(TA-TSOLAIR) + AU(TA-TO)$ summed over all surfaces
where solair temperature only applies to opaque surfaces.

Also evaluate the loss based on the whole house heat loss coefficient, both with and without the effect of sunshine:

$24*(TAV-TSOLAIRAV)*loss\ coefficient$
$24*(TAV-TOAV)*loss\ coefficient$

Notes. The actual program ACCOUNT erroneously used HC instead of HO in the solair formula, thus overestimating the effect of sunshine on the opaque surfaces by some 20%. The whole house heat loss formula above is strictly in error, since it applies the average solair temperature to the entire fabric. The solair increment should be reduced in proportion to the glazed area.

12. VENTILATION LOSS. Subroutine VENTIL and Subroutine LATENT

VENTIL estimates ventilation rates and heat losses.

MEASUREMENT

Variables

Wind speed	anemometer at weather station
Doors and windows	burglar alarm circuit. Time open recorded.
Bahco temperature	thermocouples in intake and discharge ducts
House temperature	average of all room thermocouples.
Outside temperature	thermocouple at canopy, TAB29 in TABHOUSE
Bahco settings	latching circuit on switches.

Constants

Ventilation constants	measured by tracer gas decay before occupation
Bahco flow rates	measured before occupation

RECORDING

Windspeed	Channel 3 on weather Cristie
Door opening	Channel 5 on energy Cristie
Window opening	Channel 6 on energy Cristie
Bahco temperatures	Channels 15 & 16 on Solartron
House temperatures	Channels 1-13 on Solartron
Outside temperature	Channel 29 on Solartron
Bahco operation	Channels 35-37 on Solartron

ANTECEDENT ANALYSIS

The three logger tapes involved are separately processed by CHART to give graphical outputs and cleaned up data arrays. These arrays are analysed by the three TAB programs to produce weekly summary tables, and the arrays of data required by the ventilation loss subroutine VENTIL:

AWIND(24,7)	hourly wind speeds (m/s)
ATIMP(24,7)	hourly mean indoor temperature
ATOMP(24,7)	hourly mean outdoor temperature, variable TAB19 in TABHOUSE
ABINT(24,7)	hourly Bahco intake temp., TAB15 in TABHOUSE
ABDIS(24,7)	hourly Bahco discharge temperature, TAB16 in TABHOUSE
AWDS(24,7)	hourly window opening, hours/hour
ADRS(24,7)	hourly door opening, hours/hour
LABSET(24,7,3)	Bahco settings

DATA

In addition to the above arrays, VENTIL requires constant data:

VCMIN, VCT, VCW	natural ventilation constants
VSL, VMED, VBST	Bahco flow rates (m ³ /h)

SUMMARY OF ANALYSIS

Bahco ventilation

The setting of the Bahco unit is logged on the Solartron logger. The average Bahco flow rate VBAH for the hour is taken to be the average of the flow rates in operation during this period. This overestimates the effect of short periods of a particular setting e.g. 5 min of Boost in an hour has the same effect as 55 min. The error will not be serious, given the low expected rate of Bahco switching.

The natural ventilation rate is calculated from the natural ventilation constants, the wind speed V and the inside-outside temperature difference DELTAT:

$$VNAT = VCT * DELTAT + VCW * V$$

A minimum ventilation rate VCMIN is assumed, below which VNAT cannot fall. This is increased by a factor of 3 when the windows are open, and by a

factor of 10 when a door is open. The analysis assumes that window and door opening occurs together.

The ventilation heat loss is given by:

$$Q_{BAH} = V_{BAH} * (\text{discharge-intake temp.}) * 0.33 \quad W$$

$$Q_{NAT} = V_{NAT} * (\text{internal-outside temp.}) * 0.33 \quad W$$

This assumes a volumetric specific heat of air of 1200 J/m³K.

The ventilation loss is estimated hourly. Daily totals and weekly averages are written into the output table.

Subroutine LATENT estimates total latent heat loss

MEASUREMENT

Dewpoints in hall and Bahco ducts	LiCl dewpoint sensors
External humidity	Wet and dry bulb Pt resistance in screen

RECORDING

Dewpoints	Channels 25-27 on Solartron logger, TAB 20-22 in TABHOUSE
Wet and dry bulb	Channels 1 & 2 on weather Cristie

ANTECEDENT ANALYSIS

LATENT uses the ventilation rates estimated by VENTIL. The recorded dewpoints are corrected using the manufacturer's correction chart. An additional correction of + 1K is made to the 9103 sensors installed in the ducts in Gairloch Close, to compensate for the cooling effect of the airflow.

SUMMARY OF ANALYSIS

The latent heat loss from the house is derived from the difference in indoor and outdoor vapour pressures and the ventilation rate. The mechanical and natural losses are treated separately. The loss is estimated using daily averages of ventilation rate and vapour pressure.

Equation (2.24) of Croome & Roberts gives

$$\text{Latent loss (kW)} = 864000 * V * (g_1 - g_2) / (273 + T_2)$$

V ventilation rate m³/s

g moisture content kg/kg

T₂ supply air temperature deg C

Equation (3.2) gives

$$\text{Moisture content } g = 0.622 * pa / (P - pa)$$

pa moisture vapour pressure kPa

P atmospheric pressure kPa

Approximations:

$$P - pa = 100 \quad \text{kPa}$$

$$273 + T_2 = 280 \quad \text{deg C}$$

Formula used by LATENT:

$$\text{Latent loss (W)} = 5.3 * V * (p_1 - p_2)$$

(p₁ - p₂) vapour pressure difference kPa

13. ELECTRICAL HEAT INPUTS. Subroutine POWERIN

MEASUREMENT

Variables

Electrical inputs
Bahco settings

Constants

Utilisation factors estimated from other trials
Bahco power manufacturer's data

RECORDING

Electrical inputs energy Cristie
Bahco settings Solartron logger

ANTECEDENT ANALYSIS

The logger tapes are processed by CHART. This produces a graphical plot and cleaned up data arrays. The arrays are analysed by the TAB programs, which produce weekly summaries, and data on file for use by ACCOUNT.

SUMMARY OF ANALYSIS

The routine POWERIN estimates heat inputs to the house from electrical sources.

Bahco. The settings of the Bahco unit are recorded on four logical channels. E

The data is analysed so that the average Bahco power in a one hour interval is taken to be the average of the settings in operation during that interval. This gives an estimate of the Bahco energy used in one day.

The partition of electrical energy is calculated:

1	Total input	recorded directly
2	Heaters (storage+lounge radiant)	recorded directly
3	Cooker input	recorded directly
4	Bahco input	estimated from settings
5	Water heating	estimated, low rate only
6	Residual	$1-(2+3+4)$

The residual part includes water heating, lighting, power and bedroom heating. Manual weekly readings of several kilowatt hour meters are available to estimate a more detailed breakdown.

Heat inputs to the house are estimated from

Electrical input * utilisation factor

The overall utilisation factor is estimated from
(heat inputs)/(total electrical input)

