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A CRITICAL EVALUATION OF THE COMPUTERISED, INSTRUMENTED RESIDENTIAL AUDIT (CIRA) PROGRAM

by

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To Aai ani Baba

ABSTRACT

The objective of this study was to make a complete evaluation of the Computerized, Instrumented, Residential Audit (CIRA) program as an energy analysis program for residential buildings. This goal was accomplished in three steps :

1. Energy consumption predicted by CIRA was compared against the metered energy use for selected residential dwellings.
2. A comparative study between CIRA and DOE-2.1a was performed. Heating loads, solar gains and internal gains were analysed and compared. Heat losses from the underground walls and floor predicted by CIRA and a finite difference heat conduction program HEATING5 were compared.
3. Finally, the calculation algorithms within CIRA were critically examined in detail.

From the first study, it was concluded that for average residential buildings the CIRA predicted energy consumption agreed within 22% of the metered energy use on an annual basis. This is a good agreement considering the simplicity of the program.

The comparative study of CIRA revealed that large discrepancies between the CIRA and DOE-2.1a-predicted heating loads occured during the swing months. The agreement was found to worsen when airtight structures with passive solar features and high insulation levels were modelled. This was attributed to

the fact that CIRA always used a 100% solar and internal gain utilization. The comparison of underground heat losses predicted by CIRA and HEATING5 showed that CIRA could be expected to yield reliable results for seasonal heat loss only.

The critical examination of the calculation algorithms used in CIRA showed that the basement model was too simplified and there was no provision to model a basement as a conditioned space. The approaches used for calculating solar gains and radiative heat loss were found to be thorough. The infiltration model ignored the effect of wind direction on infiltration. The variable base degree day procedure for calculating monthly heating load was judged to be excellent.

In summary, it is concluded that CIRA can be used with confidence for simulating houses of average construction, low or moderate insulation levels and low or moderate solar and internal gains. CIRA is not recommended for modelling very tight houses with high insulation levels, and high solar and internal gains.

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1. INTRODUCTION

The motivating force for undertaking this project is the current energy crisis. Our energy resources are finite, but energy consumption is continual. Moreover, due to limited resoures, the energy costs are also increasing. Increasing attention is therefore being paid to the conservation of energy in all walks of life. There are essentially two ways of solving this problem.

The first way is to look for alternative energy resources. It will not be very long before the World will run out of fossil fuels. Scientists and engineers are trying to economically harness the ever available solar energy. Nuclear energy and biomass are also potential sources of energy, and they could significantly reduce the consumption of natural gas and oil.

The other way is to minimize energy consumption in the built environment. Almost one fifth of the energy consumption in Canada occurs in residential structures. Conservation of energy in dwellings thus assumes a great deal of importance.

This project belongs to the second strategy outlined above. The current housing stock in Canada is 4 million units and, annually, approximately one hundred thousand new houses are built(1). Therefore, there is a great potential for reducing the national energy demand by performing a systematic study of energy use in buildings.

Energy analysis programs are essential tools in analysing energy use in buildings. Computer simulation of buildings offers numerous advantages over a corresponding experimental investigation (e.g. a monitoring study). It involves lower costs compared to actual monitoring. Modelling of a building can be done in a short time. The implications of several energy conservation features can also be studied in a short time. On the other hand, a corresponding experimental determination would take a very long time. Any situation can be simulated by computer, e.g. one may easily vary the wall resistance or the floor area of the house. In an experimental setup, such changes may not be possible due to restrictions on time, money and labour.

Computer simulation permits analysis of the various energy transfers and planning of different building designs. Moreover, an economic analysis of different retrofits can be carried out.

1.1 Literature Survey

Hall(1) used the DOE-2.1a program to calculate heating energy use for two residential houses located in Windsor. He found that the energy predictions made by this program agreed extremely well with the actual metered energy use over the entire calender year as well as on a monthly basis.

Researchers at the Lawrence Berkeley Laboratory(2) compared heating loads predicted by CIRA and DOE-2.1 for the Hastings Ranch house in seven U.S. cities. They analysed two cases. In the first case, comparisons were made for a constant indoor temperature. The difference between CIRA and DOE-2.1 predictions was 0.9 % ± 7.3 %. The second case involved a 5 °F thermostat setback. The difference between CIRA and DOE-2.1a predictions was 6.5 % ± 8.5 %.

Colborne, Hall and Wilson(3) made a critical analysis of two programs, namely HOTCAN and CIRA. They used DOE-2.1a program for comparative purposes. Heating loads, heat losses and heat gains for a conventional single storey house were calculated using HOTCAN and CIRA, and the results were compared with those obtained using DOE-2.1a. Annual heating loads, predicted by HOTCAN and CIRA, were within 9 % of the DOE-2.1a values. The individual component heat losses and gains varied from the DOE-2.1a values by over 100 % because of different calculation methods and definitions.

Little(15) has reported on work dealing with the evaluation of several energy analysis programs. As part of this work, five energy analysis programs were examined in detail with reference to their capabilities relevant to residential buildings. These were : DOE-2.1a, ENCORE-CANADA, HEAP, REAP and TRNSYS. The models for space temperature, basement, attic, solar gains and the HVAC systems were examined. Thus, it was possible to identify the strengths and weaknesses of the various models used in each program.

The following conclusions were drawn from the literature survey:

Validation of an energy analysis program can be done in two ways.

The first way is to make a comparison of the energy demand predicted by the program under question with the actual energy demand. This is a direct, and perhaps the best, way of validating any program. In order to have faith in a simulation program, however, a number of such validations have to be done for a variety of houses in different weather conditions. Therefore, this approach is not always feasible because of restrictions on time, money and availabilty of data.

The other way of validation is to compare the results predicted by the program with those predicted by another program of reference. A program of reference is one which has been previously extensively validated. Hence, this approach to validation requires the availabilty of a program in which sufficient confidence has been established.

The engineering models and assumptions upon which the program is based need to be examined to identify the scope and limitations of the program. Based upon such analyses, the prospective user can make a decision as to whether or not the program would be usable for the analysis of a particular building of interest.

1.2 Objectives

There are not many computer programs which specifically address residential buildings. Sophisticated programs like DOE-2.1a can be used for analysing residential structures. However, its complexity, which includes the ability of analysing commercial buildings, causes some limitations such as cost, running time, large computer memory requirements etc. Computerised, Instrumented, Residential Audit (CIRA) is a new energy analysis program developed at the Lawrence Berkeley Laboratory, U.S.A., specifically for residential buildings. It calculates monthly and annual heating loads for single family structures. Some prominent features of the program are:

It is user-oriented. The user does not have to spend time in learning any specific language to model a house. In most computer programs, the user has to invest a great deal of time and effort in learning a specific building description language.

It is an interactive program. If the user does not understand a question, he can ask for "help" from the program, to which the program responds by providing a detailed explanation of the question. Similarly, if the user cannot answer a question, he can get a list of possible answers as well as a default answer to the question from the program.

It needs a short simulation time, of the order of a few minutes.

It is a microcomputer based program, available on a floppy disk. It is inexpensive compared to most other energy simulation programs.

Thus, CIRA appears to be attractive from the perspective of cost, ease of use and simulation time. It will be a great asset to energy conservation programs if it is proven to be reliable. It is a new program and it has not yet been thoroughly validated. In order to have confidence in its results, it is necessary to make a thorough analysis of the program.

The present study aims at accomplishing this goal and make the prospective user aware of the scope of applications of the program, its strengths and weaknesses and in general the reliability of the program. The user can then make an educated decision as to whether or not he should use the program in the field of building energy.

The objective of this study can therefore be stated as a critical evaluation of CIRA. This will be accomplished in three phases :

First, the program will be validated against house performance data. Utility bills are available for several houses in Windsor, Ontario. This will provide a direct validation of CIRA.

Second, the program will be validated against other simulation programs. It has been previously shown that the DOE-2.1a program is in good agreement with other programs as well as with metered energy use. Therefore it can be chosen as a standard of reference. This exercise would allow a component by component comparison between CIRA and DOE-2.1a, which would reveal the areas that are not adequately treated by CIRA and hence need further attention.

Finally, the calculation algorithms used within CIRA would be examined in detail to provide insight into its strengths and weaknesses. This will help establish the scope of applications of CIRA in the field of residential building energy analysis.

2. VALIDATION OF CIRA AGAINST UTILITY RECORDS

This chapter marks the beginning of the evaluation process of CIRA. Two validation studies were done. In the first half of the study, the energy consumption predicted by CIRA was compared with the utility bills for a single house. The latter half deals with the comparison between the energy consumption predicted by CIRA and the average energy use obtained from the utility bills of 75 similar houses.

2.1 Validation Study on House A

2.1.1 Description of the Test House

House A is a single storey, 1000 ft^2 house with a heated basement. A detailed description of this house is given in Reference 1. The house has brick veneer finish on the exterior and has wood framed windows. The attic has 13" of insulation and the walls contain 2" insulation. The house is occupied by two adults and one child. Heating is provided by a natural gas-fired furnace and space cooling is provided by a central electric air conditioner. The thermostat is maintained at 70°F during Winter and at 78°F in Summer. The floor plan and elevation of this house are shown in Figure 2.1 . The structural details are given in Table 2.1.

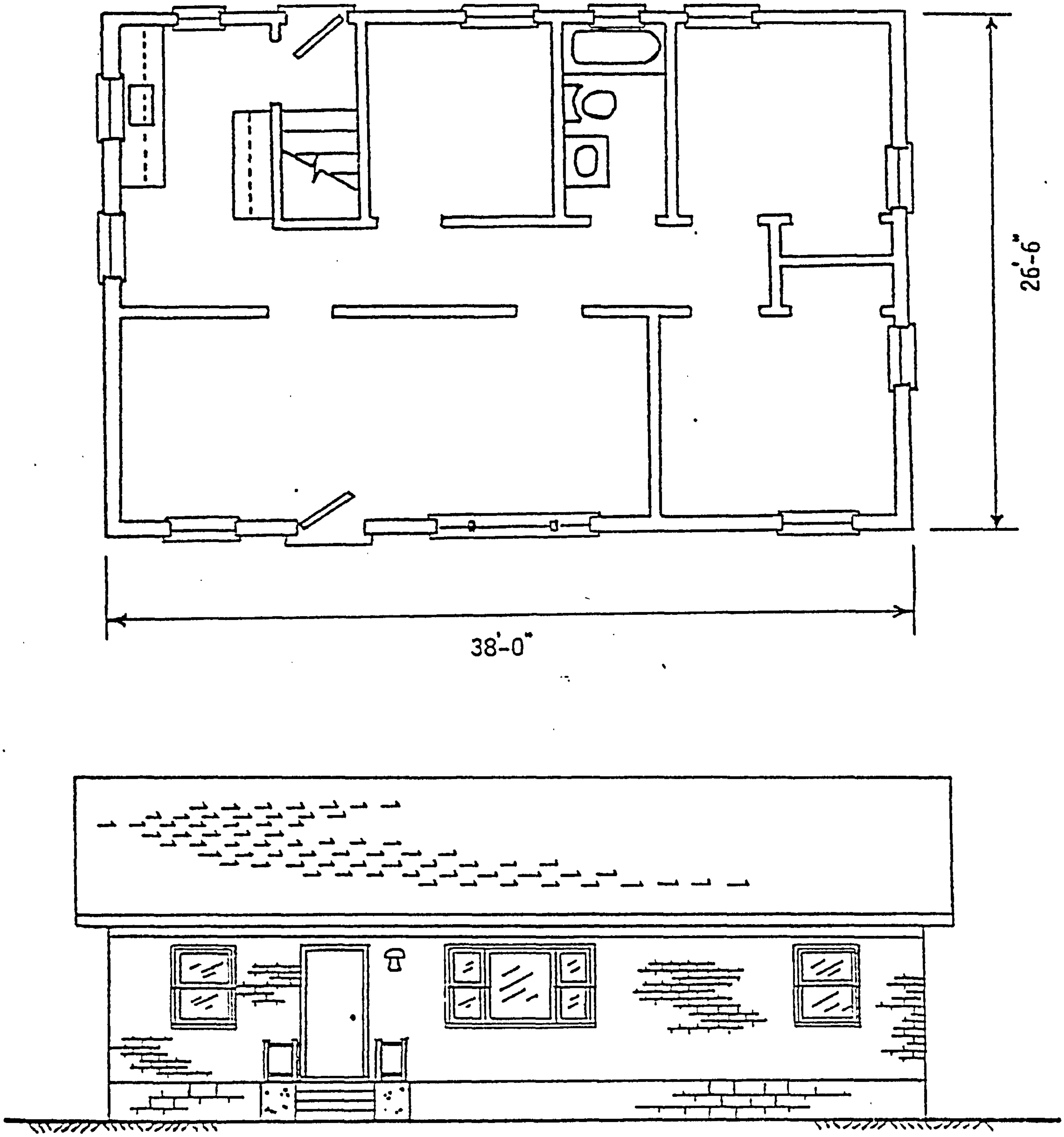


Figure 5.1 : The Floor Plan and Front Elevation of House A

Table 2.1 : Structural Details of House A

Type	:	Single storey wood frame ranch with basement.
Shape	:	Rectangular, 26.5 ft X 38 ft
Area	:	981 ft^2 of main floor area
Orientation	:	Long axis oriented north - south
Exterior Wall	:	2" × 4" stud construction with R-7 insulation, face brick outer finish
Ceiling	:	2" × 4" truss construction with R-40 insulation
Windows	:	Single-pane double-hung wood frame with exterior aluminum storms
Door	:	Front and rear wood doors with aluminum storm door for each

2.1.2 Data Gathering and Analysis

A validation study of the DOE-2.1a program using house A was done by Hall(1). His information is reproduced below in brief.

Natural gas bills were received each month from the Union Gas Co. . The gas consumption was read during alternate months and estimated for the in between months. The electricity meter was also read during alternate months.

Since any subdivision of actual bimonthly energy consumption into monthly values may introduce inaccuracy when comparing the predicted values with the metered use, all comparisons were made on a two month basis(1).

The natural gas was used for hot water heating, the furnace pilot and the space heating. The furnace pilot and the hot water heater were assumed to consume a constant amount of gas. This was referred to as " Baseline Consumption ". The baseline gas consumption was obtained from the gas bills for the summer months. This was found to be 2.62 MCF per month(1).

The electricity consumption was due to lighting, appliances and space cooling. The baseline electricity consumption was determined by calculating the average electricity consumption over the winter months(1).

Since the primary interest of the validation study in the present study was to determine how well CIRA was able to predict heating energy requirements, no effort was made to compare the cooling energy predicted by CIRA against the actual cooling energy use.

In order to make a meaningful comparison, the utility values need to be adjusted for weather. CIRA uses a weather file derived from the TRY weather file, while utility-measured energy use corresponds to actual weather. The neutral point temperature of the house for each month from October through May was obtained by modelling House A on CIRA. The input listings are given in Appendix A. The degree days for each month were calculated for a base temperature corresponding to the neutral point for each month from the actual weather(October 1981 to May 1982). This information is presented in Table 2.2. The utility-measured gas consumption was then adjusted by multiplying the utility values by the ratio of the TRY heating degree days to the actual heating degree days, both at the new base temperature(see Table 2.3).

2.1.3 Validation Results for House A and Discussion

It can be seen from Table 2.4 that the adjusted total heating energy use based on utility records is 75.3 MBtu. CIRA predicts a heating energy consumption of 91.5 MBtu. This is within 22% of the adjusted energy use. Note that on a bimonthly basis, the variation between the actual and predicted heating energy consumption ranges from 16% to 48%.

The adjustment of the utility records was based on the ratio

Table 2.2 : A Comparison of the Actual and TRY

Degree Days

Month	Neutral Point Temperature (°F)	Degree Days	
		Actual (°F)	TRY (°F)
OCT	53.2	174	145
NOV	61.4	603	592
DEC	61.9	1045	1029
JAN	57.0	1242	1095
FEB	56.0	1013	896
MAR	45.4	620	328
APR	47.0	200	79
MAY	50.7	41	37
Total		5538	4201

Table 2.3 : Adjustment of Utility Records to TRY Weather

Billing	Natural Gas Use(MBtu)				
Period	Total Measured	Baseline	Heating	Adjusted Heating	Adjusted Total
OCT/NOV	18.3	5.2	13.1	12.4	17.6
DEC/JAN	40.8	5.2	35.6	33.1	38.3
FEB/MAR	38.9	5.0	33.9	25.4	30.4
APR/MAY	14.4	5.2	9.2	4.4	9.6
Total	112.4	20.6	91.8	75.3	95.9

Table 2.4 : A Comparison of the Actual Heating Energy Use to the CIRA Predictions (House A)

Billing Period	Heating Energy Use (MBtu)		Variation from Adjusted Measured (CIRA)
	Adjusted Measured	CIRA Predicted	%
OCT/NOV	12.4	14.7	18
DEC/JAN	33.1	40.8	23
FEB/MAR	25.4	29.5	16
APR/MAY	4.4	6.5	48
TOTAL	75.3	91.5	22

of the actual degree days to the TRY degree days, both having a base temperature equal to the neutral point temperature of the house. The neutral point temperature in turn was obtained from CIRA. This means that if the internal gains are estimated fairly accurately, calculation of the neutral point temperature depends on the solar gains available to the house. CIRA uses the solar radiation data obtained from the TRY weather tape. The TRY weather data was developed to be typical in temperatures alone. Therefore, the solar data from the TRY weather tape can be significantly different from the local weather. In such a case, the adjusted energy use can be significantly different from the predicted energy use. Apart from this reason, CIRA uses a 100% utilization of solar gains through the glazing and the opaque surfaces to calculate the neutral point temperature. This is not correct, since some portion of the solar gain is not useful in reducing the heating requirements if the space temperature is to remain in tolerable limits. A detailed discussion of this aspect is provided in chapters 3 and 5.

It is seen from Table 2.5 that the natural gas use predicted by CIRA is within 1% of that predicted by DOE-2.1a on an annual basis. It is however misleading to conclude that CIRA and DOE-2.1a predictions agree closely, since on a bimonthly basis the variation between CIRA and DOE-2.1a predicted energy use ranges from -23% to 24%. Such wide variations can be explained to some

Table 2.5 : A Comparison of Natural Gas Consumption predicted by CIRA and DOE-2.1a

Billing Period	Natural Gas Consumption (MBtu)		Variation of CIRA from DOE-2.1a (%)
	CIRA Prediction	DOE-2.1a Prediction	
OCT/NOV	19.9	16.0	24
DEC/JAN	46.0	42.2	9
FEB/MAR	34.7	37.2	-7
APR/MAY	11.7	15.1	-23
JUNE/SEP	10.6	10.6	-
Total	122.9	121.1	1

extent by investigating the treatment provided by each program to the underground heat losses and the utilization of solar and internal gains. Basement models used in both the programs are extremely simplified. The ground temperatures used in the DOE-2.1a program are meant to introduce the phase lag in heat loss due to soil. CIRA, on the other hand, uses the mean monthly air temperatures to calculate the underground heat loss. It is thus clear that for any given time period, CIRA and DOE-2.1a predicted underground heat losses will be significantly different and may differ from the actual heat loss. A detailed analysis of underground heat loss is also provided in chapter 4.

Another major factor which influences the heating load is the internal heat gain due to people, appliances etc., and the solar energy available in the house. CIRA assumes that the entire free heat, consisting of internal and solar gains, contributes to reducing the heating load. This is obviously not quite true(17), especially for the Spring and the Fall months. A detailed treatment of this aspect is provided in chapters 3 and 5.

2.2 Validation Study on Villages of Riverside House

A study was done by Colborne et al (4 and 5) on the Villages of Riverside houses. The owner of each house was interviewed to obtain his estimate of the percentage of the basement heated and the percentage of time it was heated. It was found that basement heating was being done for approximately 35%. Utility records were obtained for each house. In addition, information was gathered regarding the number of occupants in each house, appliances etc.

There are several variables that make a comparison of computer predicted results with the actual energy consumption difficult. Some of these are : occupant effects, infiltration and the seasonal efficiency of the heating system. The Villages of Riverside houses were heated by electric resistance baseboard heaters. Therefore, there was no concern about the seasonal efficiency of the heating system since it could be taken as 100%. As a result of the study mentioned above, it was possible to compare the predicted energy use with the energy use of an "average" house, obtained by averaging the utility records of a group of 75 houses without air conditioners. This ensured that the effect of differences in house construction and occupant related factors such as window opening, setting of thermostat on the energy use was minimised. Since information was available on the number of occupants and appliances, an average value for internal gains could be specified in the simulation of the house on CIRA.

2.2.1 Description of the Test Houses

The house has two floors and a basement. The first floor has a brick veneer outside finish and the second floor has a wood finish. The windows are double glazed. The walls have R-11 insulation in the wall cavities and R-20 in the ceiling.

The front face of the house was oriented due South when it was modelled on CIRA. Orientation was found to cause a variation in the annual heating energy of 15%(5).

The structural details of houses are given in Table 2.6 and a typical house is shown in Figure 2.2.

2.2.2 Data Gathering and Analysis

The houses were assumed to have a medium air tight construction and an average infiltration of 0.6 ach over the heating season.

Energy consumption figures for the year 1980-81 were chosen. A comparison of actual heating degree days,as recorded at Windsor Airport, at base 65 F and the TRY degree days is presented in Table 2.7. Since the actual degree days were very close to the TRY degree days, no effort was made to adjust the utility records for weather for the purpose of comparison with the energy use predicted by CIRA.

Table 2.6 : Structural details for the House " Villages of Riverside "

Type : two - storey house with basement

Shape : rectangular, 19.5 ft × 26.9 ft

Area : 481 ft^2 for each floor

Orientation : front faces south

Exterior wall : 2" × 4" stud construction with R-10 insulation

Ceiling : 2" × 4" truss construction with R-20 insulation

Windows : double-glazed, wood framed.

Side View

Front View

Figure 2.2: The Front View and the Side View of the "Villages of Riverside" House

Table 2.7 : A Comparison between the Actual and the TRY Degree Days(Base 18.3°C)

	Windsor	Detroit(TRY 1968)
May 80	100	168
June 80	50	39
July 80	0	19
Aug 80	0	23
Sept 80	55	54
Oct 80	301	216
Nov 80	440	394
Dec 80	656	624
Jan 81	773	746
Feb 81	554	638
Mar 81	485	480
Apr 81	250	238
Total	3664	3639

The electric meter readings were obtained for all 75 houses on a bimonthly basis(5). The readings were taken between the 10th and the 15th day of every alternate month. Since the actual reading dates for each bimonthly period were not available, it was assumed that for the average house the meter readings were taken on the 13th of every alternate month.

Such an assumption introduces an error when the average energy use is computed. This approach will underestimate or overestimate the energy use over a bimonthly period depending on whether the actual bimonthly period was longer or shorter. This will affect the calculation of the baseload, which in turn will affect the calculation of the bimonthly heating energy.

There were six meter readings for each of the 75 houses during one calendar year. The average consumption for the "average" house could thus be obtained for each two month period. Since the degree days for the period from July through October were few, the energy consumption for this period was taken as the base load (see Table 2.8). It was assumed that the base load consumption would be constant over the entire year. The heating energy use was obtained by subtracting the base load from the total energy use.

Table 2.8 : The Average Bimonthly Heating Energy Use for the "Villages of Riverside" House

Billing Period / (Calender Period)	Degree Days,°C (Actual Period)	Average Electricity Use(Kwh)	Average Heating Energy(Kwh)
14 Oct 80 - 14 Dec 80 (1 Nov 80 - 31 Dec 80)	856	4110	2110
15 Dec 80 - 14 Feb 81 (1 Jan 80 - 28 Feb 81)	1541.6	7689	5689
15 Feb 81 - 14 Apr 81 (1 Mar 81 - 31 Apr 81)	793.6	4567	2567
15 Apr 81 - 14 Jun 81 (1 May 81 - 30 Jun 81)	298.8	2803	803
15 Jun 81 - 14 Aug 81 (1 Jul 81 - 31 Aug 81)	14.3	1889	-
15 Aug 81 - 14 Oct 81 (1 Sep 81 - 31 Oct 81)	159.5	2020	-
Total		23078	11169

Note : Base load from 15 June 81 to 14 October 81.

2.2.3 Validation Results and Discussion

There was 2" of foam insulation 2 feet deep along the interior of basement walls. To evaluate the effect of the basement wall insulation, two cases were modelled on CIRA by the Author. The input listings can be found in Appendix B. In the first simulation(Case 1), there was no insulation along the interior of the basement wall. In the second simulation(Case 2), insulation was placed along the full depth of the basement walls.

The bimonthly billing period was out of phase with the calendar months, e.g. the energy use recorded for October and November was, in reality, for the period from 14th of September to the 13th of November for the sample house. The heating load predicted by CIRA is from the first to the last day of the month. To compare the CIRA predictions with the actual heating energy use, the CIRA values were prorated to reflect the actual billing period. Consider Case 1 for illustration. The heating energy consumptions for December, January and February are 9.23 MBtu, 11.11 MBtu and 9.07 MBtu respectively. Hence the energy use from 15 December to 14 February is$[\frac{16}{31} \times 9.23 + 11.11 + \frac{14}{28} \times 9.07]$MBtu, which is equivalent to 5979 Kwh.

Tables 2.9 and 2.10 show a comparison of the prorated CIRA values against the CIRA values weighted by the actual degree days. The prorated and weighted results compare within 13% from 14 October 1980 to 14 April 1981 and within 24% from 15 April

Table 2.9 : A Comparison of the Prorated and Weighted CIRA values (Case 1)

Billing Period	Prorated values (Kwh)	Weighted values (Kwh)	% Variation from Prorated values
14Oct-14Dec	2890	2732	-6
15Dec-14Feb	5979	6633	11
15Feb-14Apr	3072	2686	-13
15Apr-14Jun	236	292	24
Total	12177	12343	1

Table 2.10 : A Comparison of the Prorated and Weighted CIRA values (Case 2)

Billing Period	Prorated values (Kwh)	Weighted values (Kwh)	% Variation from Prorated values
14Oct-14Dec	2682	2558	-5
15Dec-14Feb	5752	6289	9
15Feb-14Apr	2785	2511	-10
15Apr-14Jun	226	263	16
Total	11445	11621	2

1981 to 14 April 1981.

It is seen from Table 2.11 that the CIRA predictions(Cases 1 and 2) agree with the actual heating load within 9% and 3% respectively on an annual basis. The agreement however is far from good on a bimonthly basis. Note that if a comparison was made using the weighted CIRA results(see Table 2.12), the agreement between the actual heating energy use and CIRA values would marginally improve in each bimonthly period except in the period from 15 December 1980 through 14 January 1981 when it appreciably worsens.

Such wide variations can be explained as follows:

The base load was assumed to be the same for the entire year. This is not strictly true because there is more usage of lights and appliances during wintertime (e.g. a dryer). Thus the base load for winter is more than that during summer. A small mistake in the base load estimation can seriously affect the calculated heating load for swing months(i.e. a month in transition from heating to cooling or vice versa) when the heating requirements are appreciably lower than those in the winter months.

2.3 Closure

The validation study done on House A showed a good agreement (within 22%) with the heating energy use on an annual basis. On a bimonthly basis, the agreement was within 48%. In the second

Table 2.11 : A Comparison of the Actual Heating Energy Use to the Prorated CIRA Predictions

Billing Period	Actual Heating (Kwh)	CIRA Predictions(Kwh)		% Variation from Actual Heating	
		1 Basement without insulation	2 Basement with insulation	1	2
14Oct-14Dec	2110	2890	2682	37	27
15Dec-14Feb	5689	5979	5752	5	1
15Feb-14Apr	2567	3072	2785	20	8
15Apr-14Jun	803	236	226	-70	-71
Total	11169	12177	11445	9	-3

Table 2.12 : A Comparison of the Actual Heating Energy Use to the Weighted CIRA Predictions

Billing Period	Actual Heating (Kwh)	CIRA Predictions(Kwh)		% Variation from Actual Heating	
		1 Basement without insulation	2 Basement with insulation	1	2
14Oct-14Dec	2110	2732	2558	30	21
15Dec-14Feb	5689	6633	6289	17	11
15Feb-14Apr	2567	2686	2511	5	2
15Apr-14Jun	803	292	263	-64	-67
Total	11169	12177	11445	9	-3

validation study it was found that on an annual basis, an agreement within 9% was obtained between the heating energy based on the metered energy use and the heating energy calculated by CIRA. On a bimonthly basis, the agreement was inconsistent. Both House A and the Villages of Riverside house have no particular passive solar features. Each has a full basement. House A has a fairly high level of insulation in the attic and a low level of insulation in the wall cavities. The Villages of Riverside house has moderate insulation in the walls and ceiling. Both the houses are single family dwellings with an average level of internal gains.

CIRA was compared with measured house performance data in this chapter. In chapter 3, CIRA will be compared to DOE-2.1a. This will help identify the components of CIRA that are not properly and / or adequately treated. The basement component of CIRA will be examined in detail by comparison with a finite difference heat conduction program HEATING5 in chapter 4.

3. VALIDATION OF CIRA AGAINST DOE-2.1a

CIRA is compared to DOE-2.1a in this chapter. Heating load, solar gains and internal gains are analysed and compared in the first section. In the second section, the effect of variation of thermal mass, internal gains and solar gains on the heating load, taken individually, is investigated and compared.

Since CIRA and DOE-2.1a have extremely simplified basement models, it was decided to analyse heat losses through the underground surfaces as such in depth. This component of heat loss, therefore, is not considered in this chapter. A detailed analysis is provided in chapter 4.

3.1 Component Analysis

The following modelling techniques were adopted to minimize heat loss through the ground. The model house consisted of two storeys and basement. This house("Villages of Riverside") has been described in detail in the previous chapter(see Table 2.3).

3.1.1 Modelling in DOE-2.1a

The house was divided into two zones. The upper zone consisted of living area which included the first and the second floors. The basement was treated as a separate zone. Space temperatures in both the zones were held at the same value(70°F). This ensured that there was no heat loss from the upper floor to the basement (see the input listings in Appendix C).

3.1.2 Modelling in CIRA

Heavy insulation was placed on the basement ceiling and its area was kept a minimum, so that the heat loss to the ground could be ignored. The input listings of CIRA are given in Appendix D.

3.1.3 Component Study

CIRA is an energy analysis program for residential buildings(10). It uses the variable base degree day procedure to calculate the heating load. The conventional degree day method, using a neutral point temperature of 65 °F, is an elementary form of steady state heat transfer analysis. It assumes that the solar and internal gains will offset transmission losses when the outdoor temperature is 65 °F, and the fuel consumption is proportional to the temperature difference across the building envelope. This procedure however fails to account for several factors such as lowering of thermostat setting, air tightness, insulation level in wall cavities and attic, glazing area and the location of building. The degree day procedure used in CIRA accounts for the above mentioned factors which can significantly reduce the neutral point temperature of the house below 65 °F. Since it is a variable base degree day procedure, it is logical to perform a component analysis for a particular house of interest with respect to solar gains and internal gains.

3.1.4 Results and Discussion

During the simulation period, the space was maintained at a fixed temperature of 70°F. Heating loads predicted by CIRA and DOE-2.1a were compared(see Table 3.1). Free heat, consisting of solar and internal gains, was analysed(see Tables 3.2 and 3.3).

On an annual basis, the CIRA-predicted load is in excellent agreement with the DOE-2.1a predictions. CIRA predicts heating load within 7%. The agreement is better during cold months(from November through March) and it starts worsening when swing months are approached (October and April). It is seen that during October the agreement is the worst. CIRA underpredicts DOE-2.1a by 32% during this month.

This behaviour can be explained when attention is paid to solar and internal gains as shown in Table 3.2. DOE-2.1a calculates solar gains falling through the glazing area. The effect of solar energy falling on an opaque surface - e.g. an exterior wall - is treated separately. In other words, DOE-2.1a uses the concept of sol - air temperature and thus accounts for the heating of the outside surface by solar radiation. CIRA, on the other hand, calculates an equivalent glazing area due to walls and calculates the total solar energy available inside the house as the sum of solar energy falling through the equivalent

Table 3.1 : A Comparison of Heating Loads predicted by CIRA and DOE-2.1a

Month	Heating Load (MBtu) CIRA Predicted	Heating Load (MBtu) DOE-2.1a Predicted	Variation (%)
Oct	1.2	1.76	-32
Nov	4.3	4.38	-2
Dec	8.5	8.63	-2
Jan	10.2	10.58	-4
Feb	8.4	8.71	-4
Mar	4.5	5.26	-14
Apr	1.3	1.73	-25
Total	38.4	41.05	-7

Table 3.2 : A Comparison of Solar Gains used in CIRA and DOE-2.1a

Month	Solar Gains (MBtu) CIRA Useful	CIRA Available	DOE-2.1a Useful	DOE-2.1a Available
Oct	1.55	1.55	0.34	1.28
Nov	0.90	0.90	0.65	0.82
Dec	0.67	0.67	0.60	0.60
Jan	0.88	0.88	0.77	0.77
Feb	1.32	1.32	1.04	1.12
Mar	2.08	2.08	0.98	1.67
Apr	2.86	2.86	0.49	2.25
Total	10.26	10.26	4.87	8.51

Table 3.3 : A Comparison of Internal Gains used in CIRA and DOE-2.1a

Month	Internal Gains (MBtu) CIRA Useful	CIRA Available	DOE-2.1a Useful	DOE-2.1a Available
Oct	1.96	1.96	1.00	1.96
Nov	1.90	1.90	1.76	1.90
Dec	1.96	1.96	1.96	1.96
Jan	1.96	1.96	1.96	1.96
Feb	1.79	1.79	1.75	1.79
Mar	1.96	1.96	1.60	1.96
Apr	1.90	1.90	0.94	1.90
Total	13.43	13.43	10.97	13.43

glazing area and windows.

It is interesting to note that CIRA always assumes that 100% of the available solar energy is useful in reducing the heating load. This assumption is fairly valid when the transmission losses are large compared to internal and solar gains as is the case in the colder months. During a swing month, however, a certain fraction of free heat must be removed to maintain a fixed space temperature. This is so because in a swing month there can be several hours when free heat far exceeds the transmission losses. Unless the excess heat during those hours is removed, the space temperatures may become intolerable to occupants. When no means were provided for space cooling (viz. ventilation or air-conditioning), the hourly space temperatures predicted by DOE-2.1a exceeded 110 °F for a number of hours.

DOE-2.1a predicts that during October, only 0.34 MBtu out of 1.28 MBtu solar energy was useful for space heating purposes. This means that about 73% of the total available solar energy had to be removed from the space to maintain it at the reference temperature. CIRA, on the other hand, assumes that all the solar energy (1.96 MBtu) was useful. Thus CIRA shows an appreciably lower heating load as compared to that predicted by DOE-2.1a during swing months.

It can be seen from Table 3.2 that the fraction of useful solar energy ranges from 27% in October, reaches its peak in

December and January (100%) and starts falling until April to 21%.

Similar comments apply to internal gains. DOE-2.1a shows that during swing months the useful portion of internal gains can be as low as 50% of the total internal gains. CIRA, as before, assumes 100% utilization for all months(see Table 3.3).

3.2 Parametric Study

3.2.1 Internal Gains

The Villages of Riverside house, described previously (see Table 2.3), was modelled on CIRA and DOE-2.1a. Internal gains due to people, appliances and lights were chosen to be 70000 Btu per day in this study. The BEPS- recommended magnitude of internal gains is approximately 63000 Btu / day for a typical residential house. It was decided to choose two other levels of internal gains for this parametric study. One was greater than the chosen value of 70000 Btu / day and the other was less than the chosen value. Thus the parametric study included three levels of internal gains: 50000 Btu / day, 70000 Btu / day and 100000 Btu / day.

It is seen from Table 3.4 that the difference between the heating loads predicted by CIRA and DOE-2.1a does not show any fixed pattern with respect to the magnitude of internal gains.

Table 3.4 : A Parametric Study with respect to Internal Gains

Internal Gains / day

Monthly Heating Load Predictions (MBtu)

	50000 Btu			70000 Btu			100000 Btu		
	CIRA	DOE-2.1a	Diff of CIRA(%)	CIRA	DOE-2.1a	Diff of CIRA(%)	CIRA	DOE-2.1a	Diff of CIRA(%)
Oct	1.4	2.1	-32	1.2	1.8	-32	-	1.4	-100
Nov	4.8	4.9	-2	4.3	4.4	-2	3.4	3.7	-7
Dec	9.1	9.2	-1	8.5	8.6	-2	7.5	7.8	-4
Jan	10.9	11.1	-2	10.2	10.6	-4	9.3	9.7	-5
Feb	8.9	9.2	-4	8.4	8.7	-4	7.5	8.0	-6
Mar	5.0	5.7	-13	4.5	5.3	-14	3.6	4.6	-22
Apr	1.2	2.0	-40	1.1	1.8	-21	-	1.4	-100
Total	41.3	46.3	-11	38.4	41.0	-7	31.3	36.5	-14

The agreement is generally good (within 14%) on an annual basis. As the internal gains are increased from 50000 Btu / day to 70000 Btu / day, for the month of October, DOE-2.1a shows a fall in the heating load from 2 MBtu to 1.8 MBtu. CIRA shows a corresponding decrease of 0.2 MBtu . As the internal gains are increased further to 100000 Btu / day, DOE-2.1a shows that the heating load is further reduced by 0.4 MBtu to 1.4 MBtu. However CIRA predicts that there is no heating load at all when the internal gains are 100000 Btu / day. It was expected that CIRA would have shown about the same heating load as that predicted by DOE-2.1a (1.4 MBtu).

The above anomaly can be explained as follows :

CIRA calculates either heating or cooling load for a given month. Therefore, based on the effective temperature calculation if CIRA determines that the month is a cooling month, no heating load is calculated for that month. When the internal gains were 100000 Btu / day, October was treated as a cooling month by CIRA.

Residential dwellings typically do not have a high thermal mass. The indoor temperature therefore varies about the same way as the outdoor temperature if no heating is provided to the house(21). There can be several hours in a swing month, especially during nighttime, when the outdoor dry bulb temperature is quite low . Space heating may be necessary during those hours. Since a monthly average temperature is used by CIRA, it can not account for the above phenomenon. However, it must be noted here that the heating requirements are quite low in swing months and therefore the error involved by ignoring them is quite small for a typical residential structure.

3.2.2 Thermal Mass

The two storey plus basement house was modelled on CIRA and DOE-2.1a for three types of constructions : light, medium and heavy. The standard weighting factor option was chosen in DOE-2.1a to input different constructions. The floor weight was specified as 30 lb / ft^2 , 70 lb / ft^2 and 130 lb / ft^2 to represent light, medium and heavy construction respectively.

A comparison between CIRA and DOE-2.1a-predicted heating loads for light, medium and heavy constructions is given in Table 3.5.

The DOE-2.1a simulation indicates that the thermal mass has negligible effect on the annual heating energy. An increase in thermal mass from 30 lb / ft^2 to 130 lb / ft^2 reduces the annual heating load by less than 2%. Simulation done on CIRA also indicates that the heating load is reduced by less than 2%. An independent study done by G.P.Mitalas confirms this result(13). For any thermal mass, CIRA predicts the heating load within 8%

Table 3.5 : A Parametric Study with respect to Thermal Mass

Monthly Heating Load Predictions (MBtu)

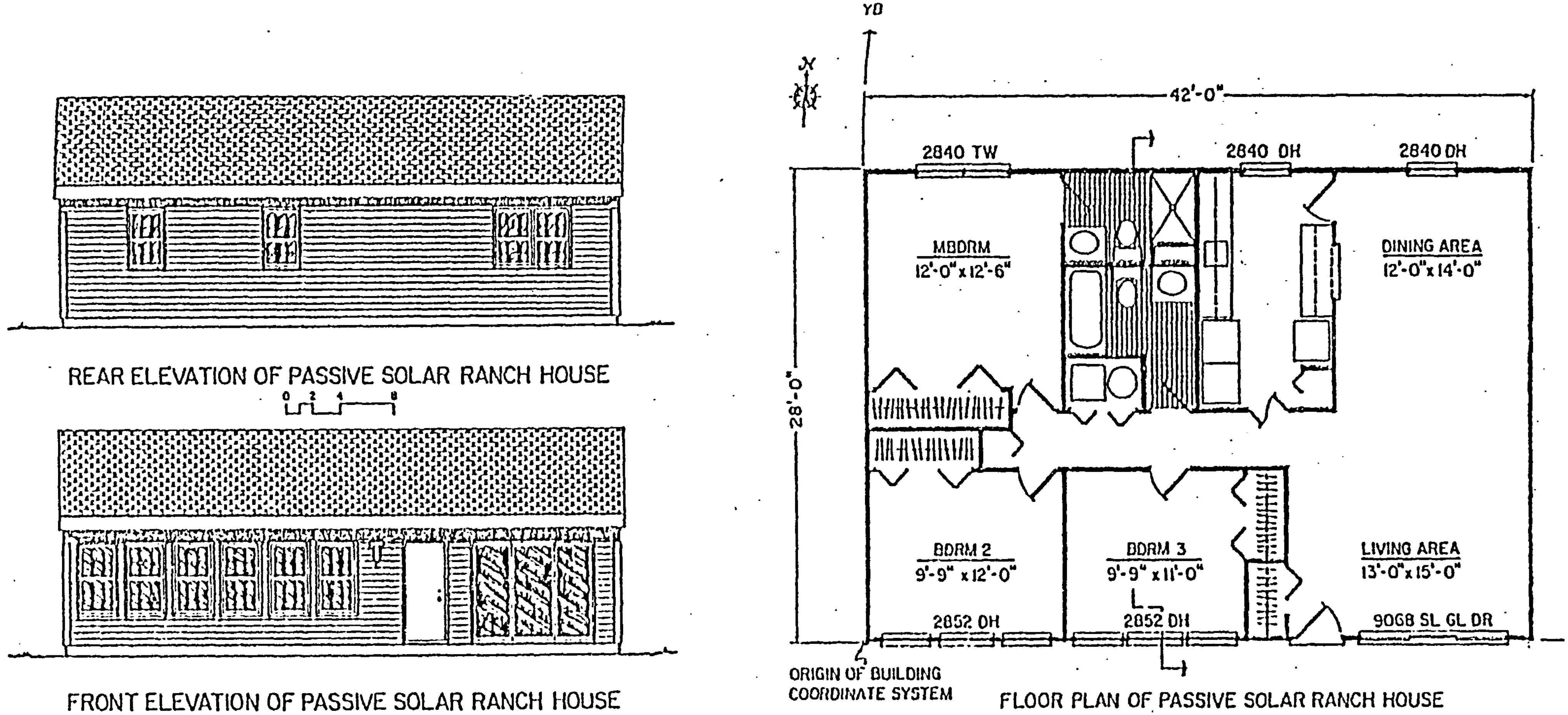
	Light			Medium			Heavy		
	CIRA	DOE-2.1a	Diff of CIRA(%)	CIRA	DOE-2.1a	Diff of CIRA(%)	CIRA	DOE-2.1a	Diff of CIRA(%)
Oct	1.2	1.7	-29	1.2	1.6	-26	1.1	1.6	-29
Nov	4.3	4.4	-3	4.2	4.4	-5	4.2	4.4	-4
Dec	8.5	8.9	-5	8.5	8.9	-5	8.5	8.9	-5
Jan	10.2	10.9	-6	10.2	10.9	-6	10.2	10.9	-6
Feb	8.4	8.9	-6	8.4	8.9	-6	8.4	8.9	-6
Mar	4.5	5.2	-14	4.5	5.2	-13	4.4	5.1	-14
Apr	1.3	1.5	-13	1.1	1.3	-18	0.9	1.2	-26
Total	38.4	41.5	-7	38.1	41.2	-7	37.7	41.0	-8

of the value predicted by DOE-2.1a .

It is instructive to note the effect of thermal mass on the heating load as predicted by CIRA and DOE-2.1a during the swing months. To illustrate, in the month of April, DOE-2.1a predicts a decrease in the heating load of about 13% and 20% as the thermal mass is increased from 30 lb / ft ^{2} to 70 lb / ft ^{2} and 30 lb / ft ^{2} to 130 lb / ft ^{2} . The corresponding decrease in the heating loads predicted by CIRA is 15% and 30%. Since the loads are small in the swing months, this decrease has little effect on an annual basis.

3.2.3. Solar Gains

Since the component analysis of CIRA done so far indicated that large discrepancies between heating loads predicted by CIRA and DOE-2.1a ocurred during swing months, it was decided to investigate this matter further by modelling a passive solar ranch located in Ottawa (see Fig 3.1). Colborne et al have simulated this ranch for several cases by using the DOE-2.1a program(6). There were four cases determined by insulation and infiltration levels. Each of these cases was provided with varying thermal mass and four thermostat settings. Two cases were selected from the above study that could be used for investigating the combined effect of large solar gains, tight house construction and high insulation levels. A light



REAR ELEVATION OF PASSIVE SOLAR RANCH HOUSE

FRONT ELEVATION OF PASSIVE SOLAR RANCH HOUSE

FLOOR PLAN OF PASSIVE SOLAR RANCH HOUSE

Figure 3.1 : The Floor Plan, Front Elevation and Rear Elevation of the Passive Solar Ranch House

construction with the heating and cooling thermostat settings at 70 °F was chosen and its tightness and insulation levels were allowed to vary. These cases were :

	R,wall	R,ceiling	Glazing	Avg.Ach
Case 1	12	20	Double	0.6
Case 2	30	50	Triple	0.3

These two cases were modelled on CIRA by the author. The listings are given in Appendix E.

3.2.4 Results and Discussion

Case 1

From Table 3.6 it is seen that the agreement between the heating loads predicted by CIRA and DOE-2.1a is good over the heating season. The agreement is within 10 %. A monthly comparison shows that the agreement is extremely good for cold months, i.e. from November through March. It starts worsening as the outdoor temperature starts rising. Thus for the months of October, April and May, the agreement is within 33 %. Although CIRA significantly underpredicts the heating load for swing months, the heating load itself is quite small.

Table 3.6 : A Comparison between Heating Loads Predicted by CIRA and DOE-2.1a(Case 1)

Month	CIRA Prediction (MBtu)	DOE-2.1a Prediction (MBtu)	Variation of CIRA from DOE-2.1a (%)
Oct	1.43	2.14	-33
Nov	4.42	4.64	-5
Dec	11.26	12.14	-7
Jan	12.90	13.85	-7
Feb	9.37	10.43	-10
Mar	6.67	7.25	-8
Apr	3.00	3.75	-20
May	1.21	1.57	-23
Total	50.26	55.77	-10

The internal gain utilization factor is defined as the fraction of the total internal gains that is useful in reducing the heating required to maintain a fixed indoor temperature. The solar gain utilization factor is defined as the fraction of the entering solar energy that is useful in reducing the heating required to maintain the space temperature at the reference level. These factors are discussed in detail in References 6 and 17. Some discussion is also provided in chapter 5.

The solar and internal gain utilization factors (see Table 3.7) are close to 100 % from November until March. They drop to as low as about 35 % and 75 % respectively in the month of May. Since CIRA assumes a utilization factor of 100% for free heat, it substantially underpredicts the heating load as compared to the DOE-2.1a predicted heating load.

Case 2

The overall agreement between heating loads predicted by CIRA and DOE-2.1a is within 23 % (see Table 3.8). CIRA does not consider the swing months of October and May as heating months any more and hence does not predict any heating requirements for these months. Notice that for each month the agreement between CIRA and DOE-2.1a is worse as compared to the agreement obtained in case 1. Conduction and infiltration losses are reduced significantly as compared to those in case 1 because of high

Table 3.7 : Variation of Solar and Internal Gain Utilization Factors with the Time of the Year(Case 1, based on DOE-2.1a simulation)

Month	N(s)	N(i)
Oct	0.489	0.878
Nov	0.853	1.000
Dec	0.983	1.000
Jan	1.000	1.000
Feb	0.982	1.000
Mar	0.898	1.000
Apr	0.659	0.911
May	0.341	0.745

Note : N(s) and N(i) represent the solar and internal gains utilization factors, respectively.

Table 3.8 : A Comparison between Heating Loads Predicted by CIRA and DOE-2.1a(Case 2)

Month	CIRA Prediction (MBtu)	DOE-2.1a Prediction (MBtu)	Variation of CIRA from DOE-2.1a (%)
Oct	-	0.52	-100
Nov	0.92	1.33	-31
Dec	3.61	4.26	-15
Jan	4.16	4.80	-13
Feb	2.74	3.46	-21
Mar	1.69	2.24	-25
Apr	0.70	1.07	-35
May	-	0.36	-100
Total	13.82	18.04	-23

Table 3.9 : Variation of Solar and Internal Gain Utilization Factors with the Time of the Year(Case 2, based on DOE-2.1a simulation)

Month	N(s)	N(i)
Oct	0.219	0.808
Nov	0.523	0.987
Dec	0.798	1.000
Jan	0.829	1.000
Feb	0.752	1.000
Mar	0.628	1.000
Apr	0.416	0.889
May	0.159	0.66

insulation levels in walls and ceiling and a tighter house construction. The internal and solar gains, however, remain unchanged. Thus the ratio of the free heat to transmission losses is increased in the second case. This in turn means that lower solar and internal gain utilization factors will be obtained in case 2(see Table 3.9). CIRA however assumes a 100% utilization of free heat and hence the agreement between the predicted heating loads worsens(see Table 3.8).

3.3 Closure

The comparative study between CIRA and DOE-2.1a showed that CIRA agreed closely with DOE-2.1a on a yearly basis as well as over the cold months. The agreement was poor during the swing months. In general the agreement was found to worsen when energy conservation measures of a tighter construction, high insulation levels and more passive solar gains were incorporated into the house.

4. BASEMENT STUDY

In the evaluation process of CIRA done so far, heat loss through underground surfaces was not considered. The objective of this chapter is to provide an analysis of heat loss through underground walls and floor , with particular reference to the basement model used in CIRA. Four computer programs were used to calculate heat loss through the below grade walls and floor of a well-defined, uninsulated basement, maintained at 70°F. These were : CIRA, DOE-2.1a, HOTCAN and HEATING5.

4.1 Introduction

Thermal properties of a basement wall above grade are easy to determine . The thermal capacity of the wall is negligibly small so that a steady state heat transfer can be assumed on a daily or a monthly basis. Calculation of the heat loss from underground surfaces is much more complicated because the thermal conductivity and thermal capacity of the soil are difficult to determine. Since soil adds a significant thermal mass between the wall and the outside air, the heat flow cannot be treated as steady state.

S.J.Raff(8) has discussed in detail the heat transfer processes associated with ground. He has also analysed earth temperature variations with respect to ground depth and the time of the year.

The method developed by Boileau and Latta(14) assumes that the steady state heat flow from underground surfaces takes place in circular paths from basement temperature to a ground surface temperature. They have concluded that precise mathematics are not warranted in calculating basement heat losses because thermal properties of soil, moisture content and temperatures will not be usually known accurately.

G.P.Mitalas(18) has developed a new method to calculate heat loss from basements. The calculation method requires the knowledge of shape factors, attenuation factors and ground surface temperatures. A comparison of the predicted and monitored basement heat losses indicated that the method was fairly accurate. Basements with simple rectangular shapes can be treated adequately, but the three dimensional heat flow of basements with irregular geometries cannot be analysed by the method. The method does not account very well for the factors that influence the variation in mean ground temperature around the basement.

The finite difference heat conduction program, HEATING5, developed by Turner, Elrod and Simon-Tov(7) was used to model a basement. This program solves a steady state or transient heat conduction problem in one, two or three dimensions. The program is capable of handling a number of situations. The thermal conductivity, density and specific heat may change spatially.

They may be temperature dependent. Materials can undergo phase change. The boundary conditions can be fixed temperatures or a combination of a given heat flux, convection and / or radiation. The program solves steady state problems by a point successive overrelaxation iterative method. Transient problems are solved by a variety of techniques such as the Crank Nicolson method. Thus the program appears to be a versatile tool for analysing complex heat conduction problems associated with the underground surfaces, that are difficult or impossible to solve by exact analytical methods.

It was, therefore, decided to select HEATING5 to calculate the underground heat loss. The underground basement heat loss obtained from HEATING5 was taken as a standard of reference. The underground basement heat losses calculated by CIRA and DOE-2.1a were compared with the heat loss calculated by HEATING5.

4.2 Description of Basement

The basement is shown schematically in Figure 4.1. It is essentially the basement of the "Villages of Riverside" house. It has a floor area of 494 ft^2 and it is 6 feet deep in the ground. The basement wall consists of 8" concrete block and is uninsulated. The floor is a 3" concrete slab.

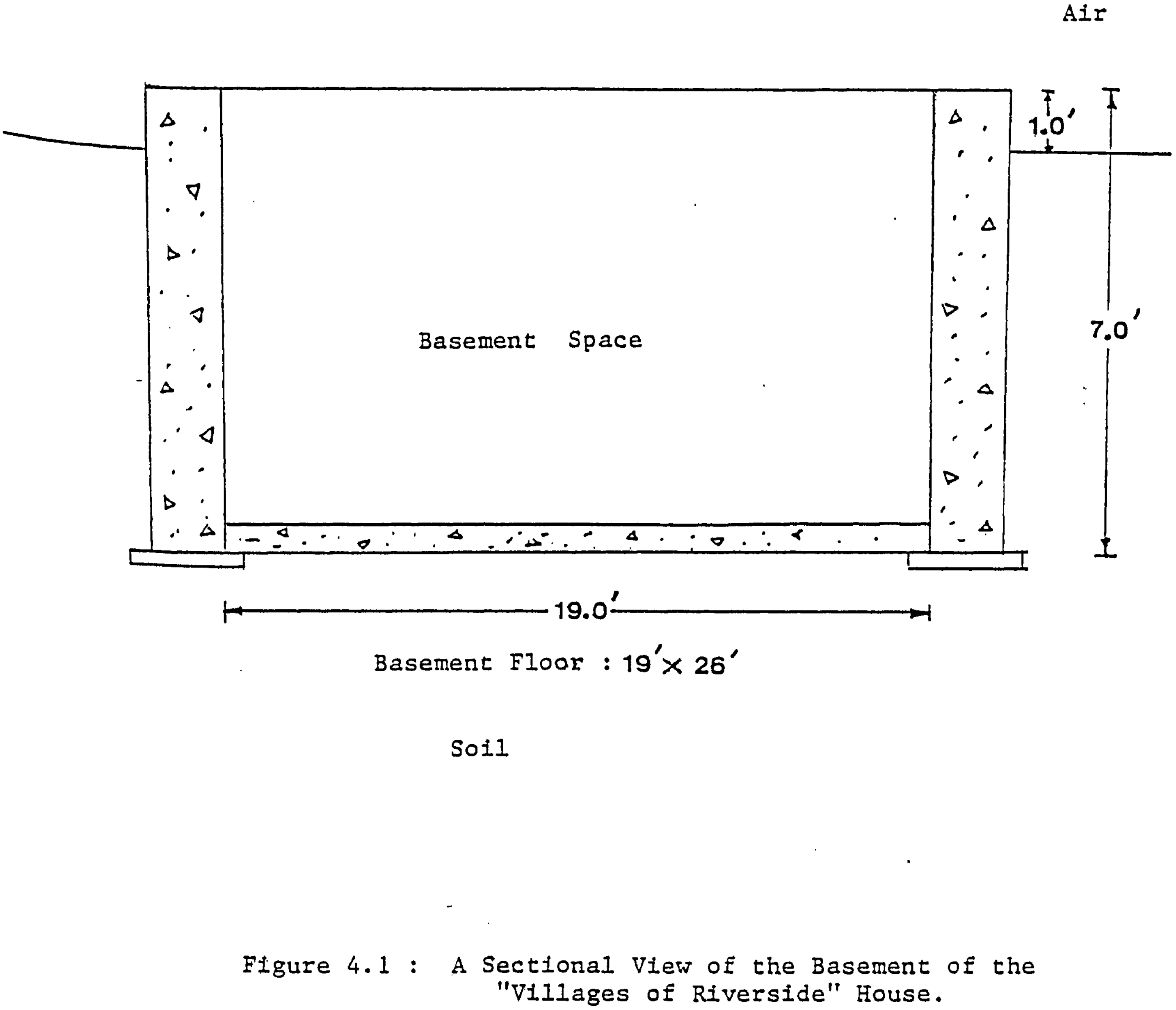


Figure 4.1 : A Sectional View of the Basement of the "Villages of Riverside" House.

4.3 Modelling of Basement in different programs

4.3.1 Modelling of Basement in HEATING5

A two dimensional basement configuration was chosen(see Figure 4.2). The input was prepared in a format recommended in the manual of HEATING5. The input listings are given in Appendix F. Since it was symmetric about the Y - axis, only half the basement was modelled. The basement configuration was defined by boundaries 1,2,3,4,5 and 6. The deep ground temperature is constant over the year and is usually slightly above the mean annual air temperature(8). This was 50°F for Detroit(boundary 4). The adiabatic boundary 5 was chosen to be sufficiently far away from the centerline. This distance was 29.5 feet. Boundary 3 was the line of symmetry and hence there was no heat transfer across this boundary. Boundaries 1 and 2 were formed by the interior surface of the basement wall. The boundary condition along these surfaces was assumed to be natural convection with constant heat transfer coefficient from the air space of the basement which was held at a fixed temperature of 70 °F. Similarly, the boundary condition along boundary 6 was specified as natural convection from the ground to the outdoor air. Average monthly outdoor air temperature was expressed as a function of time of year by a 3rd order Fourier fit (see Appendix G).

The grid size was reduced until the results were no longer

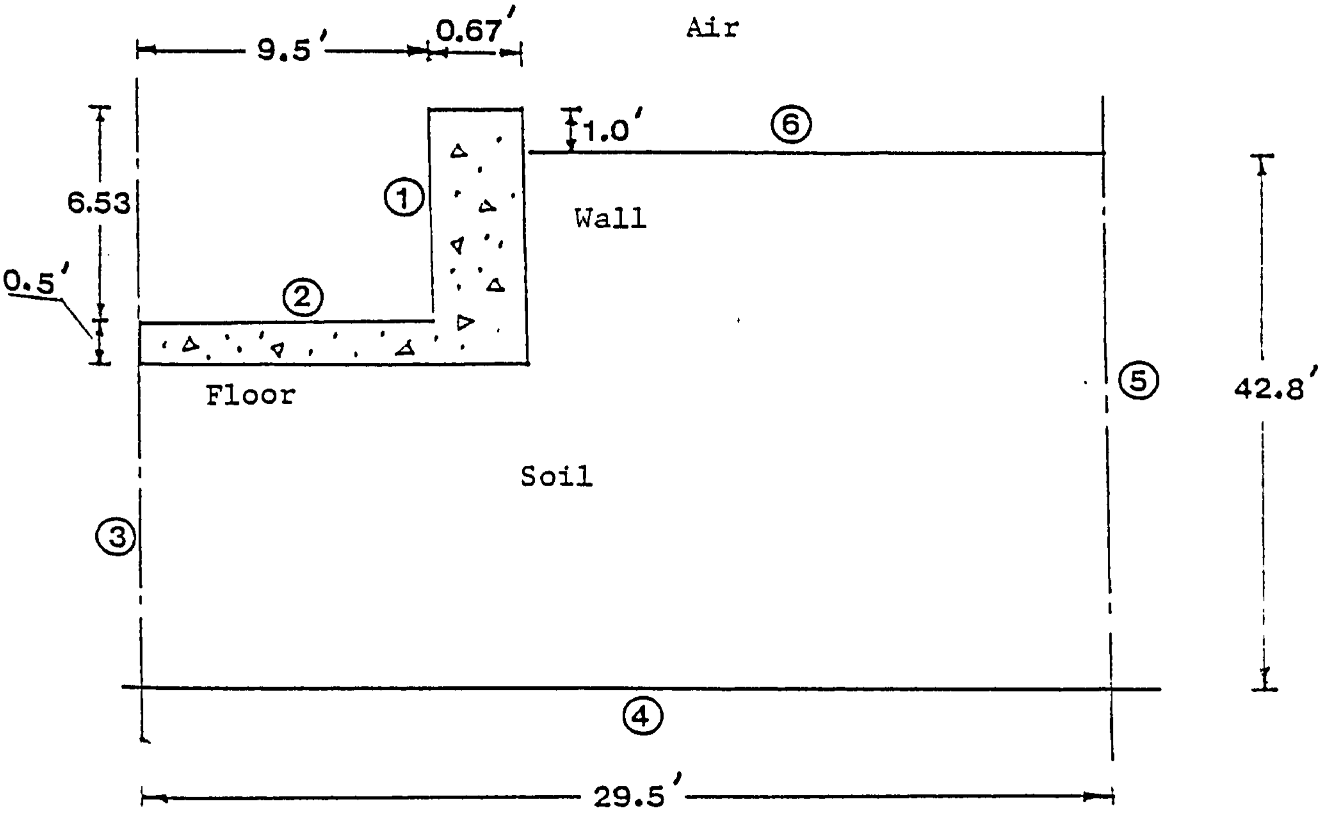


Figure 4.2 : Boundary Conditions for the Basement simulated in HEATING5.

dependent on it. The final grid pattern, consisting of 675 nodes, is shown in Appendix H. Temperature distributions for three typical days, October 15, January 15 and April 15 are also given in Appendix H. These temperatures were obtained by using a 15 - day time step. Thus two sets of temperature distributions for the basement configuration were available in each month. Since only temperatures along the interior surfaces of wall and floor were computed by the program, another program was written to read in these temperatures and calculate the heat loss from the basement space to ground. The procedure for calculating heat loss from temperatures is explained in Appendix I.

Heat loss per hour from the basement wall and floor was calculated separately. Heat loss could then be computed over any period of time by simply integrating the appropriate heat loss expression over the time period of interest. This procedure is explained in Appendix K.

The HEATPLOT code, a plotting program for HEATING5, was used to plot isotherms in the basement configuration for different times of the year.

4.3.2 Modelling of Basement in CIRA

CIRA does not explicitly output heat loss from the underground surfaces. It was therefore necessary to devise some means to extract basement heat loss from the program. First, a superstructure - in this case, the Villages of Riverside house - was modelled with basement. Second, the same house was modelled with a minimum of floor area and heavy insulation on the floor. This ensured that the heat loss through the ground was negligibly small and thus the heating load was imposed only due to the transmission losses from the superstructure. Heat loss through the basement walls and floor could then be determined by subtracting the heating load in the second case from the heating load in the first case. The program listings are given in Appendix L.

4.3.3 Modelling of Basement in DOE-2.1a

The DOE-2.1a program estimates heat loss through the undeground wall by using a steady state expression of the form :

$$Q_{bg} = U_{bg} A_{bg} (t_{ib}-t_g) \qquad \ldots.(4.1)$$

where Q_{bg} = the heat loss from the underground wall $(\frac{Btu}{h})$

U_{bg} = the effective U-value of the undergound wall $(\frac{Btu}{h.ft^2.{}^oF})$

A_{bg} = the area of the underground wall (ft^2)

t_{ib} = the basement space temperature $({}^oF)$

t_g = the ground temperature $({}^oF)$

Ground temperature " t_g " is not clearly defined in the DOE-2.1a manual. It is, therefore, difficult to calculate the effective U-value of an underground wall. In the absence of any proper information, the following approach to the calculation of the effective U-value of an underground wall was taken.

The heat loss from an underground wall can be found by taking heat flow along circular arcs with their center at the point where the basement wall and the grade line meet(11). Therefore, the R-value and U-value at a distance y below ground level is given by(10) : $R_y = R_w + \frac{\pi y}{2K_g}$ .....(4.2)

$$U_y = \frac{1}{R_y} \qquad \text{......(4.3)}$$

where R_w = the thermal resistance of the wall $\left(\frac{h.ft^2.{}^\circ F}{Btu}\right)$

K_g = the soil conductivity $\left(\frac{Btu}{h.ft.{}^\circ F}\right)$

The U-value of the wall at a distance "y" below grade is integrated over the entire below grade depth of the wall, H, and then divided by H to yield the effective U-value for the entire wall.

$$U_{bg} = \frac{2K_g}{\pi H} \ell n \{1 + \frac{\pi H}{2K_g R_w}\} \qquad \text{......(4.4)}$$

Following the procedure recommended by ASHRAE, the design heat loss from the underground wall can be calculated as follows :

$$Q_{Design} = Q_{bg} = (U_{bg}\ A_{bg})_{ASHRAE}\ \{t_{ib}-(t_a-B)\} \quad \ldots(4.5)$$

where t_a = the mean annual air temperature (°F)

B = the amplitude of fluctuation of the ground surface temperature (°F)

For Detroit, $t_a = 49^\circ F$

and $B = 22^\circ F$

$$\therefore \quad Q_{Design} = (U_{bg}\ A_{bg})_{ASHRAE}\ (70-27) \quad ..(4.6)$$

Note that the ($U_{bg}A_{bg}$) corresponds to a mean ground surface temperature (Ref.11). However the ground temperatures used in the weather file of the DOE-2.1a program do not seem to correspond to the ground surface temperature. They appear to be located somewhat below surface. The previously calculated (UA) value therefore needs to be modified before it could be input in the DOE-2.1a program.

$$\therefore \quad Q_{Design} = (U_{bg}\ A_{bg})_{DOE-2.1a}\ (t_{ib}-t_g)$$

$$= (U_{bg}\ A_{bg})_{ASHRAE}\ (70-27)$$

where $t_g = 39^\circ F$ for January (see Reference 12)

$$\therefore \quad (U_{bg}\ A_{bg})_{DOE-2.1a}\ (70-39)$$

$$= (U_{bg}\ A_{bg})_{ASHRAE}\ (70-27)$$

$$\therefore \quad (U_{bg}\ A_{bg})_{DOE-2.1a} = 1.38\ (U_{bg}\ A_{bg})_{ASHRAE} \quad ..(4.7)$$

The (UA) value thus obtained was input in the program. The input listings are given in Appendix M.

The peak heat loss from the basement floor was determined by using the ASHRAE recommended procedure(see Reference 11). Using this value and the ground temperature for January, the effective U-value of the basement floor was determined to be 0.0289 (Btu / h-ft -°F). This value was input in the program to estimate the floor heat loss.

4.3.4 Modelling of Basement in HOTCAN

Basement heat losses are not explicitly given by HOTCAN. Hence it was necessary to devise some technique to extract this component of heat loss from the program. Zero above-grade wall and window areas were input to the program. Similarly, the internal gains were specified as zero. The underground wall and floor descriptions were provided in the manner specified in the user's manual for HOTCAN(19). Steady state and periodic shape factors were obtained from the engineering manual of HOTCAN(20) and input to the program. Thus the heat loss calculated by HOTCAN was through the underground surfaces only. The program listings are given in Appendix N.

4.4 Results and Discussion

The results of heat losses through underground walls and floor are presented in Table 4.1 and shown graphically in Figure 4.3. It can be seen from Table 4.1 that on an annual basis the underground heat losses predicted by HEATING5, CIRA and DOE-2.1a are in good agreement . Over the heating season, these losses are 20.5 MBtu, 18.3 MBtu and 18.1 MBtu respectively. Both CIRA and DOE-2.1a underpredict heat losses by 10% as compared to those calculated by HEATING5. This is an excellent agreement considering the simplicity of underground heat loss calculations used in these two programs.

HEATING5 accounts for the thermal mass of the soil. It is seen that due to the presence of soil, heat loss per day peaks in February, which is a month after the mean monthly dry bulb temperature reaches its minimum. The monthly heat losses from January through April are 3.6, 3.9, 4.0 and 3.1 MBtu. This shows that the soil gives a flywheel effect to the seasonal heat loss. It tends to distribute heat loss almost equally from January through April, although the air temperature rises.

ASHRAE recommends that for an uninsulated basement, the isotherms near the underground wall are radial lines centered at the intersection of the grade line and the exterior of the basement wall. Heat flow can therefore be approximated by concentric circular arcs. This is illustrated in Figure 4.4.

Table 4.1 : A Comparison of Underground Heat Loss, as predicted by CIRA, DOE-2.1a, HOTCAN and HEATING5

Month	CIRA Predicted (MBtu)	DOE-2.1a Predicted (MBtu)	HOTCAN Predicted (MBtu)	HEATING5 Predicted (MBtu)
Oct	1.1	1.17	1.6	1.15
Nov	2.4	1.85	2.23	1.83
Dec	3.4	2.67	2.89	2.70
Jan	4.1	3.21	3.22	3.59
Feb	3.5	3.19	2.90	3.91
Mar	2.7	3.32	2.86	3.96
Apr	1.1	2.70	2.19	3.10
Total	18.3	18.11	17.89	20.24

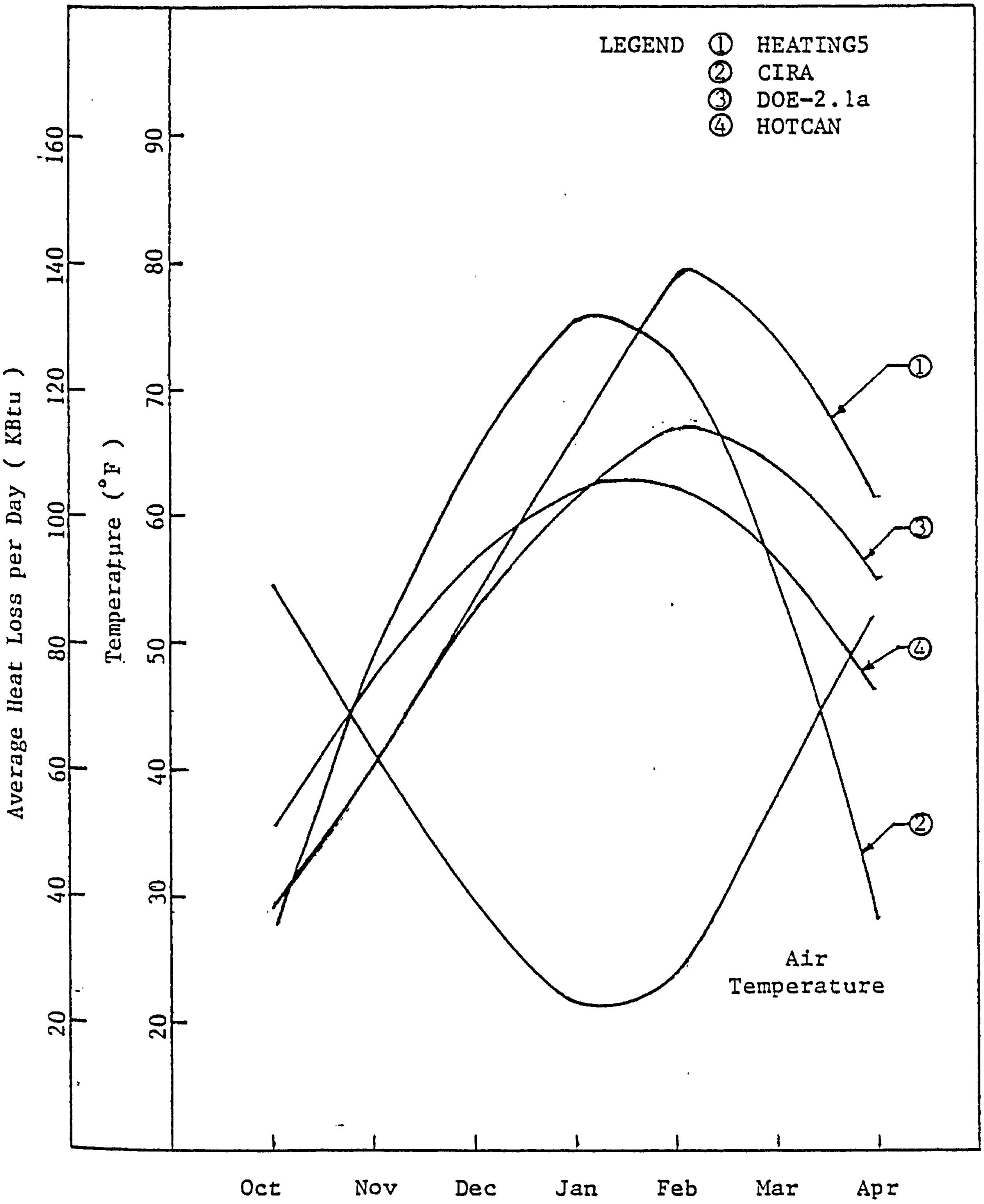


Figure 4.3 : A Comparison of the Underground Basement Heat Losses, predicted by CIRA, DOE-2.1a, HOTCAN and HEATING5

The heat flow lines run perpendicular to the isothermal lines. Isotherm plots obtained from HEATING5 indicate that during the months of January and February (see Figures 4.5 and 4.6), isotherms for a major portion of the basement wall are radial straight lines originating from points close to the point where the grade line meets the inside of the basement wall. Hence the circular arc approach is fairly valid for January and February. Moreover, these plots suggest that the center of circular arcs should be located at the intersection of the grade line and the interior, rather than the exterior, of the basement wall. The circular arc approach should not be used for other months. This is evident from the isotherm plots for April and October (see Figures 4.7 and 4.8).

CIRA, on the other hand, treats basement walls and floors as surfaces with no thermal mass. It also uses the mean monthly air temperature to calculate basement heat loss. Basement heat loss therefore follows exactly the reverse trend of air temperature. CIRA is in close agreement with HEATING5 from October to December. It predicts a maximum heat loss of 4.1 MBtu in January. This is to be expected since the air temperature reaches its minimum in January. However as the outdoor temperature starts rising basement heat losses start falling, to the extent that during April CIRA predicts a heat loss of 1.1 MBtu as against 3.1 MBtu predicted by HEATING5.

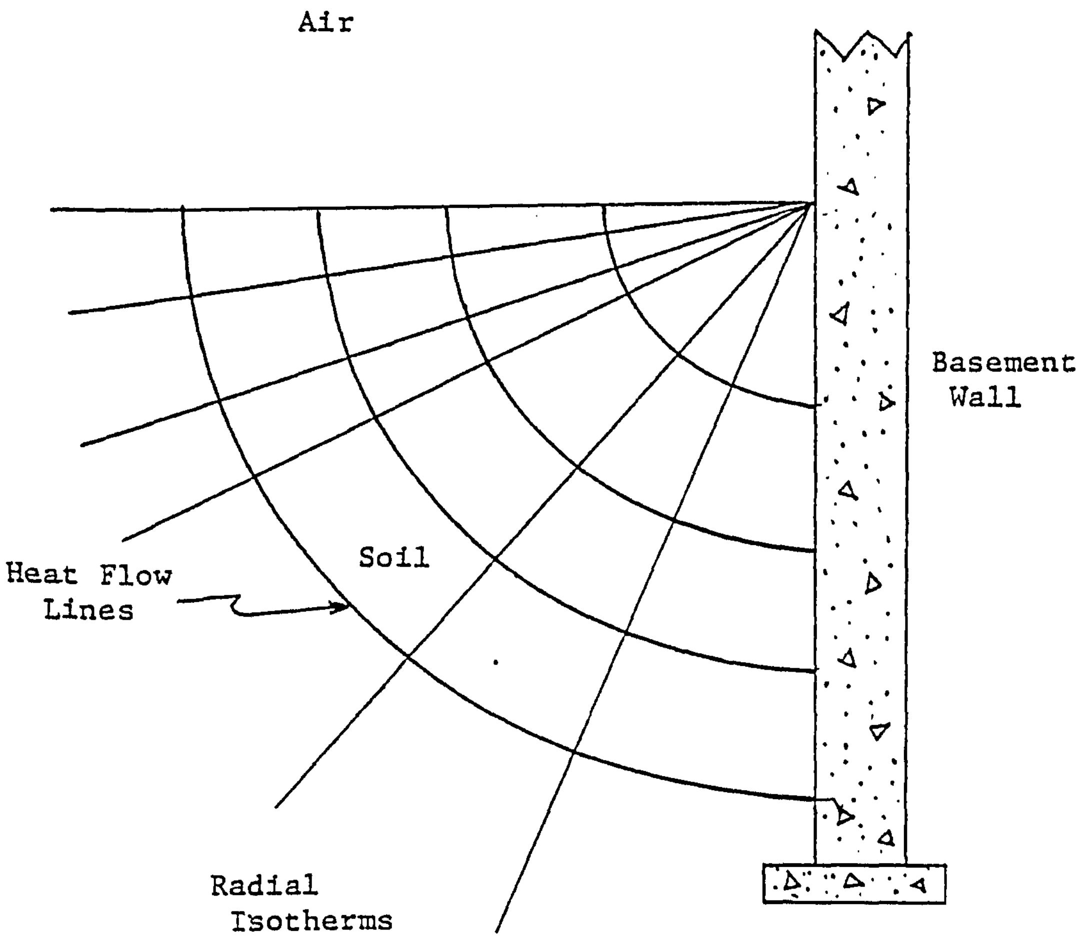


Figure 4.4 : The ASHRAE Procedure for determining the Heat Flow Lines(Uninsulated Basement)

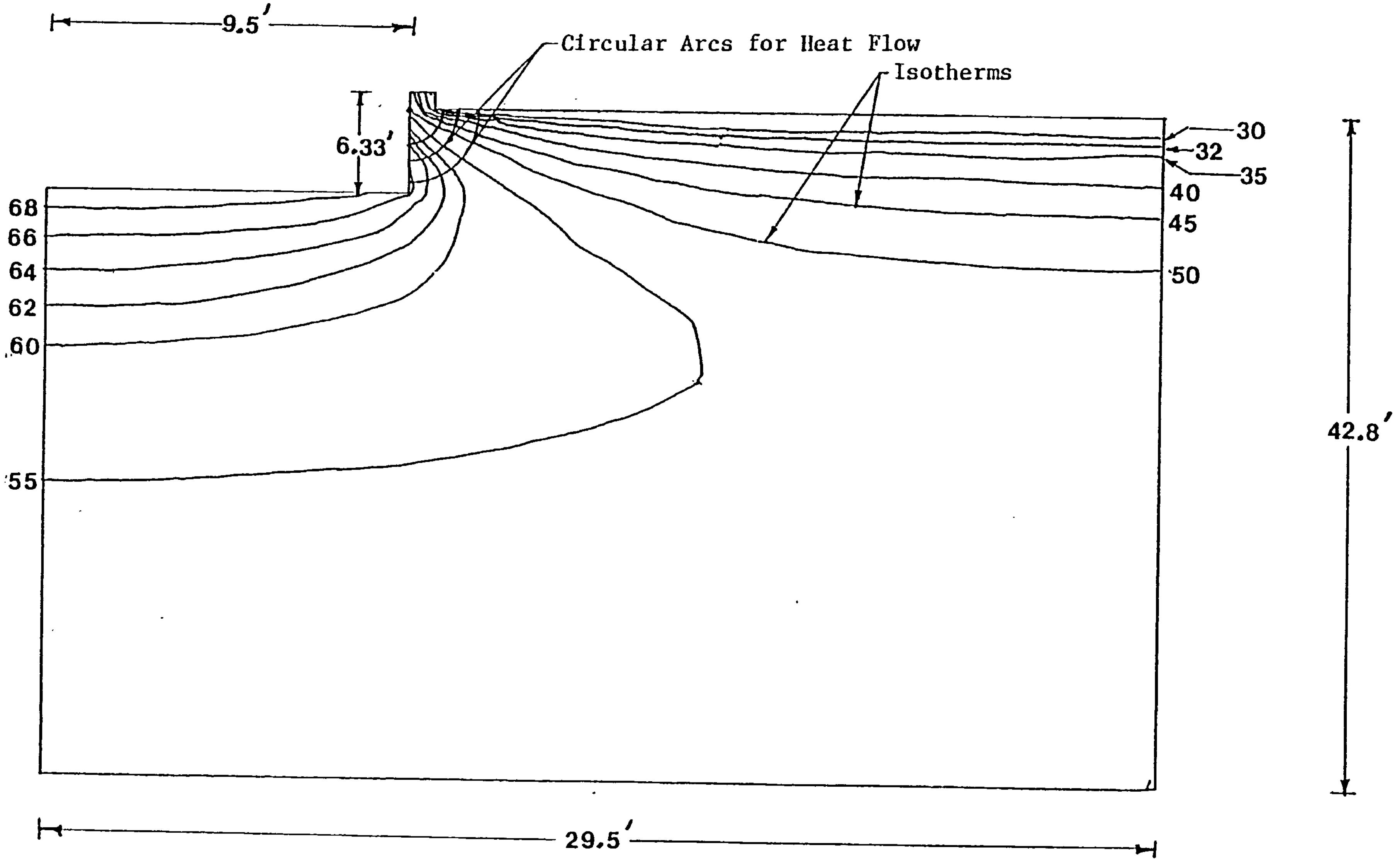


Figure 4.5 : Ground Temperature Isotherms for January 15.

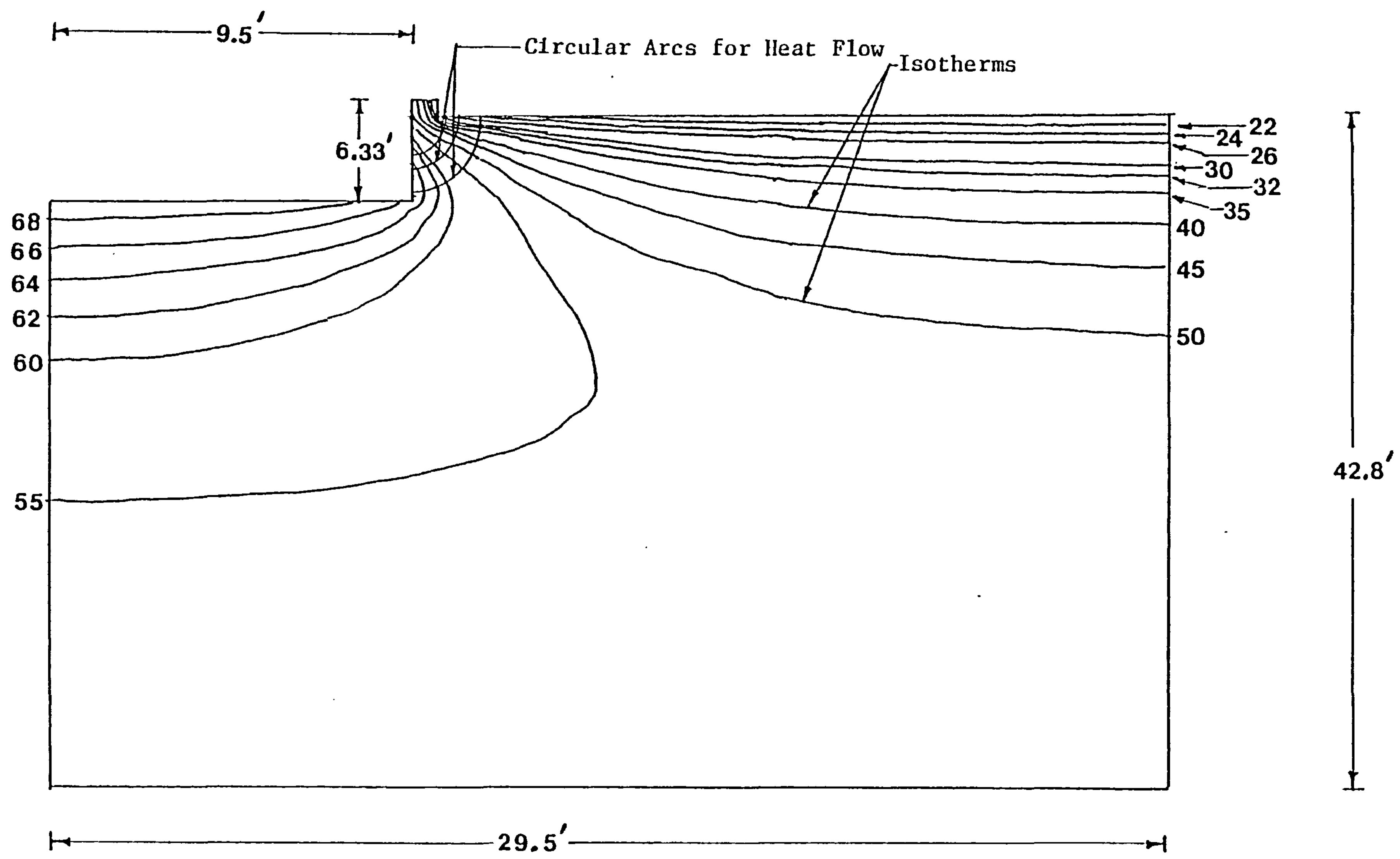


Figure 4.6 : Ground Temperature Isotherms for February 15.

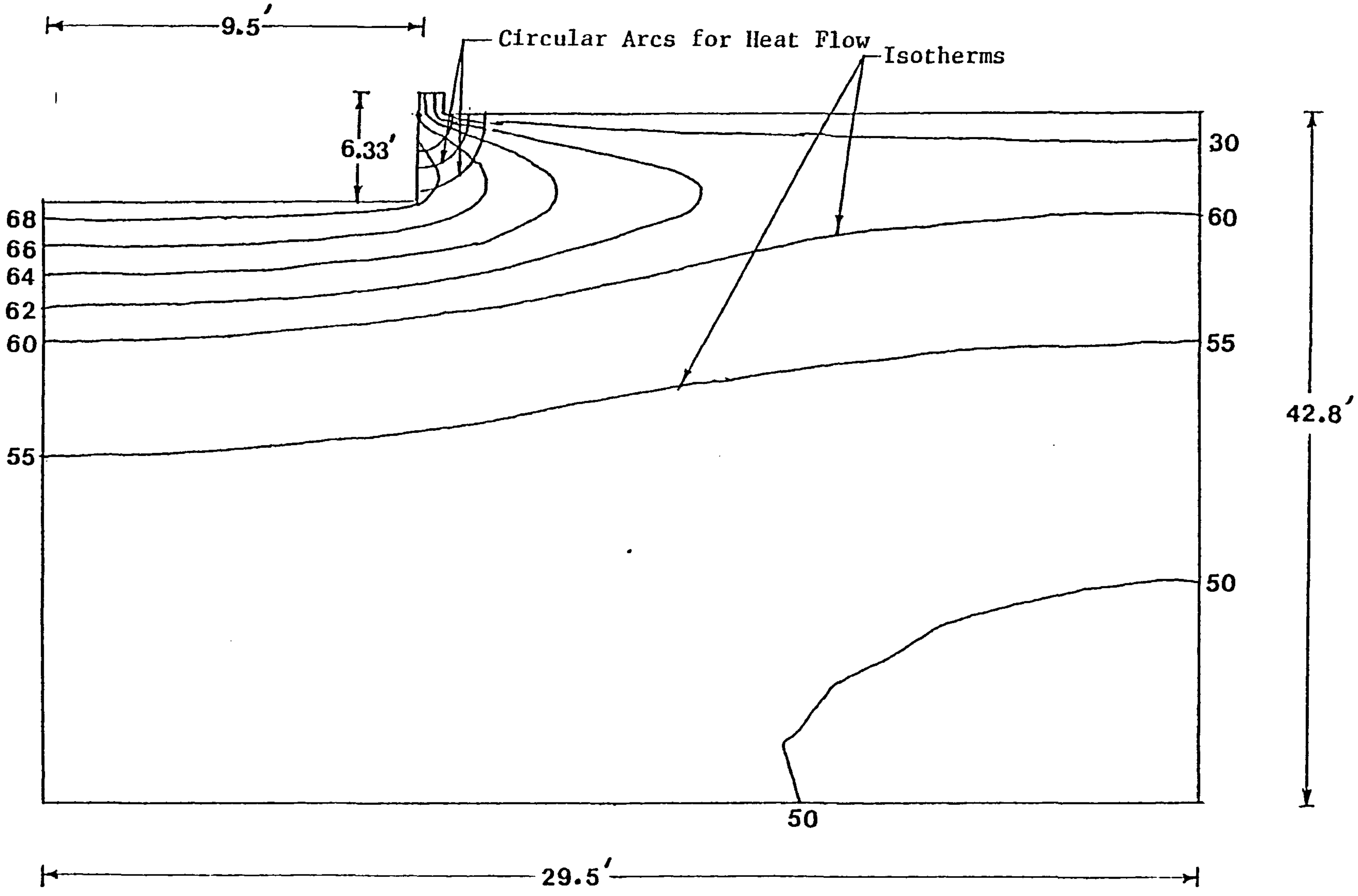


Figure 4.7 : Ground Temperature Isotherms for October 15.

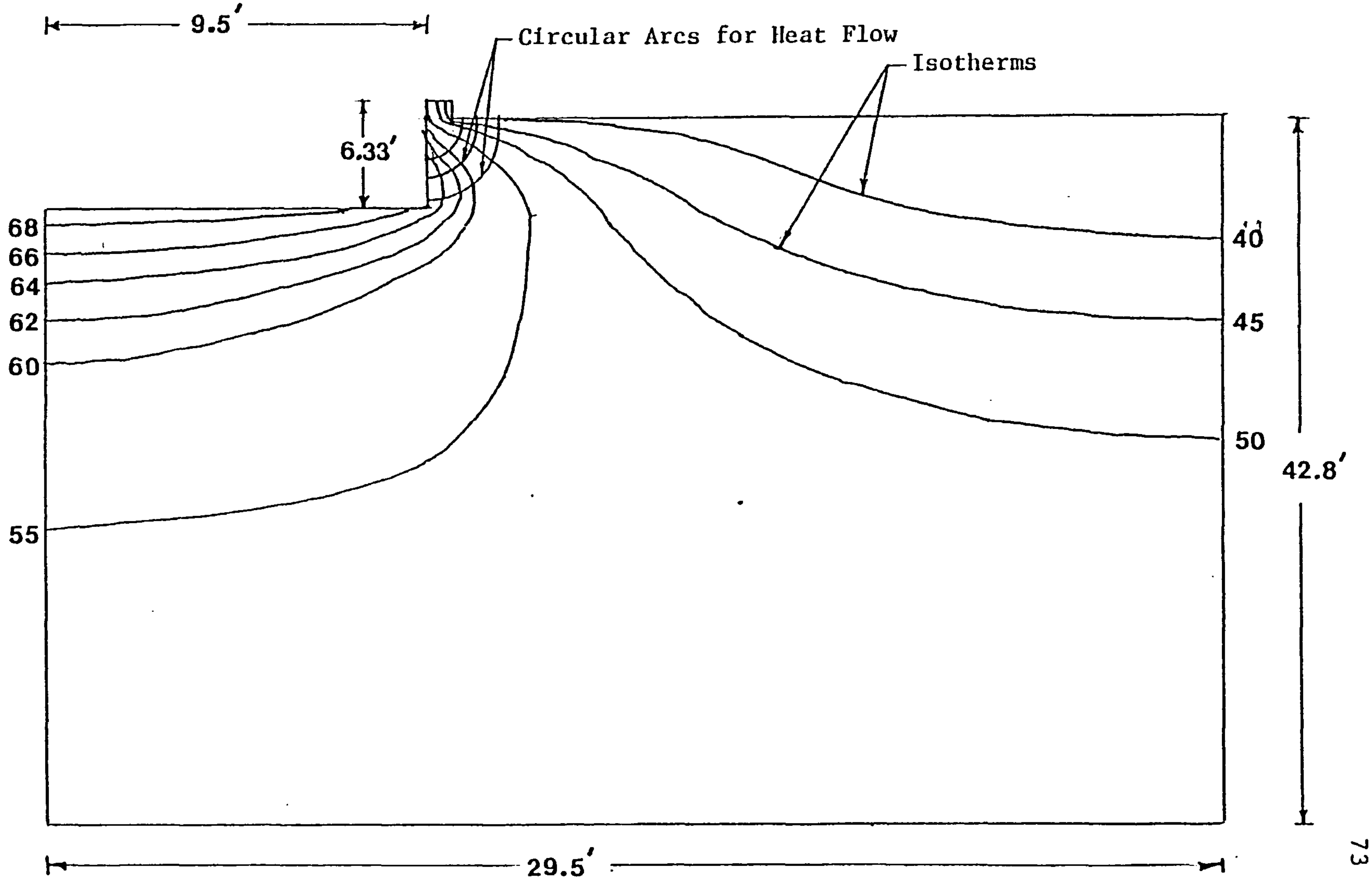


Figure 4.8 : Ground Temperature Isotherms for April 15.

The DOE-2.1a predictions of basement losses follow quite closely the HEATING5 predictions. The agreement is almost perfect from October through December. DOE-2.1a shows a peak heat loss of 3.2 MBtu in February. Hence, it can be concluded that the ground temperatures used in the weather library of DOE-2.1a are introducing an appropriate time lag in heat loss. The DOE-2.1a prediction is within 18% of the value calculated by HEATING5.

Snow cover was not taken into account when the basement was simulated using HEATING5. Since the presence of snow cover imparts an insulating effect to the underground surfaces, and thereby decreases the heat loss, it is expected that the basement heat loss values calculated by HEATING5 would be lower than the present values if the snow cover is accounted for. This in turn would make the agreement between the DOE-2.1a and HEATING5 predictions better.

The basement model used in HOTCAN has been developed by Mitalas(18). It overpredicts heat loss compared to that calculated by HEATING5 from October through December. It is interesting to note that while CIRA, DOE-2.1a and HEATING5 predicted underground heat losses are in close agreement for October, the heat loss calculated by HOTCAN is appreciably higher. From January until April, HOTCAN underpredicts the monthly heat loss as compared to that predicted by HEATING5.

HOTCAN predictions are closer to those made by DOE-2.1a, which suggests that an appropriate time lag in heat loss is being introduced by HOTCAN and it may be accounting for snow cover during winter.

The basement model used in HOTCAN is developed on the basis of experimental and analytical studies of the basement heat loss. Heat loss experiments were conducted on several basements. Comparisons of the actual and calculated basement heat loss showed that the measured losses were greater than the calculated ones when the actual soil conductivity was greater than the values used in calculation and / or the model failed to adequately account for groundwater flow(18). This in turn means that the shape factors used in the calculation of basement heat loss need to be modified if the ground thermal conductivity is known.

The existing documentation in the HOTCAN manual(see References 19 and 20) provides shape factors for only two sets of average soil thermal conductivities: 1.47 Btu / h.ft. °F and 2.25 Btu / h.ft. °F. Hence, the user has to select the shape factors corresponding to either of the above soil conductivities unless he has the knowledge and / or means to calculate the shape factors for the desired soil conductivity.

The shape factors chosen in this study correspond to a soil thermal conductivity of 1.47 Btu / h.ft.°F. A soil conductivity of 0.76 Btu / h.ft.°F was used in CIRA, DOE-2.1a and HEATING5.

4.5 Closure

CIRA, DOE-2.1a, HOTCAN and HEATING5 agreed closely with each other over the heating season. The seasonal heat loss predicted by CIRA was within 10% of that predicted by HEATING5. The agreement was not good on a monthly basis. Thus it was concluded that CIRA could be expected to predict only seasonal heat loss fairly well.

The next chapter forms the final stage of the evaluation process of CIRA, in which the calculation algorithms used in CIRA are examined in detail.

5. CRITICAL EVALUATION OF CIRA

The calculation of heating load is complicated since it involves a number of coupled heat transfer processes of varying complexity. During any given hour, there are four components of heat transfer associated with a structure : heat loss due to conduction from walls, windows etc., heat loss due to infiltration, solar heat gain through windows and finally heat gain from people, appliances etc. The calculation of conduction heat loss is essentially solving the energy equation for diffusion for each hour. The solar heat gain calculation involves information on the diffuse and direct solar radiation and glass properties. The heat gain due to people,appliances etc. is specified as an input by the user. The resultant hourly space heat loss is not equal to the space heating load since the radiant energy entering the space does not immediately cause an increase in the space temperature. The radiation is first absorbed by walls, furniture etc. causing their surface temperatures to rise. This in turn causes heat to be convected from the surface to the space air.

Calculation of the heating load from the space heat gain can be done by two methods. The first method involves heat balances on the interior and the exterior surfaces and the room air itself. This method is mathematically rigorous and hence accurate. It is however extremely time consuming. The second method uses the technique of "transfer function" to convert the heat gain to the heating load. This is the technique used in DOE-2.1a. This method, although approximate compared to the heat balance method, is still quite complicated and time consuming.

Such detailed, transient simulations are certainly required for peak load calculations. They would also predict the heating load over any time period of interest. Over a long time period such as a month, the transient behaviour of various house components smoothen out and hence it is possible to calculate the heating load by using a steady state approach provided the physics of all major conductive, convective and radiative proceses are taken care of in some manner.

CIRA uses a steady state calculation method designed to provide monthly energy audits of heating or cooling loads . It calculates monthly degree days and degree nights for heating and cooling seasons. The effective temperatures used to calculate degree days are derived from indoor temperature, solar and internal gains, radiation losses from the building skin to the sky and the thermal characteristics of the building. Degree days based on an effective temperature are calculated by using an empirical correlation. A brief description of some calculation procedures used in CIRA that are related to this study and their evaluation are presented next.

5.1 Introduction

If a steady state heat transfer through the building envelope is considered, then the heating load can be written as:

$$\text{Heating Load} = (\text{Heat Losses}) - (\text{Heat Gains}) \quad ..(5.1)$$

Heat losses can be broken down into two major parts : (i) heat loss due to conduction through the building envelope and the underground surfaces, and (ii) heat loss due to infiltration of air. Heat gains are due to the solar energy through the glazing areas and due to people, appliances and lights. Conventionally, Eq.(5.1) is written as :

$$\begin{aligned}\text{Heating Load} = {} & (\text{Conduction loss} + \text{Infiltration loss}) \\ & - (\text{Solar gains} + \text{Internal Gains}) \quad ..(5.2)\end{aligned}$$

$$H = (C + I) - (S_g + I_g) \quad ....(5.3)$$

Several steady state approaches can be developed to estimate the heating load. All of them obviously have to satisfy Eq.(5.3). In this chapter, the approaches used in CIRA to calculate heating load are examined one by one. First, the calculation procedures related to conduction and infiltration are considered.

5.2 Heat Conduction

5.2.1 Description

The overall building heat conduction coefficient "UA" is calculated as a sum of all individual components, e.g. walls, windows etc. Except for basement, it is assumed that the heat flow is one-dimensional. In computing the "U" value for the basement walls, it is assumed that the heat flow lines can be approximated by circular arcs; so that

$$U_{bg} = \frac{2K_g}{\pi H} \cdot \ln \left\{ 1 + \frac{\pi H}{2K_g R_w} \right\} \qquad \ldots\ldots(5.4)$$

where U_{bg} = effective U-value of the below grade wall $\left(\frac{\text{Btu}}{\text{h.ft}^2.{}^\circ\text{F}}\right)$

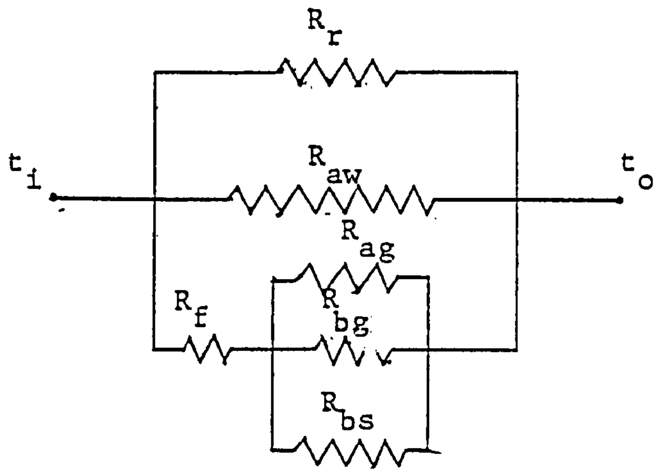
K_g = soil conductivity $\left(\frac{\text{Btu}}{\text{h.ft.}{}^\circ\text{F}}\right)$

H = the depth of the below grade wall (ft)

R_w = R-value of the basement wall $\left(\frac{\text{h.ft}^2.{}^\circ\text{F}}{\text{Btu}}\right)$

5.2.2 Discussion

Let "U", "R" and "A" stand for the conductivity, resistance and area of a component under consideration. The total "UA" value of the house including basement is calculated by CIRA from the following network(see Figure 5.1-a). Resistance due to the



where R_r = the resistance of roof

R_{aw} = the resistance of exterior walls

R_f = the resistance of basement ceiling

R_{ag} = the resistance of above grade basement walls

R_{bg} = the effective resistance of below grade walls

R_{bs} = the effective resistance of the basement slab

Figure 5.1-a : Equivalent Electric Network for a House with Basement(1)

above grade walls, below grade walls and slab form a parallel network in series with the resistance due to the floor. This is quite logical since the heat flowing from the upper space to the basement space is lost through the above- and below - grade walls and the basement slab. Hence, the heat loss from the various basement components can be expressed as :

$$Q_b = \{A_{ag}\ U_{ag} + A_{bg}\ U_{bg} + A_f\ U_f\}\ (t_i - t_o) \qquad (\frac{Btu}{h})$$

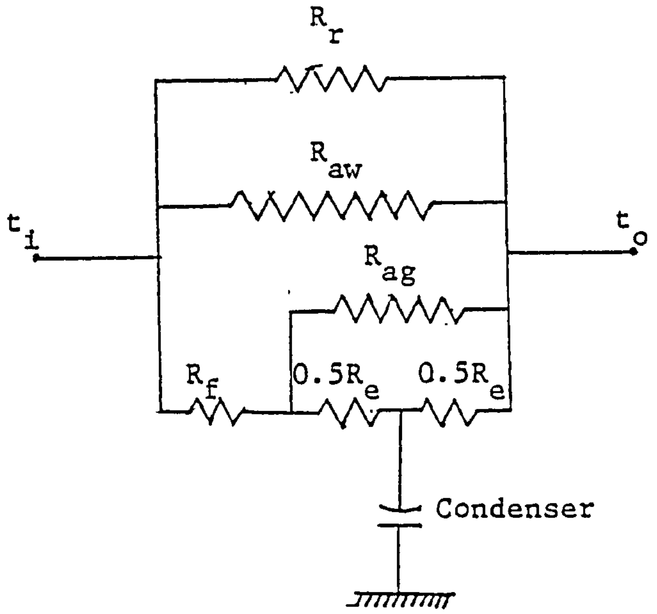
Let $Q_b = A_f\ U_b$

where U_b = the equivalent conductivity of the basement walls and slab $(\frac{Btu}{h.ft^2.^oF})$

$$\therefore\ U_b = \{\frac{A_{ag}\ U_{ag} + A_{bg}\ U_{bg} + A_f\ U_{bs}}{A_f}\}$$

$$\therefore\ R_B = \{\frac{1}{\frac{A_{ag}}{A_f}\ U_{ag} + \frac{A_{bg}}{A_f}\ U_{bg} + U_{bs}}\} \qquad (\frac{h.ft^2.^oF}{Btu})$$

The only flaw in the above logic is that the below grade basement components are treated as components with zero thermal mass. This is not correct, since the below grade portion of the basement is surrounded by the soil, which changes the whole mechanism of heat transfer. This was discussed in detail in Chapter 4. A modified network should perhaps have a condenser, denoting the presence of soil(see Figure 5.1 b).



where $R_e = \dfrac{A_f}{A_{bg}\,U_{bg} + A_f\,U_{bs}}$

Figure 5.1-b : Equivalent Electric Network for a House with a modified Basement Network

From the above model, it is clear at once that the basement is not considered as a separate zone from the living area. Since there is no provision to specify the space temperature in the basement, one cannot strictly simulate a house with a conditioned basement space. Continuing with the network(see Figure 5.2), it can be seen that the left hand end of the equivalent basement resistance, R_B, will be exposed to a temperature:

$$t_B = t_i - \left(\frac{R_f}{R_f+R_B}\right) (t_i-t_o) \qquad (^{o}F) \qquad ....(5.5)$$

If " t_i " is considered to be fixed over the heating season, " t_B " will vary from month to month, since " t_o " is different for each month. Note that $\frac{R_f}{R_f + R_B}$ is constant. In other words, the basement temperature floats between the indoor temperature and the outdoor temperature, and for a given $\frac{R_f}{R_f + R_B}$, it varies from month to month. The only way one can approximate a heated basement situation with the basement space temperature the same as that in the upper floor is to drive the second term $\frac{R_f}{R_f+R_B}(t_i-t_o)$ to zero. This implies that " R_f ", the resistance of the upper floor(i.e. the basement ceiling) should be negligibly small ($\simeq 0$), so that $\frac{R_f}{R_f + R_B}$ tends to 0. This implies that $\frac{R_f}{R_f+R_B}(t_i-t_o)$, which means that " t_B " $\simeq$ " t_i ". To illustrate, let " t_i " = 70 ^{o}F, then if " R_B " is extremely small, " t_B " = 70 ^{o}F, and hence one can model a so-called "heated" basement maintained at 70 ^{o}F. The minimum value that

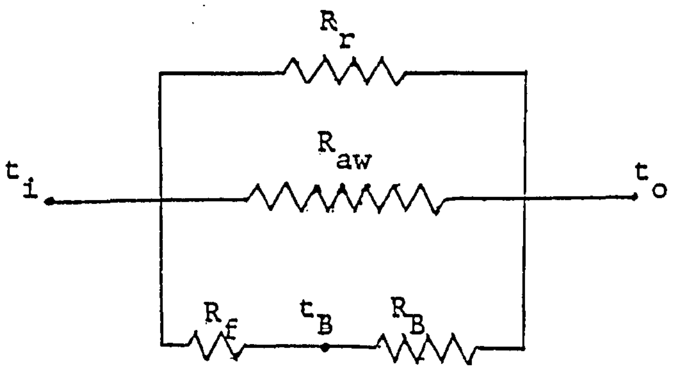


Figure 5.2 : Equivalent Electric Network for a House with Basement(2)

the resistance of the upper floor, R_f , can assume is 1 $\frac{h.ft\ .^{o}F}{Btu}$ Hence $\frac{R_f}{R_f + R_B}$ can be written as $\frac{1}{1 + R_B}$. The magnitude of the term R_B depends on a number of factors such as the floor area, the above and below - grade wall areas and resistance of the basement walls and slab. R_B should be as large as possible since R_f cannot be reduced below 1 h.ft . °F / Btu, for making a better approximation to a heated basement case. Since the magnitude of R_B is dependent on the various areas and resistances of the basement components, its magnitude is fixed for a particular basement. From the above discussion it is apparent that there is no provision to model the basement as a conditioned space. It is therefore felt that the basement should be modelled as a separate zone and mean monthly ground temperatures instead of air temperatures should be used to calculate the basement heat loss. These ground temperatures should introduce an appropriate time lag in the heat loss due to the thermal storage of soil.

It was shown in Chapter 4 that the basement heat loss calculated by CIRA did not agree well with that calculated by HEATING5 on a monthly basis. The agreement was, however, quite close(within 10%) over the heating season. Considering the highly simplistic nature of the basement model used in CIRA, it can be concluded that CIRA can be expected to predict only seasonal basement heat loss fairly well.

5.3 Infiltration

5.3.1 Description

The air infiltration model used in the program is developed by Sherman and Grimsrud(10). The infiltration for each month is calculated as a superposition of flows from stack and wind effects, which are given by :

$$Q_s = L\, f_s^* \,(g.H.\Delta T/T)^{\frac{1}{2}}$$

$$\text{and} \qquad Q_w = L\, f_w^*\, V \qquad \ldots\ldots (5.6)$$

where

Q_s = stack induced infiltration $(\frac{ft^3}{s})$

Q_w = wind induced infiltration $(\frac{ft^3}{s})$

L = the total house leakage area (ft^2)

H = the house height (ft)

T = the absolute outdoor temperature (^oR)

V = the wind speed (ft/s)

f_s^* = the reduced stack parameter

$$= \frac{1}{3}(1 + \frac{R_L}{2})\ \{1 - \frac{X_L^2}{(2-R_L)^2}\}^{3/2}$$

f_w^* = the reduced wind parameter

$$= C' \; (1 - R_L)^{1/3} \; \left\{ \frac{\alpha (\frac{H}{10})^{\gamma}}{\alpha_w (\frac{H_w}{10})^{\gamma_w}} \right\}$$

X_L and R_L are defined as

$$X_L = (L_C - L_F)/L$$

$$R_L = (L_C + L_F)/L$$

where L_C, L_f = the ceiling and floor leakage areas (ft^2)

α_w, γ_w = terrain parameters for the weather station site

C' = a local shielding parameter

H_w = the measurement site height (ft)

α, γ = terrain parameters for the house

A detailed explanation of the stack and wind reduced parameters can be found in Reference 10.

The total infiltration is calculated as:

$$Q = (Q_w^2 + Q_s^2)^{\frac{1}{2}} \tag{5.7}$$

To reduce computing time, stack and wind effects are calculated in advance for a reference house under reference conditions. These values are then corrected to reflect the actual conditions. The above expression for calculating monthly air infiltration reduces to the following form :

$$Q = L\{(C_s\ q_s)^2 + (C_w\ q_w)^2\}^{\frac{1}{2}} \qquad (5.8)$$

where q_s, q_w = monthly specific stack and wind induced infiltration $\left(\frac{ft^3}{h.ft^2}\right)$

C_s, C_w = factor to correct the non-standard house in standard surroundings

These factors are a function of the leakage area distribution, the height of the house and the actual surroundings. Leakage areas are calculated from door fan tests. If they are not available, the default values of leakage areas given by the program can be used.

5.3.2 Discussion

Infiltration is a major cause of heat loss in residences. Calculation of infiltration is an extremely difficult task. The above model calculates infiltration for a structure for any weather condition if the leakage area and distribution are known. Considering its simplicity, the agreement between infiltration measured by the tracer gas decay technique and that predicted by the model for fifteen differerent sites was good(22).

The model does not consider the directional effects of wind. For a house in an urban site, the wind direction may not be a critical factor since the surounding buildings provide a good shielding and deflection of wind. For an isolated building, however, this can be a major limitation , since the wind direction would have a significant effect on infiltration.

5.4 General Discussion

At this point, an expression for heating load can be written as :

$$H = (UA + \rho CQ)(t_i - t_o) - (S_g + I_g) \qquad \left(\frac{Btu}{h}\right) \ldots (5.9)$$

where t_i = indoor temperature ($^{\circ}F$)

t_o = outdoor temperature ($^{\circ}F$)

The reader is reminded that the models used by CIRA to calculate solar gains have not yet been dealt with. Note that Eq.(5.9) accounts for heat losses due to conduction, $UA(t_i - t_o)$, infiltration, $\rho CQ(t_i - t_o)$ and heat gains due to the solar energy falling through the glazing, S_g , and the internal gains I_g. However, (i) heating of the opaque surfaces, e.g. walls, by the incident solar radiation, and (ii) radiation heat exchange of the building envelope with the sky and the outdoor surroundings have not yet been accounted for. CIRA does account for the above factors. First, the calculation method used in CIRA for solar gains will be examined and the adequacy of the approach will be discussed.

5.5 Solar Gains

5.5.1 Description

Solar gains for windows, four walls and ceiling are calculated as follows :

$$S = \sum_{V=1}^{5} \sigma_V \, \psi_V \, \theta_V \, (I_V + \frac{1}{2} \rho_g \, I_5) \qquad .....(5.10)$$

where V = the orientation of the surface

σ_V = the solar aperture for the Vth orientation (ft^2)

ψ_V = the solar exposure modifier for the Vth orientation

θ_V = the overhang modifier for the Vth orientation

I_V = the daily average solar flux on a horizontal surface.

$I_V = 0$ for $V = 5$

ρ = the ground reflectivity

The solar aperture for windows is defined as the product of the transmisivity and area of glass.

The solar aperture for opaque surfaces(e.g. a wall) is defined as :

$$\sigma = \alpha(\frac{UA}{h_o}) \qquad ..... (5.11)$$

where α = the short wave absorptivity of the opaque surface

A = the area of the opaque surface (ft^2)

h_o = the outside heat transfer coefficient $(\frac{Btu}{h.ft^2.{}^oF})$

Hence the total solar gains, S, consist of the solar gains through the glazing, S_g, and the solar gains through the opaque surfaces, S_o.

The solar exposure modifier is the fraction of total possible solar radiation that reaches the house through any obstacles, such as trees, adjacent buildings etc.

The overhang modifier accounts for the obstruction to the incident solar radiation due to overhangs. It is set to unity for all directions except South.

5.5.2 Discussion

It is necessary to perform the following analysis to see the rational of the approach used by CIRA. A one - dimensional, steady state heat balance along the exterior of the surface (see Figure 5.3) yields :

$$\alpha I = h_o(t_x - t_o) + R_o + h_i(t_x - t_i) \qquad .....(5.12)$$

where α_w = the short wave absorpitivity of the opaque surface

I = the solar flux incident on the surface $\left(\frac{\text{Btu}}{\text{h.ft}^2}\right)$

t_x = the surface temperature (^{o}F)

R_o = the longwave radiation flux $\left(\frac{\text{Btu}}{\text{h.ft}^2}\right)$

t_o = the mean monthly outdoor temperature (^{o}F)

t_i = the indoor temperature (^{o}F)

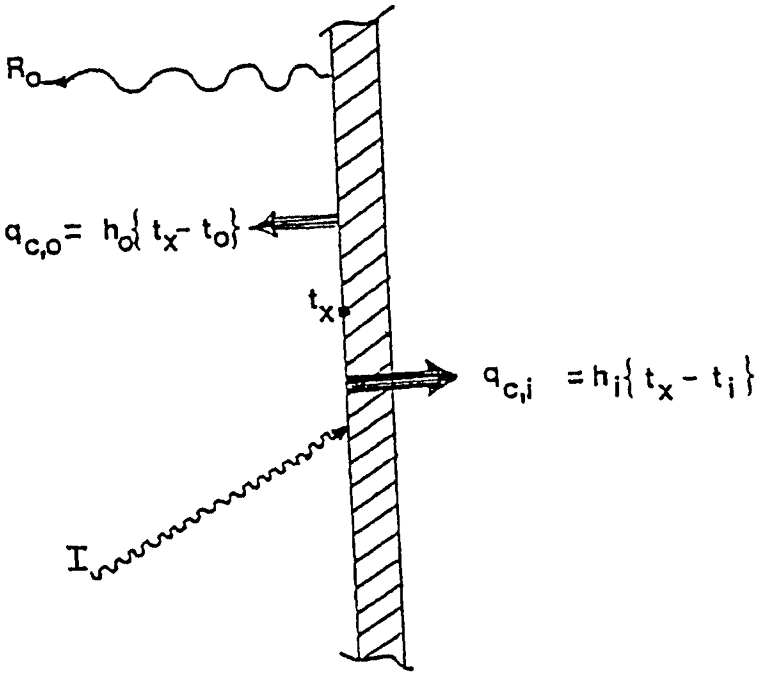


Figure 5.3 : A One Dimensional, Steady State Heat Balance along the Exterior of an Opaque Surface.

h_o = the outside heat transfer coefficient $(\frac{Btu}{h.ft^2.^oF})$

h_i = the inside heat transfer coefficient $(\frac{Btu}{h.ft^2.^oF})$

Rearranging and solving for t_x :

$$t_x = \frac{\alpha I + (h_o t_o + h_i t_i) - R_o}{h_i + h_o} \qquad \text{...... (5.13)}$$

$$q_{c,i} = h_i \{ \frac{\alpha I + (h_o t_o + h_i t_i) - R_o}{h_i + h_o} - t_i \}$$

$$= \frac{\frac{\alpha I}{h_o} + (t_o - t_i) - \frac{R_o}{h_o}}{\frac{1}{U}}$$

where

U = the overall heat transfer coefficient $(\frac{Btu}{h.ft^2.^oF})$, such that

$$\frac{1}{U} = \frac{1}{h_i} + \frac{1}{h_o}$$

then

$$q_{c,i} = \alpha \frac{UI}{h_o} + U(t_o - t_i) - \frac{UR_o}{h_o} \qquad \text{..... (5.14)}$$

A = the total surface area (ft^2)

$Q = q_{c,i} A$

$$\therefore Q = \alpha \frac{UA}{h_o} I + UA(t_o - t_i) - \frac{UA}{h_o} R_o \quad (\frac{Btu}{h}) \qquad \text{..... (5.15)}$$

Eq.(5.9) may now be refined by modifying the heat conduction term . Introducing Eq.(5.15) as the conduction heat loss term in Eq.(5.9):

$$H = \{UA(t_i-t_o) + \alpha(\frac{UA}{h_o})I - (\frac{UA}{h_o})R_o\} + (\rho CQ)(t_i-t_o) \quad .....(5.16)$$
$$- (S_g + I_g) ---$$

Term I represents the conduction heat loss. CIRA lumps $\alpha(\frac{UA}{h_o})$ with the term S and defines the sum as the total solar gain. The radiation heat loss term is included with the total solar gains and internal gains. This approach is quite logical and a simple rearrangement of terms in Eq.(5.16) results in:

$$H = (UA + \rho CQ)(t_i-t_o) - \{(S_g) + (S_o) + I_g - (\frac{UA}{h_o})R_o\} \quad ....(5.17)$$

where $S_o = \alpha(\frac{UA}{h_o})I$

Call

$F \equiv I_g$ and $\Delta R = (\frac{UA}{h_o})R_o$ ....(CIRA notation)

$$\therefore \quad H = (UA + \rho CQ)(t_i-t_o) - (S+F-\Delta R) \quad .....(5.18)$$

where $S = S_g + S_o$

The approach used in CIRA, i.e. Eq.(5.18), is just an alternate way of expressing Eq.(5.16). However, it is slightly better than Eq.(5.16) in the sense that it allows the terms related to the building structure, UA and ρCQ, to be brought together. In addition, the solar gain terms, S_g and S_o, internal gains F and the radiation heat loss term are grouped together, signifying the "net" heat input to the house (excluding the heat input from the heat equipment).

The radiation heat loss term, ΔR, will now be briefly examined.

5.6 Sky Radiation Losses

5.6.1 Description

The heat losses by long wave radiation from the walls and roof to the sky are calculated from the following expression :

$$\Delta R = 4\sigma T_o^4 \{1 - \varepsilon_{sky}^{1/4}\}\{ \sum_{roof} \frac{UA}{h_o} \varepsilon + \sum_{wall} \frac{UA}{3h_o} \varepsilon\} \qquad (\frac{Btu}{h}) \quad \text{........(5.19)}$$

σ = the Stephen-Boltzman constant

ε_{sky} = emissivity of the clear sky

ε_{wall}, ε_{roof} = emissivity of wall and roof

For the details of the derivation of this expression, the interested reader should refer to the engineering manual of CIRA(10).

5.6.2 Discussion

The approach used by CIRA to calculate heat loss due to long wave radiation is quite thorough. Radiation losses are calculated from the horizontal(i.e. ceiling) and the vertical(i.e.walls) surfaces. The calculation of radiation heat exchange of the building surfaces with the sky requires knowledge of the sky emissivity. Berdahl and Fromberg(23) conducted a study in which they measured the thermal radiation from clear skies for three locations in the United States. Based on the collected data, they developed a correlation between the sky emissivity and surface dew point temperature. Thus it is possible to produce an estimate of clear sky emissivity based solely on dew point temperature. This correlation is used in the calculation algorithm of radiation loss. In conclusion, the approach used to calculate heat loss by long wave radiation seems to be sound.

Equation(5.18) will now be considered to determine if it is adequate to calculate heating load.

5.7 Solar Storage Factor, β

5.7.1 Discussion

Eq.(5.18) is a steady state heat transfer equation used by CIRA to calculate heating load. If the calculation period is divided into day(8 a.m. to 8 p.m.) and night(8 p.m. to 8 a.m.), Eq.(5.18) can be written as :

$$H^d = (UA + \rho CQ)(t_i - t_o^d) - (S^d + F - \Delta R^d)$$

and ..... (5.20)

$$H^n = (UA + \rho CQ)(t_i - t_o^n) - (S^n + F - \Delta R^n)$$

where the superscripts d & n denote day and night respectively.

The distinction between the day and night solar energy is accomodated by using a "Solar Storage Factor", β . It is defined as the fraction of the solar energy received over a 24 hour period which is released during the night period(10). Numerical values of this factor, dependent on the thermal storage of the house, are derived from the correlations of computer runs using the BLAST program(10). This approach of partitioning the day and night solar energy is probably the best way, since it is based on hourly calculations done by the BLAST program for a variety of houses in different weather conditions. It will not be appropriate to get into the details of such calculations here. Details and further references can be found from Reference(10).

Eq. (5.20) can be written as :

$$H^d = (UA + \rho CQ)(t_i - t_o^d) - [2(1-\beta)S + F - \Delta R^d] \qquad \text{.....(5.21)}$$

$$H^n = (UA + \rho CQ)(t_i - t_o^n) - [2\beta S + F - \Delta R^n]$$

where β = the solar storage factor

$$= \frac{S^n}{S^d + S^n}$$

S = the average daily solar gain

$$= \frac{S^d + S^n}{2}$$

This logically leads to the concept of "Effective Temperature" used in CIRA.

5.8 Effective Temperature

5.8.1 Description

$$t^d_{eff} = t^d_o + \frac{2(1-\beta)S + F - \Delta R^d}{UA + \rho CQ} \qquad \ldots\ldots\ (5.22)$$

and

$$t^n_{eff} = t^n_o + \frac{2\beta S + F - \Delta R^n}{UA + \rho CQ}$$

Qualitatively, the effective outdoor temperature is that outdoor dry bulb temperature that would produce the same heat transfer through the building envelope by conduction and convection alone, as the superposition of conductive, convective and radiative heat transfer and internal free heat actually occurring(10).

Hence Eq.(5.21) can be written as:

$$H^d = (UA + \rho CQ)(t_i - t^d_{eff}) \qquad \ldots\ldots\ (5.23)$$

and

$$H^n = (UA + \rho CQ)(t_i - \bar{t}^n_{eff})$$

The necessity of the solar and internal gain utilization factors in the heating load calcualtion was pointed out in chapter 3. This requires that the calculation of the effective temperature should be modified. This is discussed in section 5.8.2.

5.8.2 Discussion

With reference to Eq. (5.18),the heating load can be written as:

$$H = (Q_C + Q_I) - (S_g + F) \qquad \text{....(5.24)}$$

where Q_C = conduction heat loss $(\frac{Btu}{h})$

$= UA(t_i - t_o) + \alpha(\frac{UA}{h_o})I - \Delta R$

and Q_I = infiltration heat loss

$= \rho CQ(t_i - t_o)$

It is obvious from equation (5.24) that the calculated heating load is based on the assumption that 100 % of the solar and internal gains are useful. Eq.(5.24) is a steady state heat balance equation. In deriving the expression however occupant comfort was ignored which led to an implicit assumption that all the solar and internal gains "stay" inside the house. This assumption may be fairly valid for very cold months, but it can be seriously violated in several other situations if the space temperature is to remain in tolerable temperature limits. This is best explained with reference to Figure 5.4.

Case 1 is a typical case for colder months(e.g. December,

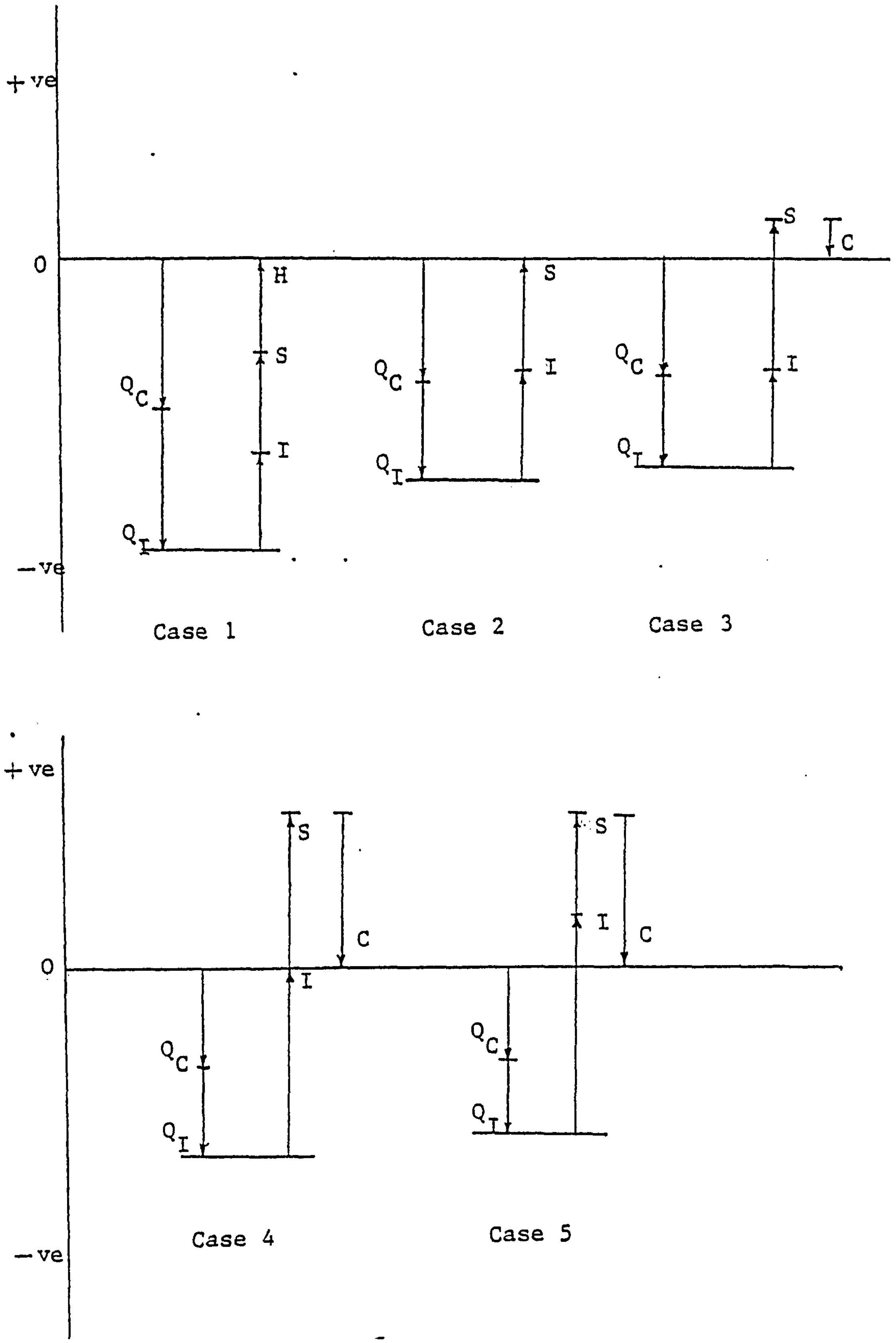


Figure 5.4 : Heat Balances on Space

January) when heat must be supplied to the space to maintain the space temperature at the heating set - point of the thermostat. There are several other situations possible when solar and / or internal gains may exceed transmission losses. In Case 2, no space heating is necessary since the gains have just offset the transmission losses. In this case the space temperature lies within the thermostat deadband. Case 3 through Case 5 illustrate the situations when solar and internal gains exceed the transmission losses and hence the excess heat must be removed to prevent the space temperature from rising above an acceptable limit. If the excess heat is not removed, the space temperature rises. This results in higher conduction and infiltration losses. These cases will be more and more frequent during the Fall and the Spring months.

The above discussion is to emphasize the fact that all of solar and internal gains simply do not contribute to reduce the space heating requirements if the space temperature is to remain within tolerable temperatures. In other words, the heating load should be expressed as :

$$H = (Q_C + Q_I) - (\eta_s S_g + \eta_i F) \qquad \text{......(5.25)}$$

where $\eta_s S$ = the portion of solar gains useful in reducing the heat supplied.

$\eta_i F$ = the portion of internal gains useful in reducing the supplied heat.

η_s = solar gain utilization factor

η_i = internal gain utilization factor

Only heating is required to bring the space temperature to the heating set point. Hence the term (Q_C+Q_I) is evaluated at the heating set point of the thermostat.

Solar and internal gain utilization factors are very high and they are close to unity in colder months when the transmission losses far exceed the solar and internal gains. Hence a utilization factor of unity used by CIRA is reasonable for colder months. In the swing months however these utilization factors are significantly lower than unity(see chapter 3 and References 6 and 17). Thus it is a gross simplification to assume a 100 % utilization factor for these months. Because of these reasons it does not seem appropriate to rely on the results given by CIRA for tight, well - insulated houses with passive solar features. This was shown by the comparison of simulations using CIRA and DOE-2.1a on a passive solar ranch(see chapter 3).

The modified expressions for calculating the effective temperature are :

$$t^d_{eff} = t^d_o + \frac{2(1-\beta)\eta_s S + \eta_i F - \Delta R^d}{UA + \rho CQ} \qquad \text{.....(5.27)}$$

and

$$t^n_{eff} = t^n_o + \frac{2\beta\eta_s S + \eta_i F - \Delta R^n}{UA + \rho CQ} \qquad \text{.....(5.28)}$$

Finally, the calculation method used in CIRA to calculate monthly heating loads from effective temperatures will be considered.

5.9 The Variable Base Degree Day Procedure

5.9.1 Description

Once the effective temperatures for day and night are known, CIRA calculates monthly degree days and degree nights from the following correlation which has been previously determined by means of a specialized regression analysis of the weather data (see reference 10):

$$DD = \frac{d}{2}\,\{(\Delta T)_+ + \mu(\lambda - |\Delta T|)^{\nu}_{+}\} \qquad \ldots\ldots \; (5.29)$$

$$\Delta T = (t_i - t_{eff}) \qquad \ldots\ldots \; (5.30)$$

where

DD = the predicted degree days or degree nights (°F)

d = number of days in the month

μ, ν = dimensionless empirical degree day coefficients

λ = empirical degree day temperature (°F)

t_{eff} = the effective monthly outdoor day/night temperature (°F)

$(\ )_+$ is an operator such that the value within the brackets is equal to itself, if positive; else, it is set to zero

The correlation splits into three regions, defined by (see Figure 5.5).

In Region I, the second term is zero since is negative. Hence,

$$DD = \frac{d}{2}\{(t_i - t_{eff})_+\} \qquad \text{........ (5.31)}$$

In Region II, both the terms are present. The indoor temperature is greater than the effective outdoor temperature. Therefore,

$$DD = \frac{d}{2}\{(\Delta T)_+ + \mu(\lambda - |\Delta T|)_+^{\nu}\} \qquad \text{........ (5.32)}$$

In Region III, the indoor temperature is less than the effective outdoor temperature. Hence the first term is zero. Therefore,

$$DD = \frac{d}{2}\{\mu(\lambda - |\Delta T|)_+^{\nu}\} \qquad \text{........ (5.33)}$$

The base temperature of the house is related to the effective temperature as:

$$t_B = t_i - (t_{eff} - t_o) \qquad \text{........ (5.34)}$$

5.9.2 Discussion

If a program were available for performing hourly calculations, then the heating degree days over a month could be computed by accumulating the degree days for the hours when the effective outdoor temperature was less than the indoor temperature. Since CIRA operates on a monthly basis, it has at its disposal only the monthly averages of the daily and nightly effective

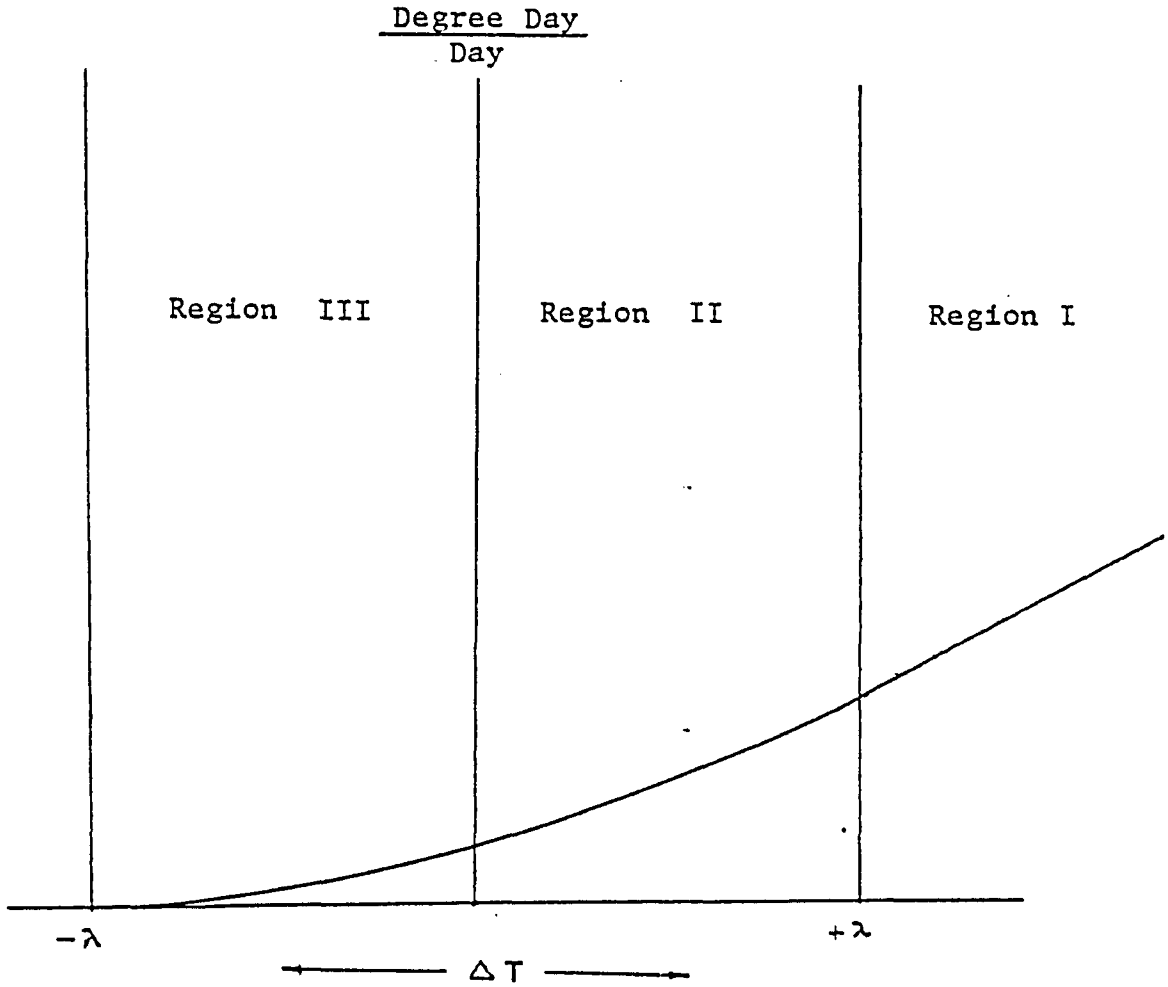


Figure 5.5 : The Variable Base Degree Day Function

temperatures. It is, therefore, necessary to have a function which would predict heating degree days based on average temperatures. The function used in CIRA serves this purpose and hence it is indispensable in the program. The details of the development of this function can be found in the Weather Library of CIRA(see Reference 10). The function consists of two terms: one is linear in ΔT and the other is non-linear in ΔT. To illustrate how efficiently this function operates, consider Regions I, II and III.

Region I corresponds to the low temperature region, i.e. when the effective outdoor temperature is appreciably lower than the indoor temperature. This situation typically occurs in colder months(e.g. January), and the function reduces to a linear form(Eq.5.31).

In Region II, the effective outdoor temperature is less than but close to the indoor temperature. In such cases, heating degree days calculated by multiplying the average T by the number of days (or nights) during a month will be lower than the summation degree days calculated hour by hour over the entire month. In this Region, both the terms of the function are retained(Eq.5.32). The second term can be considered as a corrective term.

In Region III, the effective outdoor temperature is greater than the indoor temperature. However there is still some heating load which is calculated by the second term of the function (Eq.5.33).

5.10 Closure

By now the calculation procedures used by CIRA that were related to this study have been examined. The overall conclusions and recommendations are presented in chapter 6.

6. CONCLUSIONS AND RECOMMENDATIONS

The objective of this work was to evaluate CIRA as an energy analysis program to be used in residential building applications. Various tests were designed to reach this objective. Energy consumption predicted by CIRA was compared against metered energy use. CIRA was critically examined against an established energy simulation program DOE-2.1a. The heat losses from the underground basement walls and floor calculated by CIRA were compared against those calculated by a finite difference heat conduction program HEATING5. These tests were described and their results were presented in the previous chapters. The calculation procedures used in CIRA to calculate heating load were analysed. The following overall conclusions were drawn from these endeavours :

6.1 Conclusions

1. CIRA can be expected to produce reliable results for houses of average construction with low or moderate levels of insulation and solar and internal gains. Thus CIRA may be used with confidence to simulate conventional single family houses.

2. CIRA is not recommended to simulate well - insulated, tight houses with high solar and internal gains.

3. On an annual basis basement heat losses predicted by CIRA were within 10 % as compared to those calculated by the finite

difference program HEATING5. The agreement was very good considering the simplicity of calculation procedures used in CIRA.

4. CIRA significantly overpredicted the basement heat loss in the Fall and the Winter months as compared to that predicted by HEATING5. This pattern was reversed in the Spring months. Hence it is concluded that CIRA can be expected to yield reliable results for seasonal basement heat loss only.

5. The overall calculation method used by CIRA for estimating heating load is very good. The overall method consists of several individual calculation procedures to calculate different heat loss or heat gain components . The approaches used for estimating the sky radiation losses and solar heat gain are adequate. The infiltration model does not take into account the effect of wind direction on infiltration. As noted in (4), the basement model is too simplified and it would not predict monthly basement heat loss accurately. The effective temperature calculation method ignores human comfort. The variable base degree day approach is a very efficient way of calculating the monthly heating load based on the average indoor and effective outdoor temperatures.

6.2 Recommendations

1. Solar and internal gain utilization factors should be incorporated in the effective temperature calculation.

2. It is felt that there should be a proper provision to model a conditioned basement space. This could be achieved by making a provision in the program to set the resistance of the floor, separating the living area and the basement, equal to zero.

3. Ground temperatures should be used to calculate basement heat loss. Considering the retrictions on the available computer memory, these temperatures should be such that they will introduce a phase lag in heat loss due to soil.

REFERENCES

1. Hall, J.D., " A Retrofit Strategy for two Canadian Residential Dwellings using the Building Energy Simulation Program DOE-2.1a ". A Masters Thesis in Department of Mechanical Engineering, presented to the University of Windsor, 1983.

2. Energy Performance of Buildings Group, " Engineering Methods (CIRA Reference Manual)", Energy and Environment Division, Lawrence Berkely Laboratory, University of California, Berkely, Calif., 1982.

3. Colborne W.G., Hall J.W., Wilson N.W., " A Critical Comparison of Two Building Energy Simulation Programs ", SUNFEST '83, 9th Annual Conference of the Solar Energy Society of Canada, August 1-5, 1983.

4. Wilson, N.W., Colborne, W.G.et al, " Occupant Effects on Residential Energy Consumption ", Solar Energy Society of Canada, Conference Proceedings, Volume I / II, University of Regina, Regina, Canada, August 23-29, 1982.

5. Colborne, W.G., Wilson, N.W., " A Comparative Study of Methods to determine Annual Energy Consumption for Space Heating ", Solar Energy Society of Canada, Conference Proceedings, Volume I / II, University of Regina, Regina, Canada, August 23-29, 1982.

6. Colborne, W.G. et.al., " Confirmation of Solar Utilization Factors using DOE-2 Simulation ", prepared for the National

Research Council, Division of Building Research, Ottawa, June 1982.

7. Turner W.D., Elrod. D.C.and Simon-Tov, " HEATING-5 - An IBM 360 Heat Conduction Program ", Oak Ridge National Laboratory, Oak Ridge, Tennessee, March, 1977.

8. Raff S.J., " Ground Temperature Control ", Underground Space, Volume 3., No. 1 , pp. 35-44, Permagon Press, Great Britain, 1978.

9. Szydlowski, R.F., " Analysis of Transient Heat Loss in Earth Sheltered Structures ", M.S. Thesis, Iowa State Univ., Ames,Iowa 1980.

10. " CIRA 1.0 Reference Manual ", prepared by Lawrence Berkley Laboratory, University of California, Berkeley, Calif., March 1982.

11. ASHRAE Handbook, 1981 Fundamentals, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., 1791, Tullie Circle NE, Atlanta, GA 30329.

12. DOE-2 reference manual, Part 1, Version 2.1, Group WX-4, Program Support, Los Alamos Scientific Laboratory, Los Alamos, New Mexico, May 1980.

13. Mitalas G.P., " Effect of Building Mass on Annual Heating Requirements ". A Paper presented at CIB Symposium on Energy Conservation in Built Environment ", Copenhagen, 1979.

14. Boileau G.G. and Latta J.K., " Calculation of Basement Heat

Losses ", Technical Paper No. 292, National Research Council Canada, Dec. 1968.

15. Little, Arthur D.,Inc., " Evaluation of Existing Programs for Simulation of Residential Building Energy Use ". EPRI EA-2575, Project 1775-1, GRI Report (GRI-81/0047), Sept. 1982.

16. Spielvogel Lawrence G., " Comparison of Energy Analysis computer programs ", ASHRAE Journal, January 1978.

17. Barakat S.A. and Sander D.M., " Utilization of Solar Gains through Windows for Heating Houses ", Building Research Note, National Research Council Canada, September 1982.

18. Mitalas G.P., " Basement Heat Loss studies at DBR / NRC ", DBR Paper No. 1045, National Reseach Council of Canada, Sept. 1982.

19. Lux M., " HOTCAN Program Manual for APPLE Plus Computer ", DBR Computer Program No. 48, National Research Council Canada, Ottawa, Sept. 1982.

20. Dumont R.S., " HOTCAN : A Computer Program for Estimating the Space Heating Requirements of Residences ", DBR Computer Program No. 49, National Research Council Canada, Ottawa, Sept. 1982.

21. Murphy M.E., " The Influence of the Thermal Capacity of a Building on its Energy Consumption ", CIB Proceedings of the Second International CIB Symposium on Energy Conservation in the Built Environment, Danish Building Research Institute,

Copenhagen, 1979.

22. Sherman M.H. and Grimsrud D.T., " Measurement of Infiltration using Fan Pressurization and Weather Data ", Oct. 1980, Lawrence Berkeley Laboratory, U.S.A.

23. Berdahl P. and Fromberg R., " The Thermal Radiance of Clear Skies ", Solar Energy, Volume 29 No.4, pp. 299 - 314, 1982.

Appendix A

CIRA Input Listings for House A

```
Current answers for GENERAL named J.Hall's :

   A) NAME of this house......................? 'J.Hall's'
   B) What CITY...............................? 'Detroit'
   C) AZIMUTH of north face (degrees).........? '0' degrees
   D) What type of THERMOSTAT.................? 'Dual heating & cooling'
   E) Heating THERMOSTAT setting (degF).......? '70' degF
   F) Heating NIGHT setting (degF)............? '70' degF
   G) Cooling THERMOSTAT setting (degF).......? '78' degF
   H) Cooling NIGHT setting (degF)............? '78' degF
   I) Total house FLOOR AREA (sqft)...........? '1850' sqft
   J) House MASS..............................? 'Light'
   K) Solar STORAGE factor (unitless).........? '.22' unitless
   L) SPECIFIC THERMAL MASS (Btu/Fsqft).......? '1.9' Btu/Fsqft
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for WINDOWS named East :

   A) NAME of the following windows...........? 'East'
   B) Which window ORIENTATION................? 'East'
   C) Window TYPE.............................? 'Double hung'
   D) GLAZING.................................? 'Single pane w/ OUTSIDE storm'
   E) DRAPES & SHUTTERS.......................? 'Shades or Blinds'
   F) Are window covers USED at DAYtime.......? 'No'
   G) U-value (Btun/sqft/F)...................? '.519443' Btuh/sqft/F
   H) Average sash FIT........................? 'Average'
   I) Specific LEAKAGE AREA (sqin/sqft).......? '.0790502' sqin/sqft
   J) Summer SOLAR GAIN factor (%)............? '77' %
   K) Winter SOLAR GAIN factor (%)............? '77' %
   L) Window AREA (sqft)......................? '49.06' sqft
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for WINDOWS named North :

  A) NAME of the following windows...........? 'North'
  B) Which window ORIENTATION................? 'North'
  C) Window TYPE.............................? 'Double hung'
  D) GLAZING.................................? 'Single pane w/ OUTSIDE storm'
  E) DRAPES & SHUTTERS.......................? 'Shades or Blinds'
  F) Are window covers USED at DAYtime.......? 'No'
  G) U-value (Btuh/sqft/F)...................? '.519443' Btuh/sqft/F
  H) Average sash FIT........................? 'Average'
  I) Specific LEAKAGE AREA (sqin/sqft).......? '.0790502' sqin/sqft
  J) Summer SOLAR GAIN factor (%)............? '77' %
  K) Winter SOLAR GAIN factor (%)............? '77' %
  L) Window AREA (sqft)......................? '16.77' sqft
  Y) < DELETE this Component >...
  Z) < Changes COMPLETED >...

                                          >
```

```
Current answers for WINDOWS named West :

  A) NAME of the following windows...........? 'West'
  B) Which window ORIENTATION................? 'West'
  C) Window TYPE.............................? 'Double hung'
  D) GLAZING.................................? 'Single pane w/ OUTSIDE storm'
  E) DRAPES & SHUTTERS.......................? 'Shades or Blinds'
  F) Are window covers USED at DAYtime.......? 'No'
  G) U-value (Btuh/sqft/F)...................? '.519443' Btuh/sqft/F
  H) Average sash FIT........................? 'Average'
  I) Specific LEAKAGE AREA (sqin/sqft).......? '.0790502' sqin/sqft
  J) Summer SOLAR GAIN factor (%)............? '77' %
  K) Winter SOLAR GAIN factor (%)............? '77' %
  L) Window AREA (sqft)......................? '25.1' sqft
  Y) < DELETE this Component >...
  Z) < Changes COMPLETED >...
```

```
Current answers for WINDOWS named South :

   A) NAME of the following windows...........? 'South'
   B) Which window ORIENTATION................? 'South'
   C) Window TYPE.............................? 'Double hung'
   D) GLAZING.................................? 'Single pane w/ OUTSIDE storm'
   E) DRAPES & SHUTTERS.......................? 'Shades or Blinds'
   F) Are window covers USED at DAYtime.......? 'No'
   G) U-value (Btuh/sqft/F)...................? '.519443' Btuh/sqft/F
   H) Average sash FIT........................? 'Average'
   I) Specific LEAKAGE AREA (sqin/sqft).......? '.0790502' sqin/sqft
   J) Summer SOLAR GAIN factor (%)............? '77' %
   K) Winter SOLAR GAIN factor (%)............? '77' %
   L) Window AREA (sqft)......................? '10.71' sqft
   M) Overhang PROTRUSION (inches)............? '18' inches
   N) HEIGHT above top of window (inches).....? '12' inches
   O) Average window HEIGHT (feet)............? '5.41' feet
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for WALLS named Front :

   A) NAME for the following walls............? 'Front'
   B) Which wall ORIENTATION..................? 'East walls'
   C) wall.TYPE...............................? 'Two by Four Frame'
   D) Wall INSULATION.........................? 'Fiberglass batts'
   E) Insulation THICKNESS (inches)...........? '3' inches
   F) INSULATABLE wall THICKNESS (inches).....? '0' inches
   G) Exterior INSULATING SHEATHING...........? 'None'
   H) wall R-VALUE (F-sqft/Btuh)..............? '8' F-sqft/Btuh
   I) Wall AREA wo/ windows & doors (sqft)....? '234.93' sqft
   J) No. of WINDOWS (No.)....................? '4' No.
   K) No. of VENTS in wall (No.)..............? '1' No.
   L) No. of other PENETRATIONS (No.).........? '1' No.
   M) Specific LEAKAGE AREA (sqin/sqft).......? '.0335934' sqin/sqft
   Y) < DELETE this Component >...
```

```
 Current answers for WALLS named Left :

   A) NAME for the following walls............? 'Left'
   B) Which wall ORIENTATION..................? 'South walls'
   C) Wall TYPE...............................? 'Two by Four Frame'
   D) Wall INSULATION.........................? 'Fiberglass batts'
   E) Insulation THICKNESS (inches)...........? '3' inches
   F) INSULATABLE wall THICKNESS (inches).....? '0' inches _
   G) Exterior INSULATING SHEATHING...........? 'None'
   H) Wall R-VALUE (F-sqft/Btuh)..............? '8' F-sqft/Btuh
   I) Wall AREA wo/ windows & doors (sqft)....? '201.29' sqft
   J) No. of WINDOWS (No.)....................? '2' No.
   K) No. of VENTS in wall (No.)..............? '1' No.
   L) No. of other PENETRATIONS (No.).........? '1' No.
   M) Specific LEAKAGE AREA (sqin/sqft).......? '.0269738' sqin/sqft
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...

Which menu ITEM(S).....................?
```

```
 Current answers for WALLS named Back :

   A) NAME for the following walls............? 'Back'
   B) Which wall ORIENTATION..................? 'West walls'
   C) Wall TYPE...............................? 'Two by Four Frame'
   D) Wall INSULATION.........................? 'Fiberglass batts'
   E) Insulation THICKNESS (inches)...........? '3' inches
   F) INSULATABLE wall THICKNESS (inches).....? '0' inches
   G) Exterior INSULATING SHEATHING...........? 'None'
   H) Wall R-VALUE (F-sqft/Btuh)..............? '8' F-sqft/Btuh
   I) Wall AREA wo/ windows & doors (sqft)....? '258.9' sqft
   J) No. of WINDOWS (No.)....................? '4' No.
   K) No. of VENTS in wall (No.)..............? '1' No.
   L) No. of other PENETRATIONS (No.).........? '1' No.
   M) Specific LEAKAGE AREA (sqin/sqft).......? '.0306005' sqin/sqft
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for WALLS named Right :

   A) NAME for the following walls............? 'Right'
   B) Which wall ORIENTATION..................? 'North walls'
   C) Wall TYPE...............................? 'Two by Four Frame'
   D) Wall INSULATION.........................? 'Fiberglass batts'
   E) Insulation THICKNESS (inches)...........? '3' inches
   F) INSULATABLE wall THICKNESS (inches).....? '0' inches
   G) Exterior INSULATING SHEATHING...........? 'None'
   H) Wall R-VALUE (F-sqft/Btuh)..............? '8' F-sqft/Btuh
   I) Wall AREA wo/ windows & doors (sqft)....? '195.23' sqft
   J) No. of WINDOWS (No.)....................? '2' No.
   K) No. of VENTS in wall (No.)..............? '1' No.
   L) No. of other PENETRATIONS (No.).........? '1' No.
   M) Specific LEAKAGE AREA (sqin/sqft).......? '.0277055' sqin/sqft
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for LANDSCAP named Yard & Trees :

   A) Ground SURFACE TYPE.....................? 'Green grass'
   B) Ground REFLECTANCE (%)..................? '24' %
   C) SOUTH solar EXPOSURE - DECEMBER (%).....? '60' %
   D) SOUTH solar EXPOSURE - JUNE (%).........? '30' %
   E) EAST solar EXPOSURE - DECEMBER (%)......? '50' %
   F) EAST solar EXPOSURE - JUNE (%)..........? '30' %
   G) WEST solar EXPOSURE - DECEMBER (%)......? '60' %
   H) WEST solar EXPOSURE - JUNE (%)..........? '30' %
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for DOORS named East :

  A) NAME of following doors.................? 'East'
  B) Door TYPE...............................? 'Plain (Hinged)'
  C) Door MATERIAL...........................? 'Wood Solid Core'
  D) Approximate Glass AREA (%)..............? '0' %
  E) Any STORM doors.........................? 'Outside storm'
  F) U-value (Btuh/sqft/F)...................? '.24812' Btun/sqft/F
  G) Door FIT................................? 'Average'
  H) Specific leakage AREA (sqin/sqft).......? '.0294501' sqin/sqft
  I) Door AREA (sqft)........................? '20.01' sqft
  Y) < DELETE this Component >...
  Z) < Changes COMPLETED >...
```

```
Current answers for DOORS named West

  A) NAME of following doors.................? 'West'
  B) Door TYPE...............................? 'Plain (Hinged)'
  C) Door MATERIAL...........................? 'Wood Solid Core'
  D) Approximate Glass AREA (%)..............? '0' %
  E) Any STORM doors.........................? 'Outside storm'
  F) U-value (Btuh/sqft/F)...................? '.24812' Btuh/sqft/F
  G) Door FIT................................? 'Average'
  H) Specific leakage AREA (sqin/sqft).......? '.0294501' sqin/sqft
  I) Door AREA (sqft)........................? '20.01' sqft
  Y) < DELETE this Component >...
  Z) < Changes COMPLETED >...
```

```
Current answers for ROOF-CEI named Attic :

   A) NAME for attic/roof or ceiling..........? 'Attic'
   B) Roof-Ceiling TYPE.......................? 'Unfinished attic'
   C) Insulation TYPE.........................? 'Fiberglass batts'
   D) Insulation THICKNESS (inches)...........? '13' inches
   E) Insulatable AIR SPACE (inches)..........? '0' inches
   F) Ceiling R-value (F-sqft/Btuh)...........? '43' F-sqft/Btuh
   G) Ceiling AREA (sqft).....................? '925' sqft
   H) No. of ceiling VENTS (count)............? '5' count
   I) No. of ceiling PENETRATIONS (count).....? '10' count
   J) Ceiling sp. LEAKAGE area (sqin/sqft)....? '.0435676' sqin/sqft
   K) Roof PITCH (%)..........................? '30' %
   L) Roof top MATERIAL.......................? 'Asphalt Shingles'
   M) Roof ABSORPTIVITY (%)...................? '95' %
   N) Attic VENTILATION (cfm/sqft)............? '.5' cfm/sqft
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for INFILTRA named Ventilation :

   A) Is there MECHANICAL Ventilation.........? 'None'
   B) NATURAL Cooling Ventilation.............? 'No'
   C) TERRAIN class...........................? 'Class 3'
   D) SHIELDING class.........................? 'Class 3'
   E) HEIGHT of living space (feet)...........? '8' feet
   F) Approx. house VOLUME (cubic feet).......? '7400' cubic feet
   G) HOW was leakage area MEASURED...........? 'Total only'
   H) TOTAL leakage area (sqin)...............? '60' sqin
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for SUBFLOOR named Basement :

   A) Subfloor NAME..........................? 'Basement'
   B) Subfloor TYPE..........................? 'Basement'
   C) Joist INSULATION.......................? 'Heated basement'
   D) Total joist R-VALUE (F-sqft/Btuh).......? '3' F-sqft/Btuh
   E) Floor AREA (Joists) (sqft).............? '925' sqft
   F) No. of floor PENETRATIONS (No.).........? ' ' No.
   G) Floor sp. LEAKAGE AREA (sqin/sqft)......? '.0385407' sqin/sqft
   H) Subfloor WALL INSULATION material.......? 'None'
   I) Above-grade wall R-VALUE (F-sqft/Btuh)..? '8' F-sqft/Btun
   J) ABOVE-Grade HEIGHT (feet)..............? '.100001' feet
   K) Exposed PERIMETER (feet)...............? '128' feet
   L) Soil CONDUCTIVITY (Btuh-in/F-sqft)......? '15' Btuh-in/F-sqft
   M) No. of WINDOWS (No.)...................? ' ' No.
   N) No. of wall VENTS (No.)................? ' ' No.
   O) No. of wall PENETRATIONS (No.).........? ' ' No.
   P) wall specific LEAKAGE AREA (sqin/sqft)..? '.147362' sqin/sqft
   Q) Below-grade R-VALUE (F-sqft/Btuh).......? '5.99999' F-sqft/Btun
   R) Floor R-VALUE (F-sqft/Btuh)............? '2' F-sqft/Btun
   S) Eqv Floor RESIST' outs'd (F-sqft/Btuh)..? '36' F-sqft/Btun
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for APPLIANC named Occupant :

   A) NAME of occupants......................? 'Occupant'
   B) How many DAYTIME OCCUPANTS (people).....? '1' people
   C) How many NIGHT OCCUPANTS (people).......? '0' people
   D) DAILY hot water USE (gal/day)...........? '44.0001' gal/day
   E) WATER HEATER type......................? 'Gas'
   F) Input RATING (kBtu/hr).................? '40' kBtu/hr
   G) Hot water THERMOSTAT setting (degF).....? '140' degF
   H) WHERE is water heater..................? 'Basement'
   I) Stdby/plumb. LOSSES (kBtu/hr)..........? '1.12' kBtu/hr
   J) REFRIGERATOR type......................? 'Man. defrost & sep. freezer'
   K) Average MONTHLY CONSUMPTION (kWh/mo)....? '65' kWh/mo
   L) DRYER and RANGE type...................? 'Both Electric'
   M) Internal MOISTURE generation (lb/dy)....? '2.68001' lb/dy
   N) LIGHTS & OTHER HEAT GAINS (kBtu/hr).....? '1.452' kBtu/hr
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for HVAC-SYS named Heat-Cool :

  A) What HEATING EQUIPMENT..................? 'Gas Furnace'
  B) Rated INPUT capacity (kBtu/hr)..........? '100' kBtu/hr
  C) Steady-state EFFICIENCY (%).............? '70' %
  D) FLUE gas temperature (degF).............? '250' degF
  E) What DISTRIBUTION system................? 'Forced Air'
  F) WHERE are pipes or ducts................? 'Basement'
  G) INSULATION on pipes or ducts............? 'None'
  H) Insulatable duct/pipe LENGTH (feet).....? '100' feet
  I) Distribution LOSSES to outside (%)......? '25' %
  J) What COOLING EQUIPMENT..................? 'Central Air Conditioning'
  K) Rated TOTAL capacity (kBtu/hr)..........? '24' kBtu/hr
  L) Rated SENSIBLE capacity (kBtu/hr).......? '16.3' kBtu/hr
  M) Rated COP (unitless)....................? '2' unitless
  N) Actual Fan FLOW (cfm)...................? '734' cfm
  Y) < DELETE this Component >...
  Z) < Changes COMPLETED >...
```

```
Current answers for ECONOMIC named Price & Use :

  A) Economic HORIZON (years)................? '20' years
  B) REAL DISCOUNT rate (%)..................? '3' %
  C) REPLACEMENT-RETROFIT esc. rate (%)......? '4' %
  D) Maximum INVESTMENT ($)..................? '2000' $
  E) ADJUST results to ACTUAL use............? 'No'
  F) NON-ELECTRIC fuel.......................? 'Gas'
  G) GAS price ($/Therm).....................? '.559' $/Therm
  H) GAS escalation rate (%).................? '2.8'. %
  I) ELECTRICITY price ($/kwh)...............? '.0711' $/kwh
  J) ELECTRICITY escalation rate (%).........? '1.5' %
  Y) < DELETE this Component >...
  Z) < Changes COMPLETED >...
```

Appendix B-1

CIRA Input listings for the Villages of Riverside House (without Basement Wall Insulation)

```
Current answers for GENERAL named V of R :

   A) NAME of this house.....................? 'V of R'
   B) What CITY..............................? 'Detroit'
   C) AZIMUTH of north face (degrees)........? '0' degrees
   D) What type of THERMOSTAT................? 'Heating only'
   E) Heating THERMOSTAT setting (degF)......? '70' degF
   F) Heating NIGHT setting (degF)...........? '70' degF
   G) Avg Indoor SUMMER temperature (degF)...? '78' degF
   H) Total house FLOOR AREA (sqft)..........? '1443' sqft
   I) House MASS.............................? 'Light'
   J) Solar STORAGE factor (unitless)........? '.22' unitless
   K) SPECIFIC THERMAL MASS (Btu/Fsqft)......? '1.9' Btu/Fsqft
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for WALLS named Front :

   A) NAME for the following walls...........? 'Front'
   B) Which wall ORIENTATION.................? 'South walls'
   C) Wall TYPE..............................? 'Two by Four Frame'
   D) Wall INSULATION........................? 'Fiberglass batts'
   E) Insulation THICKNESS (inches)..........? '3.5' inches
   F) INSULATABLE wall THICKNESS (inches)....? '0' inches
   G) Exterior INSULATING SHEATHING..........? 'None'
   H) Wall R-VALUE (F-sqft/Btuh).............? '11' F-sqft/Btuh
   I) Wall AREA wo/ windows & doors (sqft)...? '323.46' sqft
   J) No. of WINDOWS (No.)...................? '1' No.
   K) No. of VENTS in wall (No.).............? '1' No.
   L) No. of other PENETRATIONS (No.)........? '1' No.
   M) Specific LEAKAGE AREA (sqin/sqft)......? '.0158623' sqin/sqft
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for WALLS named Rear :

   A) NAME for the following walls............? 'Rear'
   B) Which wall ORIENTATION..................? 'North walls'
   C) Wall TYPE...............................? 'Two by Four Frame'
   D) Wall INSULATION.........................? 'Fiberglass batts'
   E) Insulation THICKNESS (inches)...........? '3.5' inches
   F) INSULATABLE wall THICKNESS (inches).....? '0' inches
   G) Exterior INSULATING SHEATHING...........? 'None'
   H) Wall R-VALUE (F-sqft/Btuh)..............? '11' F-sqft/Btuh
   I) Wall AREA wo/ windows & doors (sqft)....? '276' sqft
   J) No. of WINDOWS (No.)....................? '1' No.
   K) No. of VENTS in wall (No.)..............? '1' No.
   L) No. of other PENETRATIONS (No.).........? '1' No.
   M) Specific LEAKAGE AREA (sqin/sqft).......? '.0174103' sqin/sqft
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for WALLS named Right :

   A) NAME for the following walls............? 'Right'
   B) Which wall ORIENTATION..................? 'East walls'
   C) Wall TYPE...............................? 'Two by Four Frame'
   D) Wall INSULATION.........................? 'Fiberglass batts'
   E) Insulation THICKNESS (inches)...........? '3.5' inches
   F) INSULATABLE wall THICKNESS (inches).....? '0' inches
   G) Exterior INSULATING SHEATHING...........? 'None'
   H) Wall R-VALUE (F-sqft/Btuh)..............? '11' F-sqft/Btuh
   I) Wall AREA wo/ windows & doors (sqft)....? '260.93' sqft
   J) No. of WINDOWS (No.)....................? '0' No.
   K) No. of VENTS in wall (No.)..............? '1' No.
   L) No. of other PENETRATIONS (No.).........? '1' No.
   M) Specific LEAKAGE AREA (sqin/sqft).......? '.0150394' sqin/sqft
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for WALLS named Left :

  A) NAME for the following walls............? 'Left'
  B) Which wall ORIENTATION..................? 'West walls'
  C) Wall TYPE...............................? 'Two by Four Frame'
  D) Wall INSULATION.........................? 'Fiberglass batts'
  E) Insulation THICKNESS (inches)...........? '3.5' inches
  F) INSULATABLE wall THICKNESS (inches).....? '0' inches
  G) Exterior INSULATING SHEATHING...........? 'None'
  H) Wall R-VALUE (F-sqft/Btuh)..............? '11' F-sqft/Btuh
  I) Wall AREA wo/ windows & doors (sqft)....? '167.22' sqft
  J) No. of WINDOWS (No.)....................? '1' No.
  K) No. of VENTS in wall (No.)..............? '1' No.
  L) No. of other PENETRATIONS (No.).........? '1' No.
  M) Specific LEAKAGE AREA (sqin/sqft).......? '.0262936' sqin/sqft
  Y) < DELETE this Component >...
  Z) < Changes COMPLETED >...
```

```
Current answers for WINDOWS named Front :

  A) NAME of the following windows...........? 'Front'
  B) Which window ORIENTATION................? 'South'
  C) Window TYPE.............................? 'Double hung'
  D) GLAZING.................................? 'Double pane'
  E) DRAPES & SHUTTERS.......................? 'Shades or Blinds'
  F) Are window covers USED at DAYtime.......? 'No'
  G) U-value (Btuh/sqft/F)...................? '.519443' Btuh/sqft F
  H) Average sash FIT........................? 'Average'
  I) Specific LEAKAGE AREA (sqin/sqft).......? '.0790502' sqin/sqft
  J) Summer SOLAR GAIN factor (%)............? '77' %
  K) Winter SOLAR GAIN factor (%)............? '77' %
  L) Window AREA (sqft)......................? '9.45' sqft
  M) Overhang PROTRUSION (inches)............? '0' inches
  Y) < DELETE this Component >...
  Z) < Changes COMPLETED >...
```

```
Current answers for WINDOWS named Left :

  A) NAME of the following windows...........? 'Left'
  B) Which window ORIENTATION................? 'West'
  C) Window TYPE.............................? 'Double hung'
  D) GLAZING.................................? 'Double pane'
  E) DRAPES & SHUTTERS.......................? 'Shades or Blinds'
  F) Are window covers USED at DAYtime.......? 'No'
  G) U-value (Btuh/sqft/F)...................? '.519443' Btuh/sqft/F
  H) Average sash FIT........................? 'Average'
  I) Specific LEAKAGE AREA (sqin/sqft).......? '.0790502' sqin/sqft
  J) Summer SOLAR GAIN factor (%)............? '77' %
  K) Winter SOLAR GAIN factor (%)............? '77' %
  L) Window AREA (sqft)......................? '93.71' sqft
  Y) < DELETE this Component >...
  Z) < Changes COMPLETED >...
```

……

```
Current answers for WINDOWS named Rear :

  A) NAME of the following windows...........? 'Rear'
  B) Which window ORIENTATION................? 'North'
  C) Window TYPE.............................? 'Double hung'
  D) GLAZING.................................? 'Double pane'
  E) DRAPES & SHUTTERS.......................? 'Shades or Blinds'
  F) Are window covers USED at DAYtime.......? 'No'
  G) U-value (Btuh/sqft/F)...................? '.519443' Btuh/sqft/F
  H) Average sash FIT........................? 'Average
  I) Specific LEAKAGE AREA (sqin/sqft).......? '.0790502' sqin/sqft
  J) Summer SOLAR GAIN factor (%)............? '77' %
  K) Winter SOLAR GAIN factor (%)............? '77' %
  L) Window AREA (sqft)......................? '35' sqft
  Y) < DELETE this Component >...
  Z) < Changes COMPLETED >...
```

```
Current answers for SUBFLOOR named Basement :

   A) Subfloor NAME...........................? 'Basement'
   B) Subfloor TYPE...........................? 'Basement'
   C) Joist INSULATION........................? 'Heated basement'
   D) Total joist R-VALUE (F-sqft/Btuh).......? '5.25001' F-sqft/Btuh
   E) Floor AREA (Joists) (sqft)..............? '431' sqft
   F) No. of floor PENETRATIONS (No.).........? ' ' No.
   G) Floor sp. LEAKAGE AREA (sqin/sqft)......? '.0455011' sqin/sqft
   H) Subfloor WALL INSULATION material.......? 'None'
   I) Above-grade wall R-VALUE (F-sqft/Btuh)..? '11' F-sqft/Btuh
   J) ABOVE-Grade HEIGHT (feet)...............? '.100001' feet
   K) Exposed PERIMETER (feet)................? '92.3' feet
   L) Soil CONDUCTIVITY (Btuh-in/F-sqft)......? '9' Btuh-in/F-sqft
   M) No. of WINDOWS (No.)....................? ' ' No.
   N) No. of wall VENTS (No.).................? ' ' No.
   O) No. of wall PENETRATIONS (No.)..........? ' ' No.
   P) Wall specific LEAKAGE AREA (sqin/sqft)..? '.166979' sqin/sqft
   Q) Below-grade R-VALUE (F-sqft/Btuh).......? '4.68' F-sqft/Btuh
   R) Floor R-VALUE (F-sqft/Btuh).............? '2' F-sqft/Btuh
   S) Eqv Floor RESIST' outs'd (F-sqft/Btuh)..? '35.4501' F-sqft/Btuh
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for INFILTRA named Ventilation :

   A) Is there MECHANICAL Ventilation.........? 'None'
   B) NATURAL Cooling Ventilation.............? 'Yes'
   C) TERRAIN class...........................? 'Class 3'
   D) SHIELDING class.........................? 'Class 3'
   E) HEIGHT of living space (feet)...........? '13.23' feet
   F) Approx. house VOLUME (cubic feet).......? '11385' cubic feet
   G) HOW was leakage area MEASURED...........? 'All three measured'
   H) TOTAL leakage area (sqin)...............? '75' sqin
   I) CEILING leakage area (sqin).............? '27.7754' sqin
   J) FLOOR leakage area (sqin)...............? '16.127' sqin
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for ROOF-CEI named Top :

   A) NAME for attic/roof or ceiling..........? 'Top'
   B) Roof-Ceiling TYPE.......................? 'Unfinished attic'
   C) Insulation TYPE.........................? 'Fiberglass batts'
   D) Insulation THICKNESS (inches)...........? '6' inches
   E) Insulatable AIR SPACE (inches)..........? '6' inches
   F) Ceiling R-value (F-sqft/Btuh)...........? '22' F-sqft/Btuh
   G) Ceiling AREA (sqft).....................? '481' sqft
   H) No. of ceiling VENTS (count)............? '5' count
   I) No. of ceiling PENETRATIONS (count).....? '10' count
   J) Ceiling sp. LEAKAGE area (sqin/sqft)....? '.0551635' sqin/sqft
   K) Roof PITCH (%)..........................? '30' %
   L) Roof top MATERIAL.......................? 'Asphalt Shingles'
   M) Roof ABSORPTIVITY (%)...................? '95' %
   N) Attic VENTILATION (cfm/sqft)............? '.5' cfm/sqft
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for HVAC-SYS named Heat-Cool :

   A) What HEATING EQUIPMENT..................? 'Electric Baseboard'
   B) Rated INPUT capacity (kBtu/hr)..........? '30' kBtu/hr
   C) Steady-state EFFICIENCY (%).............? '100' %
   D) What DISTRIBUTION system................? 'In Room'
   E) Distribution LOSSES to outside (%)......? '0' %
   F) What COOLING EQUIPMENT..................? 'None'
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for APPLIANC named Residents :

  A) NAME of occupants.......................? 'Residents'
  B) How many DAYTIME OCCUPANTS (people).....? '2' people
  C) How many NIGHT OCCUPANTS (people).......? '4' people
  D) DAILY hot water USE (gal/day)...........? '75' gal/day
  E) WATER HEATER type.......................? 'Electric'
  F) Input RATING (kW).......................? '4' kW
  G) Hot water THERMOSTAT setting (degF).....? '140' degF
  H) WHERE is water heater...................? 'Living space'
  I) Stdby/plumb. LOSSES (kBtu/hr)...........? '.423336' kBtu/hr
  J) REFRIGERATOR type.......................? 'Man. defrost & sep. freezer'
  K) Average MONTHLY CONSUMPTION (kWh/mo)....? '65' kWh/mo
  L) DRYER and RANGE type....................? 'Both Electric'
  M) Internal MOISTURE generation (lb/dy)....? '4.36001' lb/dy
  N) LIGHTS & OTHER HEAT GAINS (kBtu/hr).....? '1.24' kBtu/hr
  Y) < DELETE this Component >...
```

```
Current answers for LANDSCAP named Yard & Trees :

  A) Ground SURFACE TYPE.....................? 'Green grass'
  B) Ground REFLECTANCE (%)..................? '24' %
  C) SOUTH solar EXPOSURE - DECEMBER (%).....? '60' %
  D) SOUTH solar EXPOSURE - JUNE (%).........? '80' %
  E) EAST solar EXPOSURE - DECEMBER (%)......? '60' %
  F) EAST solar EXPOSURE - JUNE (%)..........? '80' %
  G) WEST solar EXPOSURE - DECEMBER (%)......? '60' %
  H) WEST solar EXPOSURE - JUNE (%)..........? '80' %
  Y) < DELETE this Component >...
```

```
Current answers for ECONOMIC named Price & Use :

  A) Economic HORIZON (years)................? '20' years
  B) REAL DISCOUNT rate (%)..................? '3' %
  C) REPLACEMENT-RETROFIT esc. rate (%)......? '4' %
  D) Maximum INVESTMENT ($)..................? '2000' $
  E) ADJUST results to ACTUAL use............? 'No'
  F) NON-ELECTRIC fuel.......................? 'Gas'
  G) GAS price ($/Therm).....................? '.559' $/Therm
  H) GAS escalation rate (%).................? '2.8' %
  I) ELECTRICITY price ($/kwh)...............? '.0449999' $/kwh
  J) ELECTRICITY escalation rate (%).........? '1.5' %
  Y) < DELETE this Component >...
```

```
Current answers for DOORS named Front :

  A) NAME of following doors.................? 'Front'
  B) Door TYPE...............................? 'Plain (Hinged)'
  C) Door MATERIAL...........................? 'Wood Solid Core'
  D) Approximate Glass AREA (%)..............? '0' %
  E) Any STORM doors.........................? 'None'
  F) U-value (Btuh/sqft/F)...................? '.33' Btuh/sqft/F
  G) Door FIT................................? 'Average'
  H) Specific leakage AREA (sqin/sqft).......? '.0294501' sqin/sqft
  I) Door AREA (sqft)........................? '13.03' sqft
  Y) < DELETE this Component >...
```

Appendix B-2

CIRA Input Listings for the Villages of Riverside House (With Basement Wall Insulation)

The same input data as in Appendix B-1 with the following change(s) :

Subfloor

Below Grade R-value : 11 °F. sq.ft. / Btuh

APPENDIX C

DOE-2.1a Input (COMPARATIVE STUDY)

```
                 TITLE  LINE-1 *TYPICAL 2 STORY HOUSE*
                        LINE-2 *VILLAGES OF RIVERSIDE*

                         $.....HEADING.....$

                        DIAGNOSTIC     CAUTIONS..
                        ABORT          ERRORS ..
                        RUN-PERIOD     JAN 07 1968 THRU JAN 07 1968
                                     JAN  01 1968 THRU DEC 31 1968..
BUILDING -LOCATION  LAT=42.23   LON=83.33  ALT=633   T-Z=5
  WINTER=DESIGN-DAY     DB-H=8   DB-L=4
                        HH-14 H-L=22 DP-H=22 DP-L=22 W-S=22
                        W-S=10  W-D=0  C-A=0 CL=0.97
                        C-T=1  G-T=38
                      $...SCHEDULES...$
GAINS-1=DAY-SCHEDULE  $.UPSTAIRS.$
                     (1,24)
                           (.3,.3,.3,.31,.31,.31,.43,1.,.27,.3
                            .3,.5,.5,.3,.3,.3,.3,1.0,1.0,.77,
                            .77,.77,.78,.30) ..
GAINS-2=DAY-SCHEDULE (1,24) $WATER HEATER$  (1,24) (1.0) ..
GAIN-W=WEEK-SCHEDULE   (ALL) GAINS-1..
GAIN-2W=WEEK-SCHEDULE  (ALL) GAINS-2 ..
GAIN-1Y=SCHEDULE        THRU DEC 31 GAIN-W ..
GAIN-2Y=SCHEDULE        THRU DEC 31 GAIN-2W ..
                       $..MATERIALS..$
FLR-DUM-INS  = MAT  RES = 34.61 $DUMMY INSUL$..
WL-DUM-INS   = MAT RES = 2.56 $DUMMY INSUL$..
STUD-1       = MAT TH=0.83 COND=0.0677 DENS=34   S-H=0.33 ..
PLYWD        = MAT TH=.0833 COND=.0677 DENS=34   S-H=0.29 ..
WD01         = MAT TH=.0625 COND=.0677 DENS=32   S-H=0.33 ..
IN02         = MAT TH=.2957 COND=0.025 DENS=.6   S-H=.2    ..
GP01         = MAT TH=0.0417 COND=.0928 DENS=50 S-H=.2    ..
WD04         = MAT TH=.2917 COND=0.0667 DENS=32 S-H=.33  ..
BK05         = MAT TH=.3333 COND=.7576  DENS =130 S-H=.22 ..
AL11         = MAT     RES=0.90 ..
PW02         = MAT TH=.0313 COND=.0667  DENS=34 S-H=0.29 ..
AL33         = MAT      RES=0.92  ..
IN03         = MAT TH=0.5108 COND=.025 DENS=.60 S-H=0.2  ..
CC16         = MAT TH=.6667  COND=1.0417 DENS=140 S-H=0.2 ..
CC03         = MAT TH=.3333  COND=.7576  DENS=140 S-H=0.2 ..
```

```
CC05          = MAT TH=0.50   COND=0.7576 DENS=140 S-H=0.2 ..
ST01          = MAT TH=.0833  COND=1.0416 DENS=140 S-H=0.2 ..


                          $..GLAZING..$
WIN=GLASS-TYPE       PANES=2  S-C=0.88  ..
                     $..CONSTRUCTUIONS..$
UP-WALL-I=LAYERS       MAT=(WD01,IN02,GP01)   I-F-R=0.68 ..
UP-I      =CONS       LAYERS=UP-WALL-I  ABS=0.68 RO=4 ..
UP-WALL-S = LAYERS     MAT=(WD01,WD04,GP01)   I-F-R= 0.68 ..
UP-S  = CONS          LAYERS = UP-WALL-S  ABS=0.68  RO=4 ..
DN-WALL-I = LAYERS     MAT=(BK05,AL11,PW02,IN02,GP01)
                       I-F-R=0.68 ..
DN-I = CONS           LAYERS = DN-WALL-I  ABS=0.88  RO=2 ..
DN-WALL-S=LAYERS         MAT=(BK05,AL11,PW02,WD04,GP01)
                       I-F-R=0.68    ..
DN-S = CONS           LAYERS=DN-WALL-S   ABS=0.88  RO=2   ..
CON-WALL=LAYERS       MAT=(CC16)  I-F-R= 0.68  ..
C-1      =CONS       LAYERS = CONWALL  ABS=0.58  RO=3  ..
CEILING=LAYERS        MAT=(PW02,AL33,IN03,GP01)  I-F-R = .68..
CLG     = CONS       LAYERS=CEILING  ABS=0.86  RO=3 ..
LAYER-BW= LAYERS     MAT=( WL-DUM-INS,CC16 )..
BASE-WALL=CONS       LAYERS=LAYER-BW ..
LAYER-BF=LAYERS      MAT=(FLR-DUM-INS,CC05)   ..
LAYFLO = LAYERS      MAT=(STUD-1,PLYWD)   ..
BASE-FLOOR=CONS      LAYERS = LAYER-BF ..
EXT-DOOR=CONS        U=0.5   ABS=0.4   RO=5  ..
FLOOR=CONS    LAYERS=LAYFLO   ABS=0.4   RO=5  ..

                $...LIVING AREA DESCRIPTION..$

UPPER=SPACE-CONDITIONS    T=(70)
                         SOURCE-SCHEDULE=GAIN-1Y
                         SOURCE-TYPE=ELECTRIC
                         SOURCE-BTU/HR=5349
                         INF-METHOD=RESIDENTIAL
                         RES-INF-COEFF=(.0844,0.0459,0.0069)
                         FLOOR-WEIGHT=0
                         ZONE-TYPE=CONDITIONED  ..
UPPER-LEV=SPACE          AREA=481  VOLUME=11385
                         SPACE-CONDITIONS=UPPER  ..
WL-1=E-W                $..LOWER-STUD-FRONT..$
                        H=8.3  W=3.9  AZ=180  TILT=90
                         CONS=DN-S  ..
WL-2=E-W                $..LOWER INS. FRONT ..$
                        H=8.3 W=15.6  AZ=180  TILT=90
                        X=3.9 Y=0  Z=0  CONS=DN-S ..
```

```
DOOR                H=6.7 W=2.7
                    X=16.5 Y=1 SETB=0.4 CONS=EXT-DOOR..
WINDOW              H=3.5 W=2.7 X=10 Y=3.8
                    SETB=0.4
                    G-T=WIN  ..
WL-3 =E-W         $..UPPER STUD FRONT ..$
                    H=8.3 W=3.9 AZ=180 TILT=90
                   X=0 Y=0 Z=8.3   CONS=UP-S  ..
WL-4=E-W          $..UPPER INSUL FRONT ..$
                    H=8.3  W=15.8  AZ=180  TILT=90
                   X=3.9  Y=0  Z=0  CONS=UP-I  ..
WL-5=E-W           $..LOWER STUD RIGHT..$
                    H=8.3 W=21.5 AZ=90  TILT= 90
                    X=19.5  Y=0  Z=0  CONS = DN-S..
WL-6=E-W           $...LOWER INSUL. RIGHT ..$
                    H=8.3  W=21.5  AZ=90  TILT=90
                   X=19.5  Y=5.4  Z=0  CONS=DN-I ..
WL-7=E-W           $..UPPER STUD FRONT...$
                    H=8.3  W=5.4  AZ=90  TILT=90
                    X=19.5  Y=0  Z=8.3  CONS=UP-S ..
WL-8=E-W           $..UPPER INSUL RIGHT ..$
                    H=8.3  W=21.5  AZ=90  TILT=90
                    X=19.5  Y=5.4  Z=8.3  CONS=UP-I..
WL-9=E-W           $..LOWER STUD LEFT..$
                    H=8.3  W=5.4  AZ=270  TILT=90
                    X=0  Y=26.9  Z=0  CONS=DN-S ..
WL-10=E-W          $..LOWER INSUL LEFT..$
                    H=8.3  W=21.5  AZ=270  TILT= 90
                    X=0  Y=21.5  Z=0  CONS=DN-I  ..
WL-11=E-W          $..UPPER STUD LEFT..$
                    H=8.3  W=5.4  AZ=270  TILT=90
                     X=0  Y=26.9  Z=8.3 CONS=UP-S ..
WL-12=E-W           $..UPPER INSUL LEFT..$
                    H=8.3  W=21.5  AZ=270  TILT=90
                    X=0 Y=21.5  Z=8.3  ..
 WINDOW              H=3.5  W=12.9
                    X=10  Y=3.7  SETB=0.4 G-T=WIN  ..
WL-13=E-W           $..LOWER STUD REAR..$
                    H=8.3  W=3.9  AZ=0  TILT=90
                    X=19.8  Y=26.9  Z=0  CONS=DN-S ..
WL-14=E-W           $..LOWER INSUL. REAR ..$
                    H=8.3 W=15.6  AZ=0  TILT=90
                    X=15.6  Y=26.9  Z=0  CONS=DN-S ..
WINDOW              H=7  W=5  X=5 Y=0 SETB=0.4  G-T=WIN ..
WL-15=E-W           $..UPPER STUD REAR..$
                    H=8.3  W=3.9  AZ=0  TILT=90
                    X=19.5  Y=26.9  Z=8.3  CONS=UP-S ..
WL-16=E-W           $..UPPER INSULATION REAR..$
```

```
                          H=8.3  W=15.6  AZ=0  TILT=90
                          X=15.6  Y=26.9  Z=8.3  CONS=UP-I  ..
ROOF                      H=26.9  W=19.5  AZ=180  TILT=0
                           X=0  Y=0  Z=16.6  CONS=CLG ..
INTERIOR-WALL            AREA =481  NEXT-TO=DN-LEV  TILT=180
                           CONS=FLOOR  ..
                     $....BASEMENT  DESCRIPTION....$
BASEMENT = SPACE-CONDITIONS      T=(70)
                                SOURCE-SCHEDULE = GAIN-2Y
                                SOURCE-TYPE=ELECTRIC
                                SOURCE-BTU/HR=305
                                INF-METHOD=AIR-CHANGE
                                AIR-CHANGE/HR=0.0
                                FLOOR-WEIGHT=0
                                ZONE-TYPE=CONDITIONED  ..
DN-LEV  = SPACE               AREA=481  VOLUME=2694
                               SPACE-CONDITIONS=BASEMENT  ..
WL-25=E-W  $..BASEMENT STUD FRONT..$
           H=1.4  W=3.9  AZ=180  TILT=90  Z=-1.4
             CONS=DN-S  ..
WL-26=E-W  $..BASEMENT INSUL.FRONT..$
           H=1.4  W=15.6 AZ=180  TILT=90
           X=3.9  Y=0    Z=-1.4  CONS=DN-I  ..
WL-27=E-W  $..BASEMENT STUD RIGHT..$
           H=1.4  W=5.4  AZ=90 TILT=90
           X=19.5 Y=0  Z=-1.4  CONS=DN-S ..
WL-28=E-W  $..BASEMENT INSUL.RIGHT..$
           H=1.4  W=21.5 AZ=90 TILT=90
           X=19.5 Y=5.4  Z=-1.4  CONS=DN-I ..
WL-29=E-W  $BASEMENT STUD LEFT..$
           H=1.4  W=5.4  AZ=270  TILT=90
           X=0  Y=26.9  Z=-1.4  CONS=DN-S ..
WL-30=E-W  $..BASEMENT INSUL.LEFT..$
           H=1.4  W=21.5  AZ=270  TILT=90
           X=0  Y=21.5  Z=-1.4  CONS=DN-I ..
WL-31=E-W  $..BASEMENT STUD REAR..$
           H=1.4  W=3.9  AZ=0  TILT=90
           X=19.5  Y=26.9  Z=-1.4  CONS=DN-S ..
WL-32=E-W  $..BASEMENT INSUL.REAR..$
           H=1.4  W=15.6  AZ=0  TILT=90
           X=15.6  Y=26.9  Z=-1.4  CONS=DN-I  ..
U-FLOOR = U-F  A=481  CONS=BASE-FLOOR  TILT =180  ..
BGWALL=U-W    $...BASEMENT WALL BELOW GRADE ..$
               A=510  CONS=BASE-WALL ..
                           $...REPORTS...$
LOADS-REPORT               VERIFICATION = (ALL-VERIFICATION)
END  ..
```

Appendix - D

CIRA Input Listings(Comparative Study)

The Villages of Riverside house was modelled(see Appendix B).

The following changes were made in the "Subfloor" section:

1. Joist R - value = 15 h.°F. ft / Btu
2. Floor Area = 20 ft
3. Soil Conductivity = 2.5 Btu-in / h.°F. ft .
4. Below Grade R-value = 30 h.°F. ft / Btu
5. Floor R - value = 40 h.°F. ft / Btu
6. Equivalent Floor Resistance = 100 h.°F. ft / Btu

Appendix E-1

CIRA Input Listings for the Passive Solar Ranch House(Case 1)

```
Current answers for GENERAL named NRC :

   A) NAME of this house......................? 'NRC'
   B) What CITY...............................? 'Ottawa'
   C) AZIMUTH of north face (degrees).........? '0' degrees
   D) What type of THERMOSTAT.................? 'Dual heating & cooling'
   E) Heating THERMOSTAT setting (degF),......? '70' degF
   F) Heating NIGHT setting (degF)............? '70' degF
   G) Cooling THERMOSTAT setting (degF).......? '80' degF
   H) Cooling NIGHT setting (degF)............? '80' degF
   I) Total house FLOOR AREA (sqft)...........? '1176' sqft
   J) House MASS..............................? 'Light'
   K) Solar STORAGE factor (unitless).........? '.22' unitless
   L) SPECIFIC THERMAL MASS (Btu/Fsqft).......? '1.79' Btu/Fsqft
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for WALLS named Front :

   A) NAME for the following walls............? 'Front'
   B) Which wall ORIENTATION..................? 'South walls'
   C) Wall TYPE...............................? 'Two by Four Frame'
   D) wall INSULATION.........................? 'Fiberglass batts'
   E) Insulation THICKNESS (inches)...........? '4' inches
   F) INSULATABLE wall THICKNESS (inches).....? '0' inches
   G) Exterior INSULATING SHEATHING...........? 'None'
   H) Wall R-VALUE (F-sqft/Btuh)..............? '13' F-sqft/Btuh
   I) Wall AREA wo/ windows & doors (sqft)....? '173.14  sqft
   J) No. of WINDOWS (No.)....................? '7' No.
   K) No. of VENTS in wall (No.)..............? '1' No.
   L) No. of other PENETRATIONS (No.).........? '1' No.
   M) Specific LEAKAGE AREA (sqin/sqft).......? '.043483' sqin/sqft
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for WALLS named Right :

  A) NAME for the following walls............? 'Right'
  B) Which wall ORIENTATION..................? 'East walls'
  C) Wall TYPE...............................? 'Two by Four Frame'
  D) Wall INSULATION.........................? 'Fiberglass batts'
  E) Insulation THICKNESS (inches)...........? '4' inches
  F) INSULATABLE wall THICKNESS (inches).....? '0' inches
  G) Exterior INSULATING SHEATHING...........? 'None'
  H) Wall R-VALUE (F-sqft/Btuh)..............? '13' F-sqft/Btuh
  I) Wall AREA wo/ windows & doors (sqft)....? '224' sqft
  J) No. of WINDOWS (No.)....................? '0' No.
  K) No. of VENTS in wall (No.)..............? '1' No.
  L) No. of other PENETRATIONS (No.).........? '1' No.
  M) Specific LEAKAGE AREA (sqin/sqft).......? '.0154373' sqin/sqft
  Y) < DELETE this Component >...
  Z) < Changes COMPLETED >...
```

```
Current answers for WALLS named Rear :

  A) NAME for the following walls............? 'Rear'
  B) Which wall ORIENTATION..................? 'North walls'
  C) Wall TYPE...............................? 'Two by Four Frame'
  D) Wall INSULATION.........................? 'Fiberglass batts'
  E) Insulation THICKNESS (inches)...........? '4' inches
  F) INSULATABLE wall THICKNESS (inches).....? '0' inches
  G) Exterior INSULATING SHEATHING...........? 'None'
  H) Wall R-VALUE (F-sqft/Btuh)..............? '13' F-sqft/Btuh
  I) Wall AREA wo/ windows & doors (sqft)....? '293.28' sqft
  J) No. of WINDOWS (No.)....................? '4' No.
  K) No. of VENTS in wall (No.)..............? '1' No.
  L) No. of other PENETRATIONS (No.).........? '1' No.
  M) Specific LEAKAGE AREA (sqin/sqft).......? '.0245452' sqin/sqft
  Y) < DELETE this Component >...
  Z) < Changes COMPLETED >...
```

```
Current answers for WALLS named Left :

  A) NAME for the following walls...........? 'Left'
  B) Which wall ORIENTATION.................? 'West walls'
  C) Wall TYPE..............................? 'Two by Four Frame'
  D) Wall INSULATION........................? 'Fiberglass batts'
  E) Insulation THICKNESS (inches)..........? '4' inches
  F) INSULATABLE wall THICKNESS (inches).....? '0' inches
  G) Exterior INSULATING SHEATHING..........? 'None'
  H) Wall R-VALUE (F-sqft/Btuh).............? '13' F-sqft/Btuh
  I) Wall AREA wo/ windows & doors (sqft)....? '224' sqft
  J) No. of WINDOWS (No.)...................? '0' No.
  K) No. of VENTS in wall (No.).............? '1' No.
  L) No. of other PENETRATIONS (No.)........? '1' No.
  M) Specific LEAKAGE AREA (sqin/sqft).......? '.0154378' sqin/sqft
  Y) < DELETE this Component >...
  Z) < Changes COMPLETED >...
```

```
Current answers for WINDOWS named Front :

  A) NAME of the following windows..........? 'Front'
  B) Which window ORIENTATION...............? 'South'
  C) Window TYPE............................? 'Double hung'
  D) GLAZING................................? 'Double pane'
  E) DRAPES & SHUTTERS......................? 'None'
  F) U-value (Btuh/sqft/F)..................? '.48' Btuh/sqft/F
  G) Average sash FIT.......................? 'Average'
  H) Specific LEAKAGE AREA (sqin/sqft).......? '.0790502' sqin/sqft
  I) Summer SOLAR GAIN factor (%)...........? '71' %
  J) Winter SOLAR GAIN factor (%)...........? '71' %
  K) Window AREA (sqft).....................? '32.82' sqft
  L) Overhang PROTRUSION (inches)...........? '42' inches
  M) HEIGHT above top of window (inches).....? '2.76' inches
  N) Average window HEIGHT (feet)...........? '5.17' feet
  Y) < DELETE this Component >...
  Z) < Changes COMPLETED >...
```

```
Current answers for WINDOWS named Slid :

   A) NAME of the following windows...........? 'Slid'
   B) Which window ORIENTATION................? 'South'
   C) Window TYPE.............................? 'Horizontal Sliding'
   D) GLAZING.................................? 'Double pane'
   E) DRAPES & SHUTTERS.......................? 'None'
   F) U-value (Btuh/sqft/F)...................? '.43' Btuh/sqft/F
   G) Average sash FIT........................? 'Average'
   H) Specific LEAKAGE AREA (sqin/sqft).......? '.0465001' sqin/sqft
   I) Summer SOLAR GAIN factor (%)............? '71' %
   J) Winter SOLAR GAIN factor (%)............? '71' %
   K) Window AREA (sqft)......................? '60.03' sqft
   L) Overhang PROTRUSION (inches)............? '42' inches
   M) HEIGHT above top of window (inches).....? '13.5' inches
   N) Average window HEIGHT (feet)............? '6.67' feet
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for WINDOWS named Rear :

   A) NAME of the following windows...........? 'Rear'
   B) Which window ORIENTATION................? 'North'
   C) Window TYPE.............................? 'Double hung'
   D) GLAZING.................................? 'Double pane'
   E) DRAPES & SHUTTERS.......................? 'None'
   F) U-value (Btuh/sqft/F)...................? '.48' Btuh/sqft/F
   G) Average sash FIT........................? 'Average
   H) Specific LEAKAGE AREA (sqin/sqft).......? '.0790502' sqin/sqft
   I) Summer SOLAR GAIN factor (%)............? '71' %
   J) Winter SOLAR GAIN factor (%)............? '71' %
   K) Window AREA (sqft)......................? '42.72' sqft
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for APPLIANC named Life :

   A) NAME of occupants......................? 'Life'
   B) How many DAYTIME OCCUPANTS (people).....? '1' people
   C) How many NIGHT OCCUPANTS (people).......? '2' people
   D) DAILY hot water USE (gal/day)...........? '75' gal/day
   E) WATER HEATER type.......................? 'Gas'
   F) Input RATING (kBtu/hr)..................? '40' kBtu/hr
   G) Hot water THERMOSTAT setting (degF).....? '140' degF
   H) WHERE is water heater...................? 'Living space'
   I) Stdby/plumb. LOSSES (kBtu/hr)...........? '1.24' kBtu/hr
   J) REFRIGERATOR type.......................? 'Man. defrost & sep. freezer'
   K) Average MONTHLY CONSUMPTION (kWh/mo)....? '65' kWh/mo
   L) DRYER and RANGE type....................? 'Both Electric'
   M) Internal MOISTURE generation (lb/dy)....? '4.36001' lb/dy
   N) LIGHTS & OTHER HEAT GAINS (kBtu/hr).....? '.1' kBtu/hr
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for DOORS named Front :

   A) NAME of following doors.................? 'Front'
   B) Door TYPE...............................? 'Plain (Hinged)'
   C) Door MATERIAL...........................? 'Wood Solid Core'
   D) Approximate Glass AREA (%)..............? '0' %
   E) Any STORM doors.........................? 'None'
   F) U-value (Btuh/sqft/F)...................? '.4' Btuh/sqft/F
   G) Door FIT................................? 'Average'
   H) Specific leakage AREA (sqin/sqft).......? '.0234501' sqin/sqft
   I) Door AREA (sqft)........................? '20' sqft
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for INFILTRA named Ventilation :

   A) Is there MECHANICAL Ventilation.........? 'None'
   B) NATURAL Cooling Ventilation.............? 'No'
   C) TERRAIN class...........................? 'Class 3'
   D) SHIELDING class.........................? 'Class 3'
   E) HEIGHT of living space (feet)...........? '8' feet
   F) Approx. house VOLUME (cubic feet).......? '9408' cubic feet
   G) HOW was leakage area MEASURED...........? 'All three measured'
   H) TOTAL leakage area (sqin)...............? '117' sqin
   I) CEILING leakage area (sqin).............? '61.0001' sqin
   J) FLOOR leakage area (sqin)...............? '48.9999' sqin
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for LANDSCAP named Yard & Trees :

   A) Ground SURFACE TYPE.....................? 'Green grass'
   B) Ground REFLECTANCE (%)..................? '24' %
   C) SOUTH solar EXPOSURE - DECEMBER (%).....? '100' %
   D) SOUTH solar EXPOSURE - JUNE (%).........? '100' %
   E) EAST solar EXPOSURE - DECEMBER (%)......? '100' %
   F) EAST solar EXPOSURE - JUNE (%)..........? '100' %
   G) WEST solar EXPOSURE - DECEMBER (%)......? '100' %
   H) WEST solar EXPOSURE - JUNE (%)..........? '100' %
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for ROOF-CEI named Attic :

   A) NAME for attic/roof or ceiling..........? 'Attic'
   B) Roof-Ceiling TYPE.......................? 'Unfinished attic'
   C) Insulation TYPE.........................? 'Fiberglass batts'
   D) Insulation THICKNESS (inches)...........? '8' inches
   E) Insulatable AIR SPACE (inches)..........? '0' inches
   F) Ceiling R-value (F-sqft/Btuh)...........? '25' F-sqft/Btuh
   G) Ceiling AREA (sqft).....................? '1176' sqft
   H) No. of ceiling VENTS (count)............? '5' count
   I) No. of ceiling PENETRATIONS (count).....? '10' count
   J) Ceiling sp. LEAKAGE area (sqin/sqft)....? '.0408854' sqin/sqft
   K) Roof PITCH (%)..........................? '22.62' %
   L) Roof top MATERIAL.......................? 'Asphalt Shingles'
   M) Roof ABSORPTIVITY (%)...................? '95' %
   N) Attic VENTILATION (cfm/sqft)............? '.5' cfm/sqft
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for SUBFLOOR named Slab :

   A) Subfloor NAME...........................? 'Slab'
   B) Subfloor TYPE...........................? 'Slab-on-grade'
   C) Floor AREA (Joists) (sqft)..............? '20' sqft
   D) Exposed PERIMETER (feet)................? '140' feet
   E) Soil CONDUCTIVITY (Btuh-in/F-sqft)......? '2.5' Btuh-in/F-sqft
   F) Floor R-VALUE (F-sqft/Btuh).............? '40' F-sqft/Btuh
   G) Eqv Floor RESIST' outs'd (F-sqft/Btuh)..? '100' F-sqft/Btuh
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for HVAC-SYS named Heat-Cool :

  A) What HEATING EQUIPMENT...................? 'Gas Furnace'
  B) Rated INPUT capacity (kBtu/hr)...........? '50' kBtu/hr
  C) Steady-state EFFICIENCY (%)..............? '75' %
  D) FLUE gas temperature (degF)..............? '250' degF
  E) What DISTRIBUTION system.................? 'Forced Air'
  F) WHERE are pipes or ducts.................? 'Living Space'
  G) INSULATION on pipes or ducts.............? 'None
  H) Insulatable duct/pipe LENGTH (feet)......? '50' feet
  I) Distribution LOSSES to outside (%).......? '5' %
  J) What COOLING EQUIPMENT...................? 'Central Air Conditioning'
  K) Rated TOTAL capacity (kBtu/hr)...........? '24' kBtu/hr
  L) Rated SENSIBLE capacity (kBtu/hr)........? '16' kBtu/hr
  M) Rated COP (unitless).....................? '2' unitless
  N) Actual Fan FLOW (cfm)....................? '700' cfm
  Y) < DELETE this Component >...
  Z) < Changes COMPLETED >...
```

```
Current answers for ECONOMIC named Price & Use :

  A) Economic HORIZON (years).................? '20' years
  B) REAL DISCOUNT rate (%)...................? '3' %
  C) REPLACEMENT-RETROFIT esc. rate (%).......? '4' %
  D) Maximum INVESTMENT ($)...................? '2000' $
  E) ADJUST results to ACTUAL use.............? 'No'
  F) NON-ELECTRIC fuel........................? 'Gas'
  G) GAS price ($/Therm)......................? '.559' $/Therm
  H) GAS escalation rate (%)..................? '2.8' %
  I) ELECTRICITY price ($/kWh)................? '.0449999' $/kWh
  J) ELECTRICITY escalation rate (%)..........? '1.5' %
  Y) < DELETE this Component >...
  Z) < Changes COMPLETED >...
```

Appendix E-2

CIRA Input Listings for the Passive Solar Ranch House (Case 2)

The same input data as in appendix E-1, with the following change(s) :

WALLS

Wall R-value : 32 °F. sq. ft. / Btuh

ROOF

Ceiling R-value : 50 °F.sq.ft. / Btuh

WINDOWS

All windows are triple glazed.

U-value : 0.29 Btuh / sq.ft. /°F

Summer Solar Gain Factor : 61 %

Winter Solar Gain Factor : 61 %

INFILTRATION

Total leakage area : 50 sq.in.

Ceiling leakage area : 25 sq.in

Floor leakage area : 20 sq.in

Appendix F

HEATING5 Input (Basement Analysis)

```
//SYSIN  DD  *
BASEMENT ANALYSIS
      1800         7         6         3                             3         5
         4         5                   1         1
         1
         2                                                         0.0   12960.0
         1         1       0.0       9.5      6.33      6.83
         1                                       1
         2         2       0.0      29.5      6.83     42.83
         2                                                 5
         3         3       9.5     10.17       0.0      1.00
         1                   2         3
         4         3       9.5     10.17       1.0      6.33
         1                   2
         5         3       9.5     10.17      6.33      6.83
         1
         6         2     10.17      29.5       1.0      6.83
         3                                       4
         1      CC05    0.7576     140.0       0.2
         2      SOIL      0.76     100.0      0.25
         3      CC16    1.0417     140.0       0.2
         1      65.0
         2      50.0
         3      60.0
         1         1      70.0
                          1.08
         2         1      70.0
                          1.46
         3         1       1.0         1
                           1.0                             1
                            -1
         4         1       1.0         1
                           1.0                             1
                            -1
         5         2      50.0

       0.0       9.5     10.17      29.5
        15         1        15
       0.0       1.0      6.33      6.83     42.83
         2         8         1        10
         1         8
         1    46.932         2    21.457         3   -2.2082         4     0.056
         6    9.5031         7    0.4554        10    1.4725        11     183.0
         1         6
       0.0       6.0    3647.0       6.0    3648.0       5.0    6576.0       5.0
    6577.0       6.0   12960.0       6.0

     360.0       1.0       1.0
//
```

Appendix G

A 3rd Order Fourier Fit for Air Temperature

The mean monthly dry bulb air temperature was related to time of year through a 3rd order Fourier fit :

$$T_{,air} = A + A1*\cos X + A2*\cos 2X + A3*\cos 3X + A4*\sin X + A5*\sin 2X + A6*\sin 3x$$

where $X = (\frac{n}{24} + 183)*2 / 365$ (see Reference 9)

and n = hours, beginning January 1.

A ,A1...A6 = Regression constants

The Sine and Cosine functions for different months are given in Table A.1. The mean monthly air temperatures were obtained from the reference manual of DOE-2.1a. X was calculated for each month by using the above expression. A regression analysis was performed with the air temperature as the dependent variable by using the package programs made by Microstat Inc. The following regression constants were obtained :

A = 46.932 A1 = 21.457 A2 = -2.2082 A3 = -0.056

A4 = 9.5031 A5 = -0.4554 A6 = 1.4725

The Coefficient of Determination, R^2 was found to be 0.996.

A comparison of the actual monthly air temperatures and those predicted by the above model is given in Table A.2.

Appendix G(Continued)

Month	Cos 1X	Cos 2X	Cos 3X	Sin 1X	Sin 2X	Sin 3X
Jan	-.9647	.8613	-.6972	-.2632	.5079	-.7168
Feb	-.7086	.0043	.7024	-.7055	1.0	-.7117
Mar	-.2680	-.8562	.7271	-.9633	.5165	.6864
Apr	.2595	-.8653	-.7086	-.9657	-.5012	.7055
May	.7025	-.0129	-.7207	-.7116	-1.0	-.6932
June	.9668	.8695	.7145	-.2554	-.4939	-.6996
July	.7025	-.0128	-.7205	.7116	1.0	.6933
Aug	.2429	-.8819	-.6714	.9700	.4712	-.7410
Sept	-.2678	-.8565	.7265	.9634	-.5160	-.6871
Oct	-.7206	.0386	.6649	.6933	-.9992	.7468
Nov	-.9689	.8778	-.7323	.2470	-.4788	.6809
Dec	-.9621	.8514	-.6763	-.2725	.5244	-.7366

Table A.1 : A Fourier Fit for Air Temperatures

Appendix G(Continued)

Month	Actual Air Temperature (°F)	Fourier - Fit Predicted Air Temperature (°F)
Jan	20.95	20.58
Feb	22.45	23.46
Mar	34.45	34.65
Apr	47.60	46.54
May	52.70	54.74
June	64.45	62.48
July	68.00	68.94
Aug	69.10	69.40
Sep	62.65	62.04
Oct	51.10	51.41
Nov	39.45	39.49
Dec	27.65	27.81

Table A.2 : A Comparison between the Actual and Predicted Mean Monthly Air temperatures

Appendix H-1

The Grid Pattern used in HEATING5

(see Figure H-1)

Horizontal Node Numbers	Distance between Two Successive Nodes (feet)
1,2,3,.......16	0.63
16,17,18	0.34
18,19,20,....28	0.50
28,29,30,....33	2.87

Vertical Node Numbers	Distance between Two Successive Nodes (feet)
1,2	1.0
2,3,4...10	0.66
10,11,12,...18	0.50
18,19,......25	4.71

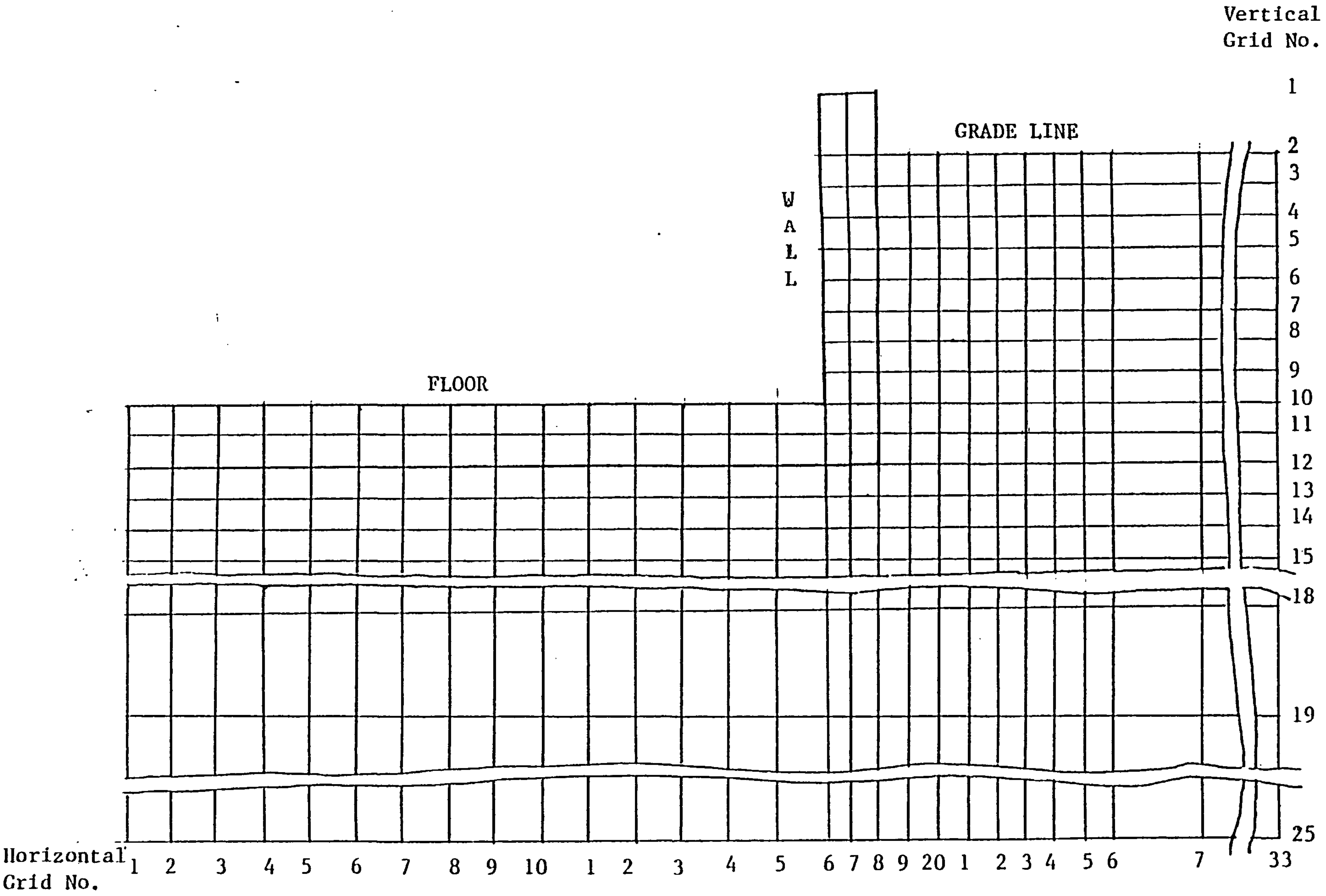


Figure II-1 : The Grid Pattern used in the HEATING5 Input

Appendix H-2

The Temperature Distribution (°F)along the Interior of the Basement Wall and Floor

Horizontal Nodes

April 15

Floor Node No:	1	2	3	4	5	6	7	8
Temperature :	69.08	69.08	69.06	69.05	69.02	68.98	68.94	68.88
Floor Node No:	9	10	11	12	13	14	15	16
Temperature :	68.80	68.70	68.58	68.41	68.18	67.84	67.25	65.87

January 15

Floor Node No:	1	2	3	4	5	6	7	8
Temperature :	69.2	69.2	69.2	69.19	69.18	69.16	69.14	69.11
Floor Node No:	9	10	11	12	13	14	15	16
Temperature :	69.07	69.02	68.96	68.87	68.73	68.52	68.13	67.09

October 15

Floor Node No:	1	2	3	4	5	6	7	8
Temperature :	69.14	69.13	69.13	69.13	69.12	69.11	69.10	69.08
Floor Node No:	9	10	11	12	13	14	15	16
Temperature :	69.06	69.03	69.00	68.95	68.89	68.80	68.63	68.24

Vertical Nodes

April 15

Wall Node No:	1	2	3	4	5	6	7	8
Temperature:	58.14	59.09	62.04	64.06	65.28	66.02	66.44	66.62
Wall Node No:	9	10						
Temperature:	66.53	65.87						

January 15

Wall Node No:	1	2	3	4	5	6	7	8
Temperature:	55.25	56.53	60.78	63.64	65.34	66.38	67.01	67.87
Wall Node No:	9	10						
Temperature:	67.46	67.09						

October 15

Wall Node No:	1	2	3	4	5	6	7	8
Temperature:	65.42	65.82	67.19	68.07	68.55	68.81	68.92	68.91
Wall Node No:	9	10						
Temperature:	68.75	68.24						

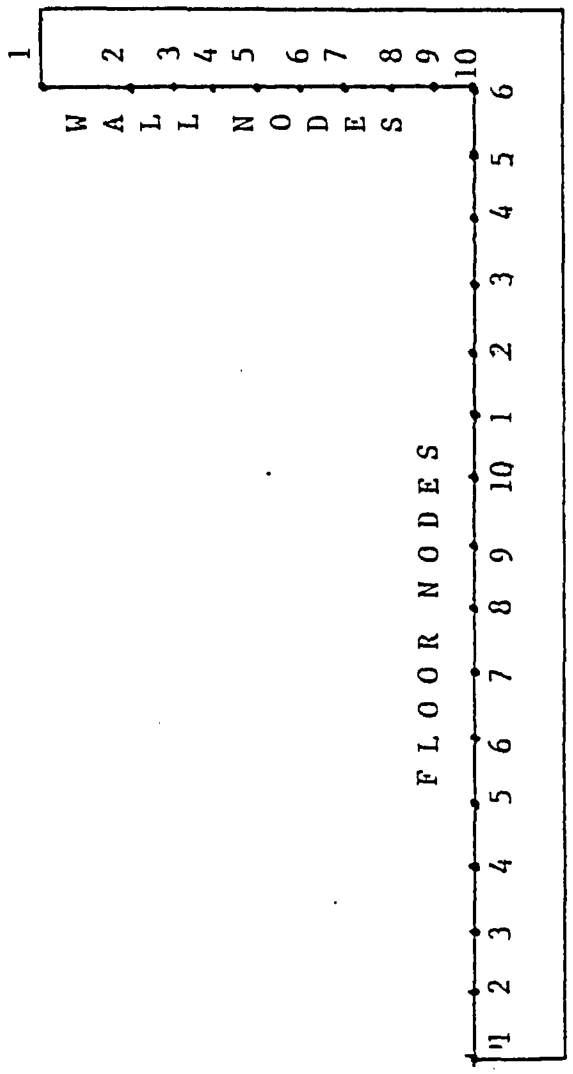


Figure II-2 : The Wall and Floor Nodes

Appendix - I

A Procedure to calculate the Hourly Heat Loss from the Underground Surfaces

1. The Heat Loss from the Floor

$$Q = \sum hi \times (ti - Hi) \Delta Xi$$

where hi = heat transfer coefficient, Btu / h. ft. °F

tib = basement space temperature, °F

Hi = temperature along the floor node, °F

Xi = grid spacing, ft.

$$Q = 1.08 \left\{ \left[70 \times 14 - (H_1 + H_2 + \ldots\ldots H_{15}) \right] \right\} \times 0.63 + \left\{ \left[70 \times 2 - (H_1 + H_{16}) \right] \times 0.63 \right\}, \text{ Btuh.}$$

2. The Heat Loss from the Below Grade Wall

$$Qw = \sum hi * (ti - Vi) \Delta Yi, \text{ Btu / h}$$

where Vi = temperature along the wall node, °F.

Yi = grid spacing, ft.

$$Qw = 1.46 \left\{ (70 - V_2) \times 0.5 + \left[70 \times 7 - (V_3 + \ldots V_9) \right] \times 0.67 + (70 - V_{10}) \times 0.33 \right\}, \text{ Btu / h}$$

Appendix - J

A Program to calculate the Hourly Heat Loss from the Underground Basement Floor and Wall

```
   DIMENSION H(20,24),V(15,24),QF(24),QW(24),QT(24),AW(24)

   READ,((H(I,J),I=1,16),J=1,24)
   READ,((V(I,J),I=1,10),J=1,24)
   DO 10 J=1,24
   QF(J) = (980 -H(2,J)-H(3,J)-H(4,J)-H(5,J)-H(6,J)-H(7,J)
             -H(8,J)-H(9,J)-H(10,J)-H(11,J)-H(12,J)-H(13,J)
             -H(14,J)-H(15,J))*.63*1.08 +( 140 - H(1,J)-H(16,J))
              *.315*1.08
   PRINT,'QF(J)=',QF(J)
   AW(J)= (70-V(1,J))*0.5*1.46 +( 70-V(2,J))*.5*1.46
   PRINT,'AW(J)=',AW(J)
   QW(J)= (70-V(2,J))*.33*1.46 +
          (490-V(3,J)-V(4,J)-V(5,J)-V(6,J)-V(7,J)-V(8,J)-V(9,J))
          *.66*1.46 + (70-V(10,J))*.33*1.46
   PRINT,'QW(J)=',QW(J)
   QT(J)= QF(J) + QW(J)
   PRINT,'QT(J)=',QT(J)
10 CONTINUE
   STOP
   END
```

Time Step	Hour	Heat Loss(Btu/h)	
		Wall	Floor
1	360	52.30	12.35
2	720	57.59	13.08
3	1080	60.59	13.79
4	1440	60.70	14.41
5	1800	57.77	14.84
6	2160	52.44	15.08
7	2520	45.81	14.99
8	2880	39.05	15.35
9	3240	32.92	14.40
10	3660	27.68	13.90
11	3960	22.27	15.38

Time Step	Hour	Heat Loss(Btu/h)	
		Wall	Floor
12	4320	17.53	14.64
13	4680	12.86	13.86
14	5040	8.74	13.08
15	5440	5.74	12.31
16	5760	4.54	11.61
17	6120	5.57	11.00
18	6480	8.65	10.56
19	6840	13.27	10.31
20	7200	19.02	10.28
21	7560	25.35	10.40
22	7920	31.89	10.71
23	8280	38.75	11.14
24	8640	45.73	11.71

Appendix K

A Procedure to calculate the Monthly Heat Loss from the Hourly Heat Loss

1. The heat loss from the below - grade wall

Two hourly heat loss values were calculated for each month(see Appendices I and J). A 4-th order polynomial equation was used to relate the hourly heat loss to the day of the year.

$$Q\ w = A0 + A1*D + A2*D^{2} + A3*D^{3} + A4*D^{4}$$

where $Q\ w$ = heat loss through the below grade wall, Btu / hr.

D = day of the year

$A0, A1 \ldots A4$ = Regression constants.

$A0 = 41.2312 \quad A1 = 0.875395 \quad A2 = -0.0116918$

$A3 = 4.13513 * 10 \quad A4 = -4.32455 * 10$

The heat loss for each month was calculated by integrating the expression for the heat loss per day over the number of days in the month.

2. The heat loss from the floor

The monthly heat loss from the underground floor was calculated by multiplying the average hourly heat loss by the number of hours in the month.

Appendix L

CIRA Input(Basement Analysis)

The Villages of Riverside House was modelled(see Appendix B) with the following basement input parameters :

	Case 1	Case 2	
1. Joist R	2	15	(h.°F.ft / Btu)
2. Floor Area	494	20	(ft)
3. Above Grade Wall R	1	30	(h.°F.ft / Btu)
4. Above Grade Wall Height	1	0.109	(ft)
5. Exposed Perimeter	90	20	(ft)
6. Soil Conductivity	9.12	2.5	(Btu-in / h.°F.ft)
7. Below Grade R	4.85	30	(h.°F.ft / Btu)
8. Floor R	1.32	40	(h.°F. ft / Btu)
9. Equivalent floor Resistance	36.32	100	(h.°F. ft / Btu)

APPENDIX M

DOE-2.1a Input (Basement Analysis)

```
                TITLE  LINE-1 *TYPICAL 2 STORY HOUSE*
                       LINE-2 *VILLAGES OF RIVERSIDE*

                        $......HEADING.....$

                       DIAGNOSTIC     CAUTIONS..
                       ABORT          ERRORS ..
                       RUN-PERIOD     JAN 07 1968 THRU JAN 07 1968
                                    JAN  01 1968 THRU DEC 31 1968..
BUILDING -LOCATION  LAT=42.23   LON=83.33  ALT=633   T-Z=5
  WINTER=DESIGN-DAY     DB-H=8   DB-L=4
                        HH-14 H-L=22 DP-H=22 DP-L=22 W-S=22
                        W-S=10  W-D=0  C-A=0 CL=0.97
                        C-T=1  G-T=38
                      $...SCHEDULES...$
GAINS-1=DAY-SCHEDULE  $.UPSTAIRS.$
                     (1,24)
                            (.3,.3,.3,.31,.31,.31,.43,1.,.27,.3
                             .3,.5,.5,.3,.3,.3,.3,1.0,1.0,.77,
                             .77,.77,.78,.30) ..
GAINS-2=DAY-SCHEDULE (1,24) $WATER HEATER$  (1,24) (1.0) ..
GAIN-W=WEEK-SCHEDULE   (ALL) GAINS-1..
GAIN-2W=WEEK-SCHEDULE  (ALL) GAINS-2 ..
GAIN-1Y=SCHEDULE        THRU DEC 31 GAIN-W ..
GAIN-2Y=SCHEDULE        THRU DEC 31 GAIN-2W ..
                    $..MATERIALS..$
FLR-DUM-INS  = MAT  RES = 34.61 $DUMMY INSUL$..
WL-DUM-INS   = MAT RES = 3.894 $DUMMY INSUL$..
STUD-1       = MAT TH=0.83 COND=0.0677 DENS=34  S-H=0.33 ..
PLYWD        = MAT TH=.0833 COND=.0677 DENS=34  S-H=0.29 ..
WD01         = MAT TH=.0625 COND=.0677 DENS=32  S-H=0.33 ..
IN02         = MAT TH=.2957 COND=0.025 DENS=.6  S-H=.2   ..
GPO1         = MAT TH=0.0417 COND=.0928 DENS=50 S-H=.2   ..
WDO4         = MAT TH=.2917 COND=0.0667 DENS=32 S-H=.33  ..
BKO5         = MAT TH=.3333 COND=.7576  DENS =130 S-H=.22 ..
AL11         = MAT     RES=0.90 ..
PWO2         = MAT TH=.0313 COND=.0667  DENS=34 S-H=0.29 ..
AL33         = MAT      RES=0.92  ..
IN03         = MAT TH=0.5108 COND=.025 DENS=.60 S-H=0.2  ..
CC16         = MAT TH=.6667  COND=1.0417 DENS=140 S-H=0.2 ..
CC03         = MAT TH=.3333  COND=.7576  DENS=140 S-H=0.2 ..
```

```
CC05          = MAT TH=0.50   COND=0.7576 DENS=140 S-H=0.2 ..
STO1          = MAT TH=.0833  COND=1.0416 DENS=140 S-H=0.2 ..


                             $..GLAZING..$
WIN=GLASS-TYPE          PANES=2  S-C=0.88  ..
                        $..CONSTRUCTUIONS..$
UP-WALL-I=LAYERS          MAT=(WDO1,INO2,GPO1)  I-F-R=0.68 ..
UP-I      =CONS          LAYERS=UP-WALL-I  ABS=0.68 RO=4 ..
UP-WALL-S = LAYERS        MAT=(WDO1,WDO4,GPO1)  I-F-R= 0.68 ..
UP-S  = CONS             LAYERS = UP-WALL-S  ABS=0.68  RO=4 ..
DN-WALL-I = LAYERS        MAT=(BK05,AL11,PWO2,INO2,GPO1)
                          I-F-R=0.68 ..
DN-I = CONS              LAYERS = DN-WALL-I  ABS=0.88  RO=2 ..
DN-WALL-S=LAYERS            MAT=(BKO5,AL11,PWO2,WDO4,GPO1)
                          I-F-R=0.68   ..
DN-S = CONS              LAYERS=DN-WALL-S   ABS=0.88  RO=2   ..
CON-WALL=LAYERS           MAT=(CC16)  I-F-R= 0.68  ..
C-1      =CONS          LAYERS = CONWALL  ABS=0.58  RO=3  ..
CEILING=LAYERS            MAT=(PWO2,AL33,INO3,GPO1)  I-F-R = .68..
CLG      = CONS         LAYERS=CEILING  ABS=0.86  RO=3 ..
LAYER-BW= LAYERS        MAT=( WL-DUM-INS,CC16 )..
BASE-WALL=CONS          LAYERS=LAYER-BW ..
LAYER-BF=LAYERS         MAT=(FLR-DUM-INS,CCO5)  ..
LAYFLO = LAYERS         MAT=(STUD-1,PLYWD)  ..
BASE-FLOOR=CONS         LAYERS = LAYER-BF ..
EXT-DOOR=CONS           U=0.5   ABS=0.4   RO=5  ..
FLOOR=CONS     LAYERS=LAYFLO   ABS=0.4  RO=5  ..

                    $...LIVING AREA DESCRIPTION..$

UPPER=SPACE-CONDITIONS    T=(70)
                        SOURCE-SCHEDULE=GAIN-1Y
                        SOURCE-TYPE=ELECTRIC
                        SOURCE-BTU/HR=5349
                        INF-METHOD=RESIDENTIAL
                        RES-INF-COEFF=(.0844,0.0459,0.0069)
                        FLOOR-WEIGHT=0
                        ZONE-TYPE=CONDITIONED  ..
UPPER-LEV=SPACE          AREA=481  VOLUME=11385
                         SPACE-CONDITIONS=UPPER  ..
WL-1=E-W                $..LOWER-STUD-FRONT..$
                        H=8.3  W=3.9  AZ=180  TILT=90
                         CONS=DN-S  ..
WL-2=E-W                $..LOWER INS. FRONT ..$
                        H=8.3 W=15.6  AZ=180  TILT=90
                        X=3.9 Y=0  Z=0  CONS=DN-S ..
```

```
DOOR                H=6.7 W=2.7
                    X=16.5 Y=1 SETB=0.4 CONS=EXT-DOOR..
WINDOW              H=3.5 W=2.7 X=10 Y=3.8
                    SETB=0.4
                    G-T=WIN  ..
WL-3 =E-W         $..UPPER STUD FRONT ..$
                    H=8.3 W=3.9 AZ=180 TILT=90
                   X=0 Y=0 Z=8.3   CONS=UP-S  ..
WL-4=E-W          $..UPPER INSUL FRONT ..$
                    H=8.3  W=15.8  AZ=180  TILT=90
                   X=3.9  Y=0  Z=0  CONS=UP-I  ..
WL-5=E-W           $..LOWER STUD RIGHT..$
                    H=8.3 W=21.5 AZ=90  TILT= 90
                    X=19.5  Y=0  Z=0  CONS = DN-S..
WL-6=E-W           $...LOWER INSUL. RIGHT ..$
                    H=8.3  W=21.5  AZ=90  TILT=90
                   X=19.5  Y=5.4  Z=0  CONS=DN-I ..
WL-7=E-W           $..UPPER STUD FRONT...$
                    H=8.3  W=5.4  AZ=90  TILT=90
                    X=19.5  Y=0  Z=8.3  CONS=UP-S ..
WL-8=E-W           $..UPPER INSUL RIGHT ..$
                    H=8.3  W=21.5  AZ=90  TILT=90
                    X=19.5  Y=5.4  Z=8.3  CONS=UP-I..
WL-9=E-W           $..LOWER STUD LEFT..$
                    H=8.3  W=5.4  AZ=270  TILT=90
                    X=0  Y=26.9  Z=0  CONS=DN-S ..
WL-10=E-W          $..LOWER INSUL LEFT..$
                    H=8.3  W=21.5  AZ=270  TILT= 90
                    X=0  Y=21.5  Z=0  CONS=DN-I  ..
WL-11=E-W          $..UPPER STUD LEFT..$
                    H=8.3  W=5.4  AZ=270  TILT=90
                     X=0  Y=26.9  Z=8.3 CONS=UP-S ..
WL-12=E-W           $..UPPER INSUL LEFT..$
                    H=8.3  W=21.5  AZ=270  TILT=90
                    X=0 Y=21.5  Z=8.3  ..
 WINDOW              H=3.5  W=12.9
                    X=10  Y=3.7  SETB=0.4 G-T=WIN  ..
WL-13=E-W           $..LOWER STUD REAR..$
                    H=8.3  W=3.9  AZ=0  TILT=90
                    X=19.8  Y=26.9  Z=0  CONS=DN-S ..
WL-14=E-W           $..LOWER INSUL. REAR ..$
                    H=8.3 W=15.6  AZ=0  TILT=90
                    X=15.6  Y=26.9  Z=0  CONS=DN-S ..
WINDOW              H=7  W=5  X=5 Y=0 SETB=0.4  G-T=WIN ..
WL-15=E-W           $..UPPER STUD REAR..$
                    H=8.3  W=3.9  AZ=0  TILT=90
                    X=19.5  Y=26.9  Z=8.3  CONS=UP-S ..
WL-16=E-W           $..UPPER INSULATION REAR..$
```

```
                         H=8.3  W=15.6  AZ=0  TILT=90
                         X=15.6  Y=26.9  Z=8.3  CONS=UP-I  ..
ROOF                     H=26.9  W=19.5  AZ=180  TILT=0
                          X=0  Y=0  Z=18.6  CONS=CLG ..
INTERIOR-WALL            AREA =481  NEXT-TO=DN-LEV  TILT=180
                          CONS=FLOOR  ..
                   $....BASEMENT  DESCRIPTION....$
BASEMENT = SPACE-CONDITIONS     T=(70)
                               SOURCE-SCHEDULE = GAIN-2Y
                               SOURCE-TYPE=ELECTRIC
                               SOURCE-BTU/HR=0.0
                               INF-METHOD=AIR-CHANGE
                               AIR-CHANGE/HR=0.0
                               FLOOR-WEIGHT=0
                               ZONE-TYPE=CONDITIONED  ..
DN-LEV  = SPACE              AREA=494  VOLUME=3458
                              SPACE-CONDITIONS=BASEMENT  ..
U-FLOOR = U-F  A=484  CONS=BASE-FLOOR  TILT =180  ..
BGWALL=U-W    $...BASEMENT WALL BELOW GRADE ..$
               A=540  CONS=BASE-WALL ..
                         $...REPORTS...$
LOADS-REPORT             VERIFICATION = (ALL-VERIFICATION)
SUMMARY=(ALL-SUMMARY) ..
END  ..
```

APPENDIX N

HOTCAN LISTINGS(BASEMENT ANALYSIS)

SUMMARY OF ENERGY CONSUMPTION

MONTH	TOTAL CONSUMPTION KWH/D
JAN	30.48
FEB	30.37
MAR	27.05
APR	21.40
MAY	0.00
JUNE	0.00
JULY	0.00
AUG	0.00
SEP	0.00
OCT	15.35
NOV	21.81
DEC	27.35

HEATING SEASON STARTS IN OCT AND ENDS IN APR.

VITA AUCTORIS

1959	Born in Malegaon, Maharashtra State, India on October 31, 1959.
1975	Completed the Higher Secondary School Examination of the Maharashtra State Board of Secondary Education.
1977	Completed the B.Sc. Part I Examination of Nagpur University, India.
1981	Completed the Bachelor of Engineering degree in Mechanical Engineering from the University of Poona, India.
1984	Currently a candidate for the Degree of Master of Applied Science in Mechanical Engineering at the University of Windsor, Canada.