Comparison of Energy Consumption Calculations Using HOTCAN With Measured Values From Unoccupied Test Huts

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ABSTRACT

Energy consumption calculations using the HOTCAN computer model are compared to the measured consumption at four unoccupied test huts at the Alberta Home Heating Research Facility. A total of 24 comparisons are performed over 7 four-week time intervals. Over the range of huts tested, the calculated energy consumption rates and the measured values agreed with a root-mean-square difference of 0.39 kW for measured values ranging between 0.68 and 6.2 kW.

1. INTRODUCTION

HOTCAN is a computer program for calculating the space heating requirement of residences and small buildings. A complete description of the computer program is contained in a paper by Dumont, Lux and Orr (1). Some of the major features of the model are as follows:

a. The program may be run on a microcomputer. To date, the program is available for use on the Apple II, Radio Shack TRS-80 and Commodore PET. The program is written in the BASIC language.

b. Weather data for 12 locations across Canada are included.

c. Passive solar gains through windows are accounted for using a technique by Barakat and Sander (2). Their method allows one to account for different thermal capacities of houses.

d. The effect of overhangs on south windows is included.

e. An improved basement heat loss calculation developed by Mitalas (3) is included.

A 1983 paper by Dumont, Orr and Hedlin (4) presents comparisons between the measured space heating consumption and the HOTCAN calculations for a group of 14 occupied houses located in Saskatoon for the period May 1980 to May 1981. A graph presenting that comparison is shown in Figure 1. For these houses, HOTCAN was able to calculate the annual space heating consumption within +24% and -17%. In this paper, comparisons based on shorter time intervals are presented.

The various algorithms used in the program have been verified by the original authors. However, to ensure that the algorithms have been properly implemented, a number of comparisons are included in this paper between the calculated performance using HOTCAN and the measured performance for four test huts located in Edmonton at the University of Alberta's Home Heating Research Facility (5,6). For each of the huts, measured space heating performance data were available in the form of a series of average energy consumption rate readings as a function of the temperature difference between inside and outside.

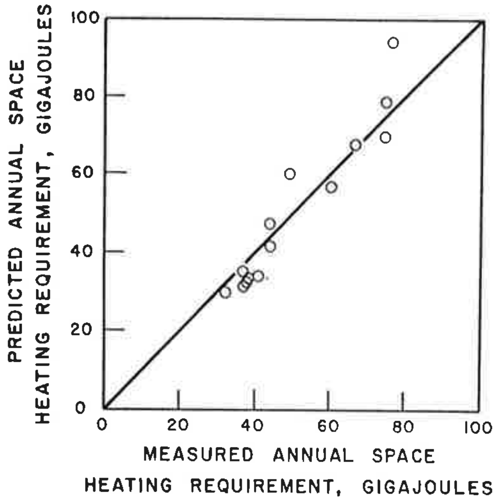

Fig. 1 Comparison of calculated and measured space heating energy consumption for a group of 14 low energy houses.

2. COMPARISONS OF HOTCAN PREDICTIONS WITH MEASURED DATA

The data from this project consisted of measured values over the heating season 1981-82. A total of four small, unoccupied research huts using electric heat were used in the comparison. The huts are rectangular, with a main floor and basement floor, each with dimensions 6.7 m × 7.3 m. The total floor area is 98 m^2, including the basement and the total volume of each hut is 219 m^3. The huts are located side by side, with a spacing of 3.0 m between each unit. In all, six huts are present at the site, all located along an east-west axis. Units 2,3,4 and 5 are used in this comparison. Unit 1 was an instrumentation storage hut, and unit 6 has an active solar air heating system, which HOTCAN cannot analyze. The four huts are identical in floor area, but have different levels of insulation, air tightness and window area. They are described in Table 1. Thermal resistance values presented in

Table 1 were calculated using the description of the huts presented in Reference 5.

Energy readings for the 28 weeks starting September 1, 1981 were used in the HOTCAN comparisons. As HOTCAN uses monthly average values for solar radiation and outside temperatures, the data from the monitoring periods were divided into seven periods of four weeks. Measured weather data for the site are presented in Table 2. As no measured values were gathered for the north, east and west exposures, the long-term average of the solar data was used for these values. Window areas on the non-south walls of the hut are relatively modest, so this should not present serious problems for this comparison. Because of the proximity of other test huts, essentially only diffuse radiation strikes the east and west windows; the shading coefficient for these windows was therefore reduced 50%, to 0.45. For the north windows, the shading coefficient is .89 for all huts. As no measurement of the deep ground temperature was made, the long-term average of 5.2°C for Edmonton was used.

During the monitoring period the huts were unoccupied, and all meter readings were gathered using a data logger. On all the modules, automatic tracer gas measurements using sulfur hexafluoride were used to measure the air change rates in the huts. Correlations between the air change rate and the wind speed and temperature difference were developed for each of the modules. These correlations were used to calculate average air change rates for each of the four modules for the seven time periods. The calculated air change rates for the modules are presented in Table 3.

On all the huts, electric forced air furnaces with continuously running fans were used. The fans had energy consumption rates as listed in Table 1. These were the only internal gains in the huts.

2.1 Module 2. Standard Module

This hut had the highest heat loss rate of the group, due to the relatively high air change rate and the low insulation levels. The basement walls and the floor were completely uninsulated. Because of the high heat loss rate through the basement, the air temperature in the lower part of the hut was about 2°C lower than the main floor temperature, even though a forced air system with continuous fan circulation was used to distribute heat within the house. Values for the interior temperature and calculated air change rate for each of the modules are presented in Table 3.

The house had no south windows; there were a total of 5.8 m^2 of double-glazed, unshuttered windows on the other 3 walls.

A comparison between the calculated and the measured energy consumption rate for this house is presented in Figure 2. Each data point represents a four-week period.

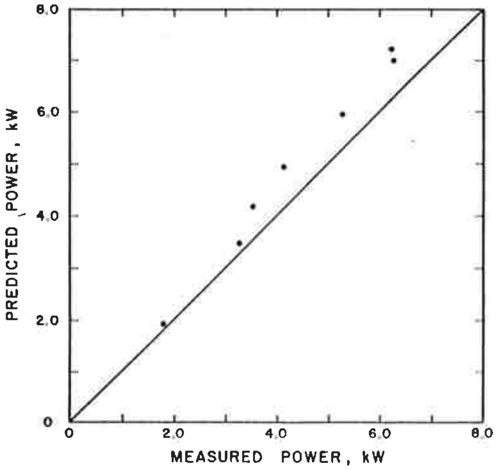

Fig. 2. Comparison of calculated and measured energy consumption rates for Module 2.

2.2 Module 3. Energy Conservation Module

This module had the lowest energy consumption rate of the four units due to its low air change rate and high insulation levels. A complicating factor in the analysis was the use of automatic night-time insulating shutters on the south windows. These windows were 5.5 m^2, or about 5.5% of the total floor area. The measured thermal resistance of the shutter proved to be considerably less than the nominal value, due to air leakage around the edges of the shutter. A value of RSI 0.95, measured with a heat flux meter (6), was used as the thermal resistance of the shutter, as the calculated value of RSI 2.3 was not achieved in the field. When the shutter was in the open position, it blocked the sunlight incident on the upper part of the window. To account for this blockage, the shading coefficient was reduced from 0.82 to 0.67 for the windows with shutters.

A comparison of the calculated and measured energy consumption rate for the hut is presented in Figure 3. For the month of January 1982, the shutters on modules 3 and 4 were left open; the shutters were fully closed for the months of February and March of 1982. During time periods 5 and 6, there were times when the

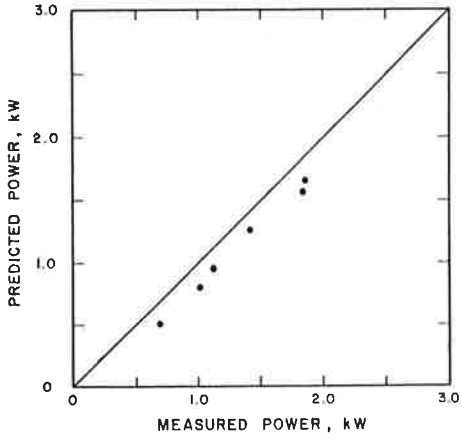

Fig. 3. Comparison of calculated and measured energy consumption rates for Module 3.

shutters were either fully open or fully closed. Consequently, comparisons were not made for these two periods. For time period 7, the shutters were fully closed on modules 3 and 4, and a comparison was possible for this period.

2.3 Module 4. Passive Solar Module

This hut has relatively large south-facing windows, with 11.1 m^2 of double-glazed windows, for a ratio of about 11% south window to total floor area. A brick dividing wall was located 1.52 m behind the south windows. The wall was 4.87 m long, 1.98 m high, and 0.2 m thick. In the HOTCAN program, there are four different levels of thermal mass which may be specified. As none of the four levels exactly matched the type of thermal mass used in Module 4, an intermediate level of thermal mass was used in the computer analysis. This level corresponded to 51 mm-thick gypsum board walls and 26 mm-thick gypsum board ceiling, or a thermal capacity of 0.153 MJ K^{-1} per m^2 of floor area. A calculation of the thermal mass in this hut yielded a value of 0.12 MJ K^{-1} per m^2 of floor area, excluding the concrete walls and floor in the basement.

A comparison between the calculated and measured energy consumption rate for this house is presented in Figure 4.

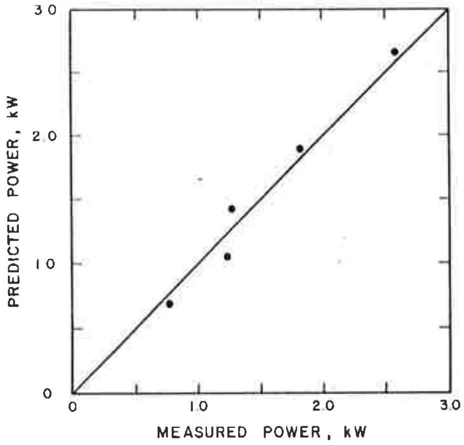

Fig. 4. Comparison of calculated and measured energy consumption rates for Module 4.

2.4 Module 5. Solar Test House

This module was originally intended to be used for an active solar system using liquid collectors. However, due to cost considerations, the liquid collectors were not installed. The module has no south windows, and an intermediate level of insulation compared with modules 2 and 3. A comparison between the calculated and the measured energy consumption rate for this module is presented in Figure 5.

2.5 Overall Comparison

In Figure 6, a plot of all the comparison points for the four huts is presented. The root mean square difference between the calculated and the measured values was equal to 0.39 kW. The averages of the x and y values were 2.84 and 3.03 kW, respectively.

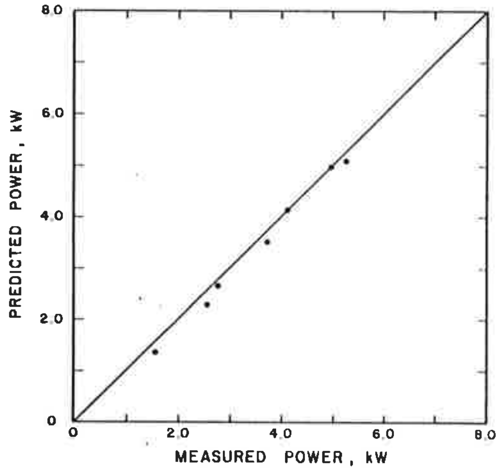

Fig. 5. Comparison of calculated and measured energy consumption rates for Module 5.

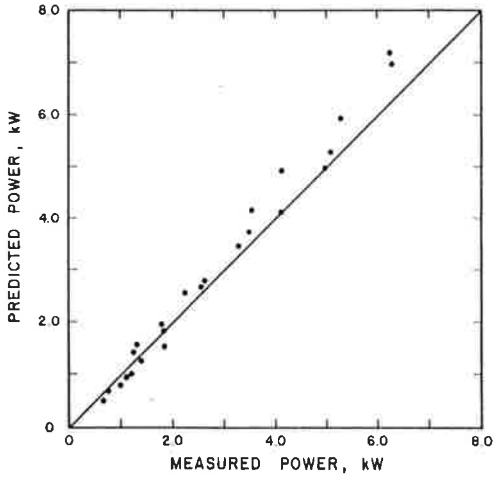

Fig. 6. Comparison of calculated and measured energy consumption rates for modules 2,3,4 and 5.

3. DISCUSSION

As may be seen from the comparison graphs in Figures 2-5, there was relatively good agreement between the calculated and the measured energy consumption rate for the four huts.

There are a number of variables which can be responsible for the differences between the calculated and measured values. Several of the more important are:

a. The exterior film coefficient on the uninsulated basement walls and the windows. For still air conditions, the thermal resistance of the film is generally taken to be RSI 0.12. For a 24 km h^{-1} wind, the film resistance drops to 0.03. The effect of this change in resistance due to wind effect is most pronounced in the case of windows and uninsulated walls. For instance, a double-glazed window with a 12.7 mm air space has an overall thermal resistance of RSI 0.36 with still air on the inside and a 24 km h^{-1} wind on the outside. If the wind speed drops to 0 km h^{-1}, the overall resistance increases to 0.45, an increase of 25%. On buildings with a high proportion of heat loss through windows, a change in the wind speed can result in a measurable increase in heat loss due to this effect alone. A similar condition exists in the case of uninsulated walls such as those used in the basement of Module 2.

b. The thermal conductivity of the soil. In the HOTCAN program, the assumption made was that the soil thermal conductivity is 0.8 W $(m\cdot K)^{-1}$ in the upper soil and 0.9 W $(m\cdot K)^{-1}$ in the lower soil. It is possible that the soil thermal conductivity at the site could be different, due to local moisture conditions.

c. Ground snow cover and its effect on below grade heat loss.

The effect of these variables on the agreement between the calculated and measured values is discussed in greater detail below.

3.1 Module 2. Standard Module

For this house, the percentage heat loss on a seasonal basis which occurs through the basement walls, all of which are uninsulated, is approximately 45%. In the HOTCAN calculation runs, it was assumed that a 12 km h^{-1} wind was blowing on the exterior surface of the above-grade wall. If, however, the wind velocity were 0 km h^{-1}, the outside film resistance would increase to 0.12, and the total wall resistance from 0.28 to 0.36. This causes a 22% decrease in the heat loss through this element. As the total heat loss occurring through this element is 28%, a change in wind speed from 0 to 12 km h^{-1} will result in about a 6% change in the heat loss of the house due to this element alone.

As noted in Table 3, the basement temperature in Module 3 was approximately 2°C cooler than the main floor temperature. The basement temperature was not monitored continuously; it would probably be lower during colder weather. This effect is a possible cause of the poorer agreement at the higher values.

Snow cover on the ground will also have an effect in reducing the heat loss through the basement walls. The effect is especially marked in the case of uninsulated walls.

3.2 Module 3. Energy Conservation Module

For this module, the calculated energy consumption rate was consistently lower than the measured energy consumption rate. Again, the below-grade portion of the heat loss was proportionately high, with 39% of the calculated annual heat loss occurring through the below-grade walls and floors.

3.3 Module 4. Passive Solar Module

For this module, the predicted and the measured values are relatively close. The two largest heat loss elements are the south windows (27%) and the air change (19%). This module had insulating shutters on the south windows, which can dramatically affect the overall heat balance. As mentioned earlier, the measured shutter thermal resistance was considerably lower than the calculated value, probably due to air leakage around the seals. The measured and calculated energy consumption rate values were generally within ±10%, with the exception of one point.

3.4 Module 5. Solar Test Module

For this module, the calculated and the measured energy consumption rate values were consistently within ±10%. For this module, the greatest losses were due to the walls (24%) and the air change (16%). As with modules 3 and 4, the calculated energy consumption rate was somewhat lower than the measured consumption at the low power consumption values.

4. CONCLUSIONS

The comparisons presented in this paper have shown HOTCAN capable of calculating the energy consumption rate of the four unoccupied research huts at the Alberta Home Heating Research Facility to within a root mean square difference of 0.39 kW for measured energy consumption rates varying between 0.68 and 6.2 kW.

The hut with the completely uninsulated basement walls was found to have the greatest percentage difference between the calculated and measured values.

Further comparisons using houses in different locations with different soil temperatures and solar radiation values would be of value.

5. ACKNOWLEDGEMENT

The authors would like to acknowledge the special contribution of D.J. Wilson and M.Y. Ackerman of the University of Alberta who generously provided unpublished monitoring data on the test houses at the Home Heating Research Facility. The assistance of J.T. Makohon of the Division of Building Research, National Research Council of Canada (DBR, NRCC) with the data analysis and presentation is also much appreciated.

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Table 1. Physical Characteristics of Test Huts

	Module 2		Module 3		Module 4		Module 5	
	Area (m^2)	RSI Value ($m^2 \cdot K$) W^{-1}	Area (m^2)	RSI Value ($m^2 \cdot K$) W^{-1}	Area (m^2)	RSI Value ($m^2 \cdot K$) W^{-1}	Area (m^2)	RSI Value ($m^2 \cdot K$) W^{-1}
Ceiling	46.3	2.23	46.3	14.1	46.3	7.04	46.3	2.23
Walls	58.7	1.6	57.8	7.04	52.2	3.58	58.7	1.82
Doors	1.9	0.53	1.9	2.11	1.9	2.11	1.9	2.11
Bsmt abv grade	16.1	0.28	16.1	3.78	16.1	2.02	16.1	2.02
Bsmt to .6 m bel gd	16.1	0	16.1	3.52	16.1	1.99	16.1	1.99
Bsmt to floor	32.2	0	32.2	3.52	32.2	1.99	34.2	0
Bsmt floor perimeter	22.5	0	22.5	0	22.5	0	22.5	0
Bsmt floor center	21.0	0	21.0	0	21.0	0	21	0
Windows S	0	0	5.54	0.36	11.1	0.36	0	
N	1.91	0.36	0		0		1.91	0.36
E	1.96	0.36	1.17	0.36	1.17	0.36	1.96	0.36
W	1.96	0.36	0		0		1.96	0.36
Internal gains* (W)	400		400		450		550	
Overhang geometry for S Windows (m)								
Window height	1.93		1.57		1.57		1.93	
Overhang separation	.42		1.2		1.2		.42	
Overhang projection	.29		1.65		1.65		.29	

*fan power

Table 2. Weather Data for Comparison Periods (Latitude, 53.6°; Deep Ground Temperature, 5.2°C)

Period	Outside Temperature (°C)	Wind Speed (M s^{-1})	Solar Radiation (S.Vert) MJ (m^2-D)$^{-1}$	Solar Radiation (N.Vert)* MJ (m^2-D)$^{-1}$	Solar Radiation (E.Vert)* MJ (m^2-D)$^{-1}$	Solar Radiation (W.Vert)* MJ (m^2-D)$^{-1}$
1	11.1	2.9	13.82	3.37	9.4	9.63
2	3	3.1	11.67	1.94	5.44	5.56
3	.5	2.7	8.18	1.23	2.93	3.01
4	-6.7	2.7	8.32	1.27	2.54	2.66
5	-19.6	2.9	7.72	1.3	2.65	2.78
6	-18.6	2.9	9.98	2.36	4.57	4.9
7	-10	3.1	14.57	4.56	8.86	9.41

*Data for N,E, and W solar radiation are the long-term averages

Table 3. Interior Temperatures and Air Change Rates

Period	Module 2*		Module 3		Module 4		Module 5	
	Air Chg (ac h^{-1})	Temp (°C)	Air Chg (ac h^{-1})	Temp (°C)	Air Chg (ac h^{-1})	Temp (°C)	Air Chg (ac h^{-1})	Temp (°C)
1	.31	21.3	.11	21.7	.32	22.1	.33	21.6
2	.36	20.9	.13	21.3	.36	21	.38	20.8
3	.33	21.2	.11	21.2	.32	21.1	.34	20.8
4	.36	18.4	.13	20.8	.35	20.2	.4	20.3
5	.44	17.1					.46	19.9
6	.46	18.9					.46	20.3
7	.45	21	.14	20.1	.41	20	.44	21

*Basement temp in module 2 approx 2°C cooler than main floor