Proceedings
4th Annual Conf.
SESCI 1978
London, Ontario

PASSIVE SOLAR HEATING - RESULTS FROM TWO SASKATCHEWAN RESIDENCES

Robert S. Dumont, Robert W. Besant;
Department of Mechanical Engineering
University of Saskatchewan
Saskatoon S7N 0W0 Canada

Grant Jones, Botting & Associates Ltd.
3337 8th St. E., Saskatoon

Rod Kyle, Aquitaine of Canada Ltd.
Rainbow Lake, Alberta

ABSTRACT

Quantitative measurements of the performance of two residences incorporating passive solar design principles are presented. One structure used 32.5 square metres of quadruple glazed south facing windows in a structure with an overall building heat loss factor of approximately 250 W/°C. The second structure (the Saskatchewan Conservation House) used 11.7 square metres of double-glazed south facing glazing with operable night-time shutters, with an overall building heat loss factor of 100 W/°C (shutters open) and 70 W/°C (shutters closed). Both houses were of the direct solar gain type, with no vertical thermal mass such as a Trombe Wall directly behind the glazing.

The heat storage capacities of the two dwellings were approximately equal. The structure with the 32.5 square metre windows (17.1% of floor area) exhibited considerable temperature swings due to the high solar radiation inputs during the day and large heat losses at night, both caused by the large window area. The second structure experienced acceptable temperature fluctuations. For southern Saskatchewan conditions, the south-facing glazing area used in the second structure (6% of floor area) appears close to an optimum for a direct gain system with conventional light frame construction.

Based on the performance to date, the Saskatchewan Conservation House under normal occupancy conditions would require approximately 5 Gigajoules of heat per year for space heating - a cost of $30 per year at present electricity prices. The passive solar gain, heat from normal electricity usage, and heat from people supply the remaining heat requirements.

Introduction

Considerable interest has been shown in the use of passive solar heating. Two conferences[1],[2] and numerous papers have dealt with this topic. The pioneering work of Trombe[3], Balcomb[4] and Anderson[5] has led to a greater recognition of the cost-effectiveness of passive solar heating. For Canadian climate conditions little detailed work has been done in this area. A number of recent papers by Cooper[6], Gilpin[7 and Jones and Tymura[8]present theoretical studies on the performance of windows and passive houses in Canadian conditions.

Passive solar heating systems are characterized as systems that make use of direct solar radiation and natural convection to provide thermal comfort within a dwelling. They are distinguished from active systems, that make use of separate solar collectors, storage tanks, pumps, fans, etc. to provide heating. The cost advantage of passive systems is that they make use of existing building components--windows, walls, floors, and ceilings for solar collection and storage.

In this paper two houses incorporating passive design principles are described. The dwellings were completed in the winter of 1977-78, one located in Saskatoon and the second in Regina. Performance tests on the houses were conducted in the spring of 1978, and the results are presented in this paper. Neither of the houses was occupied by a family, as both were used as demonstration houses. Consequently, monitoring conditions were less than ideal, with approximately 1000 visitors a week passing through the houses. In spite of these circumstances, sufficient quantitative data was gathered to provide useful results. Both of the dwellings were of a direct gain type, with southerly oriented windows and no vertical thermal mass such as a concrete wall behind the windows.

Description of the Houses

Line sketches of the two dwellings are presented in Figs. 1 and 2. The Saskatoon dwelling incorporates a quadruple glazed window system, with louver drapes between the glazings.

Cross section views of the houses are presented in Figs. 3 and 4.

Saskatoon Residence

For the Saskatoon residence a concrete slab on grade floor is used on the front part of the house; a 1/4 inch parquet wood floor is placed on top of the concrete, and one inch thick insulation R0.62 $m^2 °C/W$ is placed underneath. The concrete slab thickness is 0.41 m (16 in.).

The predicted heat losses from the two residences are presented in Table I. The mass and specific heat of the building components on the heated side of the insulation are presented in Table II. The thermal mass, or product of the mass and specific heat of the individual components is of importance in a passive dwelling, as a large thermal energy storage in the dwelling can moderate the temperature fluctuations in the dwelling. If the thermal mass has a sufficiently low Biot modulus and time constant for heat transfer, the thermal mass can be regarded as isothermal; ie. heat can be added to or removed from the mass approximately the same temperature as the room air temperature.

In the Appendix a more detailed description of this problem of the absorptive capacity and time response of building materials is presented.

Over the period Feb. 9 to Feb. 15, measurements were made of the heat loss characteristic of the Saskatoon residence. The residence was unoccupied for this period. The energy flows were as listed in Table III.

The electrical energy consumption was measured using standard kW-hr meters (the house is heated with electricity) and the passive solar gains were measured using data for the insolation on a horizontal surface and using the technique of Liu and Jordan[11] to determine the insolation on the southfacing glazings.

The heat loss characteristic in Watts per °C temp. difference can be found by the following method.

$$\text{HEAT LOSS CHARACTERISTIC} = \frac{\text{AVG. POWER CONSUMPTION (ELECTRICAL \& SOLAR \& PEOPLE)}}{\text{AVERAGE TEMP. DIFFERENCE}}$$

$$= \frac{(2614 + 1972) \times 10^6 \text{ J/144 hours}}{18.3 - (-17)^\circ\text{C}} \times (1 \text{ hr}/3600 \text{ s})$$

$$= 251 \text{ W}/^\circ\text{C}$$

This figure of 251 W/°C compares favourably with the predicted heat loss of 250 W/°C calculated in Table I. Note that the loss from the windows accounts for approximately 50% of the total heat loss, and that windows are most susceptible to variation in heat transfer coefficients due to wind velocity effects. Although quadruple glazed units (two sealed dual glazed windows) are used on the southfacing windows, the heat loss is equivalent to that of a dual glazed window, as air flows between the two sealed units as shown in Fig. 3. In retrospect, it would have been preferable to not have inside air circulate between the windows.

Dynamic Temperature Behaviour of Saskatoon Residence

With 32.5 m^2 of southfacing glazing, the Saskatoon residence will receive approximately 12 kW of solar heating in the hours around solar noon on a clear day in February. As the heat loss rate from the dwelling is of the order of 5 kW during this period around solar noon, a considerable amount of excess heat is available. If the structure has sufficient absorptive capacity, the room air temperature need not rise excessively. With the Saskatoon residence, however, there were several problems with the thermal mass; first, the upper windows had no thermal mass to shin other than the light-coloured gypsum board; second, the bottom of the lower windows was approximately 560 mm (1.8 ft) from the floor, and co: sequently the sunlight could not directly strike all the concrete floo: (see Fig. 3); third, due to the great thickness of the concrete slab (410 mm) only the upper portion of the slab would rise in temperature. From the house geometry (Fig. 3) one can see the problem more clearly.

With the combination of a relatively ineffective thermal mass, aı large window area, the building experienced considerable temperature fluctuations. In Fig. 6 the indoor air temperature for the house, outc air temperature and solar radiation on a horizontal surface are plottec for the dwelling. Note that over this three day interval there was no internal heat generation and yet the house did not fall below 7°C. The temperature rise of approximately 14°C on a clear day would be unaccept and under normal circumstances blinds placed between the windows reduce this rise in temperature.

The heat storage capacity of the house (the amount of heat requiı to change the indoor temperature by one degree of temperature) may be estimated using the data in Fig. 6. Note that the house "integrates" t excess energy provided. The heat storage capacity of the house may be pressed as,

$$\text{Effect Heat Storage Capacity} = \frac{\text{Net Heat Entering House}}{\text{Indoor Temperature Rise}}$$

$$\text{Net Heat Entering House} = \text{Solar Gain} - \text{Heat Loss}$$

For Feb. 22, taking the hours between 8 and 16, the effective hea storage capacity is calculated as follows.

$$\begin{aligned}\text{Net Heat Entering House} &= \text{Solar Gain} - \text{Heat Loss}\\ &= 441\ \text{MJ} - 135\ \text{MJ}\\ &= 306\ \text{MJ}\end{aligned}$$

$$\text{Effective Heat Storage Capacity} = 306\ \text{MJ}/12.2°\text{C} = 25\ \text{MJ}/°\text{C}$$

This number may be compared with the calculated value based on the mass and specific heat of the individual building components. In Table II, these values are listed. These values are repeated in Table IV, along with the measured values.

Note that if only the top 3 inches of the concrete floor is included in the thermal storage, the agreement between the measured value and the theoretical value is reasonable.

A second technique was used to examine the effective thermal storage capacity of the building. In Fig. 7(a), a temperature decay curve for the house is plotted for a time when the average outdoor air temperature was -30°C.

By plotting the logarithm of the temperature difference between inside and outside against time, some idea can be gained as to the predominant time constants. In Fig. 7(b) this graph is presented. Note that from about 2 hours until 7 hours, the slope is fairly constant. From this portion of the curve, a time constant of 49.8 hours is indicated. Between 0 and 2 hours the time constant is much shorter; beyond 9 hours, a longer time constant is evident. These second order effects are most likely caused by the long time constants for heat transfer associated with the mass in the concrete floors and the masonry fireplace.

Based on the temperature variations measured in this dwelling, it is apparent that the temperature swings could be greatly moderated by reducing the window area in the dwelling. Alternatively, greater thermal mass could be added, but at some cost in terms of space within the dwelling. In general, it is recommended that thermal mass be of a high absorptance to solar radiation (dark colour) and be directly irradiated by the sun during the hours surrounding solar noon. Vertical walls such as the Trombe wall have been successfully used, although at some cost of interior space within the dwelling. A high mass floor such as concrete can be used as well, but an insulating medium such as a carpet should not be placed on top of the concrete. A thin wood parquet floor or ceramic tile can be used as a covering for the concrete. The advantage of the vertical Trombe wall is that it can achieve much higher temperatures than the floor slab, as the sun's rays are more perpendicular to a vertical wall than to a concrete floor in northern latitudes in winter. An additional advantage of either reducing the window area or increasing the thermal mass is that the temperature drop at night is also reduced, assuming that window shutters are not used.

Heat Loss of the Regina Residence

A detailed report on the Regina residence is presented in a companion paper at this conference[12]. In that paper, the measured heat loss rate is listed at 69.5 W/°C. This figure compares favourably with the theoretical predictions listed in Table I. Note that this dwelling has insulating shutters on all the windows of the dwelling. When closed, the shutters reduce the heat loss of the house by approximately 30% compared to when the shutters are open.

Dynamic Temperature Behaviour of Regina Residence

The sun-oriented window area of the Regina residence is considerab smaller (11.9 m^2) than that of the Saskatoon residence (32.5 m^2). With smaller passive solar heat input rate, and approximately the same absorp tive capacity, the temperature rise during the day is considerably less the Regina residence. For February 22 to 24, 1978, the indoor temperatu outdoor temperature,heating system on-time, solar radiation 70° tilted slope with the same azimuth as the main windows are presented in Fig.8 . Note that the space heating system was on for only a very short time. A midnight the indoor temperature was set back from 20°C to 15°C. As the heat gain from people was high (and variable) because of the many group tours passing through the house, it has not been possible to estimate accurately the temperature rise due to passive solar heating. The high gains from people occur at the same time as high solar inputs, and it wi not be possible to make such an analysis until the present set of tours are completed.

An indication of the heat storage capacity of the dwelling may be determined from a time constant analysis. The time constant, assuming a first order type of temperature response, may be found for the dwelling by plotting the logarithm of the temperature difference between indoor and average outdoor temperature vs time. The slope of this line yields the time constant of the dwelling. In Fig.9 this plot is presented. F the Regina residence the time constant is 99.9 hr. Using this figure, a the known heat loss rate, the absorptive capacity of the dwelling may be determined.

$$\text{Time Constant} = \frac{\text{Heat Storage Capacity of Building}}{\text{Heat Loss Characteristic}}$$

or Heat Storage Capacity of Building = Time Constant x Heat Loss Characteri

= 99.9 hr x 69.5 W/°C x 1 Joule/1W-s x

x 3600s/hr

= 25.0 MJ/°C

In Table V the measured value of heat storage capacity is compared with the calculated value.

TABLE V

Thermal Storage Capacity of Regina Residence

Measured Value			25.0 MJ/°C
Theoretical Values	Gypsum Board	5.5	
	Wall Studs & Plates	5.6	
	Flooring Material	5.5	
	Floor Joists	6.2	
	Furniture and Appliances	2.0	
	Ceiling Joists	1.2	
		26.0 MJ/°C	

The agreement between the theoretical and the measured value of the thermal storage capacity is good, considering that small heat gains from the circulating fans and from the heat storage water tank were present when the cooling curve was measured.

Note that the Regina house, with no concrete basement is a thermally light house. Judging from the temperature swings experienced in the dwelling, the southfacing window area (11.9 m^2) in the Regina house appears to be appropriate for the floor area in the building (18 6 m^2). This percentage of southfacing window area to floor area for the Regina residence (6.4%) is approximately consistent with the figure of 8% recommended in a paper by Schick and Jones[13] for a fairly similar type of energy conserving structure.

Annual Auxiliary Heating Requirement for the Passive Structures

Using the following approximate analysis, it is possible to estimate the annual heating requirements of the two residences under study. The method involves a month-by-month calculation, based on the assumption that all of the solar energy that can be usefully absorbed by the structure can be calculated using daily average solar radiation figures. This auxiliary heat requirement may be expressed as,

Auxiliary Heat Requirement = Heat Loss from the Structure -
Heat Gain from Passive Solar Heat -
Heat Gain from Electrical Consumption -
Heat Gain from People.

In Table VI the auxiliary heat requirements are presented for a month-by-month analysis.

Note that the Saskatoon residence, although possessing a larger southfacing window area, requires a considerably greater amount of auxiliary heating (~75 GJ/yr) than does the Regina residence (~5 GJ/yr). This extra heating requirement can be attributed to two factors; first, the Saskatoon residence has too great a window area for the thermal storage capacity of the house, and only a fraction of the passive solar heat gain can be usefully absorbed; second, the heat loss from the Saskatoon house is considerably greater than that of the Regina house; this is in large part due to the amount of unshuttered glazing. By reducing the glazing area in the Saskatoon residence one could remedy the latter problem considerably.

Conclusions

Based on the measured results presented on the two dwellings, a number of conclusions can be drawn regarding direct gain passive solar heating.

1. Passive solar heating can contribute a large fraction of the heating requirement as inexpensive heat to well insulated dwellings even in a harsh climatic area of Canada. For the Regina residence, the contribution of passive gains should amount to 44% of the heating requirement during the heating months. Coupled with the "free" gains from the use of electricity and heat from people in the dwelling, the passive gain can reduce the auxiliary heat requirement to a very low value. At present electricity costs of 2.2 cents/kwhr ($6.11/GJ) the auxiliary space heat requirement for the Regina house would amount to only $31 per year, assuming that it did not have an active solar system.

2. Thermal shutters can be of significant value in reducing both the heat loss from dwellings and in moderating the temperature falls at night in well insulated dwellings.

3. For conventional light frame construction using gypsum wallboard as the interior finish, and no additional thermal mass, one should limit the southfacing window area to less than 8 percent of the floor area of the dwelling. Additional window area will only result in excessive heat gain during the day and too rapid temperature falls at night.

4. Care must be taken with thermal mass to ensure that it is directly irradiated by the sun during the period of interest. In the low sun angles experienced in the winter months, little sun will strike the thermal mass in the floor in northern latitudes if the window does not extend almost to floor level.

5. Thermal mass is of little advantage if its thickness and long thermal time response does not allow the heat to be usefully stored and returned over daily cycles: for concrete floor slabs, thicknesses greater than about 100 mm will contribute little extra to the thermal storage capacity of residences.

Acknowledgements

The authors would like to thank Mr. Keith Funk and his staff at Concept Construction for their generous assistance in monitoring the Saskatoon Passive Residence. We also acknowledge the work of the many individuals connected with the Saskatchewan Conservation House, especially Mr. Tom Brown of the Division of Hydrology, University of Saskatchewan, for his assistance in the monitoring and data processing.

List of References

1. Proceedings, Passive Solar Heating and Cooling of Buildings Conference, Albuquerque, New Mexico, 1976, American Section International Solar Energy Society.

2. Proceedings, Passive Solar Heating and Cooling of Buildings Conference Philadelphia, Pennsylvania, 1978, American Section, International Solar Energy Society.

3. Trombe, F. et al., "Concrete Walls to Collect and Hold Heat", Solar Age Magazine, August, 1977.

4. Balcomb, J.D. et alia, "Simulation Analysis of Passive Solar Heated Buildings - Preliminary Results", Los Alamos Scientific Laboratory Report, LA-UR-76-1779, 1976.

5. Anderson, B., The Solar Home Book, Cheshire Books, 1976.

6. Cooper, K., "Mean Monthly Net Heat Transfer Through Windows", Proceedings Solar Energy Update Conference, Solar Energy Society of Canada, Edmonton, Alberta 1977.

7. Gilpin, R.R., "The Use of South Facing Windows for Solar Heating in a Northern Climate", Proceedings, Solar Energy Update Conference, Solar Energy Society of Canada, Edmonton, Alberta 1977.

8. Jones, R.E. Jr. and Tymura, E.J., "Passive Solar Heating Design for Canada", Proceedings, Solar Energy Update Conference, Solar Energy Society of Canada, Edmonton, Alberta 1977.

9. Harrison, E., "The Intermittent Heating of Buildings", Institution of Heating and Ventilating Engineers Journal, Vol. 24, 1956, London, England.

10. Mazria, E., Baker, M.S. and Wessling, F.C., "An Analytical Model for Passive Solar Heated Buildings", Proceedings 1977 Annual Meeting, American SEction, International Solar Energy Society, Orlando.

11. Liu, B.Y.H. and Jordan, R.C., "The Interrelationship and Characteristic Distribution of Direct, Diffuse and Total Solar Radiation", Solar Energy, Vol. 4(3), 1960.

12. Besant, R.W. and Dumont, R.S., "The Saskatchewan Conservation House - Some Preliminary Performance Results", Renewable Alternatives Conference, Solar Energy Society of Canada, August, 1978, London, Ontario, Canada.

13. Schick, W.L. and Jones, R.A., "Illinois Lo-Cal House", Council Notes, Vol. 1, No. 4 Spring, 1976, Small Homes Council - Building Research Council, University of Illinois at Urbana-Champaign.

Appendix

In normal light wood frame construction used in Canadian residences, a large part of the thermal mass is contained in the gypsum wallboard (drywall) used. For the wallboard [normally 12.7 mm (1/2 in.) thick], the time constant (the time for the temperature of the wallboard to reach 63.2% of the temperature change of the room air adjacent to it), may be expressed as follows.

$$\text{Time Constant } (\tau) = \frac{631 \frac{\text{kg}}{\text{m}^3} \times 12.7 \times 10^{-3}\text{m} \times 1080 \frac{\text{J}}{\text{kg}^\circ\text{C}}}{8.29 \frac{\text{W}}{\text{m}^2\,^\circ\text{C}} \times \frac{1 \text{ Joule}}{\text{W-s}}} = 1044 \text{ sec (17.4 min.)}$$

The above analysis assumes that the gypsum is at a uniform temperature across the cross-section at any given instant in time. Strictly speaking, this is true only if the Biot Modulus is less than 0.1. The Biot Modulus is a measure of the ratio of the internal resistance to heat transfer in the gypsum to the external resistance to heat transfer at the surface of the gypsum. For gypsum board painted with a non-reflective paint, the combined radiation-convection heat transfer coefficient h is approximately 8.3 $W/m^2{}^\circ C$ for a vertical wall. The Biot Modulus for this situation is calculated as follows.

$$Bi = \frac{hL}{k} = \frac{8.29 \frac{W}{m^2{}^\circ C} \times 1.27 \times 10^{-3}\ m}{0.43\ W/m^\circ C} = 0.24$$

As the Biot Modulus is in the range of 0.1, one can assume that for the normal circumstances found in residences the 12.7 mm thick gypsum board will not significantly deviate in temperature from the room air temperature, provided that the room air temperature does not rise or fall too rapidly.

In the Saskatoon passive residence, a concrete floor is used. For a thick thermal mass such as this, the time constants are considerably larger. For instance, for the 0.41 meter thick concrete slab floor, the Biot Modulus is,

$$Biot = \frac{hL}{k} = \frac{6.13 \frac{W}{m^2{}^\circ C} \times 0.41\ m}{0.94\ W/m^\circ C} = 2.67 >> 0.1$$

With such a large Biot Modulus, the internal resistance to heat transfer is great, and large amounts of heat cannot be added to or removed from the slab rapidly.

For thick low thermal diffusivity slabs, the time constant is proportional to the thickness squared and inversely proportional to the thermal diffusivity of the slab [9],

$$\tau = \frac{\Delta x^2}{\alpha}$$

For a 0.41 m thick slab of concrete, the time constant is equal to,

$$\tau = \frac{(0.41\ m)^2}{0.0022\ m^2/hr} = 76\ hours$$

With such a thick low thermal diffusivity slab it is only the upper layers of the mass that experience much of a temperature fluctuation on a daily basis. (The time constant for the room air temperature fluctuations in the dwellings will be in the range of 10 to 100 hours depending on the heat loss characteristic of the house and the effective thermal mass of the dwelling. Under winter conditions, the slab will not transfer much heat to or from the room air given that the time constant for the slab is large compared to the time constant for the room air. For winter conditions, it appears that a slab thickness of approximately 100 mm (4 in.) is all that would be effective in transferring heat to and from the room air. Slabs of greater thickness would cost more and on a daily basis would not be capable of storing and releasing greater amounts of heat. This observation is made in a paper by Mazria, Baker and Wessling[10] who suggest that increasing concrete thickness beyond 100 mm (4 in.) does not significantly improve the thermal response of a passive solar dwelling. (Note that this recommendation does not hold for vertical heat storage walls irradiated directly by the sun; in this case, concrete thicknesses of approximately 300 mm are recommended.)

TABLE I - Passive Residences - Heat Losses, 55°C Design Temperature Difference

		SASKATOON				REGINA						
				W	%	Shutters Open			%	Shutters Closed		
CEILING :	Area (m^2)	97.6				106.3						
	R Value m^2°C/W		10.6				10.6					
	Design Heat Loss (D.H.L.) W			506	3.7			551	10.1		551	1
EXTERIOR WALLS:	Area	125				204						
	R Value		7.3				7.3					
	D.H.L.			942	6.8			1539	28.2		1539	4
WINDOWS : (South Facing)	Area	32.5				11.9						
	R Value		.304				.304 (6.7 m^2) .489 (5.2 m^2)			2.95 (6.7 m^2) 2.34 (5.2 m^2)		
	D.H.L.			5879	42.8			1797	32.9		247	
WINDOWS : (Other)	Area	10.3				1.9						
	R Value		.304 (7.2 m^2) :37 (1.86 m^2) .68 (1.28 m^2)				.489			2.34 (1.9 m^2)		
	D.H.L.			1682	12.3			214	3.9		45	
BASEMENT WALLS: (above grade)	Area	29.0										
			3.87	412	3.0							
BASEMENT WALLS: (below grade)	Area	53.0										
	R Value		4.68									
	D.H.L.			181	1.3							
BASEMENT SLAB :	Area	71.6				106.3						
	R Value		1.76				5.44					
	D.H.L.			651	4.7			293	5.4		293	
CONCRETE SLAB : (Living room)	Area	45.0										
	Perimeter Loss			185	1.3							
	Ground Loss			430	3.1							
DOORS :	Area	6.2				3.1						
	R Value		1.85				1.85					
	D.H.L.			184	1.3			92	1.7		92	
VENTILATION :	Volume m^3	630				456						
	Air Change		$\frac{1}{4}$ /hr				$\frac{1}{8}$ /hr					
	D.H.L.			2761 / 13725	19.4 / 100			967 / 5452	17.7 / 100		967 / 3734	2 / 1

Heat Loss per °C = 250 W/°C
13723

Heat Loss per °C = W/°C
5452

Heat Loss per °C
3734

TABLE II

Thermal Mass - Passive Solar Residences

		SASKATOON RESIDENCE		REGINA RESIDENCE	
	Specific Heat (Joules/kg-°C)	Mass (kg)	Heat Storage Capacity (Megajoules/°C)	Mass (kg)	Heat Storage Capacity (Megajoules/°C)
Gypsum Board	1088	3317	3.61	5006	5.5
Wood Studs & Plates	2720	1591*	4.33	2072	5.6
Wood Flooring	2720	787	2.14	2034	5.5
Floor Joists	2720	971	2.6	2286	6.2
2nd Floor Ceiling Joists	2720	320	.87	453	1.2
Concrete Slab (Living Room) .41 m thick	653	45800	29.9	--	--
Concrete Slab (Basement) 76 mm thick	653	12600	8.2	--	--
Furniture & Appliances		--	--		2
Masonry Fire-place	920	4900	4.5	--	--
			56.2		26.0

*Includes all interior wood plus inner studs on double stud outer walls.

TABLE III

Energy Consumption Data
Saskatoon Passive Solar Residence Feb. 9 - Feb. 15, 1978

Electrical Energy Consumption	2614	Megajoules
Passive Solar Energy Collection	1972	Megajoules
Average Indoor Air Temperature	18.3	°C
Average Outdoor Air Temperature	-17	°C

Time Interval = 144 hours

TABLE IV

Thermal Storage Capacity of Saskatoon Residence

Measured Value - Based on Solar Gain	25 Megajoules/°C
Theoretical Value from Product of Masses and Specific Heats of Building Components	56.2 Megajoules/°C
Theoretical Value Assuming That only Top 3 Inches of Concrete Slabs can be Included	31.9 Megajoules/°C

TABLE V

Thermal Storage Capacity of Regina Residence

Measured Value		25.0 MJ/°C
Theoretical Values	Gypsum Board	5.5
	Wall Studs & Plates	5.6
	Flooring Material	5.5
	Floor Joists	6.2
	Furniture and Appliances	2.0
	Ceiling Joists	1.2
		26.0 MJ/°C

TABLE VI

Energy Balances for Passive Residences

Saskatoon Residence (21°C Interior Temp.)

Month	Heat Required/Day MJ/Day	Avg. Passive Gain MJ/Day Total A	Avg. Passive Gain MJ/Day Useful B	Electrical MJ/Day	People MJ/Day	Net Auxiliary Req'd MJ/Day A	Net Auxiliary Req'd MJ/Day B
Sept	202	392	101	60	13	---	28
Oct.	346	324	144	60	13	---	129
Nov.	576	274	192	60	13	229	311
Dec.	744	224	195	60	13	447	476
Jan.	845	298	258	60	13	474	514
Feb.	780	431	325	60	13	276	382
Mar.	625	730	365	60	13	---	187
Apr.	371	590	216	60	13	---	82
		Annual Auxiliary Heat =				43.1 GJ/Yr	75.6 GJ/Yr

TWO DIFFERENT ASSUMPTIONS ARE USED TO CALCULATE THE AUXILIARY HEAT REQUIRED

A. Assumption A is that all the passive gain is useful--this is an optimistic estimate; periods of cold cloudy weather and the fact that the heat storage capacity of the building is only about 125 MJ based on a 5°C temperature swing both make this estimate too optimistic.

B. Assumption B is that the passive solar heating will supply only the heating for the building during the daylight hours. This is a more realistic estimate, as the storage capacity of the building is small.

Regina Residence (21°C Interior Temp.)

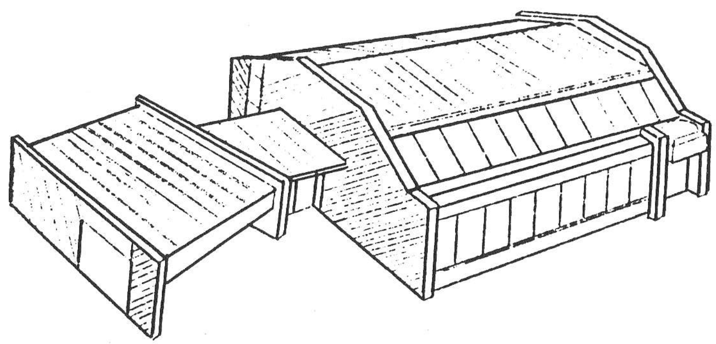
Month	Heat Required/Day MJ/Day	Avg. Passive Gain MJ/Day	Electrical MJ/Day	People MJ/Day	Net Auxiliary Req'd MJ/Day
Oct.	95.4	107	60	13	---
Nov.	158	69	60	13	16
Dec.	200	68	60	13	59
Jan.	228	92	60	13	63
Feb.	217	113	60	13	31
Mar.	175	128	60	13	---

October-March Basis

Total Heat Required	= 32.5 GJ	100%
Passive Gain (Useful)	= 14.2 GJ	43.7%
Electrical Gain	= 10.9 GJ	33.5%
People Gain	= 2.3 GJ	7.1%
Auxiliary Heat (From Solar Collector)	= 5.1 GJ	15.7%

Annual Basis

Total Heat Required	= 43.5 GJ	100%
Passive Gain (Useful)	= 14.2 GJ	32.6%
Electrical Gain & People Gain (Useful)	= 24.2 GJ	55.6%
Auxiliary Heat (From Solar Collectors	= 5.1 GJ	11.7%



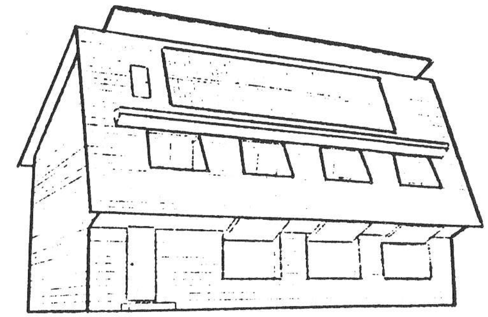
House Design - Split Level, partial basement, concrete slab on grade. at front

Floor Area - 118 m^2 excluding basement

Window Area - South facing - 32.5 m^2
- Other - 10.3 m^2

House Heat lossat -34°C 13.7 kW

Figure 1 - Saskatoon Passive Residence
Latitude 52° 10'N



House Design - Two storey, no basement

Floor Area - 186 m^2 (93 m^2 per floor)

Collector Type - Vacuum Tube, liquid system using 1/3 ethylene glycol, 2/3 water by volume

Solar Collector Area - 17.9 m^2

Collector Tilt Angle - 70°, Collector Azimuth - 21° West of South

Water Storage Volume - 12,700 liters

Window Area - 21° West of South, 11.9 m^2
- 21° East of North, 1.9 m^2
(All windows with operable shutters)

House Heat loss at -34°C 5.45 kW (shutters open)
3.73 kW (shutters closed)

FIGURE 2 - Saskatchewan Conservation House
Regina, Saskatchewan, Canada
Latitude 50°30'N

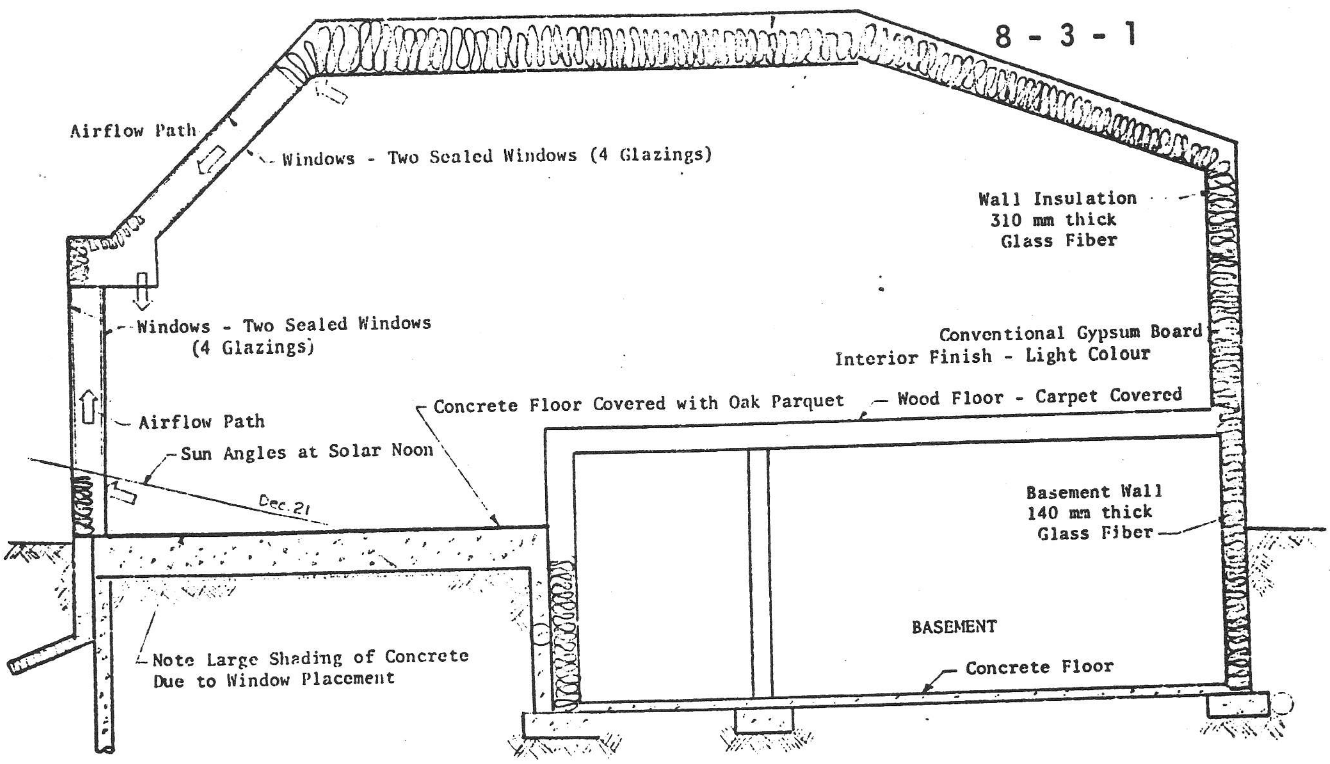
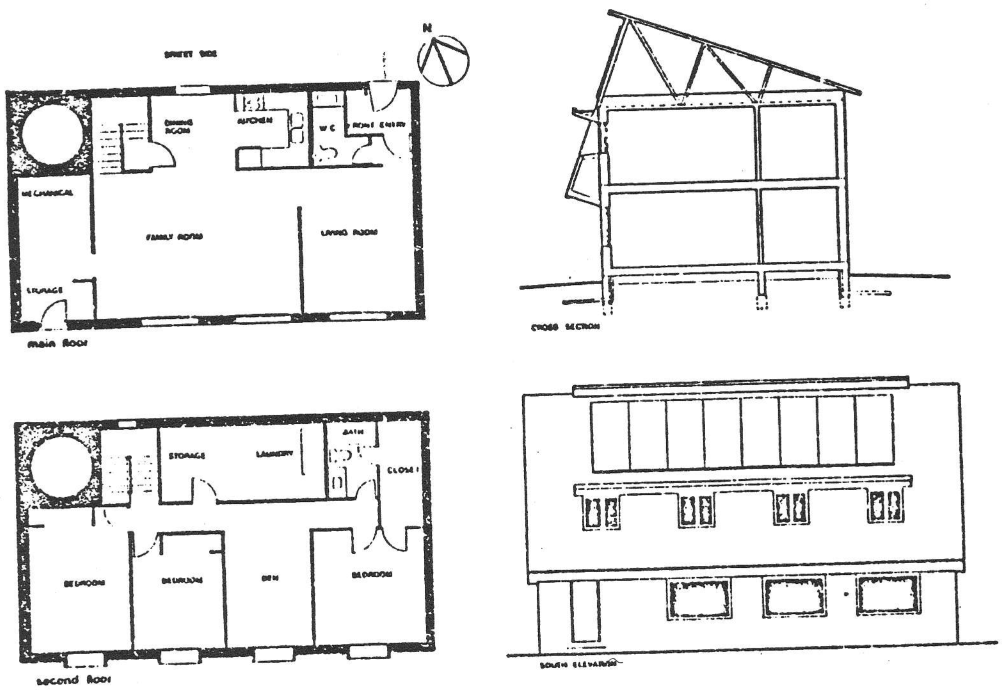


FIGURE 3 - Section Facing West - Saskatoon Residence



the saskatchewan conservation house

FIG. 4

RSD

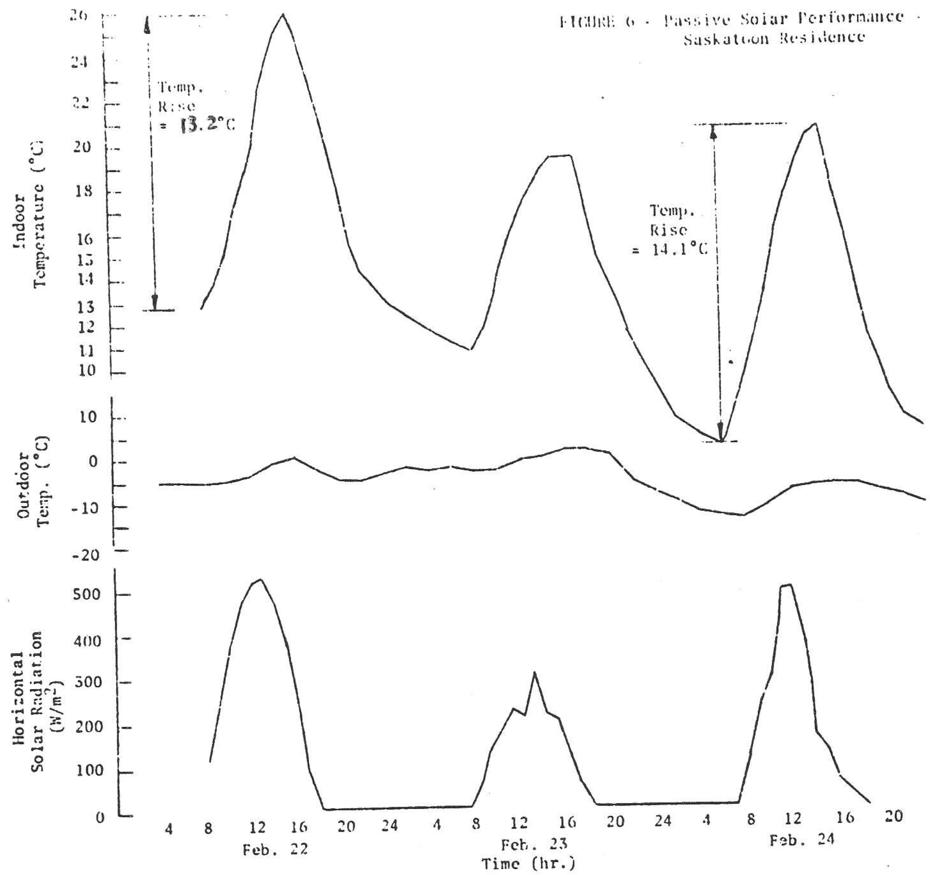


FIGURE 6 - Passive Solar Performance - Saskatoon Residence

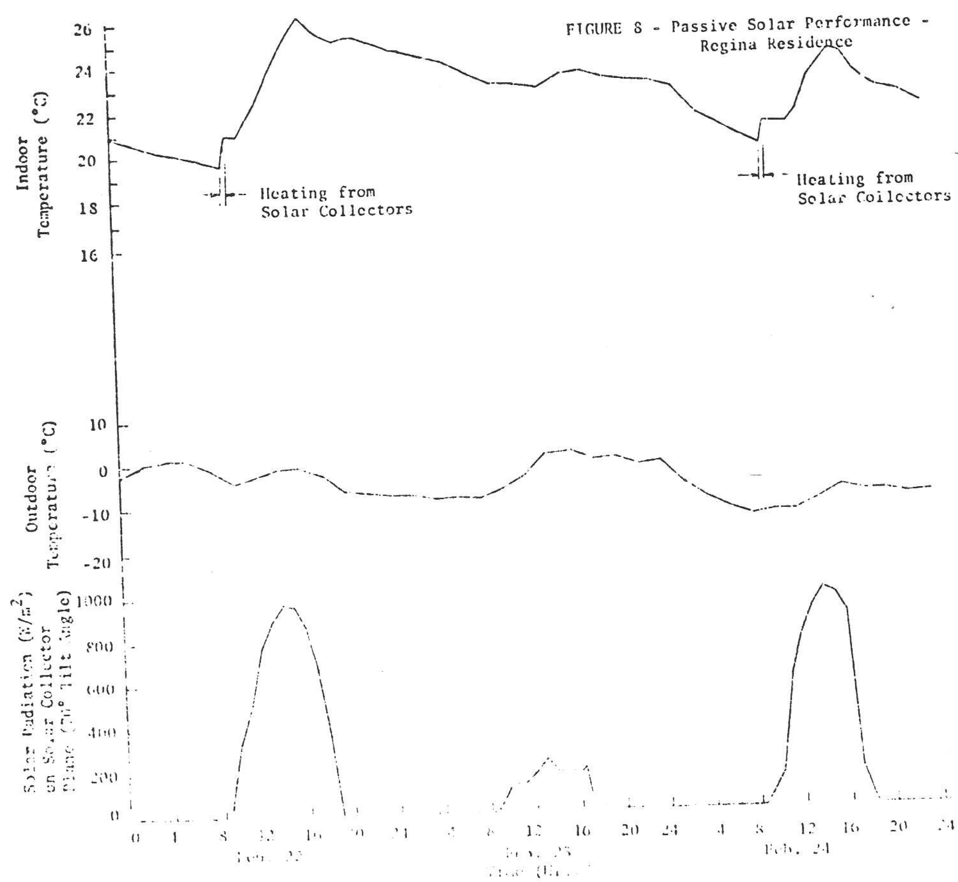


FIGURE 8 - Passive Solar Performance - Regina Residence

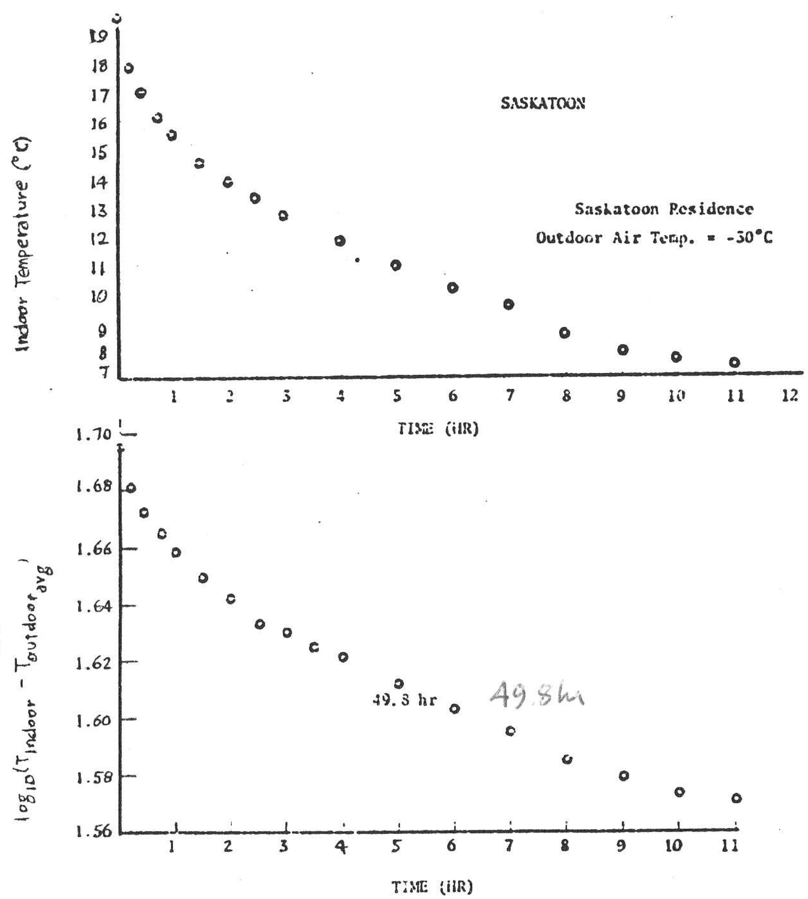


FIGURE 7 - Cooling Curves for Saskatoon Residence

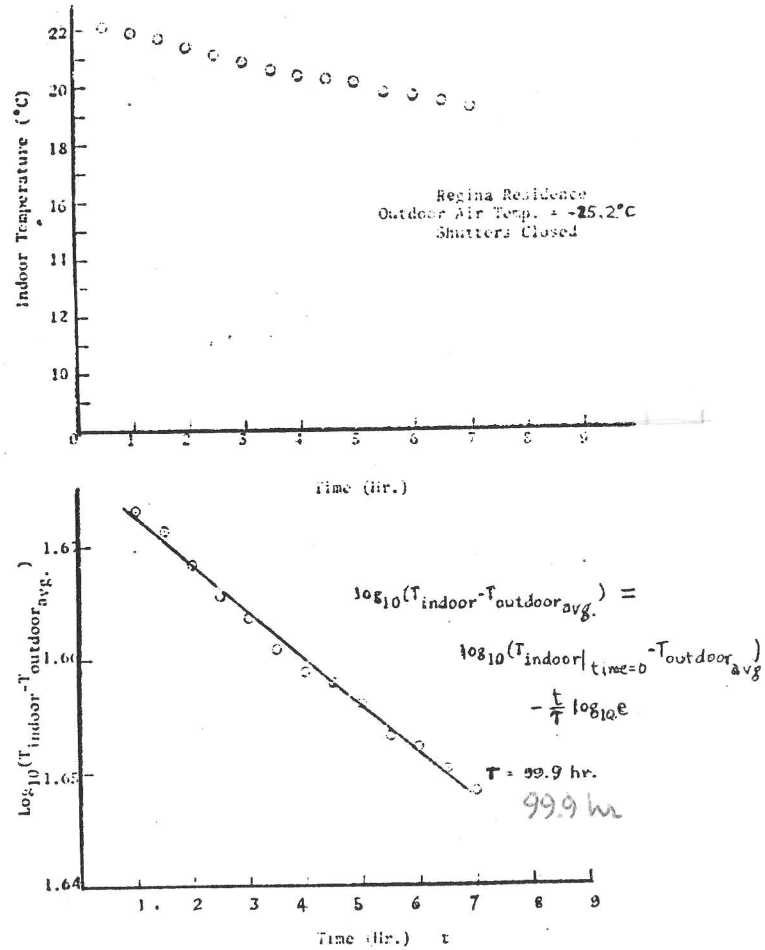


FIGURE 9 - Cooling Curves for Regina Residence