FREEHEAT - A Passive Solar System Simulation Program

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Abstract

A finite-difference, nodal computer simulation has been developed to handle various passive solar components and systems. Mass wall and direct gain systems may be analyzed. Various overhang geometries, thermocirculation heat transfer, variable thermal mass, secondary lumped thermal mass, heat pipes, selective surfaces, night insulation, and thermosyphon systems are options available in the two versions of FREHEAT (1.0 and 2.0). A radiation network can be calculated for internal heat transfer. The program has single zone capacity at present, but various ground coupling coefficients are optional. Various auxiliary heating, venting, and cooling options are available with low and high thermostat set temperatures. Although the program is well-documented, some knowledge of heat transfer is required for modification. A monthly simulation requires roughly 45 CPU seconds on a CYBER 171. The program is presently available from Colorado State University. Results from four example problems are presented. Conclusions point towards the large energy savings obtained from installing an effective night insulation system.

INTRODUCTION

Passive design may be defined as the methodology that utilizes natural features of buildings such as orientation, windows, structural members, etc. to maintain human comfort. Passive design encompasses both heat collection and storage in the cold period of the year and heat rejection in the warm period of the year. Passive solar design is intended to accomplish the collection, storage, and distribution of energy obtained from the sun while using at most very small amounts of active energy from pumps, blowers, etc. The energy is usually transferred by conduction, radiation, and natural convection. Passive design is perhaps one of the oldest arts of mankind as man tends to quickly learn, retain, and expand upon those facets of life that provide greater comfort. Yet, in the recent years of dwindling energy supplies, passive design has been approached on a quantitative basis and has metamorphosed into a developing science with a plethora of advocates. Unfortunately, sometimes a proponent of passive design will replace the "natural" aspect of the energy flows with an "intuitive" approach to design. This at times has resulted in grievous design errors causing passive design to fall from grace in some circles.

The desirability of increasing our physical intuition and obtaining some quantitative design data cannot be overemphasized. One method of empirically attaining this goal is to carefully analyze existing passive structures and correlate performance data with the relevant design parameters. This has been done with a high degree of success, resulting in "rules of thumb (1)." Yet, this only covers the subset of existing passive designs. More empirical information may be gained from constructing passive test facilities. The Department of Energy is attempting to do this now (2) at great cost. With the approach that is being taken, that is, testing for a complete heating season, it must be assumed that the data will be slow in coming. Another way of obtaining information is by conducting numerical experiments by successively running computer simulation programs. Absolute validation is unattainable. Relative validation is said to occur when the numerical results do not differ too greatly from experimental results for structures such as residences or small, specially constructed test cells. Thus, it is seen that test cells, test facilities, rules of thumb, and computer simulations all have their parts to play in attaining greater physical intuition, and further quantitative design data in the area of passive concepts.

Many passive solar simulations exist today and some of these have been "validated" against at least one system. The simulations fall into various ranges of applicability. Programs such as DEROB/PASOLE (3) UWENSOL (4) and SOLAR-5 (5) are extremely detailed and describe the building with many nodes. Such simulations require significant amounts of computer time to execute making many design runs prohibitively expensive. Indeed, one wonders whether the inaccuracy of the input parameters (heat transfer coefficients, thermal properties, etc.) can ever justify the accuracy

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of the calculations. Another class of simulations are the simplified models such as TEANET (6) and PEGFIX (7). Such simulations do not require large scale computing machines and they are usually fairly easy to use. Yet, the small number of nodes and the constant coefficients do not accurately model some types of systems and the programs will not model a wide variety of systems.

Passive solar systems simulation programs such as PASOLE (8) and FREHEAT have been developed to fill the gap between these types of simulations. FREHEAT is a computer program initially developed under contract to the Department of Energy at the Colorado State University Solar Energy Applications Laboratory. FREHEAT simulates the thermal performance of both commercial and residential buildings which have passive solar components.

The current version of FREHEAT idealizes the building as a single zone system. Room temperature output is therefore representative of the average temperature in the building. A direct gain system where the thermal mass is located on the floor of the dwelling, a sunspace, or a mass wall which may be vented or unvented are the three passive solar system configurations which can be modeled. The thermal mass may be considered to be isothermal as in a water wall or it may be allowed to have a temperature profile through the thickness with the resultant time lag and tempering characteristic of such a system. Thermal mass of any thickness and with any thermal properties may be simulated. The solar gain space is considered to be double-glazed and may exist at any orientation with respect to due south with a small degree of tilt from the vertical possible but not necessary. The solar radiation routine allows for an overhang of a very general nature when computing the effects of shading.

Both auxiliary heating and cooling are included as options with low and high thermostat set points (a user-specified dead band). Heat generated internally in the building by people and appliances and heat generated by lighting are considered to exist at two levels and to occur over two different time periods during the day (simulating a night/day duty cycle of two levels). Infiltration may be considered to exist at two user specified levels for two user-specified time periods during the 24 hour time period. Thus, summer night time ventilation cooling is a possibility. Night insulation at a user-specified "R" value is also an option. Heat pipes may be added in the mass wall if desired. This wide variety of options allows both residential and commercial buildings to be easily modeled.

FREHEAT requires the user to input the following heat transfer coefficients: (1) total building UA excluding south facing glass, (2) heat transfer coefficients for the interior of the building, and (3) the infiltration load. Additionally the geometrical dimensions of the glazing room, and overhang must be input. The material, properties and geometry of the thermal mass must also be provided. An initial temperature distribution must be input in addition to hourly weather data consisting of insolation on a horizontal surface, ambient temperature, and wind speed.

The program's outputs are user controlled and may include the temperature distribution in the thermal mass and the temperatures of all the room and glazing nodes at user controlled time intervals. Daily average temperatures and their standard deviations for the room air, wall, and floor nodes are provided. Daily, monthly, and overall energy summaries are also provided.

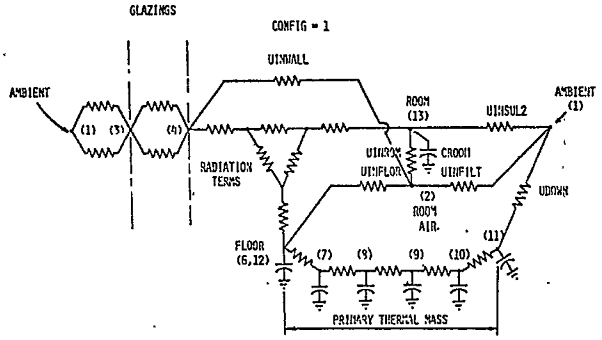
FREHEAT provides detailed results but is not prohibitively expensive to run requiring about 40 seconds of CPU execution time per month (about 8 minutes per year) on a CYBER 171 computer. This enables an exhaustive study of a particular problem or multiple design runs to be accomplished within an economic budget that is not excessive. The balance between expense and accuracy permits FREHEAT to be used by both researchers and the design/architectural environment.

PHYSICAL SYSTEM AND PROGRAM DESCRIPTIONS

If the user is well versed in heat transfer FREHEAT can be used to simulate many types of systems with only minor modifications. For complex systems, representative heat transfer coefficients must be selected with care. But, there are two general types of systems that FREHEAT may handle with ease and without any special knowledge required of the user. A sketch of these two systems is shown as Figure 1. Figure 1A shows a direct gain system where a portion of the south facade is glazed thus admitting solar energy which is collected and stored in the thermal mass of the building. Figure 1B shows an indirect gain or mass wall system. The south facade is again glazed, admitting solar energy which is collected by the massive concrete wall. The mass wall serves to reduce the temperature swings in the dwelling and provide a time lag for the heat that is transferred to the dwelling. Thus, the heat is provided to the dwelling in the evening hours when it is most needed. The mass wall may be vented as shown in the sketch to provide heat in the mornings by convection which would otherwise be blocked and stored by the mass wall. The advantage of the reduced temperature swings of the mass wall system over the direct gain systems is partially offset by the reduced amount of solar energy actually reaching the interior due to the blocking effect of the wall and thus a lower fraction of energy provided by the sun. The mass wall may simply be water contained within a blackened barrier, commonly termed a water wall.

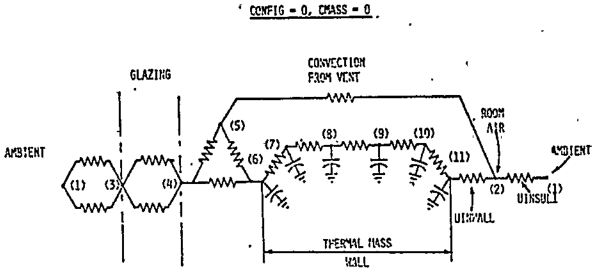
Some control options available to either of the systems are shown in either Figure 1A or Figure 1B and are listed in Table 1. The thermal mass system may be considered to have a temperature gradient within thus requiring a multiple number of nodes for simulation, or it may be considered isothermal as in a water wall. The room is defined as the entire dwelling excluding the primary thermal mass and the double south-facing glazings. The room may be made to possess thermal mass by setting CMASS equal to 1.

Figure 2B



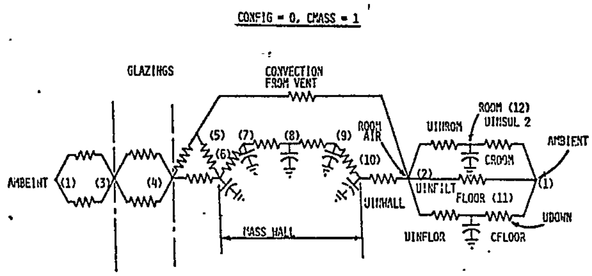
B. INDIRECT GAIN, MULTI-NODE MASS SYSTEM.

Figure 2C



C. MASS WALL SYSTEM - NO FLOOR OR ROOM MASS.

Figure 2D



D. MASS WALL SYSTEM WITH ROOM AND FLOOR MASS.

The program input variable names are used in the figure where appropriate to identify the physical locations of the heat transfer parameters. All variables are normalized per area of south facing glass. Thermal resistances are used to represent heat flow paths and thermal capacitances are used to denote heat storage material. All configurations are considered to be doubly glazed, with the southerly direction to the left. Both the glazings (node 3) and the room (node 2) lose to the ambient environment. Convective heat transfer includes radiation only in Figures 2C and 2D. In all other cases, an internal radiation network is introduced into the problem with convection existing as a parallel mode. The thermal mass is discretized in Figures 2B, C, and D.

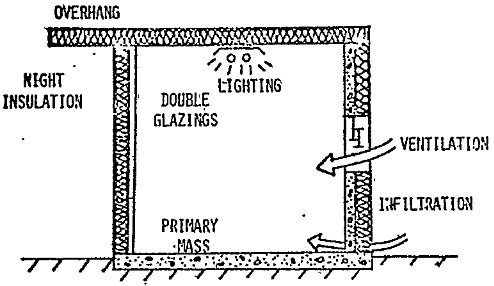
The ambient is represented by node 1. The glazings are represented by nodes 3 and 4. The room air is shown as node 2. In Figure 2A nodes 7 and 8 are the floor and the room masses, respectively. The floor transfers heat by radiation to the glazings and the room mass and by convection and/or conduction to the room air and the surroundings. Figure 2B is similar except the floor mass is not lumped and the room mass is then node 13.

In Figures 2C and D, indirect gain systems are depicted. The mass wall begins and ends at nodes 6 and 11, and 6 and 10 in Figures 2C and 2D, respectively. The number of primary mass nodes has been arbitrarily selected as 6 and 5 for these visual representations. Based on numerical experiments, at least 5 nodes should be used to get an accurate time lag, but the number of nodes is user controlled in the program. Node 5 is the thermocirculation node between the inner glazing and the mass wall. The system of Figure 2D has mass floor and mass room heat storage nodes 11 and 12, respectively. The floor stores heat and exchanges energy with the room and the surroundings as does the room mass node.

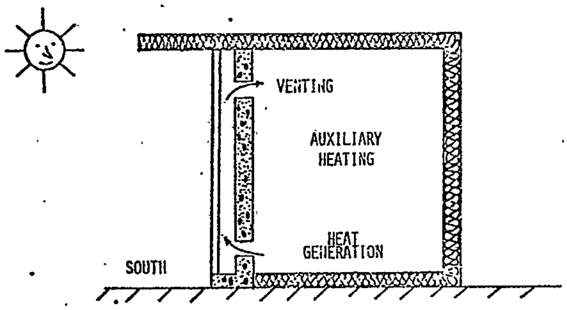
The capacitances and the resistances labeled must be supplied by the user. The dimensions and thermal properties (emissivities, specific heat capacities, thermal conductivities and densities) of the primary thermal mass must be supplied. Geometric spacings and orientations must also be input parameters. The values which are not labeled are calculated by the program. Representative values for the labeled parameters are recommended in the program documentation, so no real knowledge of heat transfer is required of the user if the ordinary systems shown are modeled. For more complicated systems, some knowledge of heat transfer is required to insert the appropriate heat transfer coefficients.

The geometry of the overhang, the glazing and the building is shown in Figure 3. As seen by viewing the geometrical variables, the shading routine in the program will handle an overhang of a very general nature. The dimensions of the building are used in computing shape factors for the radiation networks where applicable.

Figure 1



A. DIRECT GAIN SYSTEM, NIGHT INSULATION UP



B. INDIRECT GAIN, MASS WALL SYSTEM

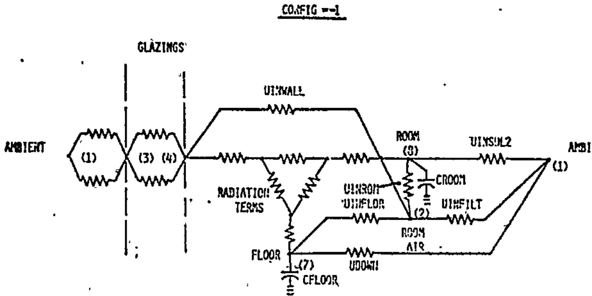
Table 1. Control Options Available in FREHEAT. 1 is Yes, 0 is No, and - is an Optional 1 or 0

	CONTROL WORDS										
	CONFIG	CTHICK	CMASS	CDAMP	CEQUI	CAUX	CPIPON	KLTS	KGEN	KNSUL	KINFIL
SYSTEMS											
DIRECT GAIN											
Isothermal Mass	-1	1	1	0	-	-	-	-	-	-	-
Multi-Node Mass	1	N	1	0	-	-	-	-	-	-	-
INDIRECT GAIN											
Isothermal Mass	0	0	-	-	-	-	-	-	-	-	-
Multi-Node Mass	0	N	-	-	-	-	-	-	-	-	-
OPTIONS											
Room Mass			1								
Vented Wall				1							
Initial Steady State					1						
Auxiliary Heat						1					
Heat Pipes							1				
Room Lighting								1			
Room Heat Generation									1		
Night Insulation										1	
Night Infiltration											1

The mass or water wall may be vented as mentioned previously by setting CDAMP equal to 1. The program may be forced to attain an initial thermal steady-state balance by setting the control indicator CEQUI equal to 1. Auxiliary energy may be input into the room to maintain the room temperature between two user-specified limits by setting CAUX equal to 1. Heat pipes may be installed into the thermal mass by making CPIPON equal to 1. Internal energy added by lights and other means (appliances, people, etc.) may be input by requiring KLTS and KGEN respectively to be 1. To prevent excessive heat loss out the glazings at night, night insulation may be added to the system by setting KNSUL equal to 1. Finally, infiltration (either forced or natural) may be inserted into the program by setting KINFIL equal to 1. As mentioned earlier, infiltration, lighting, and internal heat generation may be considered to exist at two different levels over two user specified time intervals. Figure 1A shows winter (heating) nighttime operation or summer (cooling) daytime operation. Figure 1B shows winter daytime operation or summer nighttime operation. Cooling is provided by venting or opening of the windows if the ambient temperature is less than the upper thermostat set temperature; otherwise, it is provided actively.

By setting the system control indicator CONFIG to -1, 1 or 0, the user selects an isothermal direct gain system, a non-isothermal multi-node direct gain system, or an indirect gain system, respectively. A direct gain system must have thermal mass associated with the room surface and floor nodes. An indirect gain system with no significant thermal mass may be chosen by the user by setting CMASS equal to 0 or a massive residence may be selected by setting CMASS equal to 1. The thermal networks for these systems are shown in Figure 2. Direct gain systems with isothermal and multi-node floors are shown in Figures 2A and 2B, respectively while indirect gain systems without room mass and with room mass are shown in Figures 2C and 2D, respectively.

Figure 2A

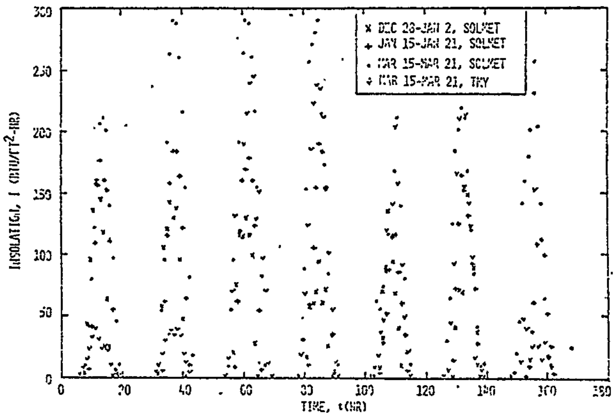


A. DIRECT GAIN, ISOTHERMAL MASS SYSTEM.

Table 2. Variables for Example Problems

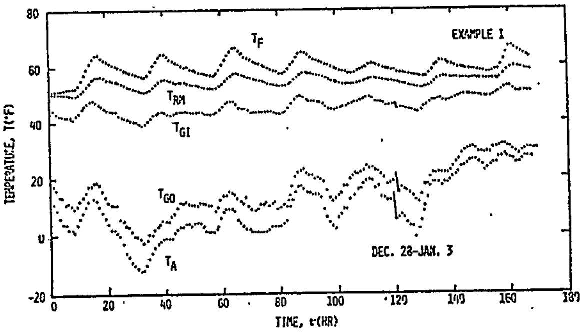
	EXAMPLE			
	1	2	3	4
SYSTEM TYPE	Direct Gain	Water Wall 100%	Mass Wall Vented	Direct Gain
STUDY PERIOD				
Start	Dec. 28	Jan. 15	Mar. 15	Mar. 15
End	Jan. 3	Jan. 21	Mar. 21	Mar. 21
CONTROL VARIABLES				
CONFIG	-1	0	0	1
CTHICK	1	0	6	4
CMASS	1	0	0	1
CDAMP	0	0	1	0
CEQUI	1	1	1	1
CAUX	1	1	1	1
CPIPOH	0	0	0	0
KLTS	0	0	0	0
KGEN	0	0	0	0
KINSUL	0	0	0	1
KINFIL	0	0	0	0
BUILDING DIMENSIONS				
Height (ft)	8	8	8	9
Length (ft)	36	36	46.7	50
Depth (ft)	28	28	30	30
GLAZING DIMENSIONS				
Height (ft)	7	7	7	7
Length (ft)	30	30	46.7	50
OVERHANG DIMENSIONS				
VERIOH (ft)	0.5	0.5	2.15	3.57
HORIOH (ft)	1.5	1.5	0	2.73
LATOH (ft)	1.0	1.0	3.17	3.57
THERMAL RESISTANCE				
WALLS (°F-hr-ft²/Btu)	R-19	R-19	R-15	R-15
FLOOR (°F-hr-ft²/Btu)	R-5	R-5	R-15	R-15
CEILING (°F-hr-ft²/Btu)	R-30	R-30	R-30	R-30
THERMAL MASS				
Floor (Btu/°F-ft²g)	72	0	0	1
Walls (Btu/°F-ft²g)	24	0	0	16.4
THERMOSTAT SETTING				
High (°F)	80	80	75	75
Low (°F)	60	60	65	65

Figure 5



INSOLATION ON A HORIZONTAL PLANE VS. TIME FOR THE TIME PERIODS

Figure 6



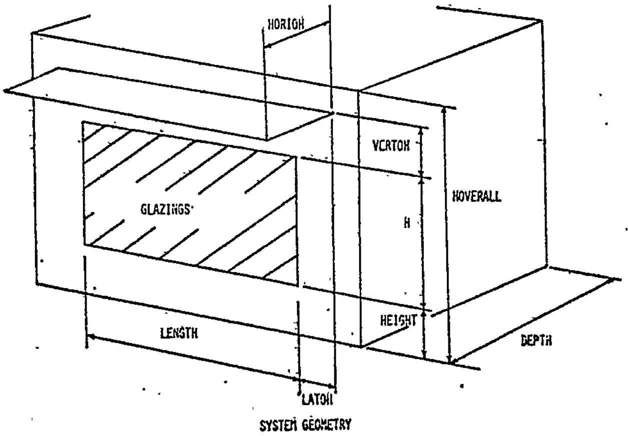
TEMPERATURE VS. TIME FOR EXAMPLE 1

Figure 5 contains the hourly insolation values on a horizontal surface for the four example problems. The ambient temperatures for the example problems are shown in Figures 6 through 9 for examples 1 through 4, respectively. Together the insolation and the ambient temperature function as the driving potential for net energy input into the building.

Example 1 is the direct gain system with an isothermal floor. The ambient temperature, the inner and outer glazing temperatures, the room wall temperature, and the floor temperature are shown as functions of time for the simulation period in Figure 6. The room air temperature is maintained at 60°F by the auxiliary heating system for the entire time period and is not shown in the plot. The discontinuities occurring at hour 120 are due to the change of the weather data for the year and are shown connected by a heavy line. That is, the data for December 1962 are used and the data for January 1962 are then used resulting in a jump in ambient temperature causing the glazing temperatures to jump. The simulation used steady-state temperature values as initial conditions, and time was begun at just after midnight, December 28. The floor temperature is the hottest, being heated by the sun. The peaks in floor temperature represent the waning of the sun at around 5 pm each day. Days 5 and 6 are observed to be low level insolation days as evidenced by the small peaks in floor temperature. The room wall temperature is seen to track the floor temperature (or the sun). The two temperatures get closer together on days 5 and 6 as the insolation level drops and the ambient temperature rises. Due to the small film resistance of the outer glazing it tracks the ambient temperature closely with small perturbations due to wind velocity (gusting). The inner glazing achieves a balance between room and outer glazing temperatures through radiative and convective equilibrium. Energy summaries for the time period are given in Table 3.

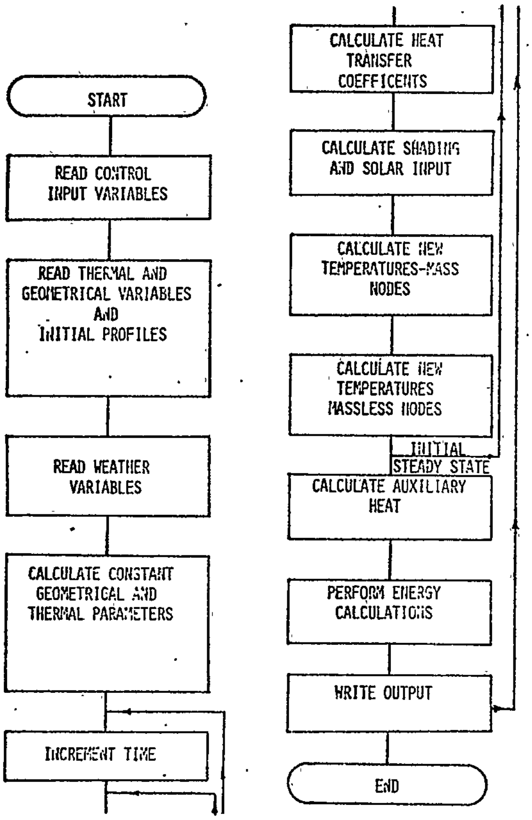
Example 2 is the isothermal water wall problem. The water wall temperature, the room air temperature, and the ambient temperature are shown in Figure 7. All other output for this problem has been suppressed. The room air temperature remains at 60°F throughout the simulation period indicating that auxiliary heat is required at all times. The water wall temperature follows the sawtooth pattern, heating up during the day

Figure 3



The FREHEAT program is flow-charted in Figure 4. The shading and solar routine is skipped if the sun is not shining. An explicit, Runge-Kutta fourth order routine (9) is used to march forward in time for those nodes with thermal capacity. Time steps are on the order of 1/4 to 1/2 hr, depending upon the stability criterion (10). The new temperatures of the nodes with no thermal mass are calculated algebraically using matrix algebra. The room temperature is allowed to float if it remains within the thermostat's dead band. Otherwise, the auxiliary energy necessary to maintain the heating or cooling temperature limit is computed. The user may select a wide variety of output options including mapping routines, periodic energy summaries, and periodic temperature values for selected nodes. The wide variety of physical, input, control, and output options renders FREHEAT a useful tool for engineers, architects, and passive research engineers.

Figure 4



EXAMPLE PROBLEMS AND RESULTS

This section presents four example problems in order to demonstrate the applicability of FREHEAT. The weather data has been taken from a SOLMET 1962 Madison, Wisconsin weather tape for examples 1, 2 and 3. The Madison, Wisconsin TMY data was used for example 4. Plots of temperature vs. time will be presented for one week for each of the four problems. Annual results will be presented for examples 3 and 4 in terms of monthly energy summaries. When designing a building, weekly runs are accomplished to optimize design parameters. It is customary to vary one parameter at a time (assuming the parameters act independently) to achieve a total design, and then these selected parameters are varied slightly to "fine tune" the design. Representative heating, cooling, and "no-load" weeks are taken from the annual weather tapes for these analyses. Then, an annual simulation is performed to assess the total performance of the building. If the annual results are deemed unsatisfactory, the user may desire to perform further weekly analyses during "trouble periods" or additional annual simulations may be performed.

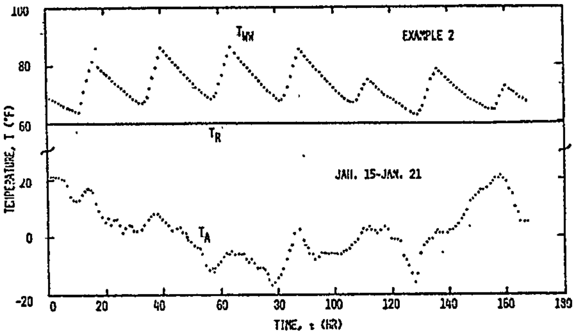
Examples 1 and 2 are done for a direct gain system with an isothermal floor (CONFIG =-1) and a water wall system (CONFIG = 0, CTHICK = 0). The house is located in Madison, Wisconsin, with the glazing normal oriented 15° west of south for both examples. Table 2 contains a list of the system type, the study period, the control variables, the overhang, building and glazing dimensions, the thermal resistance and capacitance values and the thermostat settings for examples 1 through 4. The thermal resistance and capacitance values are presented per square foot of glazing. Example 1 is a direct gain system with 6" of concrete in the floor and 4" of concrete in the walls as thermal storage mass. Example 2 is an indirect gain water wall system with the planar equivalent of 9" of water behind the double glazings.

Example 3 is an indirect gain system consisting of a 12" thick, vented mass wall with no other significant thermal mass in the building. Example 4 utilizes the TMY tapes as weather data for Madison, Wisconsin. Example 4 is a direct gain system with a 3' high clerestory and a 4' high primary window oriented beginning 4' above the ground. The only significant thermal mass in the building is in the walls which contain 8" of concrete. The glazings are oriented to point due south in examples 3 and 4. Example 4 has an R-10 beadwall insulation system wherein styrofoam beads are blown between the glazings at night and remain in place betwen the hours of 5 pm and 7 am in the wintertime. This provides a significant increase in the overall thermal resistance of the dwelling, thus increasing the fraction of heat provided by solar.

Table 3. Weekly Energy Totals - All Values in Btu/day/ft² of Glazing

	DAY							
	1	2	3	4	5	6	7	EXAMPLE
Q_{SUN}	1250	1042	1235	976	479	686	1022	1
	1122	1309	1299	1248	664	1097	566	2
	89	105	251	252	237	226	119	3
	74	88	850	883	465	628	152	4
Q_{STORED}	714	-49	154	-20	-208	91	298	1
	199	148	-8	-27	-373	119	-201	2
	-138	-23	84	9	21	43	- 61	3
	1420	15	59	- 6	-12	49	- 68	4
Q_{GL}	623	754	669	613	558	552	429	1
	568	692	803	789	700	678	523	2
	259	210	233	284	249	193	186	3
	217	208	219	252	210	147	125	4
Q_{ROOM}	1529	1877	1656	1516	1393	1374	1020	1
	1261	1541	1835	1870	1696	1730	1280	2
	712	636	609	715	602	428	445	3
	574	570	613	709	577	447	416	4
Q_{AUXH}	1616	1539	1245	1132	1265	1332	726	1
	906	1072	1331	1384	1359	1432	1035	2
	744	718	675	756	636	437	451	3
	2139	706	237	258	313	173	290	4
SSF	0.15							1
	0.24							2
	-0.06							3
	-0.04							4

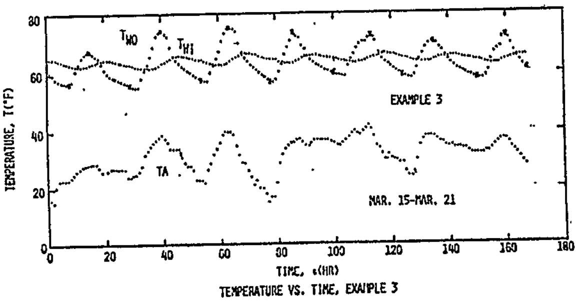
Figure 7



TEMPERATURE VS. TIME, EXAMPLE 2

and supplying heat to the house and the environment (through the glazings) at night. Days 5 and 7 are observed to be lacking in insolation. The ambient temperature is fairly warm at the beginning and the end of the period, and is cold the remainder of the time. Energy summaries of this example are also shown in Table 3.

Figure 8



TEMPERATURE VS. TIME, EXAMPLE 3

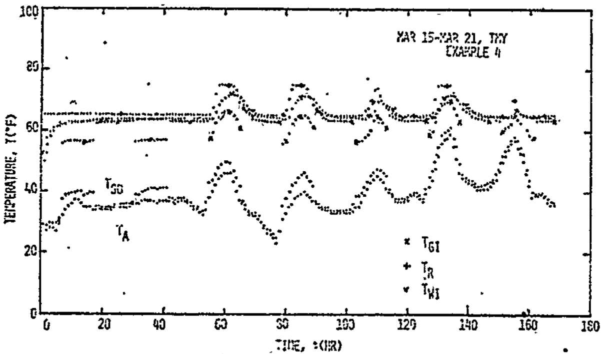
Example 3 is the vented mass wall problem. Inside and outside wall temperatures and the ambient temperature are shown in Figure 8. The room temperature is seen to track the sun and to oscillate around 65°F with about a 20°F fluctuation. The outside wall temperature values are periodically marked with an "X" so that they may be distinguished from the inside wall temperatures. The inside wall temperatures oscillate about the room temperature also, with about a 4°F fluctuation. The thermal mass of the wall is seen to provide about a seven hour time lag so that the living space is being heated from about 6 pm until about 4 am. The remaining time the room heats the wall indicating a need for night insulation. The ambient temperature is observed to fluctuate about 30°F during the time period. The week's energy summaries are also shown in Table 3 for this problem. The monthly summaries for the annual run are shown in Table 4.

Table 4. Annual Energy Summaries - All Values in 10³ Btu/ft² of Glazing

	Q_{AUXH}		Q_{AUXC}		Q_{VENT}		Q_{ABS}		SSF	
EXAMPLE	3	4	3	4	3	4	3	4	3	4
JAN	31.0	27.4	0	0	0	0.4	18.2	15.2		
FEB	23.5	19.1	0	0	0	0.9	19.2	15.9		
MAR	17.8	15.1	0	0	0	3.1	24.1	20.1		
APR	6.8	4.9	0.1	0.4	0.2	2.4	16.8	14.0		
MAY	2.9	1.8	1.2	3.0	0.5	1.7	14.8	12.3		
JUN	0.2	0	2.8	6.0	1.0	1.5	13.9	11.6		
JUL	0	0	5.1	10.2	2.0	1.7	15.4	12.8		
AUG	0	0	3.6	8.4	2.4	3.5	18.6	15.5		
SEP	0.3	0.2	1.4	2.9	2.8	7.8	21.4	17.8		
OCT	4.0	3.8	0.1	0.2	0.7	6.6	20.8	17.3		
NOV	15.3	13.9	0	0	0.7	2.9	15.8	13.2		
DEC	26.9	23.9	0	0	0	0.8	12.9	10.7		
TOTAL	129	110	14.3	31.0	9.6	33.3	212	176	0.28	0.34

The ambient, room, inside wall, and outside glazing temperatures for the second direct gain problem, example 4, are shown in Figure 9. The room temperature is seen to stay at 65°F except around solar noon where it is heated by the low mass floor which is heated by the sun. The auxiliary heating unit is therefore on most of the time. The wall temperature is seen to track the room temperature fairly closely falling somewhat below the room temperature, usually. The sun only occasionally supplies enough heat to the wall to warm it above the room temperature. The dramatic change in the glazing temperatures each day at 5 pm and 7 am is due to the R-10 beadwall insulation insertion and removal. When the beadwall is in place, the inner glazing is insulated and therefore increases in temperature. The outer glazing has much less heat flowing through it and therefore comes very close to the ambient temperature during these times. The weekly and the annual energy summaries are shown in Tables 3 and 4, respectively for this problem.

Figure 9.



TEMPERATURE VS. TIME, EXAMPLE 4

CONCLUSIONS

After examining Figures 6 through 9 and Tables 3 and 4, some general and some relative conclusions can be drawn concerning energy gains and comfort of direct gain systems and indirect gain systems. Night insulation has proved to cut the heat loss through the glazings dramatically. This is the primary reason for the SSF of 0.34 for the direct gain system versus the SSF of 0.28 for the indirect gain system. Direct gain systems sometimes overheat in the wintertime because of the objects with low thermal capacity in the room. This requires venting, causing some of the energy gained to be wasted or, alternatively, the dwelling must be allowed to overheat. Temperature fluctuations of the inside of the mass wall were limited to 40°F in Example 3, thus providing very steady and stable internal comfort. Overhangs designed for comfort in the summertime are sometimes too large to obtain a net energy inflow through the south facing glazings in the spring and fall months of the year. This is apparent when the SSF's are viewed in Table 3 for examples 3 and 4. The negative values for these SSF indicate that the south facing glazings were net losers for the weekly period. When run with no overhang, these examples did exhibit a positive SSF.

In a direct gain system, the room air temperature leads the room mass and floor temperatures. This is due both to the direct coupling between the room air and the sides of the massive elements which receive the sunlight and the fact that a fraction of the sunlight falls on nonmassive elements and is simulated as being directly transmitted to the room air node.

The following qualitative information may be garnered upon inspection of the results: (1) the elevated room temperature of a direct gain system leads to a greater loss through coupling of the room air temperature with the ambient than for an indirect gain system, (2) due to the proximity of the glazings of the primary thermal mass in an indirect gain system, there are greater radiative losses through the glazings than for a direct gain system; furthermore, the direct gain system has a greater surface area over which to absorb the sunlight, thus resulting in lower temperatures of the thermal mass which tends to accentuate the greater radiative losses through the glazings for an indirect gain system, and (3) the relative efficiencies of indirect versus direct gain systems will be determined by the relative magnitudes of points (2) and (3) above.

The passive systems simulation program FREHEAT has been demonstrated to model a variety of systems for arbitrary time periods. The flexibility in the output has been demonstrated through application to the example problems. The rudiments of passive solar design using FREHEAT have been illustrated as uncomplicated and straightforward. Finally, FREHEAT has been determined to be a utilitarian tool for the engineering, architectural and research fields involving both design and fundamental investigations.

NOMENCLATURE

CFLOOR	- relative thermal capacitance of the floor mass (Btu/°F-ft^{2}g);
CROOM	- relative thermal capacitance of the room mass (Btu/°F-ft^{2}g);
I	- insolation on a horizontal plane (Btu/ft^2-hr);
Q	- heat transfer for the time period (Btu/ft^{2}g);
SSF	- solar savings fraction, $1 - Q_{AUXH}/Q_{ROOM}$;
T	- temperature (°F);
t	- time (hr);
UDOWN	- relative thermal resistance between the floor and the environment (Btu/°F-hr-ft^{2}g);
UINFILT	- relative thermal resistance between the room air and the environment (Btu/°F-ft^{2}g);
UINFLOR	- relative thermal resistance between the floor node and the room air (Btu/°F-hr-ft^{2}g);
UINROM	- relative thermal resistance between the room mass and the room air (Btu/°F-hr-ft^{2}g);

UINSUL 1 - relative thermal resistance between the room air and the environment, when CMASS = 0 (Btu/°F-hr-ft^{2}g);

UINSUL 2 - relative thermal resistance between the room mass and the ambient (Btu/°F-hr-ft^{2}g);

UINWALL - relative thermal resistance between the inside wall node (indirect gain) or the inside glazing (direct gain) and the room air (Btu/°F-hr-Aft^{2}g);

SUBSCRIPTS

ABS - solar heat absorbed;
AUXC - auxiliary active cooling;
AUXH - auxiliary active heating;
AUXV - auxiliary passive ventilation;
F - floor;
GI - inside glazing;
GL - through the glazings; outward;
GO - outside glazings;
R - room air;
RM - room surfaces;
ROOM - total loss from the room, excluding loss through the glazings;
STORED - stored in the primary thermal mass;
SUN - from the sun and incident on the glazings;
WI - inside primary thermal mass node;
WO - outside primary thermal mass node;
WW - water wall.

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