Energy

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TECHNICAL EVALUATION OF A SOLAR HEATING SYSTEM HAVING CONVENTIONAL HYDRONIC SOLAR COLLECTORS AND A RADIANT PANEL SLAB

Final Report

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NOTE: This publication is a photocopy of Section One, SUMMARY OF FINDINGS only. The full report is available at the address on the other side of this page.

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SECTION ONE - SUMMARY OF FINDINGS

PART ONE OVERVIEW

A simple innovative solar heating design using conventional hydronic solar collectors and a radiant panel slab was partially developed by Robert J. Starr of Lyndonville, Vermont.

The invention was disclosed to the Invention Support Division at The National Bureau of Standards for their assessment of technical validity.

In May of 1981, the Bureau of Standards determined that the invention was “technically valid and worthy of consideration for appropriate Government support.”

Second stage review of the invention (termed The Radiantec Heating System) was performed by Mr. Michael Brown, a consultant evaluator, who recommended support of the invention because “the design provides utilization of solar energy at lower initial cost and with improved efficiency”.

A recommendation was made to the Department of Energy by the National Bureau of Standards to provide support in the form of a complete technical investigation.

Dr. Jon G. McGowan, of the Department of Mechanical Engineering at the University of Massachusetts was contacted. The University subsequently agreed to collaborate with Mr. Starr for the purpose of carrying out the investigation.

The status of the invention prior to federal support was that a few working models had been installed in single family homes within the Northeastern portion of Vermont. These low cost working models seemed to be working well as evidenced by high collector efficiencies (low collector inlet temperatures), and low auxiliary energy usages. The models which were designed to achieve solar performances in the vicinity of 50% were observed to have relatively stable temperatures and steady inputs of auxiliary energy. These observations suggested that higher levels of solar heating performance were possible without diminishing returns.

Market penetration was limited due to the lack of credible independent performance data. Data acquisition from working models was confounded by the presence of occupants whose habits were unpredictable and by the use of wood heat as the auxiliary backup.

The results of the research demonstrate that the invention offers significant advantages over state of the art active and passive approaches. Substantial improvements were noted in system efficiency, overall performance, initial cost and architectural flexibility.

A patent and literature search by Michael Brown, a consultant to The National Bureau of Standards revealed that the design approach is a unique one and that its benefits are not yet understood by the energy community.

PART TWO - INVENTION DESCRIPTION AND DISCUSSION

An objective of hybrid solar design is to combine the relative advantages of active and passive design approaches while minimizing their respective disadvantages.

Active collection methods tend to harvest solar energy with good efficiency and do not lose energy during periods when they are not operational (as passive collectors do). Operational efficiency is greatest when the solar resource is harvested at low temperatures relative to the ambient air. The usefulness of active heating systems has been compromised by the cost and complexity of the various mechanical systems needed to collect, store and distribute the solar energy. Cost and practical considerations limit the size of the storage component which tends to raise system temperatures and lower collector efficiency.

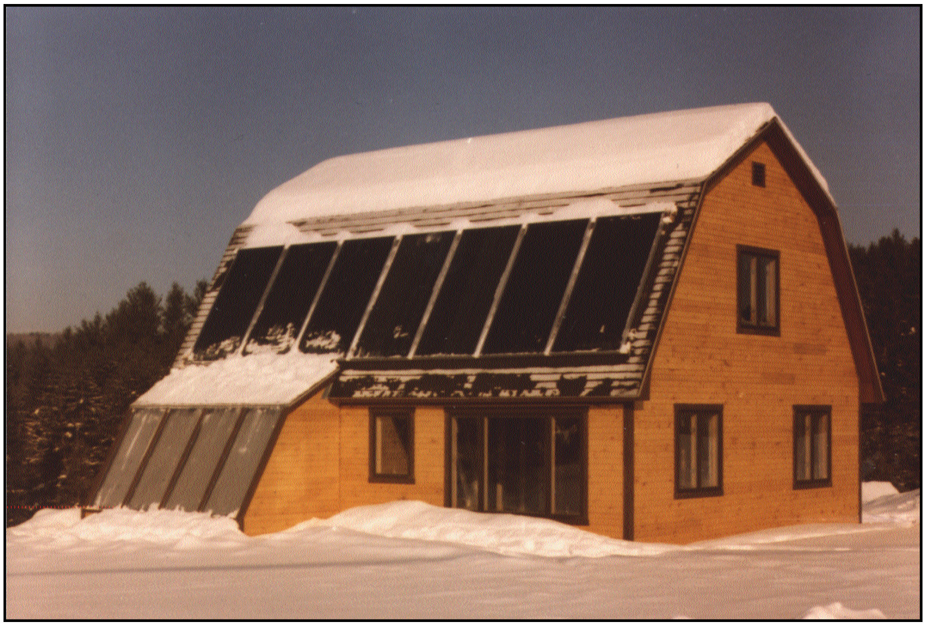
Many passive approaches reduce cost and complexity by using conventional building components to collect, store and deliver solar energy. The usefulness of passive methods is compromised by the fact that the collection element is a part of the building envelope causing it to lose heat at night. These losses lower overall efficiency and in cold cloudy regions can result in negative energy gains. The size of the storage element, as in active systems is limited by cost, architecture and other considerations.

The Radiantec invention (Figure # 1) is a hydronic heating system using conventional hydronic solar collectors to heat a radiant panel slab.

A heated fluid is pumped in an active manner from the solar collectors throughout the radiant slab whenever solar energy is available. Heat is stored within the slab and compacted earth beneath. It is released to the heated space in a passive manner without controls by radiation and convection. Solar energy which exceeds heating load requirements is diverted to the domestic hot water load in residential applications.

High collector efficiencies are achieved with active collectors. The design approach raises a uniquely large thermal mass to relatively modest temperature unlike conventional systems which raise a smaller thermal mass to relatively high temperatures. Solar energy is utilized at the lowest possible temperature resulting in the highest possible collector efficiencies. Overall cost and complexity is reduced by using a structural component of the building to store and release the solar energy.

High collector efficiencies increase the amount of solar energy harvested on sunny days and permit operation under marginal solar conditions (early AM, late PM, cloudy days) when collectors operating at higher temperatures will not reach “threshold temperature”. An increase in collector efficiency translates into fewer solar panels, lowered costs, and easier design integration into accepted building styles.



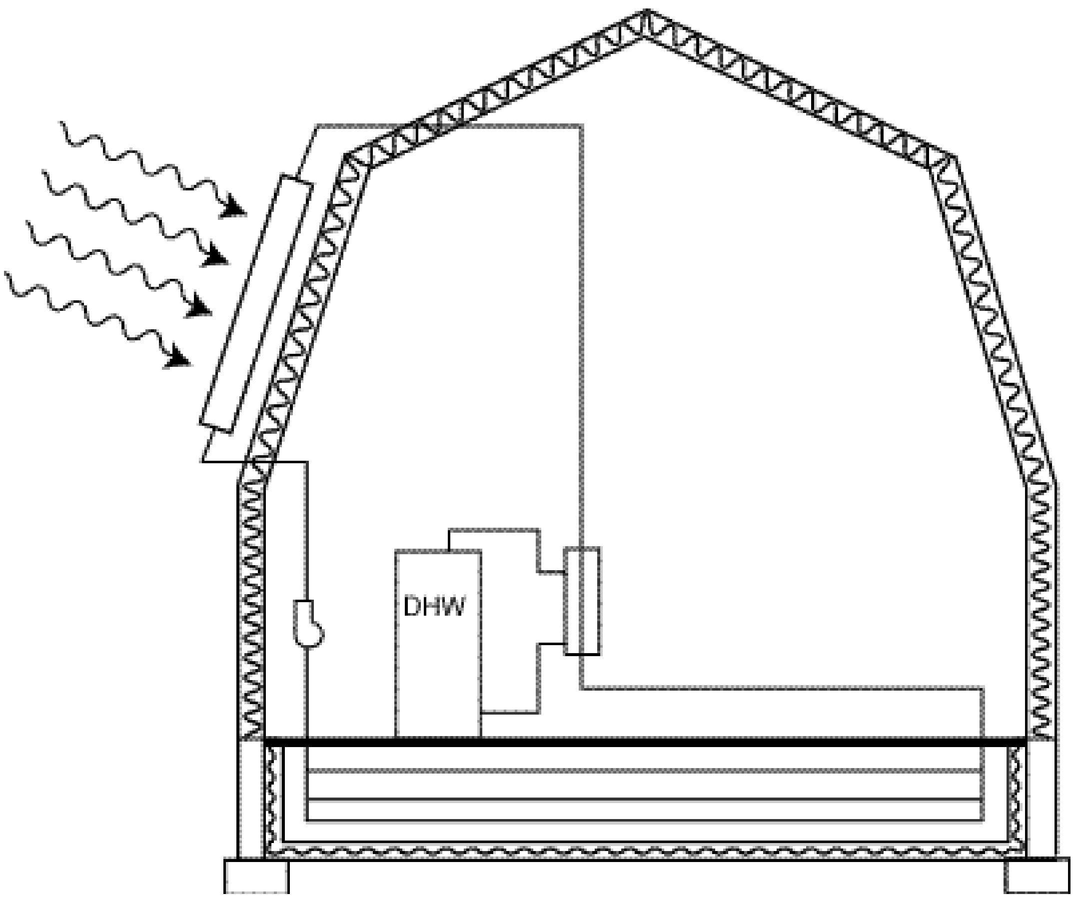


Figure # 1   Schematic of The Radiantec Heating System

A large thermal mass, integrated with the buildings structure provides prolonged solar storage, radiant comfort and further lowered costs.

The overall simplicity of the design results in improved reliability and greater consumer confidence. The design lends itself to convenient “packaging” which can lower costs, simplify design and installation, improve reliability and present the product in the manner that building professionals are accustomed to receiving it.

PART THREE - EXPERIMENTAL TEST PROGRAM

A test house using the Radiantec heating system was experimentally monitored to determine its energy based performance during the 1982-83 heating season. The test residence is located in Lyndonville, Vermont, an area which has a characteristically cold and cloudy climate. The two story residence has a floor area of about 1,400 square feet and is constructed on a 720 square foot 5.5 inch thick floor slab. A 24 inch packed gravel bed is located beneath the slab and the slab-gravel bed is insulated by two inches of polystyrene insulation.

The test building is of frame construction and uses insulation levels which have become commonplace throughout the country. The structure would not fall into the “super insulated” category but was tightly constructed so as to have a low infiltration level. The building is “sun-tempered” in that windows were concentrated somewhat on the South side and all but avoided on the North. A solar greenhouse on the South side of the building was closed off from the structure permanently throughout the testing so as to better observe the solor heating invention without confounding variables. The monitoring equipment generated an internal gain of about 17,000 BTU’s per day, roughly the equivalent of occupancy by two persons.

Section two is a full description of the experimental testing program.

PART FOUR - SYSTEM EFFICIENCY

System efficiency as discussed in this section refers to the amount of solar energy which is harvested relative to the total amount of solar insolation which is available at the site. System performance, as discussed in a following section relates to solar heating fractions and productivities which result when a particular system is applied to a particular heating load.

Table 2.19 is a summary of the measured monthly efficiencies which were observed at the test building in Vermont.

Figure 14 is based on the performance of active heating systems using air, hydronic and evacuated tube solar collectors at Colorado State University. These systems were designed, installed and operated by solar specialists in a closely controlled measurement program. (1.1)

It is seen that the low cost Radiantec heating system, in its Vermont location provides substantially higher efficiencies than the active heating systems monitored in Colorado. It is significant that Colorado receives more than twice as much winter solar insulation as the Vermont location.

TABLE 2.19

SUMMARY OF COLLECTOR PERFORMANCE

Month	TOTAL SOLAR INPUT TO COLLECTORS (BTU X 10^6)	MEASURED OUTPUT FROM COLLECTORS (BTU X 10^6)	AVERAGE MONTHLY EFFICIENCY (%)
November	3.358	1.668	49.7
December	3.926	1.972	50.2
January	4.915	2.350	47.9
February	6.632	3.334	50.3
March	6.390	3.104	48.6
April	6.030	2.967	49.2

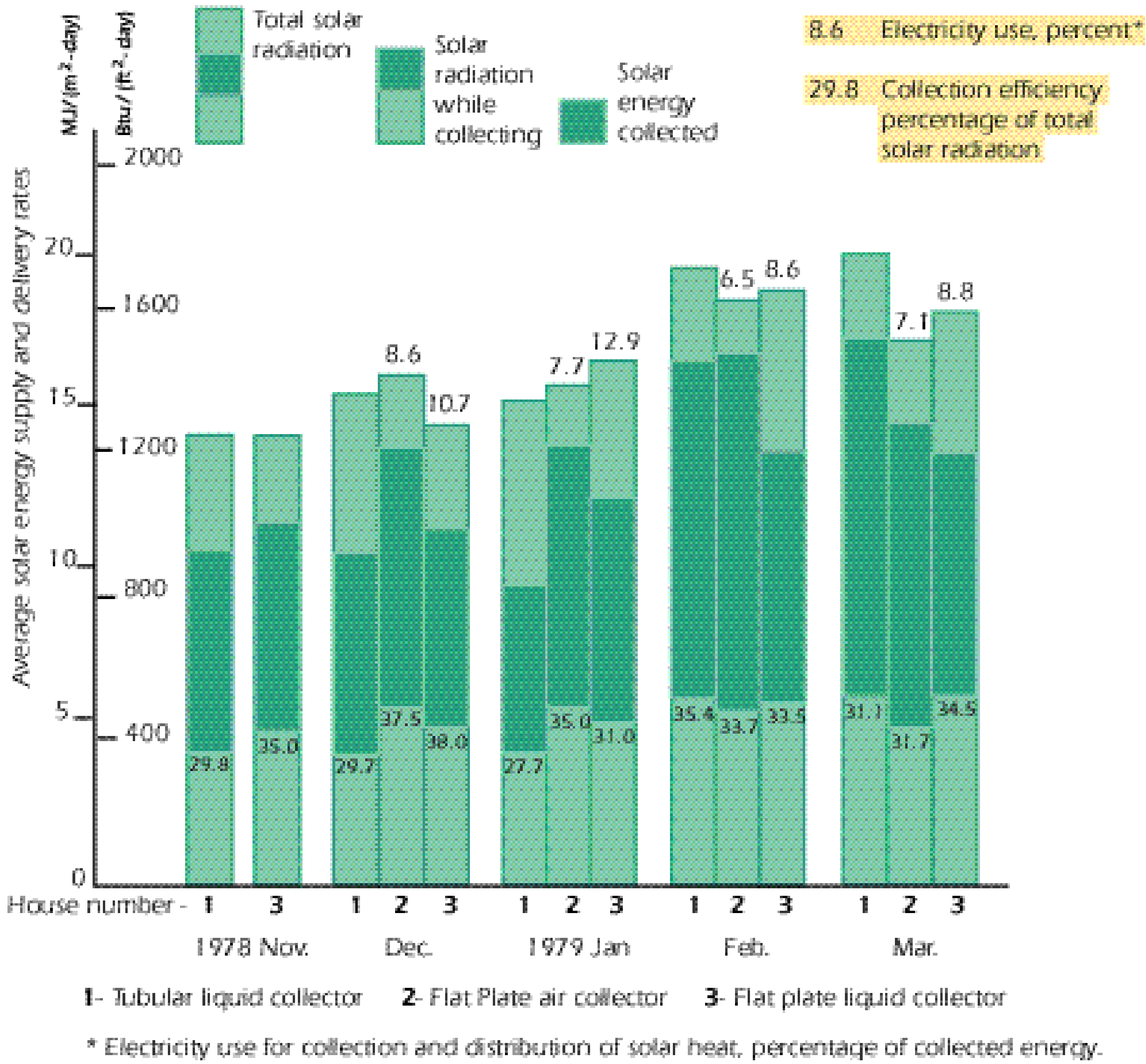


Fig.14 Performance of solar space heating systems in three solar heated houses at Colorado State Univ. [Ref. 12]

Low solar collector temperatures were the primary reason for the favorable efficiencies which were observed. Electrical energy consumed by the pump and controller at the test site was 5.3% of the total collected solar energy. The additional flow resistance of the monitoring equipment (BTU meter, flow meter etc.) resulted in a need to select a pump with 2 times the output of the pump which would be used if the monitoring equipment were not present.

The electrical energy consumed by the pump and controller in a similar system which is not monitored would therefore be about 2.7% of the solar energy harvest.

PART FIVE - SLAB STORAGE HEAT EXCHANGER EFFICIENCY

The slab storage heat exchanger is constructed of high molecular weight polyethylene tubing. This material is replacing copper tubing in radiant panel applications. It is manifolded to achieve reasonable pressure drops and appropriate flow through the system. The Final Technical Report by The National Bureau of Standards reports that the heat exchanger "is superior to copper because it is lower in cost, can be installed without inaccessible joints, and has lower friction losses, high resistance to corrosion and a long service life. The pipe's low cast permits redundancy in design." (1.2)

Figure # 2 is a temperature profile which was observed at 11:09 on Julian day # 297 (October 24), under conditions of strong sunlight all morning. Under these conditions, storage temperatures are non uniform (with temperatures higher about the pipe than throughout the mass in general), and energy output of the solar panels is high.

Collector temperatures are more closely coupled with the average slab temperature under conditions of less intense sunlight or when storage temperatures are more uniform (in the AM).

Under the observed conditions on Julian Day # 297, the collector / slab heat exchanger, operating with an efficiency of .67, harvests 97.3% of the energy which would be harvested by an ideal heat exchanger (one of infinite area and length). (61.0% of the available insulation vs 62.7%)

A heat exchanger having two times the length and area of the reference design would harvest 98.7% while an exchanger with one half of the length and area of the reference design would harvest 91.9%.

It would appear that the reference heat exchanger has a size which is effective and in the optimal range considering costs and benefits.

Redundency in the design is also apparent as the loss of one half of the heat exchanger would result in a system performance loss of only 5.4%.

PART SIX - HEAT LOSSES TO THE GROUND

Figure # 3 is a temperature profile of ground temperatures observed in the latter part of January, 1983 when earth temperatures were at their lowest.

The temperature of an unheated slab under the design conditions is estimated to be 60 degrees F. The temperature of a slab which is at a temperature which would fully heat the building to design conditions is 68 degrees F.

The additional heat loss which results from this 8 degree additional temperature requirement would be 612 BTU per hour in the reference test building or 7% of the building's average heating demand if the ground beneath the polystyrene insulation presented no additional or resistance to heat flow.

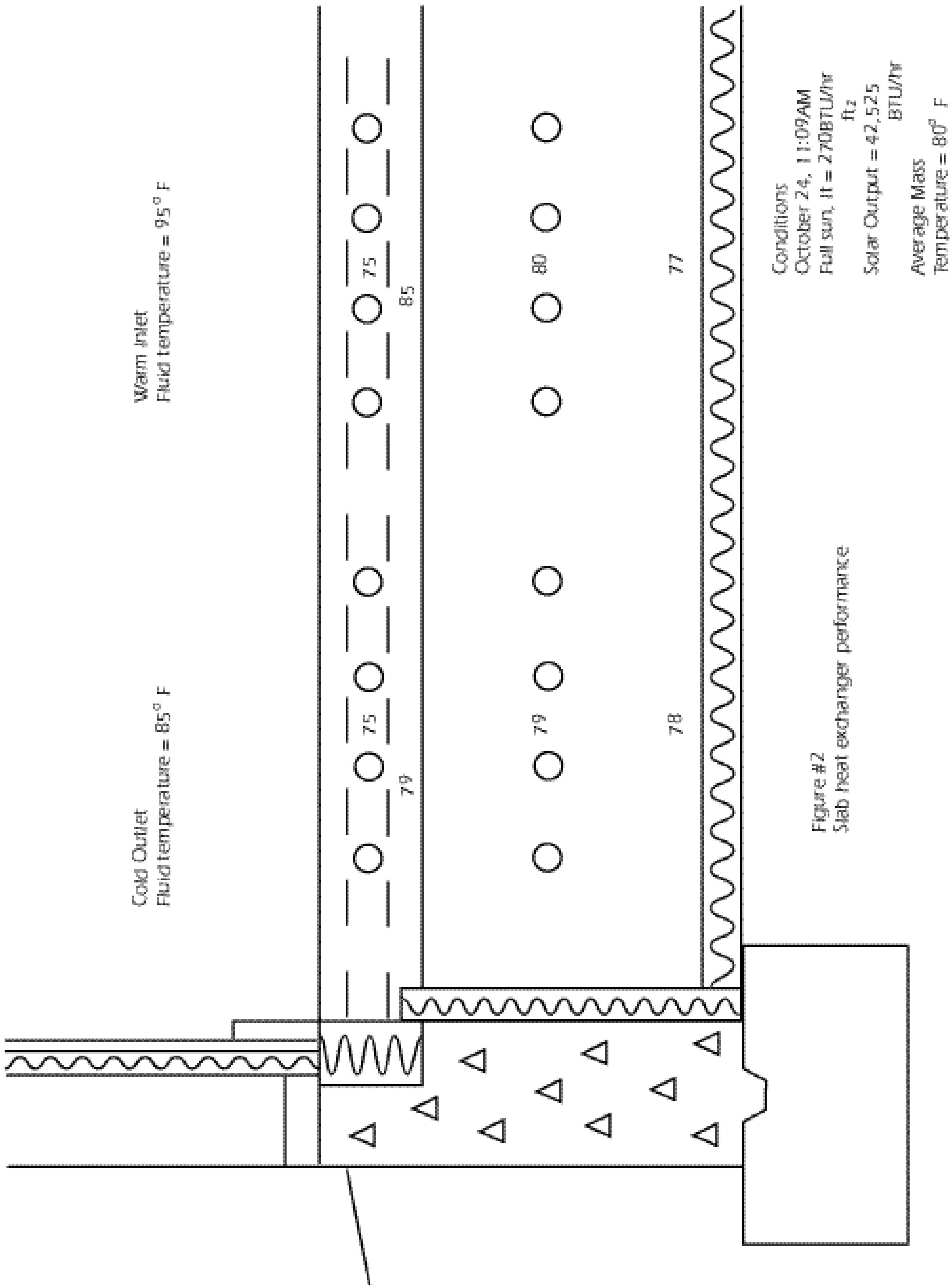


Figure #2
Slab heat exchanger performance

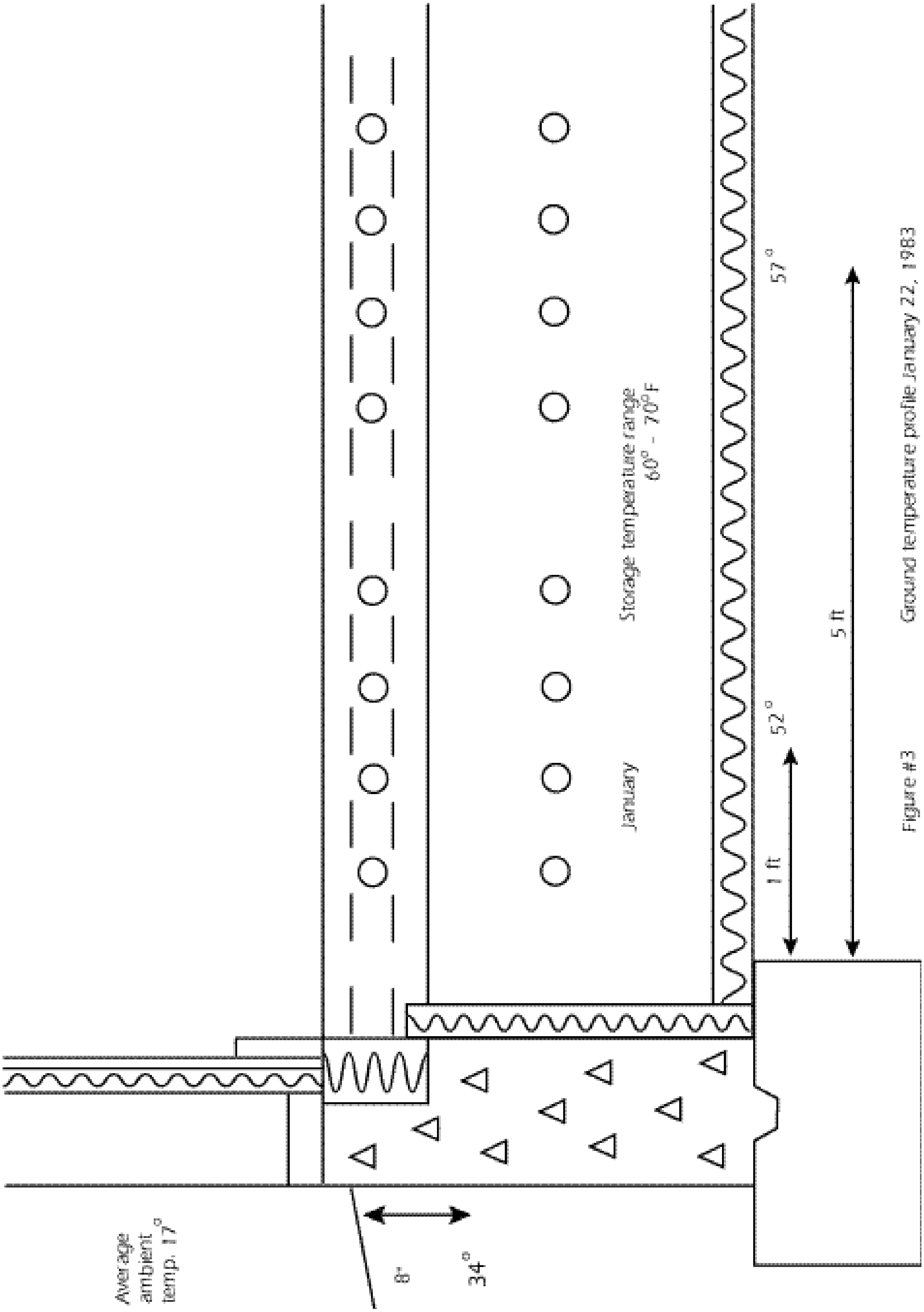

Average
ambient
temp. 17°
8"
34°
January
Storage temperature range
60° - 70°F
1 ft
52°
5 ft
57°
Ground temperature profile January 22, 1983

Figure #3

This capacitance and resistance to heat flow is observed however, and the phenomenon will result in a lower heat loss than is calculated above.

It is noted that additional comfort can be provided by a radiantly heated floor.

The Final Technical Report by The National Bureau of Standards notes the following about radiant panel system, ". . . such systems function on the basis of providing a comfortable environment by controlling surface temperatures and minimizing excessive air motion within the heated space. The occupant is not aware that the environment is being heated. As learned from physiological studies, the mean radiant temperature (MTR) strongly influences the feeling of comfort. When the temperature of room surfaces begin to deviate excessively from the ambient air temperature of the heated space, it becomes difficult for convective systems to counteract the result in discomfort felt by the occupant. Large surface heating panels neutralize this deficiency and minimize excessive radiation losses from the occupant's body." (1.3)

Calculations by Swisher at the Solar Energy Research Institute suggest that, "Introducing a warm radiant surface in a passive or hybrid design raises T_{mr} (mean radiant temperature) usually above T_r. This allows the comfort level to be achieved at a lower room air temperature. . . . Reducing the thermostat set temperature by this amount decreases the heating load by about 10% in most climates." (1.4)

PART SEVEN - PERFORMANCE

System performance as discussed in this section refers to solar heating fractions and system productivities which occur when a particular heating system is applied to a particular load.

The Radiantec heating system stores and releases solar energy in a passive manner. The storage element is integral with the building envelope and its thermal capacitance buffers the various energy flows such that the interior temperature tends to remain within the comfort zone despite the varying energy gains and losses of the building.

The amount of thermal mass strongly influences the degree to which an input of solar energy can meet a building's heating load (solar heating fraction). If thermal mass is inadequately large, lower solar heating fractions result. In the passive instance, the mass is overcharged, resulting in unacceptably high room temperatures and a dumping of heat. In the active instance, storage temperatures rise to the point where collector efficiency is impaired.

The Radiantec thermal storage subsystem differs from conventional active and passive systems in that the storage is uniquely large. In the experimental test structure, the storage mass contains 1,440 cubic feet of concrete and packed gravel and weighs over 70 tons. The incremental cost of this storage is nil in the slab on grade building.

The temperature of an unheated floor slab is coupled more closely to the mean radiant temperature than to the thermostat set temperature in a convectively heated building. The floor slab loses radiant heat to the relatively cooler walls and windows. In a building under moderate heating load, the floor temperature will be approximately 5-10 degrees F above room temperature under moderate heating load.

If acceptable daytime comfort levels lie within a room temperature range between 65 degrees F and 78 degrees F, storage temperatures could range between 60 degrees F (when fully discharged) and 83 degrees F (when fully charged).

Figure 2.23 shows the response of the residence (via slab and inside temperatures) to the outside temperature and solar collector input for six days in January. As shown, the interior is maintained at a reasonable comfort level despite wide fluctuations in solar availability and outdoor tempurature.

Table 2.20 gives a summary of the system performance on a month by month and seasonal basis. The months of November and February showed very high solar heating fractions (97.6% and 93%) of the controlled heat requirement without the need to dump heat by ventilation.

These observations suggest that the slab storage subsystem is large enough and effective enough to enable high solar heating fractions in cold months without the diminishing returns associated with periodic overheating.

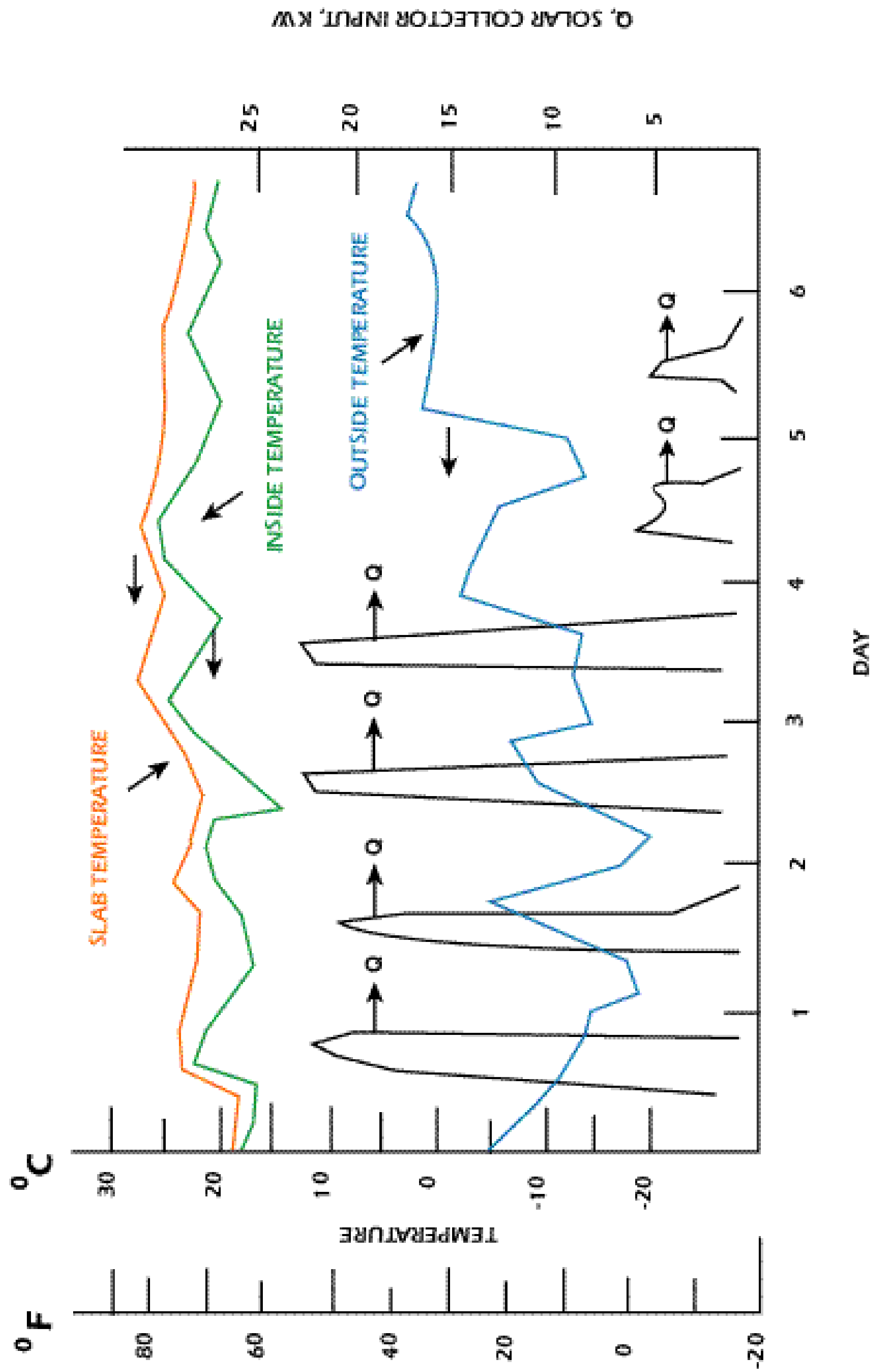
Observations of other building in Vermont using Radiantec heating system indicate that room temperature as compared to thermostat set temperature depends upon the solar heating fraction at the time.

When solar heating fractions are in the vicinity of 50 % on a monthly basis, actual room temperatures are coupled fairly closely to the thermostat set temperatures.

Observations at the experimental test site during months with higher solar heating fractions (November and February) show that daytime temperatures ranged up to 13 degrees F above the minimum thermostat setpoint. A daytime temperature profile would resemble a bell shaped curve with few observations about the 65 degree minimum, the majority of observations about 5 degrees above the setpoint within the full comfort range and a few observations at the high end of the acceptable temperature range.

The heat loss of a Vermont building in January which has an average temperature of 70 degrees F will be eleven percent greater than that of a building which maintains 65 degrees.

It would seem that a solar energy input of at least 111% of the calculated load will be required to produce a temperature profile in which few observations are seen at the thermostat setpoint (a high solar heating fraction).



Q, SOLAR COLLECTOR INPUT, KW
25
20
15
10
5
SLAB TEMPERATURE
INSIDE TEMPERATURE
OUTSIDE TEMPERATURE
Q
DAY
1
2
3
4
5
6
°C
30
20
10
0
-10
-20
TEMPERATURE
°F
80
60
40
20
0
-20

TABLE 2.20

SYSTEM PERFORMANCE SUMMARY

(ALL VALUES IN UNITS OF 1000 BTU)

	HEATING LOADS			ELECTRICAL ENERGY INPUT		
MONTH	SIMPLE ASHRAE	COMPUTER MODEL	AUXILIARY HEATING ENERGY	PUMPING ENERGY	APPLIANCE ENERGY	TOTAL ELECTRICAL INPUT
NOVEMBER	3,830	2,038	41	177	505	723
DECEMBER	5,423	3,447	653	123	522	1,298
JANUARY	6,576	4,472	859	143	522	1,524
FEBRUARY	5,664	3,655	251	164	471	886
MARCH	4,824	2,742	0	182	522	704
APRIL	3,259	1,409	0	188	505	693
TOTALS	29,576	17,763	1,804	977	3,047	5,828

Room temperature in a building with a radiant floor slab tends to be variable depending upon the degree of heating load which is placed upon the building. Heating loads during the night are higher due to the absence of passive gains, a lower ambient temperature and a lessening of internal gains. A higher temperature difference between slab temperature and room temperature is required to meet the higher load. These phenomena result in a lower nighttime room temperature and in effect give a natural night setback.

PART EIGHT - SIMPLIFIED PERFORMANCE METHOD

An objective of the simplified performance method is to provide a prediction tool which can be used by persons with basic arithmetic and graph reading skills but little knowledge of solar heating design.

Another objective is to present information about the performance of the Radiantec heating design in a way that is more familiar to people who work with conventional heating systems (BTU OUTPUTS, etc.).

Any simplified prediction tool makes certain concessions to simplicity at the expense of precision. Section three provides a detailed computer method which can be used by those who require a higher level of precision.

The method presented here will yield results which are sufficiently accurate for most residential and small commercial applications.

An important assumption is that a nighttime setback of about 5 degrees is acceptable and that temperature excursions within the comfort range (65-80 degrees F) are allowed. It must be emphasized that the method is based on long term <u>averages</u> of building load and solar insulation. The performance predictions are therefore also averages. Actual performance, particularly on a monthly basis, can and probably will be higher or lower depending upon these weather related variables.

The method standardized important variables such as collector performance, heat exchanger design, flow rates, control scheme and the amount of thermal mass to those values which were seen to work well in the research program. It is assumed that "prepackaged" systems will be developed which would eliminate the need for the end user to deal with these variables.

The five step method is:

<u>STEP ONE</u> - Calculate the average monthly heating BTU output of the solar collectors (S'). (Average monthly solar insolation in BTU's/ft^2 for the particular tilt angle is multiplied by the efficiency factor (50%) and then by the square footage of the collector array.

<u>STEP TWO</u> - Calculate the average monthly heating load of the structure using standard Methods. (L)

STEP THREE - Calculate BTUs harvested per BTUs required (S'/L) by dividing results of Step One by the results of Step Two.

STEP FOUR - Determine the Solar Heating Fraction (SHF) from a graph or with the relationship below.

1. If S'/L is greater than 120%, SHF equals 1.0/
2. If S'/L is less than 80%, SHF equals S'/L.
3. If S'/L is between 120% and 80%, interpolate by solving

$$SHF = .8 + \frac{S'/L = .8}{2}$$

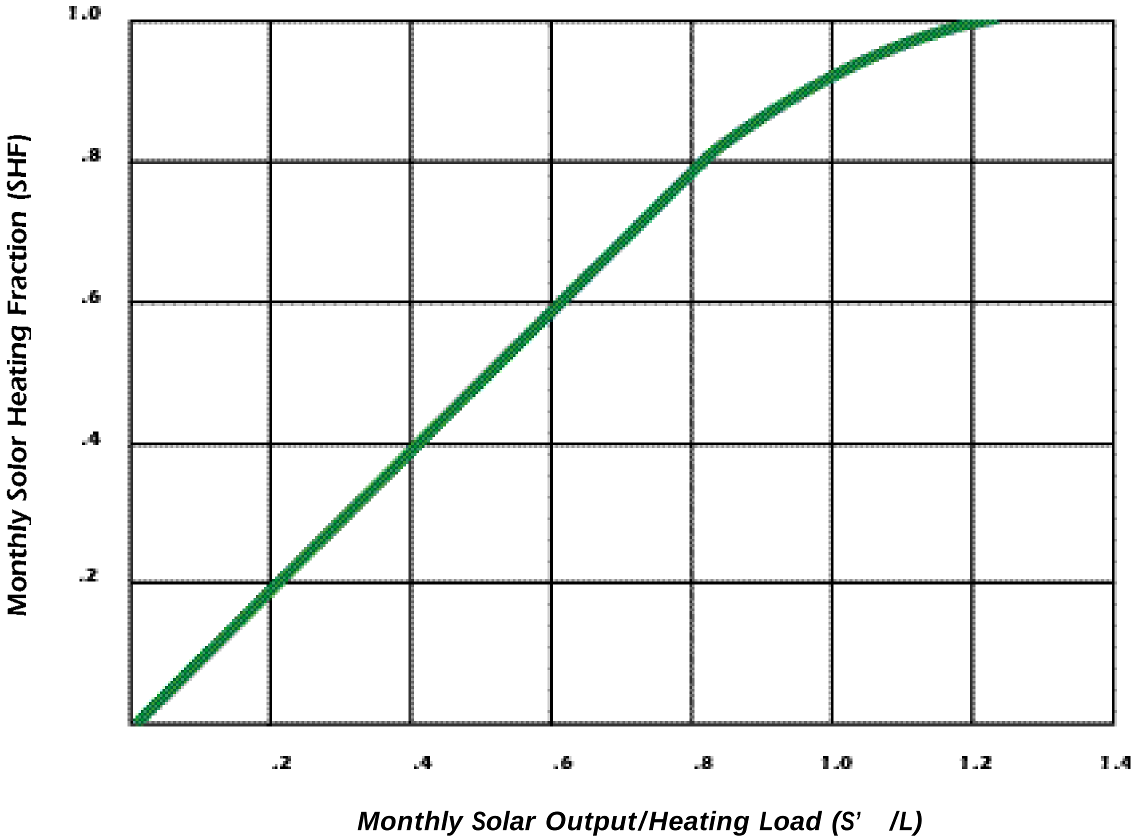


Figure #4 Solar Heating Fraction Calculation

STEP FIVE - Productive energy produced equals SHF X L.

The heating load of the domestic hot water can simply be added to the space heating load if design is such that solar energy which exceeds the space heating load can be applied to that use. The method will overstate the DHW actually produced to some extent during the swing season but will not greatly affect the overall productivity calculation.

Examples of the calculation are presented below for Boston, Massachusetts and Denver, Colorado.

EXAMPLE # 1

Calculate Solar Heating Fraction and productivity for a building located in Boston, Massachusetts having a heat loss coefficient of 200 BTU/hour/degree F and a solar aperture of 263 ft^2 (Seven 4' X 10' solar panels).

STEP ONE

	SOLAR RADIATION BTU/FT^2 60 DEGREE TILT		EFFICIENCY FACTOR		COLLECTOR AREA	AVERAGE MONTHLY BTU OUTPUT (MBTU)
JAN	30,349	X	.5	X	263	3.991
FEB	33,404	X	.5	X	263	4.392
MARCH	42,532	X	.5	X	263	5.593
APRIL	41.760	X	.5	X	263	5.491
MAY	44,206	X	.5	X	263	5.813
JUNE	46,320	X	.5	X	263	6.091
JULY	48,794	X	.5	X	263	6.416
AUGUST	49,755	X	.5	X	263	6.542
SEPT	50,640	X	.5	X	263	6.659
OCT	48,019	X	.5	X	263	6.315
NOV	30,030	X	.5	X	263	3.949
DEC	27,249	X	.5	X	263	3.583

STEP TWO LOAD CALCULATION

	DEGREE DAYS BASE 65		DAILY HEAT LOSS PER DEGREE F (UA x 24)		MONTHLY HEAT LOAD		DHW	TOTAL HEATING LOAD (MBTU)
JAN	1110	x	4.800	=	5.328	+	1.54	6.868
FEB	969				4.651		1.39	6.041
MARCH	834				4.003		1.54	5.543
APRIL	492				2.362		1.49	3.852
MAY	218				1.046		1.54	2.586
JUNE	27				.130		1.49	1.62
JULY	0				.0		1.54	1.54
AUGUST	8				.038		1.54	1.578
SEPT	76				.365		1.49	1.855
OCT	301				1.445		1.54	2.985
NOV	594				2.851		1.49	4.341
DEC	992				4.762		1.54	6.302
Total	5,621				26.981		18.13	45.111

EXAMPLE # 1

	STEP # 3 S'/L	STEP # 4 SHF	STEP # 5 USEFUL ENERGY PRODUCED
JAN	.58	.58	3.983
FEB	.73	.73	4.410
MARCH	1.01	.91	5.044
APRIL	1.43	1.0	3.852
MAY	2.25	1.0	2.586
JUNE	3.76	1.0	1.620
JULY	4.17	1.0	1.540
AUGUST	4.15	1.0	1.578
SEPT	3.59	1.0	1.855
OCT	2.12	1.0	2.935
NOV	.91	.86	3.733
DEC	.57	.57	3.592
			36.728

$$\text{Annual SHF} \quad \frac{36.728}{45.111} \quad .81$$

$$\text{Productivity/ft}^2 = \frac{36,728,000}{263} = 139,650 \text{ BTU}$$

EXAMPLE # 2

Calculate SHF and productivity for a building located in Denver, Colorado having a heat loss coefficient of 200 BTU/hour/^{o}F and a solar aperture of 150ft ^{2} 4 (4X10) solar panels.

<u>STEP ONE</u> - AVERAGE MONTHLY BTU OUTPUT

	SOLAR RADIATION BTU/FT^2 60 DEGREE TILT	EFFICIENCY FACTOR	COLLECTOR AREA	AVERAGE MONTHLY BTU OUTPUT (MBTU)
JAN	52.601	X. 5	X 150	3.945
FEB	50.490			3.787
MARCH	58.339			4.375
APRIL	52.424			3.931
MAY	52.285			3.921
JUNE	51.487			3.862
JULY	52.847			3.964
AUG	55.126			4.135
SEPT	57.509			4.313
OCT	59.241			4.443
NOV	50.331			3.775
DEC	49.242			3.693

STEP TWO - LOAD CALCULATION

	DD		UA X 24		SPACE HEATING LOAD		DHW		TOTAL HEATING LOAD (MBTU)
JAN	1088	X	4800	=	5.222	+	1.54	=	6.762
FEB	902				4.330		1.39		5.720
MARCH	868				4.166		1.54		5.706
APRIL	525				2.520		1.49		4.010
MAY	253				1.214		1.49		2.754
JUNE	80				.384		1.49		1.874
JULY	0				.0		1.54		1.54
AUGUST	0				.0		1.54		1.54
SEPT	120				.576		1.49		2.066
OCT	408				1.958		1.54		3.498
NOV	768				3.686		1.49		5.176
DEC	1004				4.819		1.54		6.359
Total	6016				28.875		18.13		47.005

	STEP # 3 S'/L	STEP # 4 SHF	STEP # 5 USEFUL ENERGY PRODUCE (BTU)
JAN	.58	.58	3.922
FEB	.66	.66	3.775
MARCH	.77	.77	4.393
APRIL	.98	.89	3.569
MAY	1.42	1.0	2.754
JUNE	2.06	1.0	1.540
JULY	2.57	1.0	1.540
AUG	2.69	1.0	1.540
SEPT	2.09	1.0	2.066
OCT	1.27	1.0	3.498
NOV	.73	.73	3.778
DEC	.58	.58	3.688

$$\text{Annual SHF} = \frac{36.397}{47.005} = .77$$

Productivity = 36.397 (BTU)

Productivity/ft^2 36.397/150 = 242,647 BTU

PART NINE - PERFORMANCE AND COST PERFORMANCE ANALYSIS: THE RADIANTEC HEATING SYSTEM vs REPRESENATIVE ACTIVE AND PASSIVE SYSTEMS

Table six presents system performance and cost performance data for the Radiantec heating system and typical active and passive systems when installed in a representative residential dwelling located in Boston, Massachusetts.
(UA=200 BTU/hr/F)

TABLE FIVE - DESIGN PARAMETERS FOR THREE SOLAR HEATING SYSTEMS
Boston, Massachusetts

	ACTIVE	PASSIVE (THOMBE WALL, VENTED)	SOLAR HEATED SLAB
COLLECTOR AREA	263 ft^2	263 ft^2	263 ft^2
COLLECTOR GLAZING	single	double	single
ABSORBER SURFACE	selective	non selective	selective
COLLECTOR TILT	60 degrees	90 degrees	60 degrees
STORAGE VOLUME	66.8 ft^3	263 ft^3	1,440 ft^3
STORAGE CAPACITY (BTU/F/FT^2 solar aperture)	15.85	30	136.88
NIGHT INSULATION	NA	R=9	NA
HOT WATER PROVIDED?	Yes	no	yes

TABLE SIX - SYSTEM PERFORMANCE AND COST EFFECTIVENESS DATA
Boston, Massachusetts

	ACTIVE	PASSIVE	SOLAR HEATED SLAB
SPACE HEAT (MBTU)	18.35	14.57	23.86
(SOLAR FRACTION)	.36	.54	.89
DOMESTIC HOT WATER	12.41	0	12.87
(SOLAR FRACTION)	.68		.71
TOTAL ENERGY DELIVERED	30.76	14.57	36.73
INSTALLED COST	$11,500 (1984)	$5,500	$6,600
CAPITAL COST/MBTU/YR	$374	$377	$180

In actual practice, consumers who elect to install a Radiantec heating system instead of a conventional heating system take a furnace credit on the backup heating equipment which varies on a case by case basis.

Some consumers will downsize the backup heating system from typical design heating requirements. Others substitute a heating system with low capital costs and higher operating costs (electric) for one with high capital costs but lower operating costs (oil or gas). Others use a low cost manually operated backup heating source (wood or coal stove).

A consumer who takes a $1,500 furnace credit will have an incremental cost for his solar heating system of $5,100 in the reference case located in Boston, Massachusetts.

His solar investment will yield a 12.66 return on his investments (tax free) in the first year if equivalent energy would cost $17.58/MBTU or $.06/KWH.

The performance of his investment will increase over time if the price of conventional energy rises due to escalation and/or inflation.

These calculations do not account for solar tax credits. To the extent that they may apply, cost performance improves. Higher cost performance is also to be expected in sunnier and milder regions.

Under a variety of cost benefit calculations which factor depreciation, avoided energy costs, avoided capital costs in the conventional system, the value of invested capital, inflation, etc., the Radiantec heating system yields attractive returns in the first year of operations with higher returns to be expected in the future.

Conventional energy prices are an aggregation of the prices of “old” energy and the price of “new” energy sources (new electric plants, off shore oil, new clean coal plants, synthetic fuels, etc.) The “new” sources of energy are considerably more expensive than the existing sources which are being depleted.

It is assumed that if a particular “new” and renewable energy source has a cost benefit which is attractive when compared to conventional energy prices, its price is even more favorable when compared to the other “new” conventional energy sources to which it is more appropriately compared.

PART TEN - MECHANICAL PERFORMANCE

Applications of the Radiantec heating system have been operating in the field for five years now. Preliminary information suggest that these systems should provide a long and relatively trouble free service life.

The Radiantec is a simple system with few moving parts and fewer components than either active solar heating systems or conventional hydronic systems.

Most components are identical to those of conventional hydronic heating system. These components have achieved very high reliability due to their long development and service history in conventional systems.

The pump should last a long time due to low operating temperatures and good lubrication by the glycol fluid. No pumps have needed replacement to date.

The solid state controllers have proven very reliable and none have been replaced to date.

The glycol heat transfer fluid is showing good service life because of low operating temperatures and lack of exposure to air (oxidation of glycol to glycoloc acids). Glycol solutions which have been in service for five years are still showing effective levels of corrosion inhibitors.

Abusive testing of the plastic slab heat exchanger tubing was conducted. Repeated dumping of collector fluid at stagnation temperatures (300+F), produced no ill effects. Prolonged exposure to very high fluid temperatures (an improbable event which requires multiple simultaneous system failures) can cause failure of the joint at the plastic to copper connection. This event leaks the glycol transfer fluid into the gravel bed and shuts down the system completely. The joint, which is accessible, must then be remade. No damage to the pipe itself occurs.

The heat exchanger tubing is flexible and resists considerable cracking of the concrete slab.

STATEMENT REGARDING THE PLANNED "NEXT STEP"

The following section will fulfill the DOE reporting requirements for a statement of the planned next step which will be taken to advance the status of the invention towards the goal of introducing a new product to the market.

TECHNOLOGY TRANSFER - This portion of the work will transfer knowledge of the invention's properties to a broader segment of the public. Whereas the invention is a simple, unpatented design approach, the technology transfer will require the cooperation of the various solar trade publications, architectural and engineering journals. If the Department of Energy feels that this work should be published, a statement to that effect would facilitate the effort. The inventor and other members of the research team will prepare papers and respond to inquiries to the extent that resources permit.

PRODUCT DEVELOPMENT - If the opportunity exists, the subject invention will be incorporated into a broader product line of heating and cooling systems which will be more responsive to current and future energy situations than the products currently available. These hydronic heating systems will emphasize high thermal mass, low initial cost, and simple conversion capability to a number different energy sources including solar.

Heating systems with higher thermal mass provide benefits which are of interest in today's marketplace.

When electricity is the choice (usually because of low initial cost), it is most efficiently and economically used during "off peak periods". The utility and the society at large benefits when utilities have high load factors. The need for expensive new generating plants is reduced due to more efficient management of the load. The consumer benefits in most regions by the availability of low "of peak" rate structures. A high thermal mass electric boiler is essentially a modified domestic hot water tank. These units are low in cost due to mass production and will be comparable in price to conventional hydronic heating systems.

If solid fuels are considered, additional thermal mass provides convenience, efficiency and low emissions. Conventional installations must be attended to frequently, and are usually “banked” (shut down with a load of fuel remaining) in order to control heat output. This practice results in pollution, creosote production and poor temperature control.

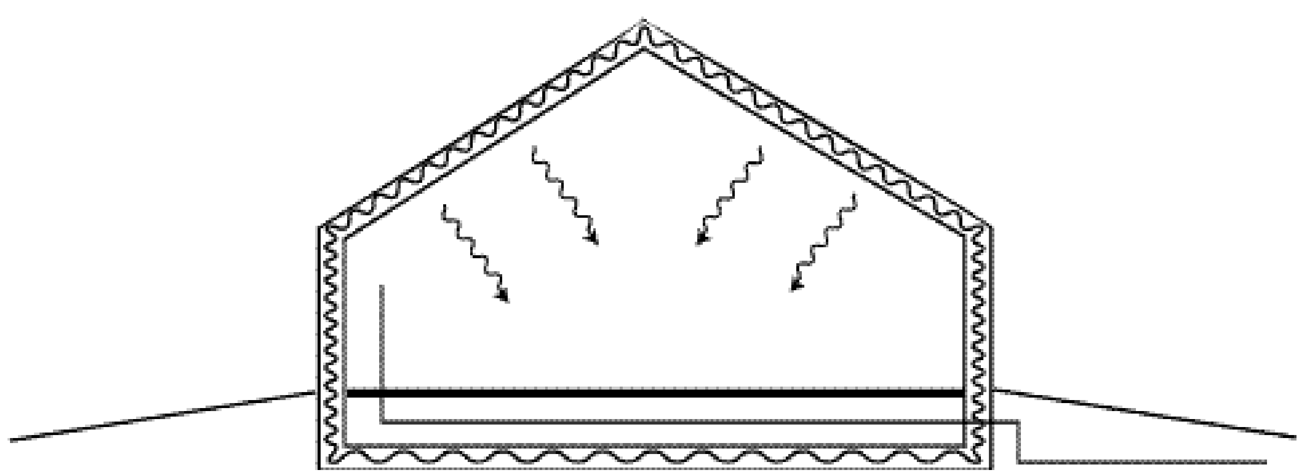
When solar is considered, either initially or at some future date, adequate thermal mass improves efficiency, performance and cost benefit. If a good conventional heating system is seen to have a higher level of thermal mass, the incremental cost of using solar heat is the cost of the solar panels.

Products will come in the form of “ packaged systems” in order to lower costs, simplify design, decrease installation problems and present the product in a format similar to conventional heating systems and thus more familiar to the public.

The production and characterization of convertible heating systems would benefit individuals and the society at large by providing resiliency and flexibility in the present uncertain energy situation.

FURTHER RESEARCH - The Radiantec research program has suggested the following corollary applications:

RADIANT COOLING WITH COLD WATER SUPPLY



OPERATION - Cold water from the supply passes through a heat exchanger within the slab on its way to the fixtures. Heat is extracted from the building in the process.

APPLICATION - Slab on grade structures in climates with a cooling load and appropriate ground water temperatures. Assuming a water supply temperature of 55 degrees, a design temperature of 78 degrees, consumption of 300 gallons per day and a heat exchanger efficiency of 90%, 51,667 BTUs per day will be extracted from the building by this natural flow of energy which is present whether it is used or not. This application has very low initial cost and of course no operating cost.

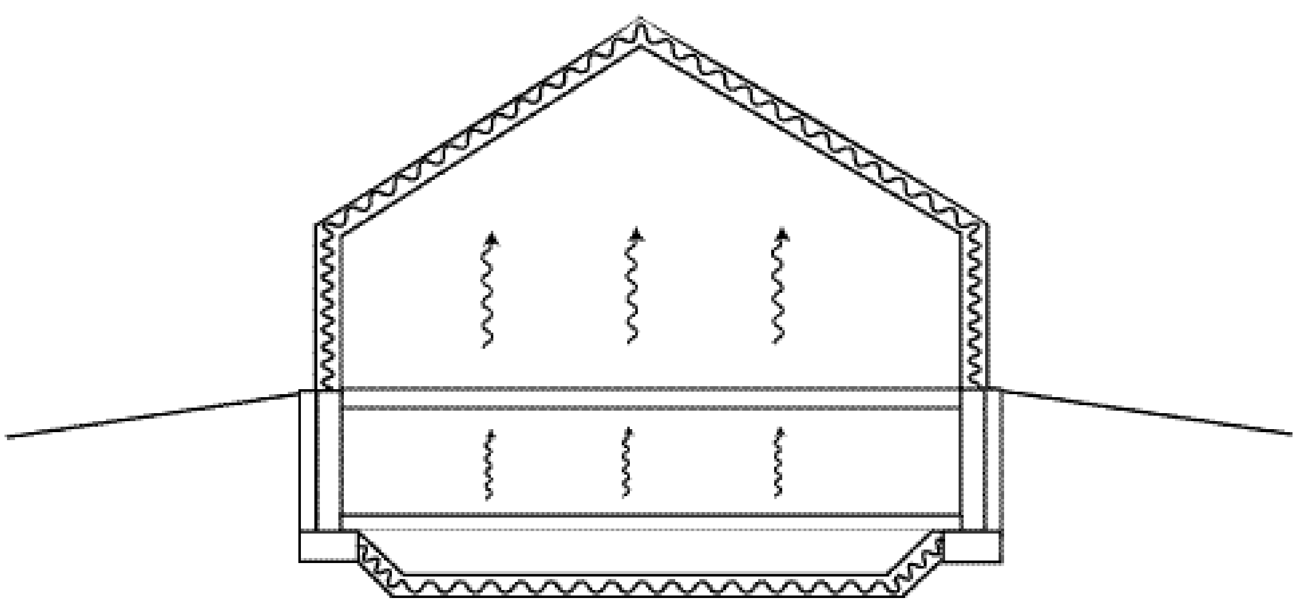
Applications in high humidity climates may still require air conditioning to lower the moisture content of infiltration air. In dry arid climates, the application will enhance comfort by not lowering the moisture content of room air.

RADIANT PANEL HEATING WITH DRAIN DOWN SOLAR AND COLD WATER SUPPLY COOLING

OPERATION - Solar heated potable water is circulated through the slab when needed for space heating. Supply water passes through the slab on its way to the fixtures and draws heat from the building. During the heating season, supply water bypasses the slab and goes directly to the fixtures.

APPLICATION - The application can be used in temperate climates where freeze protection is less pressing and where cooling loads exist. Excellent cost performance is predicted due to lowered initial cost (elimination of the glycol loop) and low cost cooling. Very high solar fractions can be expected in moderate climates.

INDIRECT RADIANT HEATING WITH SOLAR, OFF PEAK ELECTRIC OR SOLID FUELS



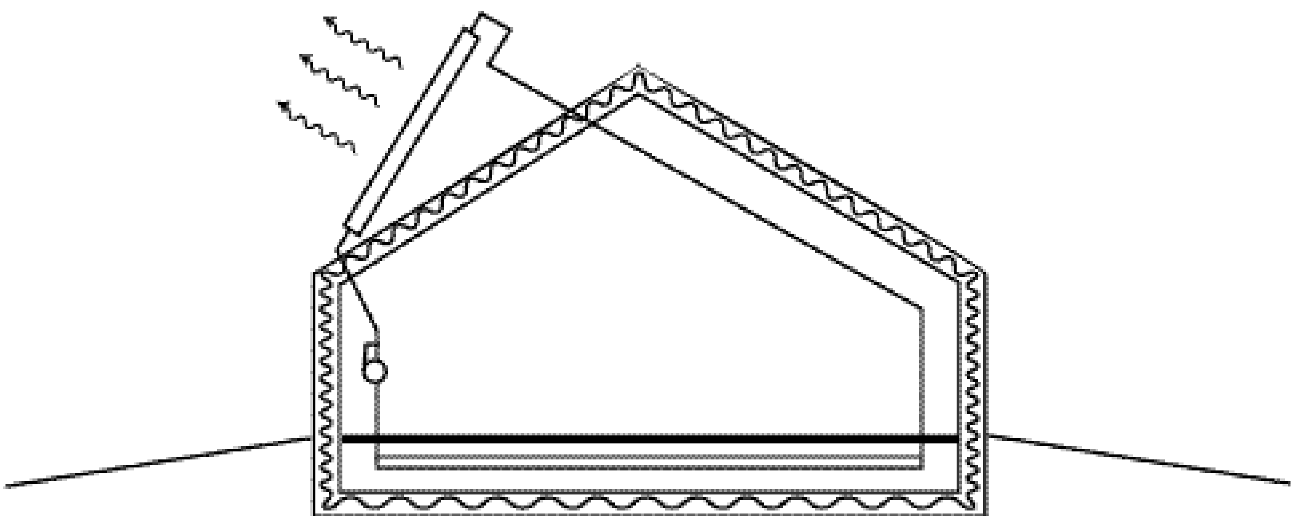
OPERATIONS - A “second story” above a radiantly heated “first story” is heated by transfer of heat through the floor ceiling structure.

APPLICABILITY - The method applies when a full basement is used or when a second story is provided with slab on grade construction.

Some knowledge of the mechanisms involved was gained in the testing program. The test building is a two story structure. Temperatures in the second story are coupled within less than 5 degrees of the first story on below zero F nights. Inputs of very small amounts of auxiliary energy to the second floor will equalize temperatures indicating that the primary heat transfer mechanism is probably radiation through the floor rather than convection through the stairwell opening.

Many Vermont buildings are now being fully heated by wood stoves in the basement. Information on these mechanisms however has not been characterized in a manner that would be useful to a designer.

RADIANT NIGHTTIME COOLING WITH UNGLAZED SOLAR COLLECTORS



OPERATION - Solar thermal energy is harvested during the day in the conventional manner and put to some use other than space heating. The building is cooled at night by radiating heat to the nighttime sky via the unglazed solar collectors.

APPLICATION - Climates which have cooling loads, particularly arid regions.

The high efficiencies which were observed in the Radiantec testing program suggest that the cover sheet in the solar collectors may not really be needed in milder climates at low collector operating temperatures.

At high operating temperatures, the cover sheet lowers heat loss from the panel by absorbing energy radiated from the absorber plate and by sheltering the panel from convective losses.
The cover sheet also blocks about 20% of the incoming solar radiation by refraction, reflection and absorption.

New selective absorber coating techniques have decreased the importance of the cover sheets ability to trap energy which radiates from the absorber.

A favorable potential exists to develop a low cost, low temperature solar collector which would have a partially selective, weather resistant absorber and no cover sheet.

A solar collector such as this may produce heating efficiencies comparable to those observed in The Radiantec testing program with glazed solar panels.

A nighttime cooling benefit coupled with possible spa or pool heating during warm months could result in very high productivities.

SOLAR RADIANT PANEL HEATING WITH PHASE CHANGE MATERIALS

OPERATION - Active solar panels charge a phase change material (eutectic salt) located within the building envelope. Heat transfers from storage in a passive manner by radiation and convection. Phase change modules are installed within interior partitions and floor joists.

APPLICABILITY - Phase change materials can store 15 times more energy than an equivalent volume of masonry material within a 15 degree temperature swing.

The development of the application would lead to retrofit possibilities and application of solar radiant panel heating systems to multi-story structures.

Statement of the status of the invention at the completion of the Grant period.

The increased use of solar energy is widely viewed as desirable.

Significant market penetration of solar heating applications have been limited by a number of factors. The more important ones are summarized below.

1. A need to reduce initial cost.
2. A need to improve efficiency.
3. A need to improve overall performance.
4. A need to reduce complexity and improve reliability.
5. A need to reduce the architectural constraints which solar design imposes.
6. A need to develop standardized designs with reasonable cost benefits over a broader range of climate conditions.

The research and development program has shown that the subject invention offers significant advantages in each of these areas.

The benefits which the invention offers were theoretical at the beginning of the R & D effort. These benefits have now been demonstrated in practice and have been verified by independent testing.

The underlying thermodynamic mechanics have been characterized in a manner that can be verified by others.

Opportunities to lower the installed cost of the invention (packaging, standardization, etc.) have been identified.

Theses opportunities could lower installed cost by about 35%.

It would appear that the prospect for market penetration have improved as a result of the federally sponsored research and development effort.

REFERENCES

1.1 Solar Energy Applications Laboratory, CSU, "Operations, Performance and Maintenance of Integrated Solar Heating, Cooling and DHW Systems", prepared for the Solar Energy Research Institute, October, 1981.

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1.3 Ibid

1.4 Solar Energy Research Institute, Active Charge/Passive Discharge Solar Heating Systems: Thermal Analysis and Performance Comparisons, Joel Swisher, June, 1981.