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COMBINING SOLAR HEATING WITH A WOOD BURNING FURNACE

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Abstract

The objective is to minimize the use of high-cost heating fuels in rural areas with the assistance of a wood burning furnace and a solar collector.

It was discovered that when the output of a wood burning furnace can be diverted into a solar storage battery, more useful heat can be supplied to a house with little extra inconvenience to the homeowner. The total amortized system of the wood burning furnace combined with the solar system will be less than if the systems were operated independently.

1. INTRODUCTION

In rural areas heating fuels can be costly. Low-cost fuels, such as natural gas, are usually not available. Other fuels, such as oil, propane, and electricity, are much higher because of increased transportation and handling costs. Alternate sources of energy, such as solar or wood burning, are more practical in rural areas. From an economical standpoint, these alternate fuels are more valuable to the customer because of the higher cost of the conventional fuels.

A country home is currently under construction west of Bonner Springs, Kansas. The objective was to minimize or eliminate the use of a propane fueled furnace with the assistance of a solar collector and a wood burning furnace. Wood burning furnaces have a high Btu capability, but they have very poor control capabilities. Most active solar collectors have good heat storage and control characteristics but generally are not high in their Btu output. After predicting the heating requirements of this house, the plan was to find a way to combine the two systems into one with both good Btu output and good controllability.

List of Symbols
(in order of appearance)

Q	Heat loss	Btu/hr
A	Area of partition	sq ft
ΔT	Change of temperature (inside-outside)	F
R	Thermal resistance	(hr)(sq ft)(F)/Btu
h'	Surface coefficients on inside wall	Btu/(hr)(sq ft)(F)
x	Thickness of insulator	in

k	Thermal conductivity	Btu/(hr)(sq ft)(F)/(in)
C	Thermal conductance	Btu/(hr)(sq ft)(F)
h"	Surface coefficient on outside wall	Btu/(hr)(sq ft)(F)
h	Change of enthalpy	Btu/lb
$\dot{V}$	Air flow	cu ft/hr
v	Specific volume	cu ft/lb
L	Length of crack	ft
n	Efficiency	%
$coll	Installation cost of collector	$
$w.f.	Installation cost of wood burning furnace	$
$f.s.	Annual fuel savings	$
i	Annual fuel increase	%
N	Payback time	years

2. BACKGROUND OF THEORY

Before any heating units can be selected, the heating requirements must be predicted. For solar calculations, daily averages of both heating needs and collector outputs are desirable. If these are calculated on a monthly basis, fairly reasonable results can be obtained.

Heat loss per degree temperature drop ($Q/\Delta T$) is calculated for the structure. The average daily requirements for each month can be calculated by multiplying $Q/\Delta T$ by the average temperature drop for that month.

Heat will flow through each partition according to the following equation:

$$Q/\Delta T = A/R$$

where $R = 1/h' + x/k + 1/C = 1/h" + \ldots$ *

The value of R is for total thermal resistance of the partition. The terms chosen are appropriate to each type of building material which makes up the partition.

Heat is also lost from the structure due to infiltration. The crack method is commonly used. This includes measuring the feet of cracks around windows, doors, etc., and multiplying this by the value of air assumed** to be flowing through each foot of crack. The heat loss due to infiltration is:

$$Q/\Delta T = h(\dot{V})/v(\Delta T).$$

From the above equation, $Q/\Delta T$ is not constant. However, by calculating this for an average outside temperature and humidity, it will be within 10% of the values ($Q/\Delta T$) at the temperature extremes.**

The average monthly heating requirements for an area can be found in the ASHRAE Handbook of Fundamentals or many solar heating texts (1). These are listed in Degree-Days with a base of 65°F. By multiplying the monthly degree-day data by $Q/\Delta T$ of the structure, the average daily and average monthly heating requirements can be determined when using the appropriate conversion factors.

Collector performance is based on the average daily output for 270-day heating season in each locality. Unfortunately, the monthly daily average and the seasonal daily averages are different. By obtaining mean daily insolation data for each month and dividing these by the average daily insolation for the nine-month season, the resulting factors can be applied to the manufacturer's rating to get the collector output for each month.

To compare collector performances, the monthly outputs must be compared with the monthly requirements to find the monthly output utilized. Their total is the useful energy contributed by the collector during a heating season. Dividing a collector (or group of collectors) installation cost by their total useful energy output, their comparative values can be assessed.***

Wood burning furnaces can be compared the same way, except there is no need for a monthly basis comparison because a cord of wood supplies the same heat value each month. A wood burning furnace is inexpensive, so it is sized to handle 100% of the heating requirements on the worst day. This becomes the backup system and thereby eliminates the need for a conventionally fueled furnace.

After both the collector and wood burning

* See Table 1.

** See Table 2.

*** See Tables 3 and 4.

furnace have been selected, the annual savings on the conventional heating fuel minus the annual cost of the wood must be compared to the installation costs. This will give the payback time for the system.*

In the wood burning furnace, the heat will build up and must be carried away whether the house needs the heat or not. Instead of opening the windows, the excess heat can be moved into storage to be used later. The resulting additional fuel savings can be determined by how much of this excess heat is used later. The total cost of the combined heating system can be reduced for a better payback time.**

3. DISCUSSION OF RESULTS

The data indicates savings in operating the wood burning furnace in series with the solar collector and storing excess heat from the furnace. The percentage of 14.2% of excess heat with a .72 utilization factor assumed would vary considerably due to the individual operating the system. This unity also provides a means of controlling the temperature fluctuation.

A diligent individual could probably keep the collector storage temperature closer to its optimum temperature and further decrease wood consumption.

The payback time (8% and 16% annual fuel increase) was provided for comparison purposes only. There is a loan cost which must be absorbed before the payback time can be decreased due to fuel increases.

The rock storage battery was selected because of the lower maintenance and longer service life. The payback time, of course, must be shorter than the service life of the unit. For this problem the most efficient collector must be used because the payback time is nearly as long as the service life.***

If the house had to be all electric, the energy cost would be 4.2¢/KWH for this house. Electricity at 100% efficiency would be 1.98 times more expensive than propane at 60% efficiency. The payback in Table 6 would be almost one-half, which would make this system attractive. Two International Solarthermics collectors will provide 47% of the house requirement, where one Model 160 collector provides 28% of the annual heating. The efficiency of two collectors is lower because of the utilization factor, but they may be justified because of operating in a shorter payback time period.

On the other hand, if this house were in Bonner Springs, Kansas, rather than several miles outside of town, natural gas would be available at $1.49/mcf @ 920kBtu/mcf and n = .6. The cost using natural gas for this house would be 2.3 times less expensive than propane; and therefore it would be nearly impossible to justify any sort of alternate energy source.

These comparisons are based purely on the economics of the individual homeowner(7). There may be community welfare considerations which may influence a citizen to go with the alternate energy sources, even though they are not economical.

TABLE 1

Heat Loss (Conduction) = A/R

Construction	R****	A sq ft	$Q/\Delta T=$ Btu/(hr)(F)
Frame Walls	18.02	1,484	82.35
Windows (double glass)	1.64	132	80.52
Windows (single pane)	.88	23	25.99
Doors	2.388	72	30.00
Exposed Concrete Walls	1.575	386	245.00
Covered Conc.Walls (7')	.93	1,161n.ft.	125.30
Covered Conc.Walls (5')	1.11	551n.ft.	49.50
Covered Concrete Walls (Basement Floor)	20.	1,581	21.00
Attic	41.58	1,696	41.58
Side Boards	6.024	160	26.56
			727.8Btu/(hr)(F)

R = (hr)(sq ft)(F)/Btu

* See Table 5.

** See Table 6.

*** See Table 6.

**** See Appendix, Note 1.

TABLE 2

Heat Loss (Infiltration)*

Location	$\dot{V}$/L cu ft (hr)(ft)	L(ft)	$\dot{V}$ cu ft/hr
Windows	15	304	4,560
Doors	100 each door + 25	80	2,400
Frame Masonry Joints	5	192	960
			7,920

$$A/\ T = \frac{h(\dot{V})}{v(\ T)} = \frac{(28.1-9.8)(7920)}{12.5(75-35)} = \frac{290\ \text{Btu}}{(\text{hr})(\text{F})}$$

TABLE 3

Average Monthly Insolation and Heating Requirements

Month	Solar Radiation** Langleys	Degree-Days***	Daily Average 1000 Btu's	Total Monthly Req.MBtu's
Sept.	.432	39	32	1.0
Oct.	.307	220	173	5.4
Nov.	.226	612	498	14.9
Dec.	.157	905	713	22.1
Jan.	.182	1,032	812	25.2
Feb.	.258	818	713	20.0
Mar.	.342	682	537	16.6
Apr.	.434	294	239	7.2
May	.528	109	86	3.4
Totals	.318 Avg.	4,711		115.8

TABLE 4

Comparing Collector Performances

ISC Model 96

Installation: $3,800****

Cost: $3,800/21.6MBtu/yr. = $176/MBtu/yr.

Month	Daily Output 1000 Btu	Monthly Output MBtu	Monthly Output Utilized
Sept.	130	3.9	1.0
Oct.	92	2.8	2.8
Nov.	68	2.0	2.0
Dec.	47	1.5	1.5
Jan.	55	1.7	1.7
Feb.	77	2.1	2.1
Mar.	103	3.2	3.7
Apr.	130	3.9	3.9
May	156	4.8	3.4
			21.6

ISC Model 128

Installation: $4,400****

Cost: $4,400/27.2MBtu/yr. = $162/MBtu/yr.

Month	Daily Output 1000 Btu	Monthly Output MBtu	Monthly Output Utilized
Sept.	174	5.2	1.0
Oct.	123	3.7	3.7
Nov.	91	2.7	2.7
Dec.	63	2.0	2.0
Jan.	74	2.2	2.2
Feb.	103	2.8	2.8
Mar.	137	4.2	4.2
Apr.	174	5.2	5.2
May	207	6.4	3.4
			27.2

ISC Model 160

Installation: $4,900****

Cost: $4,900/33.0MBtu/yr. = $148/MBtu/yr.

Month	Daily Output 1000 Btu	Monthly Output MBtu	Monthly Output Utilized
Sept.	217	6.5	1.0
Oct.	154	4.7	4.7
Nov.	114	3.3	3.3
Dec.	79	2.5	2.5
Jan.	92	2.8	2.8
Feb.	129	3.5	3.5
Mar.	172	5.3	5.3
Apr.	218	6.5	6.5
May	260	8.0	3.4
			33.0

ISC 2 ea. Model 160

Installation: $8,900****

Cost: $8,900/51.8MBtu/yr. = $172/MBtu/yr.

Month	Daily Output 1000 Btu	Monthly Output MBtu	Monthly Output Utilized
Sept.	434	13.0	1.0
Oct.	308	9.4	5.4
Nov.	228	6.6	6.6
Dec.	158	5.0	5.0
Jan.	184	5.6	5.6
Feb.	258	7.0	7.0
Mar.	344	10.6	10.6
Apr.	436	13.0	7.2
May	520	16.0	3.4
			51.8

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* See Appendix, Note 2.

** See Appendix, Note 3.

*** See Appendix, Note 4.

**** Prices vary due to distribution and installation requirements.

TABLE 5

Fuel Savings, Not Diverting
Excess Heat into Storage

Propane Fuel (Basis)		
Rating	95000	Btu/gal
Cost	.355	$/gal
Efficiency	.60	
Value	6.22	$/MBtu
Solar Collector		
Rating	160	kBtu/day
Basis	270	days/yr.
Fuel cost	None	
Annual output utilized	33	MBtu/yr.
Propane fuel savings	205.26	$/yr.
Installation cost	4900	$
Wood Furnace		
Output rating	75000	Btu/hr
Input-output efficiency	.54	
Fuel cost	60	$/cord
Desired output	83	MBtu/yr.
Net fuel cost	4.61	$/MBtu
	382.63	$/yr.
Net fuel savings	133.63	$/yr.
Installation cost	700	$
Combined fuel savings	338.89	$/yr.
Maintenance costs	100.00	$/yr.
Net fuel savings	238.89	$/yr.
Payback time	23.4	yrs.
Payback time (8% annual fuel increase)	14.7	yrs.

TABLE 6

Fuel Savings, Using Excess
Heat Diverted into Storage

Excess heat in wood furnace	14.2	%
Utilization factor	.72	
Net fuel cost	4.15	$/MBtu
	344.45	$/yr.
Propane fuel savings	516.26	$/yr.
Net fuel savings	171.81	$/yr.
Combined fuel savings	377.07	$/yr.
Maintenance costs	100.00	$/yr.
Net fuel savings	277.07	$/yr.
Payback time	20.2	yrs.
Payback time (8% annual fuel increase)	13.2	yrs.
Payback time (16% annual fuel increase)	10.8	yrs.

APPENDIX

Notes:

1. Most "R" values were obtained from James L. Threlkeld, (1970) *Thermal Environmental Engineering*, Tables 14.1 and 14.3(8).

   Glass "R" values were obtained from The Trane Co., (1965) *Trane Air Conditioning Manual*, Table 3-2(9).

   Earth covered concrete walls "R" values were obtained from Carrier Air Conditioning Co., *Handbook of Air Conditioning Design*, Tables 35, 36, and 37(3).

2. Infiltration was estimated from the crack method using information mainly from Carrier, *Handbook of Air Conditioning Design*, Chapter 6(3).

   The values of enthalpy and specific volume were read from ASHRAE "Psychrometric Chart No. 1," Sea Level(1). The assumed average conditions were 35°F with 30% relative humidity outside and 75°F with 50% relative humidity inside. Considering an outside temperature extreme of 5°F, the value would be 256 Btu/hr°F or 12% change. But the air flow will be greater because of greater stack effect, so this will decrease to only 5% or 6% deviation from 290 Btu/(hr)(F) average. Thus, using this average value as a constant for any outside temperature will not introduce a significant error.

3. Mean solar radiation in Langleys were obtained from Jan F. Kreider and Frank Kreith, *Solar Heating and Cooling*, Table C.5. The values for Manhattan, Kansas, and Columbia, Missouri, are averaged and listed in Table 3, Column 1(6)(5).

4. The Degree Days listed in Table 3, Column 2, are from Bruce Anderson, *The Solar Home Book*, Appendix 1.4(2).

5. The payback time N, allowing 8% annual fuel increase, can be computed from the following equation:

$$N(\$s.s.)(1 + iN/2) = \$coll = \$w.f.$$

Note: There are no allowances for the loan costs in computing the payback times. Perhaps "i" should really be the fuel projected increases minus the interest cost of the investment.

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BIOGRAPHY

Kenneth M. Bechtold

As Plant Engineer at Lone Star Industries in Bonner Springs, Kansas, Kenneth Bechtold heads the Engineering Department of a Portland Cement manufacturing plant.

He has been directing the design and installation of many projects involving process optimization and environmental control.

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As an Assistant Professor of Mechanical Engineering at the University of Missouri-Kansas City, Dr. Stewart teaches both undergraduate and graduate level courses in heat transfer, thermodynamics, and solar energy.

He has had industrial experience as a research and development engineer in the areas of fluid dynamics and environmental control and consulting experience in cost and efficiency analysis of energy systems.

Dr. Stewart was graduated from the University of Missouri-Rolla in 1968 and received a Ph.D. in Mechanical Engineering from UMR in 1972.