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PROPOSALS FOR ENERGY CONSERVATION MEASURES FOR A SPECIFIC SMALL BUSINESS

BY

SCOTT WAYNE SNAPP
B.S., Central State University, 1981

RESEARCH REPORT

Submitted in partial fulfillment of the requirements
for the degree of Master of Science
in the Graduate Studies Program of the College of Engineering
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Orlando, Florida

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1985

ABSTRACT

A case study into energy conservation measures for a specific building has been made. Primary emphasis is directed towards conserving energy necessary for heating the building.

Once the building outlay and the scope of energy usage trends are established, different conservation actions are considered. Extensive measurements and observations on the building were made to gather data on areas, materials, thicknesses, and means of heating the building. The goal of such action was to compare the magnitude of heat loss from different sections of the building. With this information it can be understood where to insulate, and the significance of air leaks so that appropriate action can be taken.

To improve the way that the present energy sources are utilized, suggestions are made to enhance the furnace efficiency, revamp the heating system to eliminate the more expensive electric heat, and supplement heating requirements by burning the waste oil that is available. The possibility of using solar and wind energy is introduced for future consideration.

At present, heating costs are about $4300 per year. As an indication of the significance of the research, the resulting savings the first year would be $4200, and annually thereafter, $2900, achievable with an estimated investment of $9200. This projection suggests a simple payback of 2.7 years.

ACKNOWLEDGEMENTS

I appreciate the support that my Father and Grandmother have given me in preparation of this report. Their data collecting and information hunting was invaluable to me over the past few months.

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INTRODUCTION

Building Description

The business, Five States Chevrolet-Olds, located in Boise City, Oklahoma, exists in a small building that was constructed in three phases. Referencing Figure 1, the first section built in the early 1930s originated as a small service station, consisting of walls made of brick, mortar, and clay tiles. An addition to this building was made later in the 1930s so as to include a larger service area towards the north. In this conversion the roof was built with large overhead trusses which created a very large dome-like roof. The walls are made of clay tiles and stucco, with some locations also using brick. In the early 1950s a significant expansion was undertaken towards the east, enlarging the service area and including a parts department. This addition more than doubled the floor space of the building. Material makeup consists of concrete/cinder walls, a large span of show-room window, miscellaneous other windows on the perimeter, a large garage door, and the roof consisting of large trusses forming the dome-like appearance. All floor space in the building is concrete.

Energy Sources/Utilization

The energy requirements of the building consist of natural gas for heating and electricity for all equipment and lighting. Since the final completion of the entire building in the 1950s,

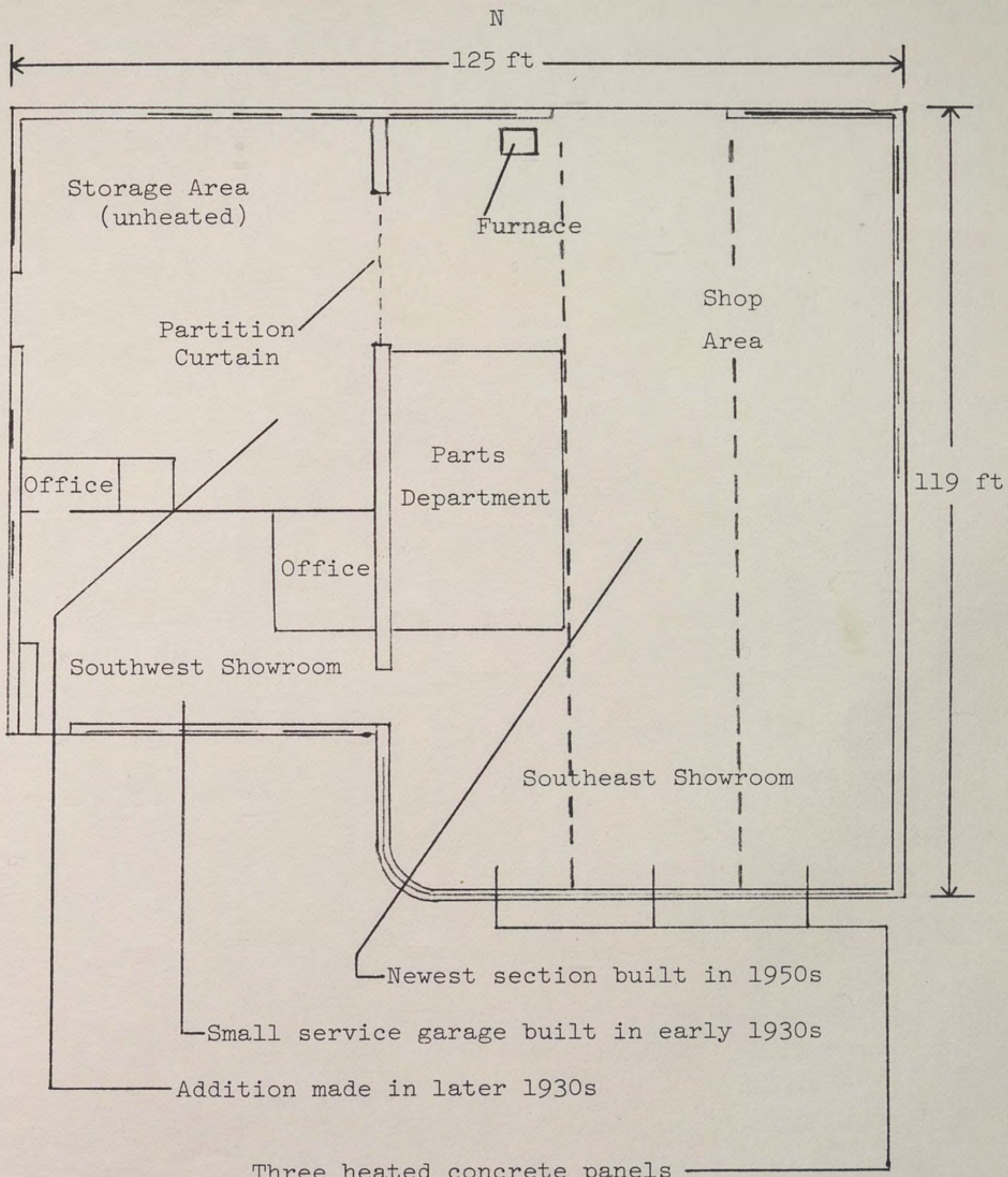

Figure 1. Building Outline

several gas heaters were located throughout the building with the primary heating system consisting of hot water circulated through looped piping in the concrete floor of the newest building section. The other individual units added supplementary heat as necessary. In the early 1980s these units were phased out. The main heat source is now one boiler (for hot water) supplying the center concrete panel of the east side. For selected office areas electric space heaters are being used for supplementary heat.

Research Objectives

Recognizing what energy is available, most analysis is aimed at how well the energy is utilized and what measures could be implemented for improvement.

1) To determine the heat loss of the building an investigation is made on the building envelope concerning type of material, thickness, and area. Furthermore, by deduction an estimate is made of the extent of air infiltration. Once both cases are evaluated, proposals for insulation are investigated.

2) The natural gas boiler is examined for possibility of improving its efficiency.

3) Comparison is made between gas heat instead of the supplementary electric heat. Note that most investigation is made on utilizing thermal energy instead of general electricity use.

4) Alternate sources of heat and/or electricity are considered with burning waste oil, utilizing an active solar system, and implementing a wind turbine near the business.

5) Ultimately, the objective is to have feasible proposals made available so that the business can genuinely make use of them.

HISTORICAL AND FUTURE PERSPECTIVE

Electrical Usage

The electric power requirements of this business are primarily for lighting and miscellaneous shop equipment. However, the usage trend is not consistent throughout the year as noted by Figure 2. During the winter months there is greater demand because of supplementary heat required by space heaters, the circulation pumps, and air fans that exist or have existed as part of the heating system. Also, as might be expected, the shorter days during the winter require the use of more lighting. The average monthly usage over the last eight years is 2494 Kilowatt-hours (Kwh) and the annual average is 29933 Kwh.

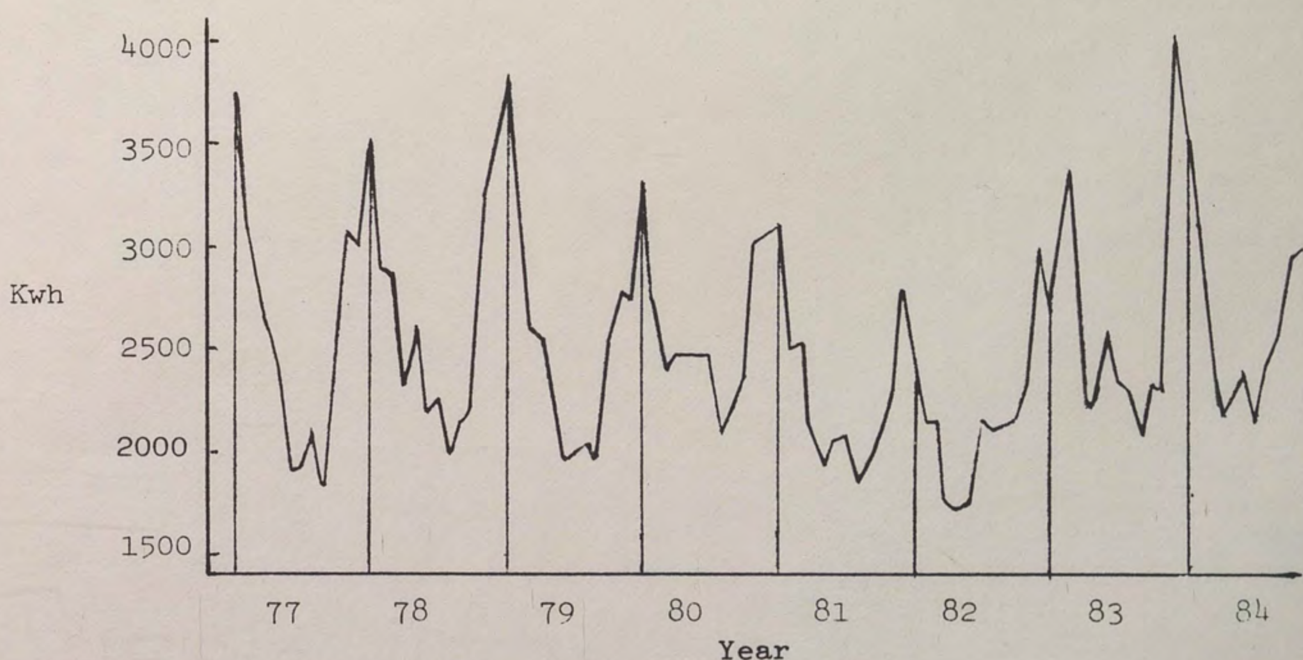

Figure 2. Electricity Usage per Month

As presented in Figure 3 the cost of electricity has had a significant increase over the past several years. This energy which is supplied by Southwestern Public Service Co. (Amarillo, TX) is generated primarily by natural gas, with more and more emphasis on burning coal. In discussions with the local representative, this move towards coal would significantly stabilize the cost of electricity implying future increases would probably be more in line with inflation (Burkhalter 1965). At present the cost of electricity with a three percent tax is about 7.6¢ per Kwh based on 2500 Kwh per month.

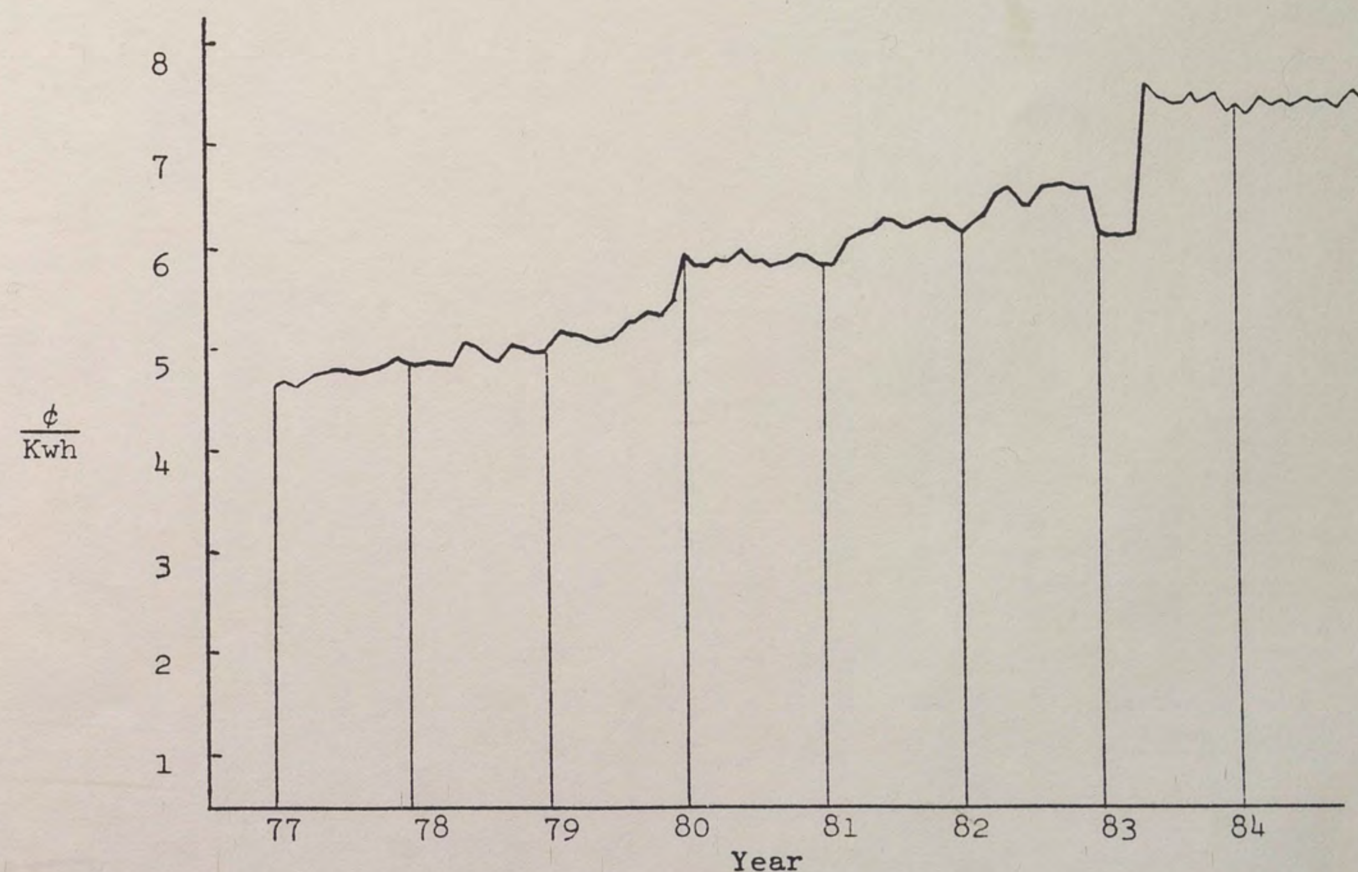

Figure 3. Cost of Electricity - Without Taxes

Considering the present situation, during the winter months the electric space heaters are estimated to draw 790 Kwh per month and assuming the circulation pumps running time to be proportional to natural gas usage an average usage is 120 Kwh per month. Since these items represent a significant increase over the summer "base" load they are a primary area investigated for energy conservation measures.

Natural Gas Usage

The major contribution toward heating the building is to burn natural gas. The usage trend over the last several years is presented in Figure 4. Prior to 1981 the entire building was heated. Two small air heating furnaces plus three large (300,000 BTU/hr) water heating boilers for the concrete panels were available. Presently, due to conservation efforts in 1981 and 1982, the only significant heating unit is the boiler used to heat the center floor panel of the east side of the building. At present the typical gas usage is 720 thousand cubic feet (Mcf) per heating season.

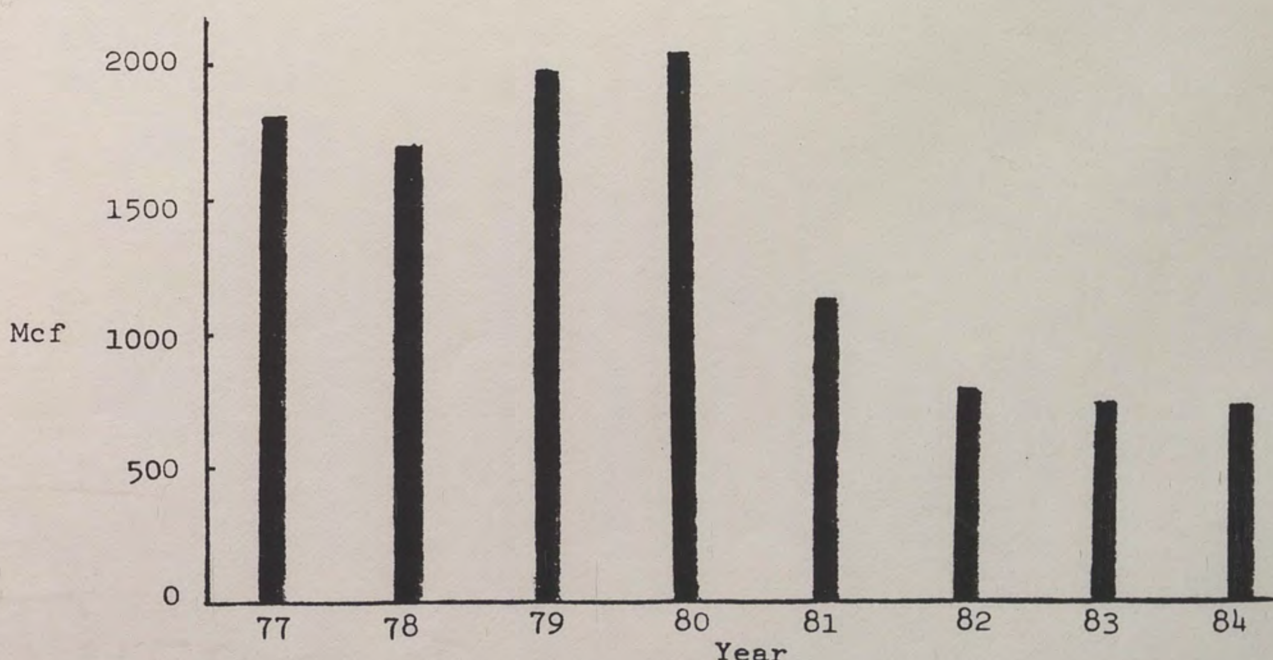

Figure 4. Annual Natural Gas Usage

The cost of natural gas has increased quite rapidly over the last few years as noted by Figure 5. Recently, this gas cost regulated by Southern Union Gas (Austin, TX) was adjusted down approximately nine percent for commercial businesses. (Ketchum 1985) [This action was instigated mostly for the sake of farmers in the region, considering their irrigation needs.] At present the cost of gas is about $5.30 per Mcf (including tax) based on 110 Mcf per month.

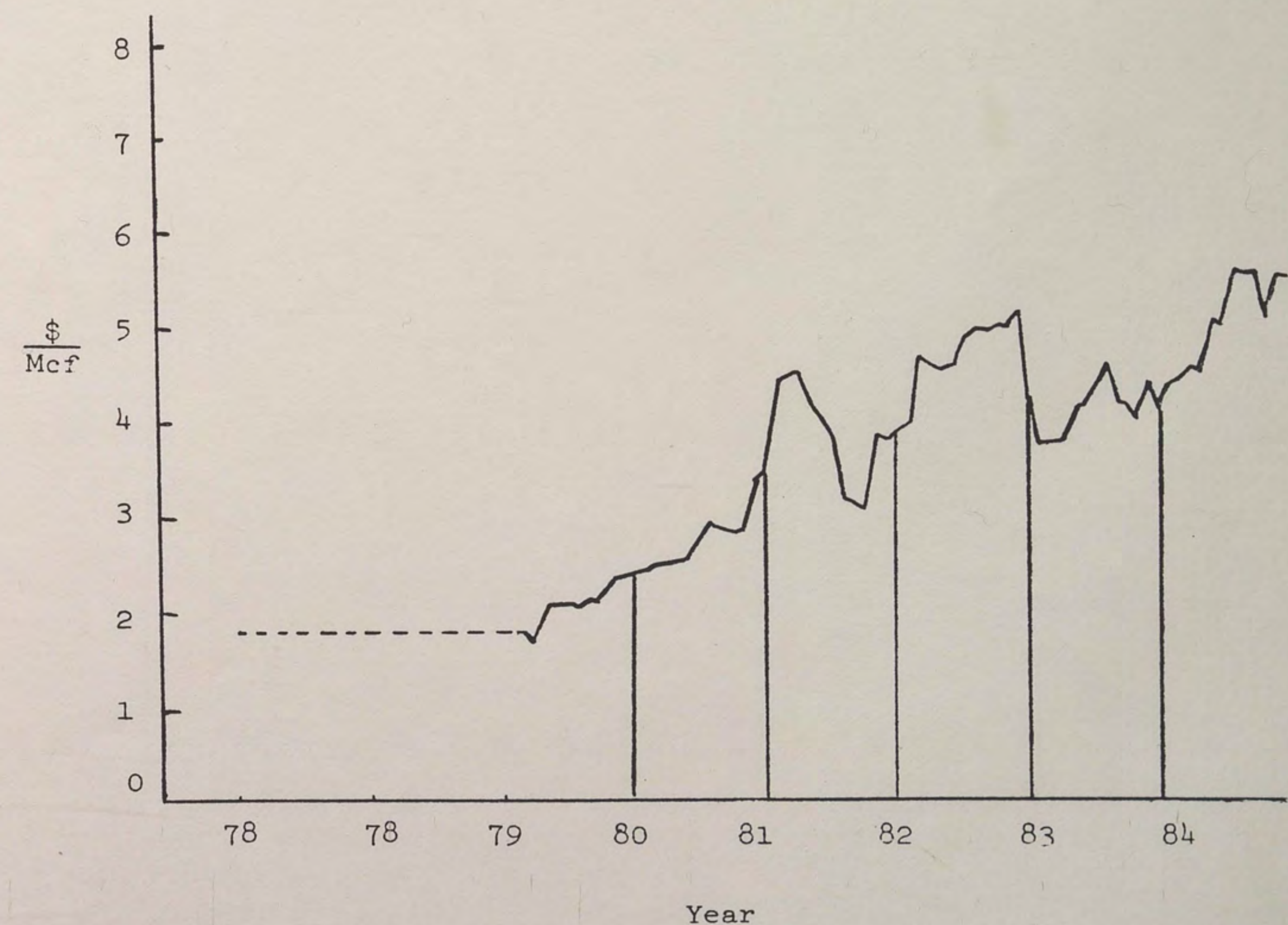

Figure 5. Cost of Natural Gas - Without Franchise Charge or Taxes

For the future it is projected that the supply will remain good and that prices remain constant as suggested by excerpts from "Proceedings of the 7th World Energy Engineering Congress, November 1984":

"There is presently more gas available than there is demand and surplus deliverability is expected to continue for the next 2 years."

"The contribution of U.S. natural gas supplies from the lower-48 states could be constant through the end of the century."

"Proved U.S. gas reserves have stabilized at a reserve-to-production ratio of about 10, remaining recoverable resources at about 60 years, with in-place resources at least ten times larger than that."

"The rapid increase in wellhead natural gas prices which followed between 1977 and 1982 was in effect a 'catch-up' period. This 'catch-up' period is over and future natural gas price increased will be markedly lower than those already experienced."

"Gas prices are expected to remain stable (in constant dollars) over the next five years. This price trajectory should insure adequate supplies at prices that will compete effectively in the marketplace."

"Overall, American Gas Association estimates that about 7% of interstate volumes are possibly subject to fly-up (worst case)."

Past Action Implemented

The noticeable reduction in natural gas usage (Figure 4) can be attributed to conservation measures implemented in 1981 and 1982. By having curtained off the northwest section of the building, and lowering and insulating the front southwest showroom the heated area of the building was considerably reduced. In the spring of 1982 the existing ceiling of the southwest showroom was insulated with four inches of blown-in cellulose. Furthermore, to eliminate the excess overhead space the ceiling was lowered by use of three-inch thick sheets of styrofoam (silvered on one side). Both major actions have helped reduce the effective heated area of the building. These efforts have cut the heat losses of the building more than half and considering the rapid increases in energy costs over recent years the monetary savings have been substantial.

HEAT LOSS EVALUATION

Loss Coefficient-Area (UA) Calculation

In efforts to conserve thermal energy, it must be understood where and how heat losses occur. The heated-building envelope must be examined for type of material, thickness, area, and locations allowing air infiltration. To evaluate the overall heat loss tendency of the building including transmission and infiltration losses an effective loss coefficient-area (UA) product is developed.

An extensive series of tests, conducted by the American Gas Association, showed that the fuel consumption in residences and public buildings varies almost directly as the difference between the outside temperature and 65F. This datum 65F indicates that when the outside temperature is 65F or above, practically no heat is required and the fuel consumption approaches zero. The difference between 65F and the average outside temperature is important as an index of heating requirements and gives the basis for the degree-day for specifying the nominal winter heating load. A degree-day accrues for every degree the average outside temperature is below 65F during a 24-hour period. (Jennings 1978) Using this degree-day method the following general equation is considered.

$$UA = \frac{\text{Gas \& electricity consumed for heating (Btu)}}{\text{Degree-days x 24 hr/day}}$$

Units: Btu/hr-F

To examine heat loss characteristics over several years, the data involving gas and electric heating requirements and weather service information were obtained for winter months to develop the (UA) value. Referencing Figure 7, the (UA) value before 1981 averaged 12456 Btu/hr-F. After implementing conservation measures over the next year the (UA) value resulted in the present day heat loss characteristic of the building, expressed as 4824 Btu/hr-F. The number incorporates the air leaks occurring day to day and the contribution for air exchange as a result of opening the large garage door. The individual calculations were developed as follows: (Note that .79 is present furnace efficiency assumed for all cases.)

January 1977 to April 1981

Applicable number of degree-days: 18458

MCF of gas: 7290.4

$$UA = \frac{(7290.4 \text{ Mcf})(965000 \text{ Btu/Mcf})(.79)}{(18458 \text{ F-days})\ (24 \text{ hr/day})}$$

$$= 12546 \text{ Btu/hr-F}$$

September 1981 to February 1982

Applicable number of degree-days: 3062.5

Mcf of gas (inclusive of equivalent electric heat): 658

$$UA = \frac{(658 \text{ Mcf})\ (965000 \text{ Btu/Mcf})(.79)}{(3062.5 \text{ F-days})\ (24 \text{ hr/day})}$$

$$= 6827 \text{ Btu/hr-F}$$

March 1982 to December 1984

Applicable number of degree-days: 12109.5

Mcf of gas (inclusive of equivalent electric heat): 1839

$$UA = \frac{(1839 \text{ Mcf})(965000 \text{ Btu/Mcf})(.79)}{(12109.5 \text{ F-days})(24 \text{ hr/day})}$$

$$= 4824 \text{ Btu/hr-F}$$

The following graph indicates the heat loss characteristics over the last several years:

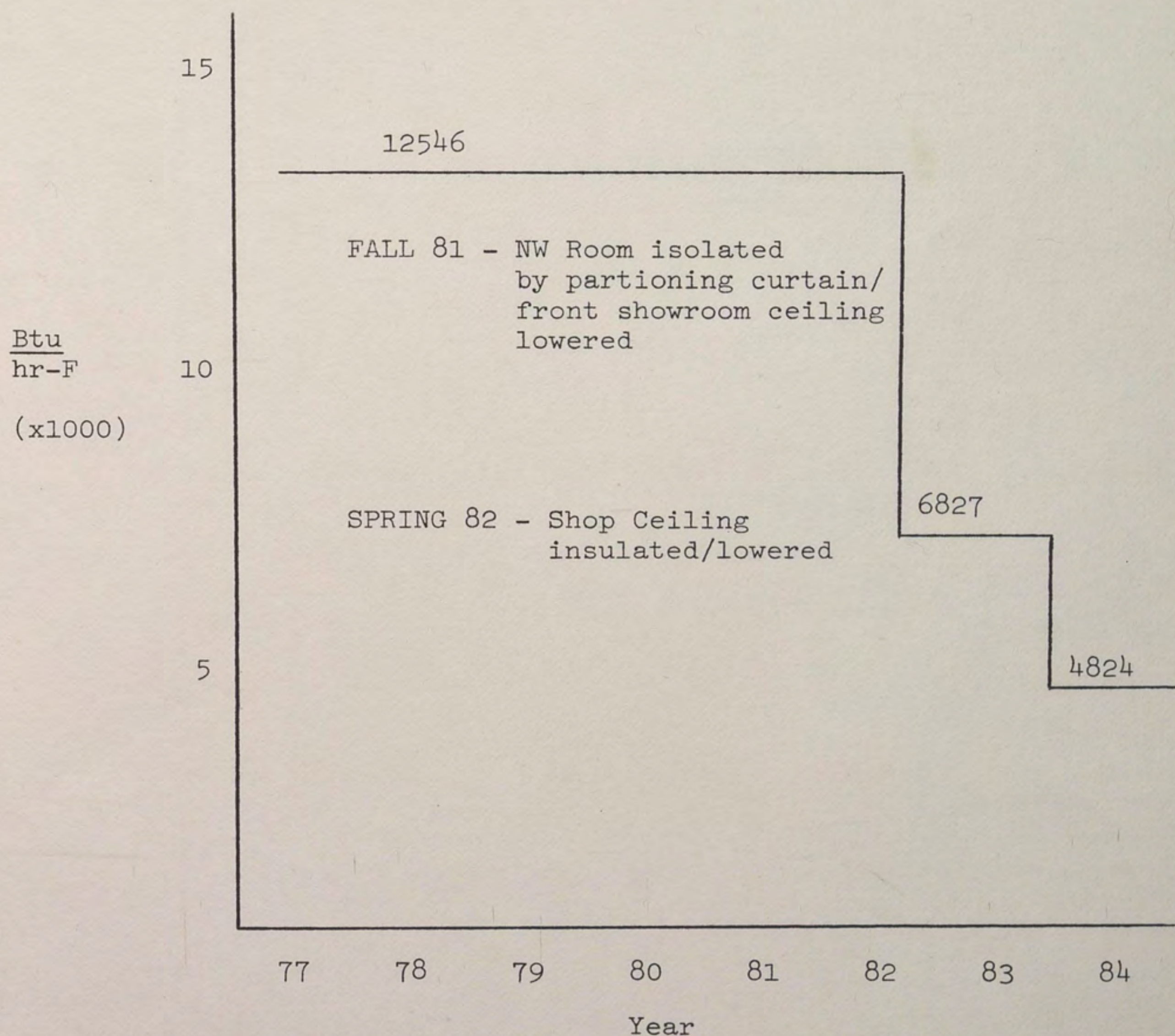

Figure 6. Effective Loss Coefficient - Area (UA) Product

Building Measurement

To evaluate the separate sections of the building the following pages represent individual measurements made throughout the building.

Units: Area - ft^2
Thickness - in
R - hr-ft^2-F/Btu
U - Btu/hr-ft^2-F
UA - Btu/hr-F

Region: East shop wall

Gross area: 1564

Section	Area	Material	Thickness	R	U	UA
Wall	1483	concrete	13	3.12		
		airfilm		.85 *		
				3.97	.252	373.7
Windows	81	glass			1.10	89.1

Total 463

*Assumes .68 inside and .17 outside for a 15 mph wind (Appendix A)

Region: North wall of the east side

Gross area: 971

Section	Area	Material	Thickness	R	U	UA
Window	230	glass	-	-	1.10	253.0
Wall	429	concrete airfilms	10.5	2.52 .85 3.37	.297	127.4
Door Framing	18	steel airfilms		assume small .85	1.18	21.2
Walk-thru door	28	steel w/ air space airfilms	1.25	1.50 .85 2.35	.426	11.9
LARGE DOOR Window	266 88	Glass			1.10	96.8
Wood strips	67	wood airfilms	1.25	1.56 .85 2.41	.415	27.4
Thin board	111	wood airfilms	.25	.31 .85 1.16		95.7
					Total	633

Region: Southeast Showroom

Gross area: 1226

Section	Area	Material	Thickness	R	U	UA
Window (including fixed doors)	603	glass			.939	566.2
Top Wall	474	concrete airfilms	8.5	2.04 1.00* 3.04	.329	155.9
Bottom Wall	73	concrete airfilms	4	.96 1.00 1.96	.51	37.2
Framing	45	wood airfilms	4	5.00 1.00 6.00	.167	7.5
Usable door	31	glass			.939	29.1
					Total	796

*Assumes .68 inside and .32 outside for a 5 mph wind

Region: South face of southwest showroom

Gross area: 412

Section	Area	Material	Thickness	R	U	UA
Window	153.0	glass			.939	143.7
Wall	220	brick mortar tile airfilm	4 1 8	.80 .20 1.85 1.00 3.85	.26	57.2
Door	24 9 15	glass wood airfilm	1.25	1.00 1.00 2.00	.939 .5	8.5 7.5
Framing	15	wood airfilm	7.5	9.38 1.00 10.38	.096	1.4
					Total	218

Region: West face of southwest showroom (office included)

Gross area: 355

Section	Area	Material	Thickness	R	U	UA
Window	52	glass			1.10	57.2
Block window	19	glass	6		.6	11.4
Framing	8	wood airfilm	7.5	9.38 .85 10.23	.098	.8
Wall	276	brick mortar tile airfilm	4 1 8	.8 .2 1.85 .85 3.70	.27	74.5

Total 144

Region: North face of southwest showroom

Gross area: 483

Section	Area	Material	Thickness	R	U	UA
Shelf area	30	Plywood airfilm	.625	.77 1.36** 2.13	.469	14.1
Display area	50	wood carpet airfilm	1.25	1.56 2.08 1.36 5.00	.2	10
Wall	154	tile mortar airfilm	8 1.5	1.85 .30 1.36 3.51	.285	43.9
Wall	87	cinder mortar airfilm	8 1	2.00 .20 1.36 3.56	.281	24.4
Door	21 10.5	glass		1.36	.735	7.7
	10.5	wood airfilm	1.25	1.56 1.36 2.92	.342	3.6

Sub Total 103.7
x .5*
51.9

continued next page

*The heat transfer is assumed 50% less because wall is adjacent to an unheated room, not to the outside. (Jennings 1978)

**Assumes .68 on both sides of wall (Appendix A)

Section	Area	Material	Thickness	R	U	UA
Door	21					
	10.5	glass		1.36	.735	7.7
	10.5	wood	1.25	1.56		
		airfilm		1.36		
				2.92	3.42	3.6
Wall	69	tile	8	1.85		
		mortar	1.5	.30		
		airfilm		1.36		
				3.51	.285	19.7
Wall	51	cinder	8	2.00		
		mortar	1	.20		
		airfilm		1.36		
				3.56	.28	14.3
					Sub Total	45.3
						x.25*
						11.3
				Total		63

*Additional resistance is assumed because this span of wall is adjacent to a small unheated room in addition to the large unheated room. (Jennings 1978) [Reasonability of heat loss value (63 Btu/hr-F) verified by more in-depth calculation not assuming the .25 factor.]

The sensitivity of results because of the assumed smaller temperature differences is of no real consequence. As will be shown, values involving the adjacent unheated room make up only about 5% of the total heat loss. It is more important to develop a general magnitude of heat loss for the different areas measured for overall comparison.

Region: West face of the east side

Gross area: 695

Section	Area	Material	Thickness	R	U	UA
Masonary	378	brick tile mortar concrete airfilm	4 8 1 8	.8 1.85 .2 1.92 1.36 6.13	.163	61.6
Girder	52	steel airfilm		* 1.36	.735	38.2
Styrofoam	20	airfilm	3	10.71 2.38*** 13.09	.076	1.5
Curtain	245	airfilm		1.36	.735	180
					Total	281.3 x.5** 141

*Assume to be of negligible resistance
**Increased resistance assumed because of adjacent room
***Assumes higher resistance because of reflective surface (Appendix A)

Region: East side ceiling

Gross area: 9064

Section	Area	Material	Thickness	R	U	UA
South	3169	cellulose airfilm	4	14 1.22* 15.22	.066	209.2
Parts department (overheat)	761	plywood airfilm	1.25	1.55 1.22 2.77	.361	274.7
North	4635	styrofoam airfilm	3	10.71 1.93** 12.64	.079	366.2
Upper Level (Parts department)	499					
	151	styrofoam	3	10.71 2.38 13.09	.076	11.5
	158	metal airfilm		--- 1.36	.735	116.1
	189	wood airfilm	.75	.94 1.36 2.30	.435	82.2

Subtotal 1060

$$***\text{Effective } "U_c" = \frac{1060}{9064} = .117$$

continued next page

*Assumes .61 on both sides of ceiling (Appendix A)

**Assumes higher resistance because of reflective surface (Appendix A)

***U_c is the overall heat transfer coefficient for the ceiling

Section	Area	Material	Thickness	R	U	UA
ROOF DECK	9520					
End Walls	571	concrete airfilm	8.5	2.04 1.00 3.04	.329	187.9
	571	concrete airfilm	10.5	2.52 .85 3.37	.297	169.6
Dome	8378	asphalt airfilm		.88 .79* 1.67	.599	5018
				Subtotal		5376

$$**\text{Effective } "U_r" = \frac{5376}{9520} = .565$$

To calculate (UA) for both ceiling and roof:

$$n = \frac{Ar}{Ac} = \frac{9520}{9064} = 1.05 \qquad U = \frac{UcUr}{Uc + \frac{Uc}{n}} = \frac{(.117)(.565)}{.565 + \left(\frac{.117}{1.05}\right)} = .098$$

$$UA = (.098)\ 9064 = 888$$

*Assumes .62 inside and .17 outside for 15 mph wind (Appendix A)
**U_c is the overall heat transfer coefficient for the roof

Region: Southwest showroom ceiling

Gross area: 1655

Section	Area	Material	Thickness	R	U	UA
Ceiling	1540	fiberboard	.5	1.25		
		fiberglass	3.5	11.0		
		airfilm		1.22		
				13.47	.074	114.0
Deck	1540	wallboard	.5	.45		
		space		.93		
		plywood	.625	.77		
		airfilm		1.22		
				3.37	.297	
		wallboard		.45		
		stud	8	9.06		
		plywood	.625	.77		
		airfilm		1.22		
				11.5	.087	
	weighted average: (.297)(.9)+(.087)(.1) =				.276	425
Wall	144	brick	4	.80		
		mortar	1	.20		
		tile	8	1.85		
		airfilm		1.00		
				3.85	.260	37.4
	96	brick	4	.80		
		mortar	1	.20		
		tile	8	1.85		
		airfilm		.85		
				3.70	.27	25.9
	144	tile	8	1.85		
		mortar	1.5	.30		
		airfilm		1.36		
				3.51	.285	41.0
		(Deck & Wall)		subtotal		529.3

continued next page

Effective "U_r" $= \frac{529.3}{1924} =$ .275

$$n = \frac{A_r}{A_c} = \frac{1924}{1540} = 1.25$$

$$U = \frac{U_c U_r}{U_r + \frac{U_c}{n}} = \frac{(.074)(.275)}{.275 + .074} = .061$$

UA = (.061)(1540)(.5)* = 47

Additional small office (UA) = (115)(.276)(.5) = 16

Total (UA) = 63

*Allowance for lessened temperature difference of adjacent room (Jennings 1978)

Calculating Transmission Heat Loss from Floor Slabs

Even though the east side of the building has been designed for heated floors, it is only the center panel that is active. This leaves most of the heated-building floor space unheated. With this consideration the following analysis is extracted from the ASHRAE Fundamentals:

Experiments with unheated floor slabs indicate that heat loss from a concrete slab floor on grade is more nearly proportional to perimeter than to area of the floor, and that the heat loss can be estimated by means of:

$$q = FP(ti - to)$$

where

q = heat loss of floor, Btu per hour
F = heat loss coefficient, Btu per hour per linear foot of exposed edge per degree Fahrenheit temperature difference between the indoor air and the outdoor air.
P = perimeter or exposed edge of floor, linear feet.
ti= indoor air temperature, Fahrenheit.
to= outdoor air temperature, Fahrenheit.

The value of F ranged from 0.81 for a floor with no edge insulation to 0.55 for a floor with 1 inch of edge insulation. (Note that this assumes that the insulation extends well below the slab.)

Perimeter measurements give the following analysis:(Present application only allows for minimal edge insulation, F estimated to be .63)

Footage exposed to the outside air:
166 ft (1" insulation) + 200 ft (no insulation) = 366 ft
Footage exposed to the unheated room: 100 ft
[Note that the temperature difference between heated and unheated rooms is to use one-half the temperature difference between inside and outside]

The equivalent (UA) product is calculated as follows:

For 1" insulation: FP = .63 x 166 = 105 Btu/hr-F
For no insulation: FP = .81 x 200 = 162 Btu/hr-F
For the inside wall: FP = .5(.81 x 100) = 41 Btu/hr-F
The total evaluated slab loss: 310 Btu/hr-F

Door Air Exchange Calculation

Evaluation up to this point has only involved transmission losses which total 3719 $\frac{Btu}{hr-F}$ the remaining heat loss involved air infiltration.

In order to evaluate the heat loss as a result of air infiltration a process of elimination is invoked. With all the transmission losses accounted for, the remaining heat loss can be attributed to normal air leaks and to the opening of the large garage door. Considering the complexity of evaluating air leaks a conservative approach is undertaken by assuming some maximum air exchange when the garage door is opened.

The assumed total time open is 30 seconds.
Raising to a height of 10 feet takes about 13 seconds.
Stay time at 10 feet is 4 seconds.
Assumed is a direct wind incoming at 22 feet per second.
Width of the door is 20 feet.
The total volume of air exchanged as a result of thorough mixing and turbulence is calculated (using an average heights (5 feet) during raise):

$$\text{Volume} = (22\ ft/sec)(100\ ft^2)\ (26\ sec) = 57200\ ft^3$$
$$\text{Volume} = (22\ ft/sec)(200\ ft^2)\ (\ 4\ sec) = \underline{17600\ ft^3}$$
$$74800\ ft^3$$

Over a month's time:

$$(4.33\ weeks)(5.5\ day/month)(10\ hr/day)(1\ opening/hr)(74800\ ft^3/opening)$$
$$= 17.8 \times 10^6\ ft^3/month$$

To evaluate the effective (UA) product for air infiltration the following density/heat capacity product is used:

$$.018\ Btu/ft^3\text{-}F = (.075\ lb/ft^3)\ (.24\ Btu/lb\text{-}F)$$

By deduction the contribution by all air exchange is 4824 -3719 =1105 Btu/hr-F. The resulting volume by air leaks is 1105/.018 = 61390 $\frac{ft^3}{hr}$

In one month: $(4.33\ weeks)(168\ hr/week)(61390\ ft^3/hr)$

$$= 44.7 \times 10^6\ ft^3/month$$

As a result the maximum infiltration by the door is 17.8/44.7 = 39.8%. The difference represents leaks through cracks that can potentially be fixed. The (UA) = 665 Btu/hr-F.

Cummulative Heat Loss

By examining all the (UA) values for transmission and infiltration losses the fractional losses can be determined for each section of the building. To make the information more meaningful, however, the representative areas of heat loss are fractioned into potentially correctable locations in terms of insulation and stopping air leaks. Figure 7 emphasizes this heat loss breakdown.

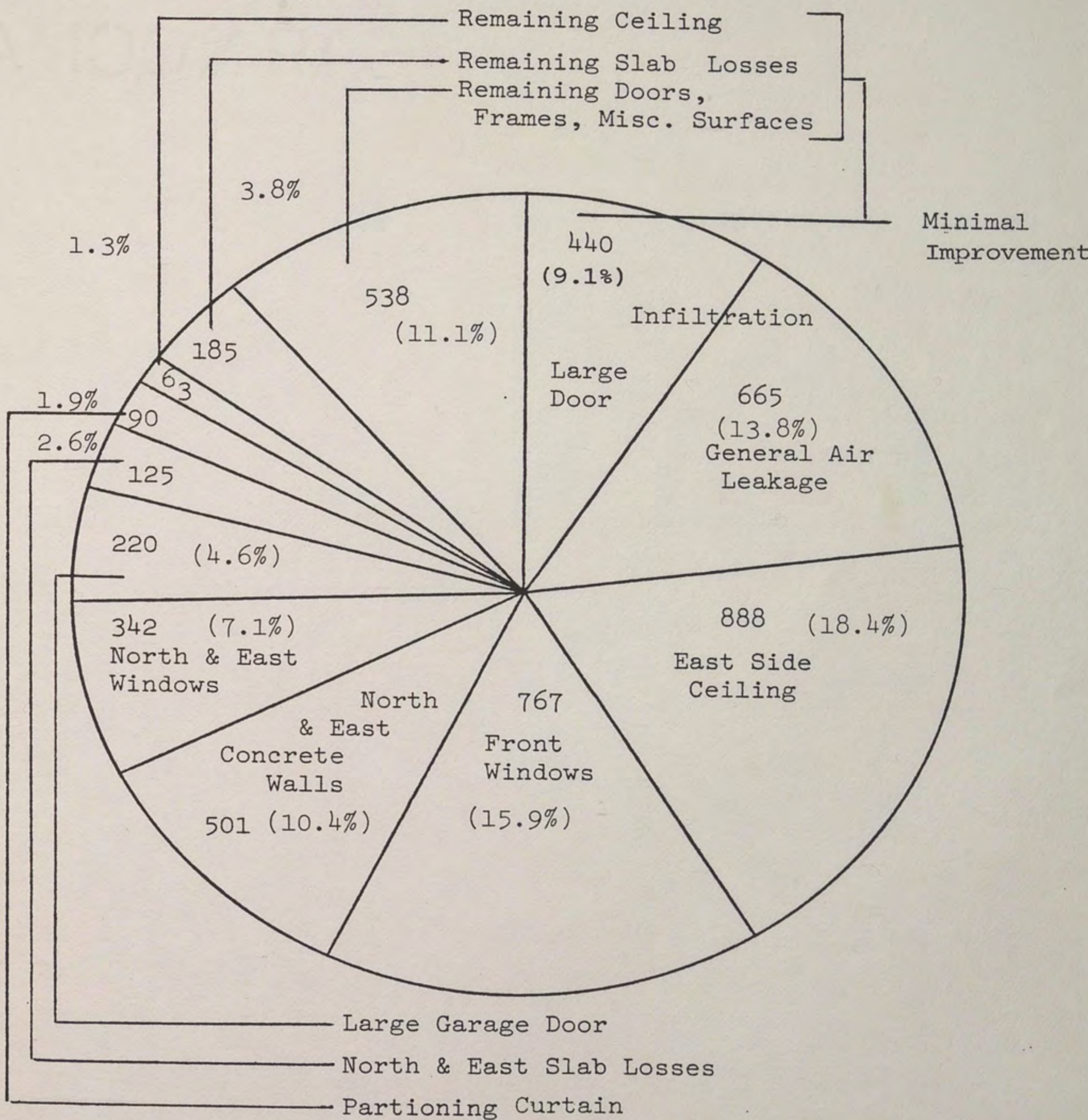

Figure 7. Comparative Heat Loss (Btu/hr-F)

Conservation Proposals

Insulation

For the sake of reducing heat loss as a result of transmission losses several options are available for implementation around the building. Figure 7 illustrates the locations of interest that can be modified. To show the improvement in energy savings and cost, a standard has been selected for comparison. Over the last two years typical gas usage has been about 720 Mcf per year. A previous estimation of electric heat was 790 Kwh per month. Over a seven month heating season and using a boiler efficiency of 79% the following equivalent amount of gas is calculated.

$$\text{Equivalent volume} = \frac{(790\ \text{Kwh/month})(7\ \text{months})(3412\ \text{Btu/Kwh})}{(965000\ \text{Btu/Mcf})(.79)} = 25\ \text{Mcf}$$

For comparison the annual gas usage has been 745 Mcf.

Considering the cost savings it is realized that electric heat is more expensive than using gas. For verification, the cost of gas plus tax is \$5.30 per Mcf and the cost of electricity is \$0.076 per Kwh. Using unit analysis:

$$\text{Cost of gas} = (\$5.30/\text{Mcf})(1\ \text{Mcf}/965000\ \text{Btu})(3412\ \text{Btu/Kwh})$$

$$= \$0.019/\text{Kwh}$$

$$\text{Weighted cost of energy} = (.034)(4)(\$5.30) + (.966)(\$5.30) = \$5.84/\text{Mcf}$$

Conservatively, \$5.80 is used for analysis. To show the corresponding cost savings in each case the following factor is implemented:

$$F = \frac{(745\ \text{Mcf/year})(\$5.80/\text{Mcf})}{(4824\ \text{Btu/hr-F})}$$

$$= .896\ \frac{\$\text{-hr-F}}{\text{Btu-year}}$$

Previous evaluation has indicated that heat loss characteristics of the east side ceiling is 888 Btu/hr-F. The south section of the ceiling is insulated with the four inches of blown-in cellulose. This insulation (combined with the air films) gives R=15.22, whereas on the north section the silvered styrofoam gives R=12.64. To enhance the thermal resistance of the north ceiling more of the cellulose could be applied. A deciding factor for possible thickness is to consider that the supporting trusses have significant gaps at their connecting points. This is an infiltration consideration that might be eliminated by "smothering" those areas, in addition to the entire region with four inches of cellulose. The new R = 26.64. Furthermore, part of the upper level parts department only allows for a metal barrier to the attic space. As a viable option, some of the available silver styrofoam may be affixed to this area, enhancing the R-value from 1.36 to 13.09. Referencing the calculations for the east ceiling (page 23), new U-values are developed giving the following calculation:

$$U = \frac{UcUr}{Ur+Uc/n} = \frac{(.084)(.565)}{.565 + .084/1.05}$$

$$= .0736 \text{ Btu/hr-ft}^2$$

$$UA = (.0736)9064 = 667 \text{ Btu/hr-F}$$

Savings: 221 Btu/hr-F x F = \$198/year

Estimated cost: \$1500

Examination of the pie chart indicates the front window losses make up 16% of building heat loss. The most elaborate proposal incorporates triple pane windows, which in effect could reduce this loss down to 5%, however this operation carries a $20,000 price tag, an investment not easily returned. In order to create a thermal barrier. and yet maintain the see-through window space (without excess expense) a sheet of see-through plastic may be stretched over the framing creating an air space with R=1.0. This reduces the U-value from .939 to .484. As a result the (UA) product is reduced from 767 to 395 Btu/hr-F.

Savings: 372 x F = $333/year

Estimated cost: $200 (mostly in-house labor)

The goal to reduce window losses is extended to the windows on the north and east sides. On a per-square-foot basis the heat loss is greater for these windows compared to the south side because of the north winds. To establish a similar thermal barrier the plastic sheet can be stretched on a removable wood framework which can be placed over the existing windows. By increasing the R-value by 1.0 the resulting U-value is reduced from 1.1 to .52 Btu/hr-ft^2-F. This action reduces the (UA) product from 342 to 162 Btu/hr-F.

Savings: 180 x F = $161/year

Estimated cost: $200(in-house labor)

This action can also aid in reducing air infiltration through the window itself.

One of the potentially most expensive, but no less important options is to insulate the north and east concrete walls. At present the heat loss is measured as 501 Btu/hr-F. By insulating the exterior with one inch of urethane (R=7.14) the heat loss is reduced to 174 Btu/hr-F. An added benefit would be that of smothering any potential cracks or general porosity of the concrete for sake of air infiltration.

Savings: 327 x F = $293/year

Estimated cost: $3300 (based on insulating 2400 square feet @ $1.35/ft^2)

In structure and thickness the large garage door is much like that of the windows, because one-third is glass and nearly one-half is quarter-inch thick wood. The options are varied for reducing the present heat loss of 220 Btu/hr-F. Depending on the desirability of light available through the glass, the efforts in spraying the urethane on the walls may extend to this door. This will reduce the heat loss to about one-eighth the present value. From a simple approach, to at least cut the loss in half, the application of the plastic sheet spread over the face of the door, both front and back, could create an R-value of 2.00. The resulting heat loss is 65 Btu/hr-F. This measure would also assist in eliminating the air leaks occuring between the door panels.

Savings: 155 x F = $139/year

Estimated cost: $50

The heat loss that occurs from the slab can be reduced on the north and east sides by application of buried insulation. (Note the remaining perimeter has concrete base.) Using the guidelines of the ASHRAE Fundamentals, by burying 2" thick insulation, such as styrofoam, two feet below slab level the heat loss may be reduced from 125 to 91 Btu/hr-F.

For area having one-inch insulation:

Heat loss = 166 x .47 = 78 Btu/hr-F

For span without insulation:

Heat loss = 25 x .50 = 13 Btu/hr-F

The values for the proportionality factor, F=.47 and F=.5, have been conservatively interpolated (or extrapolated) from listed data in ASHRAE.

Savings: 34 x F = $30/year

Estimated cost: $200 (major cost projected to be the ditch digging)

To better isolate the northwest (unheated room) from the main building the present curtain could be replaced by the already available three inch thick styrofoam. The resultant change in heat loss is from 90 to 9 Btu/hr-F. This is reflected because the thermal resistance has increased from R=1.36 to R=13.09.

Savings: 81 x F = $73/year

Estimated cost: $200 (mostly labor)

Actions to Prevent Infiltration

The heat loss associated with air infiltration has been examined collectively, instead of evaluating individual locations of air leakage. At present this total contribution to heat loss through air infiltration is 665 Btu/hr-F. The following proposals are also represented together without calculation of how individual action might affect the overall heat losses.

All cracked or broken windows (primarily in the northwest [unheated] room) should be replaced.

The north and east windows with open capability should be appropriately weather stripped to eliminate any small cracks.

The large door edges (bottom, top, and sides) should be refitted with a rubber lip or flap while the door panel joints could be covered with plastic eliminating leakage.

Leakage around window framing should be eliminated by practical means of caulking, painting, or applying putty. In some cases the frames may need to be dismantled to ensure the seal between the frame and masonry is tight.

The duct work associated with exhaust ports (two flue pipes, one car exhaust fan), should be fitted for dampers to close off openings when pipe extensions.

With six vent turbines on top of the building, although already "covered," a tighter cover fit should be implemented covering over the pipe extensions.

Some improvements are coincident with measures to insulate the building. These would include: the big door's plastic cover, blown in insulation in the northeast ceiling, secure partition offsetting the northwest room, and the plastic cover on the north and east windows.

All efforts towards reducing general air inflitration translate to the following savings.

Savings: 665 x F = $596/year

Estimated cost: $1000 (projected to be mostly in-house labor)

It is noted that through all conservation efforts involving insulation and reducing infiltration the total energy savings is 2035 Btu/hr-F which translates to $1820 per year.

HEATING SYSTEM EVALUATION

Description

The primary means of heating the building is provided by a natural gas-fired boiler used to heat water that is circulated through copper tubing laced through the concrete floor. The input is 273,000 Btu/hr and the boiler efficiency has been evaluated to be 79% by collecting temperature and mass flow rate data of the water. Specifically, this unit heats the center panel of a possible three. On rare occasion another unit comes on to assist in building heat during the coldest days.

This panel heat is transmitted by convection and radiation throughout the local shop space. Because of poor circulation tendency throughout the building, the office spaces require additional heat. This heat is presently provided by electric space heaters, as previously noted.

The furnace efficiency offers opportunity for improvement, as does the elimination of the space heaters. As a potential resource, stockpiled behind the building are several hundred gallons of waste oil that can be burned for supplementary heat.

Conservation Proposals

Furnace Efficiency

In efforts to improve the boiler efficiency the combustion air requirements have been determined to be excessive. Referencing Figure 8, once the efficiency was evaluated and the flue temperature measured at 435 F, the excess air was estimated to be 53%. By utilizing better draft control the combustion air could be reduced to a more optimum value of 10%. By examining Figure 8, or evaluating the effect numerically (Appendix B) the efficiency can be increased from 79% to 81.8%. The corresponding ratio implies that of 720 Mcf of gas used per year that 3.4% may be saved.

Savings: (24 Mcf/year)($5.30/Mcf) = $127/year

Estimated cost: $50(labor for installing dampers)

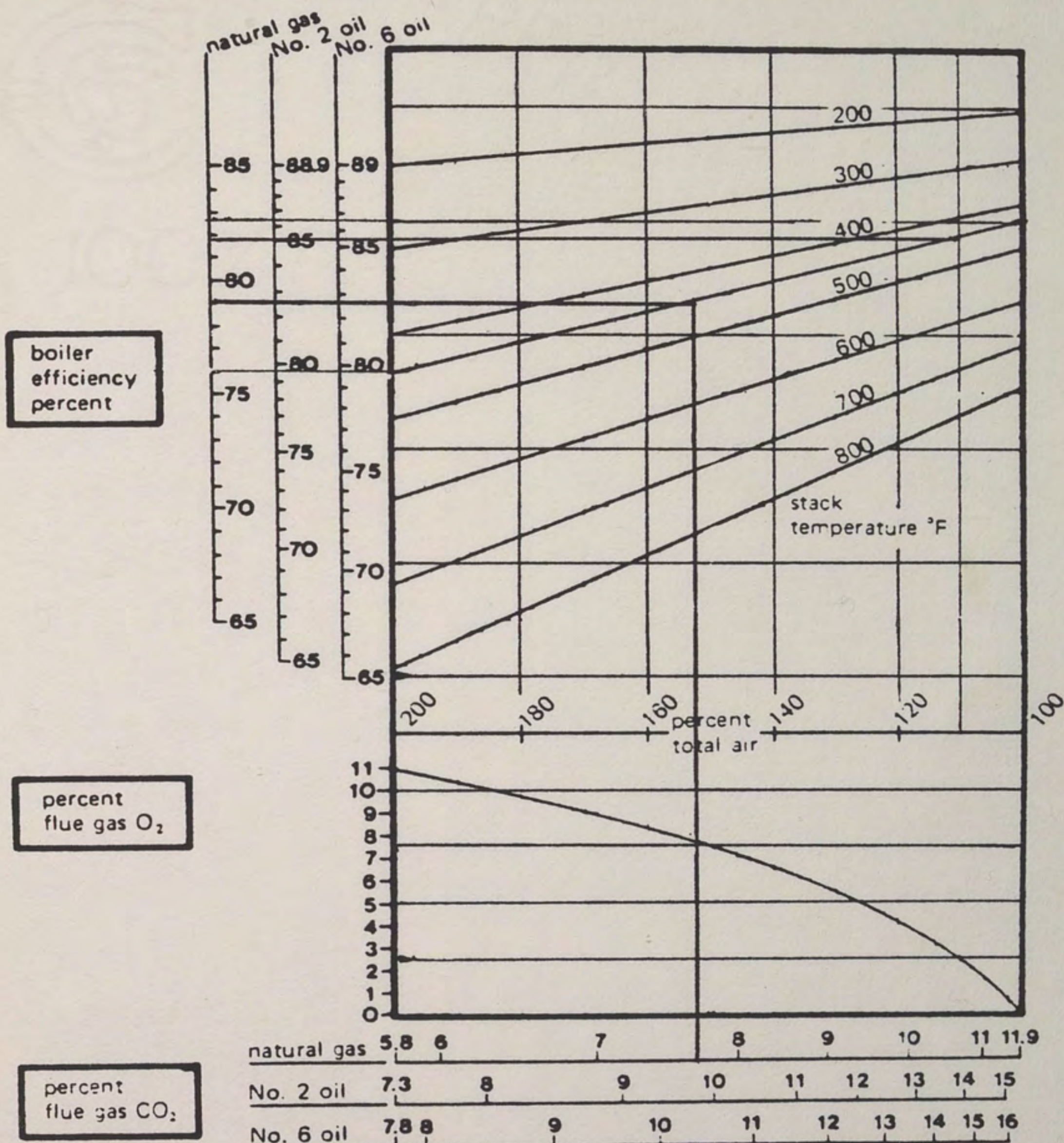

Figure 8. Effect of Flue Gas Composition and Temperature on Boiler Efficiency (Thuman 1984)

To extract the energy from the flue gas and also enhance the efficiency (beyond the draft control measures) a finned-tube heat exchanger may be placed in the flue gas stream to act an an economizer. Assuming some lowest reasonable attainable temperature at 120 F, the exchanged energy will be both sensible and latent heat. Appendix B shows the corresponding calculations. The resulting efficiency improvement is from 81.8% to 92%. This change translates to a fuel savings of 11.1% of 720 Mcf of gas is used per year.

Savings: (80 Mcf/year)($5.30/Mcf) = $424/year

Estimated cost: $400 (materials and labor of construction)

Electric Heat Replacement

The piping distribution is favorable such that if the lines were spliced in certain locations the gas heating could be made available to office spaces. The purpose is to eliminate the necessity for the more expensive supplementary heat by electricity. As previously estimated, over seven month's time the gas equivalent to the electric heat is 25 Mcf. Another consideration is that an air distribution system would have to interface the liquid system which will require electricity for a blower motor.

Cost = (10 hr/day)(5.5 day/week)(4.33 week/month)(.4 Kw)($.076/Kwh)

= $7/month x 7 months = $49/year

Replacement gas cost = (25 Mcf/year)($5.30/Mcf) = $133/year

Present cost of electricity = (790 Kwh/month)(7 months/year)($.076/Kwh)

= $420/year

Savings: $420 - $133 - $49 = $238/year

Estimated cost: $1500 (labor and materials for ductwork)

Note that when the boiler efficiency is enhanced this measure becomes more cost effective.

Waste Oil

Over several years waste oil has accumulated as a result of service on cars. This stockpile is estimated to be 2000 gallons and increasing at 350 gallons per year. Assuming a heating value of 140,000 Btu/gallon and a boiler efficiency of 80%, this energy translates to 224 MMBtu available for immediate use and 39 MMBtu available annually. Interfacing a combustion chamber and heat exchanger with the present piping system would save the equivalent amount of gas energy. Depending on the relative boiler efficiencies the cost savings are translated as follows.

First year savings: $\frac{(24 \text{ MMBtu})(\$5.30/\text{Mcf})}{(.965 \text{ MMBtu/Mcf})(.79)} = \$1557$

Annual savings: $\frac{(39 \text{ MMBtu/year})(\$5.30/\text{Mcf})}{(.965 \text{ MMBtu/Mcf})(.79)} = \$271/\text{year}$

Implementation requires investment in a combustion chamber and appropriate hook ups to match the already available oil burner unit.

Estimated cost: $500 (labor and materials)

ALTERNATIVE ENERGY OPTIONS

Solar Energy

Under the present economic trends in natural gas and electricity costs, investments in solar energy would not be cost effective (based on calculations on page 43). However, for future consideration, to illustrate its energy contribution to heating by means of an active system the following analysis is carried out.

Working strictly from average values to test for general feasibility, the necessary solar data are interpolated from that given for Amarillo, TX, latitude = 35.23° and Dodge City, KS, latitude = 37.77°. Boise City, OK, has a latitude of 36.75°. Working with information for the winter months from October through April, the following average daily insolation values on a horizontal surface (one square foot) are 1309 Btu/day for Amarillo and 1177 Btu/day for Dodge City. Interpolation yields $\overline{H}$ = 1230 Btu/day for Boise City, OK.

Estimating an average declination angle of -15°, the corresponding collector tilt so that it is approximately normal to the sun throughout the winter is 36.75° + 15° = 51.75° or about 52°. Using tables of average tilt factors, $\overline{Rb}$, over seven months; at latitude = 35°, $\overline{Rb}$ = 1.67; and at latitude = 40°, $\overline{Rb}$ = 1.91. Therefore the value of interest is $\overline{Rb}$ = 1.75.

Assuming that a collector of reasonable quality has an efficiency of .7, the following useful gain of solar energy can be made over seven months or 212 days of the heating season.

Energy Gain = (1230 Btu/day-ft^2) (212 days)(.7)(1.75)

= 319,000 Btu/ft^2 -season

If a series of panels were placed on the front face of the building, occupying 400 ft^2, the total gain for the season is 128×10^6 Btu (128 MMBtu). Assuming all conservation measures are implemented eventually, this reduces the heating requirements down to 58% of present needs. This translates to E = (.58) (745 Mcf) (965,000 Btu/Mcf)(.92) = 384 MMBtu. This contribution to heating would be about thirty percent. A local dealer of solar equipment estimated a cost of over $18,000 for this type of installation. In simple payback figures, given that the eventual heating costs can be about $2000 per year this implies that the payback time would be thirty years.

Wind Energy

In the Oklahoma Panhandle the average annual wind speed rates about 14 mph based on interpolation between Amarillo and Dodge City (Jennings 1978). Considering the electrical needs of the business at about 30,000 Kwh per year, this available wind energy could potentially assist in supplying all electrical needs.

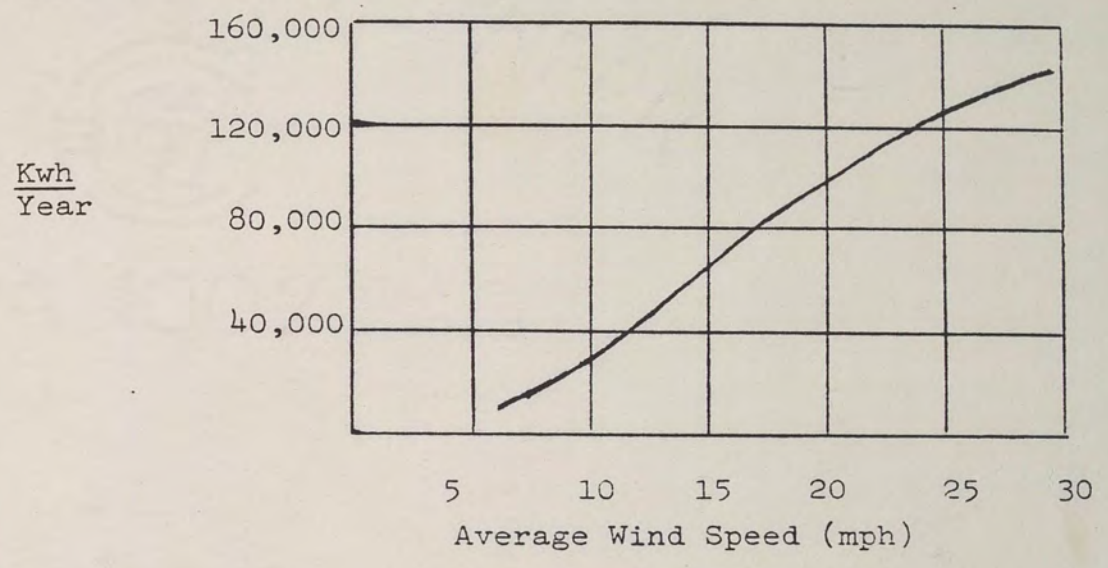

Figure 9. Kwh/year vs Average Wind Speed (Carter Wind Systems)

Realistically, a business inside a city would have to contend with considerable wind turbulence hence reducing the extracted energy. However, given a unit of adequate size and height (aesthetics within city limits and legal implications not considered) the energy requirements could be met. One manufacturer builds a unit that could supply this annual load, plus as supply outweighs demand the excess could be sold to the local utility (see Figure 9).

The installed cost of this unit is about $30,000. At the present rate of 7.6¢ per Kwh the annual cost of electricity is $2280 giving a simple payback of 13.2 years. Presently this investment would be too extended considering previous arguments about coal-fired plants to supply electricity. To test for feasibility for the future, on-site anemometer recordings should be made for one year. These values should then be compared to electricity demand to accurately determine the wind energy contribution when it is needed.

SUMMARY

The analysis carried out on the given building considers measures for insulation and stopping air leaks, improving furnace efficiency, eliminating electric heat, usage of waste oil, and general comments on solar and wind energy. Each area of investigation offers energy savings and varying degrees of monetary savings.

The recommendations involving insulation around the building in one form or another is projected to reduce transmission losses by 37% which gives a savings of $1200 per year with an initial investment of $5700. The efforts toward eliminating air leaks is assumed to be complete, bringing infiltration losses nearly to zero. This energy savings is expected to be quite conservative because of calculational methods involving the large garage door. The corresponding monetary savings is $600 per year with an initial investment of $1000.

By controlling combustion air and extracting flue gas heat the furnace efficiency can be improved from .79 to .92. This implies less fuel used per year which gives a monetary savings of $550 per year with an initial investment of $450.

To revamp the heating system within the building eliminates the necessity for electric heat. Such action does not necessarily save energy but allows the use of cheaper energy. This action could cost $1500 and tends to save $240 per year.

With the stockpile of waste oil now available and the annual supply expected, burning it for supplementary heat saves on purchase and burning of natural gas. An expected initial cost would be $500 with a first year savings of $1500 and annually thereafter, $270.

Discussion of wind and solar energy are brought out for consideration only. At present, the cost of electricity and natural gas have stabilized and their cost increases are expected to be more in line with inflation. Only in the future, with rapid price increases, would such investments be reasonably cost effective.

Overall, if the recommendations are followed, the expected costs are $9200 and the savings would be $4200 the first year and $2900 each year thereafter. This projection suggests a simple payback of 2.7 years.

APPENDIX A

THERMAL RESISTANCES

Air Film Resistances

Still Air

Orientation	Heat Flow	R (E = .9)	R (E = .05)
Horizontal	Up	.61	1.32
Sloping	Up	.62	
Vertical	Horizontal	.68	1.70

Moving Air (15 mph) .17

Building Materials Resistances

Material	Thickness (in.)	R
Plaster board	.5	.45
Plywood	.25	.31
Plywood	.625	.77
Plywood	.75	.93
Clay tile	6	1.52
Clay tile	8	1.85
Asphalt shingles	-	.44
Wood	.75	.94
Wood	1.50	1.89
Wood	2.50	3.12
Wood	3.50	4.35
Polyurethane	1	7.14
Fiberboard	.5	1.25

Material	Resistance per inch
Styrofoam	3.57
Cellulose	3.50
Mortar	.20
Concrete(floor)	.15
Concrete(wall)	.24
Brick	.20

Materials with overall coefficients

Glass	U = 1.10
Glass block (6"x6"x4")	U= .6

APPENDIX B

FURNACE EFFICIENCY IMPROVEMENT

Excess Air Calculation

	$\frac{ft^3}{ft^3}$* fuel	$\frac{lb}{ft^3}$	$\frac{lb}{ft^3}$ fuel	$\frac{lb}{lb}$ fuel	$\frac{lbair}{lb}$	$\frac{lbair}{lbfuel}$
Methane	.685	.04243	.02906	.5213	17.265	9.000
Ethane	.07	.08029	.00562	.1008	16.119	1.6248
Propane	.044	.1196	.00526	.0944	15.763	1.48236
Butane	.0099	.1582	.001566	.02809	15.487	.4350
Pentane	.0002	.1904	.000038	.00068	15.353	.01044
N_2	.1909	.07439	.0142	.25475	--	--
Total	1.000	--	.05574			12.5526 x1.53** 19.205 $\frac{lbair}{lbfuel}$

$$\text{Heating value per lb of fuel} = \frac{965 \text{ Btu/ft}^3}{.05574 \text{ lb/ft}^3} = 17311.3 \text{ Btu/lb}$$

*Values estimated from the Handbook of Natural Gas Engineering and matched with the heating value of 965 Btu per thousand cubic feet suggested by the local gas company representative.

**The 53% excess air estimated from Figure 8.

Combustion Product Calculation

	$\frac{lb}{lb\ fuel}$	$\frac{lb\,CO_2}{lb}$	$\frac{lb\,CO_2}{lb\ fuel}$	$\frac{lb\,H_2O}{lb}$	$\frac{lb\,H_2O}{lb\ fuel}$	$\frac{lb\,N_2}{lb}$	$\frac{lb\,N_2}{lb\ fuel}$
Methane	.5213	2.744	1.4304	2.246	1.1708	13.275	6.9203
Ethane	.1008	2.927	.295	1.798	.1812	12.394	1.2493
Propane	.0944	2.994	.2826	1.634	.1542	12.074	1.1398
Butane	.02809	3.029	.08508	1.55	.04354	11.908	.3345
Pentane	.00068	3.050	.00207	1.498	.001	11.805	.00803
N_2	.25475	--	--		1.5507		.25475
Total			2.0952		1.5507		9.9067

Total Combustion Product*
13.5526 lb

Excess air = 19.205 lb - 13.5526 lb = 6.6529 lb

*Excess O_2 and N_2 not accounted for. With 53% excess air, given that air is 76.85% by weight N_2 and 23.15% by weight O_2, there is 5.1127 lb N_2 and 5.1127 lb N_2 and 1.5402 lb O_2.

Energy Loss Due to Excess Air

	$\frac{lb}{lb\ fuel}$	$\frac{lb}{lb\ flue}$	$\frac{Btu^*}{lb\text{-}F}$	** 435-60	$\frac{Btu}{lb\ flue}$
CO_2	2.0952	.1037	.225	375	8.75
H_2O	1.5507	.0767	.481	375	13.83
N_2	15.0194	.7433	.2498	375	69.63
O_2	1.5402	.0763	.225	375	6.44

Total 20.2055 98.6

Latent heat of $H_2O = (.0767\ \frac{lb}{lb}\ _{flue})(1040\ \frac{Btu}{lb}) =$ 79.82

178.47 $\frac{Btu}{lb\ flue}$

Exhaust Equivalent $= \frac{17311.3}{20.2055} = 856.76\ \frac{Btu}{lb\ flue}$

Loss of energy $= \frac{178.47}{856.76} = .208$

*Heat capacity at 260F extractd from Schaum's Outline: Heat Transfer

**Assumed ambient temperature of 60F [this temperature coincident with temperature conditions for the heating values of gases. Should all flue products render their sensible (and latent) heat to the building, the furnace would be 100% efficient.]

Efficiency Improvement

Utilizing draft control and a finned tube heat exchanger in the flue pipe, values of 10% excess air and a projected low temperature of 120F is used to project some maximum (reasonably) attainable temperature.

	$\frac{\text{lb}}{\text{lb fuel}}$	$\frac{\text{lb}}{\text{lb flue}}$	$\frac{\text{Btu}}{\text{lb-F}}$	435-60	$\frac{\text{Btu}}{\text{lb flue}}$	120-60	$\frac{\text{Btu}}{\text{lb flue}}$
CO_2	2.0952	.1415	.225	375	11.94	60	1.91
H_2O	1.5507	.1047	.481	375	18.99	60	3.02
N_2	10.8714	.7342	.2496	375	68.73	60	11.06
O_2	.2906	.0196	.225	375	1.65	60	0.26
	14.8079				101.21		16.19

Latent heat of H_2O = $(.1047\ \frac{\text{lb}}{\text{lb flue}})(1040\ \frac{\text{Btu}}{\text{lb}})$ = 108.89

210.10 $\frac{\text{Btu}}{\text{lb flue}}$

Exhaust aquivalent = $\frac{17311.3}{14.8079} = 1169.06\ \frac{\text{Btu}}{\text{lb flue}}$

Lowered losses due to draft control = $\frac{210.10}{1169.06}$ = .180

Efficiency gain = (.208 - .180) = .028 or 2.8%

Given that the flue gases have a humidity ratio

$$Ws = \frac{.1047}{1-.1047} = .1169 \frac{\text{lb } H_2O}{\text{lb air}}$$, this corresponds to 132F in ASHRAE.

Furthermore 120F gives W_s = .08149 implying that $\frac{.08149}{1.08149}$ =

$$.0753 \frac{\text{lb } H_2O}{\text{lb flue}}$$ would not condense.

Latent heat of H_2O = (.0753)(1040) = 78.31

78.31
+16.19
94.50

Lowered losses due to draft control and heat exchanger:

$$\frac{94.50}{1169.05} = .081 \quad \text{or} \quad 8.1\%$$

Efficiency gain = (.208 - .081) = .127 or 12.7%

Reasonable achievable improvement: 79% + 12.7% = 91.7% or about 92%

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