ENERGY CONSERVATION IN AN OLD 3-STORY APARTMENT COMPLEX*

Jan Beyea, David Harrje, and Frank Sinden
Center for Environmental Studies, Princeton University
Princeton, New Jersey, U.S.A. 08540

ABSTRACT

We have studied the potential for energy savings in an old, low-rise, 50 unit apartment building. Standard engineering calculations, coupled with simple field measurements have been sufficient to obtain a consistent, quantitative picture of energy use and allow an assessment of conservation strategies. The results suggest a potential 30% fuel savings, above and beyond traditional strategies of attic insulation and storm windows. The methods of analysis are appropriate for a wider class of old buildings. Development of a cheap form of insulation to be applied externally to massive walls represents the major area where research is needed.

INTRODUCTION

We have studied an old, low-rise, brick apartment complex in order to find ways of analyzing, and then reducing, energy consumption in this type of housing. Old structures are important for energy conservation because they make up a significant class of housing in many countries. By our estimate, about 6% of total U.S. primary energy is consumed in connection with residential structures built before 1940 [1]. The figure for France is considerably higher [2]. The long lifetime of such structures (estimated to be 70 years for the U.S. [3], 90 years for Paris [4]) insures that these old buildings will be with us for a long time. Consequently, they should not be ignored in national energy plans.

The percentage of national energy use associated with old buildings, as well as the end to which such energy is put, varies from country to country depending upon the age of the housing stock, the nature of the economy, the climate, and the people. For instance, Mexico and India use a negligible percentage of their energy for space conditioning of old buildings, but use a significant percentage for cooking and other household purposes [5,6]. Furthermore, there can be widespread differences between countries even when temperature effects are eliminated: The per capita space heating consumption per degree-day in Sweden is approximately one-half the U.S. value [7]. Therefore, the room for improvement, as well as the priority given, will not be the same everywhere.

Nevertheless, in many places in the world energy consumption in old buildings is large enough so that a detailed analysis appears to be justified - as a survey to provide policy guidance and, possibly, to provide specific recommendations for individual units. However, old structures are particularly difficult to analyze because of lack of information about their construction and lack of information about modifications made over the years. In certain cases, gross discrepencies have been found between calculated heat loads and measured values [8]. Consequently, greater verification of heat load calculations, as compared to new structures, is likely to be necessary before the calculations can be relied on to suggest energy saving strategies. The need for special attention is particularly troublesome if one hopes, someday, to analyse individual structures on a cost-effective basis: special attention means extra costs which must be charged against future fuel savings. In extreme cases, the estimated cost of a full energy analysis, including verification of calculations, can extend the payback period beyond the remaining lifetime of the structure. Although this extreme case is not likely to occur when dealing with apartment complexes (because of economies of scale), analysis costs

---

* Partially supported by U.S. E.R.D.A.

cannot be neglected even for them.

With the payback problem in mind, we have tried to simplify our methods of analysis as much as possible, hoping to develop techniques which can be adapted in a cost-effective way to a wide class of housing. Complex instrumentation, such as SF_6 air infiltration monitoring equipment, has been introduced only to varify simpler methods in this test case, not to suggest that all old structures need be analyzed in this way.

Description of Apartment Complex

The Plainfield complex is made up of nine, 3 story, old brick structures, side-by-side, with brick walls. (A ground-floor plan is shown in Fig. 1) Numerous small airshafts help to provide ventilation. The buildings are subdivided into a total of 42 efficiency apartments and 5 three-room units. The present owner purchased the building about two years ago and knows virtually nothing about its history. We estimate that it was built around 1900. A major modification was made relatively recently to the front: wall air conditioners were installed and a 1/4 inch, decorative brick facade added. The building already is equipped with storm windows and one inch of attic mineral wool insulation. The tenants have modest incomes and represent a variety of nationalities; twenty percent speak Spanish only.

Heat to the individual apartments is provided by a central oil burner driving steam radiators. Tenants in the end sections complain of a lack of heat; tenants in the central section containing the boiler complain of a heat surplus (and open their windows for relief). The burner operates automatically according to a central thermostat, except that the manager makes "adjustments" when the oil in the tank is "low."

Hot water is also provided by the main boiler. Sewage water leaves the complex through one central pipeline.

Outline of Paper

The first part of our paper deals with the analysis required to build up a consistent, quantitative picture of energy use. We distinguish three levels of analysis which we have performed (and which might be performed on other structures):

Level 1: Standard static heat load calculations and fuel bill analysis.

Level 2: Regular meter readings; simple instrumentation for spot visits to varify Level 1 results and to supply missing parameters for the heat load model.

Level 3: Long term automatic monitoring equipment and complex instrumentation.

"Level 1" and "Level 2" represent the methods we would use if we were to study other similar structures for the purpose of making specific recommendations: "Level 3" represents research techniques.

The second part of our paper deals with strategies to reduce energy waste. In connection with reducing waste, we have looked at strategies which go beyond the obvious "roof insulation, storm windows, and good maintenance" discussed in such recent reports as the Rand study

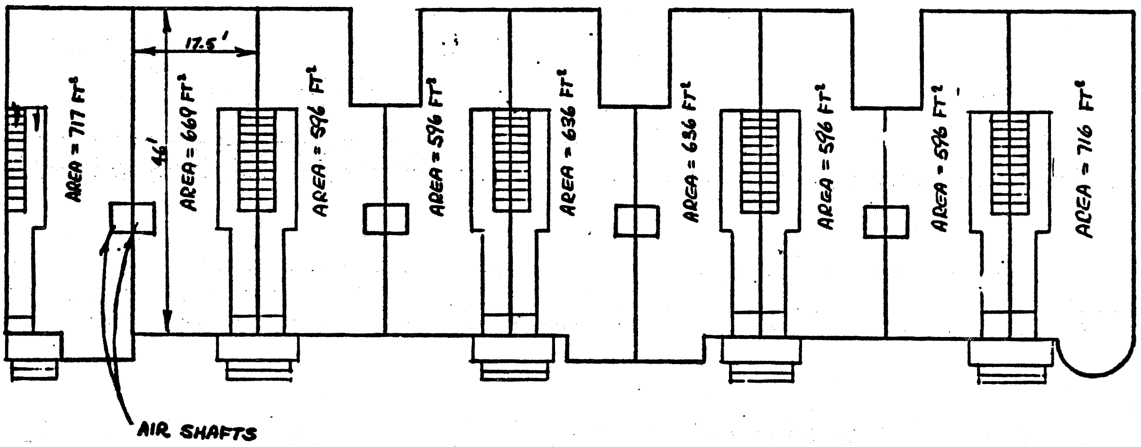

Fig. 1. Plainfield ground floorplan

of Ref. 3. Our results suggest that there are many additional small improvements which can be combined to reduce consumption by a significant percentage.

PART I - METHODS OF ANALYSIS

Level 1

Level 1 analysis was based on fuel bills and a cursory examination of the building - the kind of data that would be readily available, for many buildings. (In fact, if building plans had been available, no on-site visits would have been needed at all.) Our aim was to see how much useful information could be gleaned from meager data.

Our first step was to draw up floor plans, estimate wall parameters, and measure attic insulation. From this information, energy loss coefficients were computed. However, they could not be directly related to fuel consumption because, in the apartments under study, hot water is provided by the space-heating boiler and, therefore, separate information on space-heating fuel consumption was not directly available. We disaggregated hot water losses from space heating requirements by analyzing fuel delivery data as a function of season.* We assigned the degree-day independent part of fuel consumption to energy literally "going down the drain." For the 1975-76 winter, this procedure, based on six fuel bills, led to an estimate of 27 (±5)% for lost heat.** a number consistent with U.S. national averages. Subtracting this percentage from the total fuel consumption led to an estimate for the amount of energy required for space heating of 3.26 gallons of oil per Fahrenheit degree day (470,000 primary BTU/degree day).

With this information, it was possible to set up a useful energy balance relating the space heating energy input (from the fuel) to the conduction and air infiltration losses. This algebraic equation defines a linear relationship between the unknown net furnace efficiency and the unknown air exchange rate. If one assumes a value for the furnace efficiency, based on performance experience with similar units, then the air infiltration losses are uniquely determined. This procedure gave us our first estimate of air infiltration.

The space heating energy balance is expressed by:

$$Q(1-w)\varepsilon = (C + Af) \times D\,D$$

where

		1975-6 value
Q =	heat content of fuel burned*	$=3.24\times10^{9}$ Btu
w =	fraction of heat used for hot water	= .27
ε =	furnace efficiency	= ε
C =	conduction losses through shell	= 7000 Btu/hr/°F
A =	air infiltration coeff. = vol. of bldg's. inside air x heat cap. of air + a 12% contribution from latent heat load (see text)	= 5250 Btu/°F
f =	infiltration rate in air exchanges per hour	= f
$D\,D$ =	Number of degree hours in heating season**	= 120,000 Fahrenheit degree-hours

Using the accessible information listed above, we obtain this relation between the unknowns ε and f:

$$2.36\,\varepsilon = .84 + .63f$$

This is displayed as the middle curve in Fig. 2. (Also included on the graph are the results of certain level 2 and 3 measurements which will be discussed later.)

---

* An unexpected difficulty arose when we discovered that the oil tank was not always filled at each delivery, so that we could not directly determine the amount of fuel used between deliveries. We overcame the tank-filling ambiguity by recognizing that a delivery quantity close to a multiple of a thousand gallons represented the amount scheduled by a dispatcher, whereas a random number of gallons delivered meant that the tank filled up before the schedule amount could be added.

** Assumptions had to be made about the relationship of summer hot water use to winter hot water use, so the determination is not unambiguous. It is for this reason that we have included the ± 5% error.

* Assumes 145, 000 Btu/gal of #5 fuel oil. Any deviation from this will be reflected in the definition of furnace efficiency.

** The 65°F baseline used to determine degree days is assumed to account for internal energy sources in the complex.

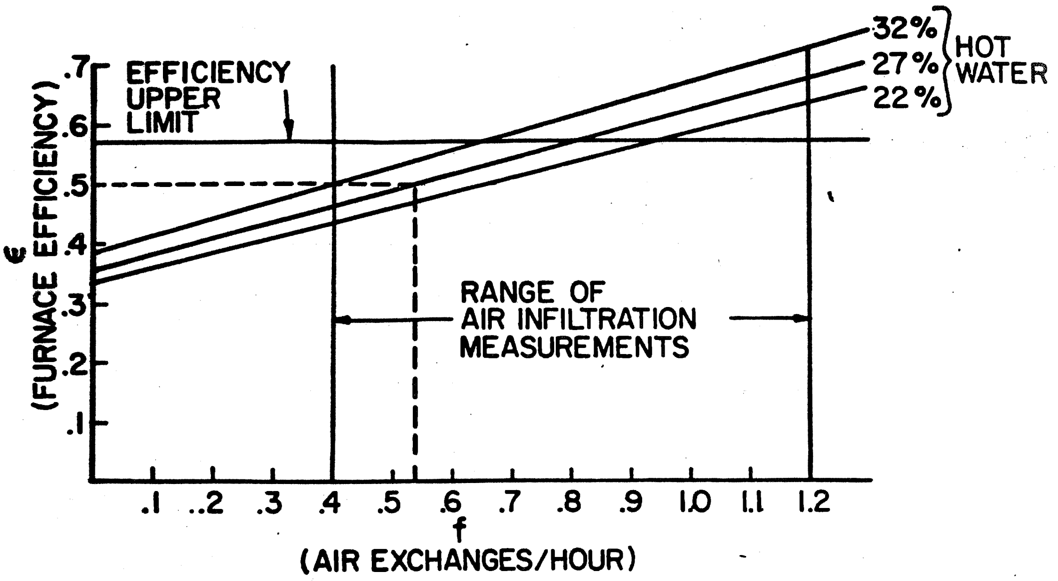

Fig. 2 Relationship between furnace efficiency and number of air exchanges per hour.

Without further information, it is impossible to separate net efficiency and air infiltration, although the equation alone does say that the net efficiency cannot be less than 36%, i.e. its intersection with the f = zero axis. If one takes estimates of performance for the particular heating system based on experience with other systems, then the value of "f" is fixed. For instance, a typical rule of thumb for the efficiency value of a steam radiator system of this form would be 50%. This in turn leads to a value of f of .54 air exchanges per hour. The result is quite reasonable in that it falls within the ASHRAE rule of thumb range for air exchange rates [.66 for rooms with storm windows and no external doors, .33/hr if the air is assumed to pass from rooms on one side of a building to rooms on the other (9)].

Level 2 Analysis

In order to verify the energy balance equation and to narrow down uncertainties, various terms in the equation were checked experimentally. These simple "level 2" measurements consisted of: 1) a crude wall heat flux measurement to verify the wall thermal resistance. 2) a flue gas measurement to determine primary furnace efficiency, and 3) a humidity "decay" experiment to measure air exchange rates. We also hired the building manager to take weekly oil readings as well as weekly tenant gas and electricity meter readings. (This, incidentally, turned out to be a very cost-effective method of date acquisition.) From this information we were able to check both our fuel bill analysis and the 65° F baseline temperature used in the determination of total degree days. In all cases, the results have been consistent with the "level 1" traditional engineering calculations and rules of thumb — a sign that we have not missed anything subtle by doing the obvious.

Hot water and furnace losses to the basement were also measured to provide a more complete picture of energy flow.

Check of Conductive Loss Term. First of all, we ran a check on the conductive loss calculations. The dominant part of the conductive losses came from the outside walls, so we performed a wall heat flux measurement. For this purpose we used a portable thermocouple surface probe with digital readout. (We have found this unit to be extremely convenient for use both as a thermometer and a heat flux meter. As such, it can serve as a "poor man's" infrared camera.) The wall heat flux was measured (as described in the appendix) at intervals of several hours over a 24 hour period.

The average of these readings agreed with our prediction, based on wall construction estimates, to within 20% - which lies just within the accuracy range of the measurements. As a result, we can have confidence in the conductive part of the energy balance equation.

Measurement of Primary Furnace Efficiency. Next, we made a simple flue gas measurement of primary furnace efficiency (62% at a stack temperature of 560°F), something incidentally the maintenance company never does. We then measured the heat flux leaving the boiler (20,000 btu/hr), again using the digital temperature probe as heat flux meter, and calculated from wall conductivities the fraction of total consumption lost to the outside (5%). Thus, the net efficiency of the heating system must be less than or equal to 57%, (62%-5%). We have included the 57% upper limit line on the graph in Fig. 2.

Measurement of Air Exchange Rate. Our third simple measurement consisted of an estimate of air infiltration using water vapor as a tracer gas. Robert Sonderegger at our lab has had considerable success in equating moisture balance with air infiltration rates measured with SF_6 as a tracer gas. Although his work has been based on long term averages, and although not all his runs are consistent, we decided to try the method on a pulsed basis. The method is potentially so cheap in comparison with other experimental methods, that one should be willing to put up with considerable difficulties in interpretation. The experiment was performed in a vacant apartment, midway up the building. The moisture content of the rooms were doubled (by running the shower) and the rate of decay of moisture monitored for a few hours.* (Humidity was measured with a sling psychrometer.) After subtracting background, we found that the data produced a straight line on a log plot with a slope corresponding to .8 air exchanges per hour. The same result was obtained 12 hours later.

Of course, one cannot confidently equate the number obtained in this way with the true rate of room air exchange. There exist other pathways by which moisture can be removed from air (i.e., it can migrate into furniture, walls, etc.). Consequently, we interpret the number as an upper limit on the net air change in the room (on the particular day on which the experiment was performed). However, we feel the number is reasonably close to the true value because the number agrees with SF_6 measurements taken in the same room under similar weather conditions. This suggests that the migration of moisture into surfaces could not have been a dominant effect. The absence of any great change in room background after our experiment supports this conclusion. So does an examination we have made of records of moisture input and balance kept by Sonderegger for a modern townhouse. His data suggests that flow in and out of "storage" amounts to about 25% of the flow rates to and from the outside. We plan to do a more careful comparison of the technique with SF_6 measurements in the future.

The number obtained, .8 exchanges/hr., is considerably higher than the average value obtained from the energy balance equation. However, it should be noted that the measurement determines room exchange rates, and not building exchange rates. It is possible, in a particular wind situation, for cold air to enter the apartments on one side of the building, warm up inside, and leave through the apartments on the other side. This would mean that the infiltration rate for the exit side apartments would be effectively zero. Thus, the true building exchange rate could be as low as one half the measured value (.4/hr), indicating that the measurement is not really inconsistent with the derived value of .54/hr.

This factor of two uncertainty in the measurement appears to be an inevitable result of trying to measure net exchange rates in a multicelled building without air ducts.

Check of Baseline Temperature. Calculations of the "free heat" provided by sources other than the furnace were made to check the baseline temperature used in the degree-day calculations. The results, shown in Table (1), suggest that the conventional 65°F baseline used in this part of the U.S. should be satisfactory.

Table 1 "Free Heat" Gain (a)

Appliances b)	...2°F	People.....	1.6°F
Gas b)	..........2°F	Sunlight... thru Windows d)	2.1°-2.6°F (24 hr average)
Sunlight energy thru roof and walls c)	.4°F		
Total			8.1° - 8.6° F

(Since the internal temperature is kept around 73°F, the highest outside temperature at which furnace heat is needed is 73°-8° = 65°. This agrees with the 65° baseline commonly used for degree-day calculations.

a) In units of temperature: Input power (Btu/hr) /Bldg's calculated loss rate (10,000 Btu/hr/°F);

b) From meter readings;

c) Crude estimate;

d) Based on 1) observed shading practices as revealed in photographs, and 2) ASHRAE tables

---

*On a day estimated to be representative of average wind and temperature conditions.

(Ref. 9).

Measurement of Fuel Consumption Rate. Weekly oil level readings by the building manager were analyzed to obtain the rate of fuel consumption for the 1976-77 heating season. A slope of 3.07 gallons per Fahrenheit degree day was obtained, which compares with the 3.26 figure determined from the previous year's fuel bills.* Consequently, our fuel bill analysis method has been confirmed.

Level 3 Analysis

As already mentioned, SF_6 tracer gas measurements (Ref. 10), were made as a further test of the derived air exchange rate. The results were similar to those obtained by the humidity experiment. Values ranged from .8 exchanges per hour to 1.2 exchanges per hour over the weekend of April 9 to 11, 1977. These measurements were taken with an inside-outside temperature difference of 30-40°F and under average wind conditions, which should be representative of average conditions. As with the water vapor tracer experiment, there is factor of two ambiguity in using these results to infer net building exchange rates. Consequently the results are consistent with a value lying between .4 and 1.2 exchanges per hour. This range was included using vertical lines in the energy balance graph of Fig. 2. A summary of all our information on air exchange rates is given in Table 2.

Table 2 Summary of Information Obtained on Air Exchange Rates

From energy balance	.54/hr a)
From water vapor tracer gas experiment	.4 - .8/hr b)
From SF_6 tracer gas measurement	.4 - 1.2/hr b)

a) Heating season average. Assumes a 12% humidity heating load (see text) and a 50% furnace efficiency.

b) For reasons given in the text, the lower limit on the range of exchange rates is determined by taking 1/2 of the lowest measured values. Note that these measurements were taken over a short period of time and, although representative of average conditions, do not necessarily reflect the seasonal average value.

Other level 3 type measurements, which we did not make but which might be useful in other situations, are 1) furnace on-time, and 2) Infrared photography scans.

It would have been helpful to have monitored humidity in several sample apartments as a check on the latent heat load. Although knowledge of the latent heat load is not needed to determine the total energy lost through air infiltration, it does enter the determination of the derived air exchange rate, "f". The energy used to evaporate water during the heating season appears as part of the air infiltration coefficient in the energy balance equation. We estimated this term to be only 12% of the total, so did not feel the expense of several humidity recorders was worth the information we would gain. However, the potential error in our estimate was large, and it would be comforting to have an experimental check. We will probably pursue this next winter as spare units become available.

Final Energy Accounting

Our experimental checks on parameters which appear in the energy balance equation do seem to confirm that standard engineering methods are applicable to this housing complex. Our energy accounting leads to the breakdown shown in Table 3. Also included in the table is a value for losses from the hot water tank. We did not know the insulating value of the tank, so losses were determined with the heat flux method described in the Appendix. Some of this hot water heat loss was retained in the building; the net loss was determined by calculation (based on knowledge of wall conductivities and estimates of air exchange rates), as was done with the boiler.

Table 3 Breakdown of Energy Use

Misc. Information:

5000 degree day heating season.
Total space heating losses: 10,000 Btu/hr/degree day; 3-3.3 gallons #5 fuel oil/degree day.

Hot water tank loss to basement: 1000 Btu/hr.

Boiler losses to basement: 20,000 Btu/hr.

continued

---

*At the time of this writing (April), we do not yet have sufficient warm weather data to make an independent determination of hot water use for this year.

Table 3 Breakdown of Energy Use (con't.)

	Percentage	10^6 Btu/yr*	Dollars/yr	Btu/ft^{2}yr*	Cost/ft^2/yr
Hot water down the drain	27%	880	$2200		
Conduction through walls (.23 Btu/ft^2/°F/hr;R4.3)	26%	860	$2150	58,000	$.15
Air infiltration	21%	680	$1750		
Windows and doors	10%	340	$ 825	128,000**	$.33**
Roof	10%	310	$ 825	48,000	$.12
Air shafts	6%	180	$ 500		
TOTAL	100%	3250	$8250/yr at $.37/gallon		

* 50% of this energy is assumed to be lost up the stack or due to poor distribution. (62% primary furnace efficiency; 5% loss in basement; 7% misc. distribution losses)

(Note that it is not only fuel oil energy which is lost to the external environment, but also the "free heat" from applicances, sunlight and people. Reducing energy losses by insulation and tightening will not only reduce the terms listed above, but also serve to make the free heat go further.)

** Figures for the (storm) windows, not doors. Does not include solar gain

PART II - CONSERVATION STRATEGIES

Having obtained a validated model for energy losses, it is possible to quantitatively assess particular conservation strategies. Some of those which we have considered are obvious, some are not. The list given in Table 4 consists of simple modifications which can be made over the years by the building manager. The list given in Table 5 is more involved and requires expert assistance. The list includes waste heat recuperation and air shaft insulation. It is our intent to implement these changes ourselves, if funding is available. Although, the expected saving shown for each improvement is small, the total savings , of the order of 30%, are significant. The estimated payback periods range from one to five years. (Payback times were calculated assuming energy costs increase at a yearly rate equal to the cost of money. The manager's labor was not included in the estimates.) We have not been specific, in Tables 4 and 5, about individual payback periods, except for the longest ones, because the cost estimates are subject to large errors. We have been most concerned with the long payback strategies and have calculated their costs conservatively - appropriate for new system designs. Persumably, their costs would drop after the prototype stage. The total savings amount to 29% excluding attic insulation. Thus, we predict this much potential saving above and beyond traditional strategies. If attic insulation is included, the predicted savings is 35%. (For apartment complexes without storm windows (the majority), at least another 10% should be added for window upgrading.) Some of these retrofits will be implemented in the summer of 1977. A 10% improvement should be easily visible in the following winter's fuel consumption data.

Table 4 Simple Improvement Strategies

	Estimated Savings (Percentage of original consumption unless starred)
1. Optimize Existing Distribution System (Includes proper sizing of air valves, shutting off radiators in hot parts of structure, tenant education.)	3%
2. Adjust Burner for Better Efficiency	5%*
3. Reduce Air Infiltration (Includes weatherstripping entrance doors, but mainly	

Table 4 Simple Improvement Strategies (con't)

	Estimated Savings
tightening basement doors which are flimsy, riddled with openings, and kept open for much of the heating season.)	2.5%
4. Insulate Basement Above Grade (6" of fiberglass)	3%
5. Increase Attic Insulation (8" of fiberglass)	7%
6. Insulate Hot Water Heater (Wrap with conventional wall fiberglass insulation)	.4%
7. Install Heat Shields in Front of Boiler (Removable polished aluminum sheets, hung from ceiling hooks)	2.5%*
8. Tighten and Insulate Air Conditioners (The losses here were detected by scanning the walls with the digital temperature probe.)	.2%
9. Block Up Old Chimneys in Basement	very small
10. Heat Recuperation from Laundry Room (The laundry room gets so hot that the tenants leave the door open in the coldest part of the winter. We propose spreading out the equipment, and venting the dryer exhaust inside during the winter.)	2%

*Percentage in this case means percentage after other improvements have been made.

Table 5 Strategies Which Cannot Be Implemented by Manager Alone and Which Required Design Work

	Estimated Savings
1. Hold Up Tank for Clothes Washer Discharge Water	.1%
2. Stack Energy Recovery. (We have designed an air heater which will be installed in the chimney and exit at the burner air inlet. Payback period estimated at 5 years. The installation will be experimental - testing the performance of the stainless steel heat exchanger.)	5%*
3. Cold Air Feed to Oil Burner or Air Shut Off. (To prevent warm air from going up the stack when the burner is off, we are considering either a cold air feed or a shut-off valve. Note that the percentage savings listed is not independent of other improvements.)	0-2.5%
4. Insulate Airshafts. (Our design uses conventional, rolled, fiberglass insulation hung from the tops of the shaft and pressed against the surface by braces. The question to be answered is how long the insulation and special backing can hold up.)	2%
5. Recuperation of Heat from Waste Hot Water. (All waste water from the nine sections exits through the sewer pipe in the basement. There is a 30 ft. flat run of pipe from which we propose to extract heat (using heat pipes) to preheat cold water heading for the hot water tank. No break of the sewer is contemplated. Heat transfer is through the pipe wall. Pipe temperatures were sampled with the temperature probe to estimate savings. Build up scale in the sewer pipe will be reduced using "snaking techniques" to improve heat transfer. Payback time is estimated at 5 years.)	3%
6. Management Strategy. (Many of the recommendations we will make to the landlord require, when in operation, intervention by a responsible party at the right time. One advantage of	

Table 5 con't	Estimated Savings
6 Management Strategy (con't.)	
housing on this scale is that the manager can be trained to do those things that an average homeowner might forget. A yearly calender and instruction book will be made for this purpose.)	Already included

*Percentage in this case means percentage after other improvements have been made.

Physically, the individual buildings in the Plainfield complex are similar to low-rise, masonry-style, row housing found in most urban centers. However, the centralized heating, hot water, and sewer systems are less common. Since one half of the potential savings we find are associated to some extent with this contralization, it would be incorrect to extrapolate the full set of results to all low-rise, urban row housing. The complete set of results apply to about 2.5% of pre-1940 U.S. dwelling units, which is 1% of all U.S. units[11].* Although a small percentage of the total, these units represent the obvious place to start testing retrofit strategies in old buildings. The most successful can be applied to less centralized units.

One improvement we have not listed is wall insulation. We have not yet been able to design a system of wall insulation with a payback period of less than ten years, although we keep dreaming of a cheap, foamy paste that could be "slapped" onto the outside walls, look attractive, and last for thirty years. Of course, such a dream paste is not available,* but the idea does suggest a useful direction for future research. If really large savings are to be made in old, massive buildings of this type, then the walls cannot be neglected.

It is possible to consider placing insulation on the inside, at the time of some hypothetical remodeling of the interior. One must then worry about the effect on the cooling load. The storage effect of the exterior walls would be lost, and, as a result, summer cooling loads would be increased. To compensate for this loss of storage (or as a general energy conserving measure) it would be desirable to strip down the interior party walls to the bare brick, something which is done often for aesthetic purposes in the U.S. when remodeling old brick townhouses. In this way, resistance to the interior walls is removed, increasing storage. We have modeled such a situation mathematically at Plainfield,** and find that, with bare party walls and upon opening and closing of the windows at the right time, peak daily temperatures can be reduced a few degrees. (The calculation was made for typical internal loads found at Plainfield.) The effect could be enhanced by installing fans (or controlling the present air conditioner fans) to force air over the inside walls, improving heat transfer. The fans would operate during the coolest part of the night, cooling the walls and thereby reducing the air conditioning load the following day. Since summer price differentials between peak and off-peak periods tend to be larege in a summer-peaking utility district, considerable inefficiencies in the fan system can be tolerated during the parts of the summer when it would be used. At Plainfield, the prospect for implementing this is poor because the tenants pay electricity costs directly. The

---

* 35% of which are found in New York State. We consider Plainfield as representative of apartment complexes containing 20 or more units, six stories or less, without elevators, and built before 1940. [Another 1% of U.S. housing units is associated with old, high rise apartments. Once again, it might be incorrect to extrapolate our projected savings to these units. New physical mechanisms become important, (such as strong stack-effect drafts) and the geometry is quite different.]

*Although external insulation products, such as Dryvit, are beginning to appear on the market.

** The model consisted of a resistance/capacitance circuit with variable resistance parameters. (Window openings or fan turn-ons changed the resistances.) Outside temperature and internal loads were given both a sinusoidal component and a static component. The circuit is similar to an electronic rectifier.

landlord has little incentive for installing new, unproven systems when it comes time to replace the present air conditioners. Possibly, in other buildings such a scheme would be consistent with the institutional arrangements.

CONCLUSION

We have found many opportunities for small energy savings. Many of the improvements would have too small an effect to be bothered with in a one family house, but on the scale here (50 apartments) they represent a large enough absolute dollar saving to motivate the owner to consider them.

Standard engineering calculations, coupled with simple field measurements, appear to be sufficient to quantitatively identify where the energy is being wasted and to allow quantitative assessment of hypothesized improvement strategies. To provide the field measurement equipment for general use we can imagine the development of a special "house doctor" kit for these old structures. Such a kit might cost about 1,000 U.S. dollars and handle some twenty complexes per year. As such, it would not add a significant burden to the analysis costs per structure.

The major area towards which research should be directed is wall insulation; development of cheap insulation for existing solid walls.

APPENDIX Heat Flux Measurements with a Digital Temperature Probe

We have used a commercial surface thermocouple [12] consisting of a curved surface which flattens upon contact, producing a reproducible pressure. The thermocouple output feeds into a commercial digital readout unit, which we have packaged into a portable chassis. [13]. (Our present unit is line powered. A battery supply would be more convenient.) The digital readout provides the resolution necessary to determine accurately temperature differences of a few degress.

However, reliable measurement of surface temperature requires more than resolution; the probe may interfere with the heat balance at the surface. We have minimized this problem by making full use of the unit's portability. We let the probe come to equilibrium at a test spot, and then move it to the desired location (at the same height and near by). In this way, the probe temperature is close to the wall temperature at the second reading, so there is little heat transfer. Also, the reading can be taken quickly which avoids disturbing the local wall equilibrium. This "iterative" procedure can be repeated along the wall to improve accuracy, but we have found one movement sufficient to produce constant readings.

Use of the Probe as a Heat Flux Meter

Our procedure for measuring heat flux is to measure the differential between surface and air temperatures. For relative measurements, all we need do is move the probe along walls, recording the differential at each point. An increase in the difference, i.e. colder wall, means increased heat flux.

To determine the heat transfer value absolutely, the measured temperature differential must be multiplied times the appropriate surface heat transfer coefficient. Since surface heat transfer takes place by both convection and radiation, in principle it is necessary to compute two heat fluxes, one using air temperature and one using the temperature of internal walls. Fortunately, in our cases, the temperature differential between air and internal walls was not great enough to significantly affect the answer. Thus we were able to use standard, combined surface coefficients to make the theoretical predictions. (1.46 Btu/ft^2/hr/°F for room temperatures, corrected upwards according to temperature for measurements on the hot water tank and the boiler.)

In the case of massive walls, the instantaneous heat flux is not equal to the average heat flux, so a time-averaged measurement was necessary. We took measurements for 24 hours, at intervals not exceeding three hours, in order to average over the diurnal cycle. (Internal wall temperatures were also monitored.) Although this meant that one of us had to spend 24 hours in a vacant apartment, the time was well spent. The time that would have been required to set up automatic monitoring equipment and make it work would have exceeded the total measurement time. Furthermore, we used the time between wall measurements to make other necessary measurements and to inspect the building.

NOTES AND REFERENCES

1) Based on U.S. Census figures that 40% of U.S. Dwelling units in 1970 were built before 1940. Due to retirement and new construction, the percentage should now be 34%. Taking 34% of U.S. residential primary energy (18.5%) gives 6%.

2) 39% of primary energy use in France is associated with residential and commercial buildings (Ref. 6). As of 1960, 83% of French buildings were built before 1945. (A statistical Survey of the Housing Situation in European Countries Around 1960, E.C.E. IIE7, United Nations, N.Y., 1965 Fig.2.3.) Allowance for subsequent retirement and new construction suggests that about 50% of present French buildings are pre-war, which leads to an estimate of 20% of French primary energy for old buildings (including commercial). This agrees with a private communication from M. Simon, session leader.

3) Energy Use and Conservation in the Residential Sector: A Regional Analysis. Stephen H. Dole, Rand Corporation, Santa Monica, California. R-1641-NSF, (1975).

4) The European Housing Situation, 1956IIE.3, United Nations, Geneva, (1956).

5) Energy Resources, Demand and Conservation with special Reference to India, Chaman Kashkari, Tata McGraw Hill (1975).

6) Energy Demand Studies: Major Consuming Countries, WAES, Paul Basile, Editor, M.I.T. Press (1976).

7) Efficient Energy Use and Well-Being: The Swedish Example, Schipper and Lichtenberg, Science, 194, 1001, (1976).

8) Evaluation of Heating Loads in Old Residential Structures, Lokmanhekim and Anderson, Hittman Associates, PB-223 138, H.U.D. - HAI-7 (1974) (U.S. National Technical Information Service, Dept of Commerce, Springfield, VA 22151), Table XI

9) ASHRAE Handbook of Fundamentals, 1972 Edition.

10) Automatic Air Infiltration Measurements and Implications for Energy Conservation, D. T. Harrje, R. Grot, this conference (1977).

11) Derived from Figures in U.S. Bureau of the Census, 1970 Census of Housing, Subject Reports, Final Report HC (7)-4, Structural Characteristics of the Housing Inventory, Table A15. Assuming a 70 year mean life, i.e. a retirement rate of 1.4% a year, there should have been a 10% decrease from the 1970 numbers during the last 7 years, leading to a prediction of 700,000 dwelling units in such structures.

12) Omega Engineering, Inc., Box 4047 Springdale Station, Stanford, Conn. 06907, Model No. 68004E. ($80).

13) Capintec Instruments, Inc. 136 Summit Ave., Montvale, N.J. 07645, Model No. 700-EF2-V115-12, ($230.)