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RETROFITTING: PLAN, ACTION, AND EARLY RESULTS
USING THE TOWNHOUSES AT TWIN RIVERS

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Abstract

Based upon home energy data from a variety of sources including three highly-instrumented townhouses, air infiltration and infrared scanning, and detailed experiments in a rented townhouse, a plan was established to retrofit a group of 25 townhouses within the Twin Rivers Planned Unit Development. The data employed in the evaluation of the effectiveness of the retrofit was gathered by both daily meter reading of the house's gas and electric meters and by a specially designed instrumentation package that monitored hourly key parameters in the dwellings. This retrofit experiment also relied upon calculated winter and summer breakdowns of energy losses and gains to aid in the establishment of priorities for retrofit. Payback periods of no greater than three years was the goal of this first round of retrofit. Action was taken during the winter of 75-76 beginning in the highly-instrumented homes and moving to the larger sample of townhouses with a basic three part retrofit that sought to reduce conduction losses, reduce air infiltration and upgrade the heating system. Attic insulation levels were raised to the R-30 level (from R-11) with careful attention to sealing passages to the floors below; doors and windows were sealed; and furnace ducting was insulated together with the insulation of the hot water heater. The retrofit measures were applied to groups of townhouses in stages in order to determine the effectiveness of each retrofit individually. Both before-after cross sample evaluations of the data were performed. The early results of these actions have shown gas savings on the order of 25% and electrical savings of 10%. The cost was approximately \$400 and when summer savings are included payback periods should not exceed the three year goal.

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Introduction

Although new advances in energy technology continue to be made each day, the facts are such that if major energy savings are to be made in this decade our only real hope is through energy conservation. Within the residential sector, comprising 18% of the U.S. energy consumption, straightforward actions such as reduction of interior house temperatures clearly have been demonstrated to result in substantial savings. For example, at Twin Rivers, N.J., a 3000 home community being studied by Princeton University researchers for the last four years, this saving was shown to take place after the 73-74 oil crisis as indicated in Fig. 1. Based upon our knowledge of this community of hundreds of townhouses, single family homes, and apartments such 12% savings resulted from a 2 to 3°F average thermostat reduction throughout the town. The unfortunate feature with such action is that further action is soon limited by considerations of human comfort. Temperatures below the 66°F - 68°F level require heavier clothing and a new approach to living. The solution that we are pursuing is to achieve substantial residential savings through improvements in the shell of the home, retrofitting, as well as through changes in temperature level wherever possible. The goal is to achieve 50% savings.

In the Twin Rivers community, which consists of four quadrants of frame dwellings built in sequence since 1971, we have been able to closely observe the way in which energy is used in the home. These details have been obtained from a number of sources: the utilities records on hundreds of similar dwellings over the years; the collection of detailed weather data from our banktop location (centered in Twin Rivers); the calculation of energy losses in typical homes;² the 60 channels of energy-related data from each of three highly-instrumented townhouses (HIT homes) since winter '74;³ the less detailed, but adequate, 9 channels of energy information from 25 Omnibus instrumentation packages;⁴ the series of highly-focused experiments from the rental townhouses;⁵⁻⁹ the information

from the infrared scanning and the data collected on air infiltration rates from various townhouses.^{10*}

In the following sections the design of the experiment is described with details on how it was implemented, the rationale for selecting this first round of retrofits is outlined and the preliminary results of the experiment are analyzed. Because of the many details in the Omnibus data, these data need to be thoroughly analysed to extract the full influence on energy consumption brought about by changing weather and internal temperature fluctuations, and hence will require a later, detailed report on this subject.* In the Appendix the actual procedures that were followed to achieve the desired retrofit are described.

Within Twin Rivers there are a number of townhouse models. The sixteen townhouses involved in this portion of the retrofit program are two floor, three bedroom designs. The floor plans are identical in each of the homes and are shown in Figure 2. Variations between townhouses are that some are the right, other the left floor plan designs, two have single glass, and there are slight variations in the appliance choices, and the homes face 10° clockwise of north, east, south or west (the town plan is laid out 10° east of north). The floor area at each level of the townhouse is approximately 720 square feet. The calculated heating load is 41,000 btu per hour for a 70°F design temperature difference.² Heating is by gas using 80,000 btu/hr input, two-burner furnaces. All other appliances are electrical in these Quad II homes (other studies are being conducted in Quad III homes, where gas dryers, ranges and water heaters are used). The townhouses are of conventional construction, with masonry bearing walls and firewalls with wood framing for floors, walls and roof. The townhouses sold for approximately \$30,000 when built and are reselling for about \$40,000 today.

* Other reports on these subjects are currently being written and should be available in the next few months.

The townhouses involved in this study were instrumented in three ways which are summarized as follows:

- Three Highly-Instrumented Townhouses (HIT units). These units shared a 200-channel data acquisition system located in the central townhouse with the satellite houses on either side, one townhouse was an end unit, the others interior units as are all the other townhouses in the study. Data was sent directly to the Energy Utilization Laboratory at the university over a phone line every 20 minutes together with weather data every hour (and recorded on magnetic tape). The more than 60 channels of energy information per home allowed: every window and door to be monitored; the temperature to be measured in every room at every register and duct; flows to be measured in furnace ducts, supplies and returns; a complete breakdown to be made to individual meters for the major appliances and segments of the electrical system; and voltage and calibration standards to be recorded as well. Air infiltration and infrared scanning data were obtained initially in these homes.

- 25 Omnibus townhouses. These townhouses had instrumentation which provided 9 channels of energy information recorded on tape cassette in each home. Table 1 lists the individual data channels. Sixteen of these homes constituted the statistical sample for the retrofit experiment described in this report.

- The rental townhouse. Occupied by members of the program staff, this townhouse was used for detailed experiments such as: solar transmission through windows; temperature probing into the firewall area; the heat distribution system including zoning; the air infiltration measurements looking at air movement from zone to zone; etc. The instrumentation was often quite specialized and included a second 200-channel data acquisition system with local recording on punched tape. As in the cases of the HIT and Omnibus units the data from this home also aided in explaining sources of energy loss that would be remedied through retrofit.

I. Design of the Retrofit Program

The purpose of the retrofit program has been to demonstrate whether or not a group of simple changes to the structure of a home can result in significant energy saving benefits. The instrumentation of each townhouse allows the individual benefits to be fully assessed for each retrofit. For example, the attic insulation upgrading to R-30 results in both higher second floor temperatures as well as lower gas consumption for a given degree-day thermal difference; both factors are measured. In designing the retrofit program, we operated under several physical, temporal and design constraints. The major constraints were as follows:

1. Minimally retrofitting a townhouse might not alter the variables we were monitoring by a large enough amount to be detected by our instrumentation package. Thus, we grouped the individual retrofit items into four groups. These groups are described in Section III. They can be referred to as Group A - retrofits which reduce conductive heat loss, Group B - retrofits which increase the tightness of the shell, Group C - retrofits which improve the performance of the heating/cooling system and Group D - the single retrofit of sealing the shaft surrounding the furnace flue at the attic, which is done to reduce air infiltration losses.

2. Several of the retrofit procedures required pre-testing in the laboratory and in our rented townhouse before they were used in the individual homes. The object of pre-testing was to perfect installation procedures and to measure whether the materials involved in the retrofits behaved as advertised.

3. We had enough data from previous winters to allow retrofitting the highly-instrumented townhouses before the 1975-76 heating season began. It was thus possible to use a "before and after" design with these townhouses without obtaining additional "before treatment" data. December was chosen as the point to begin retrofit of the HIT homes.

4. Due to the need for statistical controls and the limits of our labor pool, one week was allocated for one or more groups of retrofits to be applied to a number of townhouses.

5. In order to have pre-treatment data for the Omnibus houses these houses were not to be modified until at least one month of winter data, including relatively cold days, had been obtained. The plan was to partially retrofit these houses and collect an additional month of data before adding any additional modifications.

6. Analysis of the effects of the retrofits on the highly-instrumented houses were used to determine whether alterations would be made in the list of channels being monitored in the Omnibus experiment. For example, suppose retrofit A significantly alters the variable being monitored on a given channel in the highly-instrumented houses. Possibly the instrumentation of the Omnibus houses should be changed to insure that this variable was being monitored in the Omnibus experiment.

7. The retrofit consisting of sealing the shaft surrounding the flue at the attic (Group D) should not be grouped with the other retrofits since it is a single retrofit whose effects need not be assessed statistically. The source of heat loss being eliminated is somewhat peculiar to the design of the Twin Rivers Units and there was some question as to whether it represented a loss that is common to a wide spectrum of American housing.* Thus the source of variation being eliminated was considered to be a confounding factor and not a design factor.

Given these constraints, we designed the retrofit program as follows:

1. The possible retrofits were sorted into four groups (see Section III

* Although, in this regard, home inspections have revealed that in addition to flue shafts, plumbing vent shafts are another source of such air flow losses and even masonry chimneys have similar basement to attic air passages.

for details). We applied these groups of retrofits but avoided applying a part of a group. This strategy was taken in order to maximize the likelihood of being able to detect the effect of the physical modification on the energy consumption profile of the home.

2. We pre-tested the retrofits in our rented townhouse in order to completely check our installation methods wherever possible.

3. The highly-instrumented homes were initially retrofitted just prior to the winter season according to the following plan (also see Table 2)

House	Retrofit groups
1	B and C
2	A and C plus D
3	A and B plus D

4. During Decmeber the pre-treatment data was collected for the Omnibus houses and the ability of our instrumentation to detect the effects of the retrofits ,which were performed on the highly-instrumented houses, was assessed.

5. Analysis of the December data for the highly-instrumented townhouses allowed us to determine whether any of the monitoring devices in the Omnibus houses should be modified prior to retrofitting these houses. One adjustment was made, the addition of attic temperature which was found to be an important indicator of heat loss to the attic.

6. The design was based upon maintaining two groups: the median group which was using a moderate amount of gas for heating during the pre-retrofit period, and the high/low group that used more or less than the median group. Retrofits were first applied to the median group so that additional data could be gathered on the extreme highs or lows. In this way as improvements were made to the median group we retained comparative pre-retrofit consumption level from averaging

the highs and lows.

7. The actual schedule followed in retrofitting, as shown in Table 2, took into account item 6 as well as our manpower and the contractor availability. Not shown for clarity was movement of the D retrofit in and out of homes to check further on its contribution to energy savings now believed to be of the order of 5% (which for this low cost item is a sizeable savings).

Details of the actual statistical analysis, looking over the entire data sample, will be covered in a forthcoming report. The full analysis is necessary to separate out the effect of the various retrofit groups, determine changes in the interior conditions as monitored on 3 of the 9 channels of Omnibus instrumentation, and carefully consider pre- and post-retrofit weather conditions which are not identical.

II. Selection of the Retrofit Components

Models of heat source and heat loss in the heating season, Figure 3, and cooling source and heat gain in the cooling season, Figure 4, were used to evaluate a number of retrofit schemes proposed to reduce energy losses associated with townhouse construction. Wherever possible the models directly rely on data from the 3 highly-instrumented townhouses, our rented townhouse, and early Omnibus townhouses.¹¹ Examples of such items are the air infiltration rate measurements winter and summer; the actual losses of heat from basement ducting; flow measurements from the basement/attic shaft; appliance use patterns; heat losses through those walls adjacent to the firewall; etc. Window losses and other conduction losses have relied primarily on conventional calculations,² although infrared scanning data has allowed for more realistic firewall conduction loss estimates. The data base and techniques used for each retrofit are listed in Table 3.

It is clear from a close observation of heating and cooling data that marked variations occur between the two seasons as far as the responsible mechanisms of heat transmission. For example, the air infiltration average loss of 33.4% (percentages greater than 60% have been experienced in townhouses under test when wind velocities are above 20 mph) in the winter contrasts sharply with a less than 7% air infiltration heat gain experienced under typical summer conditions. Thus, in evaluating the merits of each planned retrofit we have taken heating costs, cooling costs and standby water heating costs into account to arrive at an estimated energy cost savings (see Table 4). We are looking for the most realistic evaluation of each retrofit recognizing subtleties such as those characteristic of appliance-type items e.g., heavier insulation on the water heater reduces heat gain to the basement both in the winter and summer, but the actual water heating savings must be analyzed taking into

account both heating/cooling implications (decreased air conditioner load versus any possible increased furnace load brought about by that retrofit item).

Considering the winter heat sources and losses diagrams in Figure 3, it is clear that care must be taken in how one catalogs the components. The diagram is for a differential temperature, outside-to-inside of 70°F. In the New Jersey climate about half that amount is more appropriate for an average winter temperature difference. In the heat source breakdown this change would result in an increase of the percentage contribution of each satellite item; solar, appliance and occupants. Our latest data indicates this breakdown for the major components is closer to 75% furnace,* 15% appliance and 10% solar. Such change would only slightly affect the heat loss breakdown since the change in differential temperature directly influences window and wall heat conduction and the heat required to raise outside air to room temperature (in the case of air infiltration).

As shown in the heat source breakdown 20-25% of the heat delivered by the furnace is immediately lost to the flue. Without adding forced convection to the exhaust system, however, there is a limit to how much one can lower the furnace exhaust temperature to extract a higher percentage of the available energy and still retain natural convective flow to remove exhaust products. This is particularly true based upon present furnace standards, design and performance. We are exploring the furnace retrofit approach further with our laboratory furnace, identical to the units found in the Twin Rivers townhouses, with the plan to then test the retrofit in our rented townhouse. These tests are pointing to as much as 10% energy savings using smaller gas orifices

*Furnace efficiency changes with load would alter this breakdown. Measured in the plenum, the furnace efficiency is essentially constant with load, the main question here is the efficiency of the overall system, including the ducting, where trapped heat during infrequent operation is more likely to be lost to the basement or structure.¹²

(resulting in less transient loss) and is particularly sensitive to reduced fan cutoff temperature.¹²

Further study of the heat source diagram, Figure 3, reveals that considerable energy is lost to the basement. Extensive measurements in the highly-instrumented townhouses and rental home have revealed the extent of flow and heat losses to the basement as shown in Figures 5, 6a and 6b. Figure 5 is a breakdown of the flow through a typical townhouse duct system. Starting from a flow rate at the plenum chamber (a value very close to the nominal blower flow rate of 650 cfm) one can trace the path of the heated air until it emerges from the individual room registers. The route includes main supply ducts, various turns, and passages within interior walls and between floors and ceilings. Approximately 75% of the initial flow makes it to the individual rooms, with 17% lost to the basement. Figure 6a concentrates on actual heat delivery while Figure 6b presents a simpler, schematic breakdown. Since the air temperature has dropped considerably, a relationship that has been modeled on our computer,¹³ only 50% of the heat reaches the rooms through the duct registers. Another 15% reaches the living area via heated walls, floors and ceilings as a result of the duct routing. Unfortunately the majority of such enroute losses are from second floor ducts losing heat to the first floor rooms. Thus, heat distribution goals are compromised. Over 34% of the heat entering the ducts ends up in the basement. Some of this heat is lost through basement air infiltration, and conduction to walls and floor, the remainder (~ 50%) leaks back up into the living space. Data from the Omnibus homes indicates that the duct insulation retrofit (part of Group C) lowers the basement temperature an average of 5°F, from 70 to 65°F.

Three facts made further sealing and application of 2-inch thick fiberglass insulation to the ducting a high priority retrofit item: (1) based upon total

furnace heat generated more than 25% of the heat ended up in the basement, see Figure 3. (2) The basement was shown to be overheated in a number of homes, sometimes reaching temperatures 5°F higher than those recorded on the first floor (in the summer this trend was reversed and the basement often was as much as 10-15°F lower in temperature than the living space). (3) An estimated 11% of total house heat was being lost through additional air infiltration losses - another clear indication that even after limiting duct losses, adequate heat would remain in the basement to provide reasonable floor temperatures on the first floor. The cost for the materials for this retrofit is relatively low~\$40 (2-inch thick, 48 inch wide, duct insulation consisting of fiberglass with aluminum backing that includes crisscross reinforcing to add durability), and estimated installation cost is also reasonable (~\$60 expense). As shown in Table 4, considering an estimated 75% reduction^{**} in heat losses,¹³ a cost payback for this retrofit based upon savings during both heating and cooling seasons is relatively rapid, 13-32 months.^{***} Benefits to the homeowner, in addition to fuel and electrical savings is that more heating and cooling is available in second floor rooms, a point that will be discussed later.

Turning our attention back to the heat loss diagram (Figure 3), the sealing of the previously mentioned shaft becomes another high priority item for retrofit. The simplest and best location to accomplish this energy savings is at the attic end of the shaft. Not only is the shaft readily accessible at that point but plugging the opening with unbacked fiberglass traps any heated air in the shaft, thus allowing it to help heat the interior. The leakage path is shown in Figure 7 where warm air enters the shaft at the basement then enters the attic space

^{**} This reduction includes treatment of the lower floor registers and the window overhang insulated for an additional~\$ 15.

^{***} Register, overhang and duct payback periods are combined in this estimate.

and finally exists through an attic vent (these hot vents were spotted with the NBS infrared scanning equipment).

Also shown in Figure 7 is the flow pattern between the masonry firewalls and the interior, uninsulated gypsum board walls. This results in additional conduction losses as shown in Figure 3. Again referring to Table 4 we find this retrofit to be inexpensive from both a materials and installation standpoint. The retrofit immediately transforms a townhouse with this flue arrangement to a configuration more representative of preferred construction practices. On the other hand, one can't help but wonder how many newly constructed townhouses or single family dwellings have used metal or transite flues and the associated shafts so as to save on the cost of masonry chimneys.* Certainly this is an important construction item to watch in the future.

The heat loss via the shaft is grouped under the larger heading of air infiltration. Using automated air infiltration data collection units¹⁰ we have measured the air infiltration rates during both winter and summer in a number of Twin Rivers townhouses. The value of air infiltration loss shown in Figure 2 is based on a winter air exchange rate of approximately .8 of an air exchange per hour. Our data point out that wind is a very important factor and that the "first line of defense" to limit air infiltration is through intelligent planting of trees upstream of the house, in the direction of prevailing winter winds so as to moderate wind conditions near the house.^{14, 15}

Measurements in the rental home have included isolating individual window areas to assess local air infiltration rates so that the infiltration rate can be broken down into finer components. Individual experiments have been accomplished to determine internal air flow patterns.^{5,6} Much of the air

*Masonry chimney construction in Quad III, townhouse B designs have surrounding air gaps at least equivalent to the townhouse A flue arrangement.

infiltration originates at the doors and windows. Improvement of the seals on the metal sliding hardware of the windows and patio door are prime candidates for retrofit. The use of better sealing systems here is estimated to reduce air infiltration as much as 50%. Strips of closed cell foam plastic into which the door and windows slide, squeeze, and seal represents one inexpensive means to reduce the air infiltration rate. From Table 4, seal materials are estimated at \$25 with a payback period of 20 months. Experience has shown that the time expenditure for seal installation can often be underestimated and depends very much on the individual home problems.

Turning to items involving conduction losses, considerable attention has been given to the firewall which under many wind conditions loses more heat than the exterior walls. The NBS infrared thermography as well as individual wall surface, and behind-the-wall temperature measurements, have documented this finding. In order to eliminate this source of heat loss the approach is to seal off the firewall along the attic seam and basement seam (where frame and firewall meet). This should be augmented by an improved resilient seal of caulking between frame structure and firewall on the external joints. In situations where these seals prove ineffective it would be necessary to blow or foam the stud spaces adjacent to the corners of the building. This may also prove necessary in those townhouses that extend out from the row to add architectural interest.

The estimated cost to isolate the party wall is \$5 in materials and \$10 in labor. The payback as shown in Table 4 is 14 months with labor. Costs can be further reduced if this retrofit is accomplished when retrofit packages A and C are being installed as discussed in Section III.

Another conduction loss reduction that can be simply accomplished is adding to the ceiling insulation.¹⁶ The reduction in the heat gain in summer

is even a greater percentage ($\approx 8\%$, if insulation quality is raised from the R-11 to the R-30 level) than the winter savings ($\approx 6\%$). To increase the insulation to a point where the resistance to heat passage is approximately R-30* requires $\approx 8 \frac{3}{4}$ inches of blown fiberglass, or $5 \frac{1}{2}$ inches of blown cellulose. This type of ceiling insulation treatment provides a cost payback in 84 months including estimated labor charges. Another additional benefit is that warmer upstairs temperatures in winter and lower temperatures in summer should result in reduced energy consumption during the nighttime period. We find that rather than night setback, some individuals prior to retrofit have turned up their thermostats when retiring to avoid overly cold bedroom temperatures. With both increased attic insulation and duct insulation aiding the heating plight of second floor rooms, we are hoping that night setback could become a habit in the future, and setback thermostats will be used in the coming winter.

The energy cost of maintaining hot water at elevated temperature is one very important item of the total home operating cost and energy picture. From Omnibus and highly-instrumented townhouse data we estimated that a minimum of \$36 of electricity (at 5¢/KWH) is consumed each year for this purpose. Tests in our laboratory indicate that cost savings of 1/2 this amount can be readily achieved by adding a single wrap of R-7 insulation** on the sides and top of an electrically-heated 82 gallon water tank. Measurements in another study at Twin Rivers, where both hot water flow and electrical energy for water heating have been measured indicate that savings depend on whether the household is a high or low user of hot water. At 5¢/KWH and 50 gallons per day usage savings

* Recommended insulation level based upon Ref. 16.

** The duct wrap described previously is a more serviceable than normal household insulation and would achieve the same end result. The use of R-11 insulation where it can be fitted in around the water heater is an even better choice from a savings point of view.

amount to more than \$3 per month; at 100 gallons per day savings are more than \$5 per month.* (At current margin cost rates (3.7¢/KWH) these savings are \$2.50 and \$4 per month.) Similar retrofit studies were made with gas water heaters with insulation only on the sides (avoiding the air inlet at the base and exhaust vent at the top). Dollar savings with 30¢ per therm gas amounts to at least \$14/year. Additional savings using lower storage temperatures were shown to be about 15% for a 10°F lowering of temperature in the 140-160° range. Since gas hot water heaters normally have a high recovery rate lowering temperatures to 120°F would appear to pose no problem in hot water availability.

Another retrofit that can save significant energy both winter and summer is the addition of storm windows. Storm windows are preferred over double glazing in that larger air gaps are thus provided and because a second chance of sealing against air infiltration is afforded. Unfortunately, the cost for storm windows in the Twin Rivers townhouses is a minimum of \$400 because of nonstandard window sizing. Thus the cost payback is estimated to be 137 months (more when one considers interest). If one considers increasing energy costs of the coming years and the fact that more of the living area is comfortable (near the window areas in living room and bedrooms) even such long term payback items should be given careful consideration. In humidified homes reduction of window condensation is another benefit over single glass. This retrofit was not included in this first round of evaluation, but will be considered further in a second phase of retrofits.

Improvements in energy savings based upon better sizing of the furnace output is another item that has been initially investigated in the laboratory¹² with incorporation into the retrofit program not envisioned until the second phase of retrofit. In connection with the heating system a zoned system with multi-zone thermostat control of warm air flow has been evaluated this past

* Note that the field data indicate savings exceeding initial expectations.

winter in our rented townhouse and gives every indication of significantly reducing energy use.

To review the plan as conceived for the retrofit action, use is made of Table 4 considering the estimated benefit of each retrofit item which is grouped as A, B, C, or D. Initial predictions were that a maximum energy savings of ~37% could be achieved for the average Twin Rivers 3-bedroom townhouse over the entire year, including winter heat, summer cooling, and water heating. The dollar saving based on current energy cost was estimated to be \$147 per year. The retrofit cost is \$145 for materials, \$155 for labor or \$400 total. The payback period without labor is 12 months, with labor it is 33 months. It is these items that make up the selected retrofit groups outlined in the next section.

III. Retrofit Groups

The rationale for providing sufficiently large changes through a choice of retrofit groups was discussed in Section I. The individual items for retrofit as well as possible benefits were discussed in Section II. This section considers the retrofit groups from the standpoint of which items fit the categories of: reduction in conduction heat loss, Group A; tightness of dwelling structure, Group B; and performance improvement of heating/cooling system, Group C. The breakdown also is based upon the consideration of the important aspects of ease of installation and the important question of how to reduce the degree of inconvenience experienced by the homeowner during retrofitting. To help with this later problem each of retrofit groups is located in a separate area of the house to limit inconvenience. The three groups are described in the following paragraphs. Details of installation are discussed in Appendix A.

Group A, located in the attic, emphasized reduced conduction loss through the provision of raising the attic floor insulation level to R-30, insulating the attic trapdoor, and sealing the crack existing between the attic floor joists and the masonry firewalls (outside caulking of this frame - masonry joint is also included).

Group B, located in the basic living area, concentrated on improved door and window seals to reduce air infiltration losses. Improved tightness of the basic living area with reduced drafts and increased comfort was the aim here. Caulking around window frames was also included (see Appendix A).

Group C, located in the cellar, emphasized the reduction of the losses from the warm air ducts and registers to this lightly used area, and reduced the losses from the hot water storage tank using the insulation techniques described in Section II. Insulating the ducts that extend under the living

room overhang also included upgrading the insulation under the entire overhang. While in the cellar the frame-masonry joint between the first floor joists and the firewalls was sealed in the same manner as the A retrofit.**

In addition to the three retrofit groups just described, in all but a limited number of control homes, the air shaft connecting the basement to the attic (surrounding the furnace flue) was sealed at the attic floor (Group D, see Section I). The primary effect of this seal was to reduce air infiltration loss of warm air from the basement to the attic.

By using combinations of the three groups of retrofits outlined in this section the goal of causing a large enough effect to be monitored by the Omnibus instrumentation was achieved. Background on the overall plan for the Omnibus experiment, the instrumentation and parameter selection, is found in References 17 and 4.

** An external resilient seal was applied, where necessary, between the outer wood structure of the townhouse and the protruding brick-covered firewall after both the upper and lower frame-masonry seals (Groups A and C) were completed.

IV. Winter Retrofit Results

As listed in Table 1, the first homes to be retrofitted were the three gas heated, highly-instrumented townhouses (electrical appliances throughout). The HIT retrofits pointed the way for the 19 Omnibus townhouse experiments that followed (16 electrical appliance homes and 3 gas appliance homes, the later results will not be discussed in this report). The past history for gas consumption in the HIT units is shown in Figure 8. As in Figure 1, the influence of the oil crisis is evident in the winter of 73-74. The addition of storm windows and a patio storm door on the western side of house #2 (prevailing winter wind) and; the completion of a finished basement* in house #3, are both evident. The downturn in gas consumption and the percentage and savings of 17, 14 and 22% were the first evidence of changes brought about the BC, ACD and ABD retrofits. The basis for comparison was daily gas consumption data compared to daily weather.

Combining the data from the three HIT units with data from the 16 other electric appliance, 3-bedroom townhouses results in Figure 9. Here we find the familiar variation in gas requirements for heating.³ In this plot of gas consumption per day for a number of approximately ten day periods, the individual gas consumption for "identical" units covers a range of more than two-to-one over a variety of weather conditions. The consumption for each unit is shown as a horizontal line with the average consumption indicated by an arrow and noted numerically. The average is based upon the nonretrofitted houses and (as stated under item 7 Section II) as time progresses the median houses are retrofitted first thus allowing the highs and lows to establish the average thereafter.

It is worthwhile to trace the HIT units on this graph. For example,

* Finishing a basement with a drop ceiling acts as a partial C retrofit.

house #2 and #3 begin at the -6% and +10% levels from the average for the 4-18 December period (23.4 degree days, calculation based on 65°F balance point). As soon as the retrofits take place these homes begin to lower their gas consumption relative to the 19 home sample. If we move to a point in time when we are free from vacation influence and where the full retrofit program has just been implemented, Jan. 18-25, we find the following resultant savings: for house #2 we have moved from 94% of the average to 66% or $\frac{94-66}{94} \times 100\%$ and a 30% savings; and in house #3 from 110% to 75% or $\frac{110-75}{110} \times 100\%$ and a 32% savings. Referring to the retrofit schedule, Table I, and the remaining units in the Jan. 18-25 period we see that although retrofits are still in progress all but one of the 8 units retrofitted has fallen below the average consumption value.

In making such cross comparisons it is important to note that based strictly on degree days one would have anticipated that the gas consumption in the December 18-27, 1975 period compared to December 29 to January 8, 1976 should have been .5% less, 34.5 versus 34.7 degree days. The period actually requires an average of 6.1% more gas or a total of 6.6% more gas per equivalent degree day. This additional energy is caused by higher wind velocities in the December 18-27th period. This is a further complication that requires an accurate residential model when one seeks to compare gains through retrofit measures.

Using eight townhouses in each set we can observe the influence of one period of retrofits during the January 19-26th period. As shown in Table I only two of the townhouses were retrofitted to the full ABCD, the others have received only a partial retrofit, ABD, ACD or BCD. When we perform a comparison over time and we normalize the daily gas consumption by dividing by

degree days, the departure from the non-retrofitted set is well defined in Fig.10. If we consider all of the points between the two retrofit periods, an average gas consumption reduction of 24% results. Again this is keeping with the HIT data, and with the full ABCD retrofit savings of 25% or more can be expected. A closer look at the data reveals that in the early period after retrofit (first 8 days) the savings were averaging 21.5%, whereas in the later period (last 8 days) the savings averaged 28.8%. This is an indication that adjustments were still being made by the home occupants, such as adjusting duct registers to rebalance the heating, during this period. This effect has been observed in other data.

A complete statistical analysis of the Omnibus data is in progress at this time, allowing the details of internal townhouse temperatures and thermostat settings to be properly considered. Furnace operation and water heating are also part of that detailed analysis. Daily electrical readings throughout the winter period have already revealed that electric consumption has also been reduced by approximately 10% through a reduction in electrical energy for water heating and reduced fan operation. All of these topics will be discussed in the forthcoming report on winter retrofit results.

V. Conclusions

The preliminary townhouse retrofit data based upon daily readings of the gas and electric meters from 19 electric appliance townhouses at Twin Rivers gives every indication that this first phase of retrofit action, when fully implemented, results in gas savings of approximately 25% and electrical savings of 10%.* Based upon the closeness of the overall actual findings to a number of the initial predictions from calculations and prior experiments one can also conclude that the summer savings should prove substantial. Based upon the heating/cooling season savings the payback goal of less than three years should be achieved for the approximately \$400 retrofit expenditure. The detailed analysis of such factors as internal townhouse temperature distribution, door openings, electrical load profiles, and actual use of heater or air conditioner, under varying weather conditions, is currently in progress. The results from this analysis should focus upon the important question of what was the individual contribution of each item in the retrofit plan. From a closer examination of the preliminary results cited here, it would appear that when the attic upgrading to R-30 included the sealing of the flue shaft (and plumbing vent piping shaft) as well as sealing the opening between attic floor joists and the masonry firewall, that this item (A plus D) constituted the largest component of energy savings. Next in order of energy savings was the basement treatment, involving ducting plus overhang, and water heater insulation. Door and window sealing placed lowest on the list but were an important part of the overall air infiltration reduction, where preliminary indications are that air infiltration may well have been reduced to one-half the previous values (order of .8 to order of .4 air exchanges per hour). Door and window sealing is wind sensitive, therefore maximum benefits would be expected in the windiest weather, a point now being analyzed.

* In terms of energy, the savings represent approximately 175 therms of natural gas and 800 KWH of electricity during the heating season.

Improved comfort within the homes has been the occupants assessment of the retrofit in virtually every instance. This comfort improvement will lead to such logical steps as night setback of the thermostat in the future in order to achieve still further savings.

The retrofit steps recommended for the Twin Rivers townhouses have implications far beyond the Twin Rivers Community and for other housing styles and methods of construction. The most important feature of this retrofit program was the extent of knowledge gained prior to retrofit as to the probable sources of energy loss so that the proper choice could be made as to retrofit procedure. Just as all energy conservation technology is effective only to the degree it is put into practice, it is equally important to be sure of the nature of the problem before arriving at a solution.

For homeowners to be persuaded to retrofit their homes for energy savings they must (1) be assured substantial benefits can be achieved, (2) know in advance how many months or years it will take them to recover their investment in energy cost savings, (3) be aware how effective low cost steps can be, (4) be confident that such savings have been demonstrated in a home similar to their own and (5) be knowledgeable as to exactly what steps to take. The retrofit program is striving to answer these important questions.

Appendix A

Materials and Techniques for Retrofit

The following is a description of the materials and techniques used in Twin Rivers' retrofits A, B, C and D as described in Section III.

Retrofit A.

The final specification to the contractors for Retrofit A (the attic retrofit) included the following: (1) Roll unbacked fiberglass and stuff openings that exist between the outer attic floor joists (two-by-fours) and the masonry firewall. For an interior townhouse unit this involves two walls between the front and rear of each dwelling. (2) Cover the hatch door to the attic space with 8 inches of fiberglass insulation, stapling or glueing in place. (3) Protect against blown insulation moving into the soffit areas or through the attic hatch opening by using unbacked insulation around the hatchway and along the front and rear portions of the attic floor that are adjacent to the area. In the case of the blown cellulose this barrier was formed by fire retardant corrugated cardboard walls stapled into place. (4) Install insulation by blowing into place (to avoid the problems of the many joists supporting the roof) to achieve a total value of thermal resistance of at least R-30. This has meant that in addition to the initial value of R-11 for the 3 1/2 inch vapor-barrier-backed fiberglass, a value of R-19 of additional insulation must be added. For cellulose this has meant a minimum of $19/3.7$ R per inch or 5.1 inches - we have called for 5.5 inches. With fiberglass this has meant $19/2.3$ R per inch or 8.3 inches - we have called for 8 3/4 inches. The area covered is 720 square feet, the prices have been \$155 for the cellulose insulation installation and \$158 for the fiberglass, however, in the later case \$70 of addition cost for materials was contributed by Certain-teed, a leading fiberglass manufacturer. Recommendations for the best method of fiberglass installation to meet our requirements were

supplied by a group of marketing and research personnel from Owens Corning Fiberglas (one recommendation was the method of crack sealing).

Retrofit D

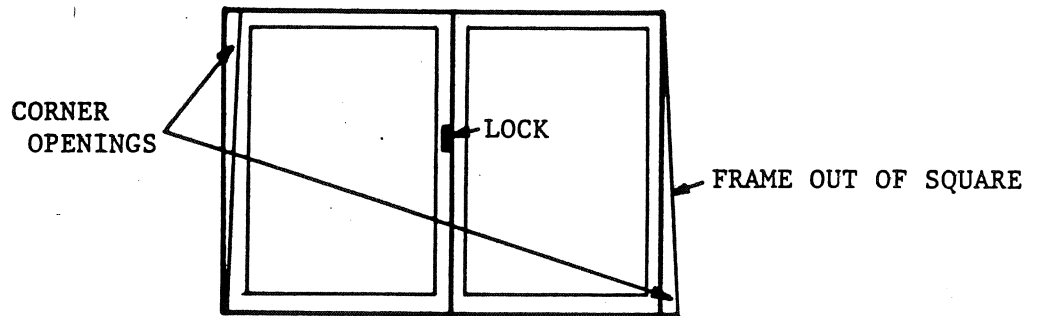
Retrofit D is discussed next because it is most closely associated with the attic retrofit. The purpose is to eliminate air communication between basement and attic (see the house cross section in Figure 7 and Reference 5). In this retrofit a plug of unbacked fiberglas is used to seal, at the attic floor, the shaft which surrounds the furnace flue. This opening varies somewhat from house-to-house but is approximately 16 inches square. The flue temperatures at this elevation were measured to be less than 130°F. The fiberglass material has a char temperature greater than 800°F, thus there is no danger of fire whatsoever* in performing this retrofit (indeed the temperatures are greater on the ducting in the basement - see Retrofit C). To perform this sealing operation a four foot section of 6-inch thick unbacked fiberglass insulation is wrapped around the flue and pressed into the shaft opening. The elimination of any vertical air movement up the shaft is readily detected using one's hand after the seal has been completed. The cost of this item is included in Retrofit A.

Retrofit B

The object of Retrofit B is to limit the amount of air infiltration resulting from crack openings around windows and doors. The problems of window sealing have been shown to result from three causes: (1) the lack of squareness of the window frames - either these frames were installed as a parallelogram (see Sketch A) or the house had settled after the window installation, thus causing openings to be present even with the windows shut, (2) the seal

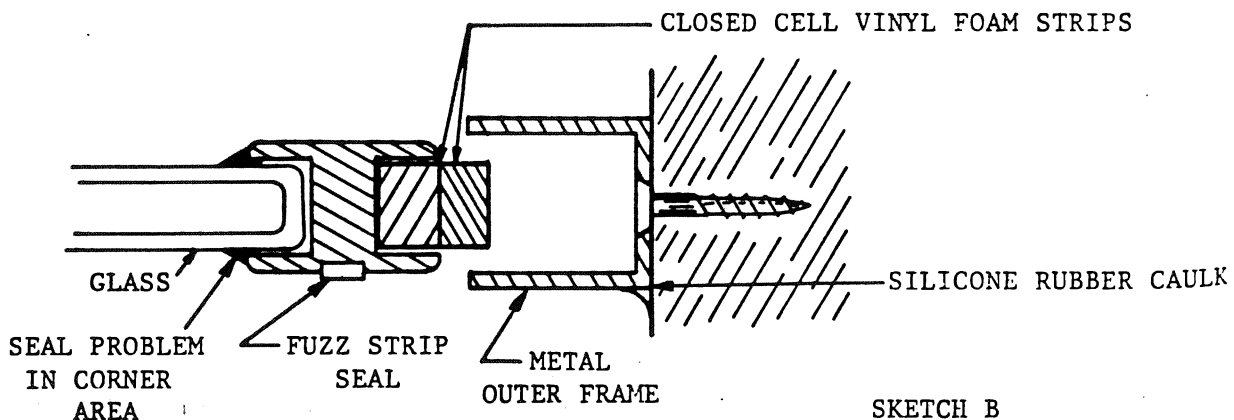
* By sealing this vertical shaft we are performing a service to the homeowner in reducing fire spread danger from a possible basement fire.

between the glass and aluminum frame, and (3) the leakage past the moulding surrounding the window. The door sealing problems were shown to have similar origins when one dealt with the patio door. The front door sealing problem centered upon the threshold alignment and the condition of the magnetic seal strips on the sides and door top.



SKETCH A

The windows were improved in the following manner; the normal side seal on the sliding window, which relies on a stiff fuzz strip, was augmented by the use of closed cell vinyl foam strips (3/16" x 3/8" cross section) attached to the sliding windows (see Sketch B). The lock mechanism was also adjusted to force the windows into the frame. A fillet of silicone sealant was provided along any suspicious joints; where the metal frames attached to the wood frame, where the glass attached to the metal frame, and where the wood moulding

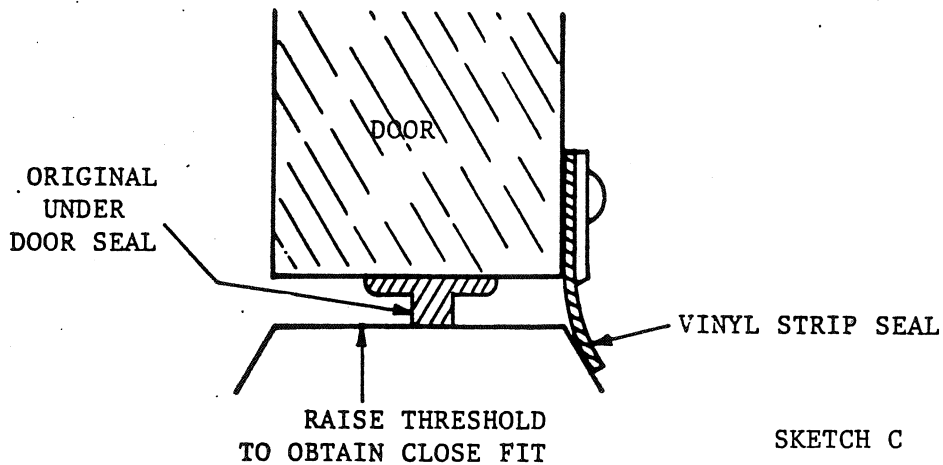


SKETCH B

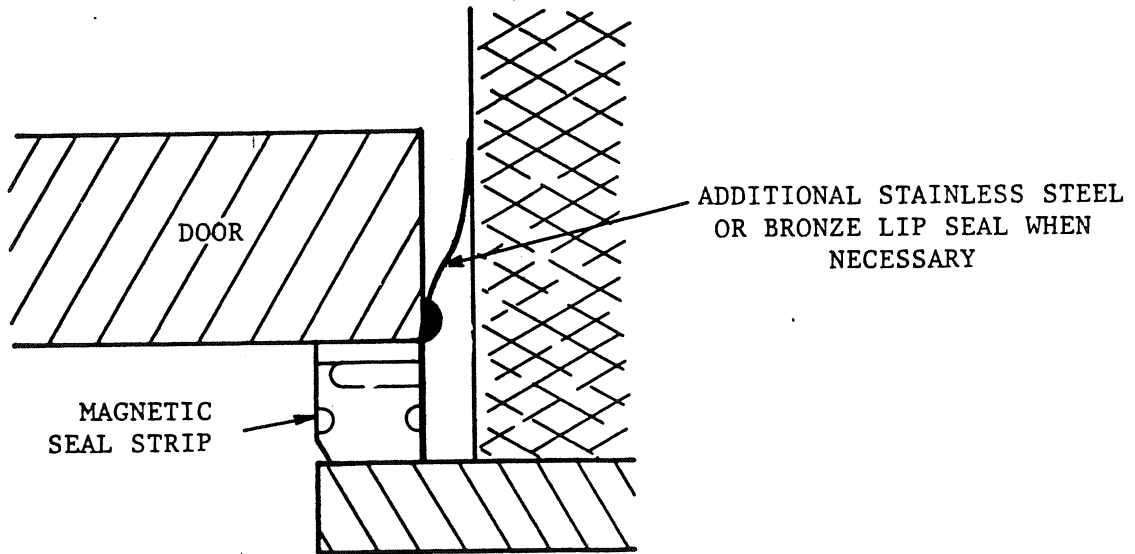
is attached to the wallboard. This material is clear, almost invisible thus matching any decor, long-lasting (10 year guarantee), and remains highly resilient. This same material was used in the overhanging closet areas immediately adjacent to the windows in bedrooms #1 and #2 wherever air leakage was present.

The patio door received similar sealing treatment but requiring a much more substantial foam strip (1/2" x 3/4"). The side panel was injected with silicone rubber in any locations where leakage could occur. Since this panel was fixed no provision need be made for motion and the silicone rubber caulk could be used.

The front door sill was adjusted in height to meet the seal surface on the lower portion of the door. When this was inadequate an additional strip of vinyl with aluminum backing was screwed to the door (see Sketch C).



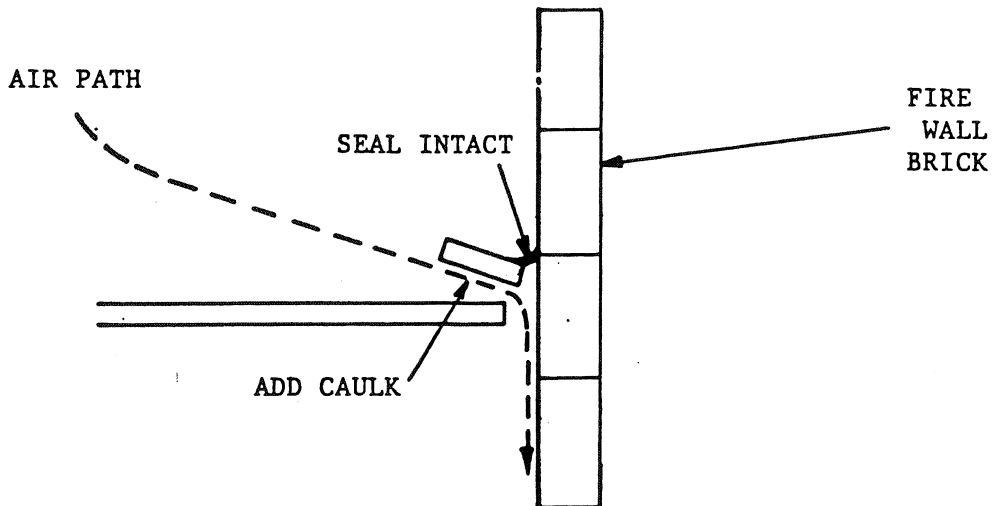
The magnetic seals on the sides and top of the door opening were repaired where problems, particularly corner gaps, occurred. In a few cases an additional lip seal was added (see Sketch D).



SKETCH D

The attic hatch cover also received a rim of the foam vinyl seal to eliminate air exfiltration at that point.

Exterior caulking was used around the patio door frame, and the closet overhang. The vertical joint between masonry and frame was inspected. It was found that the principal cause for infiltration as determined by infrared scanning was warping of the batten in the batten-board homes (see Sketch E).



SKETCH E

In these homes a caulking joint of the appropriate color polysulfide synthetic rubber sealant or use of the clear silicon rubber sealant was made.

The last item under Retrofit B is the sealing of the opening between basement ceiling joists (2" x 8") and the firewall. This was accomplished in the same manner as in Retrofit A, i.e., fiberglass forced into the opening. Included was any other openings that require sealing, piping to the kitchen, the dryer exhaust, the corner problems, and the service wiring. Caulking was used along the sill joint and smaller wall openings. Costs for materials was approximately \$25.

Retrofit C

This retrofit concentrated on the cellar and includes the insulating of the furnace warm air distribution system, the overhang area under the living room window which includes two ducts and the wrapping of the hot water heater.

The furnace plenum, main supplies left and right and the nine individual 5-inch diameter ducts are wrapped with 2-inch thick fiberglass backed by aluminum foil with reinforcing thread. In the case where the 5-ducts are in between the 2 x 8 ceiling joists, the insulation is 3 1/2" thick aluminum foil backed fiberglass stapled across the beams. Although the installation originally involved ordinary duct tape a superior product was discovered by one of the contractors. This tape has the same reinforcing thread plus a superior bonding surface thus eliminating any problems of peeling with repeated heating of the ducts. Insulation is extended to completely cover the register as well, stapling the insulation to the underside of the floor.

The same 2-inch thick fiberglass* is used on the waterheaters again using the new tape. On the gas water heaters care must be taken to use the insulation

*Where the 3 1/2 inch thick fiberglass can be fitted in, the additional heat resistance, R-11 vs approximately R-7, is worthwhile.

only on the sides of the tank, staying away from the air inlet on the bottom and the exhaust at the top.

The last item is the overhang under the front living room window. Here two ducts extend between the beams to the registers and the insulation is quite marginal, sometimes missing. The retrofit includes blowing cellulose or fiberglass into the openings, or in the case where blowing equipment isn't available, hand packing of fiberglass insulation into these cavities. Gaps to the outside are a particular problem in this location which was difficult for the builder to complete properly (since it is only 1 foot above ground level).

The cost for Retrofit C ranged from \$125 - \$145 depending on the contractor performing these tasks.

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Table 1

Channels Monitored in Our
Lightly-Instrumented ("Omnibus") Townhouses

1. Thermostat setting (°F)
2. Basement temperature (°F)
3. First-floor temperature (°F)
4. Second-floor temperature (°F)
5. Furnace operation (min/hr) or air conditioner operation (min/hr)
6. Electric hot water heater operation (min/hr)
- * 7. Front door or front window opening (min/hr)
- * 8. Back door or back window opening (min/hr)
9. Total electric consumption (min/hr)

Channels 1-8 are recorded hourly, and channel 9 is recorded at 15 minute intervals, onto a Westinghouse WR-4C magnetic tape cassette in the basement. The details of the instrumentation package are to be found in Ref. 4.

*The measurements of channels 7 and 8 were combined to channel 7, and the free channel 8 was assigned to attic temperature (°F) just prior to the 1976 winter.

TABLE 2
SCHEDULE FOLLOWED IN RETROFITTING

<u>Omnibus</u>	<u>Jan 19-23, 26-30</u>		<u>Feb 16-20, 23-27</u>		<u>Mar 15-19</u>
1			ABCD		
2			AD		
3	ACD		B		B outside*
4	ACD		B		
5			C		
6				BD	A
7	ABCD				
8	C	BD	A		
9			ABCD		B outside
10	C	BD	A		
11	ACD	B			
12				BD	
13	ABD				
14	ABD		C		
16			C	BD	
+ 17			BD	A	
+ 18			C	BD	
19			AD		
+ 21			CAD	B	

<u>HIT</u>	<u>Dec 15-19 22-26</u>		<u>Jan 12-16 19-23</u>		<u>Mar 15-19</u>
1	B	C	D	AB	B outside
2	AD	C		B	
3	ABD				C partial

* B outside refers to outside caulking which after inspection was limited to certain batton-board siding homes (see Appendix A).

+ Quad III townhouses - gas appliances.

BASIS FOR RETROFIT

RETROFIT

TECHNIQUE

HIGHLY-INSTRUMENTED
TOWNHOUSE BASIC DATA

OMNIBUS MONITORING
DATA

AIR INFILTRATION DATA

INFRARED DATA

DUCT LOSS DATA

THERMISTOR WALL DATA

WINDOW ENCL. DATA

EXHAUST GAS DATA

MODELING

WATER HEATER WRAP

IMPROVE SEALS
WINDOWS & DOORS

SEAL SHAFT

DUCT INSULATION
& SEAL

REGISTER INSULATION
& SEAL

PARTY WALL ISOLATION

CEILING INSULATION

OVERHANG INSULATION

MAINTAIN HIGHEST
FURNACE EFFICIENCY

RESIZE FURNACE

STORM WINDOWS

R-7 INSULATION WRAP

SOLID CELL PLASTIC
STRIPS - THRESHOLD & SEAL
UPGRADE

FIBERGLAS PLUG SEAL

TAPE FOR LEAKS
WRAP WITH 2" FIBERGLAS

WRAP WITH FIBERGLAS
BLOW WITH INSULATION

ROLLED FIBERGLAS
ATTIC AND BASEMENT

FIBERGLAS OR CELLULOSE
TO R-30

BLOW OF HANDPACK CAVITIES

ADJUST TO SPECIFICATIONS
CHANGE FILTERS

INSTALL ORIFICES - CHECK
WITH UTILITY

INSTALL

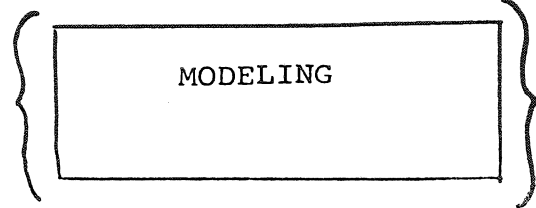
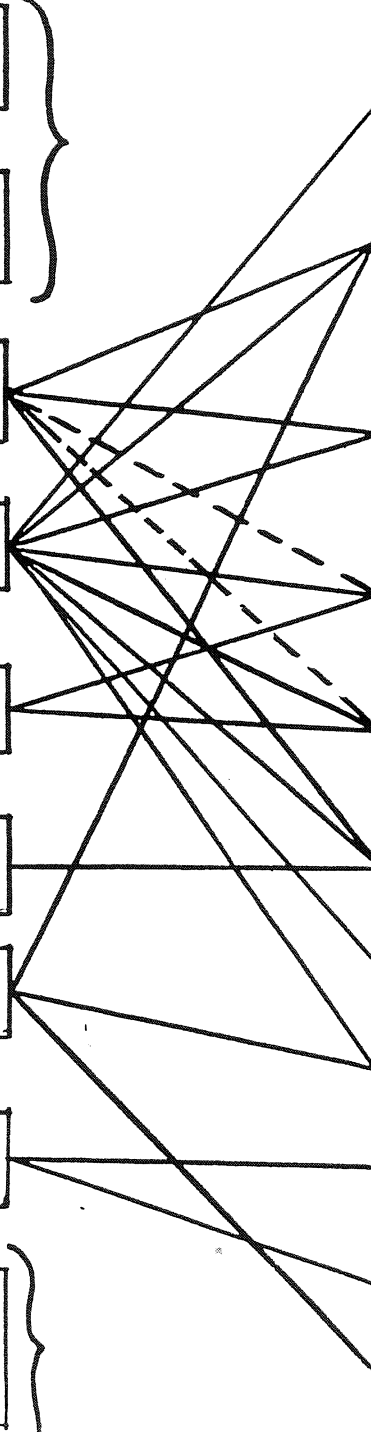
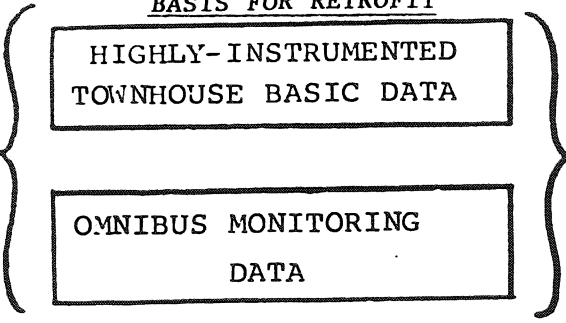


Table 4

Estimated⁺ Retrofit Costs and Payback

RETROFIT	% SAVINGS ⁺⁺	\$ SAVINGS	MATERIAL COST	LABOR COST ⁺⁺⁺	TOTAL COST	MONTHS TO PAYBACK WITH LABOR	NO LABOR
Party Wall (A)	3.2	\$13/Year	5	10	15	14	5
Ceiling* (A)	6.0	24	63	105	168	84	32
Shaft (D)	2.8	11	2	5	7	8	2
Seals (B)	3.8	15	25	50	75	60	20
Ducts (C)**	8.8	35	40	60	100	34	14
Registers (C)	2.3	9	2	5	7	9	3
Water Heater (C)***	7.5	30	3	10	13	5	1
Overhang Window (C)	1.5	6	5	10	15	30	10
Reduced Furnace Fan 1	4						
Summary	36.9%	\$147	\$145	255	\$400	33 months	12 months

result of above retrofits

+Estimates make use of best information currently available.

++Savings based on \$200 heating, \$150 cooling, \$40 HW standby. + \$15 Furnace Fan = \$405 total.

+++Labor rate based on \$10/hr.

*Night setback now becomes feasible with predicted additional savings.

**Estimate is based on 50% basement heat loss recovery even without insulation.

***Savings for 50 gal/day user-field data

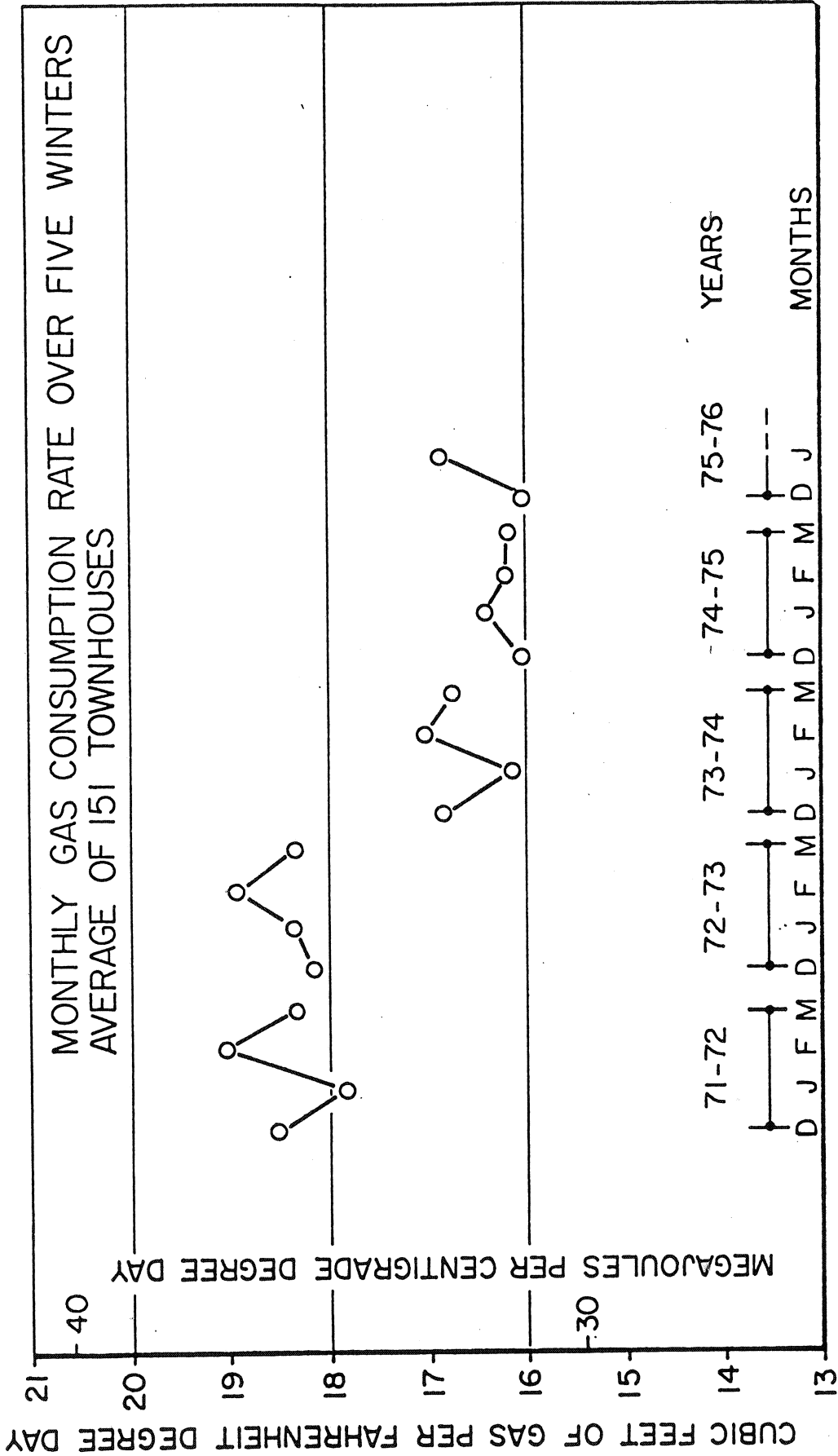


FIGURE 1

TOWN HOUSE — 3 bedroom, 2 story

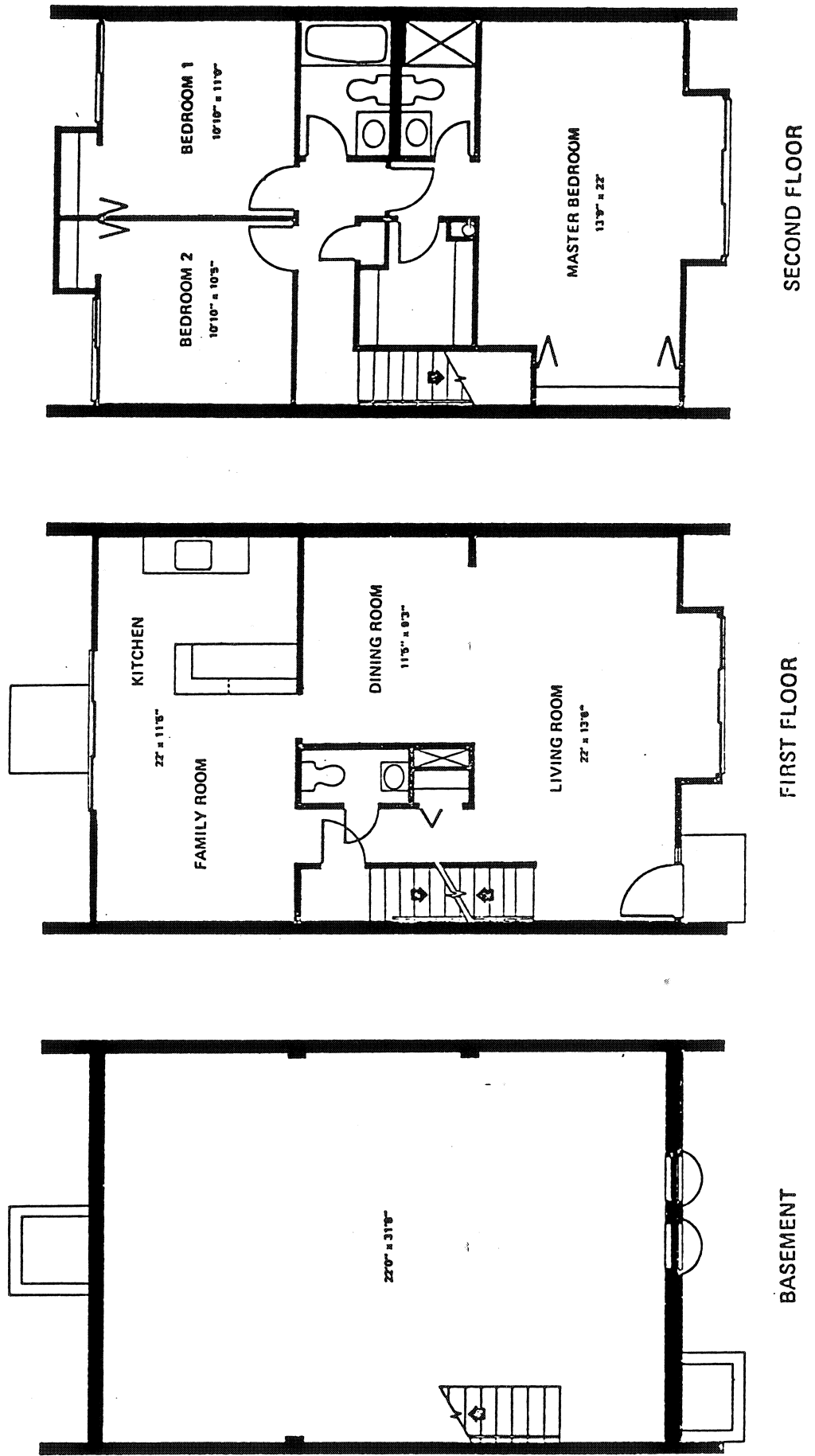
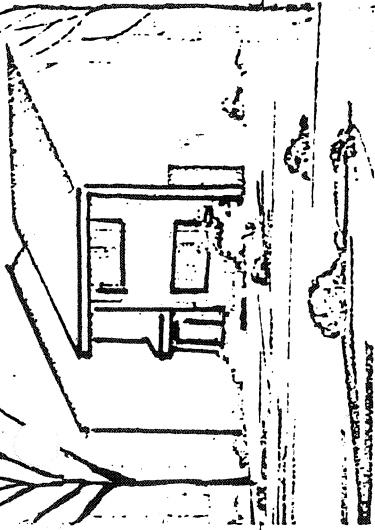
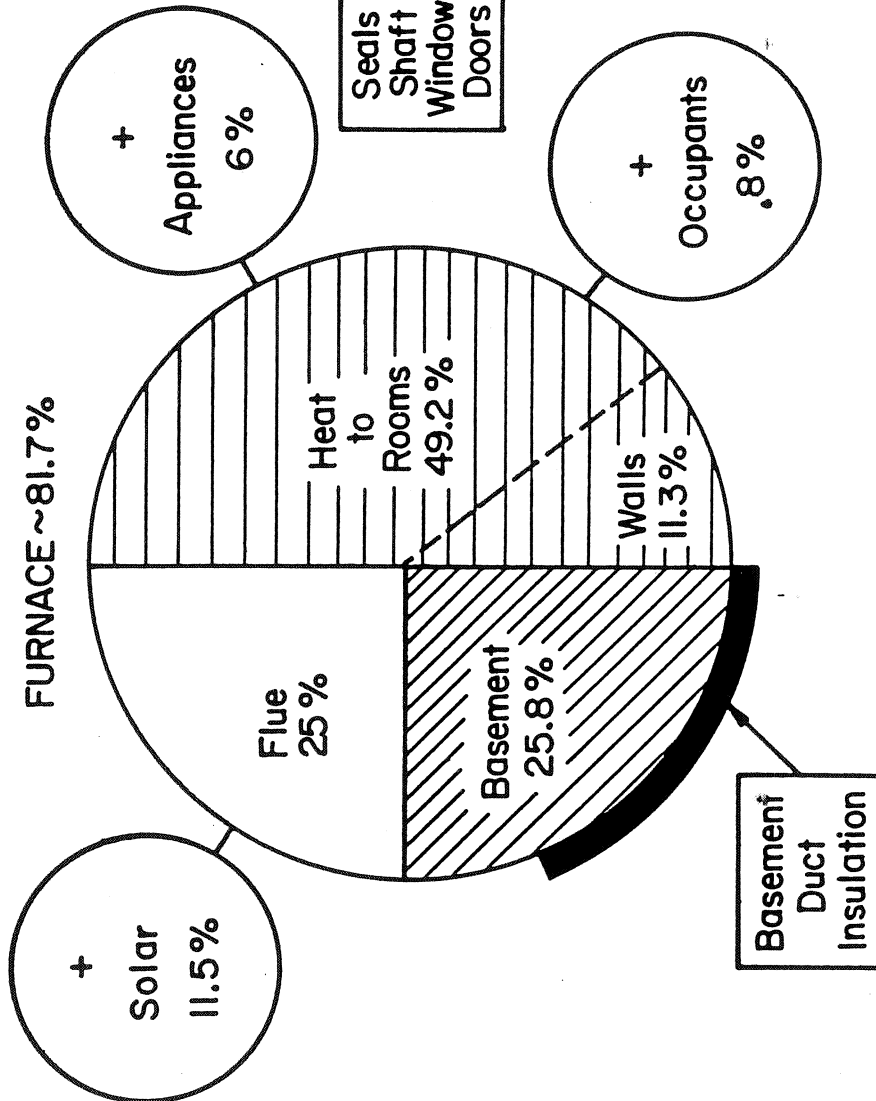


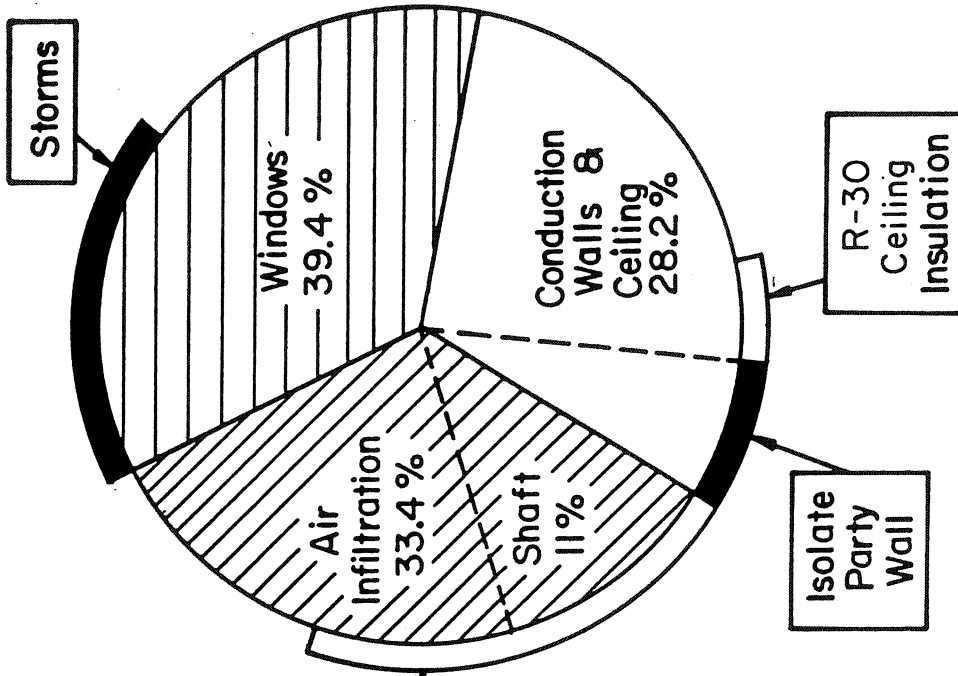
FIGURE 2

WINTER

HEAT SOURCE



HEAT LOSS

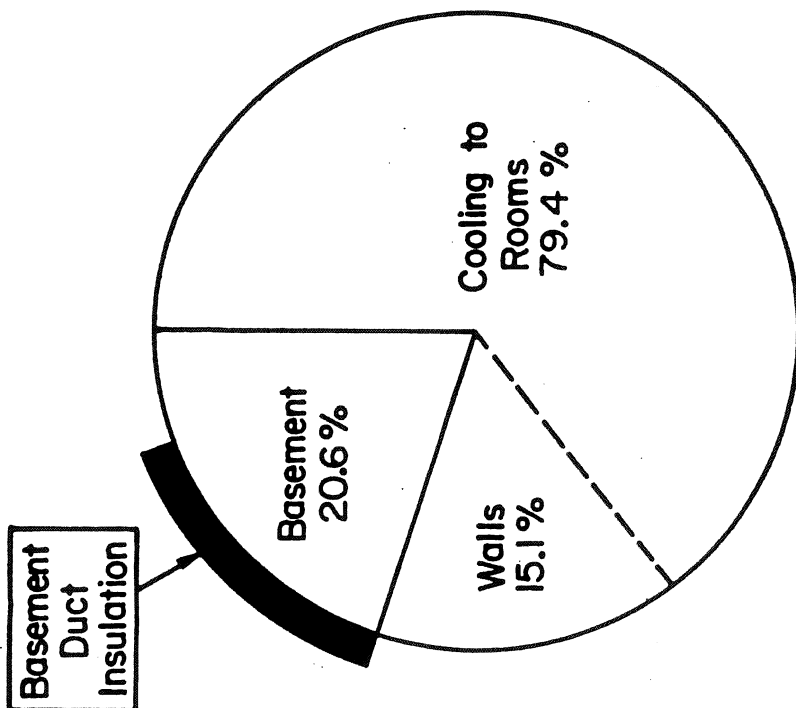


$T_{HOUSE} = 70^{\circ}F$; $T_{OUTSIDE} = 0^{\circ}F$

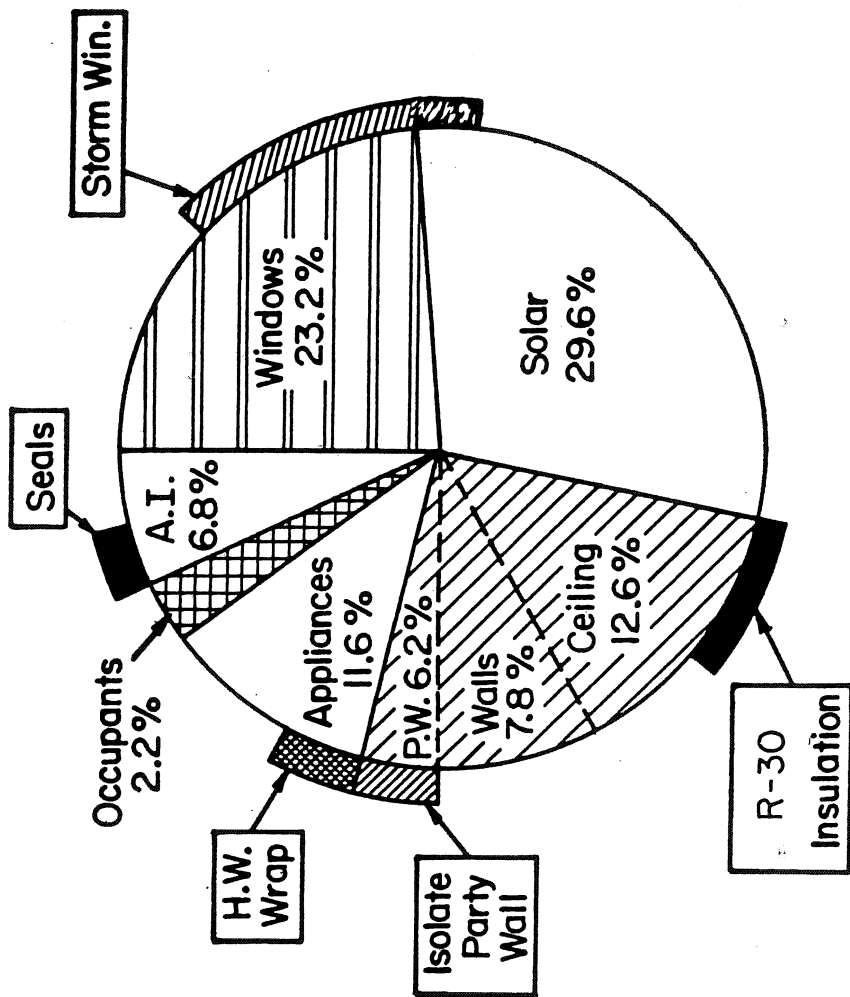
FIGURE 3

SUMMER

COOLING



HEAT GAIN



$T_{\text{HOUSE}} = 75^{\circ}\text{F}$; $T_{\text{OUTSIDE}} = 95^{\circ}\text{F}$

FIGURE 4

REGISTERS

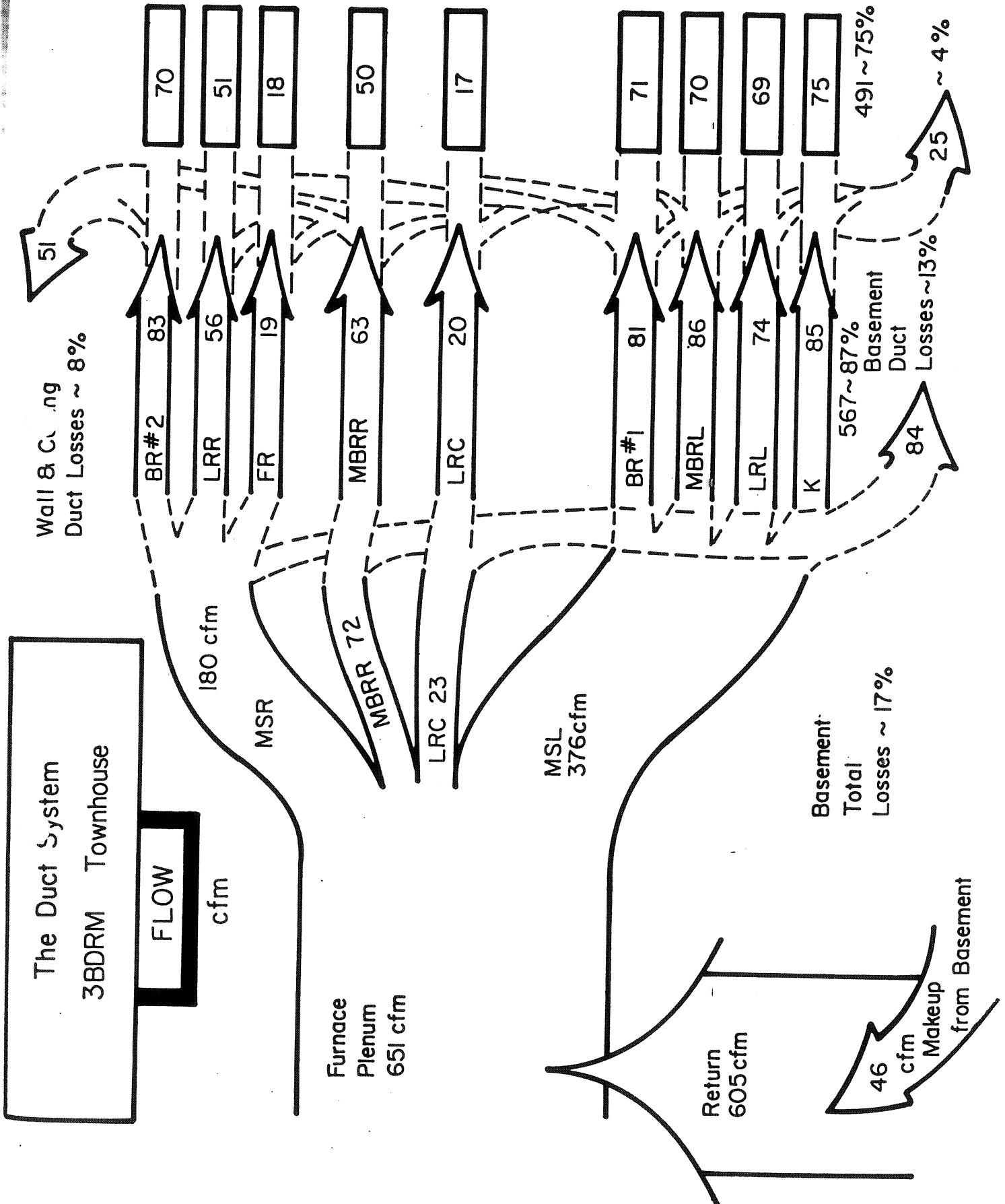
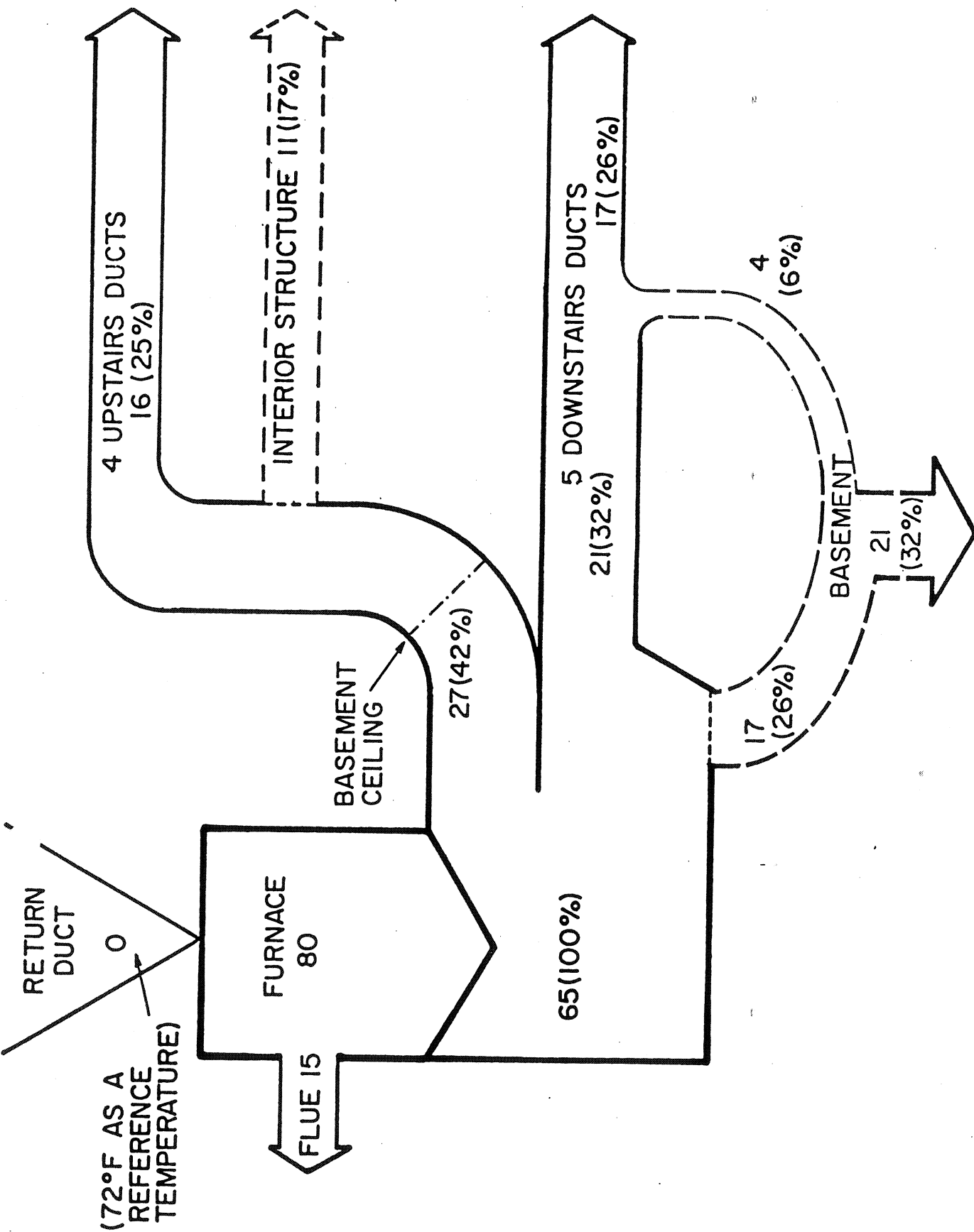
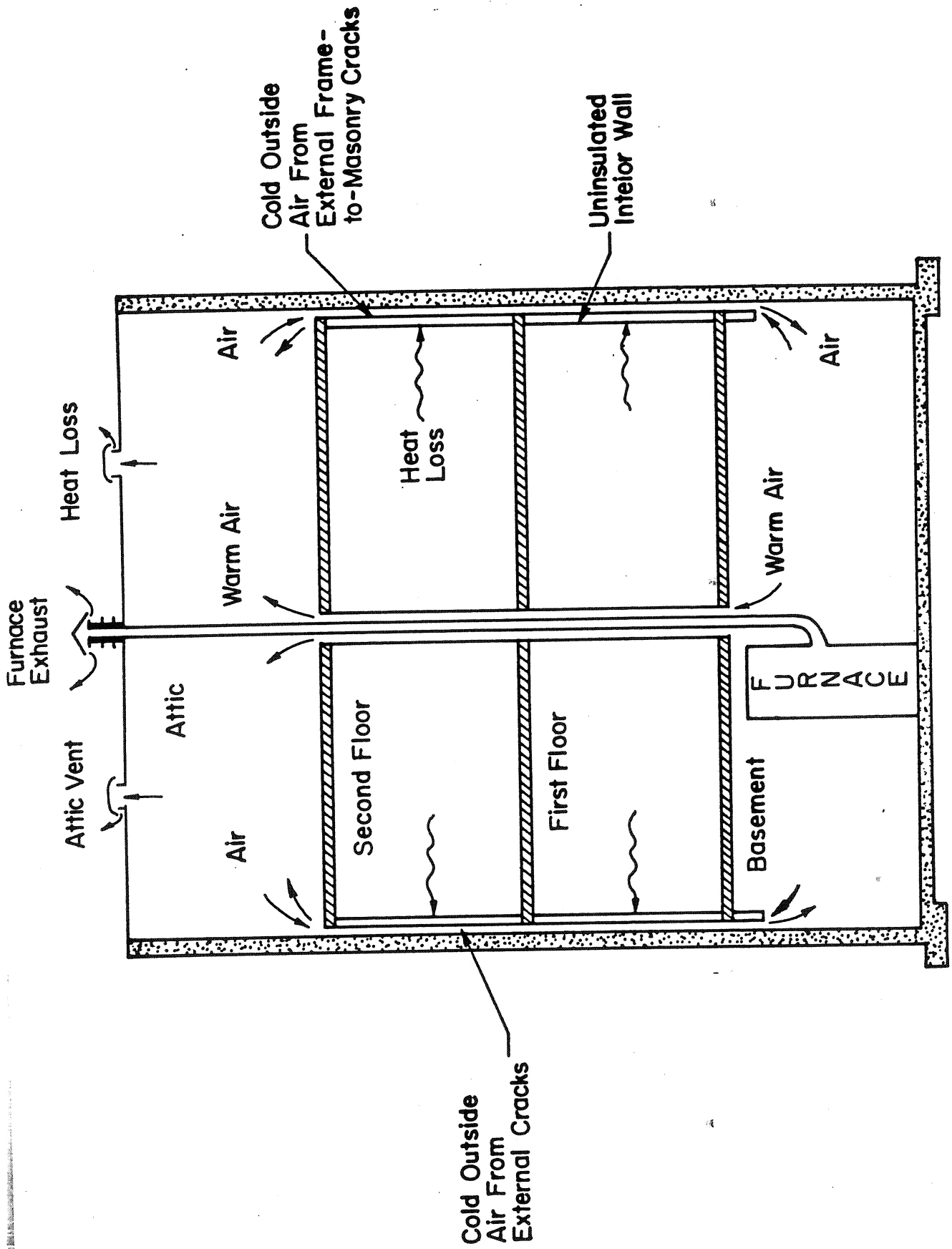


FIGURE 5



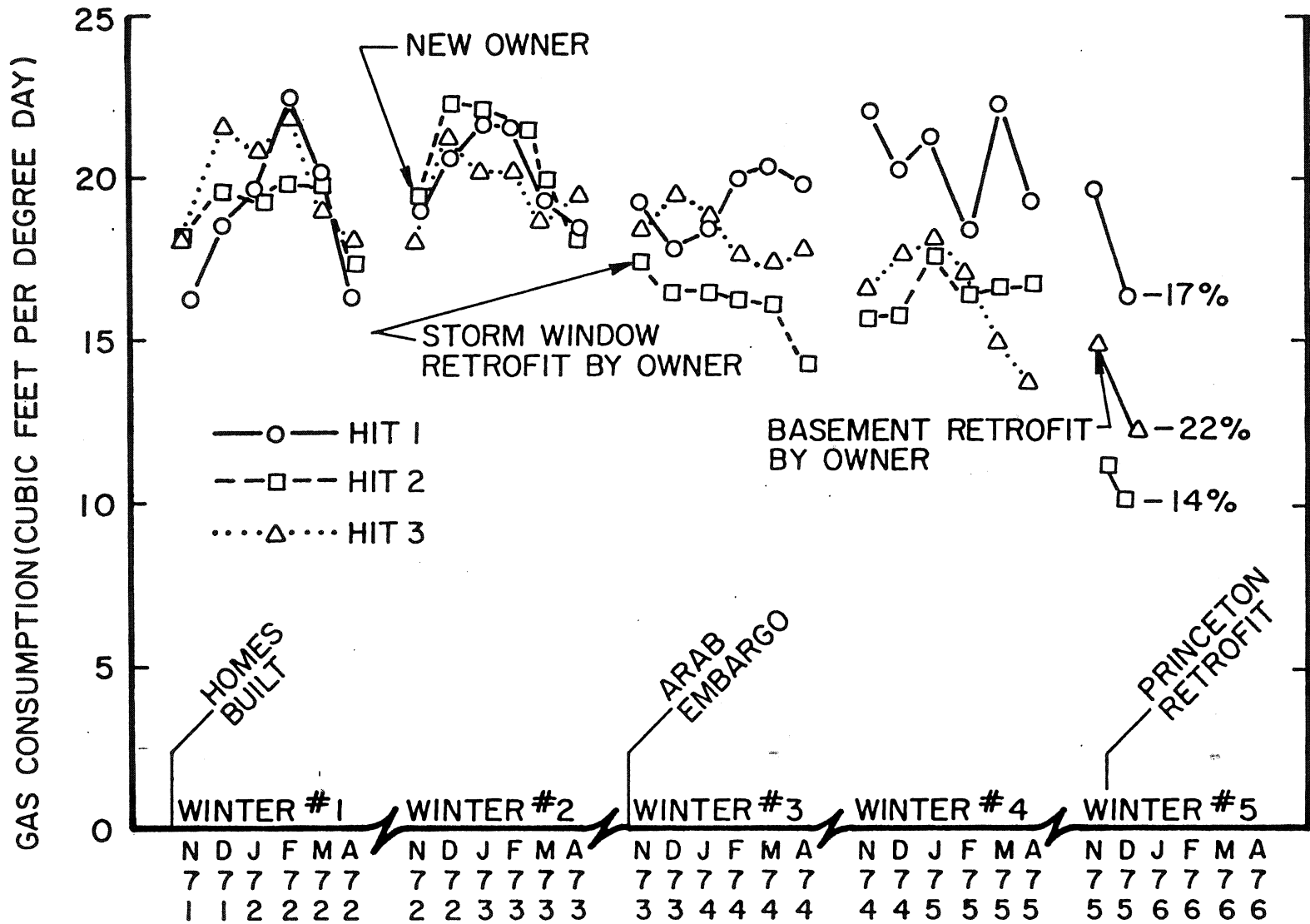
SCHEMATIC FURNACE HEAT FLOW (KILO BTU/HR) IN A 3-BEDROOM TOWNHOUSE
 DOWNSTAIRS DUCTS PARTIALLY CLOSED

FIGURE 6b

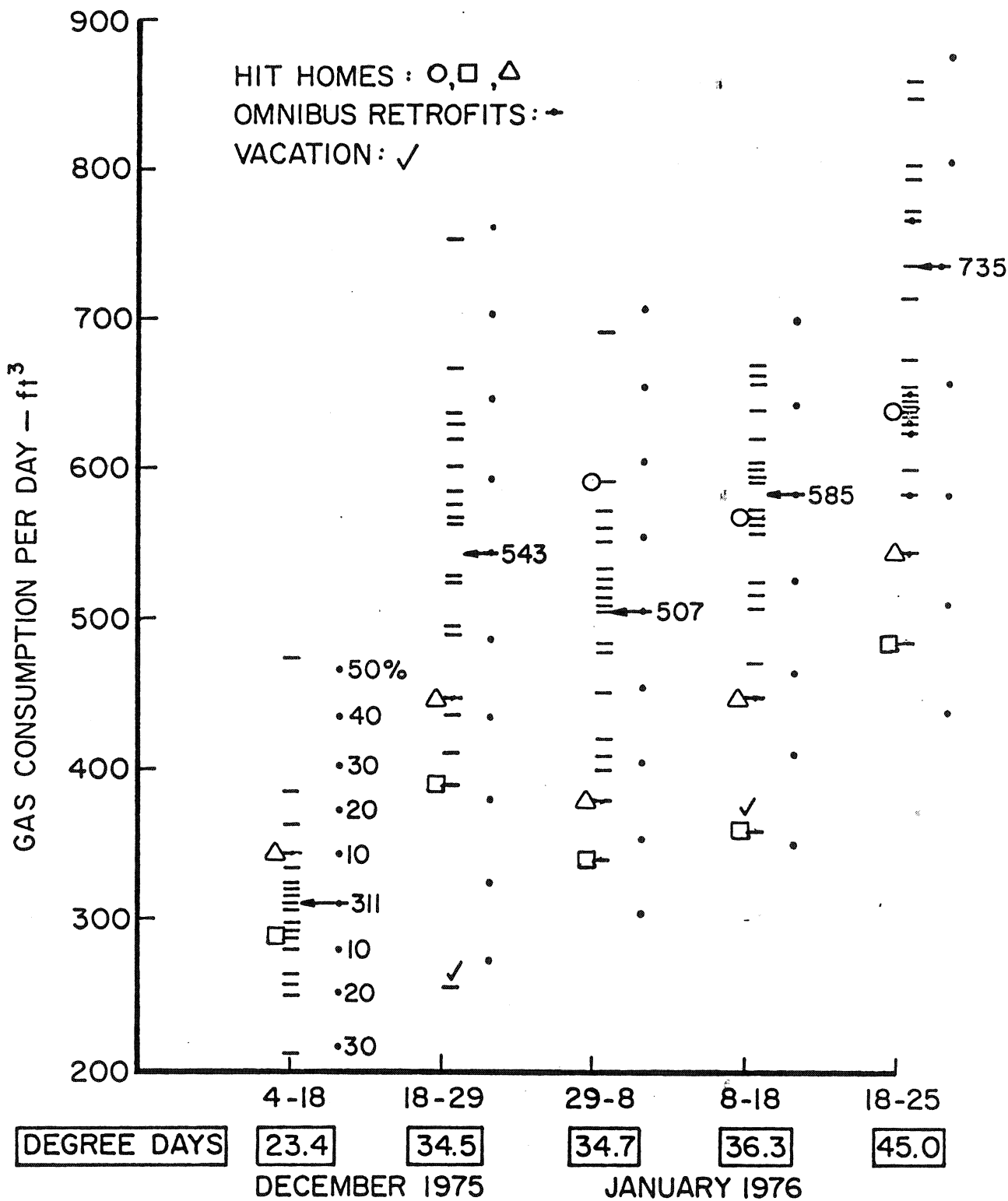


Cross - Section of Townhouse
Showing Flow Pattern

FIGURE 7



GAS CONSUMPTION PER DEGREE DAY FIVE WINTERS (1971-76)
THREE HIGHLY-INSTRUMENTED HOUSES



GAS CONSUMPTION FOR HIT AND OMNIBUS HOUSES BEFORE AND AFTER RETROFIT

FIGURE 10

