

Technical Report

**EVALUATION OF THE ULTIMATE R[®]
ATTIC DUCT INSULATION SYSTEM**

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SYSTEM**

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Summary

The report is an evaluation of the performance and cost effectiveness of the Ultimate R attic duct insulation system. Ultimate R is an insulation containment system which is installed over supply and return air ducts in attics. It is simple and fast to install and facilitates the installation of substantial amounts of blown insulation around the ducts. The result is reduced conductive and convective losses from the ducting in summer and winter, both when the air handler is working and when it is not.

This report covers energy savings results from three homes where the Ultimate R attic duct insulation system was installed; two in California and one in upstate New York. The objectives of the work were to gain installation knowledge for production of future training materials, as well as to estimate energy savings resulting from the treatment. A fourth home in Portland, Oregon was instrumented, monitored, and checked for possible moisture problems.

The annual energy savings due to the application of Ultimate R were estimated in two ways: (1) theoretically, by combining conventional heating and cooling building load calculations with ASHRAE Standard 152P, *Method of Test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems*, and (2) empirically, by monitoring energy consumption and local temperatures at the three homes both before and after application. The theoretical results produced estimates of heating and cooling savings due to these three UR treatments for four substantially different climates, while the empirical results estimate heating savings only, and only for the climate in which each house is located.

It was found that the theoretical annual heating and cooling savings due to Ultimate R equaled 13 to 36 percent of the cost of installation for the two smaller duct systems, and 63 to 125 percent of the cost of installation for the third system, which included a greater amount of ductwork. The empirically-estimated heating savings were found to generally agree with the theoretical heating savings for each home's natural climate.

Further, payback would be even quicker had these UR installations occurred in new construction, since UR costs are much less during construction of a home. The analysis here shows that the combination of flexduct/ductboard attic systems and UR in new construction can provide builders and homeowners with a confident return on investment of 30 percent in most climates, and one-year paybacks for larger systems. In addition, the greater distribution efficiency at design conditions will keep a home comfortable during more severe weather.

The UR product was found to be easy to install, even in difficult circumstances, and is a recommended component of an insulator's work, both in new homes and in

retrofit situations. Homes with and without attic trusses are good candidates for the Ultimate R system, although work may be accomplished faster in the absence of trusses, the circumstances in perhaps half of the nation's housing stock. As part of the installation process, it is also important to seal holes in both the supply and return ducts. Blown insulation contained by the Ultimate R system impedes to a modest degree convective duct losses, but should not be counted on to treat large holes.

Further work toward developing and validating a brief installation manual and training syllabus is recommended.

Introduction

Ultimate R[®] (UR) is a loose-fill insulation containment system that assembles over and around standard attic ducts quickly. Cardboard compartments are created using bi-fold panels that are pre-notched to fit over ductwork and to lock together. Once filled with blown cellulose or fiberglass, the system provides between five and eight inches of insulation around a duct, depending on the duct's size. This translates to installed R-values of between R-18 and R-30, substantially better than the R-4.35 standard often found on attic duct systems.





The objectives of the work described herein are to demonstrate the treatment of three attic duct systems with UR, and to evaluate the ensuing energy savings for both heating and cooling. The field work that produced the data included remote electronic monitoring of energy performance as well as on-site diagnostic tests.

Evaluation of energy savings here depends in part on utilization of ASHRAE Standard 152P, *Method of Test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems*. This Proposed ASHRAE Standard has undergone extensive development in the last three years and is presently being verified experimentally to allow publication as a formal Standard.

All field work was conducted during the winter of 1997/98. The two California homes were recruited during the fall of 1997 and were instrumented in December for pre-Ultimate R monitoring. Diagnostic tests and installation of the Ultimate R were conducted in January 1998, and were followed by the post-Ultimate R monitoring period. The Syracuse home was recruited and instrumented in March 1998, with diagnostic tests and installation of Ultimate R occurring in April.

Description of Houses

Houses #1 and #2 are located in Chico, California, about 100 miles Northeast of San Francisco, while house #3 is located in Syracuse, NY, in the central part of the state. All supply and return ducts are located in the attics of these three homes. Floor plans and attic duct plans are given in Appendix A.

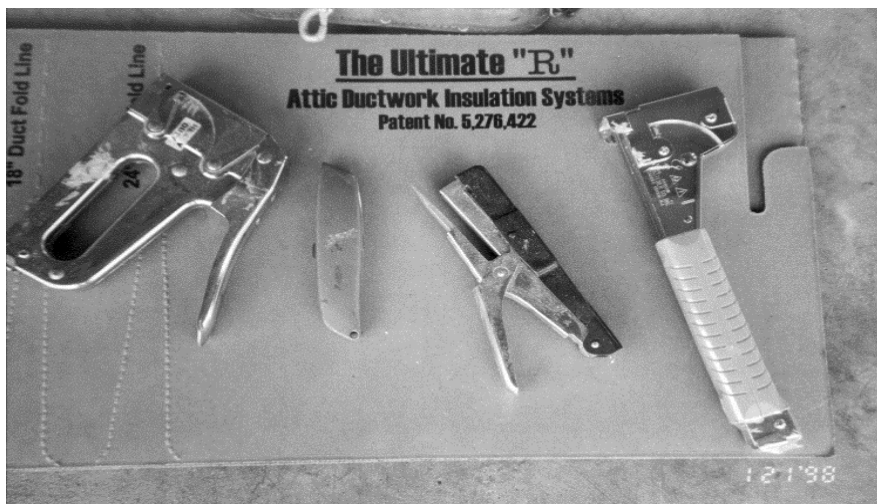
Table 1 shows some general characteristics of the homes and heating/cooling equipment as found.

Table 1. Description of Houses

	#1	#2	#3
Year Built	1989	1989	1965
Location	Chico, CA	Chico, CA	Syracuse, NY
No. of Stories	1	1	1
Foundation Type	Slab	Vented Crawlspace	Slab
Conditioned Floor Area	988 sq. ft.	954 sq. ft.	881 sq. ft.
Heating Equipment	Heat Pump	Gas Furnace	Gas Furnace
Heating Capacity	N/A	40,000 BtuH input	75,000 BtuH input
Cooling Capacity	N/A	N/A	N/A
No. of Supply Registers	7	7	8
No. of Return Registers	1	1	1
Supply Duct Types	6", 8", 10" dia. flex R-4.35	6", 8", 10" dia. flex R-4.35	6" dia. wrapped metal and flex (both R-4.35)
Return Duct Types	14" dia. flex R-4.35	14" dia. flex R-4.35	16 x 20 metal R-1
Supply Surface Area	172 sq. ft.	233 sq. ft.	373 sq. ft.
Return Surface Area	71 sq. ft.	21 sq. ft.	24 sq. ft.
Existing Attic Insulation	Avg. R-8 wool	Avg R-8 cell/fbrglass	Avg R-8 fiberglass

Installation Scenarios and Costs

The product is simple to install, requiring only a sharp razor knife, a construction stapler and hammer tacker for attaching UR to wood framing, and a box stapler for connecting UR panels together. The box stapler also allows attachment of custom braces or spreaders cut from a UR panel.



Ultimate R installations can be divided into two rough classes:

1. Installation in attics with roof trusses; and
2. Installation in attics with stick-built roof frames.

The cost of Ultimate R insulation, in both truss and stick-built attics, is substantially reduced if the compartment insulation is accomplished along with the normal attic insulation. This would most often be possible in newly-constructed homes rather than retrofit situations, but would also apply to older homes in need of additional attic insulation.

Roof trusses slow the installation process, especially for roofs with pitch less than 5/12. Trusses affect the speed with which workers can move from one position to another, both during Ultimate R installation and during insulation. They also may interfere in places with the normal assembly of the Ultimate R compartments, requiring custom cutting and/or stapling. Both of these truss roof problems could probably be lessened if the duct system was laid out with Ultimate R in mind. Such a system would avoid running ducts close under framing whenever possible, and would keep the duct runs relatively straight.

Both Chico homes (#1 and #2) had low pitch truss roof frames, while the Syracuse house (#3) included a low pitch stick frame. The photo below shows the working space available when the roof is stick-built, while the photo on the next page illustrates the slightly more complicated installation required by a truss roof frame.





Table 2 shows the installation costs for all three houses, as well as hypothetical installation costs had the UR been installed during construction. New construction labor time is based on the Ultimate R's inventor's experience in new homes with relatively unobstructed attics.

Note that the cost for UR at #3 is about the same as at #1 and #2, even though the #3 duct system was significantly larger. This illustrates the slightly higher per-unit installation costs required by the truss-built attics at #1 and #2, as well as the slightly lower per-unit costs for larger duct systems vs smaller systems.

Table 2. Installation Costs

Retrofit	#1	#2	#3
Install Ultimate R @ \$25/mhr	\$200	\$225	\$225
Insulate Ultimate R @ \$25/mhr	\$125	\$125	\$125
Insulation @ \$5.00 per bag	\$60	\$75	\$90
Cost for Ultimate R	\$50	\$50	\$50
Total Cost	\$435	\$475	\$475
New Construction			
Install Ultimate R @ \$25/mhr	\$75	\$75	\$75
Insulate Ultimate R @ \$25/mhr	\$50	\$50	\$50
Insulation & Ultimate R	\$110	\$125	\$140
Total Cost	\$235	\$250	\$265

Table 2 shows that retrofit UR installations may cost nearly twice as much as analogous installations accomplished during construction of a home. The difference in cost is entirely labor, and reflects quicker installation of the UR compartments and insulation of the UR during insulation of the attic.

Diagnostic Tests

The diagnostic tests provided required input values for the Standard 152P duct leakage and heat exchanger energy transfer calculations, and results are shown in Table 3. None of the diagnostic tests address the large change in conductive R-value that may be the principal benefit of treatment with Ultimate R. However, they do reveal the small reductions in duct air leakage that result from UR treatment.

Table 3. Diagnostic Test Results

	#1 Pre	#1 Post	#2 Pre	#2 Post	#3 Pre	#3 Post
Building CFM50 Air Handler Flow ^A (CFM)	1,112	1,108	924	1,000	2,099	2,103
Avg. Supply Register Pressure ^B (Pa)	822	809	835 ^D	898	950	886
Supply Duct Leak Flow ^A (CFM)	38.5	41.0	33.5	35.3	62.5	60
Whole System Duct Leak Flow ^A (CFM)	N/A ^C	N/A ^C	79	73	378	273
	118	114	90	85	385	286

^A During normal operation

^B Pressure pan measurements during normal operation

^C Unable to access air handler for supply/return separation; supply leak flows of 104 CFM and 102 CFM were used in 152P calculations of pre-Ultimate R and post-Ultimate R distribution efficiencies, respectively, based on similar duct system at house #2 and the measured supply/return split there

^D Windy conditions on rooftop at duct blaster resulted in fan flow of error of +/- 30 CFM; the small decreases in duct leak flow, as well as the limited increases in duct and register pressures, predict a small difference in air handler flow between pre- and post- configurations; a value of 900 CFM was used in 152P calculations of pre-Ultimate R distribution efficiencies

Standard 152P Calculations

ASHRAE Standard 152P, *Method of Test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems*, was applied to the duct system in each house, both before and after application of Ultimate R, in order to estimate the changes in design and seasonal distribution efficiency due to UR.

Design distribution efficiency is the ratio of the amount of energy that usefully conditions the living space to the amount of energy that is supplied to (heating) or taken out of (cooling) the duct system at the air handler, at design conditions. Design conditions represent demanding outside conditions and are taken from ASHRAE Handbook of Fundamentals, 1997, Chapter 26. Seasonal distribution efficiency is the ratio of the amount of energy that usefully conditions the living space to the amount of energy that is supplied to (heating) or taken out of (cooling) the duct system at the air handler, over an average heating or cooling season. It is

this seasonal value that is used in determining energy consumption. Seasonal average conditions are calculated within 152P, using the design conditions as starting points. 152P inputs that may be affected by application of Ultimate R, and therefore that may result in changed 152P distribution efficiencies, include:

1. Duct R-value and surface area;
2. Duct leakage; and
3. Air handler flow.

The distribution efficiencies calculated using 152P are specific to the ASHRAE climate design conditions that are entered, and the three houses and duct systems demonstrate different distribution efficiencies in different climates. Table 4 shows the results for the homes if they were in Chico, CA. Table 5 shows the results if the homes were located in Phoenix, AZ, a climate with many more cooling degree days than Chico, while Table 6 shows results from Tulsa, OK, a climate with many more heating degree days and slightly more cooling degree days. Table 7 shows results from Syracuse, NY, which has almost double the heating degree days of Tulsa, but nearly zero cooling degree days.

Table 4. Standard 152P Distribution Efficiency Calculations - Chico, CA

	#1 Pre	#1 Post	#2 Pre	#2 Post	#3 Pre	#3 Post
Heating, design	0.78	0.81	0.82	0.87	0.50	0.63
Heating, seasonal	0.80	0.82	0.83	0.87	0.52	0.63
Cooling, design	0.72	0.77	0.77	0.84	0.36	0.50
Cooling, seasonal	0.80	0.82	0.83	0.87	0.45	0.57

Table 5. Standard 152P Distribution Efficiency Calculations - Phoenix, AZ

	#1 Pre	#1 Post	#2 Pre	#2 Post	#3 Pre	#3 Post
Heating, design	0.79	0.82	0.83	0.87	0.52	0.64
Heating, seasonal	0.81	0.83	0.84	0.88	0.53	0.64
Cooling, design	0.70	0.74	0.74	0.82	0.33	0.46
Cooling, seasonal	0.76	0.79	0.80	0.85	0.40	0.53

Table 6. Standard 152P Distribution Efficiency Calculations - Tulsa, OK

	#1 Pre	#1 Post	#2 Pre	#2 Post	#3 Pre	#3 Post
Heating, design	0.73	0.77	0.77	0.83	0.45	0.58
Heating, seasonal	0.74	0.78	0.78	0.84	0.46	0.58
Cooling, design	0.72	0.76	0.77	0.83	0.37	0.50
Cooling, seasonal	0.79	0.81	0.83	0.87	0.46	0.57

Table 7. Standard 152P Distribution Efficiency Calculations - Syracuse, NY

	#1 Pre	#1 Post	#2 Pre	#2 Post	#3 Pre	#3 Post
Heating, design	0.70	0.74	0.74	0.82	0.42	0.55
Heating, seasonal	0.71	0.75	0.75	0.82	0.43	0.55
Cooling, design	0.79	0.82	0.82	0.88	0.44	0.58
Cooling, seasonal	0.87	0.88	0.89	0.92	0.56	0.67

House #3 demonstrates consistently greater improvements than #1 and #2 due to the larger duct surface area, and also exhibits lower distribution efficiency values both pre-UR and post-UR due to the higher amount of duct leakage flow compared with #1 and #2. In addition, house #2 shows higher improvements in distribution efficiency than house #1, again due mostly to the larger duct surface area in #2.

Energy Consumption, Savings, and Payback - Theoretical Model

The annual energy savings resulting from Ultimate R treatments in the three homes were estimated theoretically, based on heating and cooling degree days taken from the appropriate U.S. Regional Climate Centers, building CFM50 from the blower door tests, the Lawrence Berkeley National Laboratory Infiltration Model, wall, ceiling, and window R-values, and on the Standard 152P distribution efficiency results. Savings were also estimated empirically, using monitored energy and temperature data from the sites; these results are covered in the next section.

Post-UR savings in the three homes presumably result from the reduction of attic duct energy losses (heating) or gains (cooling), as well as the reduction of losses or gains directly between the house and the attic due to higher ceiling insulation levels along the duct runs.

Tables 8, 9, 10, and 11 show the annual pre-UR and post-UR energy consumption and costs for both houses, based on heating and cooling degree days and the 152P calculations. Local fuel costs, based on recent commercial rates published by *Energy User News*, were used in all three cities. The commercial rates were increased by 20 percent to give the residential rates that are used in the tables.

	Chico, CA	Phoenix, AZ	Tulsa, OK	Syracuse, NY
Natural Gas (\$/MBtu)	7.06	6.98	6.00	6.00
Electricity (\$/kWh)	0.135	0.108	0.072	0.100
Annual Heating DD	2,813	1,244	3,731	6,787
Annual Cooling DD	1,393	3,983	2,043	506

The following points are worth noting or reviewing in connection with Tables 8, 9, 10, and 11:

1. The heat pump in house #1 has been assigned a seasonal coefficient-of-performance (COP) of 2.0, while the gas furnaces in #2 and #3 have been assigned steady-state efficiencies (SSE) of 0.80. In practice, electric resistance heat would sometimes activate to support the heat pump at house #1, resulting in slightly greater energy consumption than is computed in the tables below. Both cooling units have been assigned a seasonal energy efficiency ratio (SEER) of 2.0. COP and SEER would normally both fluctuate somewhat depending on the exact outside temperature, and SEER will change according to outside humidity as well. Seasonal COPs and SEERs greater than 2.0 would result in less energy consumption by the equipment both pre-UR and post-UR, resulting in slightly smaller savings. Seasonal COPs and SEERs less than 2.0 would result in more energy consumption by the equipment both pre-UR and post-UR, resulting in slightly larger savings.
2. Heating and cooling equipment capacities, which are necessary for the 152P calculations, have been assigned values of 30,000 BtuH (2.5 tons) for cooling at all three homes, 40,000 BtuH for heating at #1 and #2, and 75,000 BtuH for heating at #3.
3. Heating and cooling degree days are both base 65 deg F, and the inside temperature used in 152P calculations is 65 deg F.
4. In the heating calculations, the following factors have been ignored:
 - Internal heat gains due to cooking, lights, and occupants; accounting for these gains would decrease the energy consumption of the heating equipment both pre-UR and post-UR, resulting in slightly smaller savings.
 - Heat losses through the floor; accounting for these losses would increase the energy consumption of the heating equipment both pre-UR and post-UR, resulting in slightly larger savings.

5. In the cooling calculations, the following factors have been ignored:
 - Internal heat gains due to cooking, lights, and occupants; accounting for these gains would increase the energy consumption of the cooling equipment both pre-UR and post-UR, resulting in slightly larger savings.
 - Heat gains through the floor; accounting for these gains would increase the energy consumption of the cooling equipment both pre-UR and post-UR, resulting in slightly larger savings.
6. Heating energy consumption at house #1 is routinely less than house #2, even though the *cost* of heating at house #1 is routinely *greater* than at house #2. The smaller energy consumption at house #1 is due to the much greater efficiency of the heat pump, compared to the gas furnace at house #2. However, the better efficiency is overwhelmed by the much higher cost of electricity per MBtu compared with gas (four to five times as expensive per MBtu), and so the cost of heating at house #1 is greater.
7. All payback terms (simple payback = cost / annual savings) are based on the actual costs of installation at the three homes; *lower-cost installations in new construction or non-truss attics would pay back more quickly.*

Table 8. Energy Savings and Payback - Chico, CA

	#1	#2	#3
Heating, MBtu/yr	1.4	4.1	16.8
Heating, \$/yr	\$57	\$29	\$118
Cooling, MBtu/yr	0.7	0.8	4.5
Cooling, \$/yr	\$28	\$32	\$179
Totals, MBtu/yr	2.1	4.9	21.3
Totals, \$/yr	\$85	\$61	\$297
Payback, yrs	5.1	7.7	1.6

Table 9. Energy Savings and Payback - Phoenix, AZ

	#1	#2	#3
Heating, MBtu/yr	0.6	1.8	7.0
Heating, \$/yr	\$20	\$12	\$49
Cooling, MBtu/yr	2.5	2.8	17.4
Cooling, \$/yr	\$79	\$87	\$549
Totals, MBtu/yr	3.1	4.6	24.4
Totals, \$/yr	\$99	\$99	\$598
Payback, yrs	4.4	4.8	0.8

Table 10. Energy Savings and Payback - Tulsa, OK

	#1	#2	#3
Heating, MBtu/yr	2.8	7.4	32.0
Heating, \$/yr	\$59	\$44	\$192
Cooling, MBtu/yr	1.1	1.2	6.0
Cooling, \$/yr	\$22	\$25	\$127
Totals, MBtu/yr	3.9	8.6	38.0
Totals, \$/yr	\$81	\$69	\$319
Payback, yrs	5.4	6.8	1.5

Table 11. Energy Savings and Payback - Syracuse, NY

	#1	#2	#3
Heating, MBtu/yr	5.1	13.5	92.5
Heating, \$/yr	\$148	\$81	\$555
Cooling, MBtu/yr	0.3	0.3	1.2
Cooling, \$/yr	\$8	\$9	\$35
Totals, MBtu/yr	5.3	13.8	93.7
Totals, \$/yr	\$156	\$90	\$590
Payback, yrs	2.8	5.3	0.8

Energy Consumption, Savings, and Payback - Empirical Model

Annual energy consumption reductions and consequential savings were estimated empirically at each house using monitored on-site data. Each home was instrumented with sensors measuring inside-outside temperature difference (ΔT) and furnace or heat pump energy input, at hourly intervals. This information was collected from each of the houses both pre-UR and post-UR in order to estimate Btu/ ΔT /day and normalized annual consumption (NAC) for each period. The two data sets from each house generally represented approximately equal-length periods from three to five weeks long within the months of December 1997 and January, February, and March of 1998.

For each period, linear regression analysis was performed on daily Btu consumption as a function of average daily ΔT , in order to estimate the dependence of daily Btu on average daily ΔT (Btu/ ΔT /day) for the period.

The estimated Btu/ ΔT /day from each period was combined with the calculated number of heating degree days for that period to estimate annual consumption. A variable base heating degree day calculation procedure was used. The regression line's x-intercept was used as a representation of the ΔT at which the heating system first calls for heat. This ΔT was subtracted from the average monitored inside temperature for the period to give T_{bal} , the outside balance temperature at which the heating system begins to consume energy. This value of T_{bal} , which was different between pre-retrofit and post-retrofit periods for most of the houses, was

used to calculate an estimated number of annual heating degree days based on each period's data.

Normalized annual consumption was calculated using a calculation method from Holt¹, and is given by a function N, such that:

$$N = \frac{(m H) \text{ Btu}}{10^6 \text{ Btu} / \text{MMBtu}} \quad (\text{eq. 1})$$

where H = the number of heating degree days in the heating season
 m = the value for Btu/ΔT/day returned by the linear regression

The quantity N thus has units of millions of Btu (MMBtu or MBtu). The quantity H is given as a function of the balance temperature, T_{bal}:

$$H = Y \frac{T_a - T_m}{\pi} \left[\sqrt{1 - X^2} - X \cos^{-1} X \right] \quad (\text{eq. 2})$$

where Y = 365.25 (days per sidereal year)
 T_a = annual average temperature
 T_m = annual monthly minimum temperature = 1.036 T_j - 0.036 T_a
 T_j = average January temperature
 X = (T_a - T_{bal}) / (T_a - T_m)

Temperatures used in eq. 2 were 50 °F and 24 °F for annual and January average temperatures in Syracuse, and 65 °F and 49 °F for annual and January average temperatures in Chico.

A certain amount of scatter around the regression lines is expected due to differences in wind, solar gains, and occupant behavior from day to day. For instance, two days with the same recorded average ΔT may have given different energy consumption values because one day was windier than another. More energy would be consumed on the windier day due to increased building infiltration. Conversely, a very sunny day would require less energy consumption than a cloudy day, given the same average ΔT.

A more advanced analysis would apply solar and wind adjustments to each day's data based on measurements from a nearby state weather station. However, differences in these effects are assumed not to have significant impacts on the conclusions drawn from the data that was recorded on-site.

Figures 1, 2 and 3 show the monitored energy consumption results from the three homes.

¹ D. Holt, "How Weather Affects Seasonal Heating Cost Estimates." U.S. Department of Energy (1985)

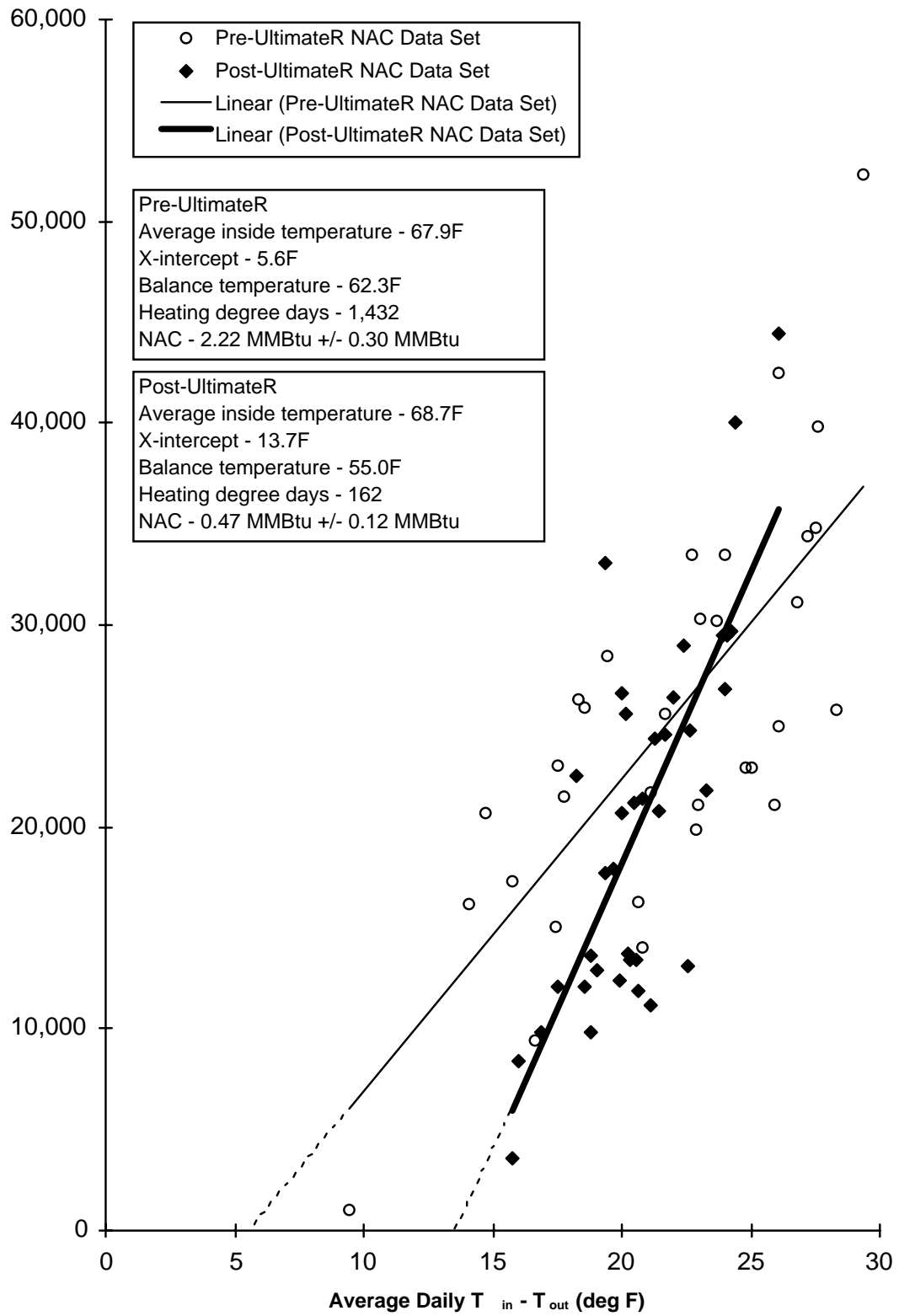


Figure 1. Energy Consumption at House #1 - Chico, CA

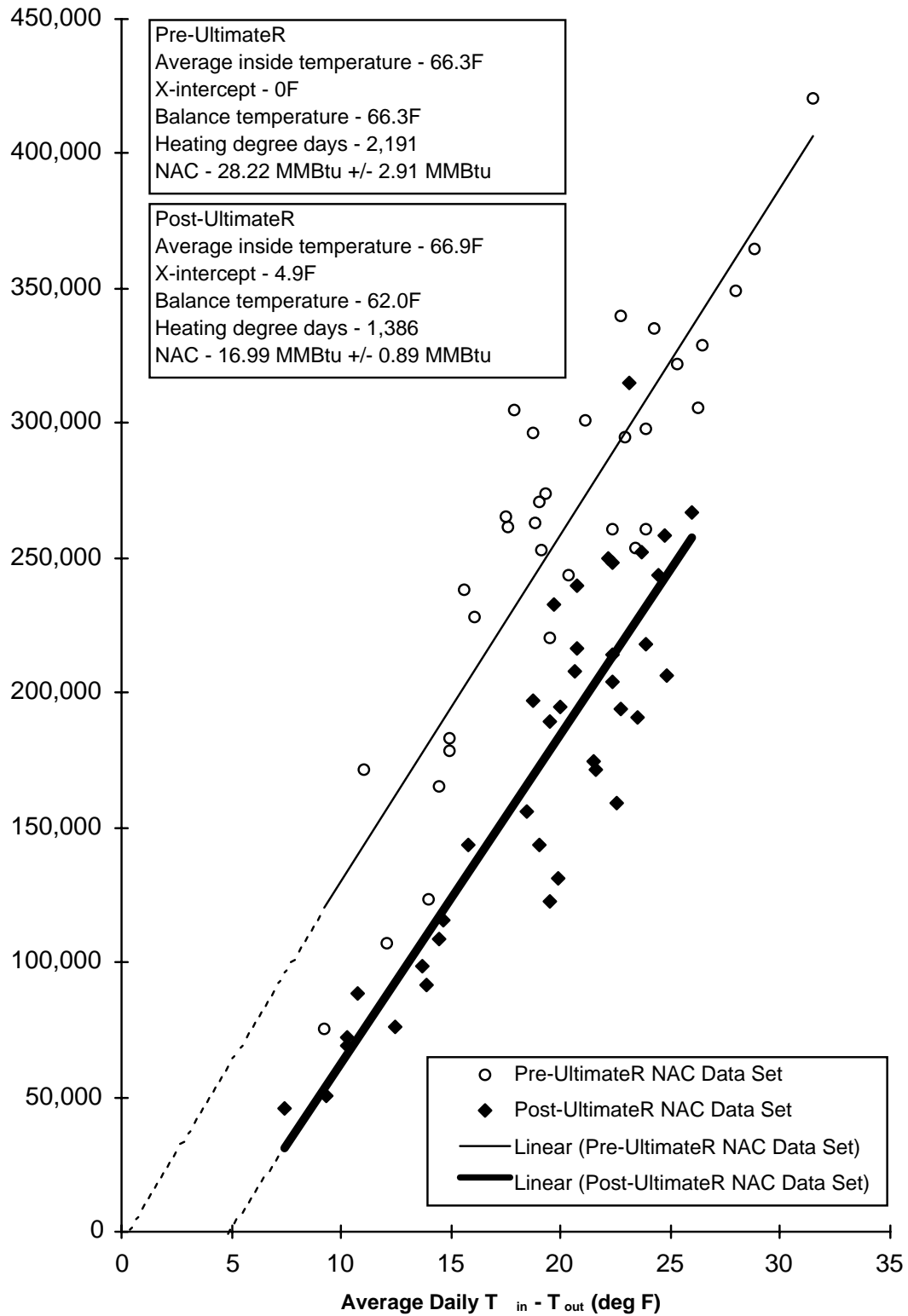


Figure 2. Energy Consumption at House #2 - Chico, CA

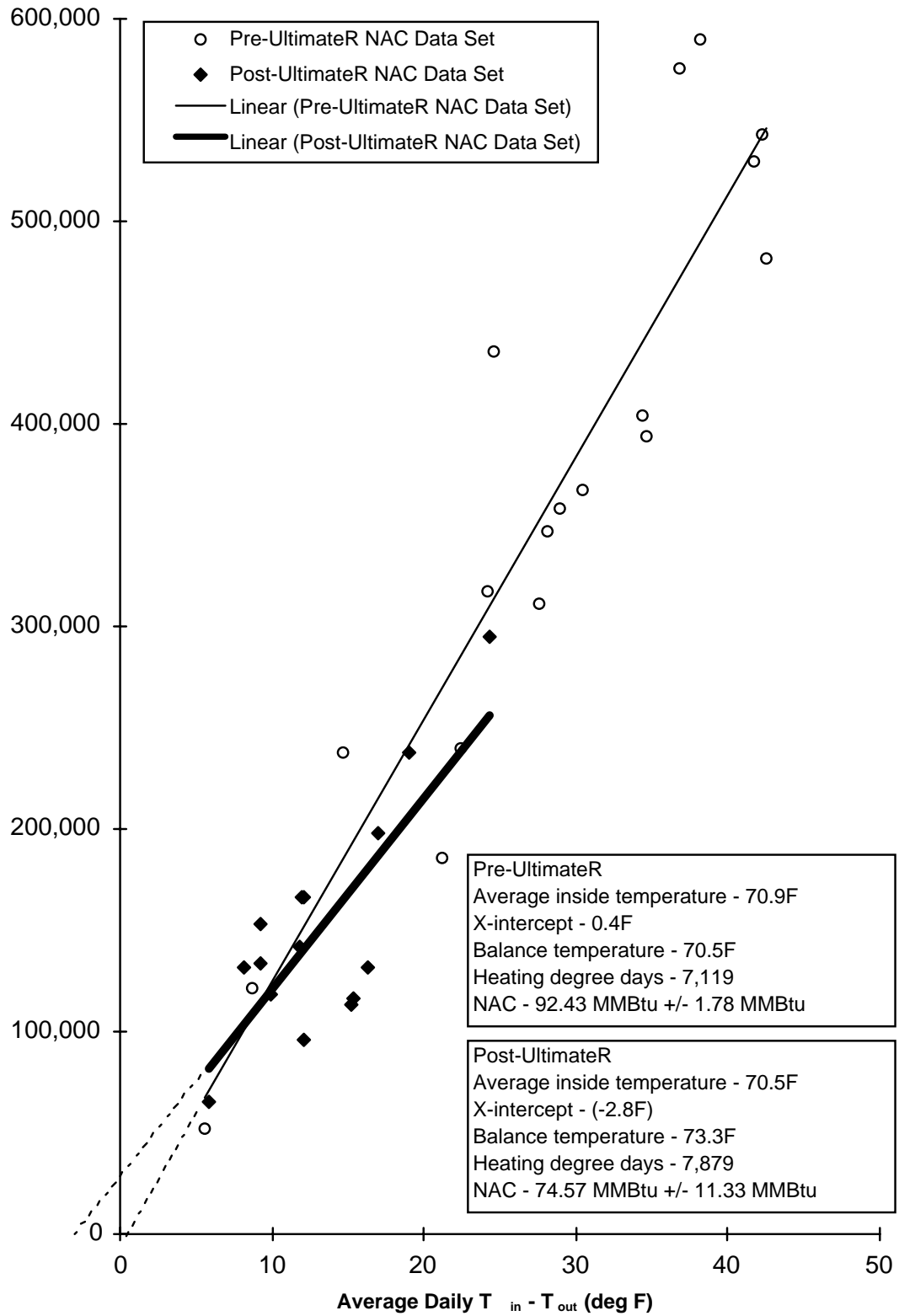


Figure 3. Energy Consumption at House #3 - Syracuse, NY

Figure 1 indicates that the UR treatment had a substantial effect on the balance temperature at house #1. The heating system activates at a lower outside temperature following installation of UR than it did in the pre-UR condition, even though average inside temperature remained about the same. This leads to the conclusion that the UR treatment reduced heat loss from the house even when the warm-air system was not running, allowing smaller internal heat sources to maintain acceptable inside temperature at lower outside temperatures. This circumstance is reflected in the much lesser number of annual heating degree days found for post-UR performance versus pre-UR performance.

Figure 1 indicates that post-UR consumption will actually be greater than pre-UR consumption at ΔT greater than about 23 °F. Theoretically, post-UR consumption should be lower than pre-UR consumption under any given set of circumstances, including higher ΔT ranges. Under ideal conditions, the pre-UR and post-UR linear regression lines are expected to be parallel or slightly divergent as they approach higher ΔT values, and closest to each other at very low values of ΔT .

Figure 2 shows the data gathered from house #2, which adhere more to the expected pattern. This house was unoccupied during both the pre-UR and the post-UR monitoring periods, removing occupant behavior as a potential source of data scatter. The regression lines formed from the two data sets demonstrate both a reduction in balance temperature and sustained savings right through higher values of ΔT .

Figure 3 shows the monitored energy consumption results from house #3. An unusually warm spring caused most of the post-UR ΔT values to be less than 20 °F, which creates substantial uncertainty in the post-UR regression's applicability to higher values of ΔT . The results in Figure 3 hint at the effect of the UR treatment, but the post-UR NAC calculation is probably not well-supported enough to use.

Table 12 shows empirical heating season savings and simple payback terms for each house, based on the NAC values calculated from monitored data. House #3 values should be applied with caution, as noted immediately above.

Table 12. Empirical Savings and Payback - Heating Only

	Annual Savings (MBtu)	Annual Savings (\$)	Simple Payback (yrs)
#1	1.8	69	6.3
#2	11.2	79	6.0
#3	17.9	107	4.4

Moisture and Ultimate R

As warm, moist air is cooled, its relative humidity increases. When it is cooled to the dew point temperature, its relative humidity reaches 100 percent and the air is saturated. As cooling continues, some of the moisture previously in the gaseous state condenses; that is, it changes to a liquid form called water.

What, then, are the circumstances of a home in winter which is insulated by blown cellulose? When warm air of 30 percent relative humidity at 70 °F temperature is inside the structure on a day when outside temperatures hover at zero, a large temperature gradient exists from the inside to the outside of the cellulose which includes 50 °F, the saturation temperature for 70 °F air at 30 percent RH. Does this mean that a moisture problem will occur in the wall?

The answer is the subject matter of a great deal of research, much of which has been conducted by Dr. George Tsongas of Portland State University. The short version is: it all depends on air **movement**. If there is a good vapor barrier, or if the cellulose is blown tight, there is only negligible air flow through the cellulose, so no moisture condenses and no moisture problems occur. If there is a pressure gradient between inside and out plus a pathway for air to flow through (due, for example, to cracks in the walls, the absence of a vapor barrier, and spotty insulation coverage), substantial flow of conditioned air through the wall will result and so will condensation. However, even in these cases, subsequent drying conditions may cause moisture to wick out of the cellulose and evaporate, so no structural damage will occur.

Given this, what if any moisture problems may be expected from insulating ducts in attics using the Ultimate R technique? If there is little or no duct leakage, the addition of blown insulation surrounding the ducts should result in no moisture problems, and should even lessen the tendency for surface condensation on cold air supply ducts in warm attics (see ASHRAE 1997 *Fundamentals*, p 23.15.) Since holes in ducts coupled with a distribution fan running is the only substantial mechanism for air flow around ducts after Ultimate R is installed, no condensation or moisture problems should occur if duct leakage is not present. Given that the Ultimate R installation technique calls for accomplishing air sealing of major duct leakage areas before blowing insulation—coupled with the fact that cellulose insulation impedes flow to at least a modest degree—moisture should not occur under any circumstances, during either the cooling or the heating seasons.

How about faulty installations in which duct leakage occurs?

Beginning with winter on the return side, cold attic air is pulled into the return air stream, where it lowers humidity, cools the air stream, and lowers the efficiency of the furnace. The addition of Ultimate R should impede this process, and in all events, no moisture problems will occur.

Holes in the supply ducts during winter will dump warm, conditioned air into the attic where it will contribute to raising attic humidity. The excess moisture is usually

partially vented and partially absorbed by the timbers in the attic, which typically follow a seasonal trend of raised levels of moisture during the winter and lowered levels in summer. Of course, the magnitude of such supply leaks is likely to be modest, both in volume and in moisture content, a few cfm of conditioned air at perhaps 40 percent RH. When cellulose is installed around a leaking supply duct, it will tend to diminish the flow, which is good for overall efficiency, but it will also tend to absorb some of the moisture as the warm moist air travels out to the attic. However, unless the volume of air leaking from a supply duct is quite substantial, it is unlikely that actual condensation will occur, and most moisture will be released into the attic. Further, the cellulose itself tends to wick out moisture and will dry in the seasonal manner of the attic wood.

In the summertime, leaks in the supply side cause no moisture problems, either with Ultimate R or without it. (Of course, the Ultimate R will save some energy by virtue of impeding flow.)

Return side leaks during the summer in the absence of Ultimate R may cause condensation at the immediate locus of the leaks. With Ultimate R, there will be a temperature gradient between the attic and the duct wherein a dewpoint temperature will lurk. Ultimate R can be expected to impede the flow of air from the attic to the leak and since the duct is sucking (rather than blowing, as on the supply side) there will be no jet of air. Accordingly, unless there is substantial air flow from a large supply duct hole, the likelihood of moisture problems developing within the insulation is modest.

In summary, no moisture problems are likely to develop with Ultimate R, but it makes good sense for energy efficiency reasons and moisture reasons to seal the ducts. Only substantial holes are likely to matter much, and these are easier to find.

Field Work

Under this evaluation, an experiment was set up to test the distribution of moisture effects with and without the Ultimate R treatment. A single story, 2200 square foot ranch house in Portland, Oregon was chosen. The home is equipped with a dehumidification system which pulls air through the kitchen ceiling at the far end of the house through a 50 foot length of 8 inch diameter duct that traverses the modestly insulated attic. The duct then descends through an interior partition to the dehumidifier in the basement, which sends dryer and warmer supply air into a hallway in the center of the house.

In Decemer, 1997, the system was instrumented with temperature and humidity sensors in the conditioned space, the attic, and at the surface of the duct itself. In March, 1998, the Ultimate R system was installed over the full length of the duct, and some additional cellulose was also blown into the attic.

Unhappily, the dehumidification system failed at about the time of the installation and other than to observe that no moisture problems have been observed, no useful quantitative data resulted from this portion of the evaluation.

Conclusions and Recommendations

This work first and foremost showcased the ease of application of the Ultimate R product. Difficult situations that were encountered in the three retrofit jobs covered here were quickly solved by customizing the cardboard panels with the knife where necessary. Braces and panel ties were easily fabricated from panel stock, and the three staplers allowed good flexibility in attachment.

The annual theoretical heating and cooling energy savings resulting from Ultimate R treatment ranged from 10 to 30 percent of the UR cost in houses #1 and #2, and paid for the UR job in less than two years at house #3, in all four climates tested. Similar energy savings were found from the on-site monitored data.

These three examples of cost-effective performance are applicable to new construction duct systems in general, since new attic ducts are almost universally constructed of insulated flexduct branches and ductboard trunks similar to those found in the three homes studied here. In addition, the lower-cost installation of UR during construction of a home would further increase savings, pushing return on investment above 30 percent in most cases. Aside from these substantial energy savings that are available through Ultimate R, the greater distribution efficiency obtained at design conditions will keep a home comfortable during more severe weather.

Installation of Ultimate R in a new home aligns comfortably with the work of the insulating sub-contractor, and there is no reason why this system should not be used on all new heating and cooling ducts in attics.

For retrofit jobs, the installation cost will usually be greater, but retrofits may be more likely to include older uninsulated metal ducts, increasing savings and maintaining high payback despite the higher cost of the work. Even when the existing ducts are insulated somewhat, as with the the three houses treated here, payback appears on par with many other commonly-used residential energy conservation products.

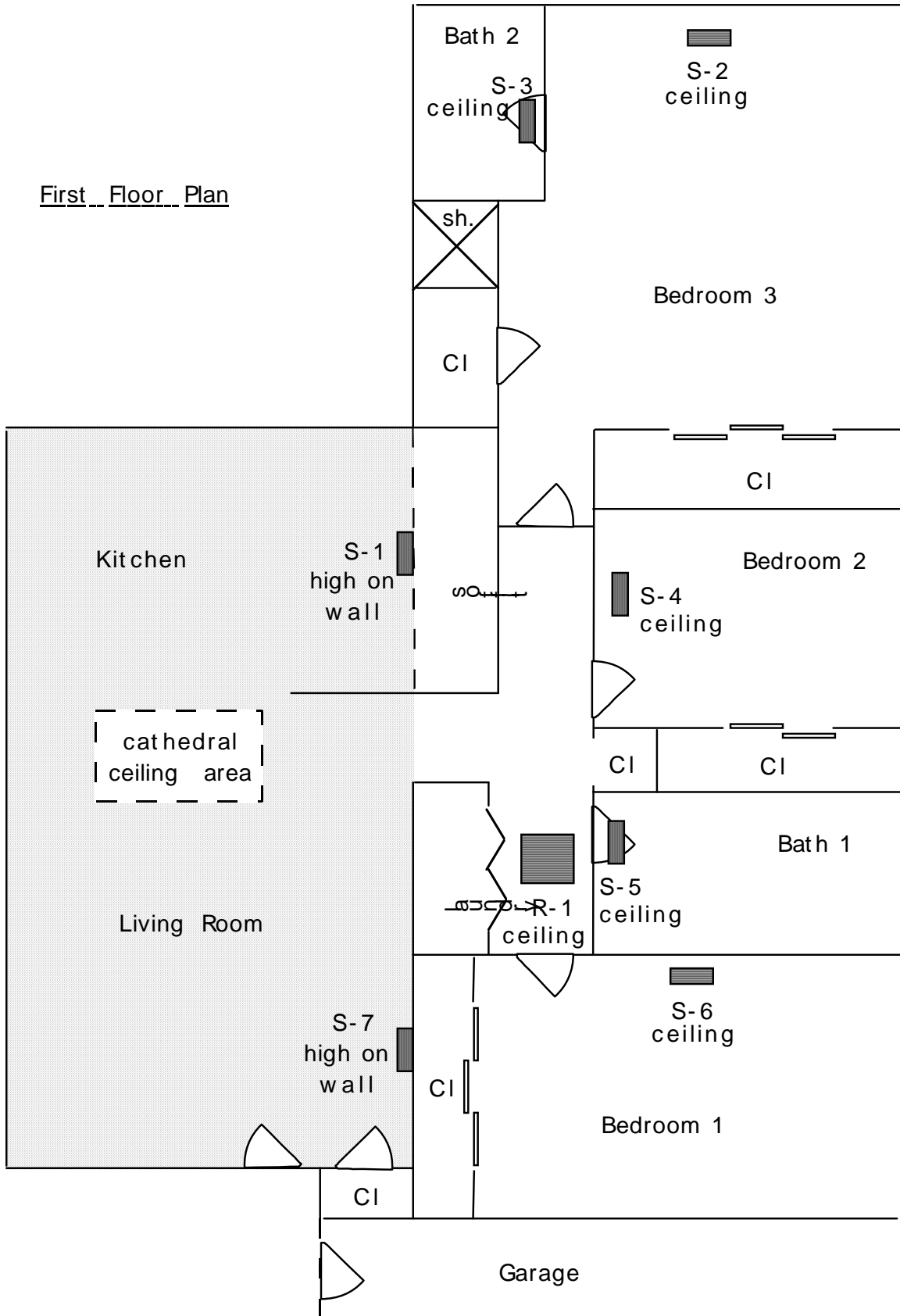
It is recommended that the Ultimate R installation manual and attendant training syllabus, which were envisioned from the beginning for this effort, be developed. The 10 to 20 page manual should include illustrations of commonly-encountered situations, in both new homes and retrofit circumstances, and the methods used to get through them quickly. Once a draft of the illustrated manual has been produced, a group of HVAC contractors and builders can be recruited to receive training and provide feedback during and after installation of Ultimate R in new

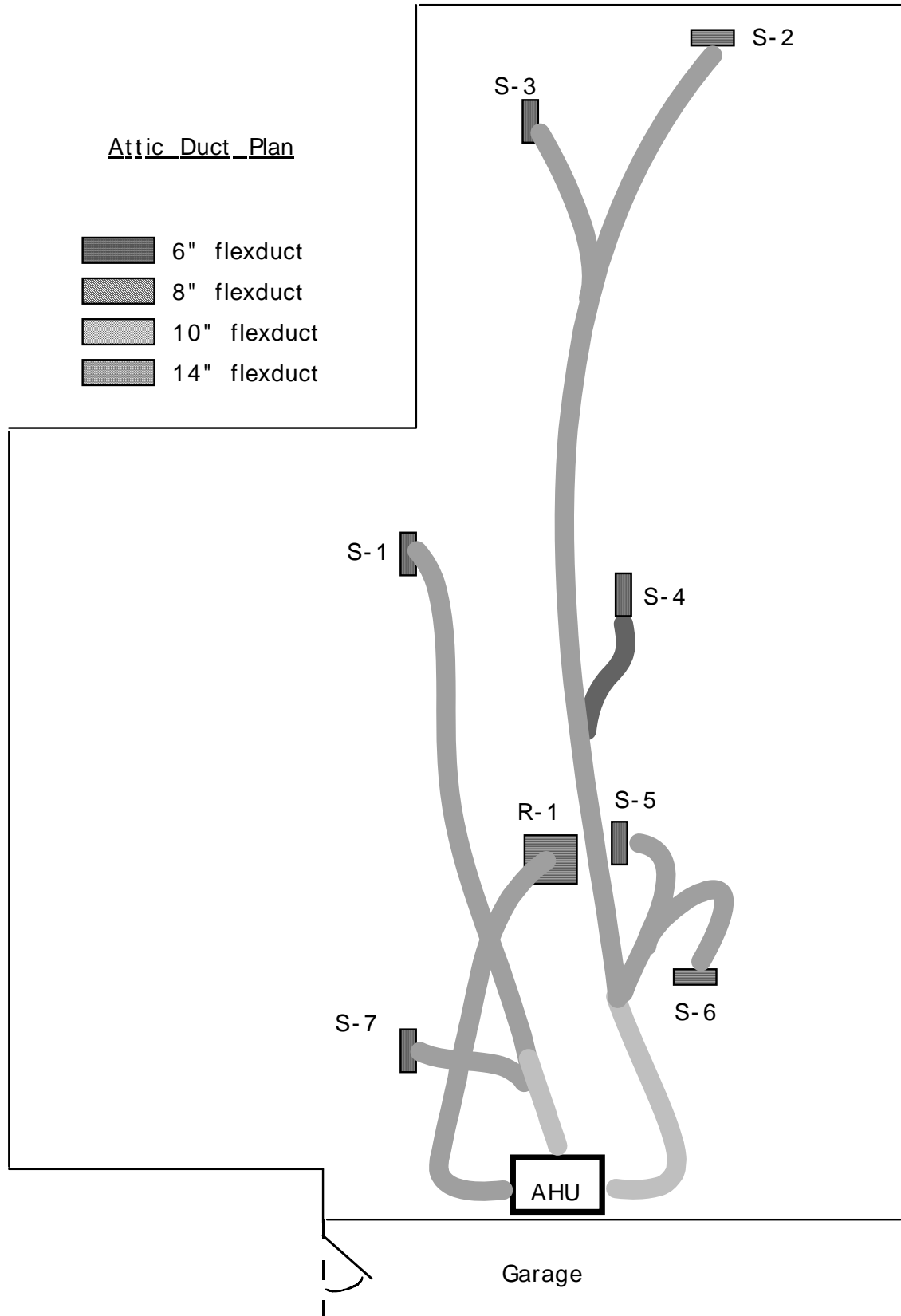
homes. Actual trade installation costs should also be gathered during this work to provide more solid information on payback and return-on-investment.

At least three builders and contractors would ideally be employed for validation, and each contractor would ideally perform three or more installations. Multiple installations for each contractor would allow evaluation of the training materials following the initial part of the learning curve.

Appendix A

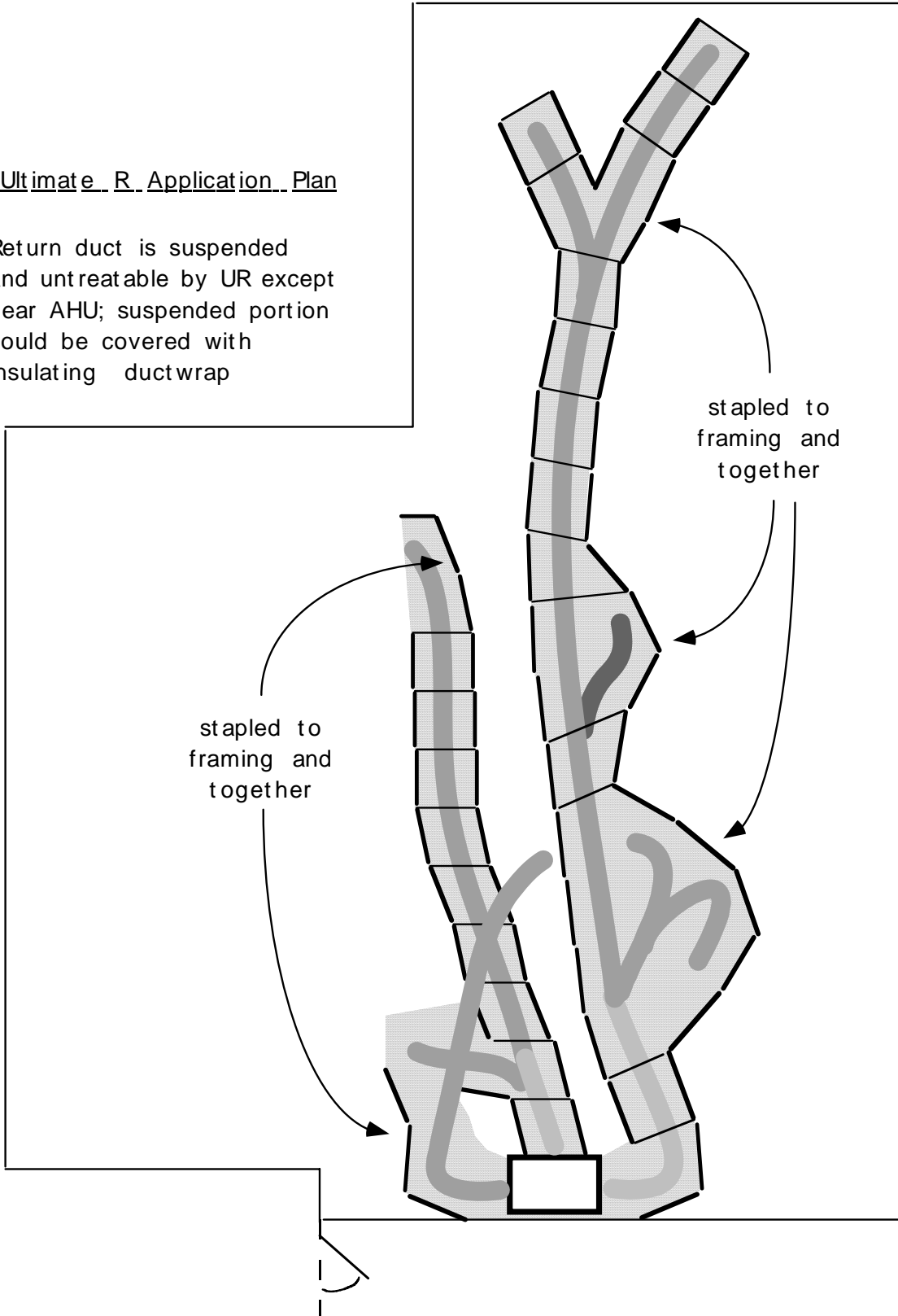
House Plans

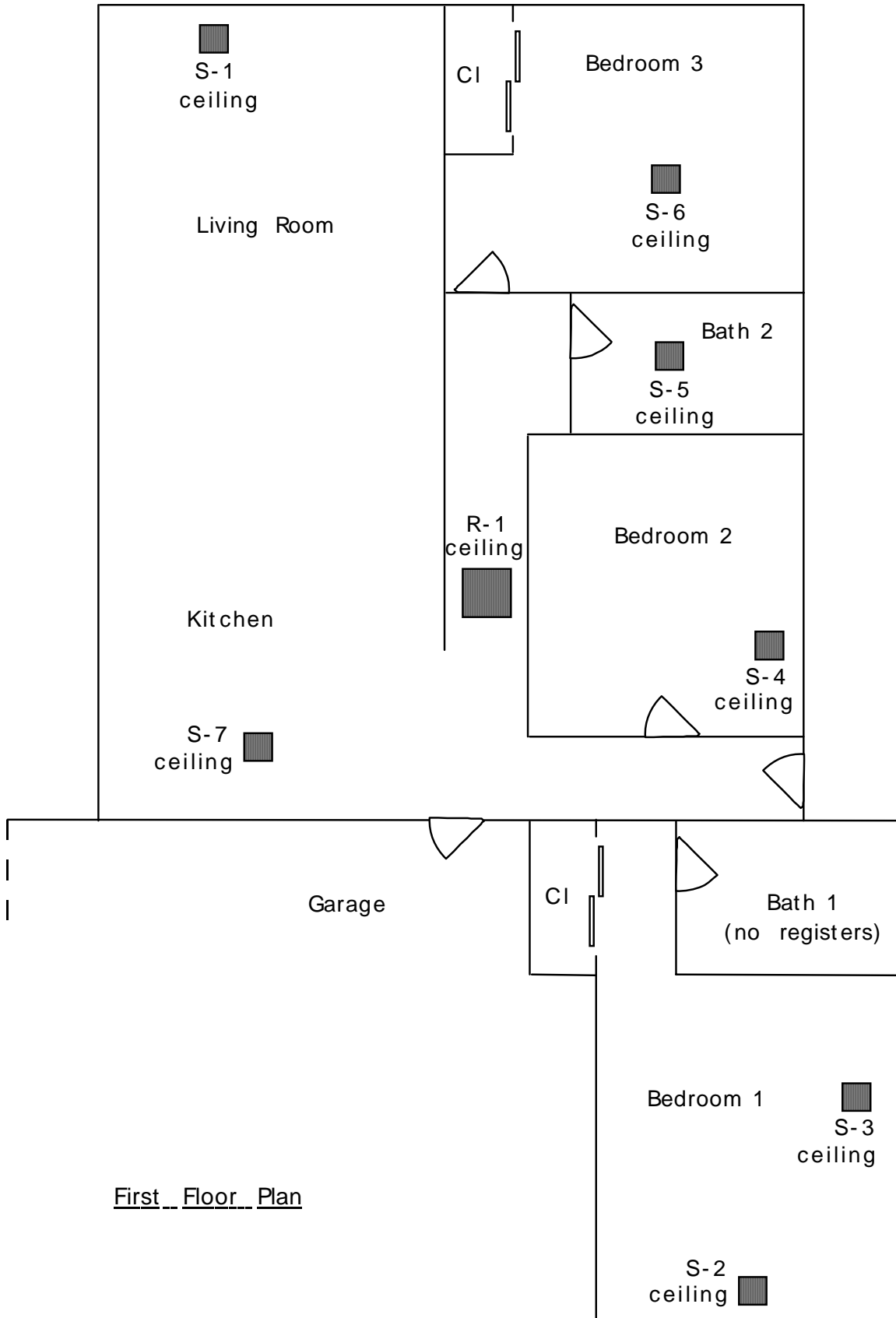


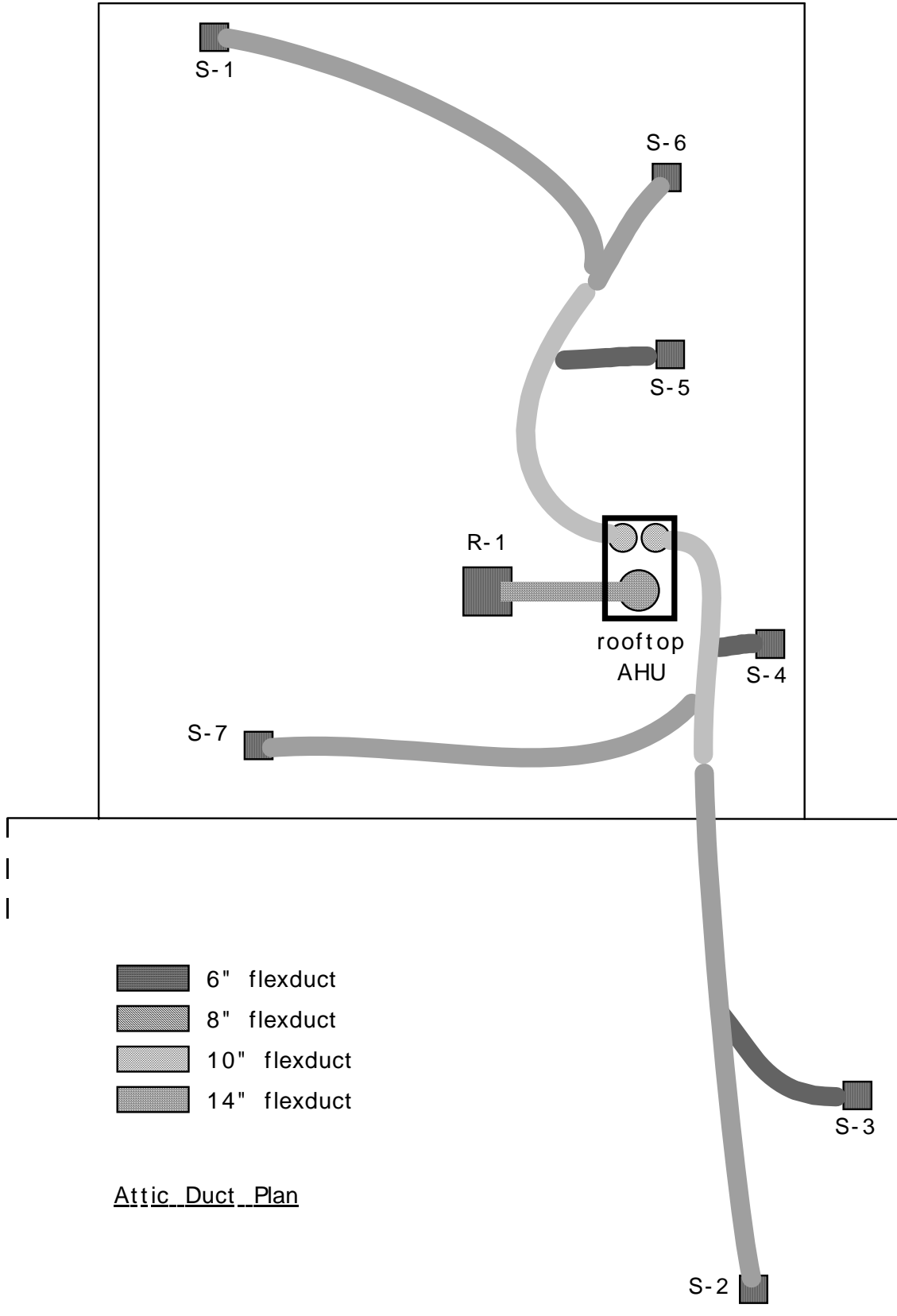


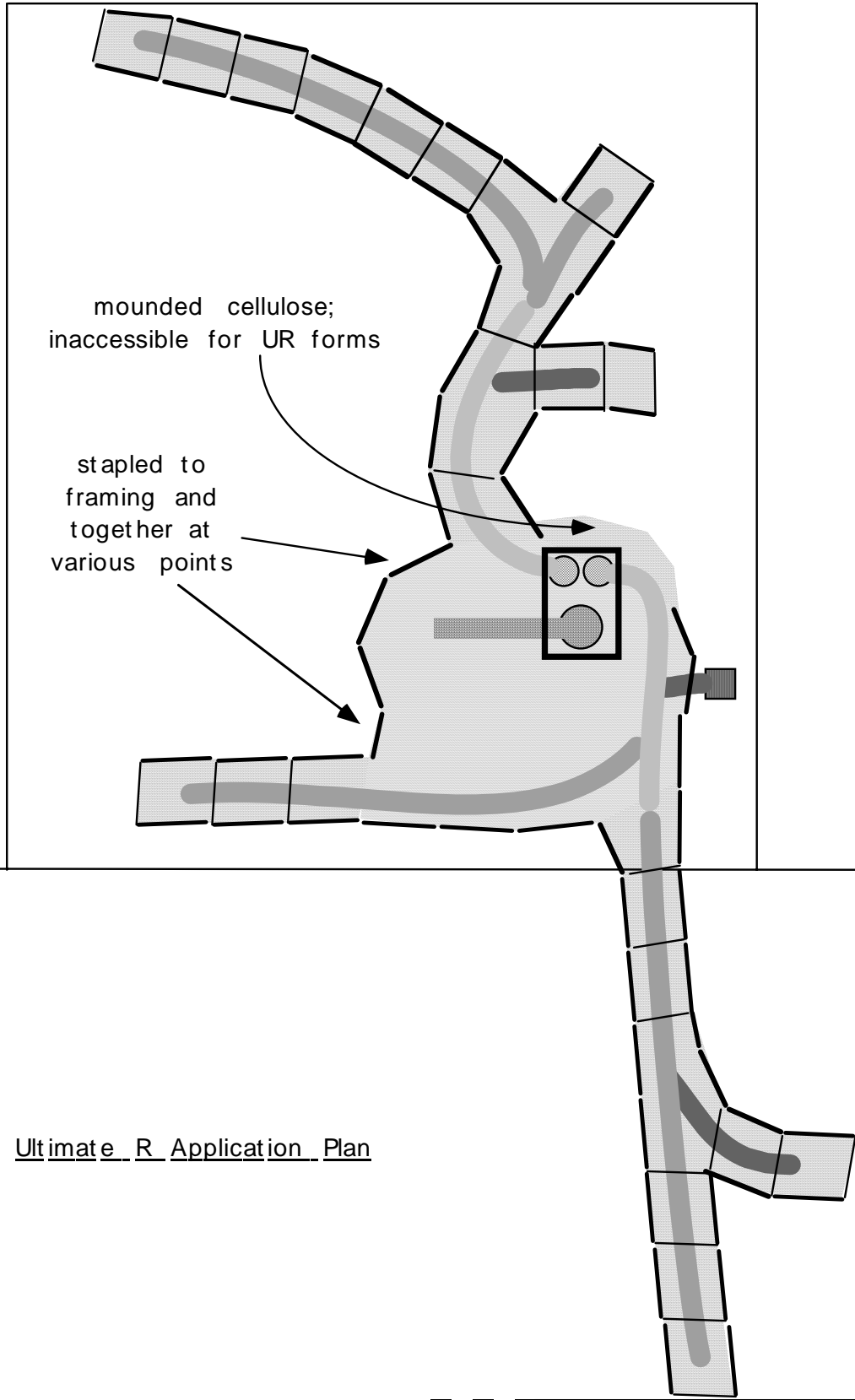
Ultimate R Application Plan

Return duct is suspended and unreatable by UR except near AHU; suspended portion could be covered with insulating ductwrap

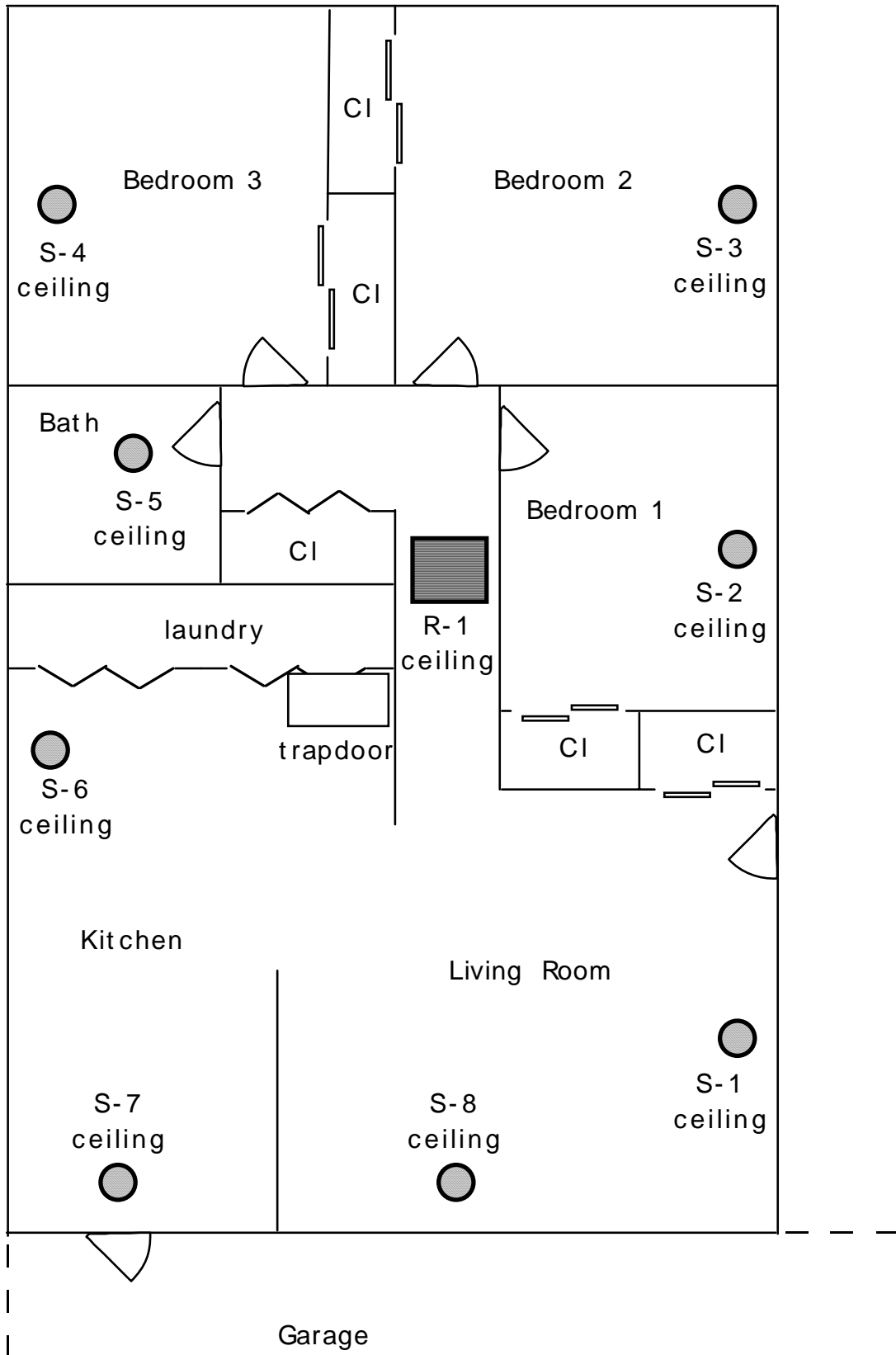




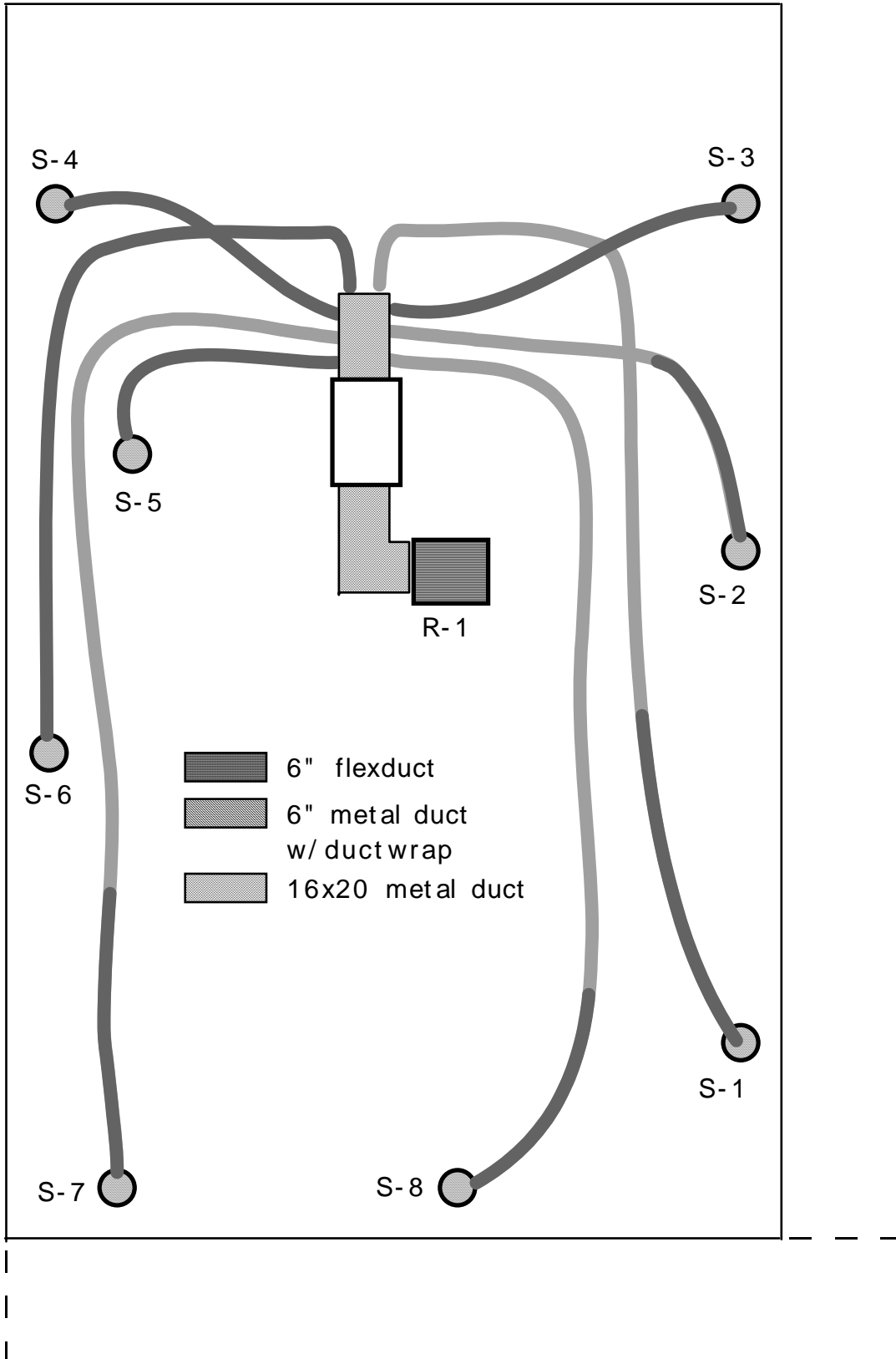




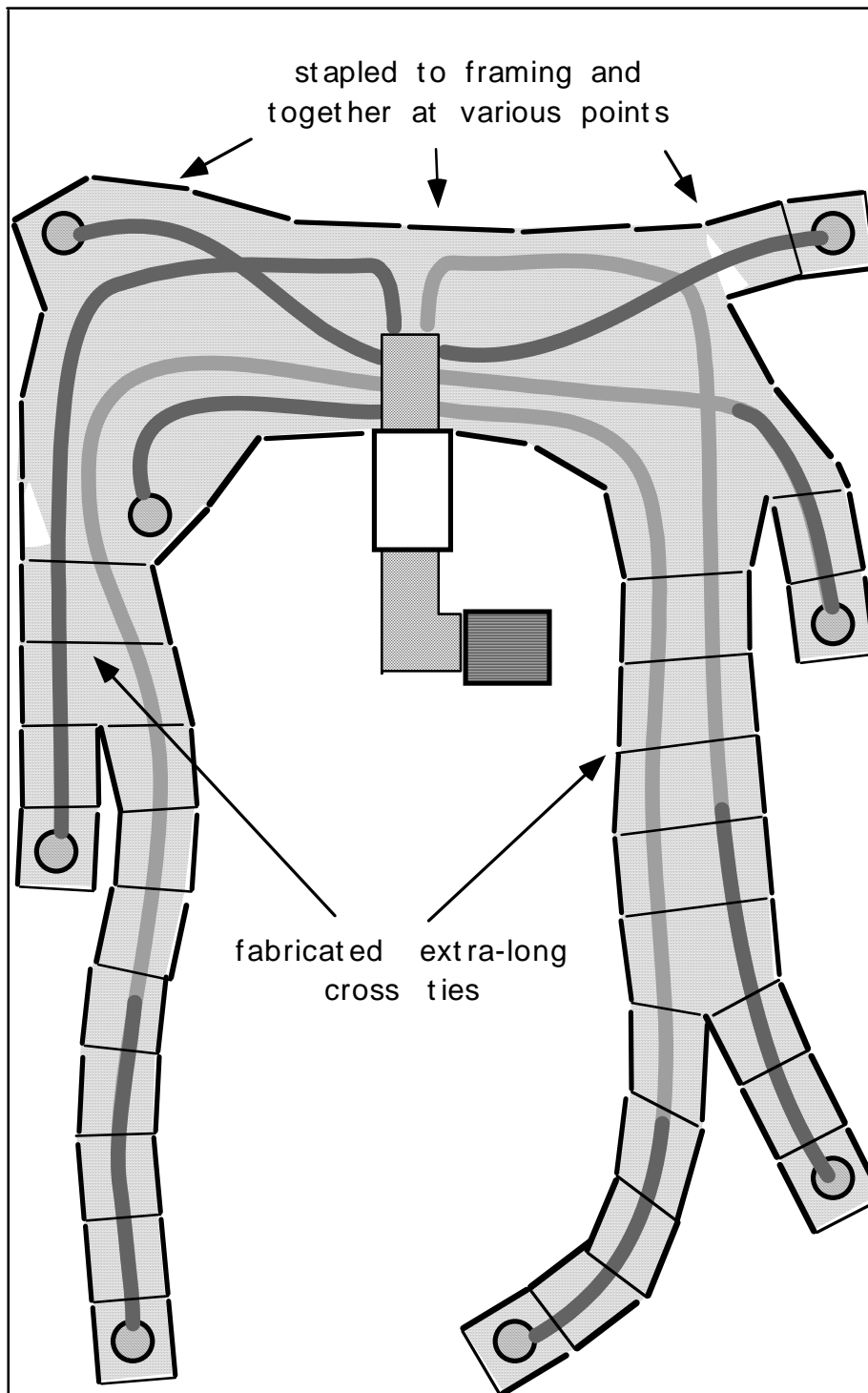
First Floor Plan



Attic Duct Plan



Ultimate R Application Plan



Return duct was not treated with UR due to its low duct surface area and proximity to the trapdoor and furnace access catwalk. In this case insulating ductwrap could be applied.