KEEPING WARM: FINDINGS FROM THE KANSAS CITY WARM ROOM RETROFIT PROJECT

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ABSTRACT

The warm room retrofit is a response to a common problem: how to stay warm in a large, poorly insulated house during the coldest parts of winter. The problem is especially acute for low-income and elderly homeowners who may not have sufficient resources to improve the thermal integrity of their entire house. Although still an experimental technique, the warm room retrofit has the potential for achieving significant energy savings in houses at costs similar to those currently allocated by low-income weatherization programs. The retrofit is a combination of zoning, heating systems modification and insulation which allows the occupant to heat selected areas of her home while maintaining the unused areas at a cooler temperature. This study presents the results from a retrofit project in Kansas City, sponsored by the Urban Consortium in 1985-1986. Nine houses were selected for the study, four controls and five houses that received the warm room retrofit. The houses are all single-family detached structures, occupied by low-income owners (with the owners' ages between 60 and 80 years), and heated with gas-fired forced-air or gravity-fed furnaces. The warm zone was designed to include the kitchen, bathroom, and one to two additional rooms, depending on family size. The costs of the retrofit averaged $1425 per house. Our analysis included regressions of total gas use versus outdoor temperatures to measure savings, which averaged 26 percent. Because of potential health and safety problems, we also measured indoor air quality before and after the retrofit, sampling levels of indoor radon, nitrogen dioxide, and formaldehyde. An important part of the study was to determine occupant response and the acceptability of the retrofit. The residents participated in the design of the retrofits, and were interviewed after the retrofits were installed to determine improvements in comfort and their satisfaction with the results.

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1.0 INTRODUCTION

Despite some recent easing in energy prices, the need for cost-effective weatherization measures remains acute, particularly for low-income and elderly homeowners. In response, some government agencies and utilities are experimenting with new retrofit strategies, including the warm room retrofit. The warm room retrofit is a modification of a familiar strategy of zoning the house into warm and cool zones, which is achieved in centrally-heated homes through the use of such measures as furnace rebalancing, portable thermostats, special heat-restricting covers for the heat-distribution system, curtains or partitions to enhance zoning, portable heaters, and selected insulation of ducts and exterior walls.

The attraction of warm rooms is the prospect of significant energy savings (theoretically double or triple that of conventional weatherization) at costs at or below current levels (Wagner 1983). But a number of questions require answers before widespread installations of warm rooms. First, is whether the theoretical savings can actually be achieved: whether the zoning is effective, whether a central heating system remains sufficiently efficient in its new operating mode, and whether the projected costs are realistic. Second are questions about health and building safety: whether indoor air quality problems arise or intensify with the zoning, how to prevent moisture damage in the cool areas of the house, and how to avoid water pipe freezing. Third are a set of social questions: whether the zoning is acceptable to occupants, or a particular set of occupants; how to insure sufficient flexibility and control over the operation of the house; what measures contribute most to occupant comfort; how the retrofit affects property value; how best to teach occupants to manage their warm rooms.

Pioneering groups in warm room research include the Tennessee Valley Authority, the Institute for Human Development in Philadelphia, and Union Electric in St. Louis. These groups have explored several different warm room approaches and gained considerable insights into the practical applications of the retrofit and occupant acceptance. To date, however, there have been few reported results of measured energy savings and no information on the affect of the retrofit on indoor air quality. Consequently, the object of this study was to measure the energy savings, the air quality, and the occupant response to warm room retrofits in a small group of carefully monitored houses. The project was sponsored by the Urban Consortium and the Department of Energy, and carried out by the city of Kansas City, Missouri, with technical assistance provided by Lawrence Berkeley Laboratory.

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2.0 PROJECT DESIGN

2.1 Selection of Houses

Our two objectives in selecting houses were to find houses where a warm room retrofit would be both practical and useful, and where an unambiguous evaluation of energy savings would be possible. Applications for participation in the program were distributed by neighborhood block groups in low-income areas throughout the city. The applications included questions about the appropriateness of the household for the retrofit (rough size of house, number of occupants, interest in project, type of heating system) and questions about fuel use patterns that could affect accurate measurements of savings (willingness to allow a submeter, ability to make weekly readings and to make past billing data available; number of years spent in the present house; planned change in number of occupants; use of fireplaces or other auxiliary heaters).

For each of the 44 houses that responded we did a regression analysis of gas consumption versus variable-base degree days and calculated the normalized annual consumption (NAC) for the past two years (Fels, Goldberg, 1981) in order to screen out those houses with weather-normalized fuel use too irregular to allow a clean measurement of warm room energy savings. We also checked the electricity-consumption data to verify absence of significant electric heating.

Results of the questionnaire and regression analysis were used to screen the original 44 applicants down to a group of 19. At that point we held a workshop to describe the warm room approach in more detail to the remaining homeowners, and did an on-site audit and interview at each of the 19 houses. In the final selection we chose five houses to receive warm rooms and nine to serve as control and back-up houses. The process was complete in early 1983, but administrative delays prevented the beginning of actual retrofit work until the fall of 1985. During that time, one of the owners of a house scheduled for retrofit left the program due largely to difficulties making required data readings, as did two of the control houses. One other control house dropped out due to illness and another control stopped sending data in early 1986. One of the control houses was chosen to replace the retrofit house that was dropped. The remaining retrofit and control houses were reliable in sending weekly gas and temperature data, as described below. The following discussion refers to the final group of five retrofit and four control houses.

2.2 Description of Houses

Table I summarizes some characteristics of the warm room and control houses. In general, the houses are of moderate size, 1000 to 1700 ft^2, except one control with 3600 ft^2, so that a warm room seemed most practical for small households (1 to 2 people) whose routines would allow use of a 2-3 room zoned portion of the house during cold weather. While the house size seems modest, it was our experience that larger houses were already strictly zoned, or housed too many people for a successful warm room. Of those households we selected, four had one occupant, four had two occupants, and one (a control) had three occupants. Of the fourteen occupants, nine were 60 years or older at the time of the initial audit, four were 70 years or older and one was under 20 years. All of the warm room houses were two stories, as were most of the controls. All had central gas systems, either forced air or gravity, and many had gas fireplaces, usually unused. The homeowners in the retrofit houses had all lived there from 25 years to 45 years. The owners of the control houses had lived there for 5 to 45 years.

2.3 Instrumentation

The Kansas City Gas Company, at the city's request, provided submeters for the warm room houses. We provided wind-up thermographs to measure indoor temperatures (at least one per house, and two per warm room house when possible). The homeowners were responsible for making total (and in the warm room houses, submetered) gas readings and changing the thermograph charts on a weekly basis. The gas readings were recorded on copies of gas company meter reading cards, which require marking the position of hands on meter dials; the actual numerical readings were made by LBL. The use of weekly intervals allows mistakes in readings to be fairly easily detected, and the few readings which cannot be corrected can be eliminated from the data set without a great loss of information (i.e., a loss of only a week, compared to a whole month with utility readings). In houses with both a total and a submeter, ambiguous readings can also often be resolved by comparing the two. In general the readings seemed reasonably accurate and most of the homeowners were very reliable about sending the data every week.

Blower door measurements were made at each of the retrofit houses before and after warm room installation. Indoor air was monitored for nitrogen dioxide, formaldehyde, and radon before and after retrofit in both the warm and cool zones.

2.4 Retrofit Design and Installation

The retrofits were planned by designers in Kansas City in consultation with the homeowners. All five houses have the warm rooms downstairs, where the occupants spend most of their time during the day. The four houses with two occupants had a total of three warm rooms each; the one house with one occupant had two warm rooms. The kitchen was included in the warm zone in all houses. One occupant moved her bed downstairs for sleeping; the rest continued to sleep in the cool bedrooms upstairs. Zoning was accomplished by closing furnace dampers to the cool rooms and opening them fully to warm rooms. Curtains were provided in doorways as necessary to maintain the zoning. Warm air registers were opened in warm rooms and closed in cool rooms. The object was not to provide complete zoning, since damage to water pipes and the building structure might result, but to maintain cool room temperatures down to about 50 °F. In addition, ducts to the warm rooms were taped and insulated, warm room exterior walls were insulated (where possible), heat lamps were provided in the bathrooms, heat tape was applied to water pipes near exterior basement walls, and general weatherization was carried out in the warm rooms (caulking, weatherstripping, plastic storm windows). Throughout the installation residents were instructed in the management of the warm room.

In February 1986, a few months after the retrofits were completed, we conducted a survey to see how well the occupants were using their warm rooms and to ask them about how it had affected their lifestyles and comfort, and if they had any suggestions for improving future retrofits. A follow-up survey in March 1986 included questions about indoor air quality, a check of the instrumentation, and an evaluation of the performance of the retrofit.

3.0 RESULTS

3.1 Effectiveness of Zoning

Table II shows the effect of zoning on indoor temperatures. The numbers are not strict averages of temperatures in the warm or cool zones; they were measured by a thermograph placed in one room of each zone and serve rather as indicators of average temperatures. (In some of the houses, only one thermograph was present pre-retrofit.) In Table II, the average temperatures are through March, to indicate the effectiveness of zoning in cold weather. By April, temperatures in the cold rooms were already rising by about 10 °F. After the retrofit we find temperature differences in the winter between warm and cool zones averaging about 12 °F. In three of the houses, WK1, WK4, and WK6, the zoning seems to be working as intended, with cool room temperatures in the 50 °F range. The occupants there are using the curtains consistently and the dampers appear to be working correctly. At WK1 and WK6 there were also 3 to 4 °F reductions in the warm room temperatures, while WK4 showed a 1 °F increase. In WK3, however, we found a difference of only 0.6 °F between warm and cool rooms. Discussions with the homeowner and a check of temperatures in earlier years reveals an interesting situation—apparently the upstairs (nominal cool zone) had been badly overheated before the retrofit. Closing the dampers at the furnace served to reduce the temperature upstairs by about 11 °F, and coupled with a smaller reduction in downstairs temperature, the homeowners now find the entire house much more comfortable. This and other observations of nominally unheated basements which were in fact warmed very well by uninsulated ducts and furnaces, suggests that more attention to duct insulation and balancing might be in order for conservation programs.

3.2 Energy Savings and Cost-Effectiveness

Table III shows the gas savings for the warm room and control houses. Normalized annual consumption (NAC) was calculated for each house before and after the retrofit. The post-retrofit period was December 1985 through April 1986. Although not a full heating season, this period included both warm and cold periods, (necessary for meaningful regression results) and the results for the control houses showed insignificant variation between this period and the full heating season.

The results are very encouraging: in the three houses where the warm rooms were observed to be used effectively, the savings ranged from 21 to 47%, averaging 32%. This savings is the percentage savings in *total* gas usage; the percentage savings in gas for space heating alone is somewhat higher (see Table III). At WK3, where zoning was not well maintained, but the overall house temperature was reduced, the savings were 31%. At WK5, the savings were 1.9% (smaller than statistical error in NAC calculation). Inspection and subsequent interviews with the residents at WK5 showed that several actions of the residents were counteracting the warm room strategy. The residents would typically leave the door from the kitchen (warm room) to the unheated basement open, saying "it doesn't matter, because warm air rises and you wouldn't lose any heat." They also would leave the hall door open that connected the two zones, and had opened the damper to one of the upstairs rooms. Overall, we measured average savings for the five houses to be 26 percent. Excluding WK5, the savings were 32%. Average savings for the control houses were 1.9%. We note that the sample is very small, and the controls only roughly matched to the warm room houses, but the fact that the warm room savings correlate with observed effectiveness of zoning, and the magnitude of the difference between savings for the warm room and control houses do indicate effectiveness of the retrofit. Our results compare favorably to results from weatherization programs nationwide, as cited by the General Accounting Office (GAO, 1985). Their estimated annual savings as a percent of total heating fuel (the same measure we used) ranged from 7.8% to 22.3%; the nationwide savings were 10.4%.

We also estimate changes in electricity consumption before and after the retrofit due to use of secondary space heaters (see Table III). The estimated change in electricity consumption is scaled to annual use from billing data according to base 65 °F days, after subtraction of base use. In the first four houses the increase or decrease is not large compared to the savings, but in WK6 there appears to be an increase on the order of 650 kWh/year—a significant fraction of the warm room savings. This is probably due to an electric heater the wife runs in one of the cool rooms to protect her plants. Whether the plants could actually tolerate 50 °F temperature may affect the future savings in this and similar houses.

The cost of the retrofits ranged from $1295 at WK3 to $1580 at WK5, averaging $1425. Table IV shows cost-effectiveness for the warm rooms as measured by simple payback, cost of conserved energy (CCE), and return on investment for several different scenarios.

We use both the current Kansas City natural gas price of $0.28/therm and the 1984 national average residential gas price of $0.60/therm, since we believe the former to be an unrealistically low indicator of gas prices (see note to Table IV). We calculate economic indicators using retrofit lifetimes of 5 and 10 years. Although the physical components of the retrofits should last 10 years or more, the effectiveness of the warm room also depends on occupant behavior, and we know very little about the persistence of this aspect, which may last considerably less than ten years. In calculating the cost of conserved energy we use a real discount rate of 7 percent (National Security Act, 1980).

At the low Kansas City price the simple payback time is 5 years and greater. Using the national average price the simple payback time ranges from 2.4 to 4.6 years for WK1-4; WK5, where negligible savings were observed, has a 125 year payback, and WK6 has a 7.4 year payback for the house without the extra heating for the plants and a 9.5 year payback with the extra heating. The cost of conserved energy (an index of retrofit cost which is used for comparison with current or expected energy prices—see note to Table IV) shows a strong relationship with retrofit lifetime: the results for a ten-year life of a retrofit compare considerably better to the average national residential gas price than those for a five-year life. For the latter, three houses are near or below the $0.60/therm benchmark; for the former, all but WK5 lie near or below, with WK1 at $0.21/therm.

Return on investment (ROI) is another commonly used investment decision tool. At the national benchmark price for natural gas, the four houses with significant savings show an ROI ranging from 11 to 42 percent, averaging 26 percent—better than most investment opportunities available to typical homeowners. Even at current low Kansas City gas prices, the four houses show an average ROI of 12 percent.

3.3 Indoor Air Quality

We measured nitrogen dioxide (NO_2), formaldehyde (HCHO), and radon (Rn) inside and outside the living space, and base gas use (total minus furnace) during the NO_2/HCHO monitoring period. All air quality measurements were made using passive samplers. Each house had ten samplers for formaldehyde and nitrogen dioxide and two samplers for radon. In addition to the air quality measurements, blower door tests were made on the houses to measure their air tightness. The blower door tests showed a post-retrofit reduction in leakage area of 12 to 26 percent for four houses, with WK6 showing an apparent increase of 35 percent. (The leakage area of WK6 also increased 15 percent, for reasons unknown.)

The pre-retrofit NO_2 measurements showed several houses with NO_2 levels in the kitchen slightly above the EPA-recommended maximum level of 50 ppb. One living room was also slightly above the maximum and another was well above (125 ppb). The latter was in WK5, where the homeowners had been using a poorly vented gas fireplace, as well as their gas oven, for heating. We therefore had some concerns about air quality after the warm room installation, since all warm areas included the kitchen and all had gas stoves. In the post-retrofit monitoring, however, we found that three houses were below the maximum in both warm and cool zones, and one was slightly above (WK6, at 57.0 ppb in the warm room and 53.0 ppb in the cool room. The 50 ppb maximum is an annual average, and it is likely that levels are lower in the summer when the house is opened up, so the slightly elevated levels are probably not a serious concern). But at WK 5, where the owners had not understood the warm room concept, the levels were even higher than before the retrofit (138.3 ppb in the warm room, 95.3 ppb in the cool room) — despite the fact that they said (and submetered versus total gas use records confirmed) that they no longer used the gas fireplace and oven for heating. The puzzle was solved during one of the household visits, when the interviewers established that not only was the gas-dryer flue disconnected, but the common furnace/water heater flue did not, as appeared to a casual glance, connect to the chimney. That the levels in the other houses showed reductions after the retrofit appears to be due, at least in part, to decreased stove/oven use for space heating. In each of the three houses showing a reduction in NO_2, there was also a drop in base gas use (total minus submetered). At WK4 the resident said that she had used her oven "a lot" for space heating before the retrofit, but has since only used the stove "once or twice" for that purpose. At WK6 the wife also had used the oven "a little" for space heating before the retrofit, but does not now. House WK6, where the post-retrofit NO_2 levels were slightly above the EPA maximum, also had the highest post-retrofit base gas use (8 therm/week, compared to the average 5.8 therm/week). Because it had been a backup house during the pre-retrofit monitoring, no initial NO_2 data are available. There was no strong correlation between changes in NO_2 levels and changes in infiltration rate.

None of the houses had formaldehyde levels above the strictest current guideline of 100 ppb. Changes in the warm-room levels ranged from -57% to +7.3%. The changes were not strongly correlated with changes in outdoor levels, stove use, or infiltration rates. The only house where new furniture had been acquired (a potential source of formaldehyde) was WK3 where there was a slight increase in formaldehyde.

The radon levels in the basements were, on average, almost three times as high as those measured three years before (ranging from 1.37 to 5.35 pCi/l compared to 0.82 to 2.42 pCi/l). The warm room levels followed those of the basements, ranging from 1.37 to 3.04 pCi/l. This put several of the houses above the maximum U.S. special standard for houses built on contaminated ground (2.1-5.0 pCi/l, assuming a range of equilibrium factor from 0.3 to 0.7). (All are below the general Swedish standard for existing houses of 7.7 to 18 pCi/l.) In four of the houses, in fact, the ratio of radon in the living space to radon in the basement was lower after the retrofit, that is, a smaller proportion of the radon from the basement was getting into the living space after the retrofit. At WK5, where the basement door to the kitchen (warm room) was left open, the basement did not show as high an increase in radon as the other houses, and the level in the warm room was the same as in the basement. These observations support the suspicion, mentioned earlier, that considerable mixing of basement and warm room air is occurring (the smaller increase in the basement could be due in part to radon escaping upstairs until warm room and basement levels were equal).

3.3 Comfort, Lifestyle, and Occupant Perception of Warm Rooms

In post-retrofit interviews, residents were asked whether the warm room had changed their lifestyles and level of comfort, and whether their reactions were positive or negative. In the four houses where the occupants used the warm rooms correctly and where significant energy savings were measured, the residents were very positive in their reactions to the warm room. They mentioned both their lower heating bills and the increased comfort resulting from the retrofit. At WK5, where problems were observed with the use of the retrofit, the residents were fairly critical. In three of the houses residents liked having the use of the downstairs instead of being forced by cold weather to go upstairs, where it was warmer (before the retrofit). Having cold bedrooms did not seem to be a problem, though in a few cases, owners resorted to some use of an electric heater. On the lifestyle changes, one resident observed that her activities had changed as a result of the retrofit, but that she accepted that as "there are things you do normally that you don't do other seasons." At WK3, where the zoning did not work as well as intended, but the overheating of the upstairs was reduced, the couple spend their time downstairs (in the nominal warm room) but like having the temperature comfortable upstairs. At WK1, the homeowner said that she had enough room in the warm zone, but if she could, she would heat the living room as well. At WK3 the residents also said they had enough room in the warm space. At WK5, the homeowners felt they had too little room, and would have preferred having a downstairs bedroom included instead of the kitchen. At WK6 the couple said they had enough room; when grandchildren visited over the holidays, they "let a little warmth go upstairs ... we had no problems."

There were several comments that the heat lamps installed in the bathrooms were inadequate for keeping warm before or after bathing. Some condensation had been noticed during the coldest weather on cool room windows, but none of the owners seemed to think there was a serious problem. With the exception of WK5, the owners liked the retrofit and offered no major suggestions for changes. It is worth noting that in a survey of warm rooms installed by the Institute for Human Development (IHD) in Philadelphia, which also pre-screens applicants and counsels them in the use of the warm room, 28% of homeowners did not adapt to or use their warm room and an additional 11% showed poor adaptation (IHD, 1984). In both cities it appears that improved screening and/or counseling might improve overall program savings.

4.0 CONCLUSIONS

We found substantial energy savings in houses where the homeowners understood the use of the warm room retrofit and used it correctly. In one case the savings appear to be due more to a reduction in overheating than to zoning. Even considering the house where the warm room was not used well, overall savings were about 26%, over twice the average savings of 10% for weatherization programs of comparable cost reported by a recent GAO report on national weatherization programs. The warm room did not appear to create or significantly aggravate problems with indoor air quality. Occupant reaction was positive, with four of the households adapting well to the warm room. These results suggest that a larger warm room project, with measurements of energy savings and indoor air quality impacts is well worth pursuing.

We suggest that several areas in particular are worth investigating:

- Improvements in screening and/or counseling the potential recipients to increase the proportion of homeowners who adapt well to the warm room.
- Reduced cost of retrofit materials, particularly the curtains, which in this project ran from $113 to $338. Care must be taken, however, not to resort to materials so cheap that they become unattractive to the homeowners.
- Persistence of savings over several years.
- Attention given to the ducts—currently the forgotten link between envelope and furnace. Judging from the overheated (nominally *unheated*) basements we observed, as well as problems in duct balancing, there may be significant savings to be realized from sealing, insulating, and adjusting the distribution system.
- The influence of climate on warm-room effectiveness. Since the warm room savings can be viewed as primarily due to a lowering of the balance point (resulting in a shorter heating season), the distribution of outdoor temperatures may have a large effect on savings. That is, the retrofit may be most effective in areas such as the Pacific Northwest, where there are long portions of the heating season near or above the post-retrofit balance temperature.

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Table I. Warm room and control house characteristics.

House ID	Number of Occupants	Occpt Ages[a] (y)	Floor Area (ft^2)	Bldg Age[a] (y)	Gas Use[a] (therm/y)	Rooms and Floors (#/#)	Years in Home (y)	Heatg System Type[b]	Gas Fireplace Exist /Used	Appliances (ex stove)	Air Conditioners
WK1	1	86	1425	NA	1717	7/2	45	FA	Y/N	N	0
WK3	2	83/70	1512[c]	69	1894	9/2[c]	28	GA	Y/N	dryer	3W
WK4	2	60/son	1598	NA	2106	9/2	26	FA	Y/N	N	0
WK5	2	69/wife	1675[d]	105	1607	7/2[d]	25	FA	Y/Y	dryer	0
WK6*	2	84/65	1292[h]	50	1365	7/2+	34	GA	N/N	dryer	0
CK4	1	57	1394[e]	˜70	1335[f]	9/2	8	GA[g]	Y/N	dryer	0
CK5	1	68	1418	77	1687[f]	8/2+	45	FA	Y/Y	dryer	3W
CK6	3	66/?	3644	NA	4346[f]	9/3	36	FA,2GU	Y/N	3 stoves	2W
CK8	1	39	984	NA	1418	6/1	5	GA	Y/Y	dryer	1W

* WK2 dropped from program, replaced by WK6. Some control houses also dropped; see text.

[a] Occupant and building ages are given as of the 1/83 audit.
Gas use is the average of 1981, 1982, and 1983/84 NAC unless otherwise stated.
# of rooms includes bathroom(s).

[b] Heating system types are all central gas, except where noted and are further indicated as:
FA=gas central forced air GA=gas central gravity air GU=gas unit heater.
None of the homeowners reported use of auxiliary heaters (gas or electric) except occasional use of bathroom heaters.
Under "Air conditioner", "W" stands for window unit.

[c] Excluding 3 unheated rooms, area = 1170 ft^2.

[d] Excluding unheated bedroom, area = 1548 ft^2.

[e] Excluding unheated back room, area = 1333 ft^2.

[f] Average of 1981 and 1983/84 NACs only.

[g] Replaced 1983/84.

[h] Excluding unheated area, area = 1215 ft^2.

Table II. Effect of zoning on indoor temperatures in warm room houses.

House ID	Start Date (Y-Mo-Dy)	End Date (Y-Mo-Dy)	Warm Room Temp. (°F)	Data Points (#)	Cool Room Temp. (°F)	Data Points (#)	Warm-Cool Room ΔT (°F)	Post-Pre Warm Room ΔT (°F)	Post-Pre Cool Room ΔT (°F)
WK1 Pre	84/10/01	85/05/31	75.1	18	76.3	19	-1.2		
WK1 Post	85/12/23	86/03/04	72.0	2	57.3	11	14.7	-3.1	-19.0
WK3 Pre	84/10/01	85/05/31	74.1	33	80.0	35	-5.9		
WK3 Post	86/02/03	86/03/24	69.9	8	69.3	8	.6	-4.2	-10.7
WK4 Pre	84/10/01	85/05/31	72.9	30	NA	-	-	-	
WK4 Post	85/12/26	86/03/22	73.8	12	59.3	8	14.5	+0.9	-
WK5 Pre	84/10/01	85/05/31	67.8	33	NA	-	-	-	
WK5 Post	85/12/26	86/03/04	72.0	10	53.8	6	18.2	+4.2	-
WK6 Pre	84/10/01	85/05/31	72.2	33	NA	-	-	-	
WK6 Post	85/12/23	86/03/24	68.1	14	53.3	7	14.8	-4.1	-

Note:

By April, 1986, temperatures in the cool room began to rise due to warmer outside weather. Each warm or cool temperature is the average temperature in one warm or cool room, respectively.

TABLE III. Gas and electric savings in warm room and control houses.

House ID	NAC[a] Pre (therms/yr)	NAC[a] Post (therms/yr)	Savings (th/y)	Error[b] (th/y)	Savings (% of NAC)	Error[b] (% of NAC)	Savings[c] (% of heat)	Error[b] (% of heat)	Change in Electricity used for Space Heating[d] (kwh/y)	Change in Electricity used for Space Heating[d] (th/y)
WK1	2041	1124	917	231	45.	11.	49	12.	-120	-12
WK3	1897	1306	592	169	31.	8.9	38	10.	140	14
WK4	1965	1398	567	169	29.	8.6	33	9.1	210	22
WK5	1075	1055	21	117	1.9	11.	NA	NA	-220	-23
WK6	1526	1218	308	149	21.	9.8	NA	NA	-650	-67
CK4	1037	965	72	182	7.0	18.				
CK5	1663	1764	-101	149	-6.1	9.0				
CK6	4234	4038	196	537	4.6	13.				
CK8	1450	1420	30	240	2.1	17.				

a) Normalized Annual Consumption (NAC) is total annual gas consumption normalized to long term average degree days to the best balance temperature found by regression (see text).

b) Error calculated for 95% confidence interval.

c) Calculated from regression of submetered fuel use versus degree days.

Second electricity savings column gives resource equivalent of savings in previous column. The factor of 0.10236 therm/kwh includes electric power generation efficiency of 0.33. Resource equivalent gives rough price equivalent of gas versus electricity per unit of delivered heat.

TABLE IV. Cost-effectiveness of warm room retrofits.

House ID	NAC Savings (th/y)	Warm Room Cost ($)	Simple Payback[a] @.28$/th (yr)	Simple Payback[a] @.6$/th (yr)	CCE[b] 5 yr ($/th)	CCE[b] 10 yr ($/th)	ROI[c] @ 0.28 $/th (%/yr)	ROI[c] @ 0.6 $/th (%/yr)
WK1	917	1323	5.2	2.4	0.35	0.21	19	42
WK3	592	1295	7.8	3.6	0.53	0.31	13	27
WK4	567	1552	9.8	4.6	0.67	0.39	10	22
WK5	21	1580	269.	125.	18.	11.	0.4	1
WK6	308	1373	16.	7.4	1.1	0.63	6	13
WK6[d]	241	1373	20.	9.5	1.4	0.81	5	11

a) Simple Payback Time (SPT) is the number of years required for accumulated energy savings to equal retrofit cost, ignoring factors such as discount and inflation rates.

SPT = (retrofit cost)/(savings per year)

The first SPT is based on the current price of natural gas in Kansas City of $0.28/therm (which had been $0.42/therm a year previously). The second is based on the 1983 national average residential price of $0.60/therm. We note that the average real (uninflated) price of residential natural gas has risen 5% per year in the last fifteen years (roughly doubling in that time), so that the current low price of Kansas City gas is not a reliable benchmark (Energy Information Administration, Annual Energy Review 1984, Washington, D.C., 1985).

b) Cost of Conserved Energy (CCE), which is the cost (in dollars) divided by the levelized savings (in therms). It can be compared directly to the cost of energy which would otherwise have to be purchased: If the CCE of the retrofit is lower than the relevant energy price, the retrofit is economical. The CCE takes into account the discount rate and retrofit lifetime, but is unaffected by fuel inflation rate.

$$\mathrm{CCE} = [i/(1- (1+i)^{-n})] \times \mathrm{cost}\ (\$)/\mathrm{savings}\ (\mathrm{therms})$$

Where i = discount rate (taken here as 7% real (above inflation))

n = retrofit lifetime (here 5 or 10 years as indicated)

c) Return On Investment (ROI) is the percentage return in energy savings (measured in dollars) for every dollar invested in the retrofit. It is used to compare the value of investing in conservation compared to alternative investments (e.g., savings account, mutual fund): the higher the ROI, the better the investment.

ROI = annual savings/retrofit cost

A levelized ROI, taking into account discount rate, fuel price escalation, and retrofit lifetime can be calculated, but for a real discount rate of 7%, lifetime of 5-10 years, and 5% real fuel escalation rate (15 year historical average) the results differ by at most about 10% (4 percentage points).

d) At WK6 an increase in electric heat for a plant room offset gas savings. Net savings are estimated by subtracting the resource equivalent (rough price equivalent) of the increase in electric use from gas savings.