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ALTERNATIVE TECHNIQUES FOR DEVELOPMENT OF ENERGY EFFICIENT RESIDENTIAL STRUCTURES

Energy Task Force
of the Urban Consortium
for Technology Initiatives

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Conducted by:
City of Kansas City, Missouri
City Development Department
Neighborhood Development Department

PREFACE

The Urban Consortium for Technology Initiatives was formed to pursue technological solutions to pressing urban problems. The Urban Consortium conducts its work program under the guidance of Task Forces structured according to the functions and concerns of local governments. The Energy Task Force, with a membership of municipal managers and technical professionals from nineteen Consortium jurisdictions, has sponsored over one hundred energy management and technology projects in thirty-two Consortium member jurisdictions since 1978.

To develop in-house energy expertise, individual projects sponsored by the Task Force are managed and conducted by the staff of participating city and county governments. Projects with similar subjects are organized into "units" of four to five projects each, with each unit managed by a selected Task Force member. A description of the units and projects included in the Sixth Year (1984-1985) Energy Task Force Program follows:

UNIT -- LOCAL GOVERNMENT OPERATIONS

Energy used to support public facilities and services by the nation's local governments in 1983 totaled approximately 1.4 quadrillion BTU's. By focusing on applied research to improve energy efficiency in municipal operations, the Energy Task Force helps reduce operating costs without increasing tax burdens on residents and commercial establishments. This Sixth Year unit consisted of six projects:

- Baltimore, Maryland - "Wastewater Treatment Process Integration: Energy Operations and Cost Optimization"
- Detroit, Michigan - "Computer Control for Municipal Water Distribution: Design for Energy Cost Savings"
- Memphis, Tennessee - "Transportation Management for Business Relocation and Expansion: A Strategy with Federal Express Corporation"
- Philadelphia, Pennsylvania - "Incinerator Residue Dewatering Transfer Trailer"
- Phoenix, Arizona - "Thermal Storage Strategies for Energy Cost Reduction"
- Washington, DC - "Energy Monitoring and Control in Municipal Facilities: System Development and Testing"

UNIT -- COMMUNITY ENERGY MANAGEMENT

Of the nation's estimated population of 232 million, approximately 60 percent reside or work in urbanized areas. The 543 cities and counties that contain populations greater than 100,000 consumed a total of 49 quadrillion BTU's in 1983. Applied research sponsored by the Energy Task Force helps improve the economic vitality of this urban community by aiding energy efficiency and reducing energy costs for public services and the community as a whole. This Year Six unit consisted of four projects:

- Chicago, Illinois - "Neighborhood Energy Conservation Project: Building Community Capacity for Conservation Services"
- Denver, Colorado - "Refuse Combustion for Power and Thermal Energy: Planning for Urban Development and Solid Waste Management"

- New Orleans, Louisiana - "Incident Prevention and Response for Hazardous Materials: A Decision Support System"

- New York, New York - "Retention and Expansion Program for High Energy Use Businesses"

UNIT -- INTEGRATED ENERGY SYSTEMS

Effective use of advanced energy technology and integrated energy systems in urban areas could save from 4 to 8 quadrillion BTU's during the next two decades. Urban governments can aid the realization of these savings and improve capabilities for the use of alternative energy resources by serving as test beds for the practical application of new and integrated technologies. This Year Six unit consisted of five projects:

- Albuquerque, New Mexico - "Residential Space Heating with Wood: Efficiency and Environmental Performance"

- Columbus, Ohio - "Modular District Heating: Feasibility Analysis"

- Houston, Texas - "The Impact of Source Separation on a Waste-to-Energy Project"

- Milwaukee, Wisconsin - "Resource Recovery from Urban Yard Wastes: Feasibility Assessment"

- San Francisco, California - "Planning for Energy Efficiency in New Commercial Buildings: Evaluation Methods during Design"

UNIT-- PUBLIC/PRIVATE FINANCING AND IMPLEMENTATION

City and county governments often have difficulty in carrying out otherwise sound energy efficiency or alternative energy projects due to constraints in the acquisition of initial investment capital. Many of these investment constraints can be overcome by providing means for private sector participation in innovative financing and financial management strategies. This Year Six unit consisted of five projects:

- Hennepin County, Minnesota - "Shared Savings Applied to Low Income Homeowners"

- Kansas City, Missouri - "Kansas City Warm Room and Superinsulation Project"

- St. Louis, Missouri - "Financing Options for Superinsulated Housing"

- San Antonio, Texas - "Measures and Investment Options for Community Energy Conservation: Strategies with a Municipal Utility"

- San Jose, California - "Energy Management and Tracking System as a Software Package"

Reports from each of these projects are specifically designed to aid the transfer of proven experience to other local governments. Readers interested in obtaining any of these reports or further information about the Energy Task Force and the Urban Consortium should contact:

Energy Program
Public Technology, Inc.
1301 Pennsylvania Avenue, NW
Washington, DC 20004

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Members of the Project Technical Advisory Committee contributed valuable assistance and committed many hours.

Members of the committee were:

Tom Bean City ARchitect	George Schluter Builder
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ABSTRACT

Space heating costs are a financial burden to many low and moderate income families. To be warm in the coldest part of the winter remains a problem to many families in poorly insulated houses. Notwithstanding recent energy price moderations, the need to develop energy efficient residential structures remains urgent.

This project defines and demonstrates the technical and economic feasibility of the warm room and superinsulation techniques in the development of energy efficient residential structures. These techniques are applied in three housing situations:

Application of the warm room approach in retrofitting five residential houses.

New construction application of the superinsulation technology in erecting an earth bermmed house.

Rehabilitation of an older residential structure using the superinsulation technology.

Major Tasks of the project were as follows:

1) To design the energy conservation measures to be applied to the three housing situations

2) To monitor the usage of the fuel power for space heating

3) To apply the warm room and superinsulation techniques to the three housing situations and

4) To analyze energy savings, cost effectiveness indoor and quality, and occupant response data.

We are able to present results from only the warm room retrofit component of the project because of delays in construction of the earth bermmed structure and in the rehabilitation of the older residential structure. These delays did not make it possible to arrange for and conduct monitoring and testing at that time. Following completion for these structures efforts will be made to arrange for monitoring and testing. The average energy savings for the four warm room houses in which warm room procedures were used correctly was 32%. There were no serious indoor air quality problems as a result of the warm room retrofits. Four out of the five families adjusted well to the warm room situation, and the reaction of the residents of those 4 houses was favorable. The positive results of this rather small sample of houses call for further research of the warm room technique on a larger scale.

PROJECT PURPOSE

The financial burden of high energy prices in over a decade, especially for low and moderate income families, presented a challenge to construct, rehabilitate, and retrofit residential structures so that energy usage could be markedly reduced. The recent moderation in energy prices has not altered this challenge.

This project defines and demonstrates the technical and economic feasibility of the warm room and superinsulation techniques in the development of energy efficient residential structures. These techniques are applied in three housing situations:

* Application of the warm room approach in retrofitting five residential houses.

* New construction application of the superinsulation technology in erecting an earth bermmed house.

* Rehabilitation of an older residential structure using the superinsulation technology.

Findings of the project analysis will include usage of heating fuel/power, energy savings, cost effectiveness, and indoor air quality testing.

REPORT ORGANIZATION

The balance of this report describes the project's process in demonstrating alternative techniques in constructing, rehabilitating, and retrofitting energy efficient residential structures.

CHAPTER 2 - describes project background and rationale as well as project concepts.

CHAPTER 3 - describes the project's three housing situations, the process by which energy conservation techniques were applied and project strategy.

CHAPTER 4 - presents analysis of the monitored data performed by Lawrence Berkeley Laboratory on the warm room project.

CHAPTER 5 - presents conclusions and major lessons learned from the project.

CHAPTER 2
Alternative Techniques for Development of Energy Efficient Residential Structures

INTRODUCTION

Space heating costs are a financial burden to many low and moderate income families. To be warm in the coldest part of the winter remains a problem to many families in poorly insulated houses. Notwithstanding recent energy price moderations, the need to develop energy efficient residential structures remains urgent.

In addressing the challenge to construct, rehabilitate, and retrofit energy efficient residential structures, this project will demonstrate the technical and economic feasibility of applying alternative energy conservation techniques in three housing situations. The project will provide monitored date and results relating to energy and retrofit of residential structures.

APPLICATION

The project involves the application of primarily the warm room and superinsulation energy conservation techniques in three housing situations:

Retrofit of five older houses using warm room techniques.

Construction of a new earth bermmed structure using superinsulation and other advanced energy conservation techniques.

Rehabilitation of an older house using the superinsulation techniques.

The research component of the project which was conducted by Lawrence Berkeley Laboratory (LBL) located in Berkeley, California, included testing for air infiltration and indoor air quality, monitoring of indoor air temperature and usage of natural gas and electricity of the five houses which were retrofitted using warm room techniques. Based on the project analysis conclusions were made on the energy conservation techniques used and are discussed in Chapter 5. Concerns that needed to be addressed were: How technically feasible and cost-effective are the applications? What problems were encountered? What lessons learned? What conclusions from the analysis of this project will be useful in other projects that apply residential energy conservation measures?

DESCRIPTIONS OF CONCEPTS INVOLVED

This project deals primarily with two concepts in the application of residential energy conservation measures. These are the warm room and the superinsulation concepts.

Warm Room Concept

The warm room concept is a very simple and old one. The concept is to heat only the space most frequently occupied by people during the winter to reduce the cost of heating. It was the prevailing approach until the last 50 years or so. Only recently have we had central space heating for the entire house. Now the warm room concept of heating less than the entire house is gaining attention.

Even though the warm room concept is simple enough, applying the concept is not so simple for several reasons. There are a number of considerations, technical and otherwise, that need to be kept in mind:

> The design of the central heating system assumes the entire house will be heated. To introduce zone heating presents a concern for freeze protection of the plumbing system in the basement and in areas outside the warm room zone.
>
> Most central heating systems were designed to operate at specified heating loads and very possibly will not operate efficiently at lower heating loads.
>
> Indoor air quality becomes a concern when the warm room is weatherized and air infiltration is greatly reduced. We need to learn more about the health effects of reduced air exchanges and questionable indoor air quality.
>
> Central heating systems are designed so that restricting the heat intake of areas outside the warm room areas may well pose problems.

> Realistic budgets will be needed if and when state and local weatherization programs consider the warm room approach. The challenge is present, therefore, to use those warm room retrofit measures which provide the greatest energy effectiveness per dollar expended.

Achieving success with the warm room approach depends to a very large extent on the willingness of the occupants involved to cooperate with the warm room approach. This includes the ability of using equipment properly.

A few groups have already pioneered with the warm room approach. These are the Institute of Human Development in Philadelphia, the Tennessee Valley Authority, and Union Electric in St. Louis. They have gained valuable information in their warm room applications. However, to date reported results in these programs have been scanty.

The Institute for Human Development in Philadelphia used a flexible approach in its program. Their method allows people to heat as little or as much as desired and to leave the decision of how much space to be heated at a particular time up to the occupant. To accomplish this a portable thermostat was developed which could be moved to the area to be heated. Another feature of this approach is to place insulating covers over radiators of hot water or steam heating systems in rooms not being occupied.

St. Louis, Missouri calls their project the Comfort Zone Program. Their project established a "comfort zone" by providing a well insulated room in extreme weather. Typically, one room of an apartment in an older, usually brick building is insulated and weatherized; it is heated with a 1400 watt electric heater unit.

During the same period Lawrence Berkeley Lab (LBL) also became interested in the warm room approach and raised the following questions that required answers before widespread warm room application:

> Energy Savings. Can the warm room approach achieve the theoretical double or triple energy savings over that of conventional weatherization? Is the zoning effective? Will the central heating system be sufficiently efficient in its new operating mode? Are the projected costs realistic?
>
> Health and Building Safety. Will indoor air quality problems arise or intensify with the warm room retrofit? How does one prevent moisture damage in cool areas of the house? How does one avoid water pipe freezing?
>
> Social Questions. Is the zoning acceptable to occupants or a particular group of occupants? How does one insure sufficient flexibility and control over the operation of a warm room house? How does a retrofit affect property value? How does one best teach occupants to manage their warm rooms?

It was in the context of these questions that the City of Kansas City and Lawrence Berkeley Lab (LBL) cooperated in conducting the warm room project discussed in this report. The City of Kansas City administered the project, and LBL performed the research elements of the project.

The Superinsulation Concept

The superinsulation technology has recently been receiving considerable attention in the energy field. Evidence is accumulating that this technology has great potential in meeting the challenge of making residential structures highly energy efficient. The superinsulation concept involves several elements:

> High levels of insulation in the walls, ceilings, and floors.
>
> A continuous vapor barrier to assure that the structure will be as air tight as possible.
>
> An air-to-air heat exchanger so that the occupants will have fresh air without losing heat.
>
> A tight "envelope" of the house--ceilings, walls, windows, doors, and foundations--in order to minimize heat loss.

While research data is accumulating regarding the application of superinsulation techniques to residential housing, further data is needed particularly in the temperate zone which includes Kansas City. The data thus far gathered comes primarily from such northern states as Wisconsin, Montana and Illinois and from the Canadian Province of Saskatchewan.

In both the second and third parts of the project -- the rehabilitation of an older house and the construction of a new house-- the project demonstrates the technical and economic feasibility of applying superinsulation and other advanced energy conservation techniques. In Chapter 3 we shall describe in detail the process by which these energy conservation techniques were applied.

CHAPTER 3
Project Development

INTRODUCTION

Kansas City is located on the Missouri-Kansas border at the convergence of the Kaw or Kansas River and the Missouri River. With a total land area of 316 square miles contained in its city limits, Kansas City has a population of nearly 500,000 and is the center of an SMSA population of more than 1.3 million persons.

The city is governed by a mayor/council - city manager form of local government that, in effect, provides the city with two formal leaders. The mayor, as the elected political head, works in conjunction with an elected City Council to set policy for the City Council and the city manager. The city manager works within this policy guidance to serve as the administrative and operation executive for the city.

The City of Kansas City has responded to escalated energy costs by developing several energy management projects to promote energy conservation. These include formation of the Kansas City Energy Commission, establishment of the City Energy Office which serves in a coordination role for the city's energy programs, the Regional Ridesharing Program and the home weatherization program. The City's Weatherization Program has weatherized at least 10,000 low income homes as of January 1, 1986. Approximately 14,000 low income homes remain to be weatherized. In addition, an estimated 60,000 low/moderate income homes need to be weatherized in Kansas City.

Kansas City's housing stock is characterized by predominately single-family houses in small neighborhood settings. At least 77% of all the houses in the central city were built before 1930.

The occupants of these older houses -- which are usually energy inefficient -- are frequently burdened by high heating costs. Recognizing that natural gas prices have risen three, four, and even fivefold in the past 12 years, it is understandable that the need to increase the energy efficiency of Kansas City's housing stock has become a priority concern.

PROJECT PROCESS AND STRUCTURE

The following describes the development of the three components of the projects.

Warm Room Retrofit

The beginning of the warm room project described in this report began more than three years ago when LBL became aware of Kansas City's interest in the superinsulation technology and proposed to the city a cooperative effort in a demonstration warm room project. A work plan was developed, houses were selected, and the monitoring of the houses began; however, funding did not materialize until one year later. (For a detailed description and analysis of this project, see Appendix C.)

Selection Process. Five houses were selected to be retrofitted as warm room houses and eight selected as control houses. Both groups of houses were to be monitored using the same procedure.

The criteria used in selecting these houses were:

- Occupants were to be low/moderate income families.
- One or two occupants to a house.
- Older, larger single family houses.
- Occupants were to be mature and preferably senior citizens.
- Houses were to be consistent in fuel/power usage - determined by reviewing natural gas and electric utility receipts.
- Houses had not previously been involved in City's weatherization program.
- Houses meet minimal indoor air quality standards.

With the assistance of the Community Development Division, a city agency which serves in a liaison capacity between community groups and City Hall, and community groups in Kansas City, project staff distributed informational sheets and application forms to interested persons residing in central city neighborhoods.

The City Development Department received 44 applications during a two week period, which included the holiday period between Christmas and New Years' Day. This was remarkable, and showed the effectiveness of the City's community organization agency and the neighborhood organizations.

With the aid of a computer printout provided by the local natural gas utility, LBL pared down the number of applications by analyzing natural gas usage of the houses for the prior two years. Consistency in usage of natural gas was the criteria used.

In the next phase, a representative from LBL conducted air infiltration measurements by using a blower door instrument on each of the candidate warm room houses.

Following interviews with the occupants involved, the initial selection of the warm room and control houses was made, dependent on indoor-air quality testing, described below.

Canisters testing for indoor air quality were placed in the five selected warm room and eight control houses. Three pollutants were measured: radon-222, nitrogen dioxide and formaldehyde. LBL's analysis of these test results indicated that one of the warm room houses had pollutant levels for radon-222 and nitrogen dioxide to such a degree that it caused concern.

Realizing that the retrofit process of the warm room houses would reduce the air exchange factor, LBL recommended dropping the warm room house with questionable levels of radon-222 and nitrogen dioxide and replacing that house with one of the back-up houses. Replacement of the one house with questionable pollutants completed the selection phase of the five warm room houses.

This matter raised a concern regarding indoor air quality. Out of this concern, the project initiated a study to explore the extent of the indoor air quality problem and to consider recommendations. This study is described in Appendix A.

Monitoring Process. With the five warm room houses and the eight control houses selected, the monitoring process began. An essential component of the project was to obtain data regarding fuel/power usage, indoor temperature, indoor air quality, and local weather conditions.

Seven-day recording thermographs to record indoor temperatures were placed in each of the project warm room and control houses. Occupants of the warm room and control houses sent in weekly thermograph disks as well as gas meter cards to LBL. In that additional gas meters were hooked up to the furnaces of the five warm room houses, occupants of these houses sent in additional cards for the furnace gas meters.

The monitoring process began in the spring of 1983; thus LBL had pre-retrofit data on temperature and fuel usage form 1983 through 1985. The monitoring process was to continue at least through one heating season following completion of the retrofit of the five warm room houses.

Design. The warm room retrofits were designed by energy consultants in Kansas City. The design process began in the spring of 1983 and, after an interval of two years, energy consultants, project advisory committee and LBL representatives, project staff prepared the design criteria for the five warm room houses. The design criteria for the retrofit of the five warm room houses are described in the following.

Retrofit components of the warm room technique:

Zoning - Retrofit measures will be applied to selected rooms of the dwelling which is most used by the occupant; two rooms for one person and three rooms for two persons.

Shell tightening - Infiltration reduction and insulation will be methods used. Emphasis placed on zoned area; however, shell tightening for entire house not to be ruled out.

Heating system modification - Vented wall gas heaters, electric heaters to be considered as options for zoned areas.

Retrofit components to be chosen for each individual house based on its greatest cost effectiveness in order to attain maximum energy savings per dollar invested. The most cost-effective components should be chosen first.

Aim for a goal of 40% energy savings in space heating costs. Relate this goal to average retrofit cost per house of between $1,000 - $1,200.

Aim for a warm room temperature goal of 67* - 70* and 45* -50* for the rest of the house. Special attention is needed regarding possibility of frozen pipes in unzoned areas of the house.

Concern for construction quality. Project is set up for quality control inspections during warm room applications and for infiltration measurements after construction.

Acceptable indoor air quality must be satisfied in addition to concerns with retrofit costs and savings.

Consider effect of retrofit applications on human behavior.

Consider effect of warm room retrofit on resale value of structure. Preferably these retrofits will have a positive effect on resale value of house.

The design work on the five warm room houses actually had its beginning two years ago. Anticipating funding, two energy consulting firms were engaged on a competitive basis to provide designs for the retrofit of one of the five warm room houses. In that both firms presented quality designs from differing perspectives, project staff made the decision to contract with both firms and to have each firm perform the retrofit design on two houses each. When funding materialized two years later, the two firms did indeed perform the retrofit design of the four warm room houses.

Of the eight design criteria listed above, the second criterion became a focus in the design process: retrofit components to be chosen for each individual house were to be based on their cost-effectiveness in order to attain maximum energy savings per dollar invested.

We list here the retrofit components used in the warm room design in order of their maximum energy savings per dollar invested.

Warm Room Retrofit Components	Simple Payback (Yearly)
1. Install partition/doors/drapes	1.5
2. Insulate basement ductwork	1.5
3. Install furnace dampers	2
4. Reduce air infiltration	3.3

5. Insulate exterior (outside) walls of rooms in warm room area 12.2

Not included in this listing are components dealing directly with the heating system. Furnaces were to be cleaned and adjusted but were not to be downsized i.e., not to have smaller jets placed in furnaces of forced air or gravity air heating systems. The cost factor did not make this move feasible given our budget objectives for the warm room houses.

Another heating retrofit involved placing a heating lamp in the bathrooms of the five warm room houses.

The two design firms presented their designs to the project technical advisory committee for their review. (See Appendix B for summary of warm room designs.) With input from the technical advisory committee, the designs were approved and the project moved into the next phase.

Warm Room Retrofit Application. It was of considerable help to have assistance from the City's weatherization program during the project's bidding process. The first round of bids exceeded the budgeted amount by a considerable amount. The project staff was successful with the second round after separating the drapes from the remainder of the retrofit package and removing the task of downsizing the furnace jets.

We assumed that it was necessary to recognize a realistic construction cost for each of the warm room houses. If public weatherization were to use the warm room approach, then a realistic dollar amount was essential to their success. Therefore, initially our objective was to retrofit each house with a construction cost between $1,000 and $1,200. When we received the bids to perform the retrofit applications, we were forced to revise these figures upward to $1,200 and $1,500. Even so two houses exceeded $1,500 -- $1,552 and $1,580.

Inspection of the five houses during the warm room retrofit applications involved the assistance of an energy consultant and personnel from the City's weatherization program.

Analysis. As stated earlier, the monitoring process will continue at least through one heating season following completion of the retrofit of the five warm room houses. Blower door measurements were again taken of the houses following the completion of the retrofit applications. This provided pre - and post - retrofit air exchange comparisons. In addition, testing for indoor air quality again was performed to provide comparative data in that area.

Following the first heating season after the retrofits, LBL analyzed this accumulated data. The analysis included: comparison of energy usage before and after retrofit, analysis of air exchange ratios before and after retrofit, and analysis of results of indoor air quality testing before and after retrofit.

Survey. In the midst of the heating season, LBL staff conducted a survey of the occupants of the warm room houses to appraise their attitudes towards the warm room approach and to identify possible problems regarding warm room design and retrofit application. We present the survey results in the next chapter.

Construction of New Earth Bermmed House

The construction of the new earth bermmed residential structure serves as a demonstration of a highly energy efficient, modestly sized house in an established older residential area in Kansas City. One of the objectives in designing the house is to make it so energy efficient that heating and cooling costs will be reduced below $200 a year. The heating system will be a heat pump with base board electric heaters as back up. The design of the house follows an integrated design approach, integrating superinsulation, passive solar and the earth bermmed approaches.

The City's Architect's Office designed the structure with input from the projects advisory committee. That office also prepared the bidding specifications. This new structure will be approximately 1400 square feet, and the total construction cost will be $80,000. This includes donations of approximately $15,000.

The intent of this project is to have the earth bermmed structure monitored for temperature and fuel/power usage the first two years following construction. Both infiltration and indoor air quality in this house would also be tested. In addition, it is the intention of this project to determine the cost effectiveness of the structure compared with other recently constructed single-family houses, including highly energy efficient houses constructed in the Kansas City area.

However, the delays in the construction of the earth bermmed structure did not make it possible to arrange for and conduct monitoring and testing at that time. Efforts will be made following completion of the structure to arrange for monitoring and testing.

Rehabilitation of Older House to Superinsulated Standards

The rehabilitation of an older house to superinsulated standards demonstrates the transformation of an older previously uninsulated structure to one that is highly energy efficient. The house selected was one which the City of Kansas City acquired from the U.S. Department of Housing and Urban Development. It was a house that was in need of considerable rehabilitation.

Project objectives in rehabilitation of this structure are:

Compare BTU loss of rehabilitated house with houses of comparable size, some of which will be uninsulated and others weatherized to Missouri's weatherization program specifications.

Compare fuel/power usage of rehabilitated house with houses of comparable size, some of which will be uninsulated and others weatherized to Missouri's weatherized program specifications.

Determine cost effectiveness of rehabilitating an older structure to superinsulation standards with the objective of substantially reducing the cost of heating fuel/power usage. This includes determining the pay of superinsulation standards with savings from decreased fuel/power heating costs.

Determine extent of indoor air quality of structure after rehabilitation. An air heat exchanger will most likely be needed.

As with construction of the new earth bermmed house, delays in the rehabilitation of the older structure did not make it possible to arrange and conduct monitoring for temperature, and natural gas, and electric usage; neither were we able to test for air infiltration and indoor air quality. However, efforts will be made following completion of the structure to arrange for monitoring and testing of this rehabilitated older house.

CHAPTER 4
Findings from the Warm Room Project

INTRODUCTION

This chapter summarizes the results of the analysis by LBL on the warm room project data. LBL analyzed data pertaining to the following areas: zoning effectiveness, energy savings, cost-effectiveness, indoor air quality, and occupant comfort and perception. See Appendix C for complete LBL report.

While the data on natural gas usage is adequate for the pre-retrofit period, it is limited in the post-retrofit period in that the warm room retrofits were not completed until December 1985. This provided post-retrofit data on natural gas usage for 4 months of the 1985-86 heating season. This was the major portion of the heating season and did not pose a serious problem to LBL.

The results of the analysis are encouraging.

ZONING EFFECTIVENESS

The project goal of creating a warm zone and a cool zone in the five houses worked as intended. As stated in Chapter 3 one thermograph was placed in the warm zone of each of the five houses and one in the cool zone. Data reveals that after the retrofit, temperature difference between warm and cool zones averaged about 12*f.(See Table 2 in LBL report for effect of zoning on indoor temperatures.) In three of the houses, WK1, WK4, and WK6,* the cool room temperatures were in the 50*F range. Occupants of these houses appeared to use the retrofit equipment correctly. In the house WK3, the temperature difference was found to be only 0.6*F due apparently to inefficient management of the dampers. In the house WK5, the difference is 18*F but this raises a question as to its reliability in that the gas savings for this house was minimal.

* WK is the code term used in the project to designate the particular warm room houses.

ENERGY SAVINGS

The results of energy savings for all 5 houses are encouraging. In the four houses in which the occupants had an appreciation of the warm room approach, the energy savings ranged form 21% to 45% with an average of 32%. (See Table 3 in the LBL report which shows the gas savings for the warm room and control houses.) The house WK5, which had only a savings of 1.9% is not included in the above figures because inspection of the house and interviews with the residents revealed that the occupants were using practices which were counter to the warm room strategy. These practices were: leaving the door from the kitchen (warm room) to the unheated basement open, leaving the hall door open that connects the two zones, and opening the damper to one of the upstairs rooms. The average savings for the five houses was measured at 26%. Average savings for the control group were 1.9%.

COST EFFECTIVENESS

LBL uses the payback and the cost of conserved energy (CCE) methods in estimating the cost effectiveness of the warm room approach. (See Table 4 of the LBL report for cost effectiveness of each of the five warm room houses.) Two payback estimates are made. One is on the basis of current Kansas City gas prices of $.284/therm. On this basis the payback for WK1, WK3, and WK4, were 5.2 years, 7.8 years and 9.8 years, respectively. The other estimate was made on the basis of $0.60/therm. This gave a pay back of 2.4 years for WK1: 3.6 years for WK3: and 4.6 for WK4.

On the basis of the cost of conserved energy method (CCE) for 10 years -- which is from the government perspective -- the cost effectiveness for WK1 was $0.21 a therm, for WK3 $0.31 a therm, and WK 4 $0.39 a therm.

INDOOR AIR QUALITY

As reported in Chapter 3, information collected on indoor air quality included measurements of nitrogen dioxide (NO2), formaldehyde (HCHO), and radon (Rn). Each warm room house had ten samplers for formaldehyde and nitrogen dioxide and two for radon.

The measurement for NO2 before retrofit showed several houses with NO2 levels in the kitchen slightly above the EPA recommended maximum level of 50 PPG. LBL had some concern about air quality after warm room installation in that all warm room areas included kitchens with gas stoves. However, it was found from test results after the retrofit that three of the houses were below the maximum in both the warm and cool zones, and that one was slightly above. LBL made the observation that reductions in levels of NO2 in the three houses after retrofit appear to be due in part to decreased use of the stove/oven for space heating.

Here, mention should be made, that blower door tests were made on the five houses to measure air tightness. Blower door tests showed a post-retrofit reduction of 12 to 26% in air infiltration for four houses. In the fifth house there could have been a measurement error in that an increase in air infiltration of 35% occurred.

OCCUPANT COMFORT AND PERCEPTION

Two staff persons from LBL conducted interviews with the residents of the warm room houses following the retrofit to find out whether the retrofit had changed their lifestyles, to identify their level of satisfaction, and to identify possible problems. In four of the houses the occupants were very positive in their reactions about the warm room concept. They referred to both lower heating bills and increased comfort. In all four of these houses the occupants had used the warm room approach correctly. In the one house, WK5, where there were problems with using the warm room approach, the residents were critical of retrofits and comfort level.

CHAPTER 5
Conclusions from the Warm Room Project

INTRODUCTION

As a whole, the warm room component of the project was a decided success. The four warm room houses in which the homeowners understood the use of the warm room approach, (four of the five warm room houses,) had average energy savings of 32%. This was short of our goal of 40%. Nevertheless, the 32% savings compares very well to the average savings of 10% for weatherization programs at comparable cost reported by a recent General Accounting Office (1985) report on national weatherization programs. In regard to indoor air quality, no serious problems developed as a result of the warm room retrofits. Another positive note is that four of the five families adjusted well to the warm room situation. The reaction of the residents was very favorable.

Indeed, this was a worthy project, one that adds useful data to the warm room approach to improving residential retrofits. However, the success of the other two components of the project - construction of earth bermmed house and rehabilitation of older house to superinsulation standards - remains to be determined. Monitoring and testing of these two structures will depend on the availability of funding sources for that purpose.

LESSONS LEARNED

The Selection Process

While a commendable job was performed in selecting the five warm room and four control houses, an evaluation of the selection process is in order. In one of the five warm room houses, the occupants did not effectively use the retrofit measures. It is believed that this party did not wish to change their lifestyle sufficiently to use the retrofit measures in a effective manner. It should be the objective of the selection process to identify and select those families who would be willing to adapt their lifestyles to effectively use the warm room retrofits.

Counseling and Education

Prior to retrofits, counseling and educational efforts were made by Lawrence Berkeley Lab and project staff involving warm room occupants. Further educational efforts were made during the construction period. However, realizing there was a two year interval between selection of the houses and the actual construction of the retrofits itself, a refresher educational effort following the completion of the retrofit would have been advantageous.

Design and Retrofit

In general, the design component of the project was quite satisfactory. Under contract were two competent designers/ energy engineers. Development of the design criteria proved to be essential. We maintained our focus on the design criteria which based retrofit components on greatest cost effectiveness. We fell short, however, on a key criterion: recognition of a goal of 40% energy savings in space heating cost, and relating this goal to the average retrofit cost per house of between $1000--$1200. As it turned out, of the four warm room houses adequately performing warm room procedures we had an average energy savings of 32% and an average retrofit cost of $1425. We can draw the conclusion that to achieve a 40% or more in energy savings will cost considerably more than what is realistic for a residential weatherization retrofit project funded by a government jurisdiction.

Insulation of furnace ducts that lead to the rooms in the warm zone appeared to be a positive move. A lesson we learned was that duct tape did not work adequately in adhering the insulation to the ducts. The duct tape began to peel off when the furnace started operating during the heating season. We then applied a plastic tape that is used on hot water heaters. This proved to be satisfactory.

Closing of the dampers at the furnace to the cool rooms worked very well. LBL reported there was about a 11*F temperature reduction in rooms upstairs. This suggests that conservation programs give more attention to duct insulation and balancing.

The use of drapes worked reasonably well. They were a major factor in setting up the warm room zone. The quality and density of the fabric of the drapes proved to be quite adequate. However, improvements could be made in tightening up spaces between drapes and ceiling and in some cases between the drapes and the floor. We used velcro to fasten the drapes to the sides allowing passage through the drapes to rooms which were generally not used. In tightening up those spaces along the edges of the drapes, we could perhaps have lowered the temperature a few degrees in the cool zone.

Bidding Process

The bidding process took a considerable amount of time. Time was lost arranging an acceptable wage scale for retrofit contractors that would be within the project budget. Further time was lost in processing two rounds of releasing bids. Had we developed a coordinated working relationship with the city's weatherization program at the beginning of the project, rather than in the middle, we could have saved considerable time. The Public Works Department with which the project had its initial working relationship had a rigid wage scale that disrupted our budget.

SUGGESTIONS FOR FUTURE PROJECTS

Following are suggestions that could improve future projects which examine residential energy conservation measures.

Extended Monitoring Practices.

It is suggested that future projects have a two year monitoring period to check on temperature and fuel/power usage following the retrofit. At the very least, during the second heating season, arrangements should be made to monitor fuel/power usage. One of the limitations of the project under discussion was that post-retrofit monitoring took place for only a partial heating season following completion of the retrofit--for four months rather than six.

Larger Sample.

In future research projects a larger sample of warm room houses 25--or more--is recommended. The five houses in the project described in this report did not provide a sufficient number or variety of houses for extensive research.

Indoor Air Quality.

Further research is needed on indoor air quality. This was the conclusion not only from this project's small scale study on indoor air quality, but also from the testing performed by LBL. It is recommended that with any future warm room project indoor air quality testing be included.

Expanded Housing Types.

It is suggested that in a warm room project on a larger scale additional types of housing situations be included in the selection process. In this warm room project, the five involved were all single-family residences occupied by mostly elderly persons. Expanded projects should consider other housing situations such as apartments, rental homes, and households with small children.

Education and Training.

Setting up an educational and counseling component as part of a warm room project is essential. It is suggested that before families become eligible to receive a warm room retrofit, they must attend an educational session on the warm room approach. The use of slides would be helpful. Preparing brochures would also be helpful. Following the retrofit, a counseling session with the occupants on the use of the warm room equipment is necessary.

Well-qualified Energy Designers.

To have well qualified designers/energy engineers is essential in designing warm room retrofits. The most important design criterion for retrofit components for each individual house is cost-effectiveness. One such retrofit component was duct insulation and duct balancing of the heating system. It is suggested that a heating engineer be engaged in the design stage of a warm room project to provide expertise in the adjustment, balancing, and downsizing of furnaces. Another retrofit component was the heat lamps used in heating bathrooms. This component needs evaluation. Occupants commented during the interviews that heat lamps were inadequate in heating the bathrooms during the period baths were being taken. Other heating methods (including infrared electric heaters) need to be considered.

SUMMARY

The coordinated efforts by the city of Kansas City, Missouri and Lawrence Berkeley Lab in the warm room project produced positive findings that give considerable support for the warm room approach to residential retrofit for energy savings and human comfort. Average energy savings of 32% for four of the five houses is a respectable figure for such a retrofit project. However, the five warm room houses retrofitted in this project are rather a small sample. The positive results of this project call for further research on a larger scale.

APPENDIX A

INDOOR AIR QUALITY STUDY

Research Problem

We reported in Chapter 3 that one of the originally selected warm room houses was replaced by a back-up house. The replacement took place on the recommendation of Lawrence Berkeley Lab, who performed tests for indoor air quality on the five warm room houses. Lawrence Berkeley Lab reported that the results of the analysis of radon--222 and nitrogen dioxide (NO2) on that replaced house exceeded air quality standards recognized by specific agencies of the U.S. Government. It is to be noted that the U.S. Government has not issued a general health standard for these two pollutants.

This matter raised a concern by the project staff regarding indoor quality. If we reduce air infiltration in retrofitting warm room houses and this in turn reduces the air exchange rate, what is the effect of house tightening on indoor air quality after retrofit on the other houses in the program? This question will be addressed by Lawrence Berkeley Lab's analysis of their indoor air quality testing of the warm room houses. We are assuming that by retrofitting the five warm room houses, we are not tightening these houses to such an extent that this will cause serious indoor air quality problems.

There were other questions raised. Are there other houses in the neighborhood of the replaced warm room house that have questionable levels of radon--222? This question became particularly relevant when it became known that a nonprofit agency was considering building a few superinsulated houses for low income families in that same neighborhood. Is the level of radon--222 in other areas of metropolitan Kansas City to such an extent that it would cause serious concern? A basic question is what should be recognized as an acceptable air exchange rate for residences below which the installation of an air to air heat exchanger or other type of air exchanger is recommended?

Based on this concern and recognizing a responsibility for the public's health, the project staff launched a study project on indoor air quality. A summer student by the name of Jeff Findley, who has a background in public administration, conducted the study.

The project had the following objectives:

To become knowledgeable about and to determine the extent of the indoor air quality problem nationally and internationally.

To determine whether further testing for indoor air quality in the Kansas City area should be performed.

If it was determined that testing should be performed, then the study had the following two objectives:

1. To prepare a proposal for indoor air quality testing in Kansas City, Missouri.

2. To prepare and present recommendations on indoor air quality.

Methodology

To accomplish these objectives the following action steps were taken:

Conducted a literature search in the field of indoor air quality.

Contacted other cities to discover the extent of their involvement in indoor air quality research.

Interviewed knowledgeable staff persons from the Midwest Research Institute and the City's air quality program to appraise the extent of their involvement in the field of indoor air quality.

In an initial step of the project, Jeff Findley conducted a literature search using the University of Missouri Kansas City library's computerized data base. This was followed by the project staff conducting interviews with knowledgeable persons from the Midwest Research Institute and the City's Air Quality Program to appraise the extent of their involvement in the indoor air quality field as well as to invite their thinking and recommendations in this field. In addition, other cities and several U.S. governmental agencies were contacted to find out the extent of their involvement in the indoor air quality field and to ask their advice in this area.

Results

Following is a summary of the findings drawn from the literature search, as well as the conclusions drawn from interviews:

A primary method of reducing heat loss in cold seasons is to reduce the air exchange between indoors and outdoors. The lowering of the air exchange rate can, however, result in increased concentration of some pollutants. This concentration in turn increases the potential for health problems.

The significance of indoor air quality is that people generally spend 70%--80% of their time indoors. The old, the very young, and the ill may spend an even greater portion of their time indoors. Therefore, it is they who are particularly susceptible to the effects of indoor pollutants.

There are no conclusive findings regarding the effects of indoor pollutants on the health of occupants; nevertheless, evidence suggests that high concentrations of indoor air pollutants can have detrimental health effects. For example, radon, a radioactive decay product, is believed to contribute to lung cancer if inhaled in large quantities. Formaldehyde odors have caused nose and eye irritation. Gas stoves emit nitrogen dioxide, which if emitted in high concentrations, can cause lung ailments. Researchers are beginning to suspect that indoor pollution may contribute to serious health problems, and suggest that more research is needed on this important health hazard.

A word about pollutants. It is impractical, if not impossible, to list every pollutant that exists in the indoor environment; however, listed here are some of the main pollutants.

Radon--222 is a natural decay product of radium--226 that occurs naturally in the earth's crust. The rate of radon release varies in relationship to the geological structure in the earth's crust, with uranium rock deposits tending to have high emission rates. The primary danger of radon is the half-live decay products, or progeny. These products can become attached to fine particulate matter, and then deposit in the lungs. It has been shown that high levels of radon and progeny may lead to lung cancer. Since radon is emitted naturally, it can enter a household in various ways, but levels within a structure tend to increase as air exchange rates are lowered.

Formaldehyde is a common component of several types of synthetic resins. These resins are used in the manufacturing of many types of building materials, so exposures are common within the household. Formaldehyde is an irritant to the eyes and upper respiratory system, and has caused cancer in laboratory animals. Since indoor exposure to formaldehyde occurs in different circumstances, it is difficult to determine the extent of indoor concentrations. With the new trend of house tightening measures, formaldehyde is increasingly becoming a significant health threat.

Carbon Dioxide is not typically considered an air pollutant because it exists in the natural environment in such places as unvented fuel-fired stoves and heaters but, carbon dioxide buildup indoors has become an area of concern. House tightening measures have been responsible for much of the buildups. In fact, it is believed by many ventilation engineers that indoor carbon dioxide levels may be the most important determinant for setting ventilation standards for energy efficient buildings.

Nitrogen Dioxide is a gas emitted from a wide range of common combustion processes such as boilers and internal combustion engines, as well as gas stoves. In the indoor environment, gas stoves seem to have the most significant effect on concentrations, with smoking playing a minor role. Recent evidence indicates that nitrogen dioxide exposures in homes with gas stoves may cause an increased incidence of lower respiratory disease in children. Research is presently being conducted to determine if there is indeed a connection.

While there are other important pollutants in the indoor environment, the four above mentioned pollutants received particular attention in our study project.

State and local activities - Other than in the states of

California and New York, which have ongoing indoor air quality research programs, there is relatively very little activity by state and local jurisdictions in the field of indoor air quality.

Activities of federal agencies - The Consumer Product Safety Commission (C.P.S.C.) has been the most aggressive of the federal agencies regarding indoor air quality. This agency examines products which may release substances that become indoor pollutants. It has the authority to ban such products if it is deemed that these products are potentially harmful to consumers.

The Department of Energy (DOE) sponsors some indoor air quality research in relation to its work with energy conservation.

The Environmental Protection Agency (E.P.A.) which is normally associated with air pollution regulations, has not had a significant bearing on indoor air quality. While administering six statutes which has at least some relation to indoor air quality, the EPA is engaged principally in research related to these statutes. The Clean Air Act gives EPA authority to regulate "any air pollution agent which is emitted into or otherwise enters the ambient air." The term "ambient" usually refers to outdoor air pollution.

Therefore, EPA has the position that it does not have the authority to regulate indoor air pollution under the Clean Air Act. Nevertheless, EPA recognizes two objectives in its work with indoor air quality:

> To identify exposure to indoor pollutants for the purpose of setting controls based on the total impact of pollutants on human health.
>
> To aid in the transfer of research results produced by federal research programs to organizations that wish to use it.

The Committee on Indoor Air Quality (CIAQ) was formed in 1983 to assist federal agencies which are working in the indoor air quality field in their research and implementation relating to that field. Another promising development is the commitment made by two private sector organizations, the Electric Power Research Institute (EPRI) and the Gas Research Institute, in conducting research and alerting their members on the subject of indoor air quality.

Conclusions

The general conclusion drawn from Jeff Findley's literature search and from the interviews made with key individuals was that indeed further research is needed. We need to identify the full extent of pollutants, as well as identify their effects, both independently and synergistically, on indoor air quality. We need to promote research on the variables, including the interactions of pollutants as well as their source strengths, that affect indoor pollutant levels. This is needed to determine indoor air quality standards and pollution reduction standards.

Another conclusion was that without adequate research support and recognizing our time constraint, we, the project staff, were not in a position to prepare a proposal for a locally funded indoor air quality issue, that research conducted by federal agencies is preferable to local approaches in conducting indoor air quality research.

Recommendations

The project staff recommends that the Urban Consortium Energy Task Force initiate a working relationship with the Department of Energy, the Environmental Protection Agency, and the Committee on Indoor Air Quality to pursue further research relating to indoor air quality concerns.

We suggest that this research effort pursue the following two emphases:

Identify the full extent of pollutants, as well as identify their effects, both independently and synergistically, on indoor air quality.

Promote the determination of indoor air quality standards and pollution-reduction strategies by furthering research in regard to variables that affect indoor pollution levels.

APPENDIX B
Warm Room Designs

DESIGN SUMMARY OF HOUSE WK-1

A detailed site survey was first performed at residence. Ideas for creating a warm zone were tabulated, and field measurements were taken for future usage. The most effective ideas were selected for detailed analysis. The analysis was broken into three categories: changes to the "shell" (exterior walls and roof), changes in zoning, and modifications to the heating system. The drawing included at the end of this report illustrates the floor plan and some of the proposed changes. Two areas were chosen for the "warm room" zone, the kitchen and dining room.

Proposed changes to the shell include:

- Insulation of the exterior walls of the warm room zone, by means of cellulose fill.

Proposed changes to zoning include:

- Addition of a door to separate the dining room from the entry way.
- Relocation of the thermostat to the core of the warm room zone and minimum flow elsewhere.

Heating system modifications include:

- Balancing of air flow to achieve maximum air flow into the warm room zone and minimum flow elsewhere.

It is important to note that unsafe wiring conditions were observed during the survey. The contractor had to exert great care not to disturb the marginal wiring.

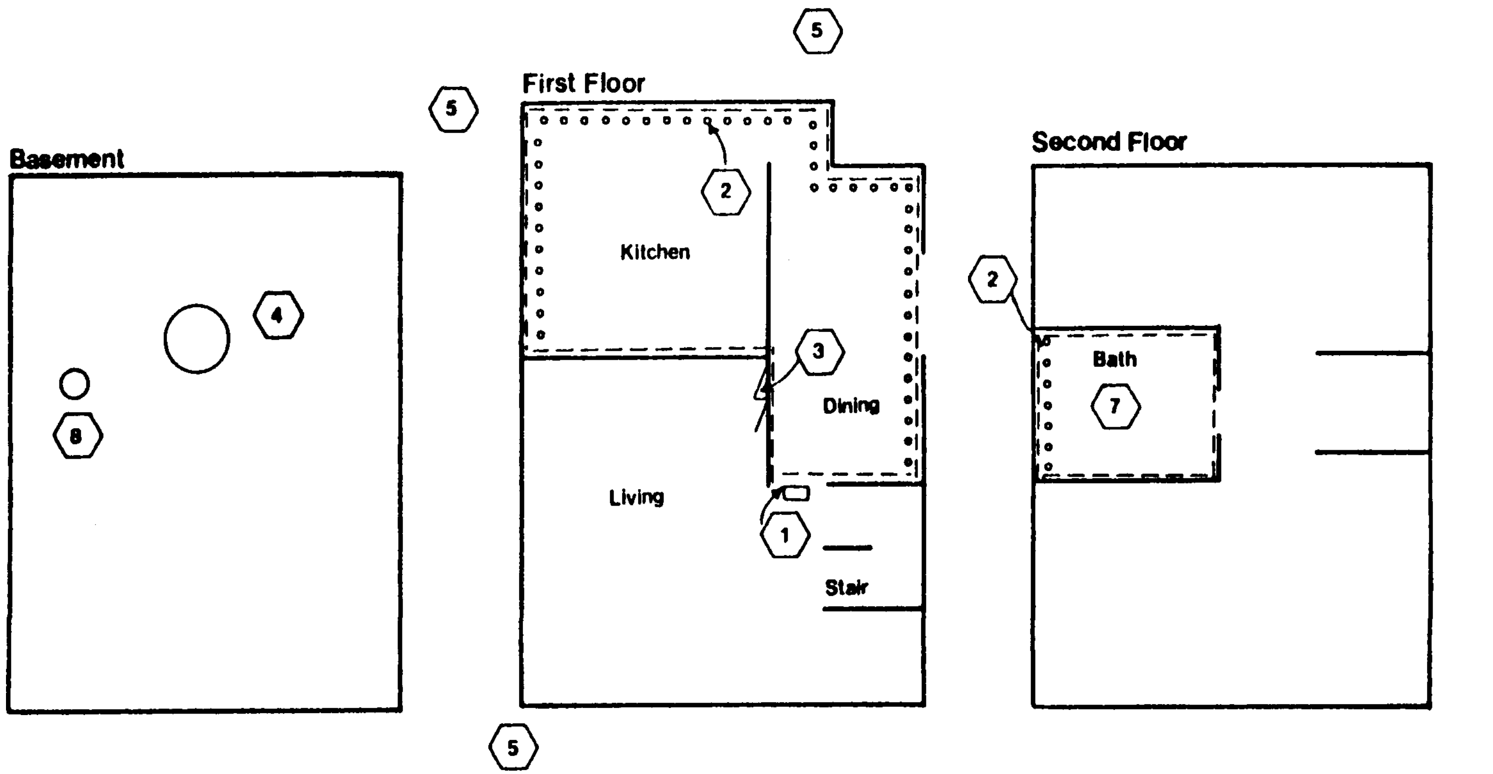
The following table presents construction cost estimates, annual cost savings, and are ranked by the most favorable payback.

Summary Table

		Install cost	Cost savings per year	Simple payback
1.	Zone for Warm Room	$325	$224	1½ years
	a. install door			
	b. relocate T-stat			
	c. adjust dampers			
2.	Insulate exterior walls	$558	$ 90	6 years

Warm Room Plan

WK-1



LEGEND

N ➔

- - - - - Boundry of Warm Room

• • • • • • Blown in Insulation

Warm Room Applications

1. Install hollow wooden door.
2. Insulate interior walls of warm room area to R-11.
3. Install drapes.
4. Clean and adjust furnace.
5. Install three storm windows.
6. Reduce air infiltration.
7. Install heat lamp.
8. Add heat tape to unconditioned water pipes to prevent freezing of pipes.

DESIGN SUMMARY OF HOUSE WK-3

Description

The WK-3 residence is a two-story house with a basement. Exterior walls are uninsulated and only a modest amount of insulation is in the attic. The first floor comprises a large area for entry, living and dining, and the kitchen. The large area cannot conveniently be broken up. There is no bathroom on the first level, this room being upstairs with the bedrooms.

The house is heated with a gravity natural gas furnace which probably operates at a seasonal efficiency of about 50%. The heating bill for the entire heating season is approximately $650.

Heat Loss Calculations

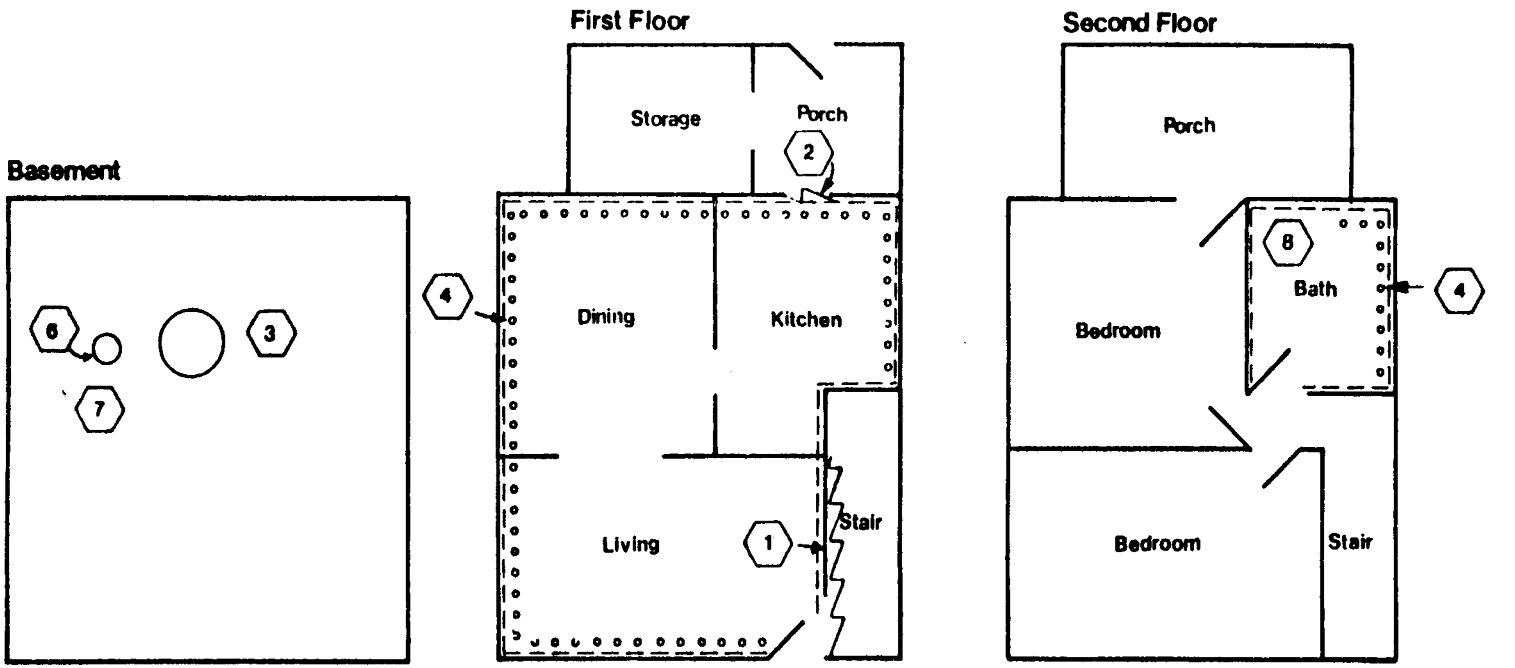
With existing conditions, the heat loss in the WK-3 residence is 1850 BTU/hr/deg f. We estimate that the operating cost for heating should be about $825 to $975 based on furnace efficiency of 50 to 60%. Assuming no error in the calculations, this suggests that some type of zoning is taking place now in the house. Whether this is consciously done by closing off unused bedrooms and the registers to them or simply occurs because of the distribution of heat and the arrangement of spaces in the house is not known.

The only practical 'warm room' approach in the residence to isolate the stairs and the bedrooms from the rest of the house. The upstairs bathroom and the kitchen must be conditioned, and the living room/ dining room would be used for daily activities and sleeping. If no action takes place other than physically isolating the 'warm room' area by means of drapes or other partitions and insulating the basement ductwork, then the heat loss would be reduced to 688 BTU/ hr/deg f, a reduction of 63%.

If, in addition to those measures, 1) the exterior walls of the 'warm room; which are also exterior walls of the house are insulated with blown-in insulation, 2) the floor below the bedrooms and the ceiling above the bathroom is blown with R-19 insulation, and 3) the air infiltration in the 'warm room' area is reduced by about a third, then the heat loss would be reduced to 462 BTU/hr/deg f, a reduction of 75%.

Further, if the exterior walls of the 'warm room' which are interior walls of the house are also insulated to R-13, the heat loss would be 429 BTU/hr/deg f. This represents a reduction of 77%.

Warm Room Plan



LEGEND

N➔

- - - - - Boundary of Warm Room

• • • • • • Blown In Insulation

Warm Room Applications

1. Install drapes.
2. Install hollow wooden door.
3. Clean and adjust furnace.
   Insulate duct work to R-6 for ducts to warm room area.
4. Insulate exterior walls of warm room area to minimum additional level of R-11.
5. Reduce air infiltration.
6. Insulate water heater to $-14
7. Add heat tape to unconditioned water pipes to prevent freezing of pipes.
8. Install heat lamp in bathroom.

DESIGN SUMMARY OF HOUSE WK-4

This report is a compilation of results of two design studies performed on warm room residence WK-4.

This residence is a two-story house with a basement. The first floor comprises an entry, living and dining rooms, kitchen, and a den which extends outside the basement foundation. There is no bathroom on the first floor; it is on the second floor with the bedrooms.

The home is heated with a gravity natural gas furnace, which both designers stated was oversized. Analysis of the 1982 gas bills for this house indicates that about $820 was spent for space heating without considering the electrical costs for distributing the heat. This indicates a heat flow of about 2460 BTU/hr.-Deg F. That is unrealistically high for the size of this house and would indicate mismanagement of energy usage and or equipment insufficiency. It is assumed that the heat flow of this house would be more in the area of 1600 BTU/hr.-Deg f, which is in agreement with the conductive loss as calculated by Lawrence Berkeley Lab.

Both designers agreed to the following retrofit recommendations:

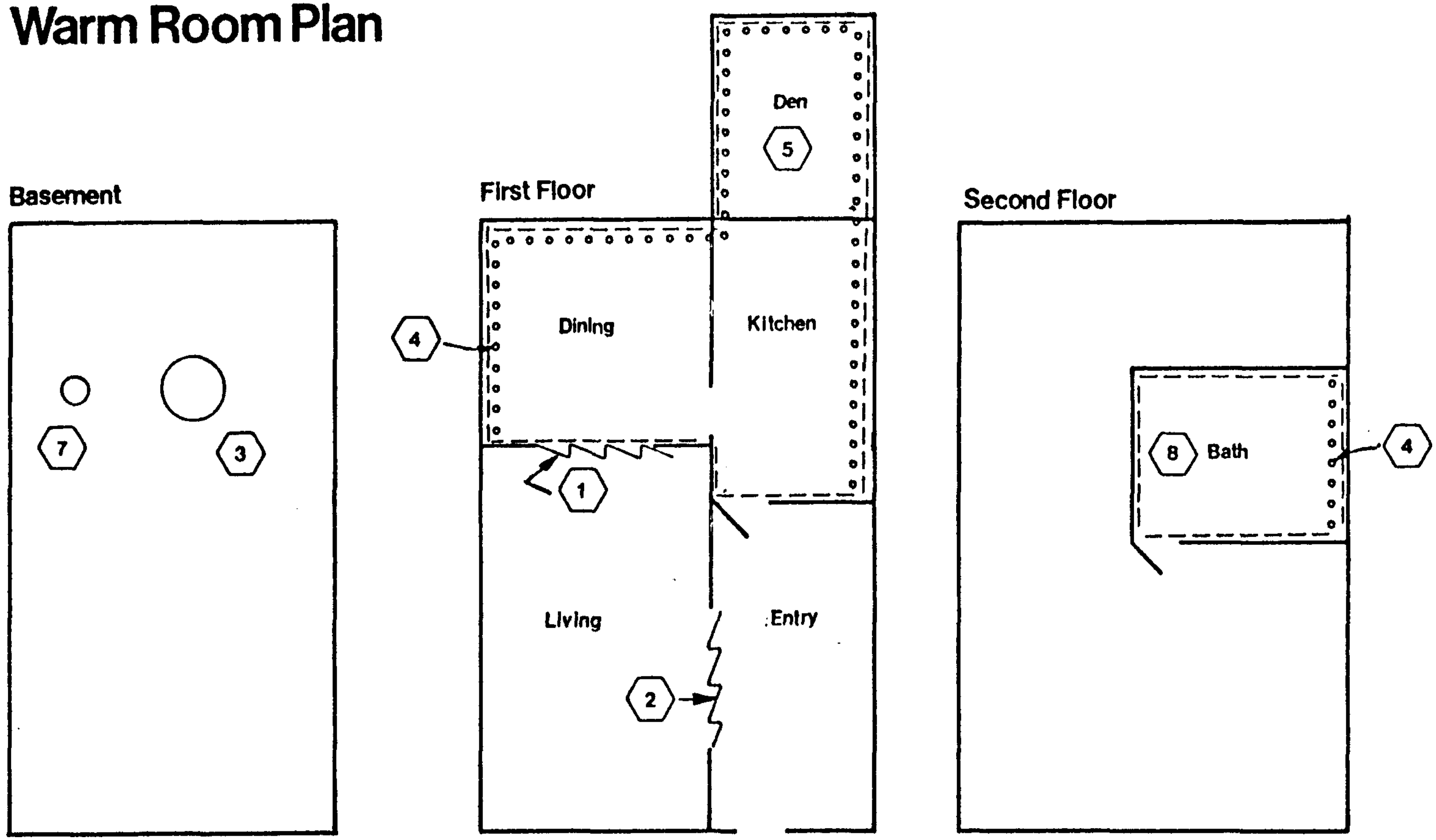
1. Modify furnace duct work.
2. Insulate furnace ducts.
3. Reduce air infiltration.
4. Insulate exterior ceiling and floor of den.
5. Insulate water heater and exposed water lines.

One of the designers recommended in addition to the above:

1. Install heavy drapes between living room and entry.
2. Install heat lamp in bathroom.

The following is a sketch of WK-4 which intergrates the design recommendations:

Warm Room Plan



LEGEND

N ➧

– – – – – Boundary of Warm Room

• • • • • • Blown In Insulation

<u>Warm Room Application</u>

1. Drapes.
2. Drapes (deleted).
3. Clean and adjust furnace.
4. Insulate exterior walls.
5. Insulate ceiling of den.
6. Reduce air infiltration.
7. Add heat tape to unconditioned water pipes.
8. Install heat lamp.

DESIGN SUMMARY OF HOUSE WK-5

This report summarizes a study performed on warm room residence WK-5.

The study began with a survey of the residence. Numerous ideas were selected for further study. The analysis was broken into three categories: changes to the "shell" (exterior walls and roof), system. The drawing included at the end of this report illustrates the floor plan, and will assist in the understanding of the proposed changes. Three areas were chosen for the "warm room" zones: the living room east, living room west, and the kitchen. Proposed changes to the shell included:

Addition of glass to one large single-glazed window on the east wall of the living room, east.

Addition of foam board insulation to the interior of all exterior walls of the warm room zone.

Sealing of sliding doorway that joins the living rooms east and west, to prevent air infiltration.

Proposed changes to zoning included:

Installation of curtains in the two doorways to reduce air flow (reference drawing).

Opening a doorway between the kitchen and living room west (doorway is currently sealed).

Relocation of the thermostat into the core of the warm room zone.

Heating system modifications included:

- Sealing of the existing return air ducts in the basement.
- Installation of dampers in all supply air ducts.
- Uncovering of return air registers in the warm room zone and a minimum flow elsewhere.
- Note that the bathroom will continue to be heated with existing furnance.

It is important to note that an unsafe condition was observed during the survey. The residents of the house are currently using a gas burner to provide warmth in the living room east. This burner is unvented, delivering products of combustion into the living area. It is imperative that this burner be removed when the changes are made.

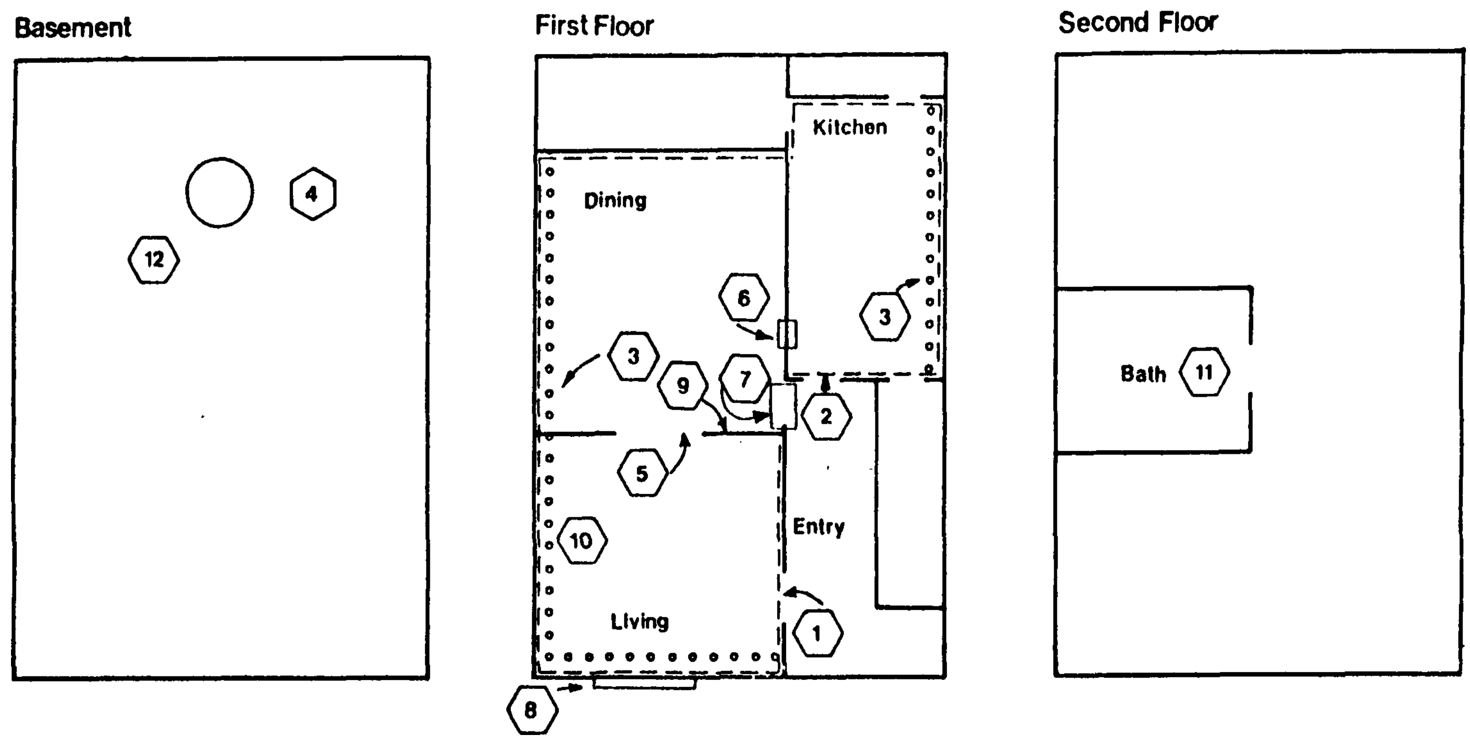
The following table presents estimates on construction cost, annual cost savings, and simple payback:

Summary Table

	installed cost	annual cost savings	Simple payback
1. Improve ducting and zoning	$439	$131	3.3 years
2. Add glass	$ 95	$ 22	4 years
3. Insulate walls	$882	$152	5.7 years
4. Seal doorway	$ 25	note 1	--

Note 1 = impossible to quantify

Warm Room Plan



LEGEND

N➔

— — — — — Boundary of Warm Room

∘ ∘ ∘ ∘ ∘ ∘ ∘ Add Insulation

<u>Warm Room Applications</u>

1. Install drapes.
2. Install hollow wooden door.
3. Insulate exterior walls. (Dropped)
4. Clean and adjust furnance. Insulate duct work.
5. Seal upper and northern seam of sliding doorway.
6. Remove existing sheetrock within door frame between dinning room and kitchen.
7. Seal existing door to prevent air infiltration.
8. Install storm window in living room.
9. Relocate thermostat to east wall of dinng room.
10. Remove gas supply line from in front of fire-place to basement and cap.
11. Install heat lamp in bathroom.
12. Add heat tape to unconditioned water pipes.
13. Reduce air infiltration.

DESIGN SUMMARY OF HOUSE WK-6

The WK-6 residence is a two-story house with a basement and a finished attic. Exterior walls and attic are uninsulated. The first floor contains an entry, living and dining rooms, and the kitchen. The living and dining area is basically one space and cannot be conveniently broken up. There is no bathroom on the first level, this room being upstairs with the bedrooms.

The house is heated with a gravity natural gas furnace which probably operates at a seasonal efficiency of about 50%. The heating bill for the entire heating season is approximately $500.

Heat Loss Calculations

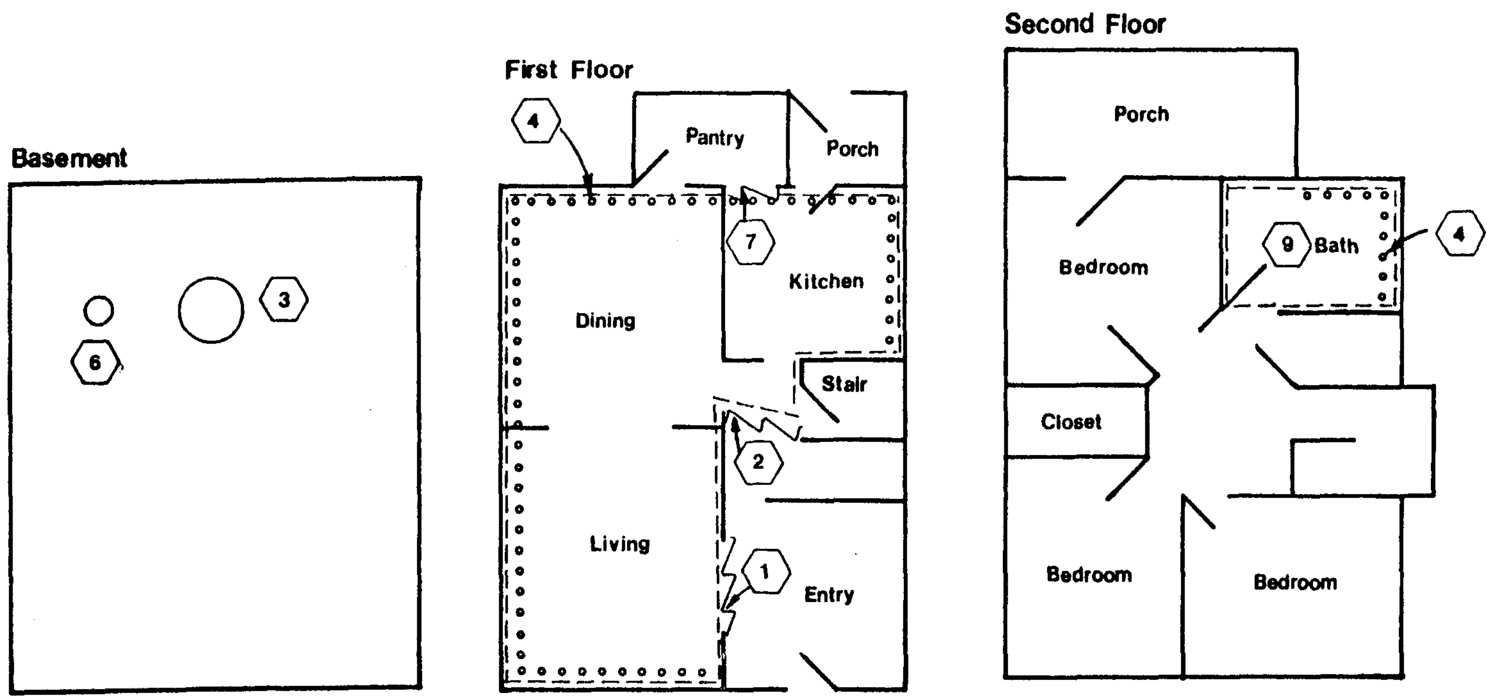
With existing conditions, the heat loss in the WK-6 residence is 1482 BTU/hr/deg F. We estimate that the operating cost for heating should be about $725 to $875 based on furnace efficiency of 50 to 60%. Assuming no error in the calculations, this suggests that some type of zoning is taking place now in the house. Whether this is consciously done by closing off unused bedrooms and the registers to them or simply occurs because of the distribution of heat and the arrangement of spaces in the house is not known.

Based on the homeowner's wishes and the existing floor plan, the recommended 'warm room' approach in this residence is to isolate the entry, stairs and the bedrooms from the rest of the house. The upstairs bathroom and the kitchen must be used for daily activities and sleeping. If no other action takes place other than physically isolating the 'warm room' area by means of drapes or other partitions and insulating the basement ductwork, then the heat loss would be reduced to 648 BTu/hr/deg F, a reduction of 56%.

If, in addition to those measures, 1) the exterior walls of the 'warm room' which are also exterior walls of the house are insulated with blown-in insulation, 2) the floor below the bedrooms (except over the entry) and the ceiling above the bathroom is blown with R-19 insulation, and 3) the air infiltration in the 'warm room' area is reduced by a third, then the heat loss would be reduced to 462 Btu/hr/deg F, a reduction of 70%.

Further, if the exterior of the 'warm room' which are interior walls of the house are also insulated to R-13, the heat loss would be 401 Btu/hr/deg F. This represents a reduction of 73%.

Warm Room Plan



LEGEND

N➔

- - - - - Boundary of Warm Room

∘ ∘ ∘ ∘ ∘ ∘ Add Insulation

Warm Room Applications

1. Install drapes between living room and entry.
2. Install drapes between stairs and entry.
3. Clean and adjust furnace.
4. Insulate exterior walls of warm room area.
5. Reduce air infiltration.
6. Insulate water heater.
7. Install door between kitchen and pantry.
9. Install heat lamp in bathroom.

APPENDIX C

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

Barbara Shohl Wagner and Richard C. Diamond
Lawrence Berkeley Laboratory

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.

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

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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 Occu- pants	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 Fire- place Exist /Used	Ap- pliances (ex stove)	Air Condi- tion- ers
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 prêvious 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.

$$SPT = (\text{retrofit cost})/(\text{savings per year})$$

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.

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

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.

$$ROI = \text{annual savings/retrofit cost}$$

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.

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