ENERGY CONSERVATION IN RESIDENTIAL HOUSING

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INTRODUCTION

The energy crisis has been discussed extensively in journals and newspapers, as well as on radio and television. Very simply, the crisis arises because of particular patterns of energy use developed by our societal and industrial system. Energy resources were always available and the costs were within the limits of our economic structure. However, as natural resources are depleted, the oil and gas companies are turning to less accessible and more expensive sources. Consequently, the existing pattern of energy usage must be disrupted if we are to use our energy sources in a sensible manner. This philosophy must carry over into our technology and the engineer and designer must realize that innovation can not be made at the expense of energy conservation. Serious considerations must be given to the levels of energy consumed during, or as the result of, a particular technological process. This is particularly true in the building and construction industry, where a philosophy of "building to save energy" (1) must be adopted.

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*Numbers in parenthesis correspond to references listed at the end of the paper.

The utilization of solar energy for residential and commercial comfort and hot water heating can significantly alleviate the problems associated with fuel shortage and high costs which affect the low-income population most severely. Solar domester water heating has been implemented on a large scale in many countries, including the U.S., Australia, Israel, Japan and the USSR. Whenever such heating did not attain major levels of acceptance, it was due to very low fuel costs in the past. Whereas solar comfort heating was confined to a relatively small number of buildings till just about two or three years ago (2) (3) (4) (5) (6) (7) (8) (9), a very rapidly increasing number of solar heated residences, schools and office buildings buildings has been built, is under construction, or is being planned. It should be noted that such buildings are spread out throughout the U.S., and are not confined to the sunnier states. The increase coincides with the significantly amplified effort on the State and Federal levels to accelerate the implementation of solar energy. The authors of this paper have been intensively involved in this effort. Some of the major projects completed in the recent years include:

1. NSF-RANN Grant GI 27976 entitled "Conservation and Better Utilization of Resources by Means of Thermal Energy Storage and Solar Heating" under which the University has worked since February 1971.
2. The University of Pennsylvania and General Electric Company were selected as one of three national Industry-University teams for the Phase 0 study (NSF Contract No. C855), of a proof-of-concept experiment on solar heating and cooling.
3. Also with G.E., the University of Pennsylvania conducted research

on U.S. Army contract DACA-23-74-C-0006 for the retrofitting of an existing building for solar heating and the equipping of a new building with solar heating and cooling.

The major conclusions from these studies (10) and supported by others (11) indicate that a Northeastern U.S. single family residence can reduce its heating fuel consumption by somewhat in excess of 50% when utilizing about 500 ft^2 of solar collector area. This area is compatible with the size of the residence, and was computed on actual weather data in Washington, D.C. and Wilmington, Delaware.

Most of the studies performed to date considered the construction of new solar heated housing, without in-depth attention to the retrofit problem. While retrofit is usually more costly than a new system which was specifically designed for this purpose, the proper combination of modern technology for housing, modern materials, and sound engineering design would result in retrofit systems which would be economically viable in view of the increasing costs of fuel.

PROBLEM DEFINITION AND SOLUTION

Research Description

The research described in this paper is divided into two distinct, but interrelated tasks. The first task is the investigation and evaluation of several energy conservation schemes in the design and fabrication of residential buildings. These investigations include the determination of the total energy requirements of several construction methods suitable for rehabilitation of existing structures as well as new construction. The major intent of this task is to develop criteria and decision making guidelines reflecting the levels of energy conservation and building costs of the various of prefabrication. Because of the magnitude and complexities involved in attempting solutions to housing and energy problems, the approach was to divide the studies into two specific tasks. The tasks are defined such that the necessary technology and information is developed so that an energy conservation philosophy can be established on sound engineering principles. Accomplishment of the two tasks described below provide the necessary information for developing energy saving schemes and techniques in the building and construction industry. At this particular point in time, the tasks have recently been initiated. However, a preliminary investigation of two types of building construction has been performed. A modular house manufactured in the State of Pennsylvania was investigated and a cost analysis and energy consumption estimate was performed and compared with cost and energy consumed from "on-site" construction techniques. This investigation revealed that adopting the modular concept in the construction of a typical residential house resulted in a cost that was approximately 22% more than the cost of "on-site" construction techniques. However, more significantly, the utilization of the modular concept resulted in an energy conservation of approximately 75%.

However, the studies performed to date have been concerned only with new construction, without specific attention given to the housing rehabilitation problem. These investigations must also be made if our society is to attempt solutions to the vast problems in urban housing and energy resources. We must apply the proper combinations of modern technology to utilize contemporary materials and engineering design in the development of viable urban rehabilitation schemes, both from a financial and energy resources basis.

The major intent of the second task was to produce practical technical and economical guidelines for retrofitting existing buildings to utilize solar energy for comfort heating and domestic hot water. These guidelines are based on a general study of facilities and associated problems of retrofitting a typical Philadelphia row house. This row house is used not only for the retrofitting of the solar energy equipment, but also to experiment and demonstrate rehabilitation schemes developed.

The building used in this proposed demonstration of Solar Energy Systems for Residential Heating and Hot Water Heating Project is an existing structure located in a typical urban area. The amount of retrofitting done on the building to accomodate the proposed solar heating system is a minimum, consistent with existing building codes and good engineering practice. A detailed description of the building is provided in the following paragraphs. It is intended that one of the results of this demonstration is to provide substantiated data concerning overall costs of retrofitting and solar equipment installation that can be used as a guide for home owners who are interested in heating their homes with solar systems. Consequently, the cost information obtained in this demonstration project reflect the minimum costs that can be expected to be incurred by urban homeowners who convert solar systems for heating and domestic hot water supply.

TASK 1: Energy Conservation in Building Systems

Objective

The overall objective of this task is to investigate and evaluate several energy conservation schemes in the design and fabrication of residential buildings. The types of buildings considered in this paper include single family dwellings and multiple family dwellings. The investigations of the energy conservation schemes include an evaluation of the total energy requirements of several construction methods suitable for new construction (12) (13) (from design to fabrication), and rehabilitation of existing housing. The Department of Civil and Urban Engineering has been given the use of a University campus row house which will function as a base of operations for interdepartmental housing and community studies, as well as providing facilities for conducting any special engineering experiments. In particular, the house is used for experiments involving energy saving building techniques applied to rehabilitated structures (14).

Method of Research and Anticipated Results

This task investigates, compares, and catalogs variations in the levels of energy consumption in the various techniques of fabrication of residential buildings, considering new building construction as well as rehabilitated structures. A thorough literature search was made to extract all available information concerning building costs and energy consumption data for the various techniques and various levels of prefabrication. At the time of preparation of this paper, the authors have not completed their investigations; therefore, specific results can not be presented. It is anticipated that the results of these studies will be finalized during the next three months. Consequently, the following discussion, at this time, pertains to anticipated results.

The results of this task will be tables, and/or curves that present the levels of energy conservation achieved as a function of the percent of prefabrication used. The range of prefabrication considered vary from total prefabricated construction to total on-site construction. Intermediate levels are also investigated in order to develop good energy consumption characteristics. Also included in these tables and curves is information concerning the total and itemized building costs between the various techniques and the various levels of prefabrication.

The study will delineate and describe the characteristics of the different construction systems. In particular, the following construction methods are considered: (1) on-site; (2) varying degrees of component prefabrication units, that is, factory fabrication of sub-assemblies which are then erected at the building site, (e.g., floor units, wall units, partition units, sanitary units, heating and air conditioning units); (3) industrialized, factory fabrication of large units which require a minimum of on-site erection; (4) mobile homes. The methodology used in achieving the goals of this task is:
(1) critical examination of all of the present building techniques described above and develop respective cost figures, in terms of labor costs and material costs (considering material utilization and waste minimization characteristics of each technique); (2) determination of the amounts of total energy and material and labor resources consumed by the building techniques. The research accomplished in this task determines the complete spectrum of energy requirements and energy consumption for the various forms of construction systems considered. The total costs of each construction method are estimated as accurately as possible using information and techniques provided by the Department of Housing and Urban Development, builders, contractors, factories located throughout the country. Recommendations regarding which construction tech-

niques should be considered for short range and long range planning purposes to assist the nation in husbanding its energy resources are presented. The information required for these tables and curves will be obtained from the questionnaire shown in Figure 1.0 of this paper. This questionnaire was sent to approx. 200 residential builders in the state of Pennsylvania. Information requested by this document concentrated on "On-Site Residential Buildings", and was divided into two basic categories of information: Construction Costs; and Energy Consumption. The information contained in the questionnaire includes the following:

1. Type of dwelling: this item categorizes the costs and energy consumption according to the type, size and selling price of the building;

2. On-Site Labor and Materials: this item provides information to determine labor and material costs in the construction of the building, according to the various phases of construction (i.e., carpentry, masonry, plumbing, landscaping, etc.).

3. Prefabricated and Pre-assembled Components: this item provides information concerning the cost and quantity used of preassembled components, such as roof trusses, floor system, walls, etc.

In order to determine the energy consumption characteristics of the building industry, the questionnaire contains another set of questions which lead to the determination of the energy consumed during the construction process. The information contained in this phase include the following:

4. Transportation of Materials to Site: this item categorizes

the distance of transport, mode and cost of transport for all of these different materials and components comprising the building. Information concerning prefabricated and pre-assembled components are also included.

5. Transportation of Construction Equipment: this item provides information on the average distance and mode of transportation, as well as cost and fuel consumed during transport.

6. Energy Consumed at Site: the remaining items provide information concerning the quantities of fuel and energy consumed on the building site by the construction equipment, as well as energy and fuel consumed during the construction process.

Similar questionnaires are developed and are being sent to producers of factory built homes and mobile homes. The final results will include tables and curves of energy conservation as a function of prefabrication level; total and itemized building costs for new and existing structures and criteria for selecting particular types of construction and material, for new construction as well as rehabilitated structures (as a function of physical state of existing structures).

TASK 2: Solar Energy Retrofit System for Residential Heating and Hot Water System

Objectives:

In order to demonstrate the practicality and feasibility of using solar energy for one major type of residential building, the row house, the objectives of this work are:

A. to produce technical and economical guidelines for retrofitting existing row houses; to utilize solar energy for the cost effectiveness of retrofitting a row house with a variety of occupants.

B. to obtain and analyze data over an extended period for determining the cost effectiveness of retrofitting a row house with a variety of occupants.

The residential building used for demonstration is located in the City of Philadelphia, adjacent to the University of Pennsylvania campus. The building is situated on the south side of Spruce Street (3920 Spruce Stree) and is a conventional three story row house with a full basement. The building is abutted on both the east and west walls by similar row house buildings. Figure 2.0 below shows the general plot plan of 3920 Spruce Street, indicating vegetation, predominate wind direction and design intensity, neighboring buildings and access.

The structural modification to the 3920 Spruce Street building is minimum. The major modification will consist of providing adequate structural support of the solar collectors to the roofing system and bearing walls of the structure.
Figure 3.0 shows the installation of the solar panels on the roof of the building and indicates the impact on the exterior appearance of the project on the surrounding environment.

Implementation of Solar Retrofit

The solar retrofit is based on low cost, system simplicity and good maintainability. These are achieved by implementing the following design principles:

A. Optimal utilization of existing heating equipment.

B. Utilization of copper absorbers in the solar collectors, and copper piping, to avoid both the corrosion problems and the maintenance problems associated with corrosion inhibition.

C. Freeze protection by automatic drainage to avoid maintenance and corrosion problems associated with the utilization of an anti-freeze solution in the collector flow loop.

Schematic and Description of Solar System for Retrofit

The flow and control diagram is shown in Figure 4.0. The comfort heating system consists of three loops:

A. The Solar Energy Collector Loop

When the temperature of the solar collector, T_c, is higher than the temperature measured in the middle-height of the thermal storage tank, T_{sm}, the controller TCI turns on the collector pump PI which circulates water from the bottom of the storage tank to the solar collectors where the water is heated, and returns it to the top of the storage tank. Protection against freezing is provided by a system which automatically drains the collectors into the storage tank. Activated when the collector absorber plate temperature drops below 45^{o}F, the pump PI is stopped and water from the collectors is drained into the thermal storage tank by gravity. Proper automatic venting of the collectors and the tank, as well as proper monotonical downwards-grading of the piping assures reliable drainage, and later refill when the solar energy collection loop is restarted. Based on an initial analysis, the only system protection implemented against high temperature are the automatic vents and safety valves which would not allow temperature build-up above 212^{o}F, by venting any steam, and allowing automatic refill of the storage tank by cold domestic water, controlled by a float-valve.

B. The Heat Demand Loop

When the room temperature T_r drops below the preset thermostat value T_{th}, and if the temperature of the water at the top of the storage tank T_{st} is larger than (T_r x 10^0F) demand pump P2 is started to circulate water through the water-to-air heating coil in the warm air duct. The warm air fan is started at the same time and the air in the duct is thus warmed. Further, if $T_{st} < T_{th} + 10^0$F the auxiliary furnace is turned on too. In this way, the hot water heated by solar energy is utilized to at least preheat the air, when its temperature is not sufficiently high to bring Tr to the value T_{th}. Lower temperature air preheat does indeed require some function of the auxiliary furnace, but allows a more efficient operation of the overall solar energy system.

The heat demand loop is inoperative when $T_{st} < T_r + 10^0$F, and the heating is entirely provided by the auxiliary furnace. If $T_r < T_{th}$, neither the best demand loop nor the auxiliary furnace are operative.

C. Thermal Storage Tanks

Two welded, mild steel tanks, with a capacity (full) of 800 gallons each serve as containers for the thermal storage medium (hot water). The tanks are primed and painted for resistance against corrosion. Since the tanks operate vented to the atmosphere, they are designed and built to withstand the hydrostatic head only, at the maximum temperature of 212^0F. The tanks are thermally insulated by at least 4 in. thick fiber glass (or similar) insulation.

Instrumentation and Data Acquisition

It is proposed to measure temperatures and flow rates at points which allow the determination of needed heat balances. In addition to the measurement of temperatures, temperature differences are measured directly by thermopiles or differential resistance thermometers to achieve the needed accuracy of measurement. Consumption of fuels and electrical power, as well as the actual operating periods of various equipment (pumps, fans, etc.), will be measured and recorded, to provide a detailed energy-flow picture.

CONCLUSIONS AND RECOMMENDATIONS

In addition to the more direct energy conservation benefits associated with these investigations, the research provides a sound basis for initiating legislation and policies. These could be in the form of tax incentives and changes in regulatory codes, which will aid existing industries, as well as attract new industries. In addition, these results can be used to develop and formulate criteria, tables and comparison curves, in terms of energy conserved and consumed, labor and material costs of construction techniques and new materials. However, most importantly, the results provide a sound technological base for continuing research into broader aspects of the housing and energy problems.

The solar retrofit demonstration, partially funded at present by the Pennsylvania Science and Engineering Foundation, and the University of Pennsylvania, with participation from the International Environment Corporation, is an integral part of the extensive effort by the directors of this paper and by the University of Pennsylvania in the areas of urban housing and rehabilitation and in solar energy research, development and application for heating and cooling of buildings. It draws on the University's experience in these areas, on the existing in-house solar test facilities and most advanced computer programs for design and analysis. These include both programs designed at the University of Pennsylvania and those maintained by it which were acquired elsewhere, such as the National Bureau of Standards heat load program NBSLD, and the solar program TRNSYS.

A general objective of the University of Pennsylvania program is to tie solar retrofit together with urban rehabilitation in part to reduce the rapidly increasing fuel costs which the lower-income urban dweller is facing. The row house constitutes about 60% of the residential housing in some of the larger eastern cities in the U.S. (such as Philadelphia) and the selection of this type of building for retrofit is thus naturally relevant and significant. Integrally related to this project is low cost of retrofit, minimal maintenance, maximal reliability and simple design which allows a fair amount of construction and assembly by the homeowner himself.

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UNIVERSITY OF PENNSYLVANIA

DEPARTMENT OF CIVIL AND URBAN ENGINEERING

ENERGY CONSERVATION IN THE BUILDING INDUSTRY

ON-SITE RESIDENTIAL BUILDING

PART A: CONSTRUCTION COSTS

1.0 Type of dwelling

The data provided in this questionnaire pertains to the following types of dwelling (check one):

Single family detached		Semi-attached		Apartment buildings		Other	
Bi-level	____	Bi-level	____	Low-rise (1-5 stories)	____	Duplex	____
Colonial	____	Colonial	____	Med.rise (6-10 ")	____	Rowhouse	____
Ranch	____	Ranch	____	Highrise (over 10 ")	____	Townhouse	____
Split-level	____	Split-level	____	Garden Apartments	____		

Number of stories ____ Number of family units/dwellings ____

Size (sq. ft.)

Living area ____ Attic ____ Basement ____ Garage ____
Total ____

Selling price $ ________

Living area (including basement) $ ________ Garage $ ________

Land $ ________ Landscaping $ ________

Approximate number of dwellings of this type built per year ________

Since records may not be available, please provide "best estimates" to the following questions:

1. Average number of man-days to prepare site ____
2. Average number of man-days to construct dwelling ____
3. Average wage per man-day to prepare site ____
4. Average wage per man-day to construct dwelling ____
5. Average number of workers per dwelling ____
6. Average distance workers travel between home and construction site ____

2.0 On-Site Labor and Materials - Please provide answer with units shown in parenthesis. If other units used, please indicate.

		Material Cost Unit Cost of Material (e.g. $/sq.ft.)	Total Quantity of Material Used	Wage per Unit Time	Total Time
2.1	Carpentry (sq.ft.)				
2.2	Concrete (cu.yd.)				
2.3	Conveying systems, e.g. elevators (per unit)				
2.4	Doors (per unit)				
2.5	Electrical system				
2.6	Finishes (sq.ft.)				
2.7	Flooring (sq.ft.)				
2.8	Glass (sq.ft.)				
2.9	Heating and cooling systems				
2.10	Insulation (cu.ft.)				
2.11	Landscaping (sq.yd.)				
2.12	Lumber (bd.ft.)				
2.13	Masonry (sq.ft.)				
2.14	Steel (lbs.)				
2.15	Aluminum (lbs.)				
2.16	Other metals (lbs)				
2.17	Plastics (sq.ft.)				
2.18	Plumbing				
2.19	Pre-cast concrete (cu.yd.)				
2.20	Roofing (sq.ft.)				
2.21	Sitework (sq.yd.)				
2.22	Temporary utilities at site				
2.23	Wall covering (sq.ft.)				
2.24	Waterproofing (sq.ft.)				
2.25	Windows (per unit)				
2.26	Miscellaneous				

3.0 Prefabricated and Pre-assembled Components - Information under this heading is to be on a per dwelling basis.

		Cost per sub-assembly or component	Quantity Used
3.1	Mechanical core. (e.g. factory assembled components which may contain the kitchen, one or more bathrooms, a utility room, and all wiring, plumbing, heating and cooling ducts that are factory installed)		
3.2	Pre-assembled components (e.g. roof truss)		
3.3	Prefabricated floor		
3.4	Prefabricated panels (e.g. floor, roof, wall)		
3.5	Prefabricated roof		
3.6	Prefabricated wall		
3.7	Other (specify)		

Figure 1.0 - Building Cost and Energy Consumption Questionnaire

4.0 Summary

4.1 Total material cost $ ______

4.2 Total labor cost for site preparation $ ______

4.3 Total labor cost for construction of dwelling $ ______

4.4 Total construction cost $ ______

Part 5: Energy Consumption

5.0 Transportation of Materials to Site

5.1 On-Site Labor and Materials

		Source*	Avg. Distance of Transport (miles)	Mode of Transport (see List 1)**	Total Cost of Transport ($)	Energy Consumed (e.g. gals.)
5.1.1	Concrete					
5.1.2	Conveying systems					
5.1.3	Doors					
5.1.4	Electrical system					
5.1.5	Finishes					
5.1.6	Flooring					
5.1.7	Glass					
5.1.8	Heating and cooling systems					
5.1.9	Insulation					
5.1.10	Landscaping					
5.1.11	Lumber					
5.1.12	Masonry					
5.1.13	Metals					
5.1.14	Plastics					
5.1.15	Plumbing					
5.1.16	Pre-cast concrete					
5.1.17	Roofing					
5.1.18	Site work					
5.1.19	Temporary utilities at site					
5.1.20	Wall covering					
5.1.21	Waterproofing					
5.1.22	Windows					
5.1.23	Miscellaneous					

5.2 Prefabricated and Pre-assembled Components

		Source*	Avg. Distance of Transport (miles)	Mode of Transport (see List 1)**	Total Cost of Transport	Energy Consumed (e.g. gals.
5.2.1	Mechanical core					
5.2.2	Pre-assembled components					
5.2.3	Prefabricated floors					
5.2.4	Prefab. panels					
5.2.5	Prefab. roof					
5.2.6	Prefab. walls					
5.2.7	Other					

6.0 Transportation of Construction Equipment to Site

6.1 Average distance of transport (miles) ______

6.2 Check mode of transport

air ____ rail ____ truck ____ water ____ other ____

6.3 Total cost of transport $ ______

6.4 Fuel consumed (e.g. gallons) ______

7.0 Energy Consumed by Construction Equipment at Site

7.1 Total quantity of fuel and energy consumed:

electric (kwhr) ______ gasoline (gals.) ______ gas (cu.ft.) ______

oil (gals.) ______ other ______

7.2 Total Fuel and energy costs:

electric $ ______ gasoline $ ______ oil $ ______ other $ ______

8.0 Energy Consumed during On-Site Construction

		Energy Type (see List 2)***	Quantity of Energy and Fuel Consumed (e.g. kwhr., gals.)	Total Energy Cost
8.1	Heating			
8.2	Lighting			
8.3	Power			
8.4	Other ______			

* Indicate source of materials, e.g. lumber yard, factory, steel mill, own warehouse

** List 1: a) air b) rail c) truck d) water e) other (specify)

*** List 2: a) electric b) gas c) oil d) other (specify)

9.0 Additional Comments and Information

9.1 Would you be willing to fill out a more detailed questionnaire? yes ___ no ___

9.2 Do you wish a copy of the final report? yes ___ no ___

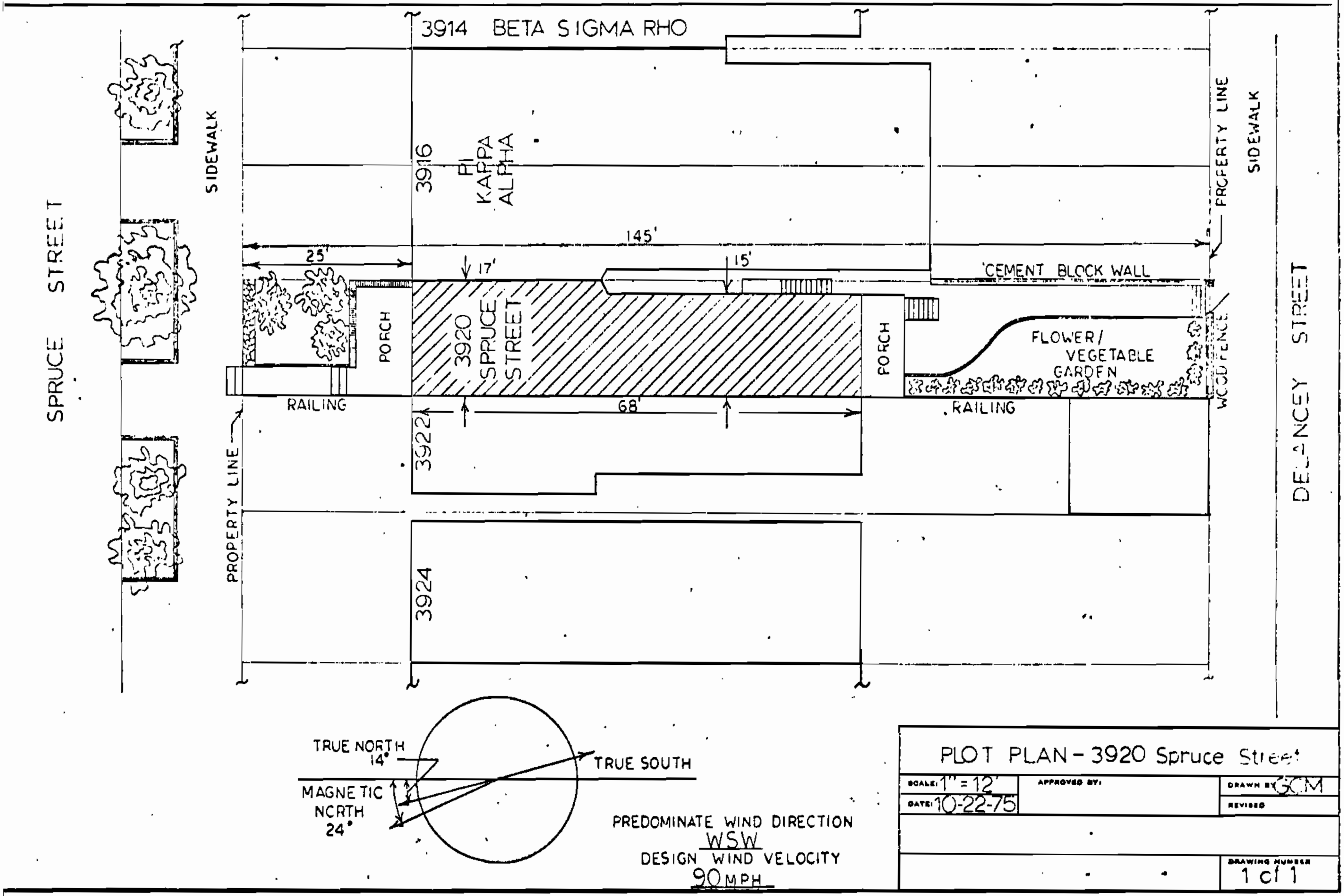
9.3 Please use space provided below for additional comments.

University of Pennsylvania
Philadelphia, Pa.

November 1975

Figure 1.0 (continued) Building Cost and Energy Consumption Questionnaire

Figure 2.0 - Plot Plan of Solar Retrofitted House



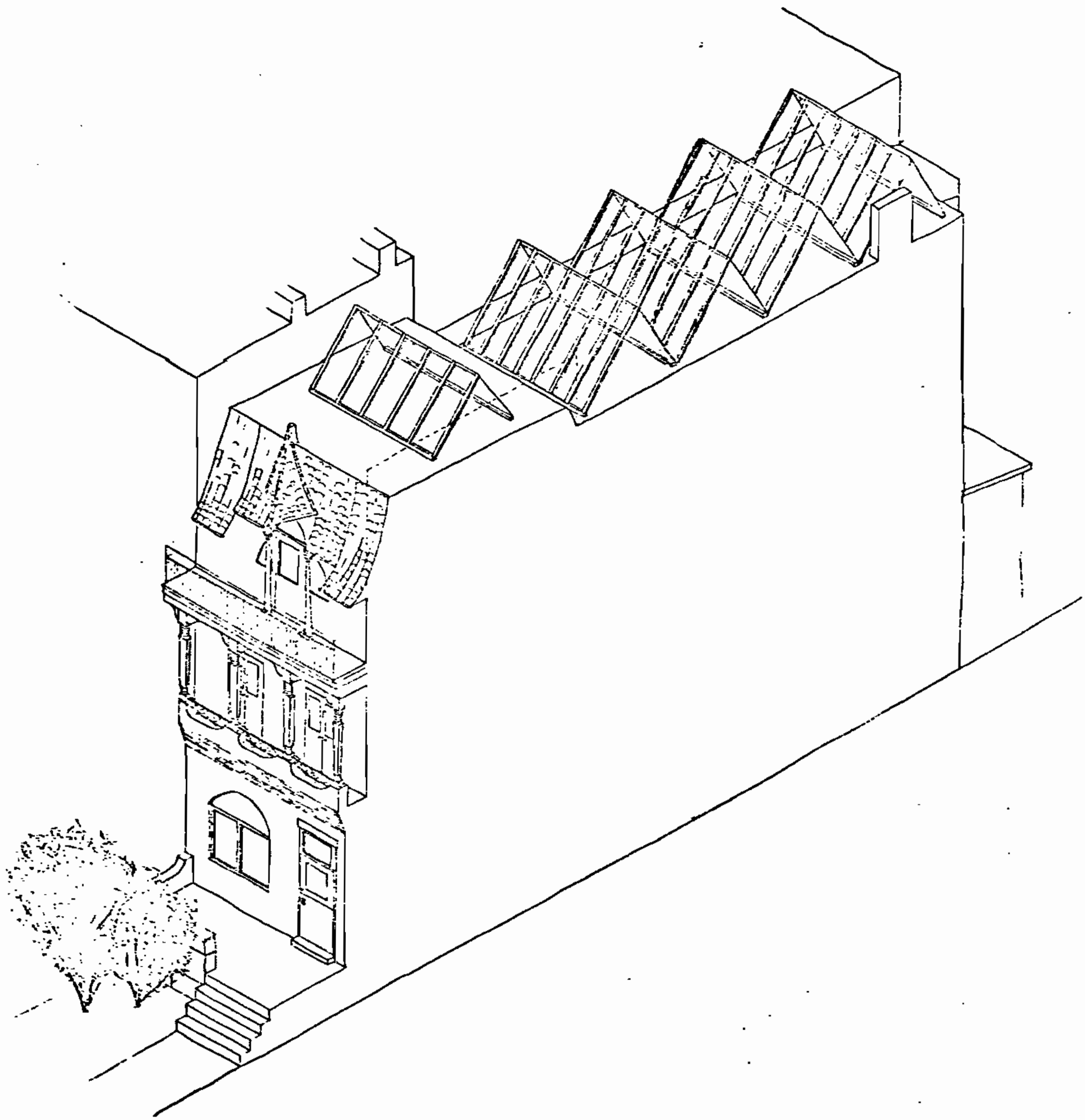
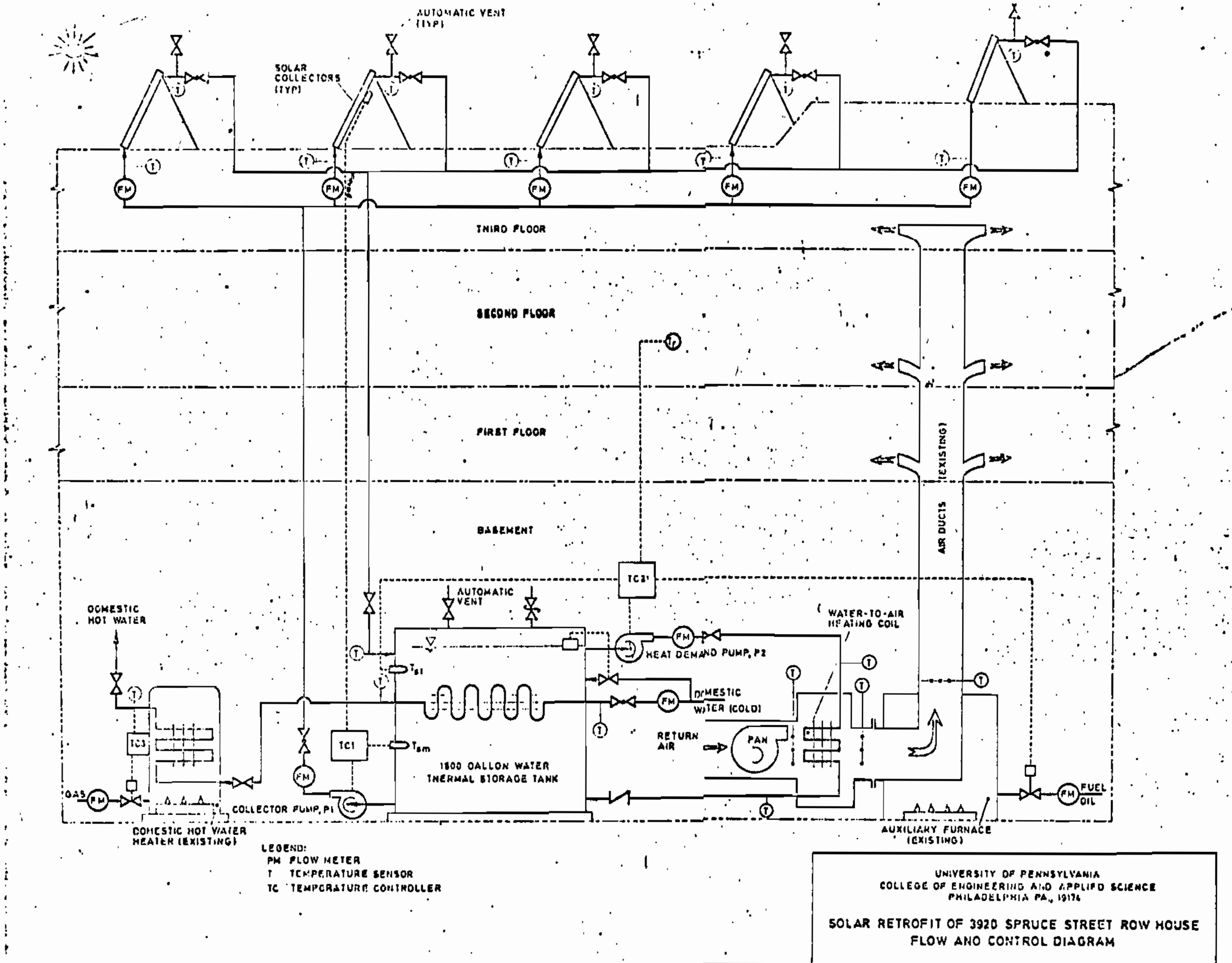


Figure 3.0 - Isometric View of Solar Retrofitted Hot e


AUTOMATIC VENT (TYP)
SOLAR COLLECTORS (TYP)
THIRD FLOOR
SECOND FLOOR
FIRST FLOOR
BASEMENT
AIR DUCTS (EXISTING)
TC2
AUTOMATIC VENT
DOMESTIC HOT WATER
WATER-TO-AIR HEATING COIL
HEAT DEMAND PUMP, P2
DOMESTIC WATER (COLD)
TC3
TC1
1500 GALLON WATER THERMAL STORAGE TANK
RETURN AIR
FAN
GAS
COLLECTOR PUMP, P1
FUEL OIL
DOMESTIC HOT WATER HEATER (EXISTING)
AUXILIARY FURNACE (EXISTING)
LEGEND:
FM FLOW METER
T TEMPERATURE SENSOR
TC TEMPERATURE CONTROLLER
UNIVERSITY OF PENNSYLVANIA
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PHILADELPHIA PA., 19174
SOLAR RETROFIT OF 3920 SPRUCE STREET ROW HOUSE
FLOW AND CONTROL DIAGRAM

Fig. 4.0