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An Economic Evaluation of End-User Conservation Measures Applied to Buildings Served by a Proposed District Heating System

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ABSTRACT

This study examines the economic implications of applying end-user conservation measures to buildings that are served by a proposed district heating system in the Minneapolis-St. Paul area. End-user conservation is a demand-side conservation strategy typified by changes in building operating procedures and changes in the building shell. District heating with cogeneration is a supply-side conservation method that allows scarce fossil fuels to be more efficiently converted into thermal and electrical energy. Technically, these two conservation methods can be applied simultaneously to a densely populated urban area such as Minneapolis-St. Paul, but the implementation of one tends to reduce the economic feasibility of the other. This analysis suggests that building conservation measures will be difficult to justify economically in buildings that are connected to the proposed Minneapolis-St. Paul system.

CHAPTER I

AN ECONOMIC EVALUATION OF END-USER CONSERVATION MEASURES APPLIED TO BUILDINGS SERVED BY A PROPOSED DISTRICT HEATING SYSTEM

Executive Overview

Rapid escalation of fuel prices and threatened national security because of extensive dependency on foreign oil make the conservation of energy important in every sector of the economy. One area with significant potential for energy conservation is space and water heating in buildings, which are responsible for about 20% of the total U.S. energy demand. Approximately 90% of this energy is supplied by oil and natural gas (5).

Conservation of the energy used for space heating and water heating requirements can be realized in two ways. The first one is end-user conservation brought about by reducing the thermal demands of buildings through improved shell characteristics and energy systems or modified operating schedules. This represents a demand-side conservation strategy. Conservation can also be effected from the supply side by using more efficient methods of converting fuel energy into heat such as through district heating with cogeneration.

Even though these two basic conservation approaches are not technically mutually exclusive and can be applied simultaneously, the implementation of one tends to reduce the economic attractiveness of the other. The more expensive the supply of energy is, the more economical the end-user conservation measures become. On the other hand, district heating is more economical in geographical areas with higher heat densities because it is an extremely capital intensive option, and higher heat density provides better utilization of this expensive system. End-user conservation results in reduced heat density and reduced utilization of the district heating system.

This study examines the economic attractiveness of reducing the heating loads of buildings served by a cogeneration/district heating system by improving the building shell characteristics. The results show that there are no substantial economic benefits from further reducing the heating loads by shell improvements if the buildings are connected to a district heating system. The results were obtained from data that apply specifically to Minneapolis-St. Paul, Minnesota, but the authors judge that the qualitative results can be generalized to other locations. Both the shell improvements and district heating are economically attractive when applied separately. The reason that the shell improvements are not attractive when applied to buildings served by district heating is that the costs of district heating are dominated by fixed capital charges; these costs are not significantly reduced when the heat load is reduced, so there is little savings to offset the costs of the shell improvements.

CHAPTER 2

INTRODUCTION AND BACKGROUND

I. Introduction

The objective of this study is to evaluate the economic attractiveness of applying end-user energy conservation measures, as defined below, to buildings served by a hypothetical district heating system proposed for the urban Minneapolis-St. Paul area (Ref. 8). Different levels of end-user conservation measures are assumed to be implemented for three building types at various times during development of the district heating system. A model for calculating the present-worth of costs for each scenario is developed. Present worths are then determined for selected parameters of interest and conclusions are made regarding the feasibility of implementing end-use conservation measures in a setting where an economically viable district heating system will be built. The remainder of this chapter provides background information and sources of data for end-user conservation and district heating.

II. End-User Conservation

A. Background

End-user conservation involves the reduction of energy demand of buildings by applying various conservation measures which can be put into three general categories (7):

1. Change in building use and operating procedures.

   The most common example in this category are thermostat setback, reduced ventilation, and reduced lighting. Application of these measures requires little investment, and the measures are highly effective in reducing energy demand. However, they may require some changes in the accustomed comfort level and the life styles of the building users. This type of conservation measure can best be applied to commercial buildings, where they are becoming quite popular as fuel prices continue to rise.

2. Change in energy systems and equipment.

   This category of energy conservation measures involves improvements to the heating, ventilating and air conditioning systems in buildings. The measures are applied primarily to commercial and multi-family buildings; examples include recovery of chiller waste heat, elimination of reheat, and thermal energy storage systems.

3. Change in the building shell.

These measures involve change in the building itself. Some common examples are sealing and caulking, addition of insulation, storm doors, dual-paned windows, and reducing window areas. The implementation of these measures is costly, but it requires virtually no change in the comfort level or the life style of building users.

In this study, only the third type of single building measures, changes in the building shell, are considered. The use of district heating implies that there would be no conventional heating systems in the buildings to improve, and we reject the use of conservation measures that require lifestyle changes as second-best measure if efficiency improvements that require no such changes are available at an attractive cost.

The cost of implementing the conservation measures depends on whether they are being incorporated during the construction of a new building or are being applied in retrofitting an existing building. Application of conservation measures is more difficult and costly for retrofitting existing buildings. To simplify this analysis, the building stock in the Minneapolis-St. Paul area is assumed to remain constant during the study period. Therefore, only retrofit conservation measures are considered.

The cost of conservation also varies according to the building type upon which it is being implemented. In this regard, buildings are classified into three general categories: commercial buildings, multifamily buildings and single family residences.

In this report, only moderate levels of conservation (5% and 10% energy savings) are considered so that an existing computer model could be utilized in analyzing the district heating system. A significantly different system design would be required for higher conservation levels (e.g., 30%), thus necessitating the construction of a completely new computer model. Moderate levels of conservation do not have a large enough impact on the heat load to necessitate the redesign of the district heating system.

Conservation measures evaluated in this report should reduce the cooling load in all building types. This omission has a more substantial effect on multifamily and commercial buildings (8). The cooling component of total energy demand has been ignored, which makes conservation look less attractive in all cases considered.

B. Available Data Sources Regarding End-User Conservation.

Commercial Buildings: Three reports dealing with energy conservation in commercial buildings were considered for possible use for this study. They are an ORNL report by W. S. Johnson and F. E. Pierce (4), an article written by Eric Hirst (2), and a Mellon Institute report by

R. W. Sant and S. C. Carhart (8). Conservation measures considered in the first two references include the types that require changes in the operating procedures of commercial buildings. Shell changes considered in these two reports are applied only in combination with operational changes, and the effects of shell changes are difficult to isolate. Only the Mellon Institute report presented information about shell changes in such a way as to be useful for this study.

Multi-family Buildings: The Mellon Institute report (8) dealt with conservation in multi-family buildings and was used as the principal source of data in this study.

Single-family Houses: Available data sources regarding conservation measures applied to single family houses include a report on the Bowman house in Washington, D.C. by R. H. Williams and M. H. Ross (9), an ORNL report by P. R. Hutchins and Eric Hirst (3) and the Mellon Institute report by R. W. Sant and S. C. Carhart (8).

Results given in Ref. 3 apply to new construction, not to the retrofitting of existing houses. Although the Bowman house and Mellon Institute reports were found applicable for this project, data consistency between them is poor. For instance, the cost of conservation given in the Bowman house report is considerably lower than the cost given in the Mellon Institute report.

An examination of the above reports showed that only the Mellon Institute study provides consistent data for all three building types. Other reports concentrate on a single building type. Also, the types of conservation measures considered in the present report and the climatic characteristics of the Minneapolis-St. Paul area most closely matched those used for the analyses in the Mellon report. Consequently, data provided by the Mellon report were used for all building types in the present study. However, the conservation costs from the Mellon report tend to be high compared to costs from other sources.

C. Discussion of the Mellon Institute Report (Ref. 8).

The Mellon Institute report provides reasonably detailed data on how the energy demand of buildings is affected by end-user conservation measures and how much it costs to implement these measures. The Mellon report divides the country into four climatic regions: North East, North Central, South and West. For this project, data developed for the North Central region were utilized. The climatic characteristics of Detroit, Michigan were chosen as representative of the North Central region. Adjustments were made in the heating loads used for the Mellon study to account for the fact that Minneapolis-St. Paul is colder than Detroit. The Detroit heating loads were multiplied by the ratio of heating degree days in Minneapolis-St. Paul to those in Detroit to obtain estimates of building heating loads in Minneapolis-St. Paul.

The cost of conservation is given in 1975 dollars in the Mellon Institute report. These costs were escalated with a 10% per year rate to 1980 dollars to correspond to the beginning of the 20-year study period in this analysis.

The Mellon Institute report divides commercial buildings into five classes: offices and banks, retail stores, schools, hospitals, and others. It provides data for existing floor areas of each building type in the North Central region and relationships between energy use and conservation capital cost for each building type. An overall average relationship between the energy used in commercial buildings and the amount of money invested in conservation measures was developed by calculating a weighted average over all five commercial building types. Results are shown in Figure 1 along with similar results for single-family and multi-family residential buildings. They constitute a primary source of data for this report. A base load of 100% is shown in Fig. 1 when no investment in conservation has been made. As money is spent on conservation measures, the reduction in heating load is indicated.

Multi-family buildings were divided into two categories: low-rise and high-rise multi-family buildings. The data given for these two building types were averaged to obtain the results shown in Figure 1.

Single family residences are not subdivided further in the Mellon Institute report. Therefore the data provided for them, shown in Figure 1, were directly used in this project.

III. District Heating

A. Background

District heating is the central generation of thermal energy at one or more heat sources and the distribution of that energy to commercial and residential buildings for space heating and water heating purposes by a hot water or steam pipeline. Figure 2 illustrates the operation of a district heating system (1). The system is comprised of three subsystems: (a) the thermal energy source, (b) the transport and distribution system and (c) the consumer heat exchange systems.

The primary energy source for a new district heating system is likely to be a cogeneration plant that produces electricity and thermal energy.* Many existing power plants can be modified for cogeneration at a relatively low capital cost of \$20 to \$30/kW_t (1). The incremental cost of incorporating cogeneration in a new power plant is even less.

There are two basic cogeneration methods. The first one is called the back pressure method. The condenser is replaced with a district water heater which recovers most of the thermal energy normally rejected to the environment. The second method extracts steam from the crossover between the high pressure and low pressure turbine units. This steam is supplied directly to a district water heater. Although the electricity

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*Many district heating systems in the U.S. presently rely on heat only boilers, but the economies strongly favor cogeneration for new systems.

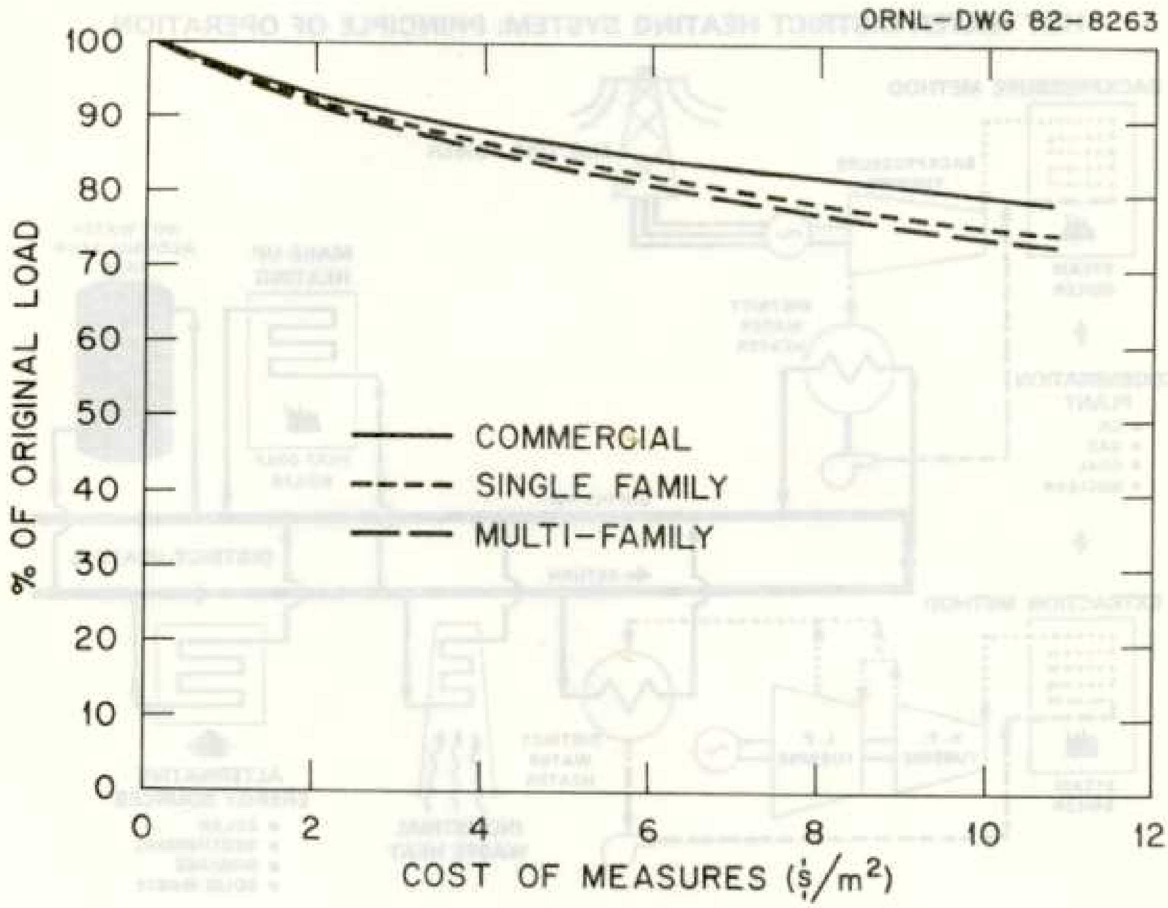

Fig. 1. Relationship between energy savings and required capital investment for building envelope changes (1980 dollars).

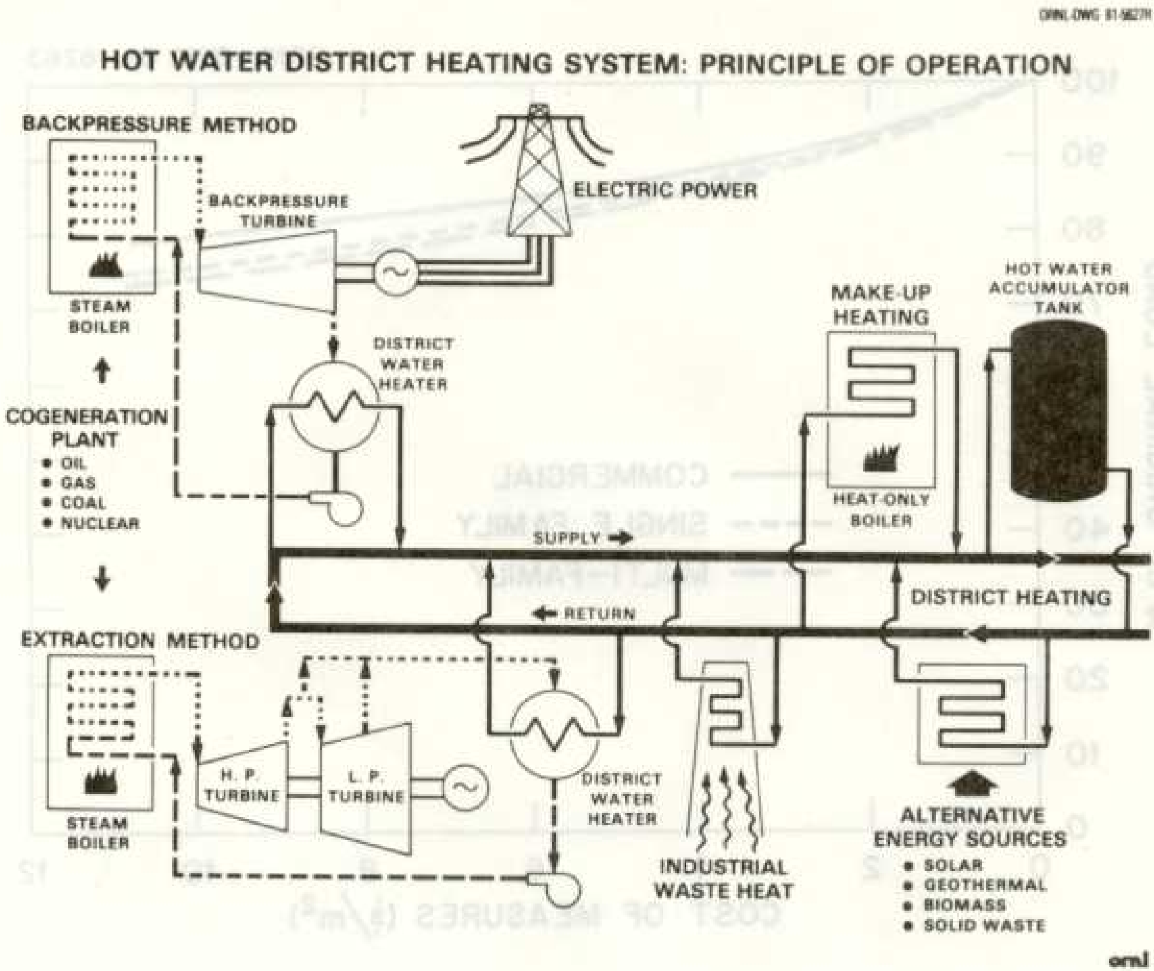

Fig. 2. Schematic diagram illustrating the major components in a district heating system.

generating efficiency of a power plant is reduced with cogeneration, the overall thermal efficiency is improved greatly. A power plant is roughly 33 percent efficient when producing electricity only. When it is modified for cogeneration, its electricity generating efficiency falls to around 25%, but it works with a combined efficiency of approximately 80% (5). Generally, for each unit of electricity sacrificed, 5 to 10 units of thermal energy are recovered. Because of this increase in energy efficiency, we call district heating with a cogeneration heat source a supply-side conservation measure.

Cogeneration plants usually comprise the baseload energy source for a district heating system, and the peak load requirements are supplied by heat-only boilers due to their low capital costs. Peak load capacities typically correspond to about 50% of the total capacity, but they supply only about 10% of the annual heat load.

The thermal energy produced in the central heat source is transported to the district heating areas and distributed to customers with a network of underground pipes. The transmission and distribution network is the most expensive component of a district heating system. It represents about 55% of the total capital cost (1).

Thermal energy from the district heating distribution system is then supplied to customers through heat exchangers usually owned by the customers. Thermal energy is transferred in the heat exchangers to hot water that circulates through the customer's secondary heating system. This secondary heating system may consist of two subsystems: one for space heating and one for water heating. Each has its own heat exchanger.

The most important advantage of a district heating system based on cogeneration is that it provides thermal energy less expensively than conventional systems because most of its energy comes from sources that otherwise would be wasted. Also, by using central heat sources; fuels that are more abundant and cheaper than petroleum (e.g., coal, uranium) can be used. New buildings can be connected to a district heating system with a lower capital cost than the cost of installing individual boilers, and more useful floor area is made available because a boiler room is not needed. Additionally, the cost of maintaining the in-building heat exchangers is lower than the cost of maintaining boilers.

Data used in this study for the district heating application are obtained from the Studsvik report (6), which provides a thorough discussion of the design and economic analysis of a district heating system designed for the Minneapolis-St. Paul area.

B. Discussion of the Studsvik Report

The Minneapolis-St. Paul area has a high population density and a cold climate with over 4600 Celsius-degree heating days (8300 °F days) per year. These factors, combined with availability of nearby coal-fired power plants that can be converted to cogeneration units make the area suitable for a district heating system. The Studsvik report proposes for the Minneapolis-St. Paul area a district heating system that develops over a 20-year period.

Two scenarios are considered in the Studsvik report. Scenario A covers the downtown and high density commercial and residential districts. Scenario B extends to a larger area including medium density residential districts. In this study, only the system considered in scenario A is evaluated. Scenario A divides the Minneapolis-St. Paul area into 33 districts, 17 of which are in Minneapolis and 16 are in St. Paul. The heat demand of each district is estimated primarily from historical records of natural gas consumption. The estimated total thermal demand for the area considered in Scenario A is 2600 MW_t. This demand is assumed to remain constant over the 20-year development period. Moreover, the period of time that the district heating system is utilized after the development period is assumed to be indefinitely long.

The base load is supplied by cogeneration plants that provide about half the total peak load capacity but nearly 90 percent of the annual heat load. The remaining half of the peak load capacity requirements are supplied by oil-fired heat-only boilers.

The total connected capacity of this proposed system at the end of the 20-year development period is 3044 MW_t including backup capacity for the largest unit in the system. The capacity is increased to this level over 20 years according to a proposed connection schedule for each district.

Estimates of the cost components of this system are mainly based on local data sources and Swedish experience with similar conditions. The total investment cost of scenario A is estimated to be \$625 million (in 1978 dollars). Components of this estimated cost are as follows:

	Investment (\$ x 10^6)
Cogeneration Plants	55
Peak load boilers	66
Hot water transport	104
Hot water distribution	274
Building conversion	126
TOTAL	\$625

In the economic analysis of this system, two types of financing are considered in the Studsvik report. They are municipal utility financing and private utility financing. For the present report, only municipal financing is considered. Based on conditions in 1978, a combined (i.e., marketplace) interest rate of 6.5 percent is used in the Studsvik report. This interest, or discount, rate includes a 4 percent allowance for inflation and provides a real, or inflation-free, return to investors of approximately 2.5%. All capital costs are levelized over 20 years with the 6.5 percent interest rate and are charged against the district heating system as yearly revenue requirements. The yearly estimated operating costs are composed of the fuel costs for the base-load plants and peak-load boilers and the operating and maintenance costs.

The economic analysis in the Studsvik report shows that the district heating system pays for itself and accumulates a net present worth of 183 million dollars (1978 dollars) over the 20-year development period under municipal financing. This assumes that the system charges a rate for the sale of heat that is 10% less than the cheapest alternative.

The projected results also show that implementation of this district heating system in the scenario A area would result in an oil savings of 0.30 exajoules (49 million barrels) over the 20-year development period. After correction for extra coal consumption of 0.11 exajoules, the net savings in energy is 0.19 exajoules.

The present study makes use of most of the key assumptions and conditions of the original Studsvik study. A 6.5 percent interest rate is also utilized, which appears to be outdated in terms of 1981 interest rates. However, if a real interest rate of approximately 2.5% is realistic, economic study results in today's marketplace would not change appreciably if higher interest rates (e.g., 12% combined, 9.5% inflation) had been employed in the original study. For this reason, the revenue requirements of the Studsvik study are believed to reflect adequately the cost of capital in real terms to the municipal financing authority.

CHAPTER 3

ANALYSIS OF END-USER CONSERVATION MEASURES APPLIED TO A PROPOSED DISTRICT HEATING SYSTEM IN MINNEAPOLIS-ST. PAUL

I. Introduction

The problem under consideration is to determine the costs and relative economic attractiveness of four options for supplying the heat demand of urban Minneapolis-St. Paul. The alternatives being investigated are:

1. Conventional gas- and oil-fired heating systems without end-user conservation.
2. Conventional heating systems with end-user conservation.
3. District heating without end-user conservation.
4. District heating with end-user conservation.

Of particular interest in this study is the fourth alternative.

It should be recalled that end-user conservation, as defined here, is the application of building shell modifications to an existing/planned stock of commercial and residential buildings in a fixed geographic region.

II. Methodology

The maximum 2600 MW_t heat load has been divided among three types of buildings:

1. Commercial (900 MW_t)
2. Multi-family (1290 MW_t)
3. Single-family (410 MW_t)

This breakout was mainly based on the descriptions of subdistricts provided in the Studsvik report because no other source of information regarding the relative amounts of three building types in the study area was available. First, an assumption was made regarding the percentage of a given district's total heat load for each building type according to the description of that district. Then, by using these assumed percentages, the total heat load of the district was divided among the three building types. The total load for a given building type in the entire study area was determined by summing all the districts' heat loads for that building type.

When the district heating system is implemented, the connection of the entire 2600 MW load is assumed to take 20 years. Therefore, in a given year only a fraction of the total load is served with district heating and the remainder of the heat load is served with conventional systems, which are fueled by oil and natural gas.

Thus, for a given year N these relationships apply:

$X_C(N)$ - gives the commercial load served by the district heating system.

$X_M(N)$ - gives the multi-family load served by district heating.

$X_S(N)$ - gives the single family load served by district heating.

$Y_C(N) = 900 - X_c(N)$ is the commercial load not connected to district heating.

$Y_M(N) = 1290 - X_M(N)$ is the multi-family load not connected to district heating.

$Y_S(N) = 410 - X_S(N)$ is the single family load not connected to district heating.

When only end-user conservation is considered, it is assumed to be implemented at a constant rate. The implementation rate is denoted by IR. For example, if IR = 5% then 5% of all buildings apply conservation measures in the first year. In the second year, another 5% adopt conservation, bringing the total to 10%. At the end of 20 years all buildings have adopted end-user conservation measures.

The conservation level is identified as CL. For instance, a 5% conservation level means that the total annual heat load is reduced by 5% because of the effectiveness of the end-user conservation measures.

In the fourth alternative listed earlier, district heating and end-user conservation are applied together, and the following definitions apply:

$E_C(N)$ - is the commercial load connected to district heating in year N.

$E_M(N)$ - is the multi-family load connected to district heating in year N.

$E_S(N)$ - is the single family load connected to district heating in year N.

$F_C(N)$ - is the commercial load <u>not</u> connected to district heating.

$F_M(N)$ - is the multi-family load not connected to district heating.

$F_S(N)$ - is the single family load not connected to district heating.

The relationship between the heat loads with and without conservation is as follows:

$$E_C(N) = X_C(N) - X_C(N) \times CL \times IR \times N$$

$$E_M(N) = X_M(N) - X_M(N) \times CL \times IR \times N$$

$$E_S(N) = X_S(N) - X_S(N) \times CL \times IR \times N$$

$$F_C(N) = Y_C(N) - Y_C(N) \times CL \times IR \times N$$

$$F_M(N) = Y_M(N) - Y_M(N) \times CL \times IR \times N$$

$$F_S(N) = Y_S(N) - Y_S(N) \times CL \times IR \times N$$

The measure of economic attractiveness in this study is the total present worth of costs at an interest rate of 6.5% [6]. The configuration that minimizes the present worth of the cost is the preferred choice. Total present worths of supplying the 2600-MW heat load over 20 years for the four alternatives are computed as follows.

1. Conventional Heating Systems

For this option, no capital investment is involved. The demand is served with existing individual building heating systems.

$R_{out}(N)$ is the cost of one MW-Hr. of heat supplied by existing systems in year N [6].

LD = annual heat load divided by peak heating capacity

LD = 2465 hours/year

i = 0.065 is the discount rate (decimal)

Then, the total annual cost of this alternative in year N is

$$A(N) = [X_C(N) + X_M(N) + X_S(N) + Y_C(N) + Y_M(N) + Y_S(N)] \times LD \times R_{out}(N)$$

$$= 2600MW \times LD \times R_{out}(N)$$

The total present worth of costs over 20 years is computed with this expression:

$$TPWC = \sum_{N=1}^{20} A(N)/(1 + i)^N$$

Annual costs for commercial, multi-family and single family buildings are as follows:

$A_C(N) = (900\ MW) \times LD \times R_{out}(N)$

$A_M(N) = (1290\ MW) \times LD \times R_{out}(N)$

$A_S(N) = (410\ MW) \times LD \times R_{out}(N)$

2. Conventional Systems with End-User Conservation

This option requires investments in various conservation measures. To estimate the cost of end-user conservation, total floor space within the boundaries of the study region for each building type was needed. These estimates were obtained in the following manner. The Mellon Institute report provides data on annual heat loads per unit of floor area of typical commercial, multi-family and single family buildings. However, the data provided by this report are for Detroit, Michigan, which has an annual heating season averaging 3400 Celsius (6200 Fahrenheit) degree-days. The Minneapolis-St. Paul area has an average heating season of 4600 Celsius (8300 Fahrenheit) degree days (3). By assuming that the annual heat load is proportional to the heating degree days, data for the annual heat load per unit area of each building type in Detroit are corrected for Minneapolis-St. Paul area. Then, the total annual heat load for a given building type within the study region is divided by the annual heat load per unit area of that building type to obtain an estimate of the total floor space for that building type.

FS_C is the total commercial floor space

FS_M is the total multi-family floor space

FS_S is the total single family floor space

By applying the above procedure, estimated amounts of floor space are as follows:

$FS_C = 20.9 \times 10^6\ m^2$

$FS_M = 12.4 \times 10^6\ m^2$

$FS_S = 3.9 \times 10^6\ m^2$

Because the study period is 20 years, the economic returns on end-user conservation measures are terminated at this time even though measures implemented after the first year have useful lives remaining. For example, if a conservation measure is implemented at the beginning of year 15, only six years of returns from year 15 through year 20 are considered. Actually, a conservation measure implemented in year 15 would have a useful life extending beyond year 20. To correct this situation and obtain more realistic results, the following approach is used. First, useful lives of all conservation measures are assumed to be 20 years. Then, the actual cost of implementing a conservation measure is multiplied by the number of years the return on it is considered and divided by its useful life of 20 years. This prorated cost is regarded as the approximate cost of implementing the conservation measure.

Costs of conservation measures adopted in year N for commercial, multi-family and single family buildings are, respectively:

$$CC_C(N) = [(FS_C \times IR \times CPFS_C)(1 + r)^N] \times (20 - (N - 1)/20)$$

$$CC_M(N) = [(FS_M \times IR \times CPFS_M)(1 + r)^N] \times (20 - (N - 1)/20)$$

$$CC_S(N) = [(FS_S \times IR \times CPFS_S)(1 + r)^N] \times (20 - (N - 1)/20)$$

where $CPFS_C$, $CPFS_M$ and $CPFS_S$ are the costs per m^2 of building shell changes to commercial, multi-family and single family structures. The escalation rate is denoted by r (a decimal). An average value of 0.04 is assumed during the 20-year study period.

The total annual cost is

$$A(N) = [2600 - 2600 \times CL \times IR \times N] \times LD \times R_{out}(N) + CC_C(N) + CC_M(N) + CC_S(N)$$

The total present worth of cost over 20 years is

$$TPWC = \sum_{N=1}^{20} A(N)/(1 + i)^N$$

Annual costs for commercial, multi-family and single family buildings are as follows:

$$A_C(N) = [900 - 900 \times CL \times IR \times N] \times LD \times R_{out}(N) + CC_C(N)$$

$$A_M(N) = [1290 - 1290 \times CL \times IR \times N] \times LD \times R_{out}(N) + CC_M(N)$$

$$A_S(N) = [410 - 410 \times CL \times IR \times N] \times LD \times R_{out}(N) + CC_S(N)$$

3. District Heating Without End-User Conservation

The Studsvik report [6] estimates all capital costs required for district heating. These capital costs are given as the carrying charge component of levelized revenue requirements over 20 years. RRDH(N) is the revenue requirement of district heating in year N. The total revenue requirement in year N is divided into three portions, one for each building type, according to the connected load of each building type in that year. This division, which assumes a linear relationship between the capital cost and the connected heat load, favors the multi-family and single family buildings because the investment per MW of connected commercial building load is actually lower than for multi-family and single family buildings. However, the investment cost of the district heating system is assumed to remain the same for moderate levels of end-user conservation so that this cost component affects the magnitude of the results but not their behavior.

$RRDH_C(N)$ is the revenue requirement in year N for commercial buildings.

$RRDH_M(N)$ is the revenue requirement in year N for multi-family buildings.

$RRDH_S(N)$ is the revenue requirement in year N for single-family buildings.

The Studsvik report also gives the total maintenance cost of district heating for every year. M(N) is the maintenance cost of district heating in year N. The maintenance cost is also divided among the three building types according to the connected load of each: $M_C(N)$, $M_M(N)$ and $M_S(N)$, respectively.

The district heating system has heat losses from its transmission and distribution pipelines. Therefore, the actual amount of heat produced by the system each year is higher than the annual heat consumed. L(N) is the average heat loss rate in MW in year N. The annual heat loss is given as L(N) times 8760, the total number of hours in a year. The heat loss is divided among the three building types according to the connected load of each as $L_C(N)$, $L_M(N)$ and $L_S(N)$, respectively.

$O_{DH}(N)$ is the operating cost of district heating per MW-Hr. of heat produced in year N. Therefore, the total annual cost of the district heating system is given as:

$$A(N) = [(X_C(N) + X_M(N) + X_S(N)) \times LD + L(N) \times 8760] \times O_{DH}(N)$$
$$+ [Y_C(N) + Y_M(N) + Y_S(N)] \times LD \times R_{out}(N)$$
$$+ RRDH(N) + M(N)$$

The present worth of total cost over 20 years is

$$TPWC = \sum_{N=1}^{20} A(N)/(1 + i)^N$$

Yearly costs allocated to commercial, multi-family and single family buildings are as follows:

$$A_C(N) = [X_C(N) \times LD + L_C(N) \times 8760] \times O_{DH}(N) + Y_C(N)$$
$$\times LD \times R_{out}(N) + RRDH_C(N) + M_C(N)$$

$$A_M(N) = [X_M(N) \times LD + L_M(N) \times 8760] \times O_{DH}(N) + Y_M(N)$$
$$\times LD \times R_{out}(N) + RRDH_M(N) + M_M(N)$$

$$A_S(N) = [X_S(N) \times LD\ L_S(N) \times 8760] \times O_{DH}(N) + Y_S(N)$$
$$\times LD \times R_{out}(N) + RRDH_S(N) + M_S(N)$$

4. District Heating with End-User Conservation

For moderate levels of conservation such as 5% and 10%, it is assumed that the district heating system design remains unchanged from the Studsvik design. Therefore, the capital charges and the maintenance cost of the system are assumed not to change. The operating cost per MW-Hr. of heat produced [$O_{DH}(N)$] and the heat losses are assumed to remain constant, but, because less heat is produced in a given year when conservation measures are added, the total yearly operating cost is lower.

The total annual cost is

$$A(N) = [(E_C(N) + E_M(N) + E_S(N) \times LD + L(N) \times 8760] \times O_{DH}(N)$$
$$+ [F_C(N) + F_M(N) + F_S(N)] \times LD \times R_{out}(N)$$
$$+ RRDH(N)$$
$$+ M(N)$$
$$+ CC_C(N) + CC_M(N) + CC_S(N)$$

Total present worth of cost over 20 years is

$$TPWC = \sum_{N=1}^{20} A(N)/(1 + i)^N$$

Annual costs for commercial, multi-family and single family buildings are estimated as follows:

$$A_C(N) = [E_C(N) \times LD + L_C(N) \times 8760] \times O_{DH}(N) + F_C(N) \times LD$$
$$\times R_{out}(N) + RRDH_C(N) + M_C(N) + CC_C(N)$$

$$A_M(N) = [E_M(N) \times LD + L_M(N) \times 8760] \times O_{DH}(N) + F_M(N) \times LD$$
$$\times R_{out}(N) + RRDH_M(N) + M_M(N) + CC_M(N)$$

$$A_S(N) = [E_S(N) \times LD + L_S(N) \times 8760] \times O_{DH}(N) + F_S(N) \times LD$$

$$\times R_{out}(N) + RRDH_S(N) + M_S(N) + CC_S(N)$$

All of these calculations were performed with a computer model that was developed for this study. The program listing is included in the Appendix.

III. Economic Results with Moderate Levels of Conservation (5% and 10%)

Figure 3 compares the alternatives of district heating only and district heating with conservation. The implementation rate for conservation in Figure 3 is 5% a year. From Figure 3 it can be seen that the present worth of total cost is insensitive to the level of end-user conservation. A more precise display of the results plotted in Figure 3 is given in Table 1. There, one sees that the present worth of costs is lower with conservation, but the reductions are only 0.2% with a 5% level of conservation and 0.1% with a 10% level. The basic conclusion that can be drawn from these data is that there is no strong economic incentive for implementation of end-user conservation measures if the district heating system has already been constructed.

Table 1. TOTAL PRESENT WORTH OF COSTS OVER 20-YEAR STUDY PERIOD OF SUPPLYING HEAT FOR THE CASE OF DISTRICT HEATING WITH CONSERVATION (X10^6 1980 DOLLARS)

	Conservation Level (%)		
	0	5	10
Commercial Buildings	527	533	542
Multifamily Buildings	756	751	747
Single Family Buildings	269	265	262
TOTAL	1552	1549	1551

Figure 3 and Table 1 also show the behavior of three components of total cost (commercial, multi-family and single family). The costs for multi-family and single family buildings decrease with conservation, indicating the desirability of the combination of conservation and district heating for them. However, the percentage reductions of the costs are still very low (between 1% and 3%). From the behavior of the data for multi-family and single buildings, it appears that their heating costs would decrease further with higher levels of conservation, but at a slowing rate. The present-worth of heating costs for commercial buildings increases with conservation, indicating that implementing conservation in combination with district heating is uneconomical.

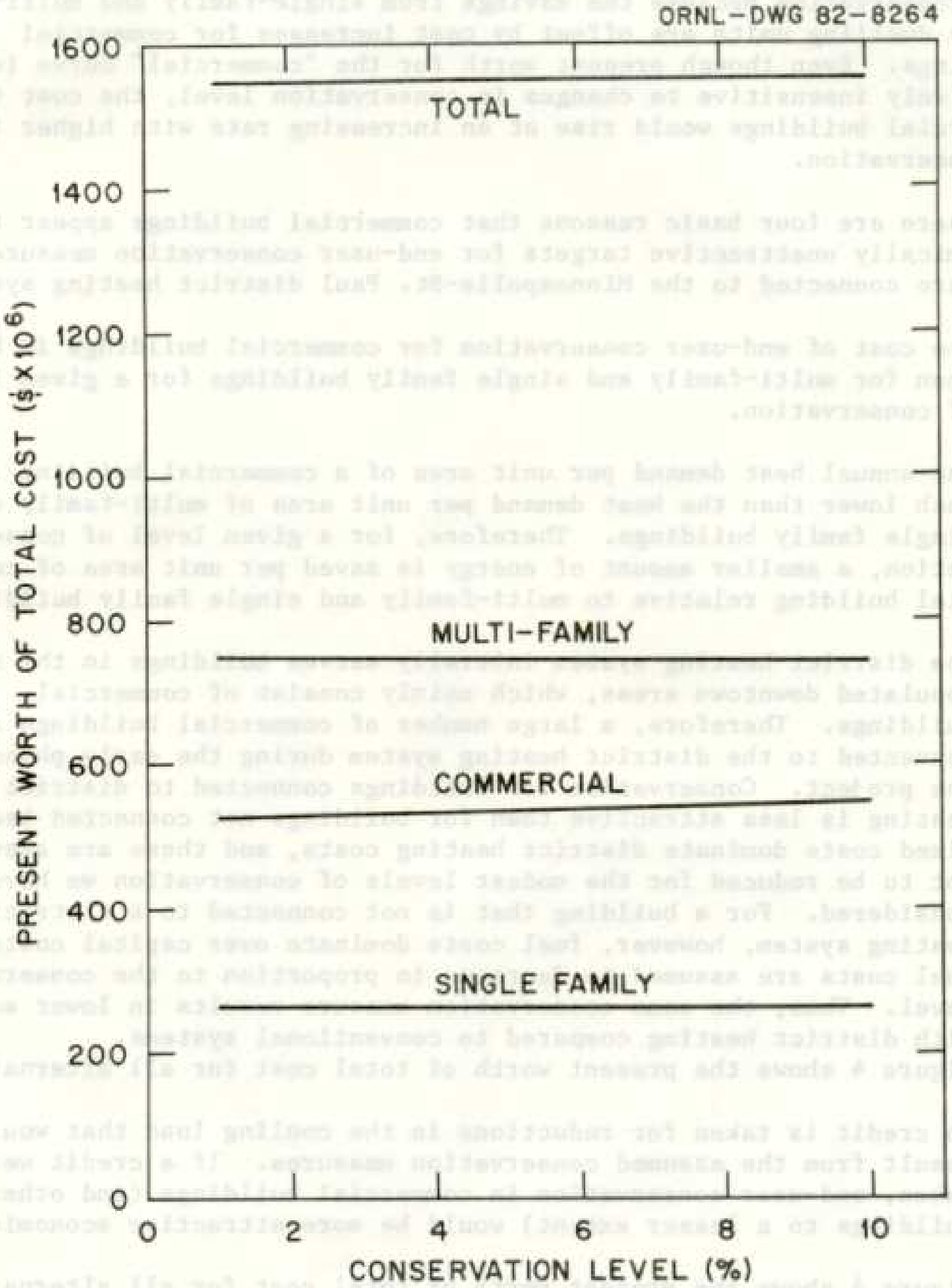

Fig. 3. Change in the present worth of the cost of providing heating services as conservation measures are added to buildings served by a district heating system (1980 dollars). Costs include capital and fuel costs over the time period 1981-2000 discounted back to 1980.

The present-worth of total costs is insensitive to the level of end-user conservation because the savings from single-family and multi-family dwelling units are offset by cost increases for commercial buildings. Even though present worth for the "commercial" curve is relatively insensitive to changes in conservation level, the cost for commercial buildings would rise at an increasing rate with higher levels of conservation.

There are four basic reasons that commercial buildings appear to be economically unattractive targets for end-user conservation measures if they are connected to the Minneapolis-St. Paul district heating system:

1. The cost of end-user conservation for commercial buildings is higher than for multi-family and single family buildings for a given level of conservation.

2. The annual heat demand per unit area of a commercial building is much lower than the heat demand per unit area of multi-family and single family buildings. Therefore, for a given level of conservation, a smaller amount of energy is saved per unit area of commercial building relative to multi-family and single family buildings.

3. The district heating system initially serves buildings in the densely populated downtown areas, which mainly consist of commercial buildings. Therefore, a large number of commercial buildings are connected to the district heating system during the early phases of the project. Conservation for buildings connected to district heating is less attractive than for buildings not connected because fixed costs dominate district heating costs, and these are assumed not to be reduced for the modest levels of conservation we have considered. For a building that is not connected to a district heating system, however, fuel costs dominate over capital costs, and fuel costs are assumed to decrease in proportion to the conservation level. Thus, the same conservation measure results in lower savings with district heating compared to conventional systems.
Figure 4 shows the present worth of total cost for all alternatives

4. No credit is taken for reductions in the cooling load that would result from the assumed conservation measures. If a credit were taken, end-user conservation in commercial buildings (and other buildings to a lesser extent) would be more attractive economically.

Figure 4 shows the present worth of total cost for all alternatives with moderate levels of conservation (5% and 10%). The implementation rate is again 5% per year. An immediate conclusion that can be drawn from Figure 4 is that doing something is always better than doing nothing. Without the district heating system, end-user conservation looks attractive. Total cost is decreased as the conservation level is increased. However, the trend in Figure 4 suggests that the initial decline in total cost will level out for higher levels of conservation. A close examination of the components of the total cost shows that the decrease in the present worth of cost with increased levels of conservation decreases more slowly for commercial buildings than for the other

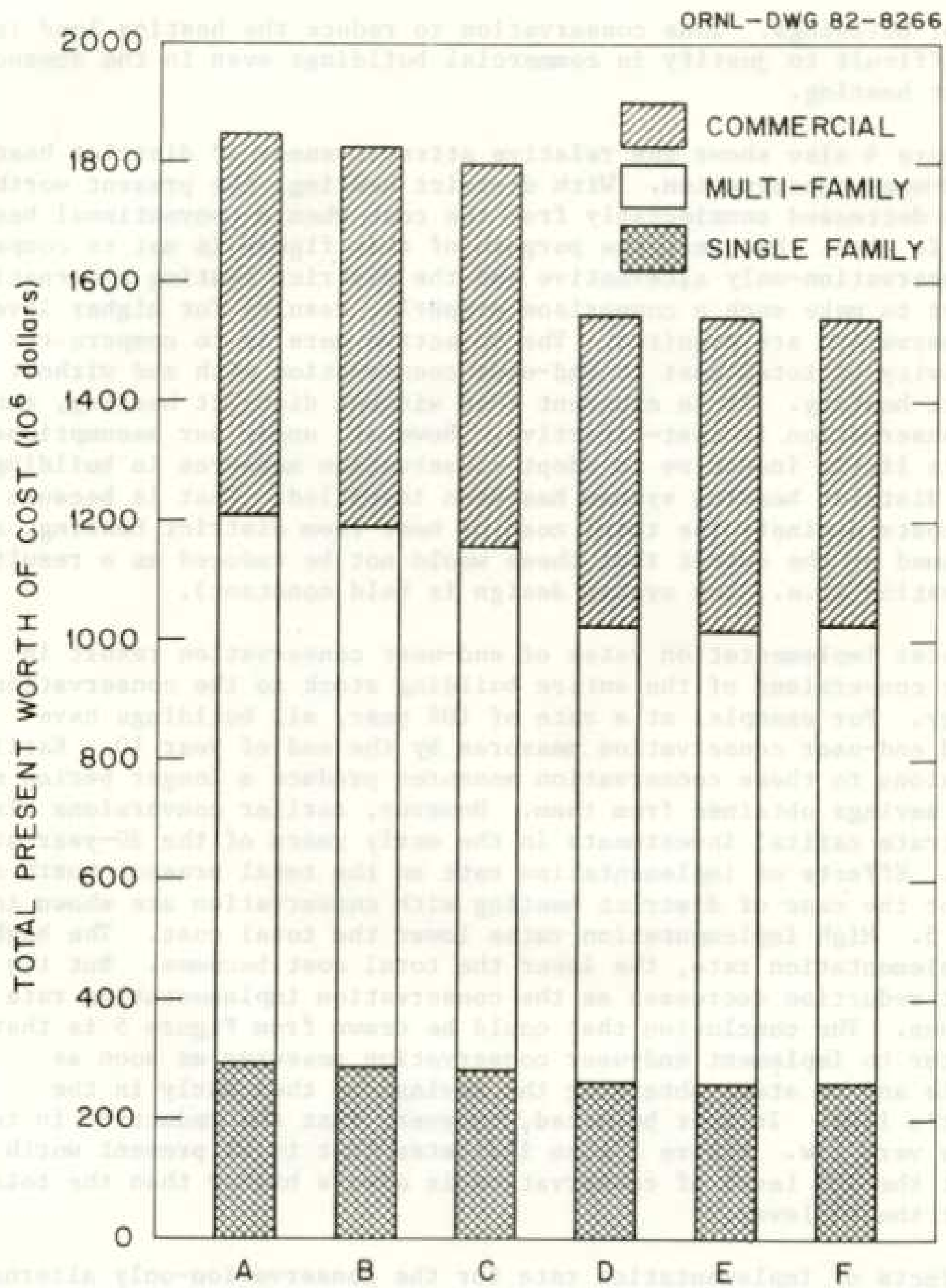

Fig. 4. Change in the present worth of the cost of providing heat as conservation measures are applied to buildings. Legends as follows:

Bar	Connected to District Heating	Conservation Level
A	No	0
B	No	5%
C	No	10%
D	Yes	0
E	Yes	5%
F	Yes	10%

types of buildings. Thus conservation to reduce the heating load is most difficult to justify in commercial buildings even in the absence of district heating.

Figure 4 also shows the relative attractiveness of district heating and end-user conservation. With district heating, the present worth of cost is decreased considerably from the cost when a conventional heating system is used. However, the purpose of this figure is not to compare the conservation-only alternative and the district heating alternative. In order to make such a comparison properly, results for higher levels of conservation are required. The objective here is to compare the sensitivity of total cost to end-user conservation with and without district heating. It is apparent that without district heating, end-user conservation is cost-effective. However, under our assumptions, there is little incentive to adopt conservation measures in buildings once a district heating system has been installed. That is because fixed costs dominate the total cost of heat from district heating, and we assumed at the outset that these would not be reduced as a result of conservation (i.e., the system design is held constant).

Faster implementation rates of end-user conservation result in earlier conversions of the entire building stock to the conservation strategy. For example, at a rate of 10% year, all buildings have adopted end-user conservation measures by the end of year 10. Earlier conversions to these conservation measures produce a longer period of energy savings obtained from them. However, earlier conversions also concentrate capital investments in the early years of the 20-year study period. Effects of implementation rate on the total present-worth of cost for the case of district heating with conservation are shown in Figure 5. High implementation rates lower the total cost. The higher the implementation rate, the lower the total cost becomes. But the rate of cost reduction decreases as the conservation implementation rate increases. The conclusion that could be drawn from Figure 5 is that it is better to implement end-user conservation measures as soon as possible and to start obtaining the savings on them early in the project's life. It must be noted, however, that the reduction in total cost is very low. Figure 5 also indicates that total present worth of cost at the 10% level of conservation is always higher than the total cost at the 5% level.

Effects of implementation rate for the conservation-only alternative are shown in Figure 6. The results are consistent with what one might expect in that the higher the implementation rate, the lower the total present-worth of cost. However, the rate of reduction decreases as the implementation rate increases.

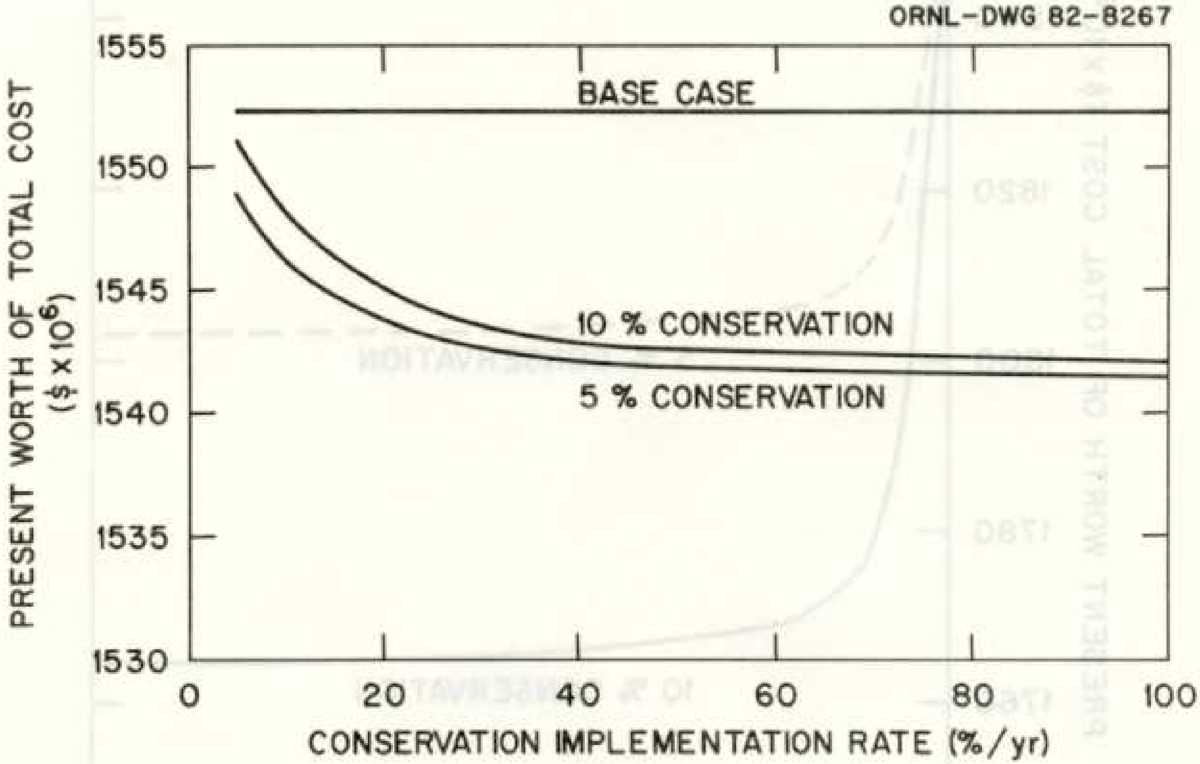

Fig. 5. Effect of the rate of implementation of conservation measures on the present worth of total heating costs for buildings connected to a district heating system (1980 dollars). The base case is the case with district heating without end-user conservation in buildings.

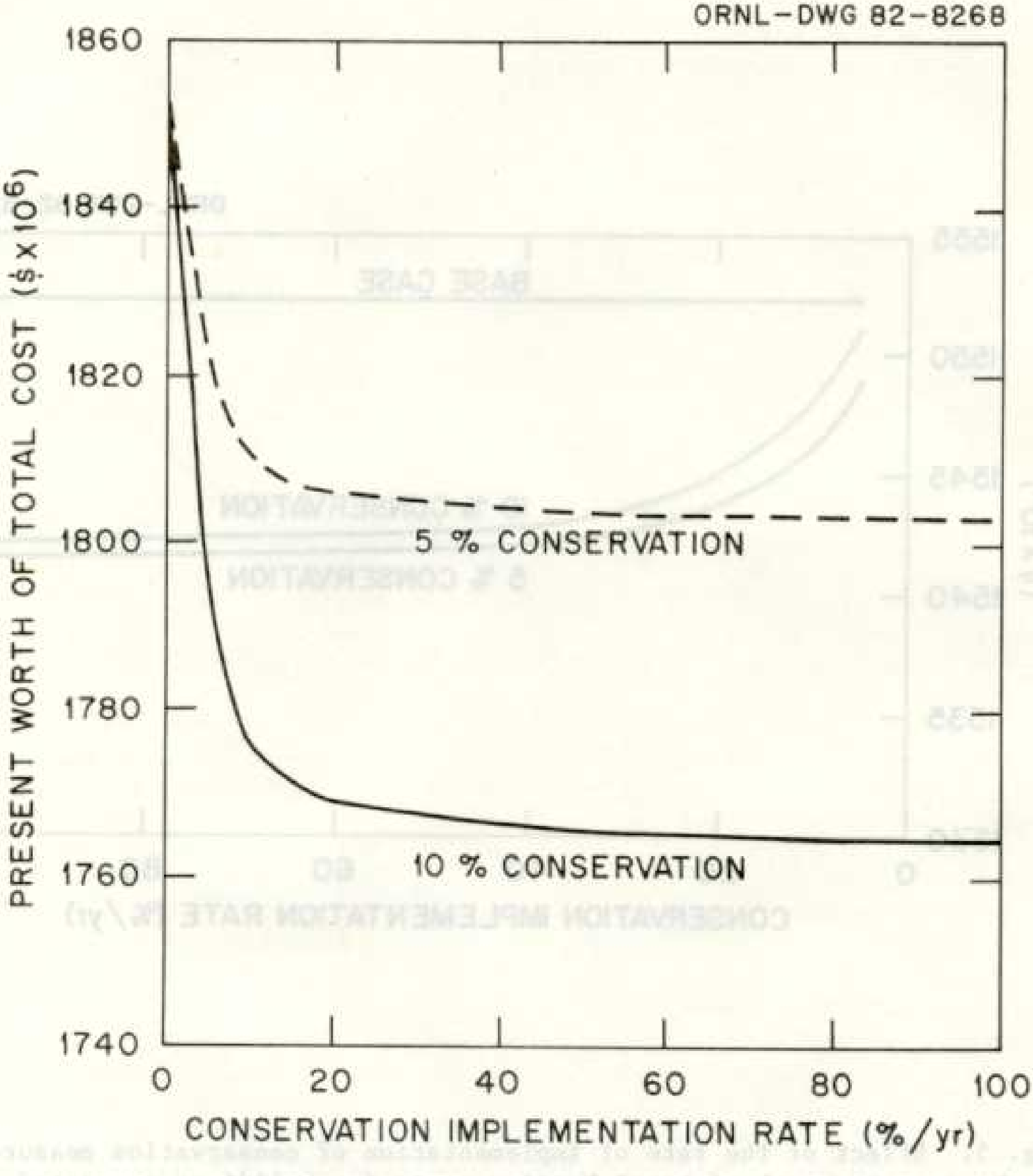

Fig. 6. Effect of the rate of implementation of conservation measures on the present worth of total heating costs for buildings not connected to a district heating system (1980 dollars).

CHAPTER 4

SENSITIVITY OF TOTAL COSTS TO TIMING
OF END-USER CONSERVATION INVESTMENTS

I. Introduction

The economic attractiveness of end-user conservation measures depends primarily on two factors:

1. The year in which the conservation measure is implemented.

When the effects of implementation rate on total present-worth of cost were discussed in the previous section, it was shown that the total cost decreases with higher implementation rates.

2. Year of connection to the district heating system.

The money that would be saved on conserved energy is much lower when a building is connected to district heating compared to when it is not connected and instead utilizes conventional fuels. Therefore, the sooner the connection time to the district heating system, the less economical is the conservation measure.

The purpose of this chapter is to quantify the effects of changes in these parameters on the total present-worth of the heating bill over the 20-year study period.

II. Methodology

The economic effects of changes in conservation implementation timing are examined by using a single square meter approach. That is, calculations are based on one square meter of each building type. As mentioned in the previous chapters, the capital cost and maintenance cost of the district heating system are assumed to remain the same for moderate levels of end-user conservation. Two cost components that are affected by end-user conservation are the annual operating costs and the investment required to implement the conservation measures. In this chapter, we calculate, for each building type, the sum of these two costs per square meter of building area as a function of the year in which the end-user conservation is implemented relative to the year in which construction of the district heating system begins. The year that gives the minimum sum is the economically optimum year to install end-user conservation measures in that building type.

Definitions of factors utilized in the analysis are given below:

D is the heat demand for one m^2 of a building in MW.

CL is the conservation level considered.

CC is the cost of implementing conservation for one m^2 at that level.

N1 is the year at which the building is connected to the district heating system.

N2 is the year at which the conservation measures are implemented.

L(N) is the heat loss of the district heating system per MW of connected load for year N. It is obtained by dividing the total heat loss by the total connected load for each year.

Then the annual heat demand for year N, U(N), for one m^2 is given as follows:

$$U(N) = D \times LD \qquad \text{for } N < N2$$

$$U(N) = (D - D \times CL) \times LD \text{ for } N \geq N2$$

Consequently, the annual operating cost is as follows:

$$Y(N) = [U(N) + L(N) \times D \times 8760] \times O_{DH}(N) \text{ for } N \geq N1$$

$$= U(N) \times R_{out}(N) \qquad \text{for } N < N1$$

Again, $O_{DH}(N)$ is the operating cost of district heating per MW-Hr. of heat supplied in year N, and $R_{out}(N)$ is the price of one MW-Hr. of heat if not connected to district heating.

Capital and maintenance costs of the district heating system are again assumed to be constant. The cost of conservation is as follows:

$C = [CC \times (1 + r)^{N2}] \times [(20 - (N2 - 1))/20]$ where r is the inflation rate expressed as a decimal. Then the total present worth of supplying the heat demand of one m^2 over 20 years is

$$TPWC = \sum_{N=1}^{20} Y(N)/(1 + i)^N + C/(1 + i)^{N2}$$

III. Results

Figures 7, 8, and 9 present the results obtained for commercial, multi-family and single family buildings, respectively, which are connected to the district heating system in year 10. Curves for both 5% and 10% levels of conservation are shown. Although the results shown assume a specific year (i.e., year 10) of connection to the district heating system, the conclusions that can be drawn from these figures can

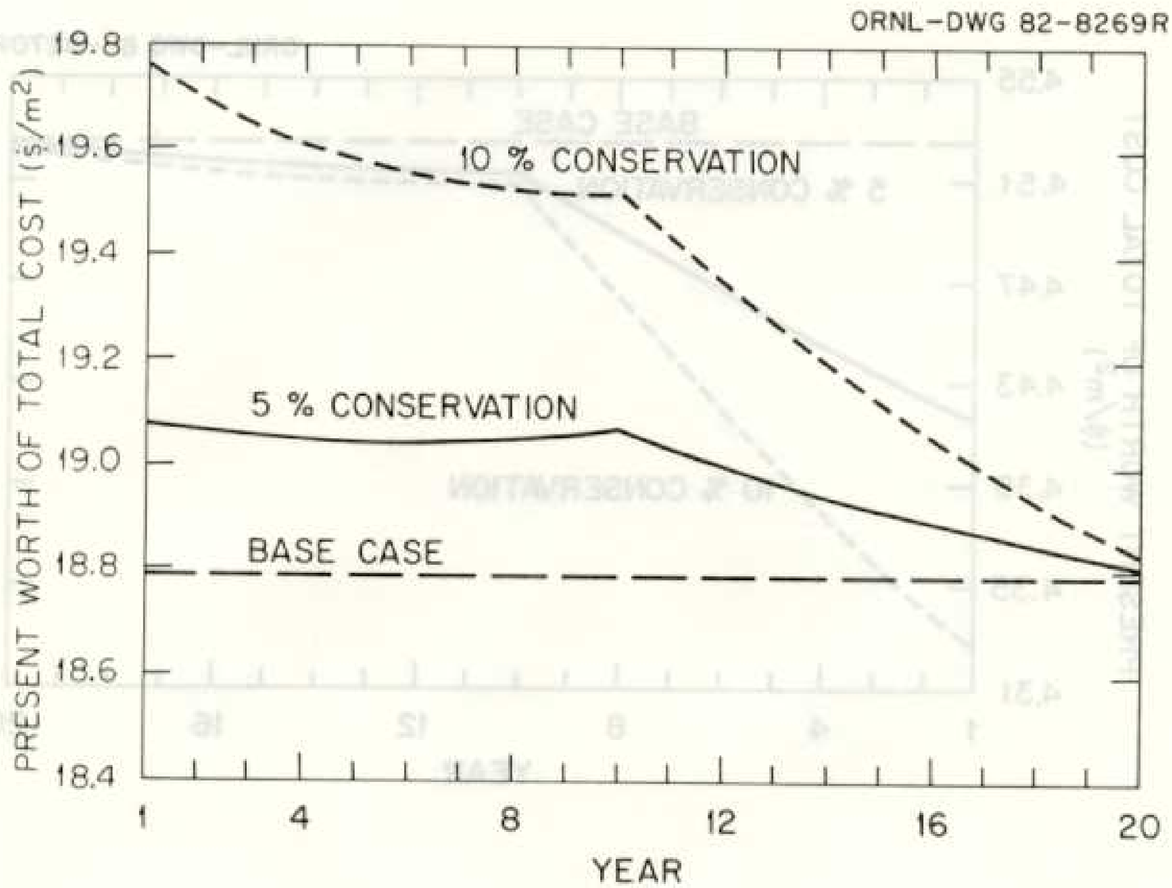

Fig. 7. Present worth of heating per square meter of commercial buildings as a function of the year in which conservation measures are installed (1980 dollars). Buildings connected to a district heating system in year 10. The base case is the case with district heating without end-user conservation in buildings.

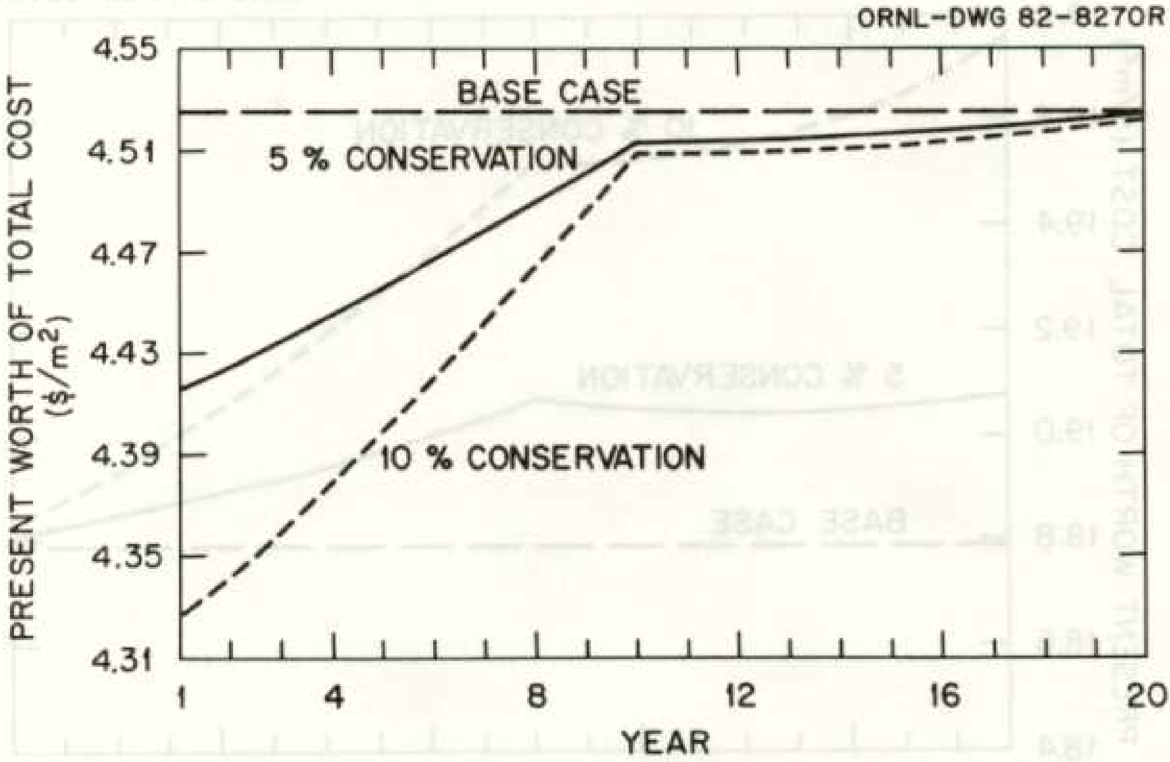

Fig. 8. Present worth of heating cost per square meter of multi-family buildings as a function of the year in which conservation measures are installed (1980 dollars). Building is connected to a district heating system in year 10. The base case is the case with district heating without end-user conservation in buildings.

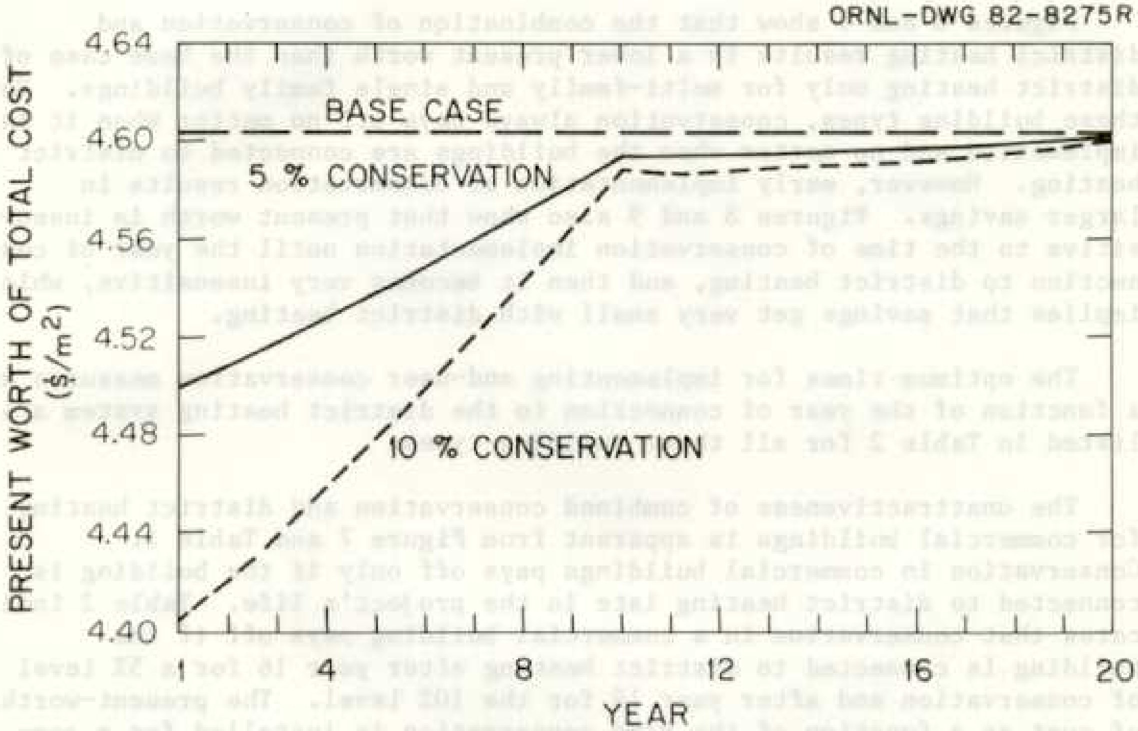

Fig. 9. Present worth of heating cost per square meter of single family buildings as a function of the year in which conservation measures are installed (1980 dollars). Building is connected to a district heating system in year 10. The base case is the case with district heating without end-user conservation in buildings.

be generalized to other connection years. Figure 7 shows that changes in present worth are very insensitive to when the conservation measure is implemented up to the year of connection to district heating. The cost becomes more sensitive later on, indicating that a substantial economic penalty is associated with improving the shells of commercial buildings served by district heating.

Figures 8 and 9 show that the combination of conservation and district heating results in a lower present worth than the base case of district heating only for multi-family and single family buildings. For these building types, conservation always pays off no matter when it is implemented and no matter when the buildings are connected to district heating. However, early implementation of conservation results in larger savings. Figures 8 and 9 also show that present worth is insensitive to the time of conservation implementation until the year of connection to district heating, and then it becomes very insensitive, which implies that savings get very small with district heating.

The optimum times for implementing end-user conservation measures as a function of the year of connection to the district heating system are listed in Table 2 for all three building types.

The unattractiveness of combined conservation and district heating for commercial buildings is apparent from Figure 7 and Table 2. Conservation in commercial buildings pays off only if the building is connected to district heating late in the project's life. Table 2 indicates that conservation in a commercial building pays off if the building is connected to district heating after year 16 for a 5% level of conservation and after year 18 for the 10% level. The present-worth of cost as a function of the year conservation is installed for a commercial building that is connected to district heating in year 18 is presented in Figure 10. For this case of connection to district heating in year 18, the total costs curve for 10% conservation (and 5% for that matter) dips below the baseline curve (no conservation). This is quite different from Figure 7 which is for connection to district heating in year 10. In that case, the total cost curves with conservation never dip below the baseline curve, indicating that conservation is never attractive. As indicated in Table 2, for multi-family and single family buildings the optimum year of connection to district heating is year one.

Table 2. OPTIMUM YEAR FOR CONSERVATION IMPLEMENTATION

Year of Connection to District Heating System	Commercial		Multi Family		Single Family	
	5% Con.	10% Con.	5% Con.	10% Con.	5% Con.	10% Con.
1	Never	Never	1	11	10	11
2	Never	Never	1	1	1	1
3	Never	Never	1	1	1	1
4	Never	Never	1	1	1	1
5	Never	Never	1	1	1	1
6	Never	Never	1	1	1	1
7	Never	Never	1	1	1	1
8	Never	Never	1	1	1	1
9	Never	Never	1	1	1	1
10	Never	Never	1	1	1	1
11	Never	Never	1	1	1	1
12	Never	Never	1	1	1	1
13	Never	Never	1	1	1	1
14	Never	Never	1	1	1	1
15	Never	Never	1	1	1	1
16	6	Never	1	1	1	1
17	6	Never	1	1	1	1
18	6	9	1	1	1	1
19	6	9	1	1	1	1
20	6	9	1	1	1	1

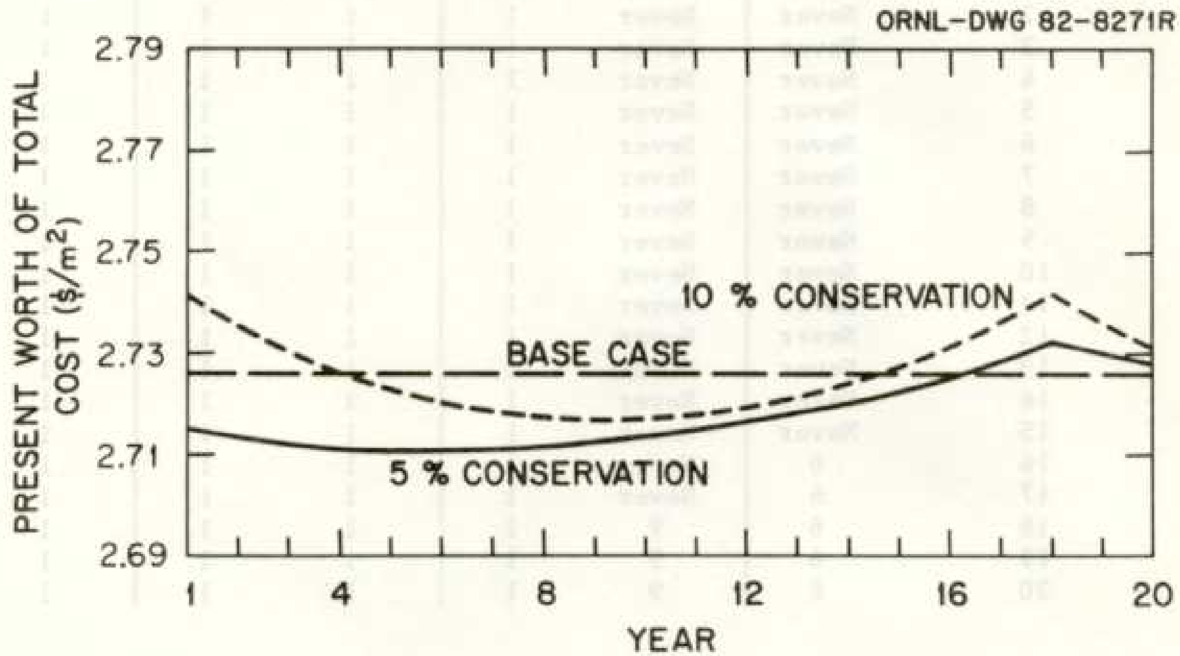

Fig. 10. Present worth of heating cost per square meter of commercial buildings as a function of the year in which conservation measures are installed (1980 dollars). Building is connected to a district heating system in year 18. The base case is the case with district heating without end-user conservation in buildings.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The problem under consideration has been an assessment of the economic attractiveness of simultaneous building shell improvements to reduce the heat load and district heating with cogeneration in the Minneapolis-St. Paul region. In general it was concluded that there are no substantial net economic benefits from reducing the heat loads by improving the shells of buildings connected to a district heating system. The attractiveness of conservation would improve if the reductions in cooling loads were considered in addition to the heating load reductions or if the costs of conservation measures were lower than we assumed. Of the three types of buildings investigated, two (single family and multi-family) offered potential savings in net present-worth of costs as the level of end-user conservation was increased from 5% to 10%. However, commercial buildings exhibited just the opposite effect on costs. Consequently, the total cost of providing heat to the entire Scenario A area was insensitive to changes in conservation level.

Changes in the implementation rates for conservation measures produced modest reductions in the net present-worth of cost. Again, the relative insensitivity of the cost was caused by the balancing effect of reductions in cost for single and multi-family residences and simultaneous increases in cost for commercial buildings.

Another part of the study was concerned with the effects of timing of conservation implementation on net present-worth of cost. The year in which conservation should be applied to each building type to minimize costs was calculated as a function of the year in which the connection to district heating occurs. It was found that conservation measures always appear economically attractive for single and multi-family dwellings no matter when they are connected to the district heating system. Furthermore, earlier connection times for these types of buildings result in larger savings. For commercial buildings it was discovered that conservation became attractive only when the buildings were connected to the district heating system in year 16 or later.

Only two modest levels of conservation were investigated in this study. The question regarding the best level of conservation to pursue (e.g., 30% versus 50%) was not addressed because a complete redesign and re-costing of the district heating system would be required. This level of effort was not possible in the present study.

It is recommended that further investigation of this problem be undertaken by challenging many of the assumptions noted throughout the report. The effect of nonlinear implementation rates is one example of this; another example would involve checking the sensitivity of the present worth of costs to changes in the cost of conservation measures from those shown in Figure 1.

A better data base is imperative to future studies of the district heating and conservation interaction. It is suggested that research be directed at systematically collecting conservation cost, building stock, and heat load data in large U.S. cities such as Minneapolis and St. Paul. These data would also be useful in evaluating the need for conservation programs and the success of any future government programs.

Finally, it is recommended that the redesign of the district heating system be explored to determine to what extent the total costs could be lowered by optimizing the design of the district heating system for lower levels of demand associated with higher levels of end-user conservation than considered in this study.

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APPENDIX

COMPUTER PROGRAMS

```
00010 REM THIS IS THE COMPUTER MODEL USED TO MAKE AN ECONOMIC
00020 REM EVALUATION OF APPLYING END-USER CONSERVATION
00030 REM MEASURES TO A DISTRICT HEATING SYSTEM
00040 REM IT CONTAINS TWO SEPERATE PROGRAMS WHOSE DESCRIPTIONS
00050 REM ARE GIVEN IN THEIR CORRESPONDING SECTIONS
00060 REM BOTH PROGRAMS MAKE USE OF THE SAME DATA STATEMENTS.
00070 REM CASH FLOWS START IN THE YEAR 1981 AND GO THROUGH
00080 REM THE YEAR 2000.THEREFORE, 1981 IS TAKEN AS THE YEAR 1.
00090 REM BUT WHEN DETERMINING THE PRESENT WORTH, ALL CASH
00100 REM FLOWS ARE DISCOUNTED BACK TO THE YEAR 1980.
00110 REM THEREFORE, A CASH FLOW IN A GIVEN YEAR N IS
00120 REM DISCOUNTED BACK (N+1) YEARS WHEN DETERMINING ITS PRESENT
00130 REM WORTH.
00140 REM
00150 REM
00160 REM
00170   DIM C(20),X1(20),X2(20),X3(20),Y1(20),Y2(20),Y3(20),L(20)
00180 DIM U1(20),U2(20),M1(20),M2(20),R(20),R2(20),H1(20)
00190 DIM O1(20),Y5(20),P(20),O2(20)
00200 DIM E1(20),E2(20),E3(20),F1(20),F2(20),F3(20),E5(20),E6(20)
00210 DIM E7(20),F5(20),F6(20),F7(20),G1(20),O3(20),Y6(20)
00220 DIM O4(20),C1(20),C2(20),P7(20)
00230 DIM C3(20),P8(20),E8(20),F8(20)
00240 DIM P9(20),L7(20),L8(20),L9(20),M7(20),M8(20),M9(20)
00250 DIM M(20),C7(20),C8(20),C9(20),O7(20),O8(20),O9(20)
00260 DIM X(20),L1(20)
00270 REM
00280 REM
00290 REM
00300 REM____________START READING THE DATA__________
00310 REM
00320 REM
00330 REM READ IN THE REVENUE REQUIREMENTS IN MILLION DOLARS (C(N))
00340 FOR N=1 TO 20
00350 READ C(N)
00360 NEXT N
00370 REM
00380 REM READ IN HEAT LOADS THAT ARE CONNECTED TO D.H. SYSTEM
00390 REM FOR EACH BUILDING TYPE (X1-COMMERCIAL, X2-MULTI FAMILY,
00400 REM X3-SINGLE FAMILY)
00410 FOR N=1 TO 20
00420 READ X1(N)
00430 NEXT N
00440 FOR N=1 TO 20
00450 READ X2(N)
00460 NEXT N
00470 FOR N=1 TO 20
00480 READ X3(N)
00490 NEXT N
00500 REM
00510 REM
00520 REM READ IN HEAT LOADS THAT ARE NOT CONNECTED TO D.H. SYSTEM
00530 REM FOR EACH BUILDING TYPE (Y1-COMMERCIAL, Y2-MULTI FAMILY,
00540 REM Y3-SINGLE FAMILY
00550 FOR N=1 TO 20
```

```
00560   READ Y1(N)
00570   NEXT N
00580   FOR N=1 TO 20
00590   READ Y2(N)
00600   NEXT N
00610   FOR N=1 TO 20
00620   READ Y3(N)
00630   NEXT N
00640   REM
00650   REM
00660   REM  READ IN HEAT LOSSES (L(N)).
00670   FOR N=1 TO 20
00680   READ L(N)
00690   NEXT N
00700   REM
00710   REM
00720   REM READ IN THE RUNNING COST FOR THE BASE LOAD (U1(N))
00730   FOR N=1 TO 20
00740   READ U1(N)
00750   NEXT N
00760   REM
00770   REM
00780   REM READ IN THE RUNNING COST FOR HEAT-ONLY BOILERS (U2(N))
00790   FOR N=1 TO 20
00800   READ U2(N)
00810   NEXT N
00820   REM
00830   REM
00840   REM READ IN THE MAINTENANCE COST IN MILLION DOLARS FOR
00850   REM THE BASE LOAD (M1(N))
00860   FOR N=1 TO 20
00870   READ M1(N)
00880   NEXT N
00890   REM
00900   REM
00910   REM READ IN THE MAINTENANCE COST IN MILLION DOLARS FOR
00920   REM HEAT-ONLY BOILERS (M2(N))
00930   FOR N=1 TO 20
00940   READ M2(N)
00950   NEXT N
00960   REM
00970   REM
00980   REM READ IN THE BASE LOAD/HEAT-ONLY RATIO (R(N))
00990   FOR N=1 TO 20
01000   READ L(N)
01010   NEXT N
01020   REM
01030   REM
01040   REM READ IN THE COST OF HEAT FOR THE DEMAND NOT CONNECTED TO
01050   REM D.H. SYSTEM (R2(N))
01060   FOR N=1 TO 20
01070   READ R2(N)
01080   NEXT N
01090   REM
01100   REM
```

```
01110   REM READ IN THE LOAD DURATION (V) AND HOURS IN A YEAR (W)
01120   READ V,W
01130   REM
01140   REM
01150   REM READ IN THE FLOOR AREA ESTIMATES (C5-COMMERCIAL,
01160   REM M5-MULTI FAMILY, S5-SINGLE FAMILY)
01170   READ C5,M5,S5
01180   REM
01190   REM
01200   REM READ IN THE INFLATION RATE (Q)
01210   READ Q
01220   REM
01230   REM
01240   REM READ IN THE DISCOUNT RATE (I)
01250   READ I
01260   REM
01270   REM
01280   REM
01290   PRINT"IF YOU WANT TO RUN THE SECOND PROGRAM TYPE 0";
01300   INPUT A8
01310   PRINT
01320   PRINT
01330   IF A8=0 GO TO 5200
01340   REM
01350   REM
01360   REM*****************************************************
01370   REM____________START THE FIRST PROGRAM__________
01380   REM
01390   REM THIS PROGRAM DETERMINES THE PRESENT WORTH OF THE TOTAL
01400   REM COST OF SUPPLYING THE HEAT DEMAND OF THE ENTIRE
01410   REM AREA OVER A 20 YEAR TIME PERIOD FOR THE OPTIONS OF
01420   REM DISTRICT HEATING ONLY AND THE COMBINATION OF CONSERVATION
01430   REM AND DISTRICT HEATING
01440   REM
01450   REM
01460   REM
01470   REM  DIVIDE THE CAPITAL COST OF D.H. SYSTEM,HEAT LOSSES AND
01480   REM  MAINTENANCE COST BETWEEN THE THREE BUILDING TYPES
01490   REM  ACCORDING TO THEIR CONNECTED LOADS (7-COMMERCIAL,
01500   REM  8-MULTI FAMILY, 9-SINGLE FAMILY)
01510   FOR N=1 TO 20
01520   X(N)=X1(N)+X2(N)+X3(N)
01530   C7(N)=C(N)*X1(N)/X(N)
01540   C8(N)=C(N)*X2(N)/X(N)
01550   C9(N)=C(N)*X3(N)/X(N)
01560   L7(N)=L(N)*X1(N)/X(N)
01570   L8(N)=L(N)*X2(N)/X(N)
01580   L9(N)=L(N)*X3(N)/X(N)
01590   M7(N)=(M1(N)+M2(N))*X1(N)/X(N)
01600   M8(N)=(M1(N)+M2(N))*X2(N)/X(N)
01610   M9(N)=(M1(N)+M2(N))*X3(N)/X(N)
01620   NEXT N
01630   REM
01640   REM
01650   REM  ____START THE TOTAL BASE CASE______
```

```
01660   REM       D.H. SYTEM WITHOUT CON.
01670     FOR N=1 TO 20
01680   REM  DETERMINE THE ANNUAL HEAT PRODUCTION OF D.H. SYSTEM
01690     H1(N)= (X1(N)+X2(N)+X3(N))*V+L(N)*W
01700   REM  DIVIDE THE ANNUAL HEAT PRODUCTION BETWEEN THE BASE
01710   REM  LOAD PLANTS AND HEAT-ONLY BOILERS
01720   B=R(N)*H1(N)/(1+R(N))
01730   H=H1(N)/(1+R(N))
01740   REM  DETERMINE THE ANNUAL OPERATING COST FOR D.H. SYSTEM
01750   O1(N)=(B*U1(N)+H*U2(N))/1000000+M1(N)+M2(N)
01760   REM  DETERMINE THE ANNUAL DEMAND OUTSIDE THE D.H. SYSTEM
01770   H2=(Y1(N)+Y2(N)+Y3(N))*V
01780   REM  DETERMINE THE ANNUAL OPERATING COST OUTSIDE
01790   O2(N)=H2*R2(N)/1000000
01800   REM  DETERMINE THE TOTAL ANNUAL COST AND ITS PW.
01810   Y5(N)=O1(N)+O2(N)+C(N)
01820   P(N)=Y5(N)/(1+I)**(N+1)
01830   NEXT N
01840   REM  OUTPUT THE TOTAL BASE CASE
01850   PRINT"        TOTAL BASE CASE"
01860   PRINT
01870   PRINT"OPER.COST.       OPER.COST.       TOTAL          CUMM. PW."
01880   PRINT"IN               OUTSIDE          OPER.AND          OF"
01890   PRINT"SYSTEM           SYSTEM           CAP.COST         COST"
01900   PRINT"__________       __________       ________       ________"
01910   REM  INITIALIZE THE CUMMULATIVE PW TO ZERO
01920     P5=0
01930     FOR N=1 TO 20
01940     P5=P5+P(N)
01950   PRINT O1(N),O2(N),Y5(N),P5
01960     NEXT N
01970   PRINT
01980   PRINT
01990   REM
02000   REM
02010   REM____BASE CASE COMMERCIAL___
02020   REM
02030   FOR N=1 TO 20
02040   REM DETERMINE THE ANNUAL HEAT SUPPLIED BY BASE LOAD PLANTS
02050   REM AND HEAT ONLY BOILERS TO COMMERCIAL BUILDINGS
02060   B=R(N)*(X1(N)*V+L7(N)*W)/(1+R(N))
02070   H=(X1(N)*V+L7(N)*W)/(1+R(N))
02080   REM DETERMINE THE TOTAL ANNUAL OPERATING COST
02090   O7(N)=(H*U2(N)+B*U1(N)+(Y1(N)*V)*R2(N))/1000000
02100   REM DETERMINE THE PW OF TOTAL ANNUAL COST
02110   P7(N)=(O7(N)+C7(N)+M7(N))/(1+I)**(N+1)
02120   NEXT N
02130   PRINT"  BASE CASE COMMERCIAL"
02140   PRINT
02150   PRINT"YEARS          PW OF Y. C.     CUM. PW"
02160   PRINT"_____          __________      _______"
02170   REM INITIALIZE THE CUMMULATIVE PW OF TOTAL COST TO ZERO
02180   P5=0
02190   FOR N=1TO 20
02200   P5=P5+P7(N)
```

```
02210   PRINT N,P7(N),P5
02220   NEXT N
02230   PRINT
02240   PRINT
02250   REM
02260   REM
02270   REM____BASE CASE MULTIFAMILY______
02280   REM
02290   FOR N=1 TO 20
02300   REM DETERMINE THEANNUAL HEAT SUPPLIED BY BASE LOAD PLANTS
02310   REM AND HEAT-ONLY BOILERS TO MULTI-FAMILY BUILDINGS
02320   B=R(N)*(X2(N)*V+L8(N)*W)/(1+R(N))
02330   H=(X2(N)*V+L8(N)*W)/(1+R(N))
02340   REM DETERMINE THE TOTAL ANNUAL OPERATING COST
02350   O8(N)=(H*U2(N)+B*U1(N)+Y2(N)*V*R2(N))/1000000
02360   REM DETERMINE THE PW OF TOTAL ANNUAL COST
02370   P8(N)=(O8(N)+C8(N)+M8(N))/(1+I)**(1+N)
02380   NEXT N
02390   PRINT"  BASE CASE MULTI FAMILY"
02400   PRINT
02410   PRINT"YEARS          PW OF Y. C.      CUM. PW"
02420   PRINT"_____          ___________      _______"
02430   REM INITIALIZE  THE CUMMULATIVE PW OF TOTAL COST TO ZERO
02440   P5=0
02450   FOR N=1  TO 20
02460   P5=P5+P8(N)
02470   PRINT N,P8(N),P5
02480   NEXT N
02490   PRINT
02500   PRINT
02510   REM
02520   REM
02530   REM____BASE CASE SINGLE FAMILY_____
02540   REM
02550   FOR N=1 TO 20
02560   REM DETERMINE THE ANNUAL HEAT SUPPLIED BY BASE LOAD PLANTS
02570   REM AND HEAT-ONLY BOILERS TO SINGLE FAMILY RESIDENCES
02580   B=R(N)*(X3(N)*V+L9(N)*W)/(1+R(N))
02590   H=(X3(N)*V+L9(N)*W)/(1+R(N))
02600   REM DETERMINE THE TOTAL ANNUAL OPERATING COST
02610   O9(N)=(H*U2(N)+B*U1(N)+Y3(N)*V*R2(N))/1000000
02620   REM DETERMINE THE PW OF TOTAL ANNUAL COST
02630   P9(N)=(O9(N)+C9(N)+M9(N))/(1+I)**(1+N)
02640   NEXT N
02650   PRINT"  BASE CASE SINGLE FAMILY"
02660   PRINT
02670   PRINT"YEARS          PW OF Y. C.      CUM. PW"
02680   PRINT"_____          ___________      _______"
02690   REM INITIALIZE THE CUMMULATIVE PW OF COST TO ZERO
02700   P5=0
02710   FOR N=1 TO 20
02720   P5=P5+P9(N)
02730   PRINT N,P9(N),P5
02740   NEXT N
02750   PRINT
```

```
02760   PRINT
02770   REM
02780   REM
02790   REM
02800   REM__________COMBINATION OF CONSERVATION AND ___________
02810   REM          DISTRICT HEATING STARTS
02820   REM
02830   REM
02840     PRINT "INPUT THE IMPLEMENTATION RATES ";
02850   REM T1-COMMERCIAL, T2-MULTI FAMILY, T3-SINGLE FAMILY
02860     INPUT T1,T2,T3
02870     PRINT "INPUT % ENERGY SAVINGS RATE ";
02880   REM S1-COMMERCIAL, S2-MULTI FAMILY, S3-SINGLE FAMILY
02890     INPUT S1,S2,S3
02900     PRINT "INPUT COST PER SQ. FT.";
02910   REM C6-COMMERCIAL, M6-MULTI FAMILY, S6-SINGLE FAMILY
02920     INPUT C6,M6,S6
02930   PRINT
02940   REM
02950   REM
02960   REM DETERMINE THE HEAT LOADS WITH CONSERVATION INSIDE AND
02970   REM OUTSIDE THE DISTRICT HEATING SYSTEM FOR ALL THREE
02980   REM BUILDING TYPES(E-INSIDE, F-OUTSIDE)
02990     FOR N=1 TO 20
03000   T4=N*T1
03010   T5=N*T2
03020   T6=N*T3
03030   IF T4<=1 GO TO 3050
03040   T4=1
03050   IF  T5<=1 GO TO 3070
03060   T5=1
03070   IF T6<=1 GO TO 3090
03080   T6=1
03090   E1(N)=X1(N)-X1(N)*T4*S1
03100   E2(N)=X2(N)-X2(N)*T5*S2
03110   E3(N)=X3(N)-X3(N)*T6*S3
03120   F1(N)=Y1(N)-Y1(N)*T4*S1
03130   F2(N)=Y2(N)-Y2(N)*T5*S2
03140   F3(N)=Y3(N)-Y3(N)*T6*S3
03150   REM DETERMINE THE REDUCTION IN HEAT LOADS WITH CONSERVATION
03160   E5(N)=X1(N)-E1(N)
03170   E6(N)=X2(N)-E2(N)
03180   E7(N)=X3(N)-E3(N)
03190   F5(N)=Y1(N)-F1(N)
03200   F6(N)=Y2(N)-F2(N)
03210   F7(N)=Y3(N)-F3(N)
03220     NEXT N
03230   REM
03240   REM
03250   REM
03260   REM START THE CALCULATION OF THE COST ITEMS
03270   REM
03280   REM
03290     FOR N=1 TO 20
03300   REM
```

```
03310   REM DETERMINE THE ANNUAL HEAT PRODUCTION BY D.H. SYSTEM
03320   G1(N)=(E1(N)+E2(N)+E3(N))*V+L(N)*W
03330   REM DIVIDE THE ANNUAL HEAT PRODUCTION BETWEEN THE BASE LOAD
03340   REM PLANTS AND HEAT ONLY BOILERS
03350   B=R(N)*G1(N)/(1+R(N))
03360   H=G1(N)/(1+R(N))
03370   REM DETERMINE THE ANNUAL OPEATING AND MAINTENANCE COST OF
03380   REM DISTRICT HEATING SYSTEM
03390   O3(N)=(B*U1(N)+H*U2(N))/1000000+M1(N)+M2(N)
03400   REM DETERMINE THE ANNUAL OPERITING COST FOR OUTSIDE THE
03410   REM D.H. SYSTEM
03420   REM
03430   O4(N)=(F1(N)+F2(N)+F3(N))*V*R2(N)/1000000
03440   REM CALCULATE THE COST OF CONSERVATION FOR COMMERCIAL
03450   T4=N*T1
03460   IF T4<=1 GO TO 3490
03470   C1(N)=0
03480   GO TO 3510
03490   C1(N)=(C5*T1*C6*(1+Q)**(N+1))*(20-(N-1))/20
03500   REM
03510   REM CALCULATE THE COST OF CONSERVATION FOR MULTI FAMILY
03520   T5=N*T2
03530   IF T5<=1 GO TO 3560
03540   C2(N)=0
03550   GO TO 3580
03560   C2(N)=(M5*T2*M6*(1+Q)**(N+1))*(20-(N-1))/20
03570   REM
03580   REM CALCULATE THE COST OF CONSERVATION FOR SINGLE FAMILY
03590   T6=N*T3
03600   IF T6<=1 GO TO 3630
03610   C3(N)=0
03620   GO TO 3660
03630   C3(N)=(S5*T3*S6*(1+Q)**(N+1))*(20-(N-1))/20
03640   REM
03650   REM
03660   REM DETERMINE THE TOTAL ANNUAL COST AND ITS PW
03670   Y6(N)=O3(N)+O4(N)+C(N)+C1(N)+C2(N)+C3(N)
03680   P(N)=Y6(N)/(1+I)**(N+1)
03690   REM
03700   REM
03710   REM START DETERMINIG THE TOTAL ANNUAL COST FOR COMMERCIAL
03720   REM
03730   REM ANNUAL HEAT SUPPLIAD BY BASE LOAD PLANTS AND HEAT-ONLY
03740   REM BOILERS TO COMMERCIAL BUILDINGS
03750   B=R(N)*(E1(N)*V+L7(N)*W)/(1+R(N))
03760   H=(E1(N)*V+L7(N)*W)/(1+R(N))
03770   REM TOTAL ANNUAL OPERATING COST OF COMMERCIAL
03780   O7(N)=(H*U2(N)+B*U1(N)+F1(N)*V*R2(N))/1000000
03790   REM PW OF TOTAL ANNUAL COST OF COMMERCIAL
03800   P7(N)=(O7(N)+C7(N)+M7(N)+C1(N))/(1+I)**(1+N)
03810   REM
03820   REM
03830   REM START DETERMINING THE TOTAL ANNUAL COST FOR MULTI FAMILY
03840   REM
03850   REM ANNUAL HEAT SUPPLIED BY BASE LOAD PLANTS AND HEAT ONLY
```

```
03860  REM BOILERS TO MULTI FAMILY BUILDINGS
03870  B=R(N)*(E2(N)*V+L8(N)*W)/(1+R(N))
03880  H=(E2(N)*V+L8(N)*W)/(1+R(N))
03890  REM TOTAL ANNUAL OPERATING COST OF MULTI FAMILY
03900  O8(N)=(H*U2(N)+B*U1(N)+F2(N)*V*R2(N))/1000000
03910  REM PW OF TOTAL ANNUAL COST OF MULTI FAMILY
03920  P8(N)=(O8(N)+C8(N)+M8(N)+C2(N))/(1+I)**(1+N)
03930  REM
03940  REM
03950  REM START DETERMINING THE TOTAL ANNUAL COST FOR SINGLE FAMILY
03960  REM
03970  REM ANNUAL HEAT SUPPLIED BY BASE LOAD PLANTS AND HEAT ONLY
03980  REM BOILERS TO SINGLE FAMILY RESIDENCES
03990  B=R(N)*(E3(N)*V+L9(N)*W)/(1+R(N))
04000  H=(E3(N)*V+L9(N)*W)/(1+R(N))
04010  REM TOTAL ANNUAL OPERATING COST OF SINGLE FAMILY
04020  O9(N)=(H*U2(N)+B*U1(N)+F3(N)*V*R2(N))/1000000
04030  REM PW OF TOTAL ANNUAL COST OF SINGLE FAMILY
04040  P9(N)=(O9(N)+C9(N)+M9(N)+C3(N))/(1+I)**(1+N)
04050  REM
04060  REM
04070    NEXT N
04080  REM
04090  REM
04100  REM
04110  REM ___________OUTPUT STARTS___________
04120  REM
04130  PRINT
04140  PRINT
04150  PRINT"IF YOU DON'T WANT THE DEMAND PROFILE TYPE 0"
04160  INPUT A5
04170  IF A5=0 GO TO 4540
04180  PRINT
04190  REM
04200  REM
04210  PRINT"     DEMAND PROFILE"
04220  PRINT
04230  PRINT"YEAR        DEM INSIDE      DEM OUTSIDE"
04240  PRINT"____        __________      __________"
04250  FOR N=1 TO 20
04260  E9=E1(N)+E2(N)+E3(N)
04270  F9=F1(N)+F2(N)+F3(N)
04280  PRINT N,E9,F9
04290  NEXT N
04300  PRINT
04310  PRINT
04320  PRINT"YEAR         RED IN DEM      RED IN DEM"
04330  PRINT"              INSIDE          OUTSIDE"
04340  PRINT"____        __________      __________"
04350  FOR N=1 TO 20
04360  E9=E5(N)+E6(N)+E7(N)
04370  F9=F5(N)+F6(N)+F7(N)
04380  PRINT N,E9,F9
04390  NEXT N
04400  PRINT
```

```
04410  PRINT
04420  PRINT"   ANNUAL ENERGY SAVINGS"
04430  PRINT
04440  PRINT"INSIDE        CUM INSIDE        OUTSIDE      CUM OUTSIDE"
04450  PRINT"______        __________        _______      ___________"
04460   PRINT
04470  FOR N=1 TO 20
04480  U5=(E5(N)+E6(N)+E7(N))*V
04490  U6=U6+U5
04500  U7=(F5(N)+F6(N)+F7(N))*V
04510  U8=U8+U7
04520  PRINT U5,U6,U7,U8
04530  NEXT N
04540  PRINT
04550  PRINT
04560  PRINT"   TOTAL SYSTEM WITH CONSERVATION"
04570  PRINT
04580  PRINT"OPER.COST.      OPER.COST     TOTAL        CUM. PW."
04590  PRINT"IN             OUTSIDE       OPER.AND      OF"
04600  PRINT"SYSTEM         SYSTEM        CAP.COST      COST"
04610  PRINT"__________     __________    __________    __________"
04620  P5=0
04630  FOR N=1 TO 20
04640  P5=P5+P(N)
04650  PRINT O3(N),O4(N),Y6(N),P5
04660  NEXT N
04670  PRINT
04680  PRINT
04690  PRINT" COMMERCIAL BUILDINGS WITH CONSERV."
04700  PRINT
04710  PRINT"YEARS          PW OF Y. C.     CUM. PW"
04720  PRINT"_____          ___________     _______"
04730  P5=0
04740  FOR N=1 TO 20
04750  P5=P5+P7(N)
04760  PRINT N,P7(N),P5
04770  NEXT N
04780  PRINT
04790  PRINT
04800  PRINT" MULTI FAMILY BUILDINGS WITH CONSERV."
04810  PRINT
04820  PRINT"YEARS          PW OF Y. C.     CUM. PW"
04830  PRINT"_____          ___________     _______"
04840  P5=0
04850  FOR N=1 TO 20
04860  P5=P5+P8(N)
04870  PRINT N,P8(N),P5
04880  NEXT N
04890  PRINT
04900  PRINT
04910  PRINT" SINGLE FAMILY HOUSES WITH CONSERV."
04920  PRINT
04930  PRINT"YEARS          PW OF Y. C.     CUM. PW"
04940  PRINT"_____          ___________     _______"
04950  P5=0
```

```
04960   FOR N=1 TO 20
04970   P5=P5+P9(N)
04980   PRINT N,P9(N),P5
04990   NEXT N
05000   PRINT
05010   PRINT
05020   REM
05030   REM
05040     PRINT"IF YOU WANT TO RUN FOR A DIFFERENT CASE"
05050     PRINT"TYPE 0,OTHERWISE 1";
05060     INPUT A
05070     IF A=0 GO TO 2840
05080   GO TO 7850
05090   REM
05100   REM
05110   REM
05120   REM
05130   REM*****************************************************
05140   REM---------START THE SECOND PROGRAM----------
05150   REM THIS PROGRAM DETERMINES THE EFFECTS OF
05160   REM CONSERVATION IMPLEMENTATION TIME BY USING
05170   REM A SINGLE SQUARE FOOT APPROACH
05180   REM
05190   REM
05200   PRINT
05210   PRINT
05220   PRINT"TYPE 1 FOR COMMERCIAL, 2 FOR MULTI FAMILY"
05230   PRINT"3 FOR SINGLE FAMILY";
05240   INPUT A9
05250   PRINT"INPUT THE CONSERVATION LAVEL";
05260   INPUT S
05270   PRINT"INPUT THE COST PER SQUARE FEET";
05280   INPUT C9
05290   PRINT"INPUT THE ANNUAL DEMAND PER SQUARE FEET";
05300   INPUT D
05310   PRINT
05320   PRINT
05330   PRINT
05340   REM
05350   REM DETERMINE THE ANNUAL HEAT LOSS  PER MW-HR OF CONNECTED
05360   REM ANNUAL DEMAND
05370   FOR N=1 TO 20
05380   L1(N)=L(N)*W/((X1(N)+X2(N)+X3(N))*V)
05390   NEXT N
05400   REM
05410   REM
05420   REM OUTPUT PREPARATION
05430   IF A9=2 GO TO 5470
05440   IF A9=3 GO TO 5490
05450   PRINT"COMMERCIAL BUILDING"
05460   GO TO 5500
05470   PRINT"MULTI FAMILY BUILDING"
05480   GO TO 5500
05490   PRINT"SINGLE FAMILY HOUSE"
05500   PRINT"LAVEL OF CONSERVATION=";
```

```
05510   PRINT S
05520   REM
05530   REM
05540   REM START THE LOOP FOR THE YEAR OF CONNECTION TO D.H.
05550   REM SYSTEM (N1)
05560   FOR N1=1 TO 20
05570   REM
05580   REM INITIALIZE THE MINIMUM PW OF COST AND OPTIMUM CONSERVATION
05590   REM IMPLEMENTATION YEAR TO ZERO--ZERO IS INTERPRETED AS THE
05600   REM CASE FOR WHICH THE CONSERVATION IS NEVER IMPLEMENTED
05610   M(N1)=0
05620   M9(N1)=0
05630   REM
05640   REM ____START THE BASE CASE (NO CONSERVATION)____
05650   REM
05660   FOR N=1 TO 20
05670   IF N>=N1  GO TO 5720
05680   REM ANNUAL OPER. COST IF THE BUILD. IS NOT CONNECTED TO D.H.
05690   O=D*R2(N)
05700   GO TO 5770
05710   REM ANNUAL HEAT PRODUCTION BY D.H. SYSTEM
05720   D1=D+L1(N)*D
05730   REM ANNUAL OPERATING COST IF THE BUILD. IS CONNECTED TO D.H.
05740   O=(R(N)*D1/(1+R(N)))*U1(N)+(D1/(1+R(N)))*U2(N)
05750   REM ADD THE PW OF ANNUAL OPERTING COST TO MINIMUM PW OF
05760   REM TOTAL COST
05770   M(N1)=M(N1)+O/(1+I)**(N+1)
05780   NEXT N
05790   PRINT
05800   PRINT
05810   PRINT"YEAR OF CONNECTION TO D.H. =";
05820   PRINT N1
05830   PRINT"BASE CASE COST=";
05840   PRINT M(N1)
05850   REM
05860   REM
05870   REM
05880   REM -----START THE CASE WITH CONSERVATION______
05890   REM
05900   REM START THE LOOP FOR THE YEAR OF CONSERVATION
05910   REM IMPLEMENTATION (N2)
05920   FOR N2=1 TO 20
05930   REM
05940   REM INITIALIZE PW OF TOTAL COST (P) TO ZERO
05950   P=0
05960   D2=D
05970   FOR N=1 TO 20
05980   IF N<> N2 GO TO 6010
05990   REM DETERMINE THE ANNUAL DEMAND WITH CONSERVATION
06000   D2=D2-D2*S
06010   IF N>=N1 GO TO 6060
06020   REM ANNUAL OPER. COST IF THE BUILD. IS NOT CONNECTED TO D.H.
06030   O=D2*R2(N)
06040   GO TO 6100
06050   REM ANNUAL HEAT PRODUCTION BY D.H. SYSTEM
```

```
06060  D1=D2+L1(N)*D
06070  REM ANNUAL OPER. COST IF THE BUILD. IS CONNECTED TO D.H.
06080  O=(R(N)*D1/(1+R(N)))*U1(N)+(D1/(1+R(N)))*U2(N)
06090  REM ADD PW OF ANNUAL OPER. COST TO PW OF TOTAL OPER. COST
06100  P=P+O/(1+I)**(N+1)
06110  NEXT N
06120  REM
06130  REM  DETERMINE PW OF TOTAL COST FOR THIS CASE
06140  T=P+((C9*(1+Q)**(N2+1))*(20-(N2-1))/20)/(1+I)**(N2+1)
06150  REM OUTPUT THE RESULT OF THIS CASE
06160  PRINT T;
06170  PRINT ",";
06180  REM
06190  REM
06200  REM COMPARE THE RESULT OF THIS CASE WITH THE MINIMUM AND
06210  REM IF IT IS SMALLER SET THE MINIMUM EQUAL TO IT
06220  IF T>M(N1) GO TO 6280
06230  M(N1)=T
06240  M9(N1)=N2
06250  REM
06260  REM
06270  REM FINISH THE LOOPS
06280  NEXT N2
06290  NEXT N1
06300  REM
06310  REM
06320  REM START THE OUTPUT OF THE OPTIMUM YEARS OF CONSERVATION
06330  REM IMPLEMENTATION
06340  PRINT
06350  PRINT
06360  PRINT"YEAR OF          OPT. YEAR        PWC"
06370  PRINT"CONNECTION       FOR"
06380  PRINT"TO D.H.          CONSERVATION"
06390  PRINT"__________       ____________     ___"
06400  FOR N1=1 TO 20
06410  PRINT N1,M9(N1),M(N1)
06420  NEXT N1
06430  REM
06440  REM
06450  REM _____END OF SECOND PROGRAM_____
06460  REM
06470  REM
06480  REM
06490  REM******************************************************
06500  REM ______________DATA__________________
06510  REM
06520  REM THE FOLLOWING DATA IS OPTAINED FROM THE STUDSVIK REPORT.
06530  REM PAGE AND TABLE NUMBERS IN THIS REPORT IS GIVEN FOR
06540  REM EACH DATA ITEM.
06550  REM
06560  REM
06570  REM
06580  REM             ______________________________
06590  REM REVENUE REQUIREMENTS (C(N))-COLUMN 7. OF TABLE 9.12 ON
06600  REM PAGE 103
```

```
06610   DATA 3.52,6.74,10.38,14.99,19.42,24.28,29.16,34.31,38.17,40.63
06620   DATA 45.41,50.44,56.36,65.61,73.54,84.06,89.26,91.45,94.47,93.67
06630 REM
06640 REM
06650 REM
06660 REM HEAT LOADS THAT ARE CONNECTED TO D.H. SYSTEM FOR
06670 REM EACH BUILDING TYPE (X1(N),X2(N),X3(N))-
06680 REM COL.2 OF TABLE 6.2 ON PAGE 68 GIVES THE HEAT LOADS OF
06690 REM ALL DISTRICT HEATING AREAS.
06700 REM THE LOAD OF EACH DISTRICT IS DIVIDED BETWEEN THE THREE
06710 REM BUILDING TYPES ACCORDING TO THE DESCRIPTIONS GIVEN
06720 REM ON PAGES 19 THROUGH 29.THEN THE CONNECTED LOAD FOR
06730 REM EACH YEAR IS DETERMINED FROM THE CONNECTION SCHEDULE OF
06740 REM DISTRICTS GIVEN IN FIG.9.2 ON PAGE 82.
06750 DATA 75.95,157.2,275.85,388.65,505.95,544.11,585.16,616.91
06760 DATA 646.81,667.66,721.08,778.6,819.86,828.16,867.46,873.76
06770 DATA 878.76,890.6,902.44,907.44
06780 DATA 18.05,36.8,73.15,140.35,214.59,351.79,487.14,639.64
06790 DATA 754.24,829.39,907.97,970.2,1027.69,1118.64,1237.89
06800 DATA 1241.64,1245.39,1266.24,1287.09,1290.84
06810 DATA 0,0,0,0,0,5.6,11.2,16.95,22.49,22.49,22.49,38.7,54.95
06820 DATA 95.7,136.45,203.4,302.65,351.96,401.27,417.52
06830 REM
06840 REM
06850 REM
06860 REM HEAT LOADS THAT ARE NOT CONNECTED TO DISTRICT HEATING
06870 REM SYSTEM FOR EACH BUILDING TYPE (Y1(N),Y2(N),Y3(N))-
06880 REM HEAT LOAD NOT CONNECTED TO D.H. IN EACH YEAR FOR A GIVEN
06890 REM BUILDING TYPE IS OPTAINED BY SUBSTRUCTING THE CONNECTED
06900 REM LOAD IN THAT YEAR FOR THAT BUILDING TYPE FROM THE TOTAL
06910 REM LOAD FOR THAT BUILDING TYPE.
06920 DATA 831.49,750.19,631.54,518.74,400.98,362.76,321.73
06930 DATA 289.98,260.08,239.23,185.81,128.29,87.03,78.73,39.43
06940 DATA 33.13,28.13,16.29,5,0
06950 DATA 1272.79,1254.04,1217.79,1150.59,1076.35,939.15,803.8
06960 DATA 651.3,536.7,461.55,382.97,320.74,263.25,172.3,53.05
06970 DATA 49.3,45.55,24.7,3.75,0
06980 DATA 417.52,417.52,417.52,417.52,417.52,411.92,406.32
06990 DATA400.57,395.07,395.07,395.07,378.82,362.57,321.82,281.07
07000 DATA 214.12,114.87,65.56,16.25,0
07010 REM
07020 REM
07030 REM
07040 REM HEAT LOSS (L(N))- OPTAINED FROM COL.8 OF TABLE 9.7 ON
07050 REM PAGE 97.
07060   DATA 2.6,5.5,9.8,14.8,20.3,27,33.6,40.6,45.5,48.2,51.9,56.3,60.1
07070   DATA 64.6,70.8,74.2,79,82.7,86.4,87.7
07080 REM
07090 REM
07100 REM
07110 REM RUNNING COST OF BASE LOAD (U1(N))-
07120 REM OPTAINED BY SUBSTRUCTING THE MAINTENANCE COST GIVEN
07130 REM IN COL.8 OF TABLE 9.8 ON PAGE 98 FROM THE TOTAL
07140 REM OPERATING AND MAINTENANCE COST GIVEN IN COL.6 OF THE
07150 REM SAME TABLE.
```

```
07160     DATA 3.74,3.95,4.15,4.35,4.57,4.89,5.25,5.58,6.14,6.71,7.03,7.38
07170     DATA 7.71,8.07,8.46,8.82,9.3,9.73,10.2,10.67
07180   REM
07190   REM
07200   REM
07210   REM RUNNING COST OF HEAT ONLY BOILERS (U2(N))-
07220   REM OPTAINED BY SUBSTRUCTING THE MAINTENANCE COST GIVEN
07230   REM IN COL.9 OF TABLE 9.8 ON PAGE 98 FROM THE TOTAL
07240   REM OPERATING AND MAINTENANCE COST GIVEN IN COL.7 OF THE
07250   REM SAME TABLE.
07260     DATA 11.01,11.81,12.61,13.42,14.23,15.36,16.17,17.27,18.75,19.89
07270     DATA 21.33,23.13,24.55,26.7,28.45,30.56,32.92,35.35,37.68,40.13
07280   REM
07290   REM
07300   REM
07310   REM MAINTENANCE COST OF BASE LOAD (M1(N))-
07320   REM OPTAINED FROM TABLE 9.8 ON PAGE 98 BY MULTIPLYING
07330   REM THE MAINTENANCE COST PER  MWHR GIVEN IN COL.8 WITH
07340   REM THE TWHRS OF ENERGY PRODUCED GIVEN IN COL.4.
07350     DATA 0,.8332,1.23,1.6121,1.9278,2.4042,2.9252,3.328,3.6639,4.12
07360     DATA 4.6656,5.2589,6.0425,7.2085,8.2713,10.4106,11.5787,12.3549
07370     DATA 13.3207,14.0095
07380   REM
07390   REM
07400   REM
07410   REM MAINTENANCE COST OF HEAT-ONLY BOILERS (M2(N))-
07420   REM OPTAINED FROM TABLE 9.8 ON PAGE 98 BY MULTIPLYING
07430   REM THE MAINTENANCE COST PER MWHR GIVEN IN COL.9 WITH
07440   REM THE TWHRS OF ENERGY PRODUCED GIVEN IN COL. 5.
07450     DATA .0484,.0527,.0539,.1613,.2933,.3505,.4183,.5768,.7171,.746
07460     DATA .871,1.0837,1.1683,1.3467,1.4042,1.4545,1.5247,1.5884
07470     DATA 1.653,1.7457
07480   REM
07490   REM
07500   REM
07510   REM BASE LOAD/HEAT ONLY RATIO (R(N))-
07520   REM OPTAINED FROM TABLE 9.8 ON PAGE 98 BY DIVIDING THE
07530   REM BASE LOAD HEAT PRODUCTION GIVEN IN COL. 4 WITH THE
07540   REM HEAT-ONLY BOILERS HEAT PRODUCTION GIVEN IN COL. 5.
07550     DATA 0,.2989,5.665,4.776,5.666,5.667,5.667,5.667,5.667,5.667
07560     DATA 5.667,5.667,5.667,5.667,5.667,5.667,5.667,5.667,5.667,5.667
07570   REM
07580   REM
07590   REM
07600   REM OUTSIDE OPERATING COST (R2(N))-
07610   REM OPTAINED FROM TABLE 9.9 ON PAGE 100 BY DIVIDING THE
07620   REM DISTRICT HEATING RATES GIVEN IN COL. 4 WITH 0.9 .
07630     DATA 14.19,16.76,18.01,19.17,20.33,21.94,23.09,24.67,26.74,28.4
07640     DATA 30.47,33.03,34.08,38.14,40.64,43.67,47.03,50.51,53.83,57.37
07650   REM
07660   REM
07670   REM
07680   REM LOAD DURATION (V) AND HRS IN A YEAR (W)-PAGE 11.
07690     DATA 2465,8760
07700   REM
```

```
07710  REM
07720  REM      ________________________________
07730  REM FLOOR SPACE ESTIMATES (C5,M5,S5)-
07740  REM OPTAINED BY DIVIDING THE TOTAL DEMAND FOR A BUILDING TYPE
07750  REM WITH THE DAMAND PER SQUARE FOOT OF THAT BUILDING TYPE.
07760  DATA 225,133,42
07770  REM
07780  REM
07790  REM      ______________________________
07800  REM INFLATION RATE (Q)-IT IS AN ASSUMPTION
07810  DATA 0.04
07820  REM
07830  REM
07840  REM      ________________________________
07850  REM DISCOUNT RATE (I)-FROM STUDSVIK REPORT
07860  DATA 0.065
07870  REM
07880  REM
07890  REM      ________________________________
07900  REM
07910  REM
07920  END
```

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