BNL 50905

UC-95c

(Energy Conservation-Systems Modeling
and Performance Assessment - TID-4500)

METHODOLOGY FOR MODELING GEOTHERMAL DISTRICT HEATING FOR RESIDENTIAL MARKETS

JOHN KARKHECK AND RAYMOND G. TESSMER, JR.

August 1978

Prepared for the
DIVISION OF GEOTHERMAL ENERGY
UNITED STATES DEPARTMENT OF ENERGY

ECONOMIC ANALYSIS DIVISION
DEPARTMENT OF ENERGY AND ENVIRONMENT

BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK 11973

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

[Handwritten signature]

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy (DOE), nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price: Printed Copy \$4.50; Microfiche \$3.00
December 1978 . 250 copies

ABSTRACT

Methodology is presented for modeling geothermal district heat service and for evaluating the economic market potential for such nonelectrical utilization of the geothermal resource. It is based upon accurate determination of the heating demand and its spatial and temporal profile in each potential market, determination of the cost to provide such service, and correlation of markets and resource sites.

Two components of the model are discussed in this report. The residential demand submodel and data base, which includes building characteristics and population distribution on a census tract or minor civil division grid for the nation, projects heating demand densities and temporal profiles along with building service modifications and costs. The service submodel and data base designs and costs a subtransmission and distribution network, and it evaluates operating losses at design conditions.

TABLE OF CONTENTS

	Page
I. Introduction	1
II. Methodology for Modeling 1970 Residential Heating Demands	1
II.1 Space Heating Demand Equations	2
II.2 Water Heating Demand Equations	7
II.3 Residential Heating Demand Data	12
III. Methodology for Modeling the Supply System	12
III.1 Building Connection and Retrofit	12
III.2 Subtransmission and Distribution	16
III.3 Data Sources for Supply System	20
References	21

LIST OF TABLES

Table No.		Page
1	Significant Factors Affecting Space Heat Fuel Demand	3
2	Independent Variables in Space Heat Demand Functions	4
3	Space Heat Demand Variables Having Discrete Categories	5
4	Classification of 1970 Occupied Housing Units	8
5	Household Cross-Classifications in Space Heat Fuel Demand Equations	9
6	Significant Factors Affecting Water Heat Fuel Demand	10
7	Independent Variables in Water Heat Demand Functions	11
8	Household Cross-Classifications in Water Heat Fuel Demand Equations	13
9	Residential Demand Data	14

LIST OF FIGURES

1	Typical Hourly Load Curve	18
---	---------------------------------	----

I. INTRODUCTION

The modeling of geothermal district heat service and the evaluation of the market potential for such nonelectrical utilization of the geothermal resource rely on accurate determination of the heating demand and its spatial and temporal profile in each potential market, on realistic assessment of the cost to provide such service, and establishment of a correlation between markets and resource sites.

This report presents the methodology that will be applied to the residential sector of the space and water heating market. The full model will consist of three parts. The demand submodel and data base, which includes residential building characteristics and population distribution on a census tract or minor civil division grid, serves to project heating demand densities and temporal profiles along with building service modifications and costs. The service submodel with its data base designs and costs a subtransmission and distribution network and evaluates the operating losses at design conditions. The well development submodel with its data base, which includes resource characteristics and site identifiers, designs and costs a transmission line, gathering lines, supply and recharge wells, and heat exchange equipment at the well site. The demand submodel for 1970 heating demands and the service submodel are discussed here. A report on the methodology for projecting demands to 1982 and the well development submodel will be published at a later date.

The master variable in regard to the residential stage of this program, for both demand and service modeling, is population density. Heat demand density for a given climate depends strongly on population density and the housing profile. Both of these are known on a small-scale basis from the Census Tract/Minor Civil Division data of the 1970 census. Projections from the census data have been made for the years 1977 and 1982. Climatological data for the 30-year period 1941-1970, which details the temporal variation of temperature of each weather station, will be joined to the geographic data as the foundation for heat demand estimates. The lengths and diameters of distribution piping depend on the density of streets within each census tract, as well as on the density of demand and design point. For the purpose of generic analysis, the density of streets and the requisite street penetration percentage for service to all customers will be functionally correlated to population density. Provision will be made to accommodate detailed specific input in this regard for specific market analysis.

Geographical identifiers such as latitude and longitude will be attached to each market, weather station, and resource to allow computerized mapping, via minimal distance of separation, between markets and adequate resources.

II. METHODOLOGY FOR MODELING 1970 RESIDENTIAL HEATING DEMANDS

In order to evaluate the economic potential of a geothermal district heating system in any U.S. market, one must estimate heating demands and

have a picture of the conventional systems with which district heating must compete. The cost of energy from a district heating system (estimated from a supply model) plus the cost of retrofit can then be compared with conventional home heating costs. This section presents the methodology that is used to estimate the 1970 structure of space and water heating systems along with fuel demands for residential consumers with respect to measured housing, population, and weather characteristics. It is set up on a small area basis--census tract and minor civil division (MCD). The year 1970 is chosen as a starting point so that fuel demand equations can be structured around the large and detailed 1970 census data base. The year 1970 also permits comparison of estimated fuel consumption with other published estimates¹ and, thus, model validation.

Future work will involve projection of heating demands and heating system choice to 1982 or 1985, also on tract/MCD basis. It is these projections which will be used for evaluation of geothermal district heating systems.

A census tract/MCD geographic basis is chosen for two reasons. First, it is sufficiently small to permit estimation of retrofit requirements and enable reasonably good design and costing of a district heating transmission/distribution system (about 4,000 persons). Second, a wealth of housing and population data are available in the 1970 Census of Population and Housing on this basis, permitting fairly accurate representation of the nation's existing housing and heating system mix. If a smaller area were chosen, it would not be possible to establish a data base and demand model structure that spanned the entire country.

II.1 Space Heating Demand Equations

A demand model for space heat fuel can be structured in a number of ways. A typical engineering approach is to look at a particular structure, a type of heating system, and the local weather data; estimate heat loss coefficients; assume certain occupant behavior characteristics; and calculate the amount of fuel needed to maintain room air at specified temperature levels during the heating season.² It is not, of course, practical to estimate fuel demand in this manner for representative structures regionally for this project. The engineering approach does, however, permit one to write a generalized fuel demand equation for an individual housing unit in the following form:

$$\text{unit fuel demand} = f(\text{occupant behavior,} \\ \text{weather,} \\ \text{heating system characteristics,} \\ \text{building structural characteristics}). \quad (1)$$

Table 1 lists major factors that affect these variables.

It should be noted that these factors may not be independent. A family may behave differently if it is in a multifamily rather than in a

single-family dwelling, or if there is thermostatic heating control rather than none. Also, heating system overall cycle efficiency is a nonlinear function of the weather and occupant behavior.³ There can be a measurement problem, also. Directly observable variables may affect more than one of the factors listed above. Annual heating degree days, for example, are a summary measure describing outdoor temperature, and thus, weather. But degree days also affect cycle efficiency of combustion heating systems. Further, the number of rooms per unit is frequently one of the determinants of the type heating system and furnace location as well as being related to structure size and shape.

Table 1
Significant Factors Affecting
Space Heat Fuel Demand

Occupant behavior	thermostat setting opening windows/doors % of rooms heated fuel prices
Weather	outdoor temperature wind conditions solar insolation
Heating system	outdoor temperature and wind thermostat setting furnace location furnace efficiency (steady state) type system and fuel
Building structure	size and shape (No. of floors cellar vs crawl space, layout, etc.) construction characteristics (in- sulation, window area, ceiling/ wall materials and thickness, etc.) orientation

The general approach taken in this demand model is to specify average annual fuel demand functions for relatively homogeneous classes of residential consumers in each census tract. Annual fuel consumption can then be computed by inserting necessary data, including the number of households in each classification, and by summing across all household classes. The classifications are chosen such that major variables affecting annual fuel demand are identified. They are also chosen on the basis of available

observable variables. It is assumed at the outset that structure size, geographical location, and type heating system are the most important factors. It is also assumed that individual occupant behavior is least important in determining aggregate *average* behavior over large *groups* of households. Although the variance of fuel demand in three-bedroom houses is likely to be great, say, on Long Island, average fuel demand is very likely to be similar to that of comparable houses in other locales having similar weather patterns.

The independent variables chosen for the space heat demand functions are listed in Table 2. Weather and heating system factors are combined because of the dependence of the heating system performance (for combustion units) on the weather. Percentage of units built prior to 1940 will be employed to separate the difference in room size (and, thus, heating demand) between post- and prewar housing, both in floor area and ceiling height, if such a difference can be documented. Average thermal integrity of the building measures the level of insulation in the building shell. Cyclic efficiency of heating systems (efficiency under part-load conditions) is employed in place of steady state efficiency in order to capture the dependence of combustion furnace performance on weather and part-load operation.³ Although floor area would be a much better descriptor of dwelling unit size than the number of rooms, such information is not available for the entire existing housing stock.

Table 2
Independent Variables in
Space Heat Demand Functions

Occupant behavior	SH	average unit demand per degree
		day for heat supplied to room air
	HH	number of households
Weather, heating system	DD	annual heating degree days
	HS	heating system type
	fe	cyclic efficiency of heating system
	f	fuel type
Building structure	R/U	number of rooms per unit
	U/B	number of units per building
	V	vacancy rate
	be	average thermal integrity of building
	P	percentage of units built prior to 1940

The generalized form of a space heat fuel demand equation in a tract/MCD for fuel type 'f' is thus

$$\text{SHFD}_f = \sum_i \sum_j \sum_k \frac{\text{HH}_{ijk} \cdot \text{SH}_{ij} \cdot \text{DD}}{\text{fe}_{fk} \cdot \text{be}_j} \times \frac{1 + a_j \cdot \text{VR}_j}{1 - \text{VR}_j} \times (1 + P_j \cdot (b_j - 1)), \quad (2)$$

where

- SHFD_f = Annual space heat fuel demand (delivered fuel Btu) for fuel/electricity type 'f' in tract/MCD 't',
- i = Rooms/housing unit (5 categories),
- j = Housing units/building (5 categories),
- k = Heating system type (4 categories),
- HH = Number of households,
- SH = Annual quantity of energy per degree day per household (Btu/DD-HH) delivered to room air from heating system to provide space heating,
- DD = Average annual degree days (cumulative average daily variation below 65°F,
- fe = Cyclic heating system efficiency,
- be = Level of insulation in building shell,
- a = Quantity of space heat demand in vacant units divided by demand in occupied units (<1.0),
- VR = Housing vacancy rate,
- P = Percentage of housing units built prior to 1940,
- b = Average size of pre-1940 units divided by average size of post-1940 units.

The first quantity in parenthesis represents annual fuel demand for post-1940 occupied housing units. Annual degree days are assumed to be directly proportional to fuel demand, a conventional assumption.^{2,4} Average household space heat demand per degree day, SH_{ij} , must be specified

for 20 structural categories (4 rooms/unit classes and 5 units/building classes). It will be assumed that these average unit demands per degree day are constant across the country unless evidence to the contrary is found. The employment of variables expected to influence household behavior, e.g., income and relative fuel prices, will thus be limited to the problem of projecting fuel demands to a future year. A future project report will discuss how income, prices, and other factors will be used to project future heating system choice, tenure, insulation level, space heat demand, etc.

This formulation of demand equations requires that households in each tract/MCD be cross-classified with respect to heating fuel, heating system type, rooms/unit, and units/building. The U.S. census has not done this. They do cross-classify occupied and vacant units by tenure and units/building. However, heating equipment type, heating fuel, and rooms per unit are only classified with respect to tenure. Additional assumptions must be brought into the methodology to derive the necessary cross-classification of housing units. Table 4 shows the national breakdown of owner- and renter-occupied units with respect to the four discrete variable classifications.

Each fuel demand equation for a tract will not, of course, be written to include households in every possible household cross-classification. The utility gas equations, for example, will not include households with built-in electric heating systems. And the bottled/LP gas equation will not include households in multifamily structures. The eligible household cross-classifications that will be permitted in each of the five fuel demand equations are shown in Table 5. Utility gas has 32 classes, fuel oil/kerosene has 48, electricity has 64, bottled/LP gas has 12, and coal/other has 2.

The second quantity in parenthesis in Eq. (2) adds space heat demand in vacant units to that for occupied units. For vacant single-family homes it will be assumed that demand is negligible ($a = 0$) because utilities are very often turned off in vacant homes. For vacant multifamily homes, a non-zero level of demand will be assumed. Vacant units normally comprise 5 to 7% of multifamily units, and, unless the entire structure is vacant, such units are generally maintained above outdoor temperature during the heating season.

The third quantity in parenthesis in Eq. (2) says that space heat demand in old structures is different from that in new structures because old structures have different-size rooms. This will only be incorporated in the demand equations if sufficient evidence to support this hypothesis is located.

II.2 Water Heating Demand Equations

The demand model for water heat fuel is structured in a fashion similar to that for space heat fuel. A generalized fuel demand equation

Table 4
Classification of 1970 Occupied Housing Units
(10⁶ units)

	Owner-occupied units	Renter-occupied units
by rooms/units:		
1-4	7.7	2.8
5	11.3	5.4
6	10.7	7.0
7-8	8.3	7.0
9+	1.9	1.3
Total	39.9	23.5
by units/building:		
1	34.4	7.7
1-attached, 2-4	3.3	7.0
5-19	0.2	4.5
20+	0.2	4.0
mobile home, trailer	1.8	0.3
by heating fuel:		
utility gas	22.3	12.7
fuel oil, kerosene	10.5	6.0
electricity	2.8	2.1
coal/coke/wood	1.5	1.3
bottled, tank, LP gas	2.7	1.1
none	0.1	0.3
by heating equipment:		
steam/hot water	6.4	6.8
central warm air	20.9	6.6
built in electric	1.8	1.4
other furnaces, room heaters, stove	10.7	8.4
unheated	0.1	0.3

for an individual housing unit can be written as

$$\text{unit water heat fuel demand} = f(\text{occupant behavior} \\ \text{heating system} \\ \text{end-use equipment}). \quad (3)$$

Table 5
Household Cross-Classifications in Space Heat Fuel Demand Equations

Housing characteristic			Fuel demand equation*				
			Utility gas	Oil, kerosene	Elec- tricity	Bottled LP gas	Coal, other
rooms/unit,	0-0	R-0					
	1-4	1-2	X	X	X	X	
	5-6	3-4	X	X	X	X	X
	7-8	5-6	X	X	X		
	9+	7+	X	X	X		X
units/building,	1		X	X	X	X	X
	attached, 2-4		X	X	X		
	5-19		X	X	X		
	20+		X	X	X		
	mobile home, trailer				X	X	
heating equipment,	steam/hot water		X	X		X	X
	warm air		X	X	X**	X	
	built-in electric				X		
	other furnaces,			X	X	X	
	space heaters unheated						
Total cross-classifications of households:			32	48	64	12	2

*The symbol X indicates that this housing characteristic is included in a fuel demand equation.

**Other data sources will be employed to split out electric furnaces and heat pumps.

Table 6 lists major factors that affect these variables. Quantification of factors such as lifestyle and hot water demand by family size is impossible on a small areal basis because the necessary studies do not appear to exist. A more common assumption is therefore made--that there is a fixed average demand per person throughout the U.S.¹

Table 6
Significant Factors Affecting
Water Heat Fuel Demand

Occupant behavior	No. of occupants lifestyle hot water set temperature fuel prices
Heating system	type system and fuel storage capacity and insulation burner design
End-use equipment	type and No. of equipment (dishwasher, washing machine) equipment efficiencies

The general modeling approach, again, is to specify *average* annual fuel demands per person, separating those households having clothes washing machines from those that do not. The detail on washing machines is included because relevant sample data were collected in the 1970 census. The independent variables chosen for the water heat demand functions are listed in Table 7. Only the two major types of water heating systems are modeled: storage tanks with an integral heater or burner, and heating coils withing the space heating boiler.

Households in each tract/MCD are cross-classified with respect to five categories for rooms/unit, five categories for units/building, the two heating systems mentioned above, and five fuel types. In addition, persons per housing unit must be cross-classified with respect to rooms per unit and units per building. BNL will develop the necessary algorithms for these cross-classifications. The generalized form for a water heat fuel demand equation in a tract/MCD for fuel type 'f' is thus

$$WHFD_f = \sum_i \sum_j \sum_k \left[\left(\frac{HH_{ijk} \cdot WH \cdot P/U_{ij}}{fe_{fk}} \right) \cdot (1 + W \cdot WM) \right], \quad (4)$$

Table 7
Independent Variables in
Water Heat Demand Functions

Occupant behavior	WH	average demand per person for heat supplied to domestic hot water (without washing machine)
	WM	average demand per person for heat supplied to domestic hot water for clothes washing machine
	HH	number of households
	P/U	number of persons per household
Heating system	HS	heating system type
	fe	cyclic efficiency of heating system
	f	fuel type
End-use equipment	W	percentage of households with clothes washing machine

where

WHFD = Annual water heat fuel demand (delivered fuel Btu) for fuel/electricity type f in tract/MCD 't',

i = Rooms/housing unit (5 categories),

j = Housing units/building (5 categories),

k = Heating system type (2 categories),

HH = Number of households,

WH = Annual quantity of energy (Btu) per person delivered to water from heating system to provide domestic hot water (other than for washing machines),

P/U = Persons per household,

fe = Cyclical heating system efficiency,

W = Percentage of households with clothes washing machines,

WM = Annual quantity of energy (Btu) per person delivered to water to provide hot water for washing machines.

The first quantity in parenthesis represents annual fuel demand for domestic hot water, exclusive of that needed for clothes washing machines. The second quantity represents the additional washing machine demand. As with space heating, the employment of variables expected to influence household behavior, such as income and relative fuel prices, will thus be limited to the problem of projecting fuel demands to a future year. A future project report will discuss projection methodology.

Each fuel demand equation for a tract will not be written to include households in every possible cross-classification. The eligible classes that will be permitted in each of the five fuel demand equations are shown in Table 8. Utility gas has 32 classes, fuel oil/kerosene has 32, electricity has 20, bottled/LP gas has 4, and coal/other has 4.

II.3 Residential Heating Demand Data

Basic raw data being collected for the demand model are listed in Table 9. Some of the census data are from a very small sample and may need adjustment, primarily those for house and water heating fuels (5% sample). The various cross-classifications of households and population that are needed are listed in the second part of Table 9--"Imputed Data." Brookhaven will develop the necessary algorithms using published data and personal contacts. On a small area basis (tract/MCD) it is doubtful that large errors will be introduced with respect to heating system and fuel type. It is expected that one or two fuel and heating system types will predominate in most tracts. Sources of inaccuracy and uncertainty will be addressed more fully as actual data sources are examined.

III. METHODOLOGY FOR MODELING THE SUPPLY SYSTEM

Modeling of the supply system is done on several levels. These are well development and transmission, subtransmission and distribution, connection, and retrofit. Building connection and retrofit will be incorporated as a subroutine into the demand submodel. Well development and transmission comprise the well development submodel, and subtransmission and distribution comprise the service submodels.

III.1 Building Connection and Retrofit

Modeling. The data base for this subroutine will be founded on 1970 census building heating service data, and case studies of retrofit of typical building service units done by an engineering subcontractor to

Table 8
Household Cross-Classifications in Water Heat Fuel Demand Equations

Housing characteristic			Fuel demand equation*				
			Utility gas	Oil, kerosene	Elec- tricity	Bottled, LP gas	Coal, other
rooms/unit,	0-0	R-0					
	1-4	1-2	X	X	X	X	
	5-6	3-4	X	X	X	X	X
	7-8	5-6	X	X	X		
	9+	7+	X	X	X		X
units/building,	1		X	X	X	X	X
	attached, 2-4		X	X	X		X
	5-19		X	X	X		
	20+		X	X	X		
	mobile home, trailer				X	X	
heating equipment,	tank w/heater		X	X	X	X	
	tankless coil in furnace		X	X			X
Total cross-classifications of households:			32	32	20	4	4

* The symbol X indicates that this housing characteristic is included in a fuel demand equation.

Table 9
Residential Demand Data

	Data item (No. of items per record)	Areal basis	Coverage	Source*
I. Raw data				
geographic identifiers	1. State and county code	tract/MCD		NPDC
	2. SMSA code	"		"
	3. City, MCD codes	"		"
	4. Census tract/MCD	"		"
	5. Latitude/longitude of population centroids	"		"
1970 population	6. Population (also 1960	"	100%	NPDC
	7. Occupied units by tenure, race, persons per unit (60)	"	"	"
	8. Population density (also 1960)	tracts only	"	"
	9. Persons in school by level of school (15)	tract/MCD	15% sample	"
1977 & 1982 populations	10. 1977 population	"	100%	NPDC
	11. 1977 population density	tracts only	"	"
	12. 1982 population	tract/MCD	"	"
	13. 1982 population density	tracts only	"	"
1970 housing	14. Ocpd. & vacant units by tenure, race, rooms per unit (80)	tract/MCD	"	NPDC
	15. Ocpd. & vacant units by tenure, race, year structure built (72)	"	20% sample	"
	16. Households	"	100%	"
	17. Ocpd. & vacant units by tenure, race, units in structure (108)	tract/MCD	20% sample	NPDC
	18. Ocpd. & vacant units by tenure, race, heating equipment (96)	"	"	"
	19. Ocpd. & vacant units by source of water, tenure, race (18)	"	15% sample	"
	20. Ocpd. & vacant units by type sewage disposal, tenure, race (18)	"	"	"
	21. Ocpd. & vacant units by air conditioning, tenure, race (24)	"	"	"
	22. Ocpd. units by house heating fuel, tenure, race (40)	tract/MCD	5% sample	NPDC
	23. Ocpd. units by water heating, fuel, tenure, race (40)	"	"	"
	24. Ocpd. units by clothes washing machine, tenure, race (15)	"	"	"
	25. Annual unit space heat demand, per person water heat demand	n.a.		BNL
	26. Cyclical heating system efficiency (space, water heat)	?		BNL
	27. Level of insulation	census region	survey	AGA
	28. Heat demand in vacant vs ocpd. units	n.a.		BNL
	29. Size of pre-1940 vs post-1940 units	?		DOC

Table 9 (cont'd)
Residential Demand Data

	Data item (No. of items per record)	Areal basis	Coverage	Source*
1977 & 1982 housing	30. 1977 households 31. 1982 households	tract/MCD "	100% "	NPDC "
income	32. 1969 per capita income 33. 1969 average HH income 34. 1976 per capita income 35. 1976 average HH income	" " " "	" " " "	" " " "
geographic area	36. Total area 37. Land area 38. Water area 39. Nonresidential area 40. Institutional area	tracts only " " " "		" " " " "
weather	41. Daily heating and cooling degree day normals	weather station 379 stations		NOAA
II. Imputed data	42. Households by space heating fuel, water heating fuel, space & water heating systems, rooms per unit, units per building 43. Space heat to room air demand by rooms per unit, units per building 44. Persons per unit by units per building, rooms per unit	tract/MCD tract/MCD " "		14,16,17,18, 22,23 above plus BNL algorithms BNL average values plus other studies 6,7,14,16,17 above plus BNL algorithms
* Data Source Code: NPDC - National Planning Data Corp. BNL - Brookhaven National Laboratory AGA - American Gas Assoc. DOC - U.S. Dept. of Commerce NOAA - National Oceanic and Atmospheric Administration				

Brookhaven. These case studies will produce a parametric description of the materials, labor, and cost to substitute heat exchange equipment for individual burners and to interface directly with existing service media. The parameters accommodated in these case studies are burner size and water inlet and outlet temperatures. Provision for climatic, building type, size, construction, and existing service media differences will be made on merging with the demand data base.

Interfacing with existing service media places restrictions on water outlet and inlet temperatures and retrofit strategy. Continuous flow and on-off operation of heat exchangers will be studied, but retrofit with heat pumps to utilize very low-grade resources is beyond the scope of this initial study.

The Subsystem. The building connection and retrofit subsystem consists of insulated supply and return piping between street mains and the structure, flow control valving, heat exchangers for space and water heating, storage devices such as hot water tanks, and circulating equipment if necessary. Two distinct modes of heat exchanger operation will be assessed. The first is continuous flow wherein the heat exchanger is sized to reproduce the heat rate of a furnace, under conditions of constant flow of hot water. Temporal variation in heat demand is met by externally controlling the inlet water temperature. This control is manifested in the distribution system. Such a strategy is used commonly in district heating with power plants as heat sources wherein the water temperature is controlled by varying conditions of extraction at the turbine. This variability can be simulated also for geothermal sources. The other mode simulates the operation of a furnace wherein the heat exchanger is engaged and disengaged by an existing thermostatic control, and temporal variation in demand is matched by frequency and duration of operating periods. Peak demands are then met by varying flow rates in the distribution system while maintaining a constant inlet temperature.

Clearly the number of controllable parameters for matching heat supply and demand with a district heating system is much greater than provided by a furnace. Thus, a large number of strategies could be examined. Those discussed above can be found in practice and each furnishes particular operating advantages.

Connection lines will be small in diameter, from about one to four inches, and may be of plastic or steel or novel alternatives depending on the range of inlet temperatures and pressures. Insulation materials will also vary and range in thickness from one to three inches.

III.2 Subtransmission and Distribution

Modeling. The distribution network will be designed in small sections. That is, the demand submodel will be capable of merging contiguous census tracts of nearly equal demand density into larger service areas. Each tract has a geographical identifier and each service area will be

given an identifier. The service submodel will design and cost a service system emanating from the central point of the service area, assuming the demand to be uniform over the service area. The central points of all service areas will be connected by a subtransmission network which emanates from a key position within, or near, the city. The parameters relevant to the design are demand density, peak demand, supply and return temperature, density and penetration percentage of streets in each section, and retrofit strategy.

Through case studies of actual cities, the correlation between population density and street density and width will be investigated, and from existing city services data the penetration percentage in streets will be correlated to population density. Finally, the total area of each service area will be known from the census tract data. These variables then allow computation of pipe length for each service area.

Installation cost will be determined on the following basis. European literature discusses total installation costs and cost breakdowns. American prices may be inserted into each category to tailor installation cost to specific conditions of labor, etc. The various American prices will be obtained from several sources including water authorities, gas companies, oil and gas pipeline job figures, sewer and water job figures, and quote tables on labor and materials. Incremental cost factors for installation in densely populated areas will be developed from existing utility data. These are necessary to make system costing more realistic. Because of the expected result that construction in streets in heavily populated areas would be highly disruptive and overly expensive, alternatives to street construction may be desirable and worth examining in a prototype study.

Finally, the sections within each market can be ranked by cost-to-benefit ratio and service levels and established at any cost level. Optimal service levels may also be obtained⁴ because transmission cost per unit of heat decreases as service level increases, but distribution cost per unit of heat may increase as service penetrates low-density areas.

The Subsystem. The design point will be the average demand over the coldest month, typically January. As shown in Figure 1, which is a typical profile of demand, it is necessary to operate the system at supply rates beyond the design point for only a small fraction of the time. But for a considerable fraction of the time the system will operate near the design rate. Flow rates commensurate with this design point will be determined as a function of resource temperature and anticipated heat losses in the supply lines. The distribution system design will begin at the point of demand and hinge on the heat exchanger operation mode. Proper optimized diameters for street mains will be chosen to provide the requisite flow rates and then trunk lines connecting these to the central point of the section will be included. This feature will eliminate the iteration that GEOCITY⁵ requires to ensure sufficient flow rate.

The strategy of designing autonomous section distribution systems is technically sound because it reflects how a large-district heating

Figure 1. Typical hourly load curve.

system may be built, with the densest areas served first, by fossil boilers which go on standby once the system reaches demand levels sufficient to utilize the geothermal resource. There is also the advantage that street mains are held to smaller diameters which are easier to install, are cheaper, and have lower operating losses. Experience^{4,6} has shown that distribution piping is by far the dominant cost element because of the overwhelming length requirement, followed by subtransmission and transmission.

The pipe system will be a closed loop between well heat exchangers and building heat exchangers. The layout geometry will be rectangular. Return temperatures between 40° and 50°C will be sought, although in some cases these may be too low for existing building service forms. Two pipe system construction designs will be examined. Conventional materials and installation as employed in Europe and Iceland, i.e., welded steel, suitable insulation dependent on supply temperature, and installation in pre-cast concrete conduit to inhibit corrosion, will be compared to advanced materials, e.g., lined high-strength concrete, plastic, or fibrous pipe and foam insulations, and installation techniques typical of other pipeline systems, i.e., trench burial as practiced by the water, sewer, oil, and gas pipeline industries. The latter approach potentially can cut piping costs in half.^{7,8}

Operating losses arise from conductive heat losses and pumping power to overcome frictional drag. These can be held to several percent of the design power capacities of the pipes and in addition the latter tends to counterbalance the former. The transmission and subtransmission lines account for the greatest part of these losses, whereas the distribution network, which is actually a parallel network, may contribute losses less than one percent of the power capacity. The pressure head will be controlled by the building heat exchanger designs, but is expected to be in the range of 50 to 150 psi.

The control for temporal variation of demand can be had by varying the supply water temperature at constant flow rate or by varying the flow rate at constant temperature or by combinations of these. The highest peaks are best met by peaking boilers, but variation on longer time scales can be matched by one to two extreme transport strategies. Mixing or other means may be used to vary the temperature of the supply water. Such controls may be placed at the well or at the key position for each city. Alternatively, direct supply of water at the temperature obtained at the well head would in most cases allow use of very small pipe diameters, but the conductive losses occurring at low flow rate conditions may be prohibitive. This option is not feasible with power plant district heating since higher quality heat imposes lower electric generating efficiency. With power plant sources, it is most cost effective to follow the load variation by varying the supply temperature. With geothermal sources, four distinct service strategies are possible: two controls on the water supply end and two heat exchanger operating modes. These will be studied with the object of developing an optimal strategy.

III.3 Data Sources for Supply System

Resource Data Sources

1. USGS Circular 726 for Western resources, including latitude and longitude, quantity and quality estimates of known deposits.
2. G.A. Waring, 1965 - Thermal Springs of the United States and other Countries of the World - A summary: U.S. Geol. Survey Prof. Paper 492, 383p.
3. Virginia Polytechnic Institute - for Coastal Plain deposits and characteristics.
4. Johns Hopkins University, Applied Physics Laboratory - for revised and upgraded lists on eastern resources.
5. Idaho National Engineering Laboratory - revised and upgraded lists on western resources.

Well Development Data Sources

1. S. Milora and J. Tester - for parametric cost components to be compared to Icelandic, Boise, etc. experience.
2. INEL - in conjunction with BNL to assemble parametric cost component data base to reflect variance in resource characteristics-- temperature, depth, impurity concentrations and acidity.
3. INEL - for engineering assessment of developable resources, including considerations for corrosion, pump rate, recharge location.
4. GEOCOST/GOECITY will be consulted and implemented suitably.

Piping System Data Sources

1. Engineering News Record, Oil and Gas Journal and others - for labor and material quotes, job cost breakdowns.
2. Utilities in selected markets - for installation costs and distribution maps, and installation practices.
3. Street maps in selected markets - for street densities and widths.
4. European literature - for cost breakdowns.
5. Electric utilities in selected markets - for bulk electric rates to compute pumping energy cost.

REFERENCES

1. Dole, Stephen H., Energy Use and Conservation in the Residential Sector: A Regional Analysis, R-1641-NSF, Rand Corp., Santa Monica, CA, June 1975.
2. Berlad, A.L., A Field Method for Determination of the Performance Parameters of an Operating Structure and Its Heating System, BNL 50684, June 1977.
3. Batey, John, et al., Energy Management in Residential and Small Commercial Buildings, Annual Report FY 1976, BNL 50576, July 1976.
4. Karkheck, J., E. Beardsworth, and J.R. Powell, The Technical and Economic Feasibility of U.S. District Heating Systems Using Waste Heat from Fusion Reactors, BNL 50516, February 1976.
5. McDonald, C.L., C.H. Bloomster, and S.C. Schulte, GEOCITY: A Computer Code for Calculating Costs of District Heating Using Geothermal Resources, Battelle Northwest Lab., BNWL-2208, Richland, WA, 1977.
6. Zoega, J., The Reykjavik municipal heating system, in Proc. Int. Conf. on Geothermal Energy for Industrial, Agricultural, and Commercial-Residential Uses, Oregon Inst. of Tech., Klamath Falls, Oregon, 1974.
7. Karkheck, J., and J.R. Powell, The Application of District Energy Systems to U.S. Urban Areas, The 144th Annual Meeting of the American Association for the Advancement of Science, Washington, DC, February 1978.
8. Larson, Kjell, District heating: Swedish experience of an energy efficient concept, from the Swedish Seminar, The Swedish Approach to Current and Future Energy Issues, 1977.