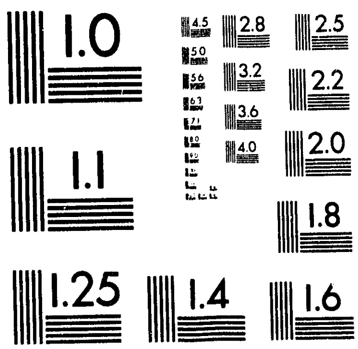
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Estimating Market Penetration of Steam, Hot Water and Chilled Water in Commercial Sector Using a New Econometric Model[1]

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Abstract

For the first time in the public domain, we have estimated the energy consumption and expenditures of district steam, hot water, and chilled water. Specifically, the combined energy consumption and expenditures of steam, hot water, and chilled water in 1989 were approximately 800 trillion Btu and 7 billion dollars, respectively. The purpose of this paper is to introduce a new model developed at Argonne National Laboratory (ANL) for estimating market penetration of steam, hot water, and chilled water systems in commercial buildings over the next 20 years.

This research sponsored by the U.S. Department of Energy (DOE) used the 1989 Commercial Building Energy Consumption Surveys (CBECS) to provide information on energy consumption and expenditures and related factors in about 6,000 buildings. A general linear model to estimated parameters for each of the three equations for steam, hot water, and chilled water demand in the buildings. A logarithmic transformation was made for the dependent variable and most of the explanatory variables.

The model provides estimates of building steam, hot water, and chilled water consumption and expenditures between now and the year 2010. This model should be of interest to policymakers, researchers, and market participants involved with planning and implementing community-based energy-conserving and environmentally beneficial energy systems.

District heating and cooling (DHC) systems are more energy efficient than conventional systems, and they emit fewer pollutants. The U.S. Department of Energy DOE) has supported research into and development of district steam, hot water, and chilled water systems in the residential and commercial sectors. In 1991, DOE sponsored a research project at Argonne National Laboratory (ANL) for re-estimating market penetration of these district systems fuels over a 20-yr period. The DHC markets were last estimated in 1982 (Teotia and Poyer, 1983). These estimates were obtained with the use of the ANL DHC market penetration model developed between 1979 and 1981 (Teotia, Davis, and Poyer, 1981). ANL conducted a literature search to identify major data sources on historical DHC markets and any past studies on the future market potential of DHC systems. Extensive related information was obtained from government and industry sources, including DOE's Energy Information Administration (EIA); Data Resources, Inc. (DRI); the International District Heating and Cooling Association (IDHCA); the Electric Power Research Institute (EPRI); RCG/Hagler, Baily,

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Inc.; and the Gas Research Institute (GRI). The gathered information verified that no research study providing national market projections of DHC systems had been made over the last 10 years. The projections made by ANL in 1992 remain the most recent. Nevertheless, major improvements were noted with regard to the availability of historical data on energy consumption and expenditures for district steam, hot water, and chilled water through DOE/EIA Commercial Buildings Energy Consumption Surveys (CBECS) conducted for 1979, 1983, 1986, and 1989. No other data source was identified for national estimates of the DHC market.

DOE/EIA CBECS Data

The DOE/EIA has collected data on steam systems since its first survey in 1979 and on hot water and chilled water systems since its third survey in 1986. Each of these surveys encompasses several thousand observations on energy consumption and expenditures in individual commercial buildings. In its report (DOE/EIA, April 1992), the DOE/EIA notes that the 1979 and 1983 CBECS asked for purchased steam, the 1986 CBECS (DOE/EIA, 1989) asked for purchased and nonpurchased steam and hot water, and the 1989 CBECS asked for steam or hot water piped into the building. The DOE/EIA also noted that the quantities reported for district heating (steam and hot water) are increasing with each CBECS iteration. The increase may, however, be more a result of better identification than actual increases. For example, the 1989 survey has additional information on multibuilding facilities. The DOE/EIA expects estimates from future CBECS to remain in the range of the 1989 estimates. A similar pattern was noted by ANL in the analysis of the chilled water data on the 1986 and 1989 CBECS data tapes. For these reasons, the 1989 CBECS was selected for the analysis of historical market of the steam, hot water, and chilled water. A 1989 CBECS public-use data tape was received from DOE in June 1992. The data set included 5,876 records pertaining to all commercial buildings, of which 531 records were for buildings using steam, hot water, or chilled water systems.

1989 DHC Market

On the basis of an analysis of 1989 CBECS computer tape data, Table 1 provides estimates of the number of buildings, floor space, energy consumption, energy expenditures, and average energy prices for district steam, hot water, and chilled water. Among other data comparisons, these data were rationalized against IDHCA data (IDHCA, 1989). One or more district fuels were supplied to 106×10^3 buildings with floor space of $6,945 \times 10^6$ ft^2 in the United States. The energy consumption and expenditures were estimated to be 487×10^{12} Btu and \$3.2 billion for steam, 98×10^{12} Btu and \$0.6 billion for hot water, and 220×10^{12}Btu and \$3.1 billion for chilled water. The average prices for steam and hot water were very close, but the average price for each of these was approximately half that of chilled water (Table 1). Among the three district fuels, the energy intensity is highest for chilled water and lowest for hot water (Table 1).

Of the total DHC consumption of 805×10^{12} Btu, the South accounts for a 26% share, offices account for a 30% share, medium-sized (50-200,000 ft^2) buildings account for a 41% share, the private-sector accounts for a 46% share, and the buildings built after 1973 (post-oil embargo) account for an 18% share.

Table 1 Characteristics of U.S. DHC Market, 1989[a]

Characteristic	Unit	Steam	Hot Water	Chilled Water	All DHC Fuels
Number of buildings	1,000	81	18	24	-
Floor space	10^6 ft^2	5,353	1,357	1,946	-
Energy consumption	10^{12} Btu	487	98	220	805
Energy expenditures	10^6\$	3,239	618	3,073	6,930
Average energy price	\$/10^6 Btu	6.64	6.31	13.97	8.61
Energy intensity	10^3 Btu/ft^2	91	72	113	-

[a] Source: DOE/EIA 1989 CBECS Tape.

DHC Market Projection Methodology

The purpose of this research was to estimate market penetration of steam, hot water, and chilled water in commercial buildings over the next 20 years.

In the first step, the ANL DHC market penetration model developed between 1979 and 1981 was restored. This step tested the model after almost a 10-yr disuse. This model combined an economic cost model and a diffusion model (Teotia and Raju, 1986). A key reason for selecting this methodology was the unavailability at that time of historical data on DHC applications in residential and commercial markets.

In the second step, all feasible approaches were evaluated to provide the most suitable market penetration methodology. The following methodologies, discussed in an earlier ANL report (Raju and Teotia, 1985), were considered: subjective estimation methods, market surveys, historical analogy models, time series models, diffusion models, economic cost models, and discrete choice models.

The econometric model was considered to be most suitable for the objectives of the underlying research. A key factor in the selection of this methodology was the availability of the 1989 CBECS. The econometric model uses the CBECS data to estimate the functional relationships between the demand of steam, hot water and chilled water, and independent variables that influence the demand. For this study, among many variables tested, the following explanatory variables were found to have a major impact on one or more demands (i.e., of steam, hot water, and/or chilled water:

- Building characteristics.
  - Square feet heated/cooled.
  - Government building.
  - Building activity (office, lodging, health, assembly, laboratory, education, and other).
  - Main heating fuel: steam/hot water.
  - Weekly operating hours.
  - Workers per square feet.
  - Number of hospital beds.
- Energy cost.
  - Electricity price.
  - Steam price.
  - Hot water price.
  - Chilled water price.
- Climate Variables.
  - Cooling degree-days.
- Energy management.

- Demand-side management (DSM) program.
- Reduced use during off-hours.

The general specification of the building energy demand model can be represented as follows:

$$\log(y) = a + \sum_{i=1}^{n} b_i \bullet X_i + \sum_{j=1}^{m} c_j \bullet \log(Z_j)$$

where y = demand of steam, hot water, or chilled water; a, b_i, and c_j are constants; X_i = binary independent variables, 1 if the chosen building characteristic (such as government ownership) is present, or 0 if not; and Z_j = continuous independent variables such as floor space.

Steam Demand Model

Table 2 shows the parameter estimates derived by the general linear procedure. The model has six binary variables: government ownership (GOV), steam as the main heating fuel (DV1), participation in the utility DSM program (DV4), the principal activity of the building — laboratory (ACT2), health care (ACT4), or other (ACT8). Additionally, the model has four continuous variables: square feet heated (LSFHEAT), workers/square feet (LWKFS), electricity price (LPEL) and steam price (LPST). All explanatory variables have the correct sign. The variables LPST,

Table 2 Parameter Estimates for District Steam Demand Model[a]

Parameter		Estimate	Standard Error of Estimate	t-Ratio
Intercept	Int	-1.174	1.117	-1.05
Building ownership				
Government	GOV[b]	0.209	0.171	1.22
Building main heating fuel				
Steam	DV1[b]	0.510	0.369	1.38
Participated in utility DSM program	DV4	0.127	0.180	0.70
Principal building activity				
Laboratory	ACT2[b]	0.760	0.428	1.78
Health care	ACT4[b]	0.799	0.263	3.04
Other	ACT8[b]	0.306	0.277	1.10
Log (workers/sq. feet)	LWKFS	0.114	0.063	1.81
Log (sq. feet heated)	LSFHEAT	0.991	0.058	17.05
Log (electricity price)	LPEL	0.120	0.237	0.50
Log (steam price)	LPST	-1.014	0.191	-5.31
Log (steam demand)	LQSTEAM	(dependent variable)		

[a] $R^2 = 0.667$

[b] Binary variable (yes=1, no=0)

LSFHEAT, and ACT4 are statistically the most significant (all have a t-ratio of <-2 or >2, corresponding to 95% confidence levels). The regression equation explains about 67% of the variation in building steam demand.

Hot Water Demand Model

Table 3 shows the parameter estimates. The model has four binary variables: hot water as the main heating fuel (DV2), participation in the utility DSM program (DV4), reduced use during off-hours (DVRDHC), and education as the principal activity of the building (ACT7). Additionally, the model has four continuous variables: square feet heated (LSFHEAT), weekly operating hours (LWKHFS), workers/square feet (LWKFS), and number of hospital beds (LHCCBED). All explanatory variables have the correct sign. The variables LSFHEAT, LWKFS, and DV2 are statistically the most significant with a t-ratio of <-2, or >2. The regression equation explains about 91% of the variation in building hot water demand.

Chilled Water Demand Model

Table 4 shows the parameter estimates. The model has four binary variables: government ownership (DV2), principal activity of the building assembly (ACT5), lodging (ACT6), or other (ACT8). Additionally, the model has four continuous variables: square feet cooled (LSFCOOL), weekly operating hours (LWKHRS), cooling degree-days (LCDAY), and chilled water price (LPCW). All explanatory variables have the correct sign. The variables LSFCOOL, LPCW, LWKHRS, and the intercept term (INT) are statistically the most significant with a t-ratio of <-2, or >2. The regression

Table 3 Parameter Estimates for District Hot Water Demand Model[a]

Parameter		Estimate	Standard Error of Estimate	t-Ratio
Intercept	Int	0.147	1.521	0.10
Building main heating fuel				
Hot water	DV2[b]	1.455	0.374	3.90
Participated in utility DSM program	DV4[b]	0.346	0.230	1.51
Reduced use during off-hours	DVRDHC[b]	-0.377	0.287	-1.32
Principal building activity				
Education	ACT7[b]	-0.303	0.211	-1.43
Log (workers/sq. feet)	LWKFS	0.440	0.096	4.60
Log (sq. feet heated)	LSFHEAT	0.840	0.054	15.66
Log (weekly operating hours)	LWKHRS	0.214	0.205	1.04
Log (no. of hospital beds)	LHCCBED	0.115	0.080	1.44
Log (hot water demand)	LQHW	(dependent variable)		

[a] $R^2 = 0.667$

[b] Binary variable (yes=1, no=0)

Table 4 **Parameter Estimates for District Chilled Water Demand Model**[a]

Parameter		Estimate	Standard Error of Estimate	t-Ratio
Intercept	Int	-8.489	3.652	-2.32
Building				
Government	GOV[b]	0.673	0.581	1.16
Principal Building Activity				
Assembly	ACT5[b]	-0.901	0.619	-1.46
Lodging	ACT6[b]	-0.971	0.736	-1.32
Other	ACT8[b]	0.880	0.903	0.97
Log (sq. feet cooled)	LSFCOOL	0.983	0.137	7.16
Log (weekly operating hours)	LWKHRS	1.320	0.518	2.55
Log (cooling degree-days)	LCDAY	0.365	0.270	1.35
Log (chilled water price)	LPCW	-1.257	0.331	-3.80
Log (chilled water demand)	LQCW	(dependent variable)		

[a] $R^2 = 0.667$

[b] Binary variable (yes=1, no=0)

equation explains about 77% of the variation in the building chilled water demand.

Projection of Steam, Hot Water and Chilled Water Demand

The model was used to estimate market penetration under the base case. The explanatory variables were projected into the future. The 1989 market share of each variable (government buildings [GOV], steam as main heating fuel [DV1], hot water as the main heating fuel [DV2], participation in the utility DSM program [DV4], reduced use of heating and cooling during off-hours (DVRDHC), and principal activity of the buildings [ACT2, ACT4, ACT5, ACT6, ACT7, and ACT8]) was assumed to remain unchanged during the 1990-2000 forecast period. The square feet heated (SFHEAT) and cooled (SFCOOL) were projected at the same rates as those of the DOE's *Annual Energy Outlook 1992* projections of total floor space in the commercial sector between 1990 and 2010 (DOE/EIA, Jan. 1992). No change was made in any of the following variables during the forecast period: cooling degree-days (CDAY), workers per square feet (WKFS), weekly operating hours (WKHRS), and number of hospital beds (HCCBED). The projections of average price of electricity in the commercial sector (PEL) between 1990 and 2010 were taken from the DOE's *Annual Energy Outlook 1992* (DOE/EIA, Jan. 1992). Certain assumptions had to be made because of the lack of published price projections for any of the district fuels and the lack of research funds to develop a model to project such prices. Because of the relatively mature technologies used in steam and hot water systems, it was assumed that current prices of steam (PST) and hot water (PHW) will escalate at the rate of inflation in the U.S. economy, i.e. the prices in constant 1989 dollars will remain the same during the forecast period. The changes in the chilled water technology (such as ice slurry systems, which reduce the piping cost and pumping costs) and markets (CFC's dephasing) are expected to boost its market penetration in future years. The chilled water model at this stage cannot directly measure these changes. Many of these favorable changes are tantamount to the reduction in the effective cost of chilled water. In its preliminary evaluation of the cooling data in 1986 and 1989 CBECS, a double-digit cumulative growth rate is indicated for the chilled water demand (Btu/sq. feet) for three year 1986-89 period. To capture these changes for future, it was arbitrarily decided to reduce the constant dollar price of chilled water by about 1% annually between 1990 and 2010. Primarily, because of the arbitrary assumptions made with regard to the future prices of steam and chilled water; the projections of the demand of steam, hot water and chilled water under this base case (Table 5) are considered to be preliminary.

As shown in Table 5, between 1989 and 2010, the cumulative percent change in the demand of the chilled water will be almost twice the changes in each of demands of steam and hot water. The total annual consumption of steam, hot water, and chilled water will approach about 1 quad (10^{15} Btu) by 2000 and 1.25 quad by 2010. The chilled water market will double during the forecast period.

Table 5 DHC Market Projections Under Base Case

	Consumption (10^{12} Btu), Year			% Chg.
Fuel	1989	2000	2010	1989-2010
Steam	487	582	690	42
Hot water	98	120	141	44
Chilled water	220	298	399	82
Total	805	1,000	1,231	53

Conclusions

The preliminary analysis shows that the total market of district steam, hot water, and chilled water could grow from 0.8 quad in 1989 to 1.0 quad by 2000 and 1.25 by 2010. A key assumption in this analysis is that, due to improvements in technology, the effective cost of chilled water can be reduced by 20% over the forecast period. The demand of chilled water could nearly double in the forecast period, and its share could approach one, third of the total DHC market. It should be again noted that these DHC projections are preliminary. These projections are subject to revisions as and when additional research will be carried out at ANL upon the availability of research funds from DOE.

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References

International District Heating and Cooling Association; *1989 District Heating and Cooling Industry Statistics Report;* New York, NY.

Raju, P.; Teotia, A.; *An Evaluation of Market Penetration Forecasting Methodologies for New Residential and Commercial Energy Technologies*; report ANL/EES-TM-315, Argonne National Laboratory: Argonne, IL, 1985.

Teotia, A.; Raju, P.; *The Journal of Product Innovation Management;* 1986; Vol 3, no. 4, pp 225-237.

Teotia, A.P.S.; Davis, A.A.; Poyer, D.; *Cogeneration Energy Systems Show Promoting Market Potential in Residential and Commercial Sector Over Next 25 Years*; American Society of Mechanical Engineers, New York, N.Y.; Proc. 16th Intersociety Energy Conversion Engineering Conference, 1981.

Teotia, A.P.S.; Poyer, D.; *Macroeconomic Effects Under the Proposed District Heating and Cooling Tax Incentives Act of 1982*; report ANL/CNSV-TM-155, Argonne National Laboratory: Argonne, IL, 1983.

U.S. Department of Energy; *Annual Energy Outlook 1992: with projections to 2010;* report DOE/EIA-0383(92); Washington, DC, Jan. 1992.

U.S. Department of Energy; *Commercial Buildings Consumption and Expenditures;* report DOE/EIA-0318(86); Washington, DC, 1989.

U.S. Department of Energy; *Commercial Buildings Energy Consumption and Expenditures;* report DOE/EIA-0318(89); Washington, DC, April 1992.

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