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Retrofit Energy Studies Using the DOE-2 Computer Simulation Program

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ABSTRACT

The DOE-2 computer program has been used extensively in recent years for modeling energy conservation measures (ECMs). Due to the complex and time-consuming data gathering process demanded by the program, use of the model is most appropriate for complicated buildings. Methods that can streamline the input and output effort are possible. Retrofit measures simulated on a DOE-2 computer model, as opposed to manual methods, are simply executed and produce more reliable results. In addition, a completed computer model can be a powerful resource for an energy manager if used periodically to understand and control building energy use.

INTRODUCTION

This paper examines one firm's experience with computer modeling of existing buildings. The primary focus is on more complex and sophisticated facilities. It is recognized that many structures are less complicated and therefore easier to model.

THE PROBLEMS OF MODELING

The arduous process of gathering data is the primary difficulty with DOE-2 computer modeling of existing structures. This problem is not readily apparent, since most examples in the documentation are deceivingly simple because they involve uncomplicated buildings. Moreover, these examples use a high percentage of built-in program default values.

On the other hand, when modeling existing complex buildings, very few of the program default values are suitable. Instead, a significant amount of investigative work is necessary to obtain realistic setpoints, usages, infiltration rates, operation profiles, and equipment energy consumption. Generally this information is not readily available from either building staff or vendors. On one project, staff spent an excessive amount of time trying to quantify elevator daily energy consumption. Much of the time spent was because either the elevator manufacturers contacted were not interested in providing information or they lacked knowledge on this subject. An information gap exists for a wide range of building energy-consuming devices, ranging from electrical transformers to laboratory equipment.

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The difficulty of finding realistic energy consumption applies to HVAC machinery as well. Unless one has actual electrical readings for fans, pumps, chillers, etc., there is good reason to believe that they are not performing as shown on the design drawings. For example, an adjustable drive-side fan pulley that has loosened over the years on a major air system will move considerably less air than suggested by the design drawings. Also, it has been discovered, existing chillers often do not perform as well as projected. In one instance, after having carefully modeled an absorption machine, actual on-site performance was found to be much poorer than the catalog ratings. A very high average steam rate of 25 pounds per ton-hour (as opposed to 18 pounds per ton-hour) was found to be approximately correct. Subsequently, chiller experts were found who have documented similar poor performance after testing many absorption units.

Experience to date shows that, after a careful effort is made to gather data, computer models have excellent heating and cooling load correlation when compared to meter readings. On the other hand, domestic hot water consumption and energy overheads such as pipe losses are much more difficult to determine accurately and can sometimes distort the results. Since these values are estimated and not computed in the model, it is necessary to make some calibration with actual metered consumption. In a building that has electric-drive chillers and minimal reheat, measured summer oil/steam consumption would be a good indication of actual pro-rata annual domestic hot water and steam overhead losses.

Some have suggested as an alternative procedure that a rough model of an existing building should be executed and then the input loads should be adjusted to match the actual consumption. Although some calibrations of the model are required as described in the above paragraph, it wouldappear that the rough model approach is very risky for complex locations. For example, how much winter-fall steam consumption should be allocated for heating use as opposed to steam-drive chiller use? If the energy is misallocated, modeling results for an ECM could be affected. It may be possible to eventually develop a procedure using "cut and try" methods with multiple computer simulations to define consumption patterns. For the present, the preferred approach is to ascertain actual usage.

A secondary problem with DOE-2 is that despite updated manuals, there are still a significant number of deficiencies in the documentation. One firm's manuals are filled with handwritten corrections and clarifications, and new problems are still found to this day, even though the firm was the largest private user of this program in 1981 with the major DOE-2 time-sharing service. These documentation problems certainly put a burden on new users.

STREAMLINING INPUTS AND OUTPUTS

Time-sharing services that are used for DOE-2 and other programs have a broad range of costs and support services. This is one area of the computer simulation process where cost savings are possible. It requires a user with an in-depth understanding of the model, since the less expensive time-sharing services also provide less assistance with the program. By price comparing various services, one user reduced time-sharing costs by over 60%, although this also meant accepting some inconveniences, such as delayed access during peak afternoons. However, for the novice user of DOE-2, the time-sharing service with better support will probably be more cost-effective.

DOE-2, like all energy programs, uses lists of commands and keywords that follow repeatable patterns. By developing software for an in-house microcomputer, it is possible to display these forms on the computer screen and then fill in the values for the variables displayed. This can result in a considerable reduction in time-sharing costs, since the program can prompt the user and display rules and error messages to correct the input before going on-line with the outside computer firm. When reviewed and double checked, the final input is then transmitted in about <u>one-twentieth</u> the time normally involved for an interactive time-sharing service. Input errors are avoided and modeling time is decreased. See Tab: 1 for a typical input file from a program called CREDOE.

Refining DOE-2 outputs into unique reports for an energy manager presents a challenge. Again, using an in-house microcomputer and software, it is possible to develop specific reports for each client. For example, asshown in Tab. 2, one manager wanted reheat and other characteristics displayed for each HVAC system by season. The information in Tab. 2 was processed by software developed for a microcomputer using DOE-2 output. Of interest to the person was the difference in BTU's per square foot for both heating and cooling on AC-6 and AC-7 as compared to the other systems. These two systems serve animal storage rooms requiring 100% outside air for 24 hours a day. While they serve only 4% of the floor area, AC-6 and 7 account for 45% of the heating, cooling, and fan energy used by the building. Such secondary analysis can highlight the most important opportunities for energy conservation.

MODELING FOR ENERGY CONSERVATION

When clients are investing hundreds of thousands of dollars on major energy-conservation retrofits, they need positive assurances that the predicted savings will occur. Manual techniques cannot give the same reliability in complex buildings that computer models can give. Tab. 3 shows typical ECMs generated by computer simulation. Options 1, 2, 3, 4, 5, 8, 9, and 11 are particularly appropriate for analysis by computer. Even simple architectural changes performed by computer simulation can yield unexpected results, e.g., when the addition of insulation to the roof of a one-story structure was modeled (Option 11). Contrary to what one might expect, this insulation actually increased total energy consumption. This was due to the greater cooling load resulting from slower dissipation of internal loads. In contrast, routine use of nomographs from the F.E.A. manuals and other hand calculations project energy savings. Proposed lighting reductions are also an example of simple changes that could benefit from computer modeling, because these changes impact both cooling and heating consumption.

Comparing alternative schemes for renovating major HVAC systems in existing buildings can be an excellent computer model application. Tab. 4 demonstrates the capability to analyze an existing single-glazed structure using reheat systems and a panel heating and cooling system. Three types of glazing and three combinations of systems were modeled to find the optimal solution. Once the model of the existing building was made, each proposed change was very simple to simulate, not unlike what would be done for new construction. All of the proposed changes are extremely costly, and the energy consumption for each is important. Thus, accurate results are essential.

HANDLING PROGRAM LIMITATIONS

Not all systems or HVAC modifications can be easily accommodated by the present version of the DOE-2 or DOE-2.1 computer program. The following are not available as modeling options according to the DOE-2 manuals.

1. Radiant panel cooling
2. Scheduling pump operation consumption consistent with actual operation
3. Serving one zone with more than one system
4. Night cycle cooling
5. Multiple distributed chiller plants

Depending on the level of effort and money expended, it is possible to model all of the above. In the case of multiple chiller plants, program software changes are necessary from the original program developers. In the other cases, different procedures, such as creating negative heat additions or fictitious zones, can overcome these limitations. One method is to prepare very detailed schedules. For example, by analyzing in advance the hourly weather data, which one can have printed out, it is feasible to create schedules to turn fans or other equipment off and on at precise times according to outside air conditions. This process is somewhat time-consuming but still significantly easier and more accurate than manual calculations.

The above technique was used to simulate night-cycle cooling in which 100% outside air is used to pre-cool spaces at night to save cooling energy. Night-cycle cooling is a frequently suggested energy-conservation technique, although there is a dearth of literature documenting its effectiveness. The mass of the structure and its furnishings obviously affect the performance. To accomplish the analysis, each nighttime cooling season hour was reviewed and scheduled where appropriate as input to the model. The model building used was an existing low-rise office-laboratory in New York City with a low-pressure absorption chiller. The results indicated that night-cycle cooling failed to offset the cost of electricity to run the fans. Realizing that the local New York City weather is moderated by the ocean, the firm tried the analysis in the colder, dryer climate of Minneapolis. Surprisingly, night cycle did not fair much better. In Minneapolis, the structure released its internal heat by conduction quickly through its exposures at night because it is cooler, and again the fan energy more than offset the savings from night-cycle cooling (when using NYC steam and electric rates). More study of this ECM is required, but it appears that the technique has limited use for traditionally designed buildings. The weather scheduling technique in the above example is certainly laborious. However, one can imagine how much more effort would be required to calculate it manually, since the addition or subtraction of sensible heat to the structure's mass has to be accounted for daily.

OTHER APPLICATIONS FOR COMPUTER MODELING

Another computer model use is the determination of building sensitivity to annual temperature variations. It has been recognized that energy-consumption patterns for commercial structures are not linear with respect to degree-days. Building types respond differently to climatic variations. By comparing computer outputs for construction in warmer and colder weather, one can determine how energy consumption varies. Minimum and maximum energy use can be calculated for a particular locale. Figs. 1 and 2 show that despite up to 20% variation in heating degree-days and 30% in cooling degree-days, energy consumption for this building varied by only ±8% on heating and ±10% on cooling energy. It should be noted that cooling degree-days are unreliable indicators, as shown on Fig. 2 by the 1957 Washington, DC point, since they do not take humidity into account. Another measure that considers wet-bulb would be more desirable. Boston's summer weather, on the other hand, although cooler, is very similar to New York City's. The above structure is representative of a particularly complicated facility with many zones and reheat.

There are two uses for this type of analysis. First, one can develop a characteristic equation for a building based on heating degree-days. Fig. 3 has a formula for such a monthly comparison. From this formula, the energy consumption of a facility in a given year can be compared to what it should have been. If one can isolate the other energy increases in the building, which is not often easy to do for institutional sites, it becomes a good alternative to running a model each year to determine how well the building energy was controlled. There is also the possibility of developing characteristic formulas for classes of buildings in a given climate (e.g., apartment houses, offices buildings), which could then be used to determine ongoing energy performance in relation to degree-days or some other measurement. Office buildings may be in a category of those that respond well to this analysis, whereas institutional buildings like hospitals and colleges probably would not.

PERMANENT COMPUTER MODELS

As a tool for retrofit studies, many clients would not be persuaded to pay 20% to 40% more for an energy study done with a computer model. However, as energy costs continue toescalate, more decisions will be made on the basis of energy considerations. For example, in a large hospital, administrators must eventually consider the energy implications of building changes. A large fume exhaust system, electronic equipment with rigorous temperature/humidity requirements, or a major energy-intensive computer system are all examples of revisions that could adversely affect energy consumption. With a permanent computer model, the plant and maintenance director can have the proposed changes simulated for a modest cost to determine energy consumption. Also, at the end of a year, a computer run can be executed for the building using the year's weather tape incorporating all the new changes.

The plant and maintenance director can then analyze the new energy consumption pattern as a result of the type of modifications described above and develop a new strategy for the future.

Fig. 3 shows an example of a similar use in which a computer run was made for a structure using 1980 weather data. It compares the in-house metered consumption with the computer model for the same period. Apparent from the graph are two events occurring in the recorded steam data. The first bump in the graph is a large on-site steam leak, while the second shows up metering drift. This analysis determined what the building's real energy consumption should have been. In addition to this graph, it was possible to project the energy costs to operate a new computer facility within the building, which was surprisingly high at $18.43 per foot or $168,000 a year.

CONCLUSION

As energy costs continue to account for larger and larger segments of a building's operation, more sophisticated techniques will have to be employed to analyze energy-conservation options. Sophisticated computer models of existing buildings can play a part in such analyses, although not all buildings are appropriate candidates. On the other hand, those who are involved with this process should be aware of the significant time and cost to model.

TABLE 1

Examples Of A Credoe Menu

1.	BUILDING-LOCATION = B-L	2.	BUILDING-SHADE = B-S
3.	MATERIAL = MAT	4.	LAYERS = LA
5.	CONSTRUCTION = CONS	6.	GLASS-TYPE = G-T
7.	SPACE = S	8.	SPACE-CONDITIONS = S-C
9.	EXTERIOR-WALL = E-W (OR ROOF)	10.	INTERIOR-WALL = I-W (SPEC. FL. OR CEIL.)
11.	UNDERGROUND-WALL = U-W	12.	WINDOW = WI
13.	BUILDING-RESOURCE = B-R	14.	DESIGN-DAY = D-D
15.	LOADS-REPORT = L-R	16.	HOURLY-REPORT = H-R
17.	REPORT-BLOCK = R-B	18.	DAY-RESET-SCH = D-R-SCH
19.	DAY-SCHEDULE= D-SCH	20.	WEEK-SCHEDULE = W-SCH
21.	SCHEDULE		

WHICH ONE? WHEN FINISH, TYPE 22; TO INSERT DESCRIPTIONS,TYPE 23; HARD COPY, TYPE 24; TO DISPLAY FILE, TYPE 25?

THE ABOVE "MENU" FOR COMMAND WORDS ALLOWS THE USER TO CALL UP AND DISPLAY THE LISTING OF KEY-WORDS ASSOCIATED WITH A GIVEN COMMAND, THEREBY AVOIDING TYPING ERRORS AND ACCIDENTAL DELE-TIONS. THE "SPACE" COMMAND, FOR EXAMPLE, EVOKES A FORM REQUESTING DATA ON THE LOCATION, SIZE, INTERNAL LOADS, AND SCHEDULES FOR A PARTICULAR ZONE.

DO YOU WANT TO APPEND, INSERT, DELETE, MOVE, SEARCH, OR CHANGE DATA, 'A', 'I', 'D', 'M', 'S', 'C', OR 'N' FOR NO? N

DISPLAY THE DATA OR SAVE ON DISK, 'D' OR 'S'? D

FROM WHICH ROW TO WHICH ROW? 200, 209

200	A = 6430	205	L-KW = 7.752
201	V = 77160	206	E-SCH = ESVC
202	P-SCH = POFF	207	E-KW = 13
203	N-O-P = 21	208	N-Z-H = 6..
204	L-SCH = LOFF	209	UNDERGROUND-WALL

MORE?

DO YOU WANT TO APPEND, INSERT, DELETE, MOVE, SEARCH, OR CHANGE DATA, 'A', 'I', 'D', 'M', 'S', 'C', OR 'N' FOR NO? C

ONCE A LISTING HAS BEEN FILLED IN, IT MAY BE ADJUSTED, MOVED, RECALLED, ETC., BY UTILIZING CREDOE'S OPTIONS. ABOVE, WE HAVE INDICATED THAT WE WANT LINES 200 TO 209 OF OUR INPUT TO BE DISPLAYED IN ORDER TO MAKE CHANGES IN INPUT DATA PRIOR TO SENDING IT TO THE TIME-SHARING SERVICE.

TABLE 2
(SAMPLE REPORT PRODUCED IN-HOUSE)

SUMMER REHEAT & COOLING ENERGY

SYSTEM	% O.A.	CFM/FT²	HRS/SEASON	REHEAT MBTU DELIVERED	REHEAT BTU/FT²	COOLING MBTU DELIVERED	COOLING BTU/FT²
AC- 1	32	1.37	1,088	272.07	22,255.2	498.28	40,759.1
AC- 2	20	1.84	389	0.81	191.2	105.21	24,960.9
AC- 3	18	1.86	530	40.88	10,297.2	155.43	39,151.1
AC- 4	30	1.61	2,074	321.35	58,278.9	520.88	94,465.0
AC- 5	31	2.96	409	46.98	12,123.9	142.07	36,663.2
AC- 6	100	10.72	2,926	301.11	494,434.0	657.08	1,078,950.0
AC- 7	100	5.86	2,926	144.91	245,610.0	350.09	593,373.0

WINTER REHEAT ENERGY

SYSTEM	% O.A.	CFM/FT²	HRS/SEASON	REHEAT MBTU DELIVERED	REHEAT BTU/FT²
AC- 1	32	1.37	1,075	262.32	21,457.7
AC- 2	20	1.84	688	121.13	28,737.8
AC- 3	18	1.86	853	109.95	27,695.2
AC- 4	30	1.61	2,056	224.19	40,658.3
AC- 5	31	2.96	770	264.61	68,286.5
AC- 6	100	10.72	2,904	331.66	544,598.0
AC- 7	100	5.86	2,903	155.95	264,322.0

NOTE

1) NO COOLING ENERGY IS LISTED IN WINTER BECAUSE THE CHILLER IS OFF.

INTERMEDIATE SEASON REHEAT & COOLING ENERGY

SYSTEM	% O.A.	CFM/FT²	HRS/SEASON	REHEAT MBTU DELIVERED	REHEAT BTU/FT²	COOLING MBTU DELIVERED	COOLING BTU/FT²
AC- 1	32	1.37	1,114	308.75	25,255.6	148.10	12,114.5
AC- 2	20	1.84	694	30.87	7,323.8	61.24	14,529.1
AC- 3	18	1.86	866	92.82	23,380.4	80.59	20,299.7
AC- 4	30	1.61	2,074	304.92	55,299.2	150.03	27,208.9
AC- 5	31	2.96	780	138.54	35,752.3	90.26	23,292.9
AC- 6	100	10.72	2,926	321.89	528,555.0	119.71	196,568.0
AC- 7	100	5.86	2,926	152.51	258,492.0	64.40	109,153.0

NOTE: WINTER MONTHS ARE JANUARY, FEBRUARY, MARCH, AND DECEMBER; INTERMEDIATE SEASON COVERS APRIL, MAY, OCTOBER, AND NOVEMBER; SUMMER COVERS JUNE, JULY, AUGUST, AND SEPTEMBER.

TABLE 2 (SI)
(SAMPLE REPORT PRODUCED IN-HOUSE)

SUMMER REHEAT & COOLING ENERGY

SYSTEM	% O.A.	$M^3/S/M^2$	HRS/SEASON	REHEAT KJ DELIVERED	REHEAT JOULE/M^2	COOLING KJ DELIVERED	COOLING JOULE/M^2
AC- 1	32	0.007	1,088	257.87	227.0	472.27	415.7
AC- 2	20	0.009	389	0.76	2.0	99.72	254.6
AC- 3	18	0.009	530	38.75	105.0	147.32	399.3
AC- 4	30	0.008	2,074	304.58	594.4	493.69	963.5
AC- 5	31	0.015	409	44.53	123.7	134.65	374.0
AC- 6	100	0.054	2,926	285.39	5,043.2	622.78	11,005.3
AC- 7	100	0.030	2,926	137.35	2,505.2	331.82	6,052.4

WINTER REHEAT ENERGY

SYSTEM	% O.A.	$M^3/S/M^2$	HRS/SEASON	REHEAT KJ DELIVERED	REHEAT JOULE/M^2	NOTE
AC- 1	32	0.007	1,075	248.63	218.9	1) NO COOLING ENERGY IS LISTED IN WINTER BECAUSE THE CHILLER IS OFF.
AC- 2	20	0.009	688	114.81	293.1	
AC- 3	18	0.009	853	104.21	282.5	
AC- 4	30	0.008	2,056	212.49	414.7	
AC- 5	31	0.015	770	250.80	696.5	
AC- 6	100	0.054	2,904	314.35	5,554.9	
AC- 7	100	0.030	2,903	147.81	2,696.1	

INTERMEDIATE SEASON REHEAT & COOLING ENERGY

SYSTEM	% O.A.	$M^3/S/M^2$	HRS/SEASON	REHEAT KJ DELIVERED	REHEAT JOULE/M^2	COOLING KJ DELIVERED	COOLING JOULE/M^2
AC- 1	32	0.007	1,114	292.63	257.6	140.37	123.6
AC- 2	20	0.009	694	29.26	74.7	58.04	148.2
AC- 3	18	0.009	866	87.97	238.5	76.38	207.1
AC- 4	30	0.008	2,074	289.00	564.1	142.20	277.5
AC- 5	31	0.015	780	131.31	364.7	85.55	237.6
AC- 6	100	0.054	2,926	305.09	5,391.3	113.46	2,005.0
AC- 7	100	0.030	2,926	144.55	2,636.6	61.04	1,113.4

NOTE: WINTER MONTHS ARE JANUARY, FEBRUARY, MARCH, AND DECEMBER; INTERMEDIATE SEASON COVERS APRIL, MAY, OCTOBER, AND NOVEMBER; SUMMER COVERS JUNE, JULY, AUGUST, AND SEPTEMBER.

TABLE 3

Existing Hospital Building, 280,000 Ft², Electric Chillers, Induction Units, Reheat, and VAV Systems/NYC Climate

NO.	OPTION	Steam Savings (10^3 joules)	Electrical Savings (10^3 KWH)	Demand Savings (KW)	Cost Savings ($)
1	Revise temp. setting (heating: 75°F to 72°; cooling: 75°F to 78°F)	(59.7)*	(1.6)*	(7)*	(2007)*
2	Raise discharge temperature (55°F to 62°F)	983	70.4	35.0	20,949.0
3	Install deadband thermostats and discriminator controls (after changing temp. settings)	1,150	117.6	6.0	22,912.0
4	Extend chiller service to nearby lecture hall	--	261.8	55.0	25,443.0
5	Automatic chiller tube cleaning	--	33.8	47.0	9,472.0

Existing Lecture Office Buildings, 31,000 Ft², Absorption Chiller, Seven Reheat Systems, NYC Climate

NO.	OPTION	Steam Savings (10^3 joules)	Electrical Savings (10^3 KWH)	Demand Savings (KW)	Cost Savings ($)
6	Air-to-air heat recovery	352	(5.8)*	(6)*	3,683.0
7	Reduce outside air	1,166	47.0	1.2	19,746.0
8	Temperature-demand controls	1,550	14.0	17.0	22,911.0
9	Night cycle cooling	100	(16.5)*	--	(55)*
10	Variable speed pumping	--	114.2	5.2	7,000.0
11	Roof insulation	(455)*	--	--	(480)*

* Indicates loss not savings

TABLE 4

Summary of Installation Costs and Energy Usage

ITEM	TYPICAL ANNUAL ENERGY USE			ENERGY SAVINGS $	COST TO IMPLEMENT $	PAYBACK YRS.
	ELECTRIC		STEAM			
	KWH X10^6	KW	JOULES X 10^6			
EXISTING HVAC SYSTEM & BUILDING	1.887	344	39.842	-	-	
OPTION 1 - EXISTING HVAC SYSTEM WITH NEW STORM WINDOWS	1.887	344	38.996	8,920	150,000	16.8
OPTION 2 - EXISTING HVAC SYSTEM WITH NEW DOUBLE-HUNG REPLACEMENT WINDOWS	1.887	344	38.983	9,060	400,000	44.1
OPTION 3 - EXISTING HVAC SYSTEM WITH NEW PIVOTED WINDOWS	1.887	344	38.974	9,150	550,000	60.1
OPTION 4 - NEW VAV SYSTEM, EXISTING BASEBOARD, DISCONTINUE USE OF PANEL SYSTEM	1.239	315	24.632	210,935	1,050,000	5.0
OPTION 5 - NEW VAV SYSTEM, EXISTING BASEBOARD, CONTINUE USE OF PANEL SYSTEM	1.223	311	23.039	229,818	975,000	4.24
OPTION 6 - NEW PERIMETER FAN COIL SYSTEM, NEW INTERIOR CONSTANT-VOLUME OUTSIDE AIR SUPPLY, HEAT RECOVERY	1.313	338	18,249	267,560	1,100,000	4.11

NOTES:

1. OPTIONS 4, 5, AND 6 ASSUME STORM WINDOW TREATMENT FOR ENERGY USE.
2. ENERGY COSTS ASSUME $10 LB. STEAM, $.0666 (AVERAGE) PER KWH $29 PER KW SUMMER, $13 PER KW WINTER.
3. ALL SIMULATIONS PERFORMED WITH DOE-2.

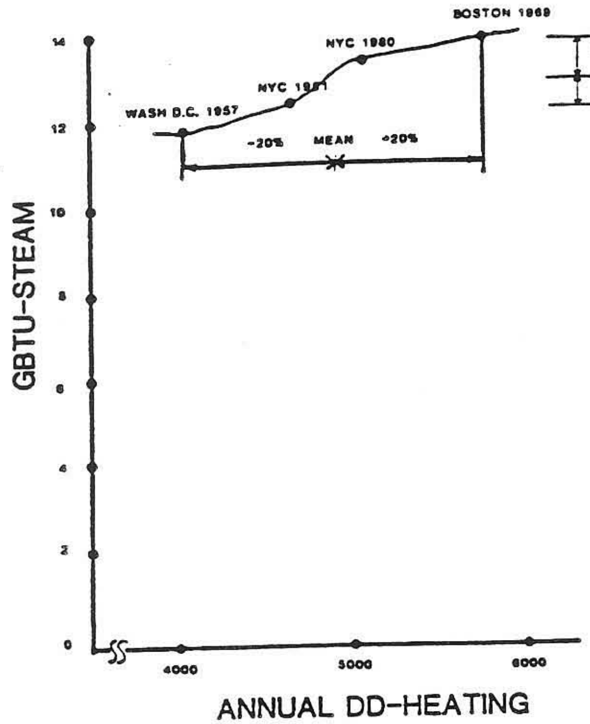

Figure 1. Weather sensitivity

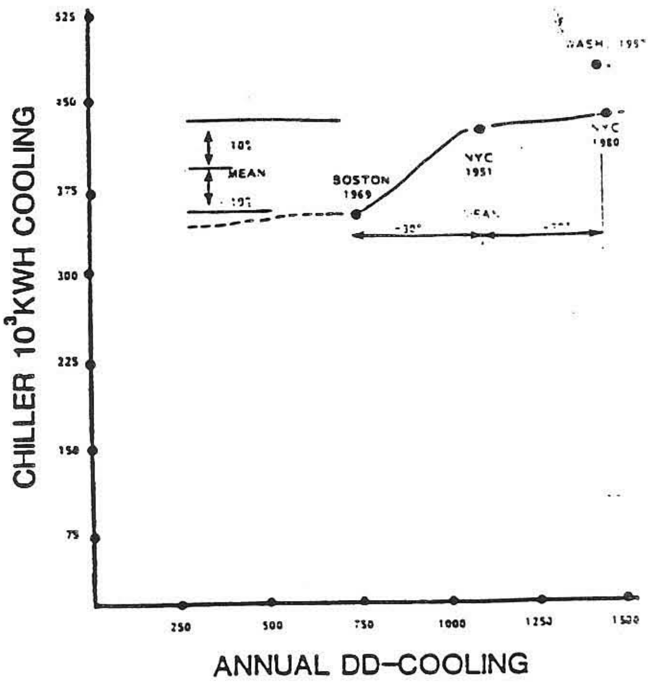

Figure 2. Weather sensitivity

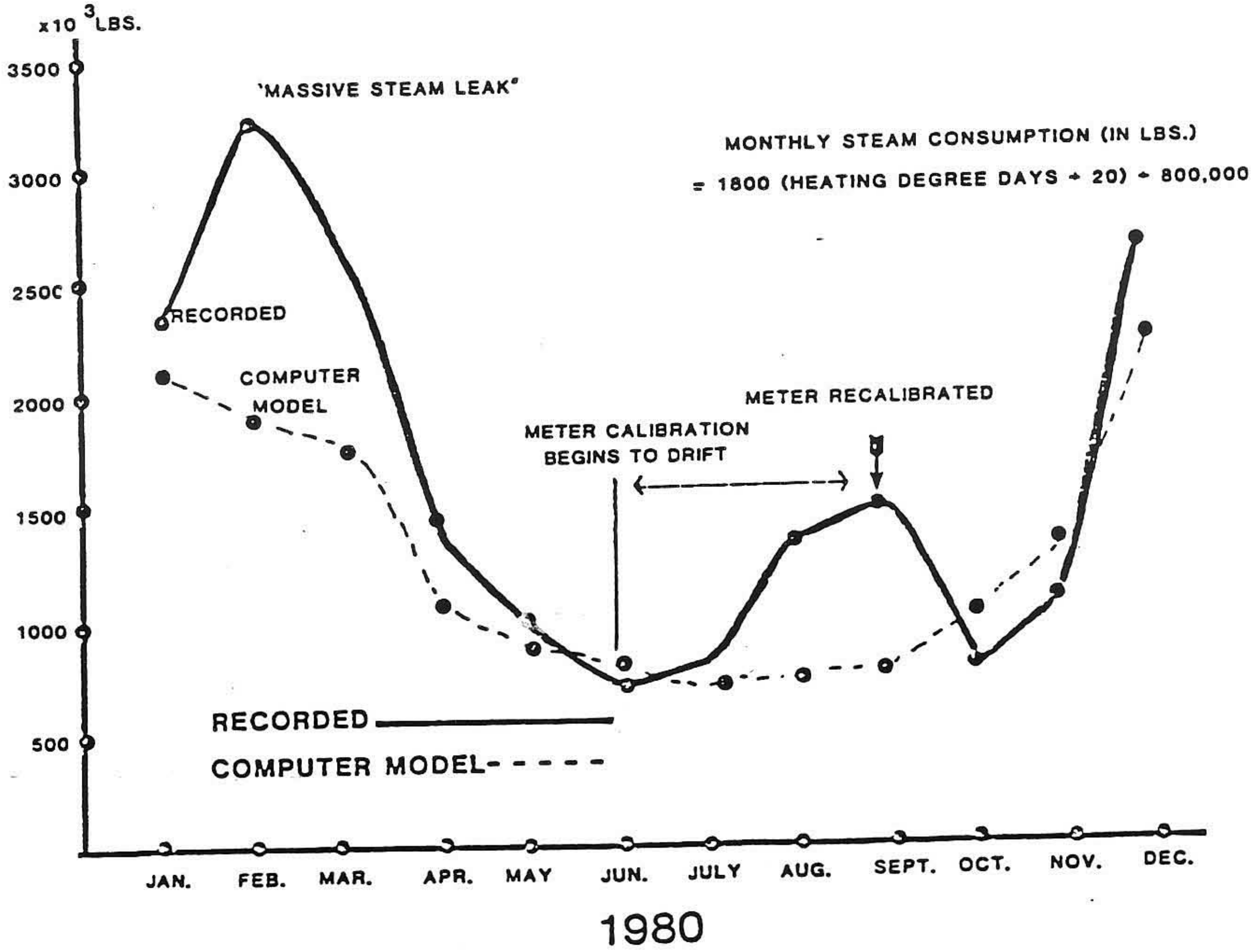

Figure 3. Steam consumption for calendar year 1980