NBSIR 76-1177

Comparison of Computer-Predicted and Observed Energy Uses in a Multi-Family High-Rise Apartment Building

James P. Barnett and Stanley T. Liu

Center for Building Technology
Institute for Applied Technology
National Bureau of Standards
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June 1977

Final Report

hudmius

MODULAR INTEGRATED UTILITY SYSTEMS

improving community utility services by supplying electricity, heating, cooling, and water/ processing liquid and solid wastes/ conserving energy and natural resources/ minimizing environmental impact

Prepared for

Department of Housing and Urban Development
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FOREWORD

The Department of Housing and Urban Development (HUD) is conducting the Modular Integrated Utility System (MIUS) Program to develop and demonstrate the technical, economic and institutional advantages of integrating the systems for providing all or several of the utility services for a community. The utility services include electric power, heating and cooling, potable water, liquid waste treatment and solid waste management. The objective of the MIUS concept is to provide the desired utility services consistent with reduced use of critical natural resources, protection of the environment and minimization of cost. The program goal is to foster, by effective development and demonstration, early implementation of the integrated utility system concept by private or public organizations.

Under HUD direction, several agencies are participating in the HUD-MIUS Program including the Energy Research and Development Administration, Department of Defense, Environmental Protection Agency, Department of Health, Education and Welfare, National Aeronautics and Space Administration, and National Bureau of Standards. The National Academy of Engineering has provided an independent assessment of the Program. Drafts of technical documents are reviewed by the agencies participating in the HUD-MIUS Program. The draft of this publication received such a review and all comments were resolved with HUD.

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ABSTRACT

A comparison has been made of the results of two computer programs, the National Bureau of Standards Load Determination Program (NBSLD) and the American Gas Association's E-CUBE Program, in predicting the energy consumption of a multi-family high-rise apartment building located in Omaha, Nebraska. Results are given on a monthly basis for the computed energy values and compared with average monthly values of metered data obtained over a five year period. Good agreement was found between the energy consumptions predicted by the two different computer programs as well as between the predicted values and the metered data (less than 7% difference on an annual basis).

Key Words: Building energy analysis; computerized energy analysis; energy consumption; heating and cooling loads

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1. Introduction

The national concern with energy use and its related problems has brought forth a large number of computer programs to estimate energy consumption in buildings. It is important that the adequacy of such computer simulations be determined since many of these programs will be:

1. used in the decision-making process which will determine future energy policy in this country;

2. used by architects and engineers in designing future buildings and in retrofitting existing ones.

At the request of the Department of Housing and Urban Development (HUD), a study involving a computerized energy analysis on a 12-story, 118-apartment building built in 1965-1966 in Omaha, Nebraska has been conducted at the National Bureau of Standards (NBS) by the Thermal Engineering Section of the Center for Building Technology. The study consisted of calculating the building energy consumption (gas and electricity) for a selected weather year by using the NBS computer program NBSLD, and comparing the results with (1) those computed by the Northern Natural Gas Company of Omaha under the sponsorship of the HUD regional office at Omaha using the E-CUBE Program [1]*, and (2) the actual metered 5-year average energy consumption record of the building supplied by the local housing authority. It should be pointed out that neither the determination of the validity of the underlying assumptions of E-CUBE nor the verification of the correctness of this application of E-CUBE was an objective of this study. Rather, its purpose was to compare the results of the two computer programs with the actual metered data, and with each other. The present report documents the procedures and results of this study.

This study is not the first attempt to verify energy consumption predictions by comparison with metered data. Probably the best known such study is the American Society of Heating, Refrigerating and Air-Conditioning Engineers' (ASHRAE) "Project Crosscheck" [2]. In the first phase of the ASHRAE project, five different energy analysis programs were used to predict the heating and cooling loads of a hypothetical 20-story building. This phase of the project served to evaluate the degree of agreement among the five programs but not the accuracy of each individual

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* Numbers in brackets indicate references listed on pages 13-14.

program. A second phase of the ASHRAE undertaking is to compare the energy consumptions calculated by four different computer programs with metered data on a four-story institutional building on the Ohio State University Campus in Columbus, Ohio. The results of this second phase should appear shortly as an ASHRAE publication.

The National Bureau of Standards computer program for heating and cooling load calculations (NBSLD) has been verified by comparison with experimental data from two separate research projects at NBS [3, 4]. In the first study [3], a small 20 ft by 20 ft by 10 ft (6.1 m by 6.1 m by 3 m) experimental masonry building was built within a large environmental chamber where the temperature could be adjusted and controlled from -50 °F (-45.5 °C) to +150 °F (+65.6 °C). The building was then subjected to typical diurnal exterior temperature fluctuations. The measured indoor temperatures and/or heating loads agreed well (never differing by more than 8%) with those predicted by NBSLD. In the latter study [4], a more realistic living unit was used--a four-bedroom, lightweight house that was completely furnished and had the activity of a six-member family simulated within. This house was also tested inside the environmental chamber where the outdoor conditions were controlled and precisely known. The measured energy consumption data for controlled winter and summer operating conditions agreed very well with the computed values. For example, the difference between the predicted and measured daily heating energy requirements averaged 3.1%, with a maximum difference of 4.9%.

2. NBSLD - A Computer Program for Design Analysis

The NBSLD Program consists of various subroutines, for calculating heat and energy transfer in structures [5], which are similar to those recommended by the ASHRAE Task Group on Energy Requirements [6]. One major extension of the program beyond the recommended ASHRAE TG procedure is a subroutine (called RMTMP), which allows the room air temperature to float between two set points instead of following a prescribed temperature profile. The details of this subroutine are given in reference 5.

Figure 1 depicts the overall calculation sequence of NBSLD. The phrases in the double lined boxes specify input data to be supplied whereas those in single lined boxes indicate calculations to be performed. The cycle indicators show how the computations must proceed through the rooms in a given building, and through the number of days for which the calculations are performed. Detailed identification of the exact input data required as well as the way in which they are prepared is given in reference 5.

It is important to point out that the hour-by-hour heating and/or cooling loads for a space as calculated by NBSLD represent the response to the hourly fluctuation of the outdoor weather conditions. The loads are calculated by solving a set of heat balance equations for the space each and every hour; there are no scaling techniques used to arrive at the loads. To permit NBSLD to predict energy consumption (i.e., the

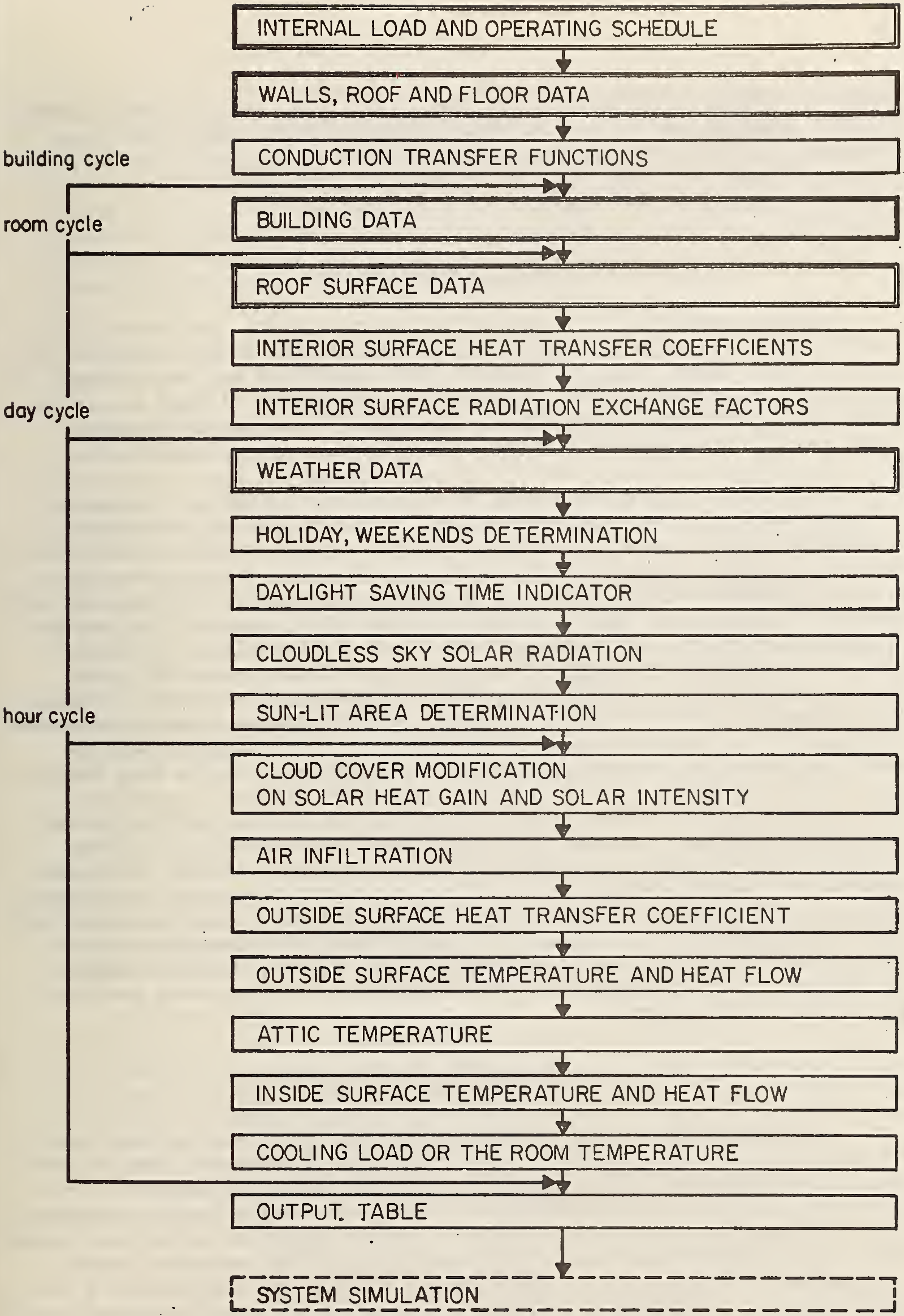

Figure 1. Calculation Sequence of NBSLD

amount of energy consumed by a heating, ventilating and air-conditioning (HVAC) system in satisfying the space heating and/or cooling load), a separate program had to be developed and added to simulate the HVAC system performance for this particular building. Details of the system simulation are given in Appendix A.

3. The E-CUBE Program

In 1967, the Group to Advance Total Energy (GATE) contracted with the Southwest Research Institute to develop the GATE Energy Analysis Program. This original version was very much simplified and was renamed E-CUBE [1], derived from the fact that the program is divided into three general areas: Energy requirements, Equipment selection and Economic comparisons. The economic portion of E-CUBE was not employed here.

The E-CUBE Program series utilizes as input the design heating and cooling loads and base electrical loads. These values are projected into hourly space loads resulting from given hourly outdoor weather data. These projected hourly loads are calculated from the design values by a scaling procedure which takes into account the variations in dry-bulb and dewpoint temperature, solar radiation, cloud cover, and building use and operating schedule. The output of the first portion of the E-CUBE Program consists of hourly values for thermal and electrical loads, peak thermal and electrical loads along with the time each occurred, and cumulative totals. The second portion of the E-CUBE Program (equipment selection) uses the loads generated by the first portion to determine the energy consumptions of various types of HVAC systems. Up to four different plant systems can be evaluated by the E-CUBE Program in each run. (See reference 1 for a more detailed description of the E-CUBE Program.) The major difference between the E-CUBE Program and NBSLD is in their procedures for heating and cooling load determination. While the former accepts the design heating/cooling loads and modifies them in accordance with a simple scaling procedure, the latter rigorously computes them every hour. Both programs can account for the effects of thermostat setback and periodic system shutdown, including the resulting thermal storage. In addition, both programs allow the treatment of simultaneous heating and cooling requirements.

4. Building Description

The building used in the present study (Kay-Jay Towers, Omaha Home for the Elderly) is a 12-story, rectangular-shaped apartment complex with the long axis running north to south. It is of brick and masonry cavity wall type construction, with windows on the east and west sides covering 17% of the surface area on both sides. The 118 apartment units are located above the ground floor. The ground floor is used for community spaces, a mechanical equipment area, the manager's office, and the manager's living quarters. The building contains a multi-zone air handling system with an economizer cycle for heating and cooling of the ground floor space;

hot-water fan-coil units for the apartment units; a central, single-duct forced-air system using 100% outside air for heating the second through the twelfth-floor corridors with exhaust through the apartment units; and window-type room air conditioners in one quarter of the apartments for summer cooling. Space heating is supplied by two gas-fired, hot-water boilers, and the refrigeration equipment for the multi-zone system consists of an electric-driven 15 kW compressor with air-cooled condenser and direct-expansion cooling coil. Domestic hot water is supplied by three 500,000 Btuh (146 kW) gas-fired hot-water heaters.

5. Description of NBSLD Input Data

As part of the input data for NBSLD a weather tape with hourly data is needed. Ideally this tape should cover the same period, 1967-1971, as the metered data. After 1965, however, the standard weather data tapes give only information taken at 3-hour intervals, and so a pre-1965 tape had to be chosen. The period April 1960 to March 1961 was selected as the test weather year by using the proposed ASHRAE procedure [7]. The E-CUBE procedure also uses weather year data which are not from the actual metered period but were selected by a special GATE procedure. Therefore, the weather data used by the NBSLD and E-CUBE Programs were not for the same twelve months. Information concerning the equipment and building operating schedules, and the indoor environmental conditions was furnished by the original design engineer, Raymond G. Alvine and Associates, and the Northern Natural Gas Company, both of Omaha, Nebraska. They in turn had obtained the data through the local housing authority and the building manager (see Appendix B). Building construction and HVAC system data were taken from the building design drawings (see Appendix C).

For the purpose of the computer analysis, the building was divided into three zones--ground floor, west zone of the tower portion, and east zone of the tower portion. This was the same procedure adopted by the Northern Natural Gas Company in using the E-CUBE Program. The same occupancy and interior lighting schedules were used by both the E-CUBE and NBSLD Programs, but the mechanical equipment simulation (e.g., boiler efficiency) was to some degree different.

For the NBSLD study the amount of air infiltration into the building (additional to that in-drawn by the mechanical ventilation) was estimated by a separate computer program developed by the National Research Council of Canada for high-rise buildings [8]. The E-CUBE analysis by the Northern Natural Gas Company neglected the natural air infiltration in the heating and cooling load computation.

The temperature and humidity settings used in the NBSLD calculation are given in Appendix D.

6. Results

The monthly and yearly total consumptions of natural gas and electricity for the building from the metered data, the E-CUBE Program, and the NBSLD Program, are given in Table 1.

The results for the cooling months (May-September) obtained by the Northern Natural Gas Company using the E-CUBE Program, as compared with the actual 5-year averaged metered data, show a large monthly deviation in total gas consumption but a much smaller deviation (0.3%-9%) in total electrical consumption. In the heating months (October-April), the monthly deviation was from 5% to 15% for total gas consumption, and from 0.7% to 13% for the total electrical consumption. The deviations in total yearly consumption between the calculated and metered results were 0.5% for natural gas and 4.5% for electricity.

The comparison of the NBSLD calculated values and the actual 5-year averaged metered data for the summer months shows a large monthly deviation in total gas consumption, with a smaller deviation in total electrical consumption (1.5%-9%). In the winter months, the deviation was from 7% to 26% for gas consumption and from 4.3% to 19% for electrical consumption. The deviations in total yearly consumption were 6.8% for gas and 6.1% for electricity.

It is seen from these results that the largest deviations in gas consumptions occurred in the summer months, which had no space heating requirements, so that demands were comprised entirely of domestic hot-water requirements. The domestic hot-water energy consumption was not included in either the E-CUBE Program or the NBSLD Program, and was added to the space heating energy requirement from an estimated load schedule provided by the Northern Natural Gas Company. This also applied to the electricity consumed for exterior lighting. (Schedules are listed in Appendix D, page 30.)

A comparison of the results of the two computer programs (see Table 1) shows that they follow the same monthly trends for both gas and electrical consumptions and that the computed monthly energy consumptions differed by less than 10% except for a difference of 14% for the February gas consumptions. The reason the two programs have exactly the same monthly gas consumptions for June, July, and August, when space heating requirements were absent, is that, as mentioned before, they used the same domestic hot-water schedule. The large percentage differences found when comparing NBSLD and E-CUBE predicted gas usage to the actual gas usage for September probably result from HVAC system operational procedures not made apparent to either NBS or the Northern Natural Gas Company.

Based on the results shown in Table 1, it is seen that both the E-CUBE Program and the NBSLD Program gave results for yearly energy consumption that agreed quite well with the metered data.

Table 1. Comparison of Metered and Predicted Results

	Gas Usage - mcf			Electricity Usage - kWh		
	Metered	E-CUBE	NBSLD	Metered	E-CUBE	NBSLD
January	1,688	1,605	1,454	63,120	59,582	54,508
February	1,518	1,308	1,124	60,744	52,982	49,233
March	1,298	1,160	1,050	56,928	56,542	54,508
April	889	719	695	55,728	53,454	53,096
May	578	504	508	56,136	57,266	56,962
June	279	216	216	59,352	54,294	54,614
July	156	223	223	67,944	66,897	65,236
August	140	223	223	61,608	62,186	65,999
September	187	436	414	56,808	56,637	61,862
October	538	681	632	57,984	56,245	54,846
November	991	1,050	987	59,856	54,525	52,750
December	1,264	1,449	1,351	65,644	59,042	54,508
Total	9,526	9,574	8,877	721,852	689,652	678,122

1 mcf = 1,000 ft^3

1 ft^3 = 0.0283 m^3

7. Conclusions

In comparing the energy consumptions predicted by the NBSLD and E-CUBE Programs for this case study, there are three factors that could cause differences (assuming both programs are correct in concept and application):

1. weather data (NBSLD used a real weather year, E-CUBE used a composite year);

2. HVAC system simulation (each program used its own);

3. air infiltration (NBSLD accounts for air infiltration and E-CUBE does not).

The above three factors undoubtedly contributed to some differences in the predicted results. However, since the results of the two programs are in close agreement, either the discrepancies were very small or else to a certain degree were self-compensating. It is possible to remove the differences caused by factor 2 above from the predictions if one compares loads (requirements) rather than consumptions.

A comparison between the predictions of the E-CUBE and the NBSLD Program on the overall space heating requirements for all building zones showed very close agreement (1.4%-6.2%) during the prime heating months (November through March). Comparison of cooling requirements could only be made for the first floor since E-CUBE results for cooling requirements of other zones were not available. Comparison of predicted cooling requirements for the first floor showed a large difference (5%-30%) between the two programs (see Tables 2 and 3*). The lower cooling requirements predicted by NBSLD may have been due to the differences in the way the two programs model thermal storage in the building materials. NBSLD uses the response factor method whereas E-CUBE uses a single building (zone) mass and specific heat to simulate thermal storage in a building (zone). The fact that the results for total electrical consumptions were in close agreement (0.5%-5%), suggests that the cooling loads for the total building were in close agreement.

It should be pointed out that this study compares energy consumptions calculated for particular weather years by the NBSLD and E-CUBE Programs to an average energy consumption value for a 5-year period. If the year period used by the respective programs is typical of the actual 5-year period, then this would cause little error in the computed results; on the other hand, if the weather year used in the calculations is not

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* Note that Table 2 contains both space/equipment loads and energy consumption. Columns 2-7 are load values. Columns 8 and 9 are energy consumptions and are computed by dividing the values in columns 2-7 by either efficiencies or COP's (see Appendix D) and then summing them. Table 3 contains only load values.

Table 2. NBSLD Predicted Loads

Omaha Home for Elderly (Kay-Jay Tower) Energy Usage

Month	Heating Load (Bldg.) (10^3 Btu)	Cooling Load (Gr. Fl.) (10^3 Btu)	Cooling Load (Apts.) (10^3 Btu)	Domestic Hot Water (10^3 Btu)	Auxil. Equip. (kWh)	Lighting Load (kWh)	Elec. Usage (kWh)	Gas Usage (mcf)
1	1,047,539	0	0	178,560	10,633	43,875	54,508	1,454
2	762,458	0	0	161,280	9,604	39,629	49,233	1,124
3	653,217	0	0	178,560	10,633	43,875	54,508	1,050
4	344,598	3,543	0	172,800	10,290	42,460	53,096	695
5	154,625	7,311	10,694	178,560	10,633	43,875	56,962	508
6	0	18,381	42,446	172,800	3,430	42,482	54,614	216
7	0	30,408	91,107	178,560	3,544	43,898	65,236	223
8	0	29,039	96,617	178,560	3,544	43,898	65,999	223
9	91,492	12,269	48,634	172,800	10,290	42,460	61,862	414
10	269,247	3,456	0	178,560	10,633	43,875	54,846	632
11	612,753	0	0	172,800	10,290	42,460	52,750	987
12	946,219	0	0	178,560	10,633	43,875	54,508	1,351
Total	4,882,148	104,407	289,498	2,102,400	104,157	516,662	678,122	8,877

Heating value of natural gas = 1,000 Btu/ft^3 [9]

Table 3. E-CUBE Predicted Loads

Summation of Energy Requirements

Kay-Jay Tower -- Modified Elec. Profile (Zone 1 + Zone 2 + Zone 3)

Cumulative Load Summation

	Heating Load (10^3 Btu)	(Ground Floor) Cooling Load (10^3 Btu)	Electrical Load (kWh)	Domestic Hot Water Load (10^3 Btu)
January	1,014,567	0	46,712	178,560
February	808,501	0	42,192	161,280
March	680,734	0	46,712	178,560
April	349,496	2,093	45,205	172,800
May	178,495	9,428	46,712	178,560
June	0	20,112	45,205	172,800
July	0	43,608	46,712	178,560
August	0	34,118	46,712	178,560
September	137,634	13,633	45,205	172,800
October	315,207	4,747	46,712	178,560
November	598,682	0	45,205	172,800
December	891,393	0	46,712	178,560
Total	4,974,709	127,739	549,996	2,102,400

representative of the real data, this would be a source of error. Figure 2 is a plot of the heating degree days for the metered period (average monthly value for the 5-year period) and for the NBSLD weather data for the primary heating months, November through April. Figure 2 shows that the NBSLD weather data has somewhat underestimated the heating degree days in the actual data (except for April), particularly in the months of January and February. Therefore, one would expect the NBSLD gas consumptions for this period to be less than the metered ones. However, Table 1 shows that this is not the case. The NBSLD predicted value for November is almost exactly equal to the metered value; the NBSLD predicted value for December is actually greater than the metered one; and it is only in the months of January, February, and March that the NBSLD-predicted values are substantially less than the metered ones. This anomaly is illustrated more vividly in Figure 3, where the monthly gas consumptions (November-April) are plotted against the heating degree days. It is seen from Figure 3 that the energy consumption per degree day remains relatively constant for the NBSLD values. This is as it should be since the program does not give more weight to some heating degree days than others (percent cloud cover, wind velocity, and sun angle have an effect on energy consumption also, but there was no significant monthly difference in these variables during the heating season between the NBSLD weather year and the actual 5-year period). However, Figure 3 also shows the metered data to have a trend of increasing energy consumption per degree day as the winter season progresses. Whether this observed trend is real or caused by erroneous data is unclear at this time.

Since the energy consumption for this case was closely related to the space load, the calculation of energy consumption for this building was really a test of how well the NBSLD and E-CUBE Programs calculated space thermal load. This may not be the case for many commercial buildings where the complexity of the HVAC system performance is a major factor affecting energy consumption. The results of this study indicate that both NBSLD and the E-CUBE Programs reliably predict energy consumption for a building which is dominated by loads due to thermal transfer through its exterior shell (skin sensitive) and which also has an extremely simple HVAC system. These results should, however, not be construed to mean these two programs would necessarily be as accurate for a building with a more complicated HVAC system. In the case of NBSLD, since it is only a load program, it is obvious that a new system simulation routine would have to be developed to calculate energy consumption for a different HVAC system.

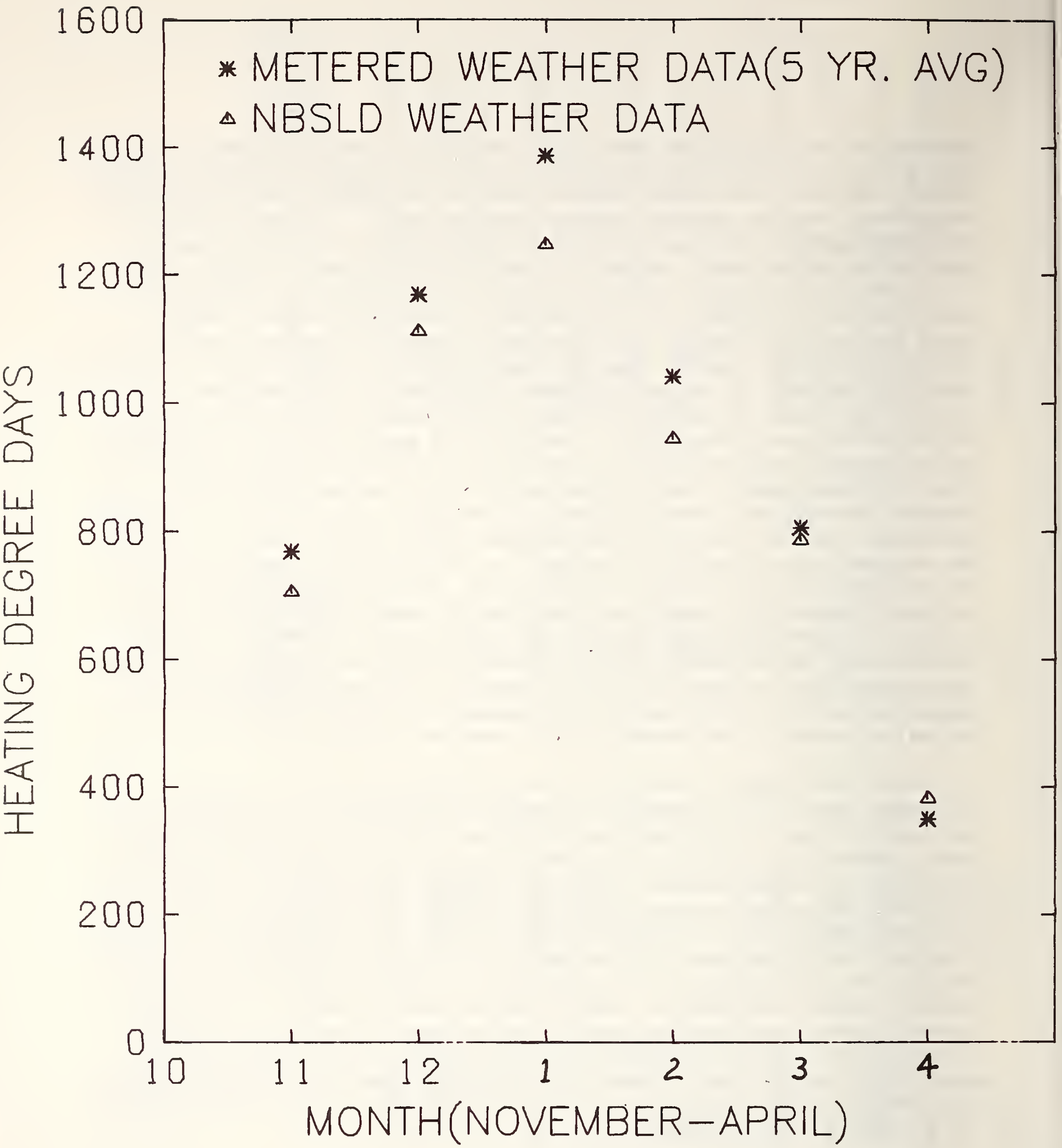

Figure 2. Heating Degree Days as a Function of Month

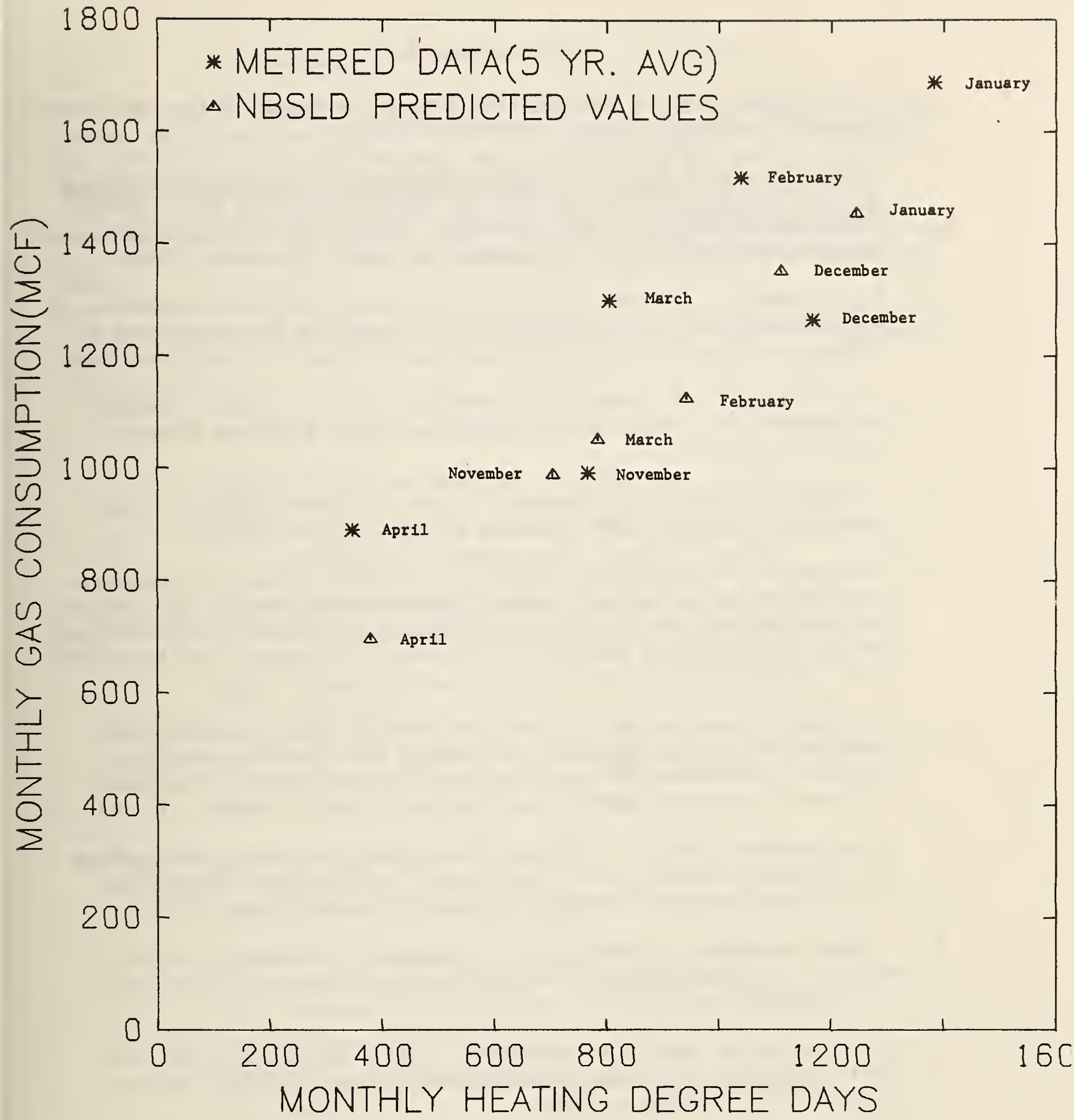

Figure 3. Monthly Gas Consumption as a Function of Heating Degree Days

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Appendix A. Air-Side Systems Simulation

The first floor of the building employed a multi-zone air handling system which supplied processed air to each of five zones. The supply air temperature to each zone was regulated by the hot and cold deck dampers according to the zone thermostat.

To simplify the analysis, all the zones are combined and the system is treated as a single zone double duct system such as depicted in Figure A1.

The following notations are used to describe the system simulation equations; most of them are depicted in Figure A1 (input variables underlined):

1. Airflow data expressed in cfm

    CFMIN: minimum outdoor air ventilation

    CFML: air leakage to the zone through cracks and openings in the building exterior walls

    CFMV: outdoor ventilation air which is brought into the air handling system

    CFMS: total airflow through the air handling system

    CFMC: airflow through the cooling coil

    CFMH: airflow through the heating coil

2. Temperature data expressed in °F

    DB: outdoor air temperature

    TA: zone temperature

    TC: temperature of the air leaving the cooling coil

    TH: temperature of the air leaving the heating coil

    TM: temperature of the air after the fan

    TSUP: temperature of the air being supplied to the zone

3. Humidity ratios expressed in lb of water per lb of dry air

    WA: humidity ratio of the outdoor air

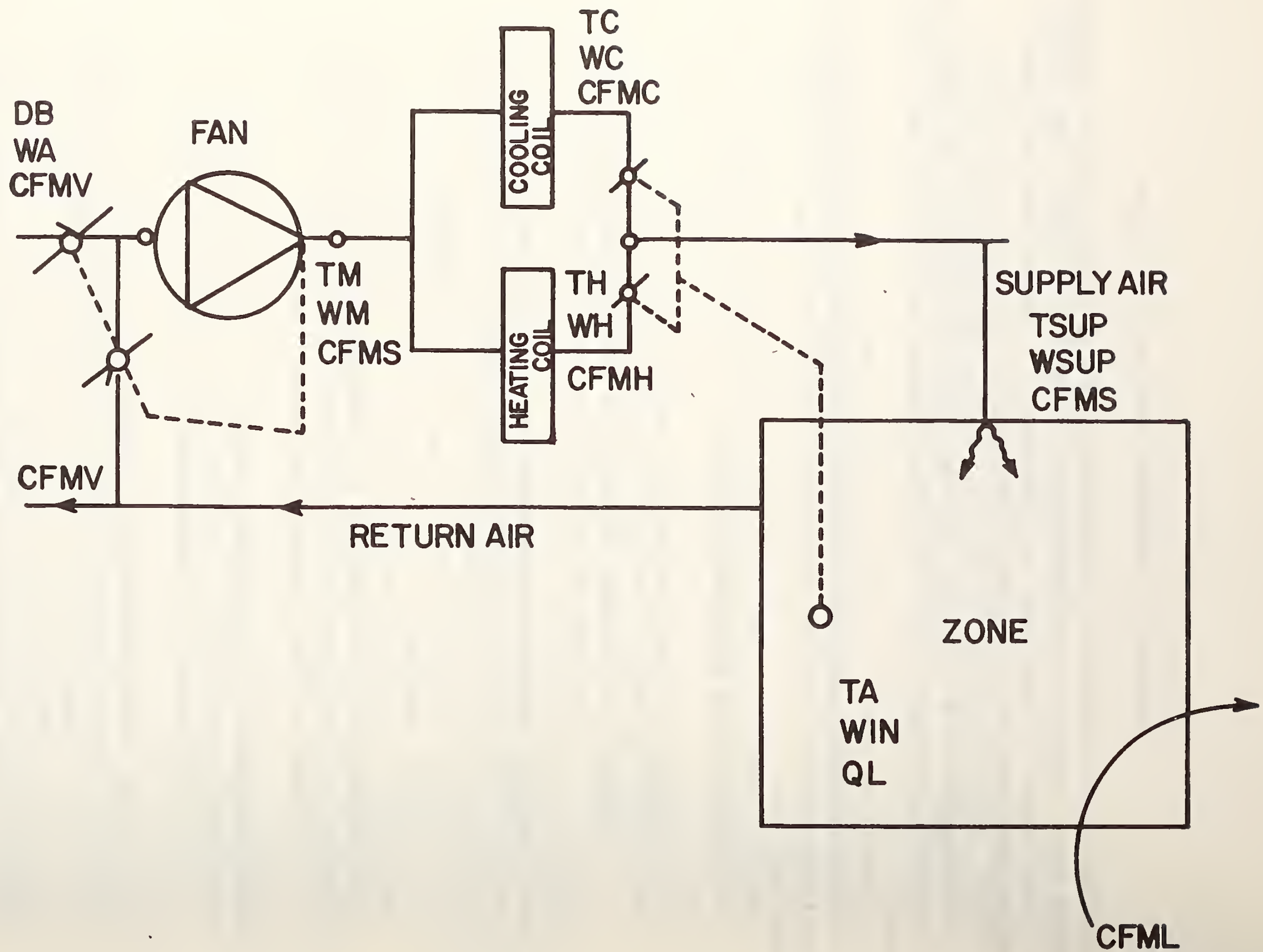


Figure A1. Multi-zone System of HUD/Omaha

WIN: humidity ratio of the zone air

WM: humidity ratio of the air after the fan

WC: humidity ratio of the air leaving the cooling coil

WH: humidity ratio of the air leaving the heating coil

WSUP: humidity ratio of the air being supplied to the zone

4. Heating and cooling loads expressed in Btu/hr

QL: zone heating and cooling load

QFAN: heat generated by the fan

QOCPL: latent heat generated by the zone occupant

QLATNT: cooling coil latent heat load

QCOILC: cooling coil load

QCOICH: heating coil load

The general equations that are used to simulate the system are then

$$\text{TSUP} = \frac{\text{CFMH} * \text{TH} + \text{CFMC} * \text{TC}}{\text{CFMS}} \tag{1}$$

$$\text{QL} = 60 * \text{RHO} * \text{CP} * \text{CFMS} * (\text{TSUP} - \text{TA}) \tag{2}$$

$$\text{CFMS} = \text{CFMH} + \text{CFMC} \tag{3}$$

where

RHO = density of air in lbm/ft^3 = 0.075

CP = specific heat of air in Btu/lbm · °F = 0.24.

These three relationships determine the values of CFMH and CFMC as follows:

$$\text{CFMC} = \frac{1}{\text{TH} - \text{TC}} \left[\text{CFMS} * (\text{TH} - \text{TA}) - \frac{\text{QL}}{60 * \text{RHO} * \text{CP}} \right] \tag{4}$$

$$CFMH = CFMS - CFMC. \quad (5)$$

By knowing the airflows through the heating and cooling coils, one can determine the coil loads as follows:

$$QCOILC = 60 * RHO * CFMC * CP * (TM - TC)$$
$$+ 60 * RHO * CFMC * (WM - WC) * 1,061 \quad (6)$$

where

1,061 = latent heat of condensation of water vapor in Btu/lbm;

$$QCOILH = 60 * RHO * CFMH * CP * (TH - TM). \quad (7)$$

The values of TM and WM can be evaluated by the following equations:

$$TM = \frac{CFMV * DB + (CFMS - CFMV) * TA}{CFMS} + \frac{QFAN}{60 * RHO * CFMS * CP} \quad (8)$$

$$WM = \frac{CFMV * WA + (CFMS - CFMV) * WIN}{CFMS} \quad (9)$$

where

CFMV = CFMIN when heating is required
when cooling is required and DB > 55 °F

The room humidity ratio WIN was calculated from the following moisture balance equation:

$$60 * RHO * CFMS * (WSUP - WIN) + 60 * RHO * CFML * (WA - WIN)$$
$$= QOCPL/1,061.$$

The value of WSUP is available from

$$WSUP = \frac{CFMC * WC + CFMH * WH}{CFMS}$$

where

WC = 0.009 when the cooling coil is on (saturation humidity ratio at 55 °F)

WC = WM when the cooling coil is off

WH = WM always.

The cooling coil was assumed "on" during the summer months (May through September) as long as TM was greater than TSUP as calculated by equation (1), while the heating coil was off during the same time. Thus the cooling coil capacity, equation (6), can be reduced identically to

$$\begin{aligned} QCOILC &= 60 * RHO * CFMS * CP * (TM - TSUP) \\ &\quad + 60 * RHO * CFMS * (WM - WSUP) * 1{,}061. \end{aligned} \tag{11}$$

The economizer cycle was simulated by shutting the cooling coil off and increasing the outdoor air quantity up to as much as CFMS while TM was maintained at 55 °F, and by letting TSUP = TM, and WSUP = WM.

Air leakage CFML was calculated by a Coblentz-Achenbach type equation [10]:

$$AC = 0.272 - 0.0071 * WS + 0.019 * (TA - DB)$$

where

AC = number of air changes/hour = 60 * CFML

WS = wind speed in mph.

When the last formula's value for AC became negative and DB was greater than TA, it was assumed that the air leakage was approximately 1/4 air changes per hour. This value was obtained by a separate calculation making use of the computer program in reference 8.

Appendix B.

Miscellaneous Correspondence

2223 Dodge Street
Omaha, Nebraska 68102
Telephone 402-348-4000

Northern Natural Gas Company

August 22, 1973

Mr. Stanley Liu
National Bureau of Standards
Building 226, Room B-104
Washington, D.C. 20234

Dear Mr. Liu:

Attached is a copy of the electric load profile used in the analysis of KAY-JAY Tower. Our synthesis was based on a combination of empirical data from the O.E.A. Apartments (a hi-rise building occupied by retired teachers) and actual observation of the KAY-JAY Tower. From Ray Alvine & Associates, the design connected load is 2.0 kw/sq. ft. in Zones 2 and 3 excluding elevators. From O.E.A. building, the actual metered sustained peak is 1.1 kw/sq. ft. I have drawn two axes on the accompanying chart to illustrate the adjustment required to account for the different definitions of peaks. Having defined the peak, the load profile was adjusted primarily by ratioing the O.E.A. building data to KAY-JAY data based on the different peaks. Further adjustment was made to eliminate the morning peak on O.E.A. based on observation of KAY-JAY and the fact that O.E.A. has a central dining room.

This load profile as derived includes all equipment within the occupied spaces. Specifically excluded are the window-type air conditioners, all elevator equipment and outside lighting. Exhaust fans were negligible and the circulating hot water pump electrical usage was included in the equipment section. All living units had electric cooking. A brief inspection of several units indicated typical domestic lighting levels, TV's (very few color), refrigerators and normal miscellaneous appliances such as irons.

The inside temperature, as indicated by the building operator, is 78° D.B. For the air conditioned portion of the tower, the inside temperature is 75° D.B. Please note that only a portion of the dwelling units were air conditioned. If you need further information, please let me know.

Sincerely,

Dave Barnes

Dave Barnes
Marketing Consultant

DWB:blg
Attachments

I. **Company & Product Information**

Type Customer: Commercial X Industrial ____

Company: O.E.A. APARTMENTS

Address: 320 NORTH 22ND STREET, OMAHA, NEBRASKA

Principal Product or Service: APARTMENTS

Operation: Hours/Day 24 Shifts/Day 3 Days/Week 7 Weeks/Year 52

Number of Buildings: 1 Square Feet: 83,662 Number of Floors 12

Number of Elevators: 2 Type: PASSENGER

Additional Building Description: AREA INCLUDES A DINING ROOM, KITCHEN, LAUNDRY, MAIL ROOM, LOUNGE, AND STORAGE AREA. TOTAL OF 132 APARTMENTS

II. **Electric Load**

Connected Load:

Lighting	106 KW
Motors (Including air handling and appliances)	754 KW
Motors (A/C and heating)	59 KW
Other	____ KW
Total	919 KW

Total Connected Load: 9.98 KW/1,000 ft.² (Excludes A/C, heating & elevator motors)

Recorded Peak Demand: 120 KW, 1.43 KW/1,000 ft.²

Largest Motor: 15 HP Application WATER PUMP

III. **Energy Requirements & Costs**

	Natural Gas		Electric			Standby Fuel (Gallons)	
	Month	Mcf	Month	KWH's	Utility Meter Demand (KW)	Propane	Oil
Maximum Month:	JULY	1,561	JULY	66,938			
Minimum Month:	OCT.	394	OCT.	41,587			
Yearly Requirement:		10,433		641,400			7,461

Average Gas Cost ____ ¢/Mcf; Average Electric Cost ____ ¢/KWH

Remarks ELECTRIC AND GAS BILL NOT AVAILABLE

IV. **Thermal Loads**

Equipment:

Heating: HOT WATER

Air Conditioning: ABSORPTION CHILLER

Refrigeration: ____

Other: ____

Capacity:

Boiler: 3,000 MBTU/Hour

A/C: 100 Tons

Refrigeration: ____ Tons

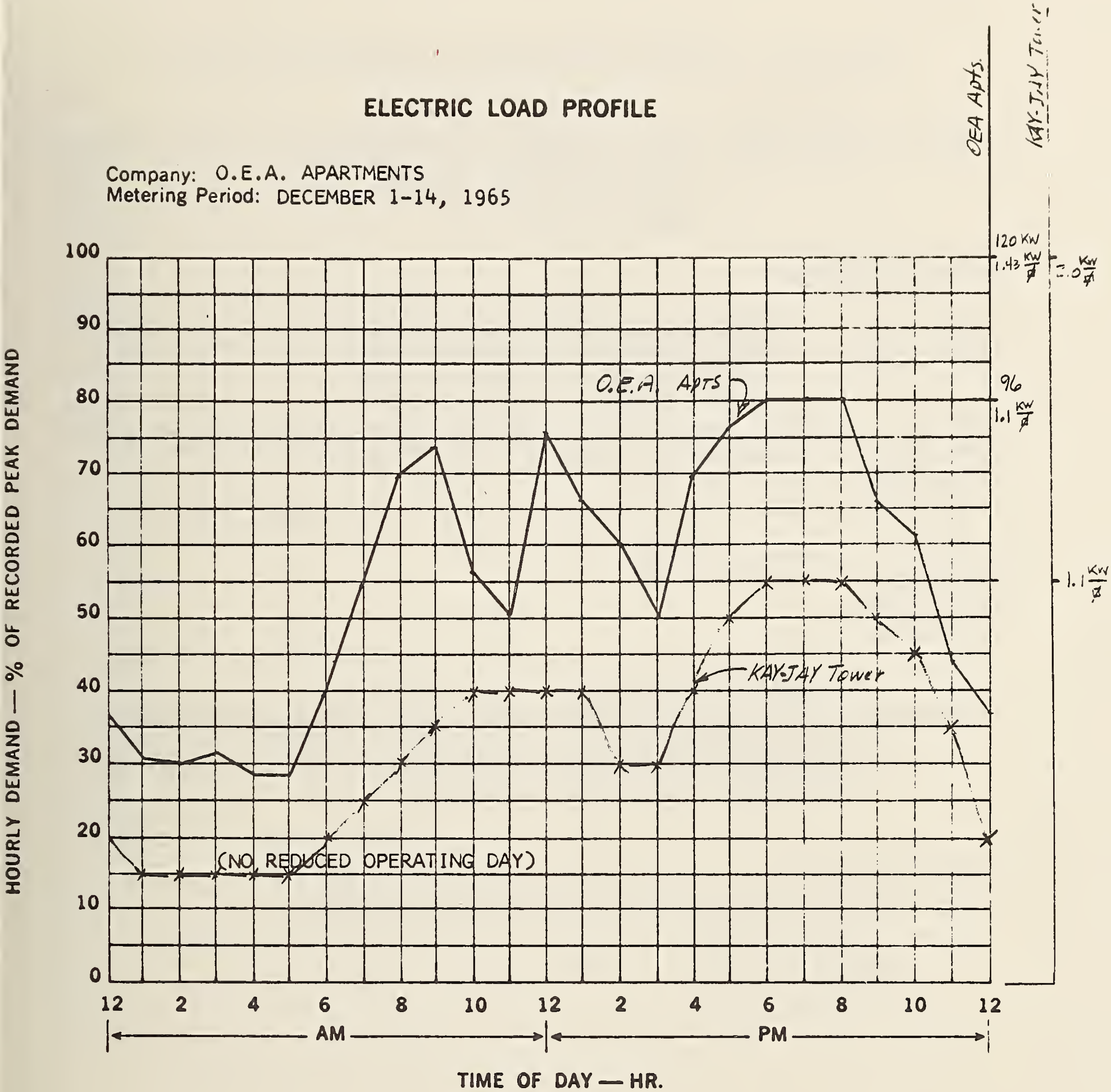
Other: ____

V. **General Information**

HIGH RISE APARTMENT FOR RETIRED EDUCATIONAL EMPLOYEES. EACH APARTMENT USES ELECTRIC RANGES AND OVENS FOR COOKING.

ELECTRIC LOAD PROFILE

Company: O.E.A. APARTMENTS
Metering Period: DECEMBER 1-14, 1965



Total Connected Electrical Load (Less air conditioning, heating, and elevator motors) .... 835 KW

Recorded Peak Demand (Normally less than 5 minutes and greater than one second) .... 120 KW

Average Daily Load Factor (Normal Operation) 56%
(Reduced Operation) .... —

Annual Load Factor .... —

Appendix C. Summary of Building and System Information*

BUILDING DESCRIPTION: Omaha, Nebraska, 40° latitude, 12 stories, rectangular with large axis on North-South orientation, all exposed glass on East and West, 82,870 sq. ft., masonry construction.

Mechanical System:

Zone #1 (First Floor) ($5,170\ ft^2$)	- Multi-zone air handling unit with hot-water coil, chilled water cooling coil, economizer fresh air cycle, high recovery domestic hot-water system.
Zone #2 East Floors (2 thru 12) ($38,500\ ft^2$)	- Individual fan-coil units with hot-water coil, fan cycle control; zone level control reset on hot water.
Zone #3 West Floors (2 thru 12) ($38,500\ ft^2$)	- Same as Zone #2.

EQUIPMENT: 2-100 ton reciprocating water chillers with cooling tower, 2-1,440,000 Btu input heating boilers, 3-500,000 Btu input gas-fired domestic water heaters, 25 kW for tower and cooling pumps, and a 10 kW heating pump.

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* This information was obtained from building drawings.

Appendix D. Input Data for NBSLD

1. Weather Data: National Climatic Center weather tape for Omaha, Nebraska, 4/61 - 3/62

2. Wall Construction Data*:

   L = thickness of the layer, ft.

   K = thermal conductivity of the layer, Btu/hr-ft-°F

   D = density of the layer material, lb per cu. ft.

   C = specific heat of the layer material, Btu per (lb) (°F)

   R = thermal resistance value of the layer in (hr) (sq. ft.) (°F) per Btu

Roof:

L	K	D	C	
.5	1.	140.	.20	6 Inch Concrete Ceiling
.208	.143	60.	.20	2.5 Inch Lightweight Concrete
.125	.0283	16.	.20	1.5 Inch Rigid Insulation
.0313	.0938	70.	.35	3/8 Inch Built-up Roofing

East/West Exterior Wall:

L	K	D	C	R	
.3333	0.22	38.0	0.2		4 Inch Lightweight Block
				0.91	1 5/8 Inch Airspace
.33333	0.77	125.	0.22		4 Inch Face Brick

North/South Exterior Wall:

L	K	D	C	R	
.04167	.12	58.	.26		1/2 Inch Gypboard
				0.91	1.5 Inch Wall Furring (Airspace)
.63542	1.0	140.	0.2		7 5/8 Inch Concrete
				.91	1 Inch Airspace
.33333	.77	125.	.22		4 Inch Facing Brick

---

* Thermo-physical data taken from ASHRAE Handbook of Fundamentals, page 431; see reference 9.

Ground Floor:

L	K	D	C	R	
0.	0.	0.	0.	.05	Vinyl Asbestos Tile
.3333	1.	140.	.2		4 Inch Concrete Floor
.6667	.20	100.	.44		8 Inch Sand and Gravel

1st Floor Ceiling:

L	K	D	C	R	
.0625	.02	21.	.20		3/4 Inch Acoustic Tile Ceiling
0.	0.	0.	0.	1.12	Airspace
.50	1.	140.	.20		6 Inch Concrete Floor
0.	0.	0.	0.	.05	Vinyl Asbestos Tile Floor

Floor/Ceiling 2-12:

L	K	D	C	R	
0.	0.	0.	0.	0.5	1/16 Inch Vinyl Asbestos Tile
.5	1.0	140.	.2		6 Inch Concrete

Partition Wall:

L	K	D	C	R	
.125	.12	.58	0.26		1 1/2 Inch Gypboard
				.91	3 Inch Airspace
.125	.12	.58	0.26		1 1/2 Inch Gypboard

3. Normalized Daily Schedule (24-hour profile) of Heat Input for Lighting, Equipment and Occupancy:

   Ground Floor Zone Lighting (maximum - 2 watts/ft^2)

   Hours 1 through 24, Fraction of Maximum

.05	.05	.05	.05	.05	.05	.50	.50	.50	.50
.80	.80	.80	.80	.80	.80	.80	.80	.80	.80
.80	.05	.05	.05						

Ground Floor Zone Occupancy (maximum - 50 persons)

Hours 1 through 24, Fraction of Maximum

0.	0.	0.	0.	0.	0.	0.	.25	.25	.25
.25	.25	.25	.25	.25	.25	.25	.25	.25	.25
.25	0.	0.	0.						

East/West Zone Floors 2-12 Lighting (maximum - 2 watts/(ft^2)-floor)

Hours 1 through 24, Fraction of Maximum

.15	.15	.15	.15	.15	.20	.25	.30	.35	.40
.40	.40	.40	.30	.30	.40	.50	.55	.55	.55
.50	.45	.35	.20						

East/West Zone Floors 2-12 Occupancy (maximum - 110 persons/zone)

Hours 1 through 24, Fraction of Maximum

.70	.70	.70	.70	.70	.70	.70	.70	.70	.35
.35	.35	.35	.35	.35	.35	.35	.35	.35	.35
.35	.35	.70	.70						

4. Interior Environment Setting:

<u>Ground Floor</u>:

Heating Season (October-April) - 75 °F, relative humidity (R.H.) unregulated

Cooling Season (May-September) - 70 °F, 50% R.H.

<u>2nd Through 12th Floor (Apartments)</u>:

Heating Season - 78 °F, R.H. unregulated

Cooling Season - 75 °F, 50% R.H. for A/C space (1/4 of total space); R.H. and temperature unregulated for rest of space

5. Infiltration, Air Changes Per Hour:

<u>Ground Floor</u>:

$$AC = 0.272 - 0.0071\ (WS) + 0.019\ (TA - DB) \quad \text{for } TA > DB$$

$$= 0.25 \quad \text{for } TA < DB$$

East/West Zone:

$$AC = 0.088 + 0.022\,(WS) + 0.0016\,(TA - DB) \quad \text{for } TA > DB$$

$$= 0.25 \quad \text{for } TA < DB$$

where

AC = air changes per hour

WS = wind speed in mph

TA = room temperature, °F

DB = outside temperature, °F

Note that the coefficients in the above formula were found by fitting the equation to points generated by the computer program of reference 8.

6. Surface Data:

GROUND FLOOR ZONE

Surface Type	Area ft^2	Absorptivity
Ceiling	5,170	
South Facing Exterior Wall	270	0.9
South Facing Window	170	0.0
West Facing Exterior Wall	540	0.9
West Facing Window	165	0.0
West Facing	760	
North Facing Exterior Wall	154	0.9
North Facing	286	
East Facing Exterior Wall	1,098	0.9
East Facing Window	366	0.0
Floor	5,170	

WEST ZONE SURFACES

Surface Type	Area ft^2	Absorptivity
Roof	3,500	0.9
South Facing Exterior Wall	2,100	0.9
West Facing Exterior Wall	14,025	0.9
West Facing Window	2,725	0.0
North Facing Exterior Wall	2,100	0.9
East Facing Partition	16,750	
Partition Wall	3,500	

EAST ZONE SURFACES

Surface Type	Area ft^2	Absorptivity
Roof	3,500	0.9
South Facing Exterior Wall	2,100	0.9
West Facing Partition Wall	16,750	
North Facing Exterior Wall	2,100	0.9
East Facing Exterior Wall	13,970	0.9
East Facing Window	2,880	0.0
South Facing Partition Wall	3,500	

7. Mechanical Ventilation:

Ground Floor:

Heating Mode - System air supply 4,100 cfm, 10% minimum outside damper (750 cfm)

Cooling Mode - System air supply 4,100 cfm, economizer controlled outside air with minimum setting at 10% (750 cfm)

East/West Zone: 3,500 cfm each, all outside air

8. System Efficiency:

Boiler - See Figure D1 for partial load efficiencies used.

Ground Floor A/C - COP = 3.0

Apartment Room Air Conditioner - COP = 1.75

Domestic Hot-Water Heater Eff. = 0.7

9. Domestic Hot-Water Schedule (24-hour profile)

Maximum Value - 1.5 x 10^6 Btu

Hours 1 through 24, Fraction of Maximum

.02	.02	.02	.02	.02	.02	.02	.30	.30	.30	.30	.30
.30	.30	.30	.30	.30	.30	.30	.20	.20	.20	.20	.20

10. Exterior Lighting Schedule (24-hour profile)

Maximum Value - 4 kW

1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0

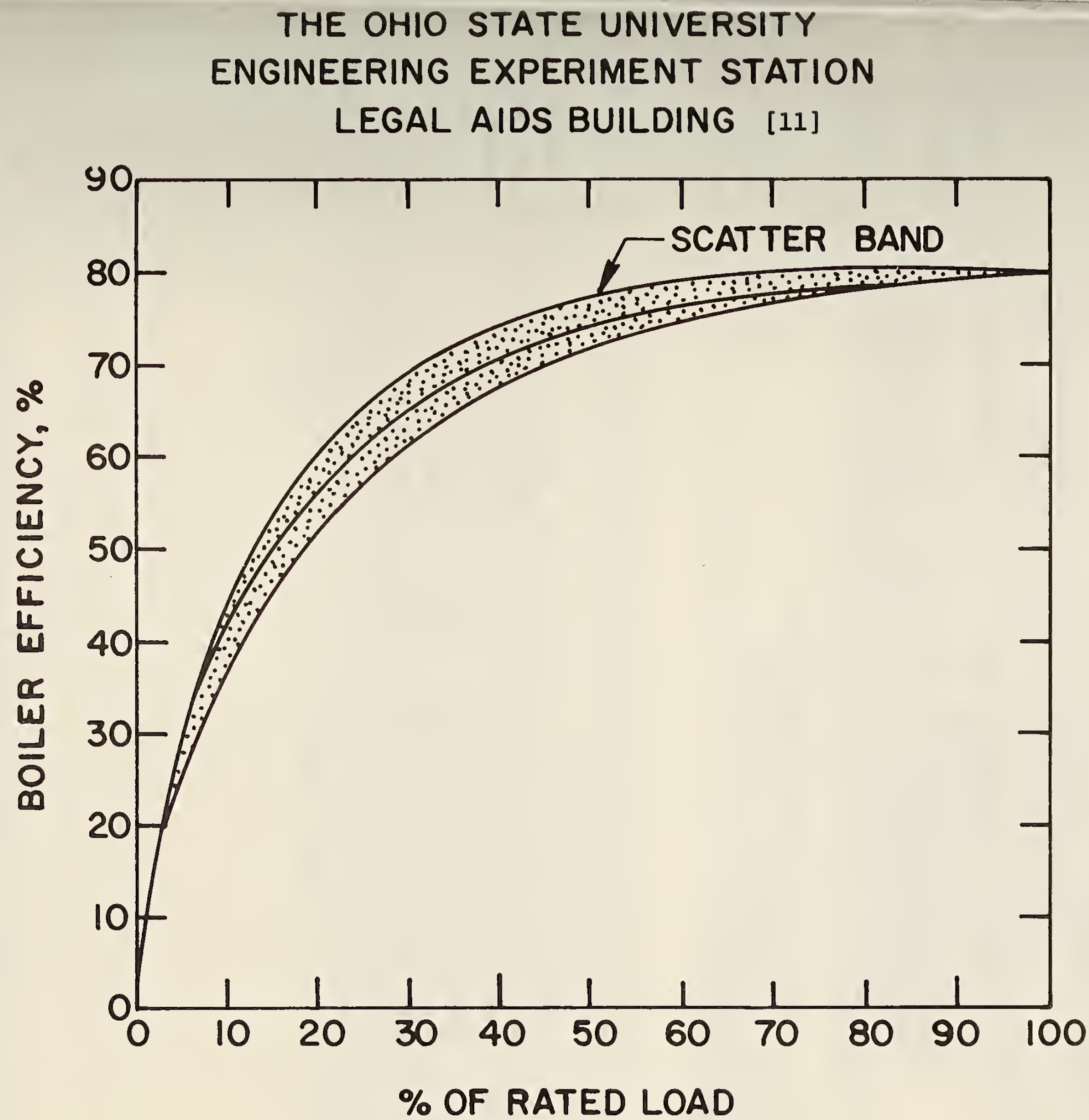

Figure D1. Boiler Efficiency Curve

NBS-114A (REV. 7-73)

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A comparison has been made of the results of two computer programs, the National Bureau of Standards Load Determination Program (NBSLD) and the American Gas Associations E-CUBE program, in predicting the energy consumption of a multi-family high-rise apartment building located in Omaha, Nebraska. Results are given on a monthly basis for the computed energy values and compared with average monthly values of metered data obtained over a five-year period. Close agreement was found between the energy consumption predicted by the two different computer programs, as well as between the predicted values and the metered data (less than 7% difference on an annual basis).

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