COMPARISON OF ENERGY ANALYSES OF A TEST BUILDING CARRIED OUT BY A NUMBER OF DIFFERENT ANALYSTS USING THE MERIWETHER E.S.A. SERIES

by

L. Jones

PREFACE

With the goal of producing a workable performance-type energy conservation code for buildings, the Division of Building Research, National Research Council of Canada, is trying to devise a suitable, practicable means of verifying compliance with an energy budget. Two methods are under consideration: measuring the annual fuel consumption of a building in use or by an energy analysis. To check the suitability of compliance by energy analysis, 22 consultants were commissioned to carry out analyses of a hypothetical test building. The results of these analyses, together with a discussion on the large variation in results that were obtained, are included in this report.

Because of the great current interest in this topic, it was decided to publish the work as an internal report and in an unedited form.

Ottawa
August 1979

C.B. Crawford
Director, DBR/NRC

NATIONAL RESEARCH COUNCIL OF CANADA

DIVISION OF BUILDING RESEARCH

DBR INTERNAL REPORT NO. 453

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Checked by: D.G.S. **Approved by:** L.W.G. **Date:** August 1979

Prepared for: Standing Committee on Energy Conservation, ACNBC

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Introduction

The Division of Building Research of the National Research Council of Canada is currently gathering information to develop a performance-type energy conservation standard for buildings. The concept of such a standard as generally understood is that a building of given type and location is allocated an annual energy allowance or energy budget.

Unlike a prescriptive standard, such as Measures for Energy Conservation in New Buildings[1], a performance standard dictates the energy allowance, not the means of achieving it.

Whilst a method for generating energy budgets[2] has been proposed the practical difficulties associated with "compliance" are viewed to be the major obstacle to the implementation of a successful performance energy conservation code. By "compliance" we mean the method by which the implementing authority satisfies itself that a building will meet or has met the specified energy budget.

Two alternative routes are generally considered as a possible means of ensuring compliance;

(a) through the approval of an energy analysis for the building or

(b) by measuring the annual fuel consumption.

The two methods, whilst each offering some desirable features suffer from quite severe although different practical limitations.

Since it is necessary to be able to predict the energy use of a building, irrespective of the method of compliance, it was considered important to assess the state of the art of energy analysis (prediction) and further to investigate the practicalities of compliance through approval of energy analyses. The study described in this paper is part of such a project; specifically it describes work carried out to determine the degree of consistency of energy analyses carried out by practising consulting engineers when asked to analyze a test building utilizing the Meriwether ESA series.

2. <u>The Energy Analyses</u>:

Twenty-two consultants who had previously accessed the Meriwether ESA package immediately prior to this exercise, were asked to participate in the study.

A specification (Appendix 3) for the test building was written based on the building specification IEA-2 used in the International Energy Agency's comparison of computer programs(3). However, the "flavour" of the specification was changed to "test" the user not the program and was written in such a way as to present the consultants with the same sort of problems they might encounter in practice. In general this was achieved by:

(1) Specifying the physical characteristics of the building and the HVAC system whilst;

(2) Leaving to the discretion of the analyst all items where engineering judgment or calculation was involved.

The underlying principle that the consultants were asked to work by was that they make whatever assumptions and simplifications that they consider necessary in order to arrive at a reasonable prediction of the building's energy consumption.

In order to minimize the effect of differing interpretations of the specification and correct any ambiguities the exercise was staged. In stage I consultants were asked to prepare all necessary input and refer any queries relating to the specification to DBR. All the consultants were informed immediately of any omission or error which required correction or when any clarification was needed. Stage II was not authorized until all consultants had completed their input and had no further questions. Stage II, the analysis,

Following their analyses, the consultants were required to provide D.B.R. with completed print-outs, summary sheets, "method of analyses questionnaires" breakdown of costs and comments. Most of this information is presented, sometimes in condensed form, in the following sections.

3. Calculated Annual Consumptions

Fig. 3.1 & 3.2 show the annual heating and electricity consumptions for the test building as calculated by the 22 consultants plus an additional 3 analyses carried out in two Federal Government departments.

Clearly consistency of results is not achieved; based on median values (which should not necessarily be construed as the "correct value") there is a range +106% and -46% on heating consumption and ±30% on electricity consumption. Of the 25 analyses, 16 did not come within ± 10% of the median

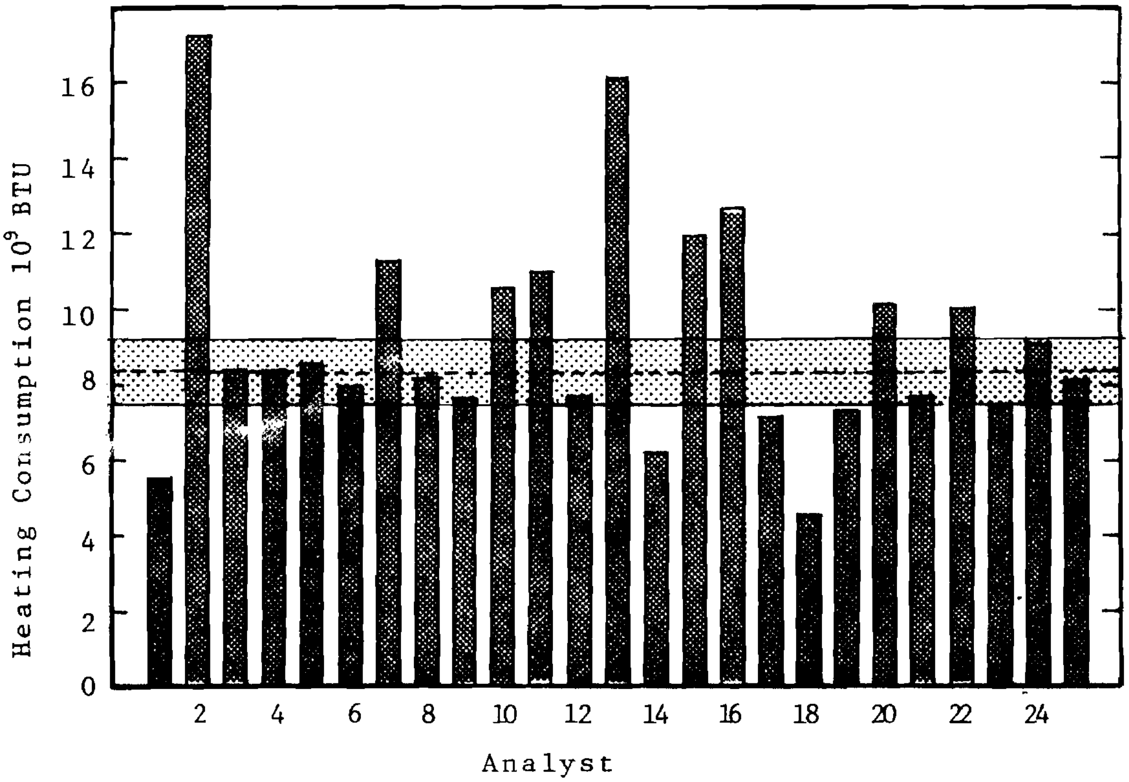

Fig.3.1 Building Heating Consumptions as Calculated by the Various Analysts

MEDIAN VALUE ±10%

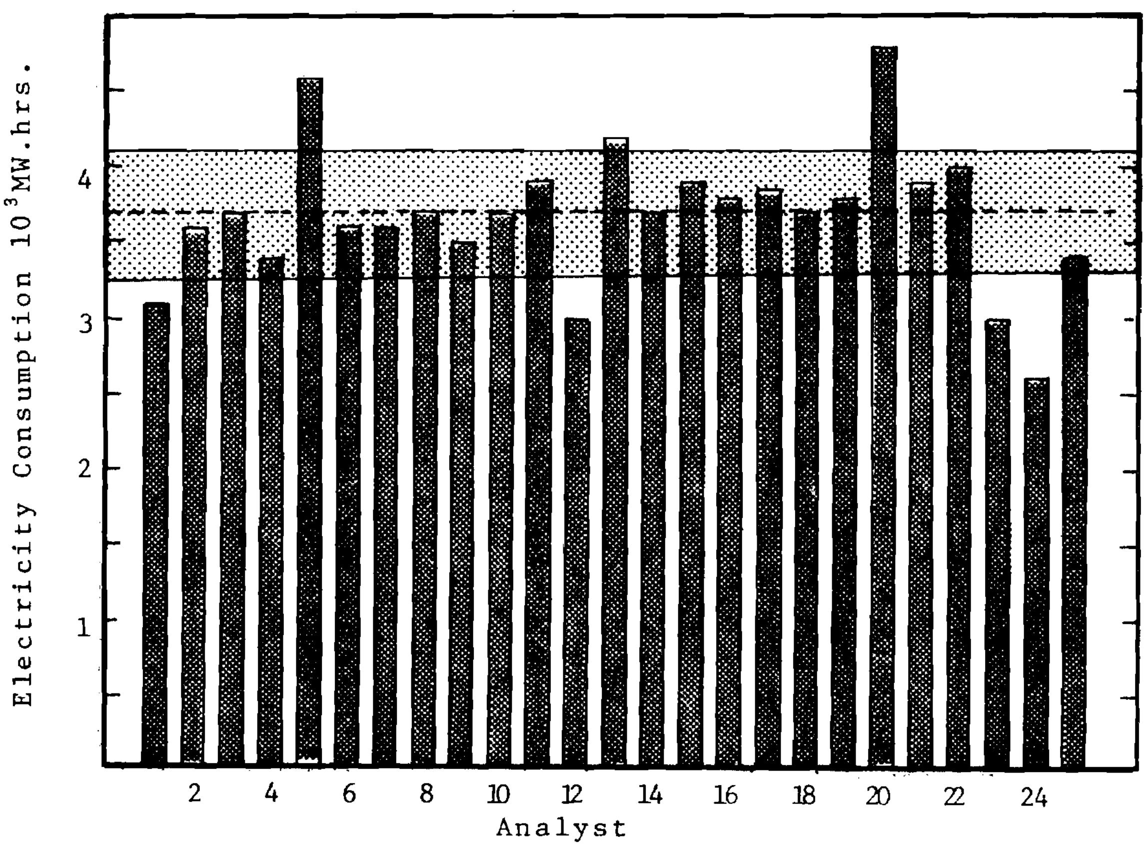

Fig.3.2 Building Electricity Consumptions as Calculated by the Various Analysts

heating consumption, and 7 did not come within ±10% of the electricity consumption.

4. Possible Reasons for Variation in Results

The reasons for a wide variation in results can be considered as resulting from "Errors" or "Method of Analysis".

"Errors" are considered to be arithmetic errors, misuse of the program, poor engineering judgment and, in this exercise, failure to follow all the specification clauses. Several errors were noted in the analyses. In some instances large variations in the calculated consumptions can be attributed to errors. Such errors can sometimes be spotted in the program input, for example analyst #20 appeared to include the fan kW load twice, once in the ERE* and again the EEC*, resulting in an electrical consumption some 630 MW.HRS higher than it should have been; others can only be identified with reference to other similarly calculated values, e.g., the comparatively low fabric loss and infiltration rate surely contributes to low heating consumption predicted by analyst 18.

"Method of Analysis" includes all those aspects of the analysis where engineering judgment is required, e.g., how many thermal blocks are necessary? Is it necessary to take account of the operation of window blinds etc? A poor choice in any of these aspects can be considered an error. Very often, however, information necessary for the making of such a decision is either not available, unreliable or debatable.

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*ERE - Energy Requirements Estimates Program and
EEC - Equipment Energy Consumption Program of the Meriwether E.S.A. series. See Reference 4

5. Comparison of Key Input Data & Methods of Analysis

In order to identify those areas that may contribute to the general wide variation in calculated energy consumption, a comparison of "Key Input Data" and "Method of Analysis" was made.

Table 5.1† lists "key" input values to the *ERE and *EEC programs as used by the various analysts. Table 5.2† summarizes some aspects of the analyses.

Figures 5.1 to 5.9 illustrate the differences in the ERE input data and highlight the general wide variation in:

- (i) Peak infiltration rate
- (ii) Reference solar gain
- (iii) Receptacle load
- (iv) Percentage lighting heat gain passing to return air stream
- (v) Supply air volume

The remaining ERE input is generally consistent with the exception of the occasional data point. The significance of each of the above items, method of analysis and other isolated factors is explored in section 6 by means of parametric analysis.

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†All tables in Appendix 1.

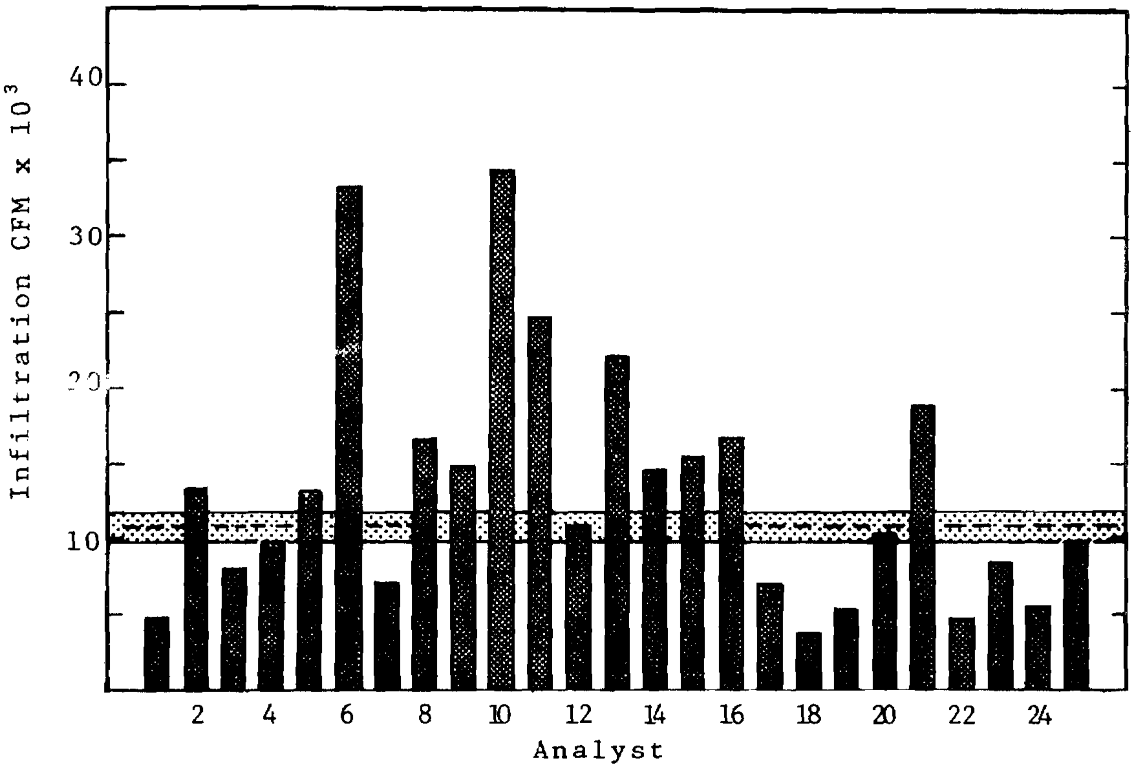

Fig.5.1 Peak Infiltration rates as used by the various analysts. Median value ±10%

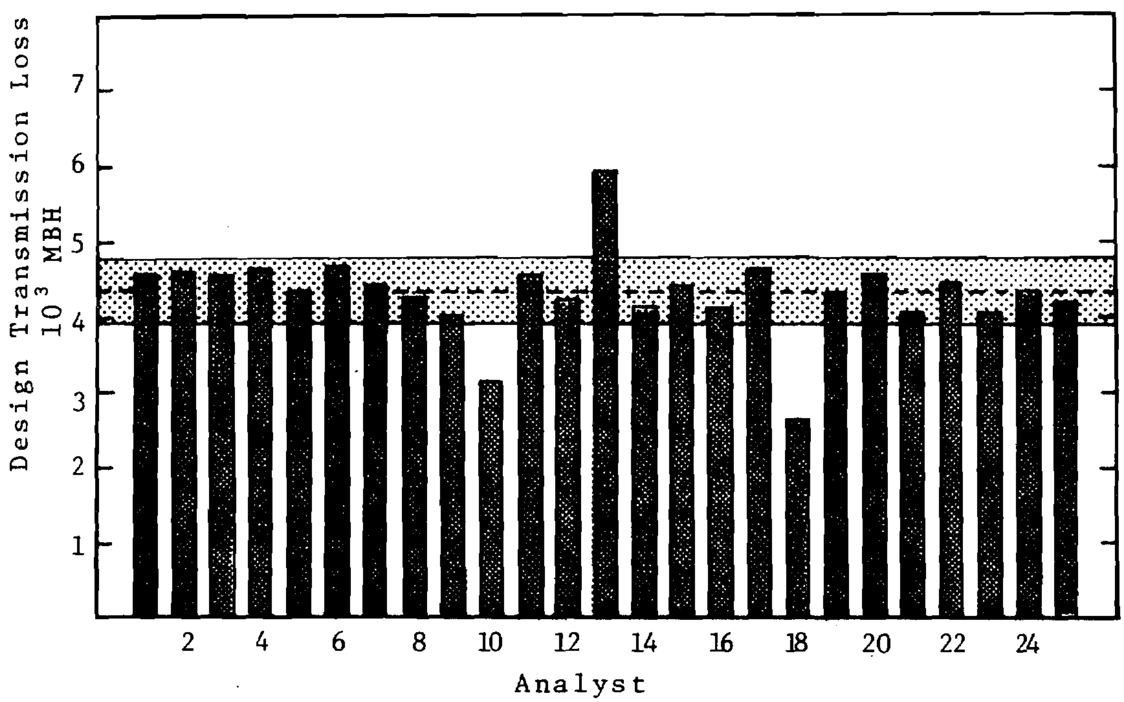

Fig.5.2 Design Transmission Losses as used by the various analysts.

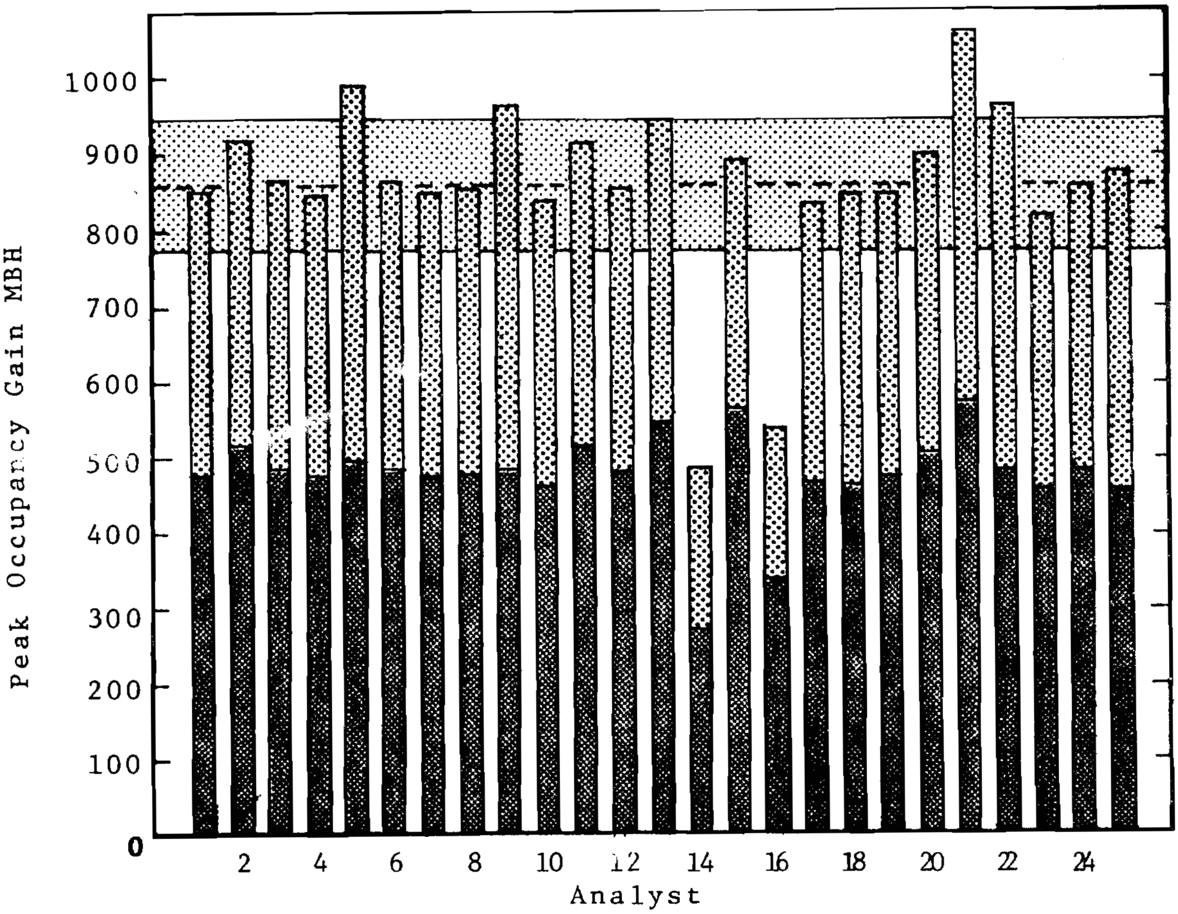

Fig. 5.3 Peak Occupancy Loads as used by the various analysts. ▓ Sensible ░ Latent Gains

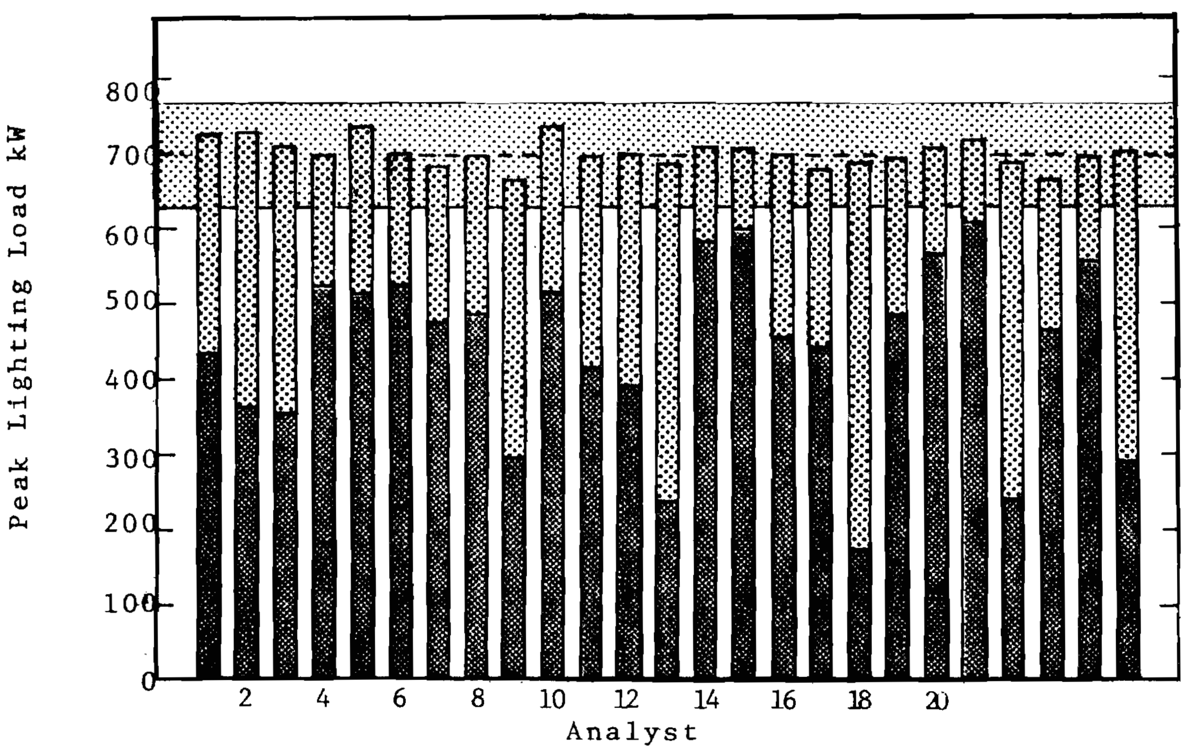

Fig. 5.4 Peak Lighting Loads as used by the various analysts. ▓ Room Load ░ Return Air Load
Median Value ±10%

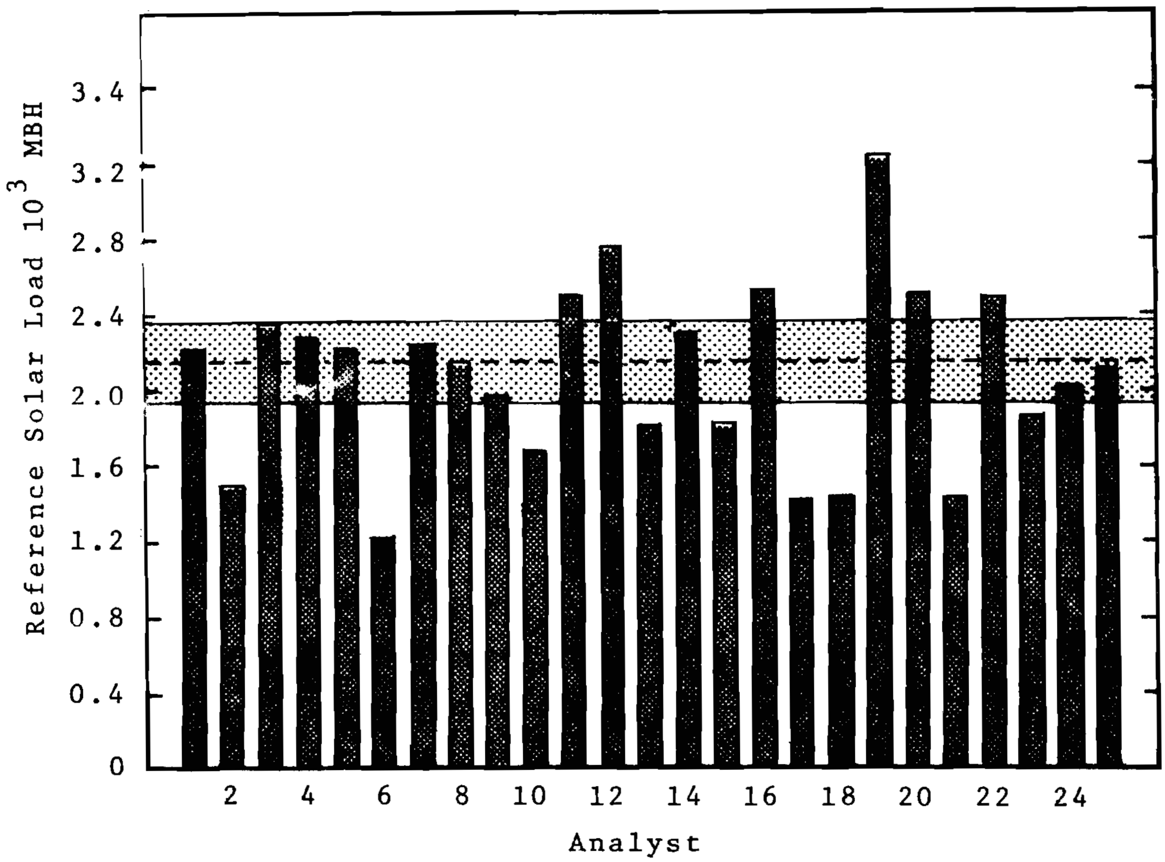

Fig. 5.5 Reference Solar Loads as Used by the Various Analysts

Median Value ±10%

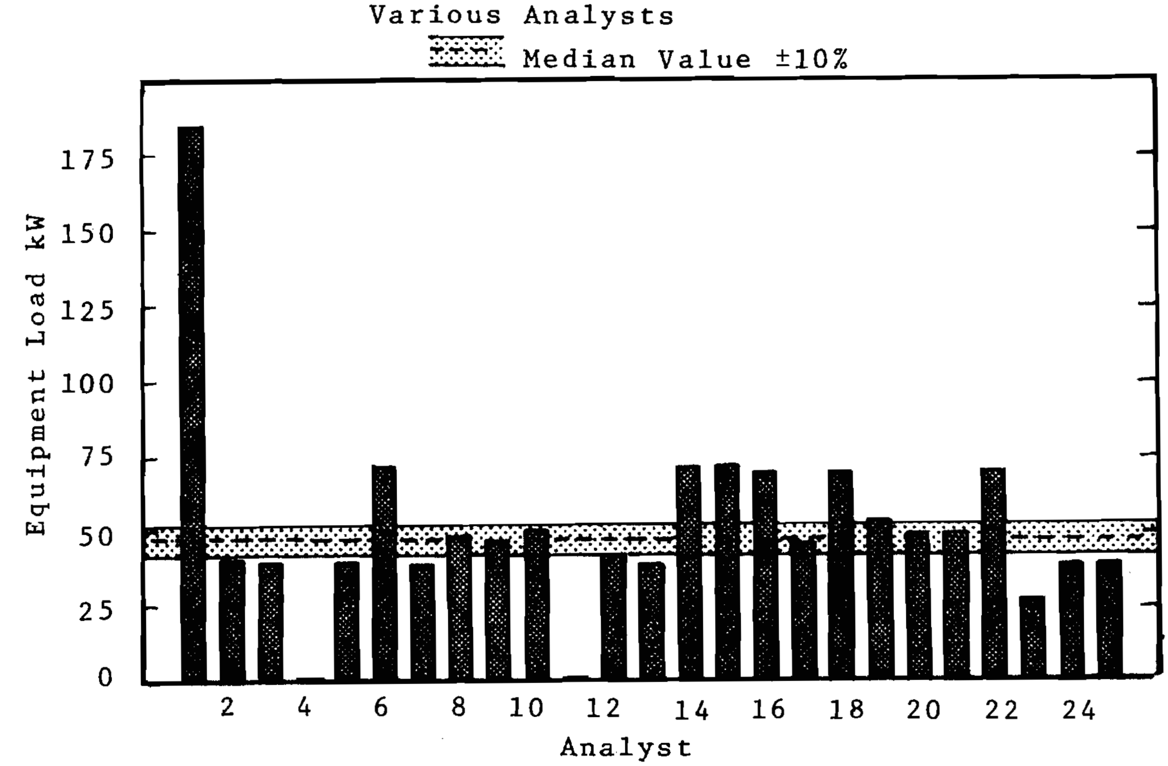

Fig. 5.6 Peak Equipment (Receptacle) Loads as Used by the Various Analysts

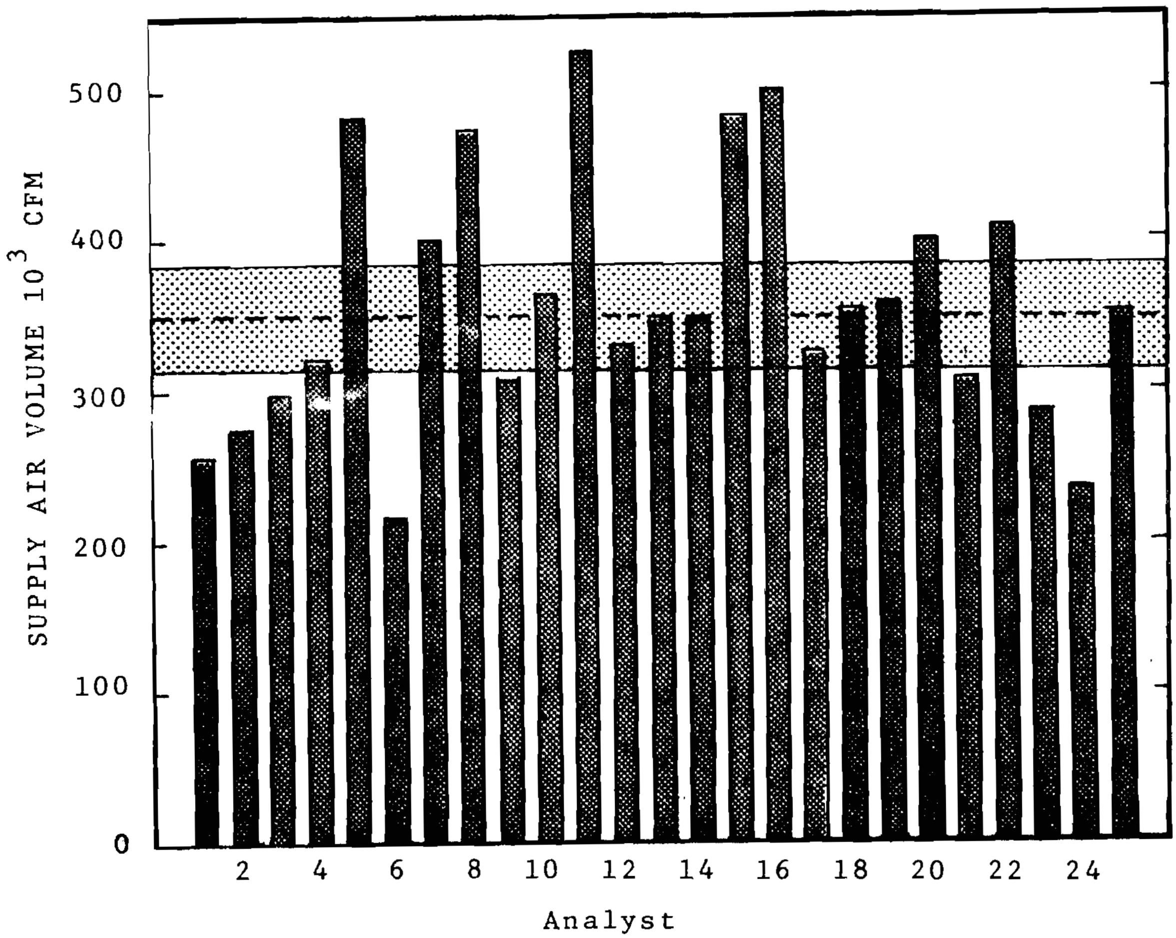

Fig. 5.7 Supply Air Volumes as Used by the Various Analysts Median Value ±10%

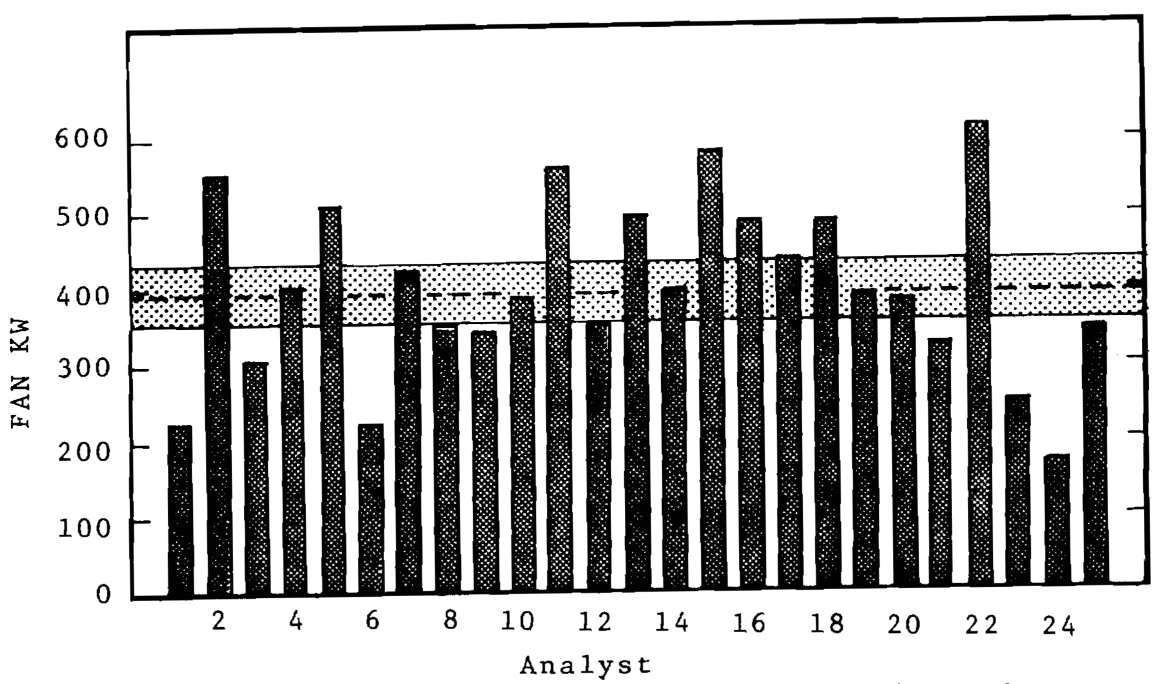

Fig. 5.8 Fan KW. Connected Loads as Used by the Various Analysts

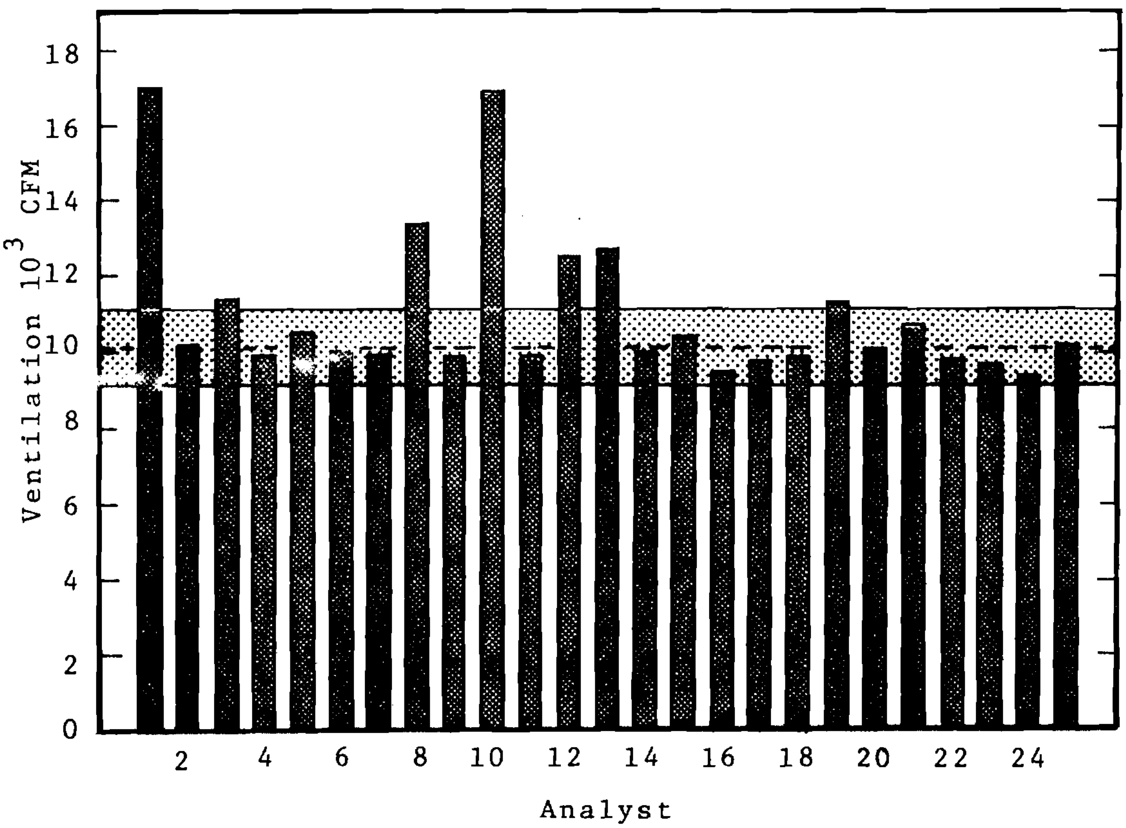

Fig. 5.9 Ventilation Rates as Used by the Various Analysts

Variation in the EEC input data is essentially dependent on the results obtained from the ERE analysis and hence it is not generally possible to construe anything about the values even though it is acknowledged that they may have significant bearing on the results. The EEC program is, however, generally more straightforward than the ERE with much less room for variance resulting from engineering judgment or method of approach. This was particularly so in this exercise where the building has a very simple HVAC plant.

6. Parametric Analyses

Section 5 identifies significant differences in the inputs and method of analyses but it is not apparent how these differences affect the overall results. To explore this aspect several parametric runs were made by the author based on a "Reference Model" and utilizing with each parametric run, key input data and method of analysis philosophy of the other analysts. The values used in the parametric runs were extreme values selected from the analysts' submissions. The results of these parametric runs are shown in Table 6.1 and illustrated in Fig. 6.1, 6.2 & 6.3. A discussion of each aspect of these runs follows.

6.1 "Reference Model": In order to make the task manageable the reference model was kept extremely simple, this entailed the use of a single thermal block. The reference model is identified as #25 in Figs. 3.1, 3.2, 5.1 to 5.9 and in Tables 3.1 to 3.3 and 5.1. It should be noted that the following

<u>results show only the sensitivity of the program to input differences for the reference model - they should NOT be construed as applying in general, to other building analyses, NOR should they be construed as necessarily predicting actual building performance.</u>

6.2 Infiltration Parametric Runs

In order to ensure that the parametric runs covered both the "high" and "low" infiltration simulations the "method of infiltration" (e.g., stack effect, constant infiltration, etc.) as well as the peak infiltration rate were considered. This involved five runs, viz. Run 1 34,555 cfm and key 8, Run 2 33,200 cfm and key 3, Run 3 24,770 cfm and key 2, Run 4 3,896 cfm and key 2, Run 5 7000 cfm and key 3.

(The "Reference Model" used Key 2, stack effect, to simulate the infiltration, the peak was calculated[5] at 9825 cfm or approximately 0.2 Ac/hr).

The variation in heating consumption is the only significant change in output, this is observed to vary between +28% and -6% of the reference model value; peak infiltration rates vary in the ratio of 1 to 9.

Since the wall leakage rate would not normally be known (a wall leakage coefficient was specified for the test building) it is likely that an even greater disparity

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*See Table 5.1 for definition of keys

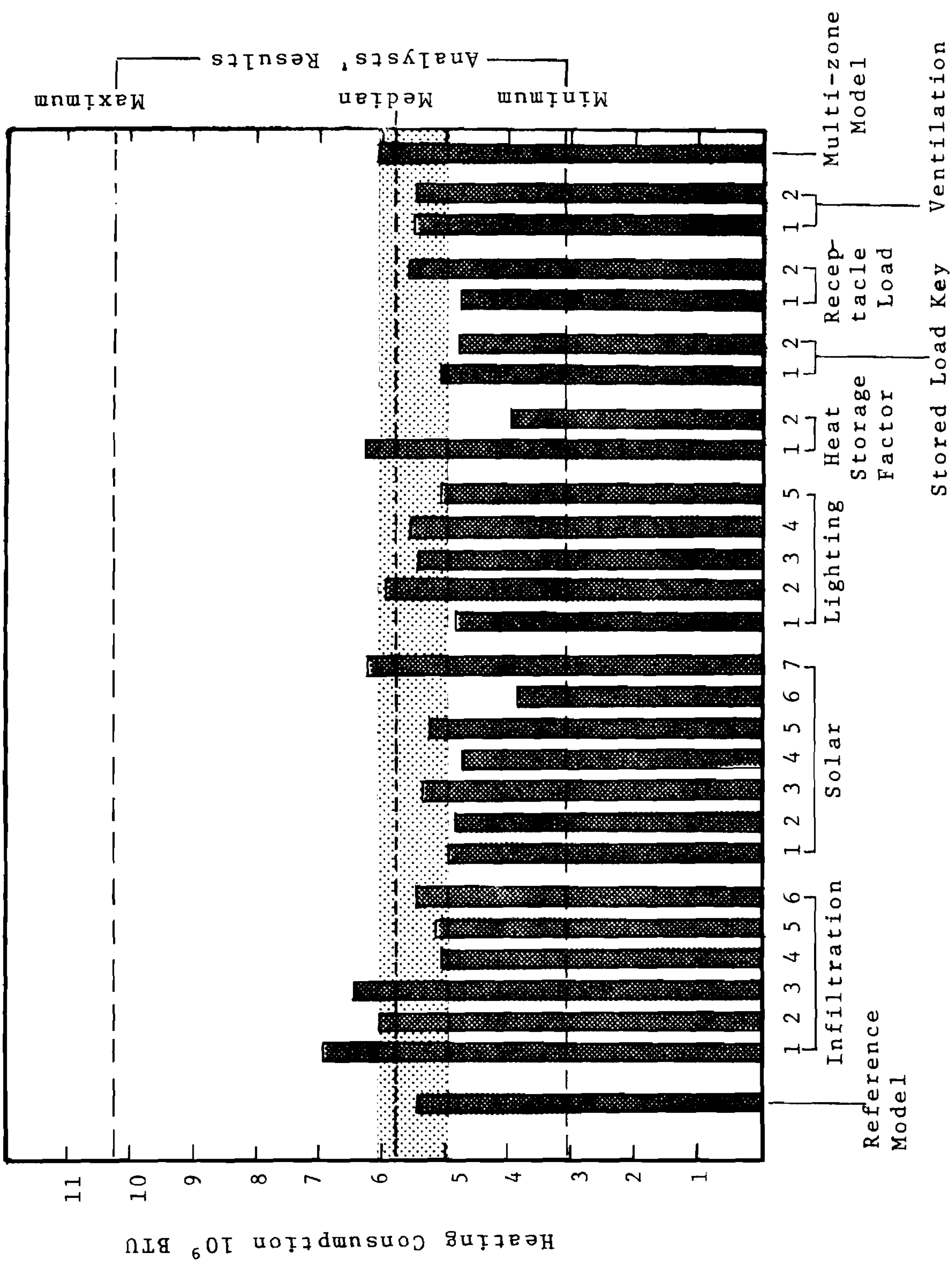

Fig.6.1 Calculated annual heating consumptions for the air side systems (E.R.E. output) for the basic model and parametric runs. [shaded box] indicates ±10% of the basic model value.

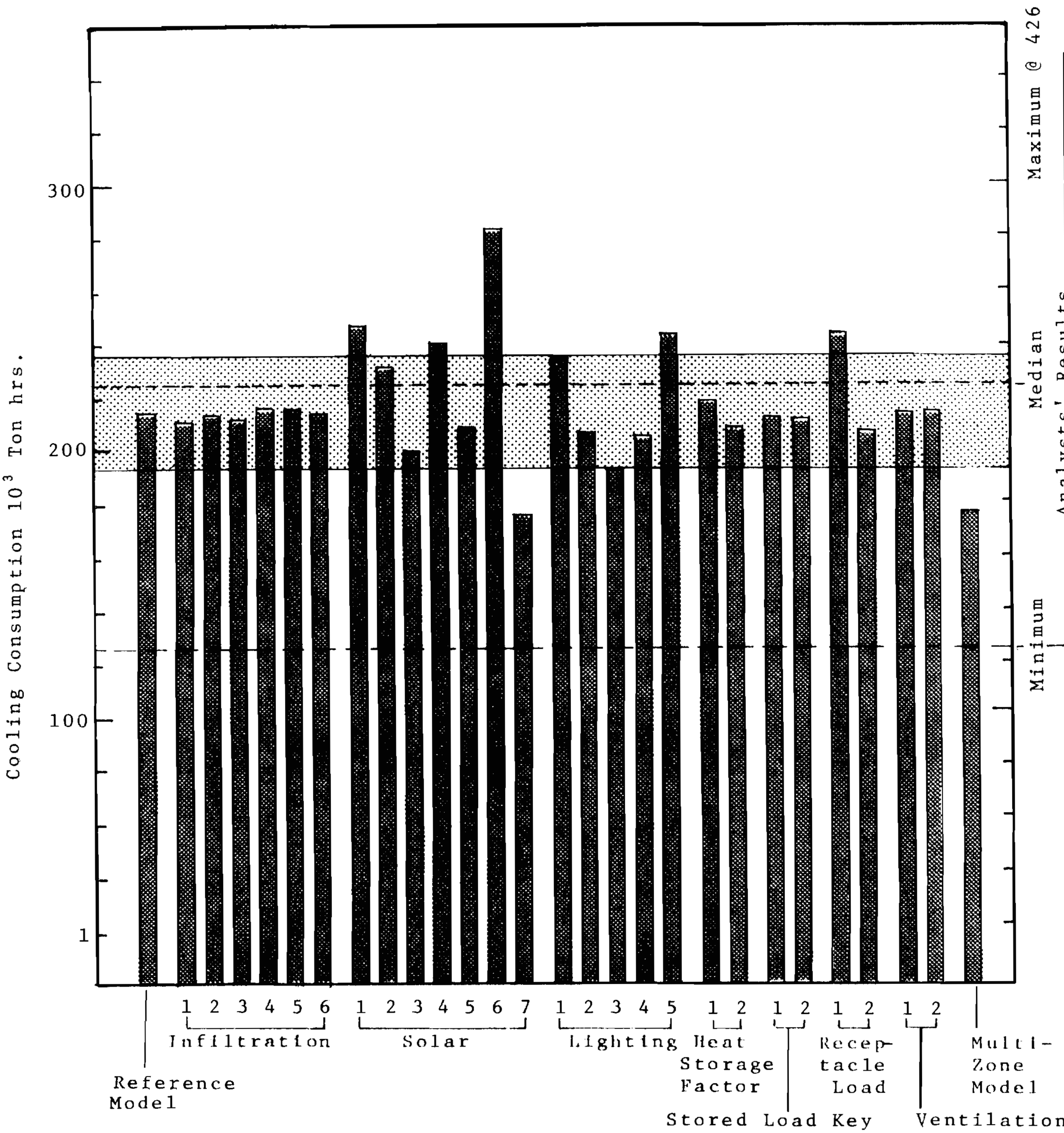

Fig.6.2 Calculated annual cooling consumption for the air side systems (E.R.E. output) for the basic model and parametric runs. [shaded box] indicates ±10% of the basic model value.

between estimated infiltration and actual infiltration would occur in practice.

An additional run was made substituting a constant average infiltration model in place of the stack model previously used. Average infiltration was calculated based on the average annual temperature for the location (~50°F) using the same methods as that used for the "Reference Model". The results are shown under INFILTRATION 6 in Table 6.1 and are essentially the same as those for the "Reference Model" (less than 1% difference).

6.3 <u>Solar Parametric Runs</u>

Seven parametric runs were made as follows:

RUN 1. Window blinds up all the year (blinds down in Reference Model).

RUN 2. With the window blinds <u>up</u> the solar gains were lagged through the use of the SL2* program (gains appear as instantaneous cooling loads in the Reference Model).

RUN 3. As 2 with window blinds down.

RUN 4. With the window blinds <u>up</u>, transmission of absorbed solar radiation through the opaque parts of the walls and roof was added through use of the *SLM program.

RUN 5. As 4 with window blinds down.

RUN 6. Utilizing the highest reference solar gain of 3243 MBH, Analyst #19 (Reference Model solar gain = 2093 MBH) - loads lagged.

RUN 7. Utilizing the lowest reference solar gain of 1230 MBH

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* SL2 - Solar Table Generating Program &

SLM - Solar Table Merging Program of the Meriwether ESA series

Analyst #6 loads not lagged.

The largest variation from the Reference Model resulted from runs 6 & 7 which produced differences of:

+ 14% & -28% on heating consumption,

+ 32% & -18% on cooling consumption &

+ 16% & -7% on fan consumption. The reason for the variation in the calculated reference gains is not known.

Of the other parametric runs it is observed that the most important aspect is the use of blinds; the difference in consumptions between blinds up and blinds down (as a percentage of the blinds down value) is:

(i) based on the Reference Model (solar loads not lagged): -9% on heating +15% on cooling

(ii) based on models with the solar loads lagged -12% on heating, +20% on cooling.

6.4 Lighting Parametric Runs:

Although peak lighting loads were one of the more consistent input variables the various profiles of use adopted by the analysts resulted in significantly different lighting consumption. Based on lighting electricity consumption, obtained from ERE outputs, analysis 21 was identified as having the highest lighting consumption whilst analysis 24 the lowest. These two two combinations of peak lighting load and profile of use were then used in the reference model to determine their effect on the overall energy consumption - the results are shown as LIGHTING 1 & 2 in Table 6.1

Additional runs were made to show the effects of:

*(a) lagging the lighting heat gain

*Reference Model assumed lighting heat gains appeared instantaneously as cooling load and that 60% of the light heat gain passed to the return air.

*(b) lighting gain passing into return air varying the percentage between 15% and 75%.

The results of these runs are shown in Table 6.1 under LIGHTING 3, 4 & 5 respectively.

The largest variation in output from the Reference Model results from runs 1 & 2, with a +11/-10% change in heating, +10%/-4% change in cooling and a +15%/-16% change in base electricity. In practice we can expect even greater differences since the profile of use and diversity of demand will be generally somewhat less defined than in this exercise.

6.5 "Heat Storage Factor*"- Parametric Runs

The range of heat storage factors used by the analysts range from a low of 4.0 to a high of 28 Btu/F sq.ft. These two values were used in the Reference Model. The results given under BUILDING WEIGHT 1 & 2 in Table 6.1, show a variation of -27%/+15% in the heating consumption. Changes in electricity and cooling are not significant. For the Reference Model a heat storage factor of 14.1 Btu/F sq. ft. was used.

6.6 "Stored Load Key" Parametric Runs

"Stored Load Keys" of 0, 1 & 2 were used by the various analysts representing 3, 5 & 7 hours distribution and duration of the pick-up period for stored loads. The only significant variation of output for the parametric runs using these keys is for heating which is reduced from the Reference model (key 0) by 6 & 12% for keys 1 & 2 respectively.

6.7 Receptacle Loads Parametric Runs

Two runs were made with 0 receptacle load and with the maximum receptacle load as used by the analysts (Analyst #1). There was no significant change in the electrical usage although heating consumption varied by +3% and -9% and cooling

*See Reference 4 for definitions

-3% and +14%.

6.8 Ventilation Rates Parametric Run

Ventilation rates varied from 9,442 cfm to 16,931 cfm in the various analyses. Using these values in the Reference Model produced no significant differences (<1%) in the results.

6.9 Coil Capacity Parametric Runs

Although the specification called for 'unlimited' coil capacities, several analysts specified coil sizes which had the effect of prolonging pick-up periods and in some cases causing a significant number of hours when, according to program output, design condition would not be met. To see what effect this would have on the calculated heating and cooling consumptions several runs were made with progressively smaller coils. The 100% coil sizes were assumed to be equal to the peak hourly demands as taken from the E.R.E. output of the reference model (it is most unlikely that such large capacity coils would be used in practice).

The results of this exercise are shown in Figs. 6.9.1 and 6.9.2 which show large reductions in heating and cooling consumptions whilst according to program output maintaining generally acceptable temperatures for most of the time.

For the analyses, the extremes of 'hours of load not met'* are 712 hours for heating, analysis 23, and 812 hours for cooling, analysis 1. (*For multi-zone analyses the 'hours of load not met' were derived from the hours of load not met for the individual zones and its contribution to the total heating or cooling load.) Extrapolating for these hours from the graphs shown in Figs. 6.9.1 and 6.9.2 indicate reductions in consumption from an unlimited coil capacity simulation of some 24% for heating (712 hours) and 72% cooling (812 hours). Whilst it may not be rigorously correct to extrapolate in such a way, it does give an indication of the sensitivity of the program to the effect of limited coil capacity.

6.10 Air Volume Parametric Runs

Another possible cause for creating a number of hours of "load not met" is in the limitation of air volumes which produces a somewhat similar relationship for cooling to that discussed above - see Fig. 6.10 (it would have no effect on the heating unless air volumes were greatly lowered and/or the maximum supply air temperature limited).

6.11 "Multizone Model"

As a final exercise an analysis was made utilizing a model as sophisticated as the Meriwether program would reasonably allow in practice; comprising:

(A) A Multizone Model with 27 different zones defined by:

- (i) use, i.e., office, circulation, lobby
- (ii) position, i.e., internal, external, orientation and height (to account for the variation of infiltration with height).

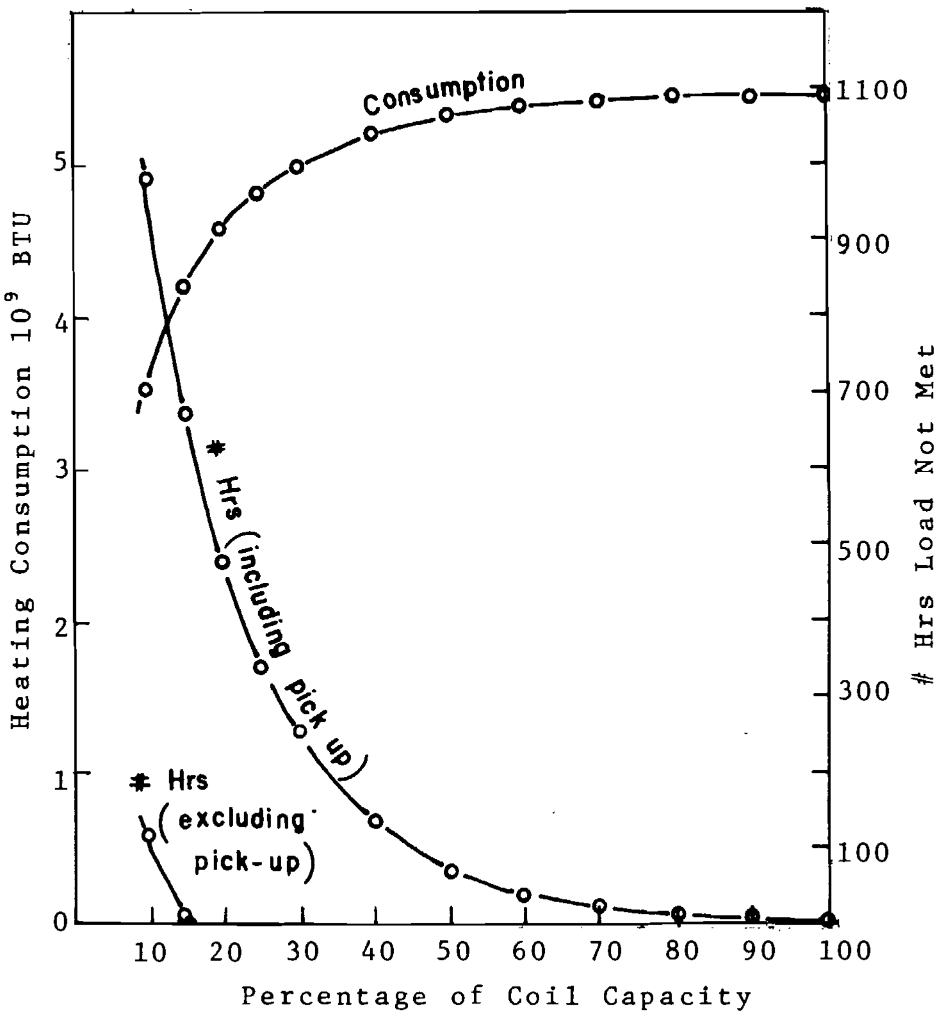

Fig.6.9.1 Annual heating consumption and "Hours of Load Not Met" as a function of coil capacity (minimum temperature during normal operation 69.8°F).

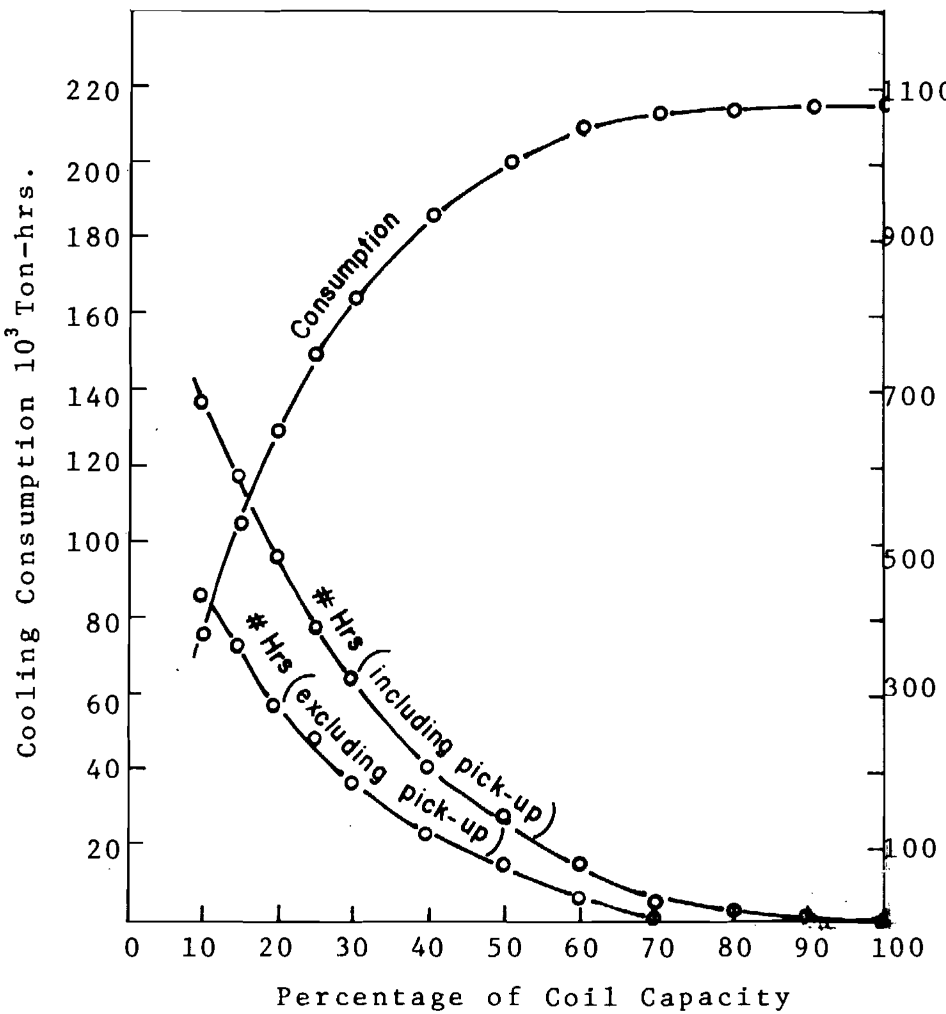

Fig.9.6.2 Annual cooling consumption and "Hours of Load Not Met" as a function of coil capacity (maximum temperature and humidity ratio during normal operation 73.9°F with 95.34 GR, and 73.12°F with 99.23 GR).

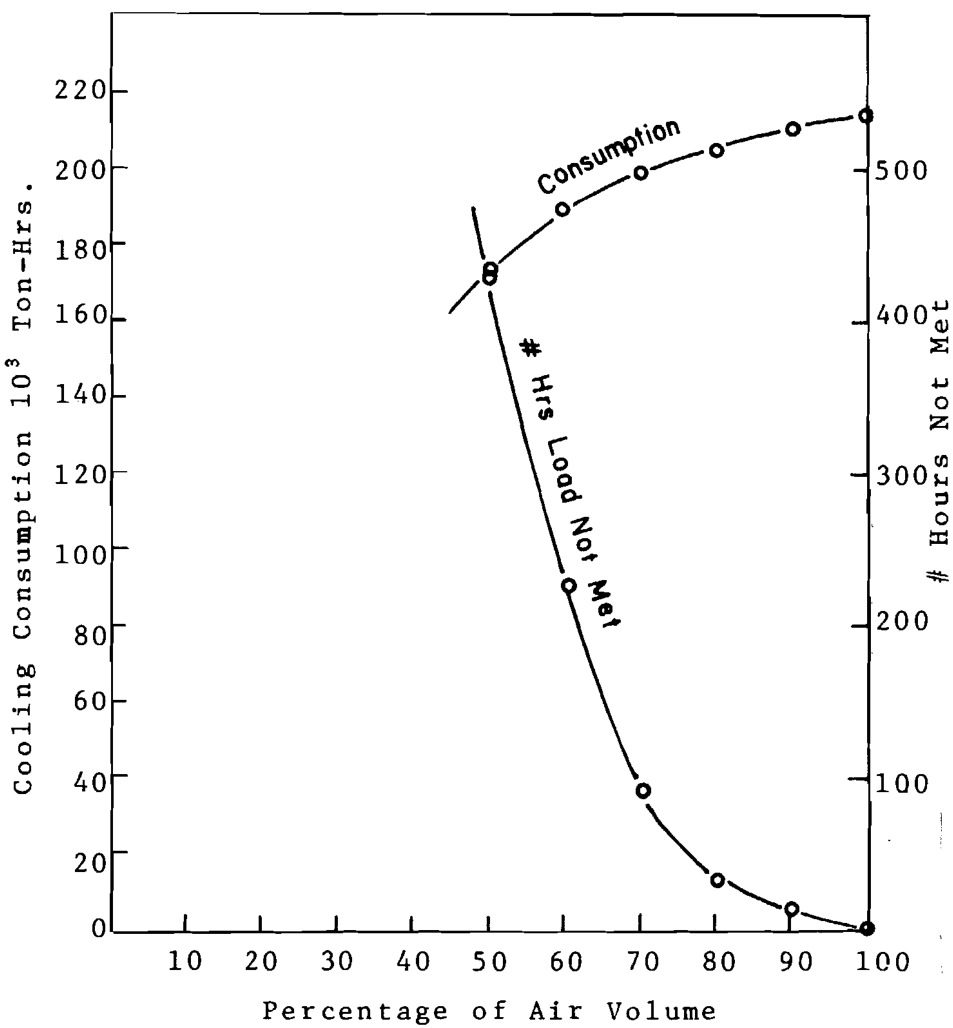

Fig.6.10.1 Annual cooling consumption and "Hours of Load Not Met" as a function of supply air volume. (Maximum temperature and humidity ratio during normal operation 71.74°F with 71.69 GR).

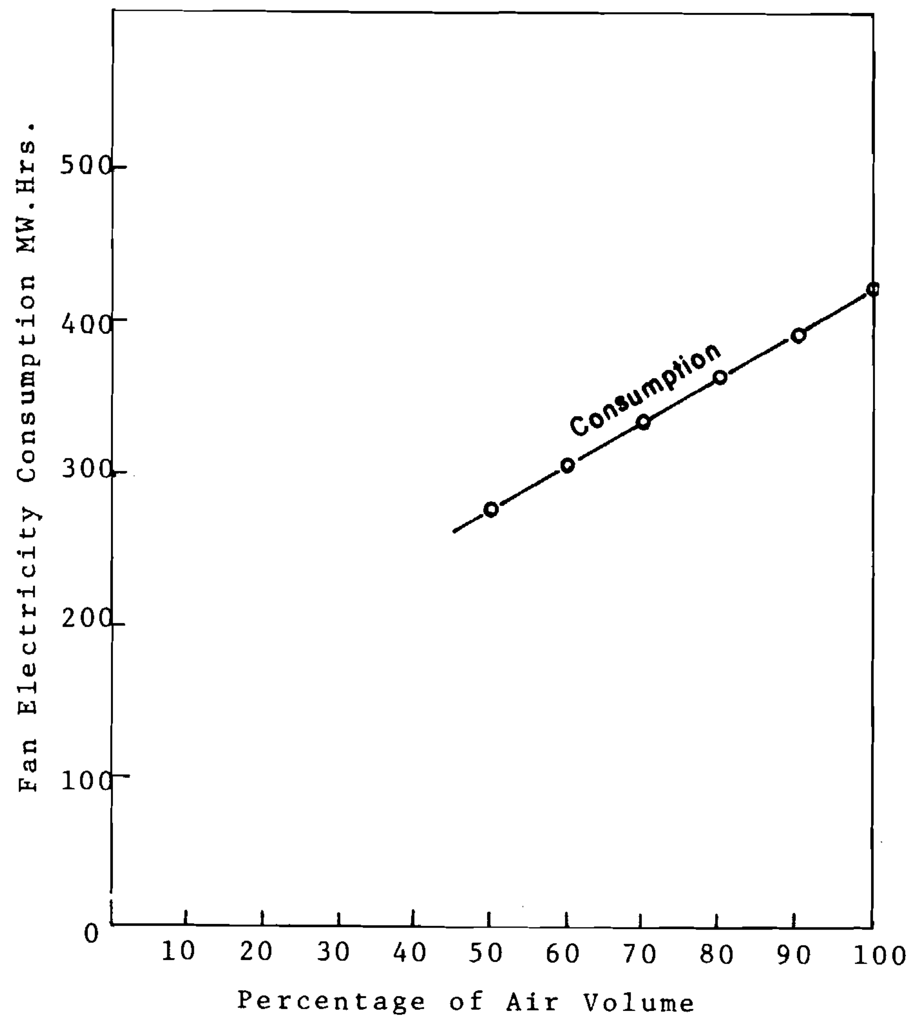

Fig.6.10.2 Annual fan electricity consumption as a function of supply air volume.

(B) The inclusion of the transmission of absorbed solar radiation through walls and roof - this involved the use of the SLM program.

(C) Lagging all sensible gains, with the exception of wall conduction. For solar gains the cooling loads were first calculated using the Transfer Function Method[7]; the best approximations of the SL2 lagging options were then used in the analysis. Profiles for cooling loads from lights, equipment and sensible occupancy gains were derived using "coefficients of room transfer function"[6] - different profiles were used for Saturday, Sunday, Monday and Tuesday through Friday.

(D) Reducing cooling loads by a suitable percentage to reflect those portions of the heat gains that are transferred to the surroundings.

The results of the ERE/T_CR show the following percentage variation from the Reference Model value:

heating +11%, cooling -19%, Fans -8%, Base electric -2%.

Because intermediate steps between the simple and the complex analysis were not taken, it is not possible to say which factors had the major influence on the variation in the overall results.

7. Comments

As previously stated the variation in predicted energy use is very large.

Further it can be assumed that the variation in results could have been even greater if the various analysts used different prediction methods (computer programs); recent work carried out with the International Energy Agencies' Energy Conservation in Buildings & Community Systems group has shown wide variations in energy predictions between several computer programs.

How then, it might be asked, can a performance or energy budget type standard be considered practical if the numbers presented in this report represent realistic attempts at predicting energy consumption?

To approach an answer or answers to this question it is necessary to consider the precise application of the energy analysis, i.e., will it be used:

(a) as a design tool to predict energy consumption, or

(b) as a basis for the granting of building permits.

If the former is the case, and the building fuel consumption records are to be used as the means of verifying compliance with an energy budget, then the predicted energy consumption could be considered of little or no interest to the budget (code) implementing authority. The responsibility for predicting the energy use of a proposed design in order to check that the building when built and operating will meet with the required energy budget will lie solely with the developer.

However, the drafting of any code should be made cognizant of the ability of the industry to work by that code. If accurate prediction of actual energy use cannot be made then it would seem questionable to adopt energy budgets enforceable by consumption monitoring.

If, however, energy analyses are to be used as the basis for granting building permits, then the prediction of energy use is of prime importance to the implementing authority, which must satisfy itself that the analysis is either:

(a) an accurate prediction of the actual energy the building would consume or

(b) an accurate prediction of the design energy use.

This design energy use could be calculated based on some standardization of input and simplification of operation so as to avoid the vagaries of actual building performance. (It should be noted that the actual performance of a building is another factor in the problem; even had all the consultants arrived at the same answer it would not necessarily be the same as the consumption of the test building if it were built.) Whilst it would be most desirable to receive accurately predicted consumptions the easier route, should this method of compliance be considered, would be to accept some form of design consumption.

Further, this exercise highlights the fact that an energy analysis cannot be taken at face value - should it be adopted as a means of checking compliance with an energy budget, some form of check must be considered necessary.

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5. Fortran IV Program to Calculate Air Infiltration in Buildings, D.M. Sander. DBR Computer Program No. 37, May 1974.

6. ASHRAE Handbook of Fundamentals, 1977.

7. Fortran IV Program to Calculate Z Transfer Functions for the Calculation of Transient Heat Transfer through Walls & Roofs, G.P. Mitalas and J.G. Arseneault. DBR Computer Program No. 33, NRC CP 33, June 1972.

APPENDIX 1

TABULATED RESULTS

Table 3.1 CALCULATED ANNUAL CONSUMPTIONS FOR THE TEST BUILDING

Analyst #	Annual Electricity Consumption MWh	Annual Heating Consumption BTUx10^6
1	3153	5486
2	3651	17232[3,4]
3	3717	8372[3,2]
4	3434	8370
5	4645	8586[4]
6	3604	8046
7	3596	11317[3]
8	3700	12835[4]
9	3483	7562
10	3707[1,2]	10612[1]
11	3875	10984
12	3009	7727
13	4169	16253
14	3734	6230
15	3868	11991
16	3855	12697
17	3943	7219
18	3676	4510
19	3828	7314
20	4823	10197
21	3923	7680[3]
22	3957	10112
23	2996	7471
24	2600	9144
25	3390	808[5]

1. This analysis was originally submitted as electricity 26073 MWh and heating 10285x10^6 BTU.
2. Median values.
3. Figures include heat used for D.H.W.
4. Figure obtained from computer printout, equivalent Total *Stm Consumption (*Steam consumption) was reported by the analyst

TABLE 3.2 COMPARISON OF OUTPUT FOR THE SECONDARY (AIR SIDE) SYSTEM SIMULATIONS (ERE OR TCR OUTPUT)

Analyst	DEMAND		CONSUMPTION	
	Heating BTU/HRx10^3	Cooling BTU/HRx10^3	Heating BTUx10^6	Cooling BTUx10^6
1	4554	7475	4430	2704†
2	31082	6772	9323	5115
3	11607	6684	5452	2262
4	22935	9566	6574	2732
5	10383	7796	5200	2967
6	6690	6124	6122	2170
7	23133	802	6830	2434
8	18956	9280	8061	2779
9	6164	6732	5197	2061
10	9125	8080	7160	2319
11	15700	10644	7027	2894
12	5083	7834	5660	2458
13	33374	6522	10256	2010
14	5181	10382	4736	3228
15	23525	937	7935	3109
16	21604	15787	7845	3938
17	7000	6900	5098	2045
18	4580	6451	3093	3977
19	8752	7188	5313	3055
20	12719	8002	6604	2738
21	6202	7404	4802	2710
22	10530	10795	7180	2600
23	6129	7463	5236	2399
24	13115	5661	5787†	1511
25	26846	10591	5466	2579

†Median Values

TABLE 3.3 COMPARISON OF OUTPUTS FOR THE CENTRAL PLANT SYSTEM SIMULATIONS (EEC OUTPUT)

Analyst	H.V.A.C. Electrical Equipment Consumption MWh			Lighting Consumption MWh	Central Plant Performance		VAV Seasonal Fan Modulation[1]	D.H.W. Consumption MWh	Elevator Consumption MWh
	Air Handling Systems	Chillers	Chiller & Boiler Accessories		Boiler Seasonal Efficiency	Seasonal C.O.P. Chillers[4]			
1	410	194	62	2117	81	0.86	0.71	0	0
2	1067	429	353	2767	54	1.00	0.75	101[2]	61
3	537	161	339	2524	65	0.85	0.68	92[2]	59
4	751	193	233	2138	78	0.85	0.72	62	62
5	570	209	178	2461	60	0.84	0.43	983	106
6	374	186	316	2432	76	1.03	0.65	80	-[3]
7	778	186	209	-[3]	60	0.92	0.71	38[2]	70
8	506	196	308	-[3]	63	0.85	0.56	65	87
9	579	146	154	2193	69	0.85	0.69	104	105
10	691	162	220	-[3]	67	0.84	0.76	76	59
11	681	408	257	2211	64	1.68	0.47	82	132
12	491	172	61	-[3]	73	0.84	0.54	15	59
13	1090	144	174	2232	63	0.86	0.85	-[3]	-[3]
14	623	226	115	2629	76	0.84	0.60	148	33
15	701	219	386	2458	66	0.85	0.46	50	80
16	595	302	275	-[3]	62	0.88	0.47	-[3]	82
17	1027	142	257	1963	71	0.83	0.89	-[3]	78
18	812	270	105	2108	69	0.79	0.99	-[3]	211
19	547	377	173	2341	68	1.48	0.53	73	157
20	631	193	1502	2025	65	0.83	0.62	0	218
21	626	189	91	2798	62	0.82	0.74	110[2]	110
22	773	185	144	2330	71	0.85	0.48	80	61
23	391	168	93	2048	70	0.84	0.61	112	91
24	326	110	-[3]	1519	63	0.84	0.75	-[3]	0
25	420	190	120	2319	68	0.88	0.47	82	62

1. 'VAV Seasonal Fan Modulation' defined as:

$$\frac{\text{Annual Fan Electrical Consumption KW.HR.}}{\text{Fan KW. x scheduled number of hours operation per annum}}$$

2. Analyst simulated DHW as an "indirect process load" - the figures reported here are the equivalent KW.hrs consumption (process load ÷ 3.413).

3. "-" indicates figures not available from output.

4. Seasonal C.O.P. is defined as:

$$\frac{\text{Annual chiller electrical consumption KW.Hrs.}}{\text{Annual cooling produced ton.hrs}}$$

Electrical consumption does not include any chiller auxilaries.

TABLE 5.1 COMPARISON OF KEY INPUT DATA

ANALYST	FLOOR AREA (FT^2x10^3)	REFERENCE SOLAR LOAD (BTU/HRx10^3)	OCCUPANCY PEAK LOAD (BTU/HRx10^3)	% LATENT	PEAK LIGHTING LOAD (kW)	% TO RETURN AIR	PEAK EQUIPMENT (RECEPTACLE) LOAD kW	DESIGN TRANSMISSION LOSS (BTU/HRx10^3) (TO 15^{o}F)	DESIGN TRANSMISSION GAIN (BTU/HRx10^3) (TO 87^{o}F)	HEAT STORAGE FACTOR (DEFAULT = 20.14)	HEAT STORAGE KEY 0=3HR,1=5HR,2=7HR,3=9HR
1	210.5	2221	850	44	722	40	209	4548	1322*	#	2
2	204.3	1489	919	44	726	50	40	4595	1392*	#	0
3	227.1	2345	864	44	709	50	39	4530	1263	12	0
4	209.8	2281	848	44	696	25	0	4615	1392*	#	0
5	209.0	2217	990	50	733	30	39	4340	1285	4.4	0
6	216.4	1230	864	44	697	25	96	4681	1373	19	1
7	210.5	2240	850	44	680	30	38	4421	1387	10	0
8	210.5	2142	854	44	696	30	48	4272	1388	16-29	0
9	211.1	1964	963	50	661	55	47	4014	1178	9.33	1
10	236.9	1667	840	45	734	30	50	3117	938	11-50	0,1&2
11	211.0	2486	916	44	693	40	0	4580	1135	15.1	0
12	209.9	2754	857	44	697	44	42	4228	1283*	18.1	1
13	212.9	1804	945	42	683	65	38	5939	1402	20.1	1
14	218.4	2302	486	44	708	18	96	4135	1289	16	0
15	219.8	1824	893	37	703	15	97	4397	1250	28	1
16	230.7	2530	539	37	698	35	94	4114	1272	#	0
17	226.5	1420	837	44	679	35	46	4642	1435	#	0
18	210.3	1430	850	45	687	75	94	2637	814*	4	0
19	210.5	3243	849	44	690	30	53	4317	1422	8	1
20	219.0	2506	901	44	704	20	48	4551	1404	12	0
21	221.7	1430	1060	46	715	15	49	4030	1317*	12&18	0&1
22	205.4	2482	963	50	686	65	94	4453	1168*	#	#
23	209.3	1848	820	44	663	30	27	4060	1255	#	2
24	226.2	2017	859	44	694	20	38	4328	1438	15.1	1
25	226.6	2093	878	48	699	60	38	4203	1307	14.1	0

* Reported at 78^{o}F, converted to gain @ 87^{o}F by ratio of inside-outside Δt'

Default value assumed

TABLE 5.1 cont'd.

ANALYST	TOTAL SUPPLY AIR FLOW (CFMx10^3)	AIR HANDLING			MINIMUM OUTSIDE AIR FLOW (CFM)	PEAK INFILTRATION RATE (CFMx10^3)	INFILTRATION KEY*	NUMBER OF THERMAL BLOCKS
		SUPPLY FAN (kW)	RETURN FAN (kW)	EXHAUST FAN (kW)				
1	256.7	154	68	2	17035	4720	2	6
2	275.0	275	275	7	10215	13346	1	1
3	296.7	218	87	2	11375	8000	2	3
4	320.0	265	136	2	9920	9820	3	6
5	481.5	354	155	3	10500	13110	3	6
6	216.4	156	66	2	10000	33200	3	1
7	400.0	293	130	2	9884	7038	2	9
8	472.7	247	102	2	13440	16628	2&3	19
9	308.0	225	98	20	9891	14770	2	19
10	364.4	--386--		4	16931	34555	8	20
11	525.0	388	172	2	9865	24740	2	6
12	330.8	243	107	2	12530	10870	2&8	6
13	348.8	343	152	3	12660	22100	2	5
14	349.0	255	142	2	10030	14612	2	6
15	482.7	--580--		2	10360	15580	3&2	19
16	499.0	365	122	2	9500	16800	2	6
17	325.0	300	140	0	9770	7000	3	1
18	353.9	--488--		2	9900	3846	2&0	6
19	357.5	262	131	2	11326	5436	2	12
20	400.0	265	119	2	10120	10450	2	6
21	307.6	226	100	2	10730	18835	8	9
22	409.2	427	186	3	9853	4749	2	11
23	286.0	170	76	3	9700	8500	2	3
24	234.6	116	51	2	9442	5505	2,8&0	43
25	350.7	257	86	2	10198	9825	2	1

*INFILTRATION KEY:

0 = constant infiltration
1 = infiltration only when fans off
2 = proportional to ambient, always on
3 = proportional to ambient, on when fans off
8 = profile - infiltration v ambient dry bulb

TABLE 5.1 cont'd.

ANALYST	CHILLERS: RATED OUTPUT/CHILLER (TONS)	CHILLERS: ENERGY INPUT @ RATED OUTPUT (kW)	BOILERS: RATED OUTPUT/BOILER (BTU/HRx10^3)	BOILERS: ENERGY INPUT @ RATED OUTPUT (kW)	COOLING SYSTEM ACCESSORIES: CONDENSER COOLING WATER PUMP (kW)	COOLING SYSTEM ACCESSORIES: CHILLED WATER PUMP (kW)	COOLING SYSTEM ACCESSORIES: COOLING TOWER FAN (kW)	HEATING SYSTEM ACCESSORIES: HEATING CIRCULATING PUMP (kW)	HEATING SYSTEM ACCESSORIES: BOILER INDUCED DRAUGHT FAN (kW)
1	748	583	5466	6148	14	11	38	9	1.6
2	564	440	31082	37000	22	22	34	37	10
3	724	564	14244	17806	32	26	38	18	0.8
4	960	748	2760	3450	37	37	34	4	1
5	650	507	9792	12240	37	30	38	19	1.6
6	600	570	8000	10000	50	30	38	30	1.6
7	960	750	27760	34700	35	29	38	31	1
8	930	726	22748	28434	41	28	34	25	1.1
9	670	524	7400	9250	30	24	37	10	1.1
10	810	632	10610	13263	35	29	34	7	1.1
11	1064	830	18840	23550	40	32	38	20	1
12	786	614	6120	7650	20	20	47	6	0.8
13	652	508	27600	34400	24	24	38	37	0.8
14	1020	796	6302	7876	45	34	38	8	2
15	1124	876	28230	35288	40	40	38	50	1.6
16	1600	1448	26000	32500	68	54	38	33	0.8
17	690	538	8400	10500	25	20	38	10	1.2
18	650	506	5500	6876	30	25	37	8	2
19	720	560	10502	13128	40	30	38	20	0.8
20	832	649	9000	11250	30	25	34	19	1.1
21	746	582	7450	9312	28	23	38	6	1
22	900	702	12636	15796	48	40	40	19	1
23	374	292	3678	4598	14	14	38	6	1
24	283	221	7870	9838	15	15	37	15	1
25	530	413	16108	20135	37	31	38	36	.8

TABLE 5.2 Method of Analysis Summary

7 Analysts simulated the transmission of absorbed solar through the roof without lagging effects,

5 simulated it with lagging effects

1 Analyst simulated the transmission of absorbed solar through the walls without lagging effects,

3 simulated it with lagging effects.

2 Analysts lagged the loads resulting from solar gains (through glazing), lighting & occupancy;

4 Analysts lagged the loads resulting from solar and lighting gains only

6 Analysts lagged the loads resulting from solar only

4 Analysts lagged the loads resulting from lighting only.

6 Analysts calculated peak infiltration based on considerations of combined wind and stack action and pedestrian traffic.

5 based calculation on combined wind and stack action

7 solely on stack effect

4 solely on wind effect

1 on stack effect and pedestrian traffic

2 calculated infiltration by the "air change method".

19 Analysts simulate infiltration as a function of outside dry bulb (stack effect)

5 simulated stack effect only when the building HVAC fans were off - otherwise it was considered to be zero.

1 Analyst used zero infiltration when the HVAC fans were ON, with constant infiltration when the fans were OFF.

TABLE 5.2 Method of Analysis Summary (Cont'd)

20 Analysts considered all the window blinds to be down continuously and closed to exclude direct sunlight.

1 Analyst considered them to be up all year.

4 considered partial operation.

TABLE 6.1 RESULTS OF PARAMETRIC RUNS

	E.R.E. Output							
	Heating			Cooling				
	Annual Consumption MBTU	# Hrs.* Space Load Not Met	Peak Coil MBH	Annual Consumption Ton Hrs.	# Hrs.[1] Space Load Not Met	Peak Coil Tons	Air Handling Systems KW.HRS.	Base Electric KW.HRS.
Basic Model	5,466,220	0	26,846	214,966	10	882.6	419,660	2,995,805
Infiltration 1	7,009,943	"	27,662	210,978	8	"	413,180	2,989,326
" 2	6,153,252	"	26,553	213,293	9	"	419,648	2,995,796
" 3	6,465,561	"	27,381	212,403	8	"	415,345	2,991,492
" 4	5,131,486	"	26,668	215,864	10	"	421,316	2,997,462
" 5	5,182,114	"	26,553	215,740	10	"	421,758	2,997,905
" 6	5,505,769	"	26,748	213,758	9		418,068	2,994,217
Solar 1	4,960,078	"	26,846	247,280	40	1010.1	450,893	3,027,041
" 2	4,877,803	"	"	232,516	21	920.3	436,953	3,013,101
" 3	5,423,658	"	"	200,337	5	793.8	406,755	2,982,901
" 4	4,764,868	"	"	241,056	25	955.1	445,273	3,021,421
" 5	5,278,295	"	"	208,848	5	849.6	413,447	2,989,592
" 6	3,951,368	"	"	283,935	95	1036.4	488,899	3,065,046
" 7	6,257,929	"	"	176,481	1	758.7	391,608	2,967,752
Lighting 1	4,655,265	"	26,837	227,407	19	882.6	429,669	3,472,865
" 2	6,525,478	"	26,841	198,034	9	882.6	408,573	2,109,079
" 3	5,490,736	"	26,822	193,055	12	871.9	402,440	2,978,583
" 4	5,606,530	"	26,847	206,679	7	882.6	412,147	2,988,291
" 5	5,054,680	"	26,845	244,361	33	882.6	451,847	3,027,993
Heat Storage Factor 1	6,272,185	"	48,899	218,962	23	930.2	422,034	2,998,180
" " " 2	3,960,360	"	11,031	208,562	3	660.0	416,731	2,992,878
Heat Storage Key 1	5,121,356	"	19,942	213,365	6	882.6	413,765	2,989,910
" " " 2	4,829,223	"	16,423	212,188	4	889.7	409,748	2,985,891
Receptacle 1	4,777,030	"	26,817	244,753	17	891.4	449,338	3,168,435
" 2	5,642,341	"	26,853	208,403	9	882.6	414,150	2,863,276
Ventilation 1	5,465,939	"	26,821	214,916	10	882.6	419,660	2,995,805
" 2	5,469,920	"	27,070	215,403	10	"	419,660	2,995,805
"Multi-Zone Model"	6,085,290	-	19,868	174,734	-	658.3	386,942	2,948,865

[1] Figures include 'pick-up load'* - (See Reference 4 for definition*)

TABLE 6.2 RESULTS OF PARAMETRIC RUNS

	HEATING			COOLING				
	Annual Consumption MBTU	# Hrs Space Load Not Met* (2)	Minimum Temp °F (Normal Operation)	Annual Consumption Ton Hrs.	# Hrs Space Load Not Met* (2)	Maximum Temperature °F (Normal Operation)	Maximum Humidity Ratio Gr	Fan Consumption (Elec) KW.HR.
Basic Model (Peak Coil Capacities:* Heating - 26,846 MBH Cooling - 882.6 Tons)	5,466,220	0	70.00	214,966	2	70.25	69.00	419,660
		(1)			(1)			
90% Peak Coil Capacities	5,443,898	9(0)	70.00	214,971	10(2)	70.25	69.00	419,699
80% " " "	5,427,356	15(0)	69.98	214,754	13(2)	70.25	69.71	419,778
70% " " "	5,409,433	22(0)	70.00	214,031	28(5)	"	75.71	420,145
60% " " "	5,377,542	37(0)	69.98	211,015	80(32)	70.31	80.33	423,022
50% " " "	5,317,204	69(0)	69.92	201,641	142(83)	71.75	88.31	428,429
40% " " "	5,206,696	132(0)	69.89	187,028	206(117)	72.07	88.33	432,661
30% " " "	4,997,364	252(0)	69.86	164,651	325(182)	73.5	85.59	437,312
25% " " "	4,831,419	341(0)	69.95	149,276	390(245)	73.82	86.97	441,212
20% " " "	4,583,196	475(0)	69.91	129,596	485(288)	73.02	89.68	446,373
15% " " "	4,194,073	675(7)	69.87	105,694	590(364)	73.86	95.34	452,915
10% " " "	3,526,882	983(113)	69.80	76,281	686(435)	73.12	99.23	459,211
90% Air Volume	5,328,669	0(0)	70.00	210,727	17(3)	70.4	69.1	390,807
80% " "	5,201,847	"(")	69.98	205,765	30(5)	70.7	69.22	361,645
70% " "	5,087,106	"(")	69.96	199,291	93(43)	71.03	69.37	334,145
60% " "	4,982,962	"(")	69.95	189,301	227(146)	71.38	69.88	305,645
50% " "	4,877,870	"(")	69.88	171,458	434(337)	71.74	71.69	274,099

(1) Figures in brackets exclude those hours when the pick-up load is being met.

(2) See Reference 4 for explanation of terms.

TABLE 6.3 Summary of Results of parametric runs expressed as percentage differences of Reference Model Values

	Percentage Differences from Reference Model, for Parametric Runs		
	Heating	Cooling	Base electric
Infiltration parametric runs			
- Maximum infiltration. (Infiltration 1)	+28	-2	<1
- Minimum infiltration. (Infiltration 4)	-6	<1	<1
- Using a constant infiltration rate. (Infiltration 6).	<1	<1	<1
Solar parametric runs			
- Highest solar gain. (Solar 6)	-28	+32	<1
- Lowest solar gain. (Solar 7)	+14	-18	<1
- Window blinds up all year. (Solar 1)	-9	+15	<1
- Window blinds up but solar loads lagged. (Solar 2)	-11	+8	<1
- As above with window blinds down. (Solar 3)	<1	+7	<1
- Transmission of absorbed solar radiation by opaque parts of envelope is added. (Solar 5)	-3	+3	<1
Lighting parametric runs			
- Highest lighting use. (Lighting 1)	-10	+10	+15
- Lowest lighting use. (Lighting 2)	+11	-4	-16
- Lighting heat gain lagged. (Lighting 3)	<1	-10	<1
- Lowest percentage of lighting gain to return air -15%. (Lighting 4)	-7	+14	<1
- Highest percentage of lighting gain to return air -75%. (Lighting 5)	+2	-4	<1

TABLE 6.3 (Cont'd)

	Percentage Differences from Reference Model, for Parametric Runs		
	Heating	Cooling	Base electric
Heat storage factor parametric runs			
- Highest value used. (Heat storage Factor 1)	+15	-3	<1
- Lowest value used. (Heat storage Factor 2)	-27	+2	<1
Stored load key parametric runs			
- 7-hour pick up for stored loads. (Heat Storage Key 2)	-12	-1	<1
Receptacle (small power) parametric runs			
- Highest usage. (Receptacle 1)	-9	+14	+6
- Lowest usage. (Receptacle 2)	+3	-3	-4
Heating and cooling coil - effect of limited capacity - (Table 6.2)			
- Lowest heating coil capacities	-24	-	-
- Lowest cooling coil capacities	-	-72	-
Ventilation rate parametric runs			
- Highest rate. (Ventilation 2)	<1	<1	<1
- Lowest rate. (Ventilation 1)	<1	<1	<1
Complex multi-zone model			
- 27 zone model, (Multi-zone model).	+11%	-19%	-2%

Notes: The statements in parenthesis identify the runs as identical to the runs presented in Table 6.1.

APPENDIX 2

List of Participants

List of consultants who took part in the study. For the sake of anonymity the order of names following is <u>not</u> the same as that presented in the text.

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APPENDIX 3

TEST BUILDING SPECIFICATION,
CORRECTION/CLARIFICATION SHEETS,
& SUMMARY TABLES

Note: This section is identical to that sent to the participants. It has not been edited in any way since except to add page numbers as part of this report.

TEST BUILDING SPECIFICATION FOR D.B.R. COMPARISON OF ENERGY ANALYSES

L, JONES

FEBRUARY 1978

CONTENTS

SECTION 1

INTRODUCTION

The intent of this specification is to define the physical characteristics of a building and its HVAC system.

The object of the exercise is to determine the degree of consistency obtained when several analysts use the same program to predict the energy consumption of the same building. The building described is basically the same building as that currently used in the International Energy Agency comparison of Load & Energy Analysis computer programs.

Where possible the specification is written in such a way as to present the consultant/analyst with the same sort of problems he might encounter in practice. In general this is achieved by:

(1) Specifying all the physical characteristics of the building and the HVAC system whilst,

(2) Omitting items where engineering judgment or calculation is involved.

In instances, in order to have a common basis for comparison, items as under (2) above, have been specified. In no instance, should it be necessary to assume physical characteristics of the building or HVAC system that would normally be known in practice. If such an assumption is found necessary the item should be referred to D.B.R. for clarification/comment before proceeding. This does not preclude, however, assumptions of the "engineering judgment" type such as would be required, for instance, in deciding how to divide the building into thermal blocks. THE PRINCIPLE TO BE ADOPTED FOR THE ANALYSIS SHOULD BE TO MAKE THOSE ASSUMPTIONS AND SIMPLIFICATIONS THAT YOU CONSIDER NECESSARY IN ORDER TO ARRIVE AT A REASONABLE PREDICTION OF THE BUILDING'S ENERGY CONSUMPTION.

Similar studies to the one considered here, have shown that it is extremely difficult to write a fully comprehensive specification; for this reason, to ensure that all analysts are modelling essentially the same building, the exercise is to be broken into 2 sections.

Stage I. The analyst is requested to prepare all necessary input. Should he have any queries referring to the specification these should be referred to NRC/DBR. ESA runs should not be made until stage II. Analysts will be advised of any omissions or items considered to need clarification, as raised in this first stage.

Stage II. E.S.A. runs will be authorized after all analysts have completed their input preparation. Analysts will be required to forward a complete computer printout of their runs and to fill out the summary forms included in Part 5 of this specification. An additional questionnaire will be sent to the analyst, for completion, after the results have been submitted.

SECTION 2

ARCHITECTURE

2.1 The architecture is shown in Figure 2, 3, 4, 5 and 6 as specified herein. The heating, ventilating and air conditioning (HVAC) criteria and systems plus load curves are specified in Sections 3 and 4.

2.2

2.2.1	Shape:	Rectangular with north facade facing 30^{o} west of true north.
2.2.2	Height:	13 stories resting on raised columns; 12 occupied typical floors and penthouse.
2.2.3	Gross Areas:	Building total of 230, 702 sq. ft. and 12 typical floors at 18,792 sq. ft. each.
2.2.4	Structure:	Steel frame with 4 inch concrete floor slabs. Lobby elevator shaft and escape staircase 8" cast-in-situ concrete. No insulation on exposed concrete.
2.2.4	Penthouse:	150 ft. long and 65 ft. wide centered on roof. Contains <u>all</u> mechanical, electrical equipment and elevator machinery.
2.2.6	Entry Lobby:	Situated at grade level, containing the six elevator hoistways, lobby and staircase. See Figure 3 for layout.

2.2.7	Grade Level Plaza:	Slab-on-grade with open landscaped area. 18 ft. floor-to-floor with 14 ft. suspended ceiling, including the Entry Lobby.
2.2.8	Typical Floor:	261 ft. long and 72 ft. wide, 13.5 ft. floor-to-floor and 8.5 ft. ceiling heights.
2.2.9	Walls:	Dark coloured glass face curtain wall with 1 inch insulation on all walls excluding east and west walls of Entry Lobby which are finished concrete.
2.2.10	Interior Partitions:	Gypsum board on each side of slab-to-slab metal studs
2.2.11	Floors:	Carpet on 4 inch concrete slab
2.2.12	Ceilings:	Suspended acoustical tile with lay-in fluorescent light fixtures on typical floors. Suspended metal lath and plaster ceiling below second floor slab
2.2.13	Roof:	Insulated built-up roof on 4 inch concrete slab
2.2.14	Window Glass:	53% of typical floor facade, 1/4 inch Solargrey (heat absorbing) single glaze mounted flush to outside wall face. Interior light color venetian blinds.

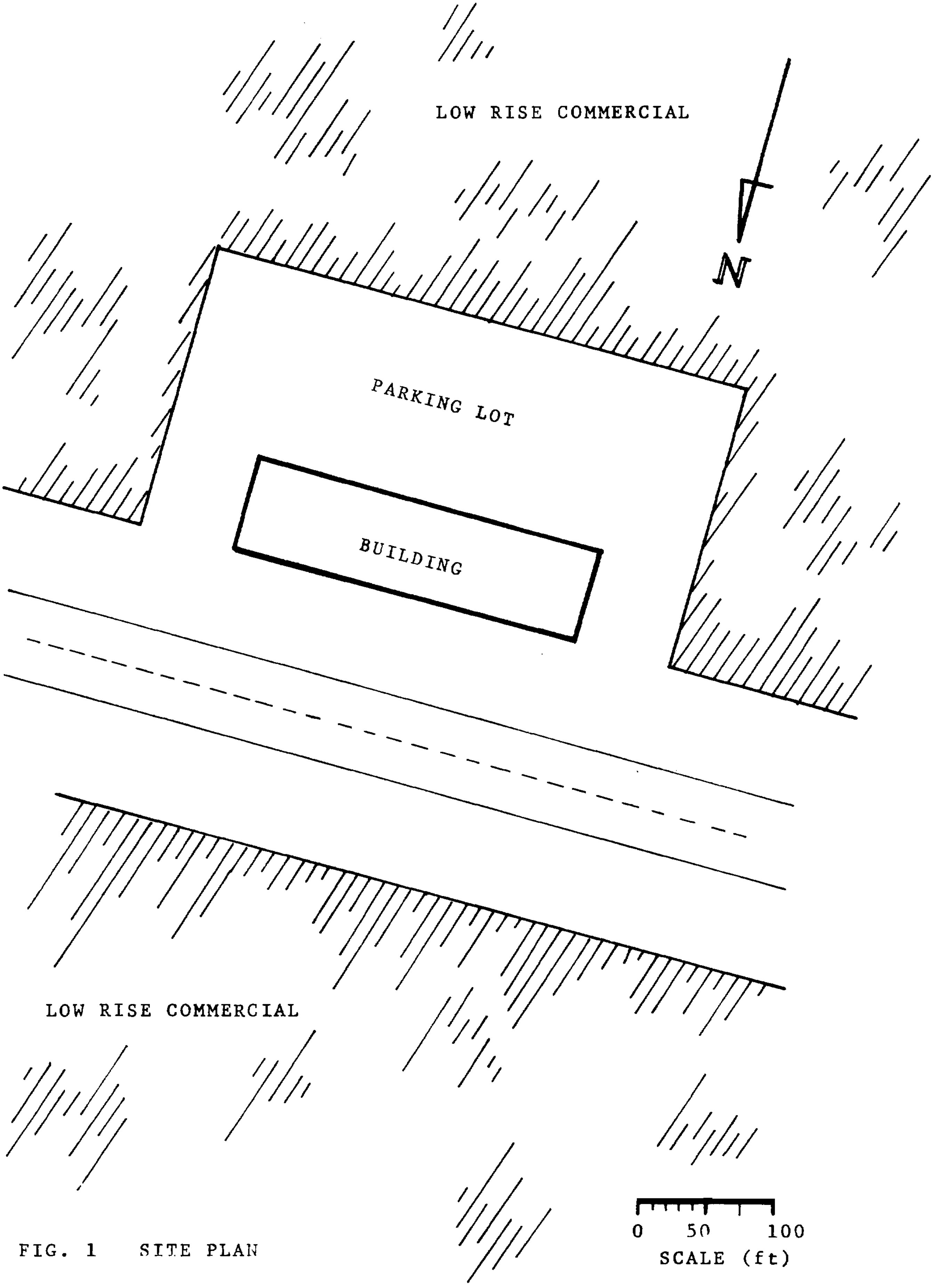


FIG. 1 SITE PLAN

		1/4 inch Solargrey single glazed side panels at north and south ends of Entry Lobby (no blinds in lobby). The windows are non-openable.
2.2.14	Lobby Doors:	Single bank glass, 1/2 inch Solargrey single glaze at north and south ends of Entry Lobby. Doors each 3'-6" wide and 11'-6" high.
2.2.16	Escape Stair Doors:	1½" solid hardwood doors, one per staircase, each 6'-6"x3'-6".

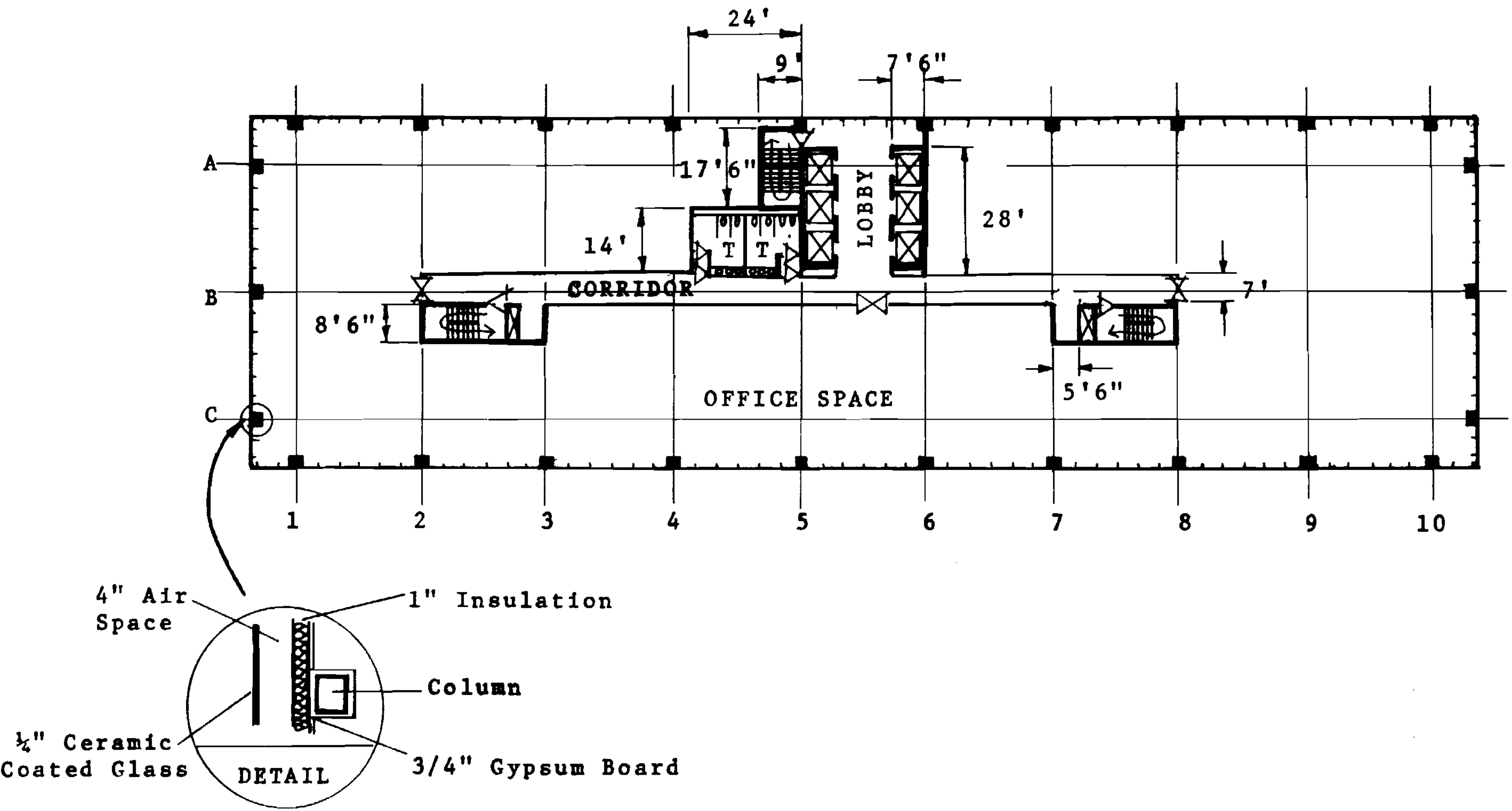


FIG. 2 TYPICAL FLOOR PLAN & WALL SECTION

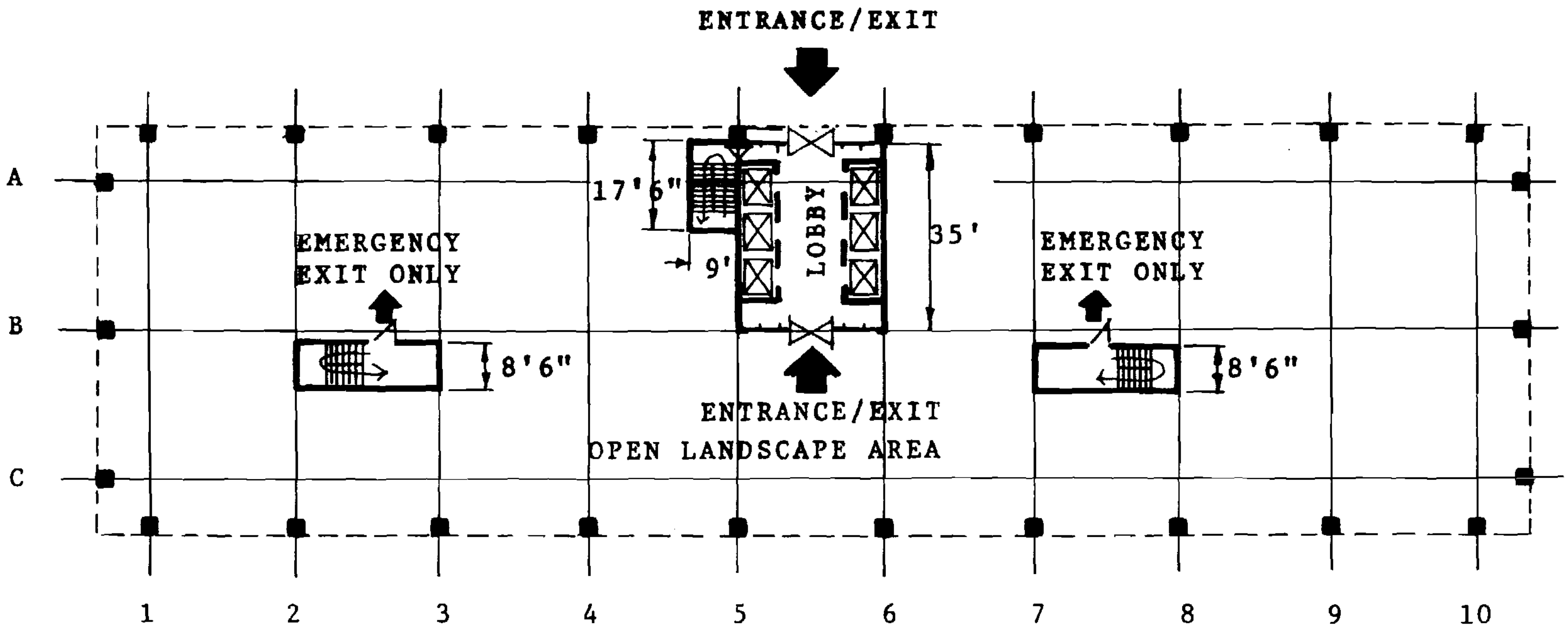


FIG. 3 GROUND FLOOR PLAN

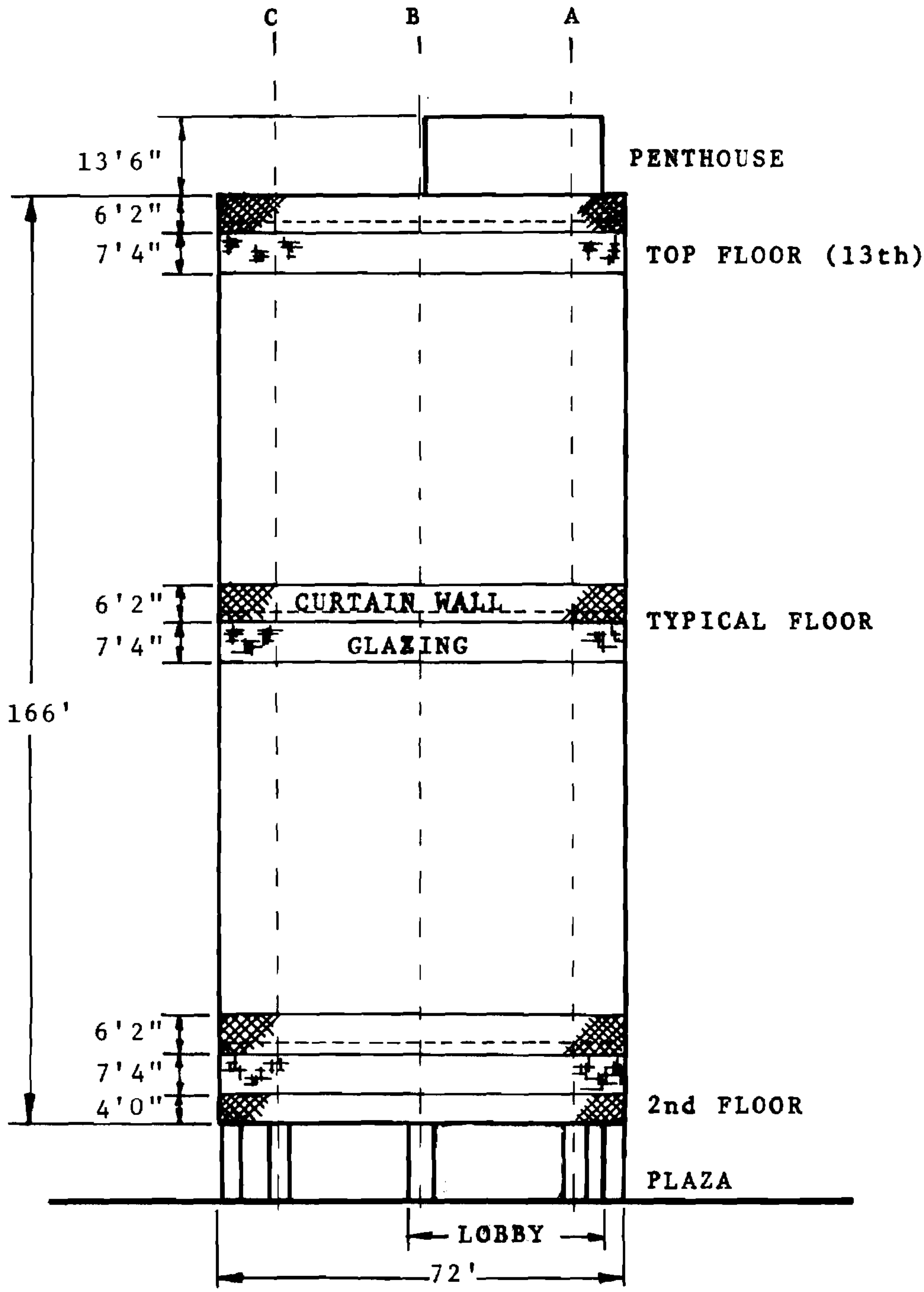


FIG. 6 WEST ELEVATION

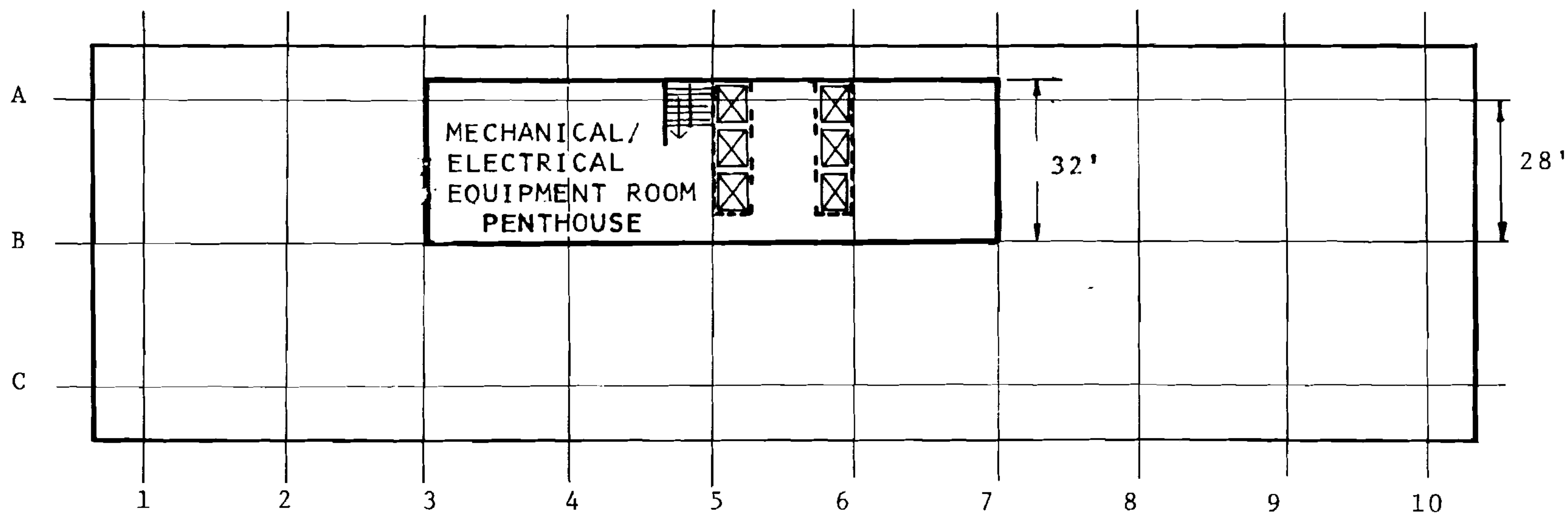


FIG. 4 ROOF PLAN

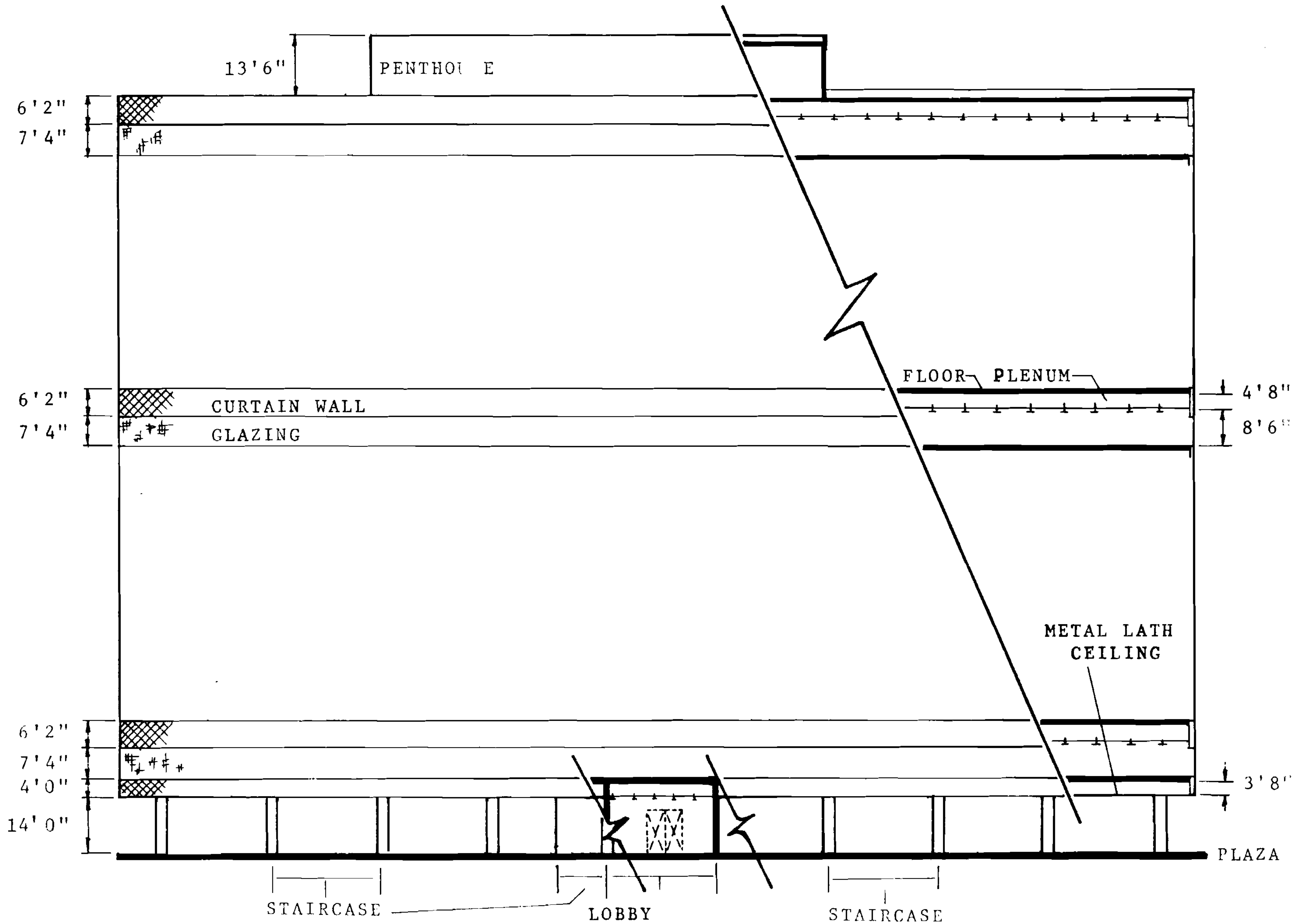


FIG. 5 NORTH (FRONT) ELEVATION

Table 2-1

2.3 CONSTRUCTION CHARACTERISTICS - THERMAL PROPERTIES

	k	D	SH	R	α
External Walls:					
¼ inch ceramic coated glass	0.590	172	0.20	-	0.90
1 inch insulation	0.025	2.0	0.20		-
4 inch air space	-	-	-	-	-
3/4 inch gypsum board	0.420	100	0.20	-	-
Interior Partitions:					
3/4 inch gypsum board	0.420	100	0.20	-	-
4 inch air space	-	-	-	-	-
3/4 inch gypsum board	0.420	100	0.20	-	-
Lobby Floor:					
1/4 inch carpet	-	-	-	2.08	-
4 inch concrete slab-on-grade (uninsulated)	1.0	140	0.20	-	-
Typical Floor:					
1/4 inch carpet	-	-	-	2.08	-
4 inch concrete	1.0	140	0.20	-	-
Return air plenum space	-	-	-	-	-
3/4 inch acoustic tile ceiling	0.033	18	0.32		-
Second Floor:					
1/4 inch carpet	-	-	-	2.08	-
4 inch concrete slab	1.0	140	0.20	-	-
Dead air space	-	-	-	-	-
3/4 inch metal lath & plaster ceiling	0.420	100	0.20	-	0.92
Roof:					
Built-up roofing (3/8")	0.665	70	0.33	-	0.97
3 inch insulation	0.025	2.0	0.20	-	-
4 inch concrete slab	1.0	140	0.20	-	-

Legend:

k = Thermal conductivity, Btu/hrft/°F
α = Solar Absorptivity
D = Density. lb/ft^3
SH = Specific heat, Btu/lb/°F
R = Thermal resistance, $hr.ft^2$°F/Btu

2.4 CONSTRUCTION CHARACTERISTICS - AIR LEAKAGE DATA

2.4.1 External Walls: Laboratory mock up of the finished wall construction showed the composite wall section (wall panel and window including all joints) to have the following leakage characteristics.

Air leakage rate: 0.3 cfm/sq.ft. at 0.3" water

Flow Coefficient (c): 0.66 cfm/sq.ft.(in. water)$^{0.65}$

It is to be understood that this standard can be maintained on site.

2.4.2 Exterior Doors: 1/8" crack around all external doors. (The escape staircase doors are normally kept closed).

TABLE 2-2

GLASS CHARACTERISTICS

Single Glazing

1/4 inch SOLARGREY (Heat Absorbing) Glass by PPG.

Glass Coefficients:

j	ABSORPTANCE Aj	TRANSMITTANCE Tj
0	-0.047467403	0.15482825
1	1.547883000	1.75132940
2	-1.270666100	-2.18134880
3	-1.030198100	-1.42009740
4	2.292256400	4.19509120
5	-1.002260200	-2.04779150

NB All office windows provided with light coloured internal venetian blind.

TABLE 2-2 (continued)

GLASS CHARACTERISTICS

Door Glass

1/2 inch SOLARGREY by PPG.

Glass Coefficients:

j	ABSORPTANCE Aj	TRANSMITTANCE Tj
0	0.13888568	-0.022547748
1	2.75137040	0.657141270
2	-3.17809300	-0.622799100
3	-2.16284660	-0.025019813
4	6.07229230	0.517362000
5	-2.91922470	-0.257125850

2.5 Special Requirements

To allow comparison of computed loads it is required that:

(a) "REFERENCE SOLAR LOAD" be calculated at June 21 at noon.

(b) "DESIGN TRANSMISSION LOSS" is calculated at an outdoor ambient temperature of 15°F.

(c) "DESIGN TRANSMISSION GAIN" is calculated at an outdoor ambient of 87°F.

SECTION 3

HVAC CRITERIA & SYSTEMS

3.1 Design Criteria

3.1.1	Location	Vancouver, B.C.
3.1.2	Weather	Vancouver 'Test Reference Year' (RY)
3.1.3	Surroundings	Located in suburban terrain with no other tall building in the area. The building is immediately surrounded by a bituminous surfaced parking lot and further away by low rise commercial buildings.
3.1.4	Lighting	Recessed fluorescent fixtures with prismatic lens throughout the building, 3.5 watts/sq.ft. in the offices, 1.0 watt/sq.ft. in the lobby, toilets and corridors. Switching arrangements for the lighting is as shown on Figure 8 . Emergency lighting constitutes 5% of the total lighting connected load.
3.1.5	Office Equipment	Equipment normally associated with general office type activities is to be assumed throughout the building. Assume no major loads.
3.1.6	Occupancy	Occupancy density of 100 sq.ft./person, in the office areas.

3.1.7 Ventilation 5cfm per person minimum, in all office areas. 2 cfm/ 100 sq.ft. in all circulation spaces. See Fig. 8.

3.1.8 Inside temperature 70°F. Humidification is not provided.

3.2 HVAC System Description

3.2.1 Variable air volume (VAV) systems with insulated sheet metal ducts extend to each floor for above ceiling distribution (by duct) to ceiling outlets. VAV boxes have 25% minimum stops with fixed cold deck temperature and reheat coils where necessary. All systems take return air from common ceiling plenums on each floor using the duct shaft to the penthouse. All systems have enthalpy controlled cycles, fan inlet guide vanes for pressure control. Air is supplied to all areas except toilets, staircases and plant rooms.

SUPPLY & RETURN
FAN PERFORMANCE CHARACTERISTICS

Percent of Rated Capacity	Percent of Rated Input
100	100
80	74
60	57
40	46
20	38

Supply and return air rates are balanced (equal) except for the plant(s) supplying the toilet area where the return air volume equals the supply air volume less the exhaust rate (see item 4.2.2). Separate plants are to be provided for those areas of the building with significantly different thermal loads.

The secondary (air) system heating and cooling coils are to be of adequate capacity to meet all necessary loads.

3.2.2	Toilet Exhaust:	600 cfm per floor at 1½ inch of water static pressure with constant 65% overall efficiency* Fan operates only when supply fan is on.
3.2.3	Supply Air:	Constant (primary) supply air 55°F. Draw through supply fans selected at 80% efficiency and 4½ inch total pressure (4 inch static plus ½ inch velocity pressure). 90% efficient motors** located outside of air stream. See Section 5 for fan performance curve.
3.2.4	Return Air:	Fans selected at 80% efficiency and 2 inch total pressure (1½ inch static and ½ velocity pressure). 90% efficient motors** located outside of air stream.
3.2.5	Chillers:	Two electric drive centrifugal chillers connected in parallel, loaded sequentially, and each sized for 60% of the peak cooling load*** with 45°F delivery temperature.

* Overall efficiency is defined to include fan (or pump), mechanical and electrical losses.

** Includes mechanical drive losses.

*** For the purposes of sizing the chillers and boilers the peak load is to be taken as the annual peak co-incident loads as obtained from the program output.

Full load chiller performance:

0.78 kWhr/ton cooling

Part load performance at constant chilled and condensed cooling water temperatures

% Load	10	20	30	40	50	60	70	80	90	100
% Max. Fuel Input	24	30	37	44	52	60	69	78	88	100

3.2.6 Chilled Water Pump: One, sized at 60 ft. of head and 75% overall efficiency (pump and motor). Chilled water $\Delta t = 10^{o}F$.

3.2.7 Condenser Water Pump: One, sized at 60 ft. of head and 75% overall efficiency (pump and motor). Condenser water $\Delta t = 10^{o}F$.

3.2.8 Cooling Tower: Induced draft with 65 HP, 89% efficient motor. The cooling tower is sized and controlled to maintain constant condenser cooling water temperature.

The cooling tower fan only operates when the desired condenser cooling water temperature cannot be obtained by natural draught through the tower. The tower performance is represented by the following:

Ambient Wet Bulb Temperature (°F)	% Capacity of Tower with	
	fan operating	fan off
72	151	23
75	127	19
78	100	15
80	81	12

3.2.9 Boilers: Two gas fired hot water boilers connected in series loaded sequentially, and each sized for 60% of the peak heating load.***

Each boiler provided with 3/4 HP induced draft fan, with motor efficiency of 72%.

BOILER PART-LOAD CHARACTERISTICS

Percent Load	Boiler Efficiency	Percent of Maximum Energy Input
100	80.0	100.0
90	79.5	90.56
80	78.8	81.22
70	78.0	71.76
60	76.8	62.50
50	74.5	53.69
40	70.9	45.14
30	65.0	36.92
20	56.0	28.57
10	42.0	19.05

3.2.10 Heating Hot Water Pump: One, sized at 80 ft. of head and 75% overall efficiency* heating circuit $\Delta t = 30^{o}F$.

---

* Overall efficiency is defined to include fan (or pump), mechanical and electrical losses.

** Includes mechanical drive losses.

*** For the purposes of sizing the chillers and boilers the peak load is to be taken as the annual peak co-incident loads as obtained from the program output.

3.3 HVAC System Controls

3.3.1 System to operate five days per week with no holidays and be turned on at 7:00 a.m. and shut off at 5:00 p.m. Nighttime and week-end setback minimum temperature is 50°F in winter, and no maximum required in summer. Supply, return and toilet exhaust fans are electrically interlocked. Should the internal temperature drop below the minimum of 50°F during 'silent hours' the HVAC system will automatically turn on to provide the necessary heating. On reaching 50°F again the system will shut off.

3.3.2 Heating System Operation: The heating system operates continuously throughout the whole year (i.e., heating is available to meet a heating requirement at all times).

3.3.3 Cooling System Operation: The cooling system operates only between, and including, the months of April and September and in those months only between the hours as scheduled in item 3.3.1.

3.4 Base Electric Loads

Elevators: 175 KW (full load)

3.5 Building Service Water

An electric automatic storage type service water heater is installed to provide 105°F hot water to the washrooms.

Service Hot Water Pump: 2.5 KW (full load)

Service Cold Water Pump: 37.5 KW (full load)

3.6 Location of Equipment

All mechanical equipment, including elevators, are located in the penthouse equipment room.

Hot and cold water pumps for service water heating are ON as per HVAC system, i.e., as per 3.3.1 above.

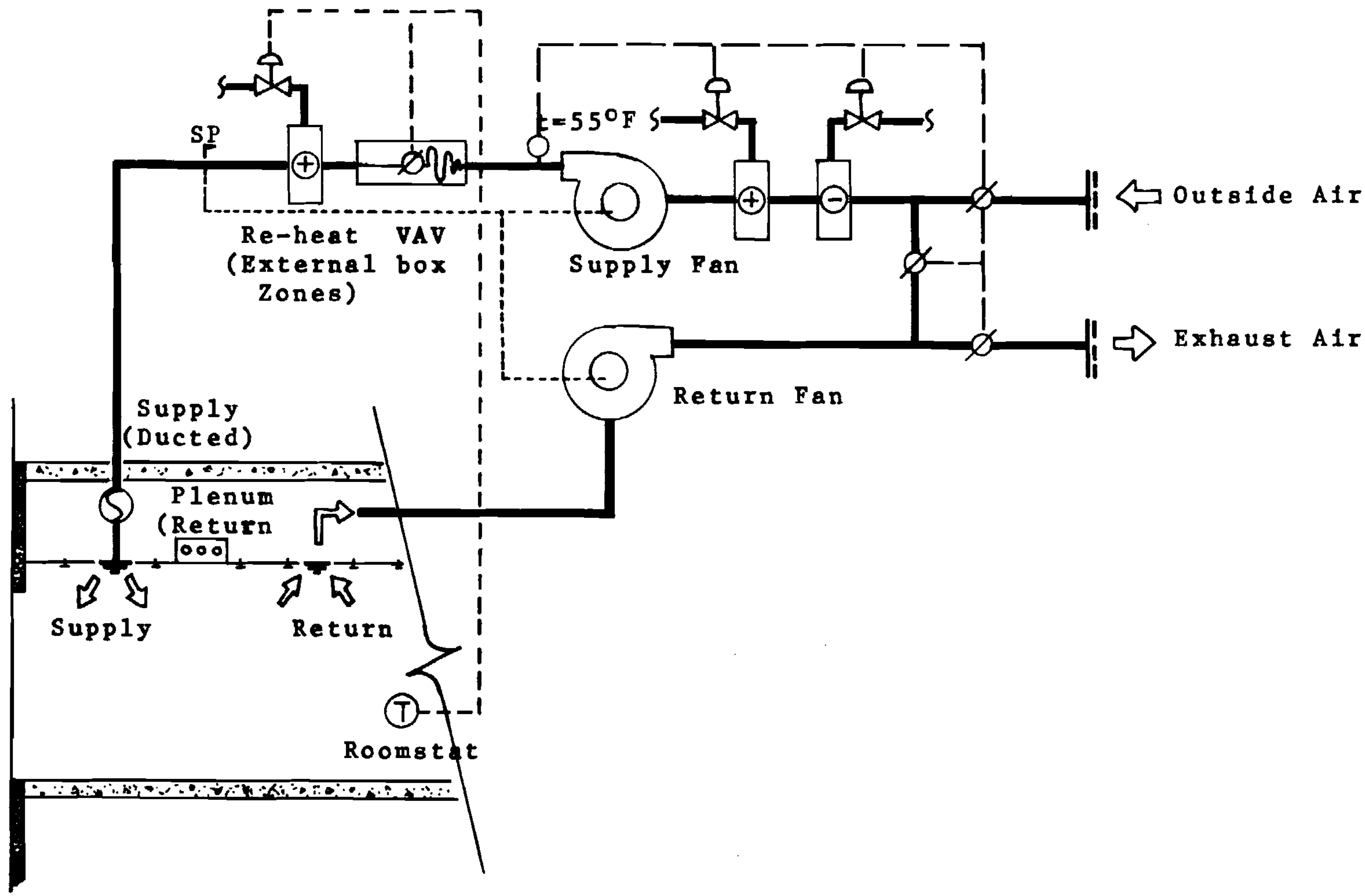
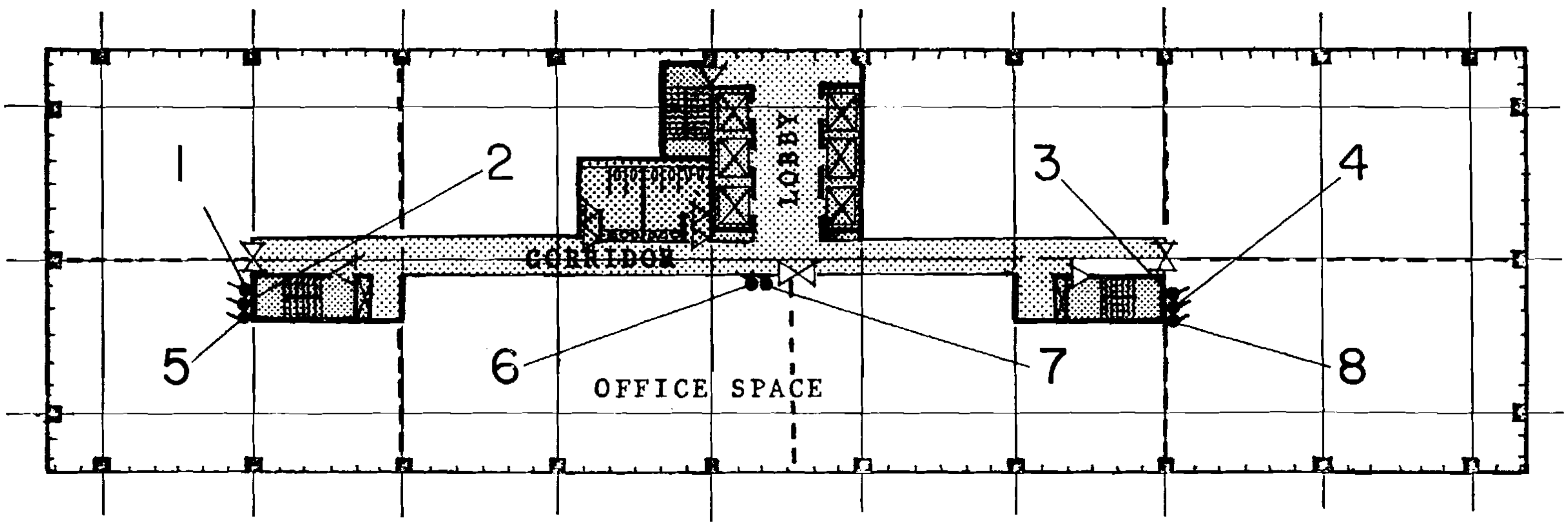


FIG. 7 HVAC ARRANGEMENT



Circulation (Supply & Extract), Ventilation 2 cfm/100 sq.ft.

Office Space (Supply & Extract) 5 cfm/person 100 sq.ft./person

Toilet Extract (Extract Only) 600 cfm total

No Supply or Extract

FIG. 8 TYPICAL FLOOR PLAN SHOWING EXTENT OF HVAC SYSTEM AND LIGHTING SWITCHING ARRANGEMENT

SECTION 4

USE & OCCUPANCY

4.1 OCCUPANCY PATTERN Normal office hours are 9 am to 5 pm with 1 hour for lunch between noon and one. The client has advised that overtime is normally not worked and at any one time some 95% of the total staff can be expected to be working (excluding lunch hour). There will be very few visitors to the building. No lunch facilities are provided in the building.

Cleaning of the building is carried out every evening between the hours of 5 pm and 9 pm by 6 gangs of 4 cleaners, each gang cleans one floor every two-hours.

4.2 LIGHTING USE

All circulation lighting (corridors, lobby, toilets, etc.) is turned on at 7 pm by the commissionaire. Office lighting will be turned on by the office staff as they arrive at their workplace. In the evening the cleaning staff are responsible for turning off the office lighting as they finish cleaning a floor. All circulation lighting, except emergency/security lighting, is turned off by the commissionnaire on leaving the building at 10:00 p.m.

Emergency lighting operates continuously.

SECTION 5

SUMMARY TABLES

(TO BE COMPLETED BY ANALYST)

INPUT DATA CHECK (LOADS & SECONDARY SYSTEMS)

SOLAR DATA KEY.................................. ________

FAN KEY (CARD 2 COL 80)......................... ________

AIR CONDITIONED FLOOR AREA...................... ________ sq. ft.

REFERENCE SOLAR LOAD (USE JUNE 21 NOON)............. ________ MBH

OCCUPANCY PEAK SENSIBLE LOAD ________MBH % LATENT ________

PEAK LIGHTING LOAD__________KW % TO RETURN AIR ________

PEAK EQUIPMENT (RECEPTACLE LOAD).................... ________KW

DESIGN TRANSMISSION LOSS (TO 15°F)................. ________MBH

DESIGN TRANSMISSION GAIN (TO 87°F)................. ________MBH

HEAT STORAGE *FACTOR (CARD 4, COLS 76-79)

HEAT STORAGE *KEY (CARD 4 COL 80)

*IF MORE THAN ONE USED ENTER VALUE USED FOR TYPICAL OFFICE SPACE AND ENTER NUMBER OF FACTORS USED________

TOTAL SUPPLY AIR FLOW.............................. ________CFM

AIR HANDLING UNIT SUPPLY FAN....................... ________KW

" " " RETURN FAN....................... ________KW

" " " EXHAUST FAN...................... ________KW

MAXIMUM OUTSIDE AIRFLOW............................ ________CFM

MINIMUM OUTSIDE AIRFLOW............................ ________CFM

PEAK INFILTRATION RATE............................. ________CFM

INFILTRATION KEY (CARD 5A COL 80).................. ________

PERCENTAGE VARIATION PROFILES:

Use attached blank profile sheet to show all variations profiles uses, list sources of information.

THERMAL BLOCKS:

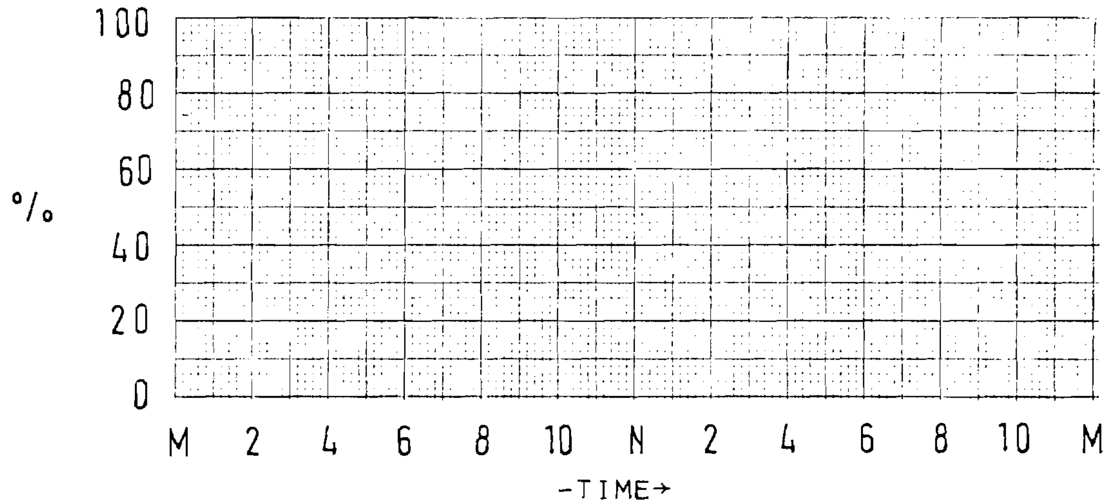
Use attached blank floor plan to show how the building was divided into thermal blocks for purposes of the analysis.

PERCENTAGE VARIATION PROFILES

SHEET.........OF.......SHEETS

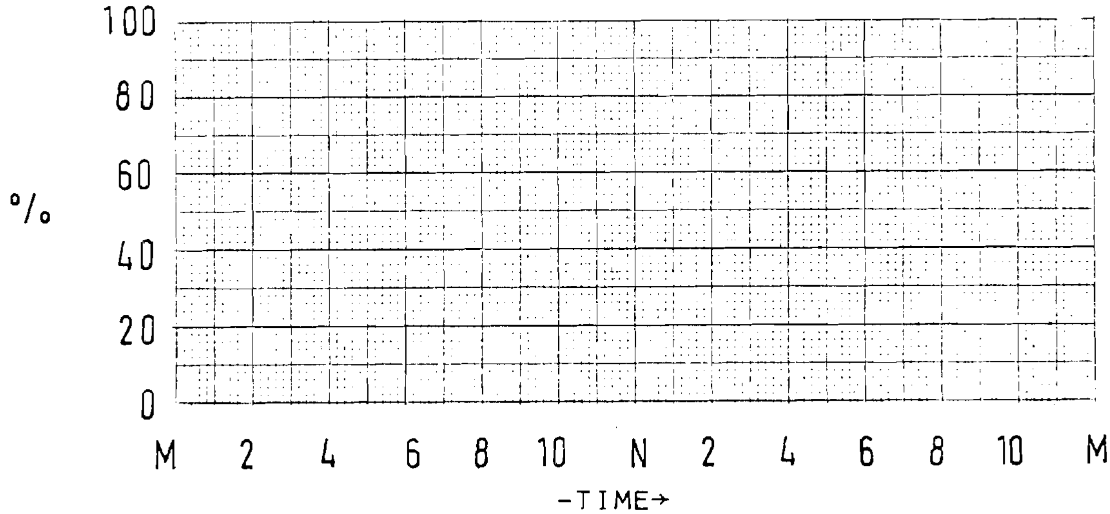
PROFILE#......REFERENCE......................

DESCRIBING...................................



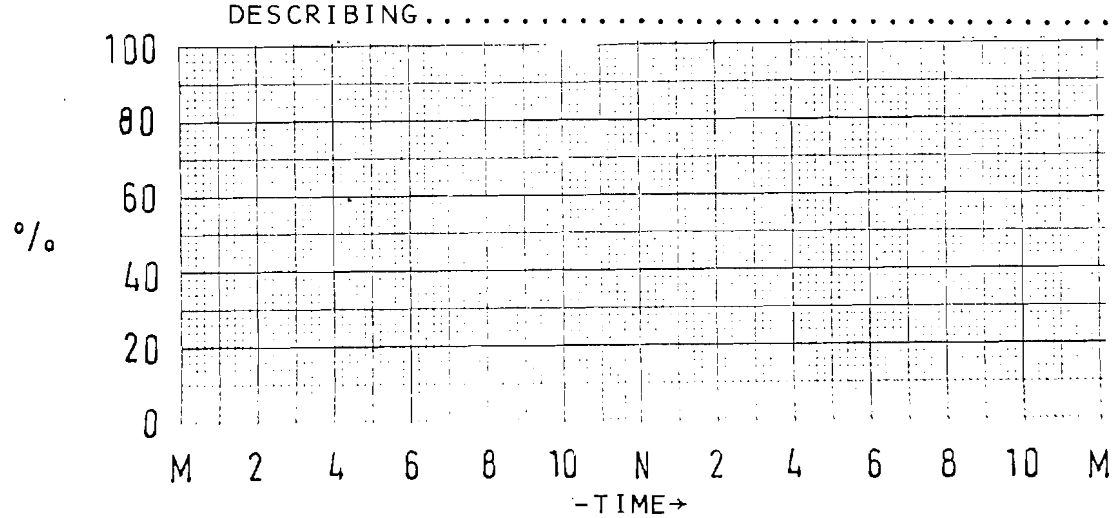
PROFILE#......REFERENCE......................

DESCRIBING...................................



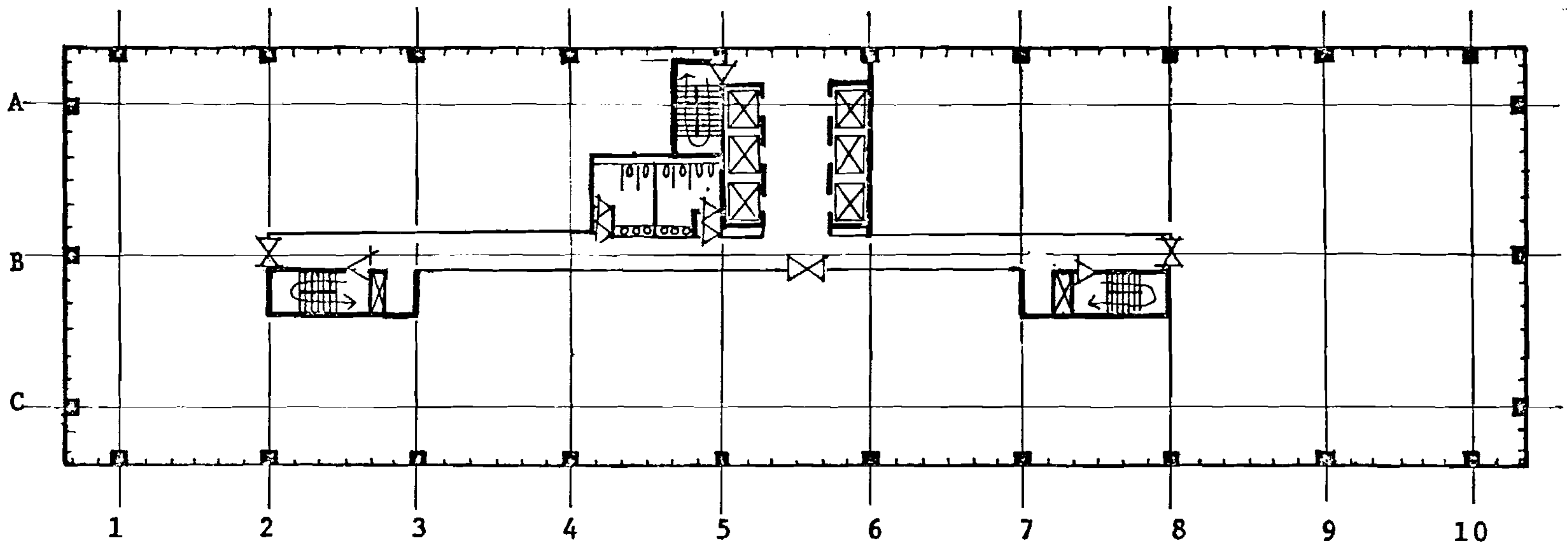
PROFILE#......REFERENCE......................

DESCRIBING...................................



DESCRIPTION OF THERMAL ZONES

- TO BE COMPLETED BY ANALYST



SHOW LAYOUT OF THERMAL BLOCKS FOR TYPICAL FLOOR ON THE ABOVE FLOOR PLAN. DESCRIBE ANY ADDITIONAL DIVISION IN THERMAL BLOCKS BELOW.

OUTPUT CHECK (1)
(LOADS AND SECONDARY SYSTEMS)
Secondary Systems Demands for Peak Hours and Consumptions for Months

A. Demand[1]		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1. Heating	MBH													
a. Date														
b. Hour														
2. Cooling	MBH													
a. Date														
b. Hour														

B. Consumption[1]		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1. Heating	MBTU (GJ)													
2. Cooling	MBTU (GJ)													

Note: 1. Heating and cooling peak demands and monthly consumptions supplied by the primary system to the secondary systems. These are the heating and cooling coil loads which include the ventilation load and the inefficiency of the secondary systems.

INPUT CHECK (PRIMARY SYSTEMS)

CHILLER RATED OUTPUT.................................__________TONS

ENERGY INPUT AT RATED OUTPUT........................__________KW

BOILER RATED OUTPUT.................................__________MBH

ENERGY INPUT AT RATED OUTPUT........................__________MBH

COOLING SYSTEM ACCESSORIES

CONDENSER COOLING WATER PUMP....................__________KW

" CHILLED WATER PUMP....................__________KW

COOLING TOWER FAN................................__________KW

HEATING SYSTEM ACCESSORIES

HEATING CIRCULATING PUMP........................__________KW

BOILER INDUCED DRAUGHT FANS.....................__________KW

PRIMARY (CENTRAL) SYSTEMS OUTPUT CHECK

HVAC Equipment Consumption		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1. Air Handling Systems[1]	KW hr													
2. Chillers	KW hr													
3. Chiller Auxiliaries[2]	KW hr													
4. Boiler	MBTU													
5. Boiler Auxiliaries[3]	KW hr													

Building Electricity Demand Consumption		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1. Peak Demand	KW													
2. Consumption	MWh													

Building Heating Fuel Demand & Consumption		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1. Peak Demand	MBH													
2. Consumption	MBTU													

Notes:
1. Supply fans, return fans and exhaust fans.
2. Chiller auxiliaries include chilled water pumps, condenser water pumps and cooling tower fans.
3. Boiler auxiliaries include boiler draft fans and heating hot water pumps.

COMMENTS:

D.B.R. COMPARISON

OF ENERGY ANALYSES

METHOD OF ANALYSIS QUESTIONNAIRE

METHOD OF ANALYSIS QUESTIONNAIRE:

Answer the following questions and add any further assumptions used that are not included in the list, or comments you feel are relevant.

1. Did you make any allowance for the Transmission of Radiant Heat (Solar) absorbed by

(a) Roof ____________ YES/NO

(b) Wall ____________ YES/NO

If so detail how:

____

____

____

____

2. Did you make any allowances for the time lag between heat gains and cooling load for:

(a) Solar Gains ______________ YES/NO

(b) Occupancy Gains __________ YES/NO

(c) Lighting Gains ___________ YES/NO

If so detail how:

____

____

____

____

3. Which method did you use to determine air infiltration rate - tick method(s) used.

(1) Stack Effect ______

(2) Wind Effect ______

(3) Air Change Method______

Was the effect of pedestrian traffic into and out of the building considered______YES/NO.

Do you assume constant or variable infiltration rate

CONSTANT/VARIABLE

If variable how do you model the variation:

____

____

____

____

4. Do you assume the internal venetian blinds are:

1. DOWN & ADJUSTED TO EXCLUDE ALL DIRECT SUNLIGHT OR

2. UP OR OPEN PART OF THE TIME

If 2 How if any was allowance made on solar entering building

____

____

____

____

ADDITIONAL COMMENTS

CORRECTIONS/CLARIFICATIONS TO TEST BUILDING SPECIFICATION FOR DBR COMPARISON OF ENERGY ANALYSES

Sheet #1 21 March 1978

1. Page 3, Para.2.2.4 — Correction, Penthouse size 32' x 112' not as stated.

2. Page 4, Para.4.2 — Correction, Circulation lighting is turned on at 7 AM not 7 PM as stated.

3. Page 9, Para.3.2.1 — Correction, the word ECONOMISER is missing from the sentence preceeding the table. The complete sentence to read 'All systems have enthalpy controlled ECONOMISER cycles and fan inlet guide vanes for pressure control'. i.e., systems make use of "free cooling".

4. Page 13, Para.3.3.3 — Clarification, This clause is intended to mean that the MECHANICAL COOLING EQUIPMENT is turned off at the end of September and turned on again at the beginning of April - during the other months 'free cooling' would be available.

   Similarly that the MECHANICAL COOLING EQUIPMENT is turned off in the scheduled off period as per item 3.3.1 - during this time, however, all the HVAC plant would be off.

   MECHANICAL COOLING EQUIPMENT is deemed to include chiller, condenser cooling and chilled water pumps, and cooling tower fan.

5. Page 6, Para.2.4.1 — Clarification, For explanation of the term "Flow Coefficient" see ASHRAE 1977 HANDBOOK OF FUNDAMENTALS, Chapter 21.

CORRECTION/CLARIFICATION SHEET #2 4 APRIL 1978

(1) Figure 1 Site Plan - CORRECTION - A corrected site plan is attached (original showed building facing due North). Clause 2.2.1 is correct, site plan now corresponds with this clause, i.e.,"North Facade faces 30° west of true North".

(2) Figure 1 & Clause 3.1.3 - CLARIFICATION - It can be assumed that the surrounding buildings cast no significant shadow on the office.

(3) Figure 5 & 6 - CLARIFICATION - The North and south elevations are similar, as are the east and west.

(4) Table 2-1 - CLARIFICATION - Appropriate resistances for the air spaces for the walls and roof should be selected by the consultant. It is not intended that these resistances are zero as might be construed from this Table.

(5) Clauses 3.2.3, 3.2.4 & Figure 7 - CLARIFICATION - It can be assumed that the static pressure controller, used to vary fan volume, is capable of maintaining constant static pressures in both the supply and return ductwork. In such an instance the outside air, at the minimum outside air damper setting, can be assumed not to vary with fan volume.

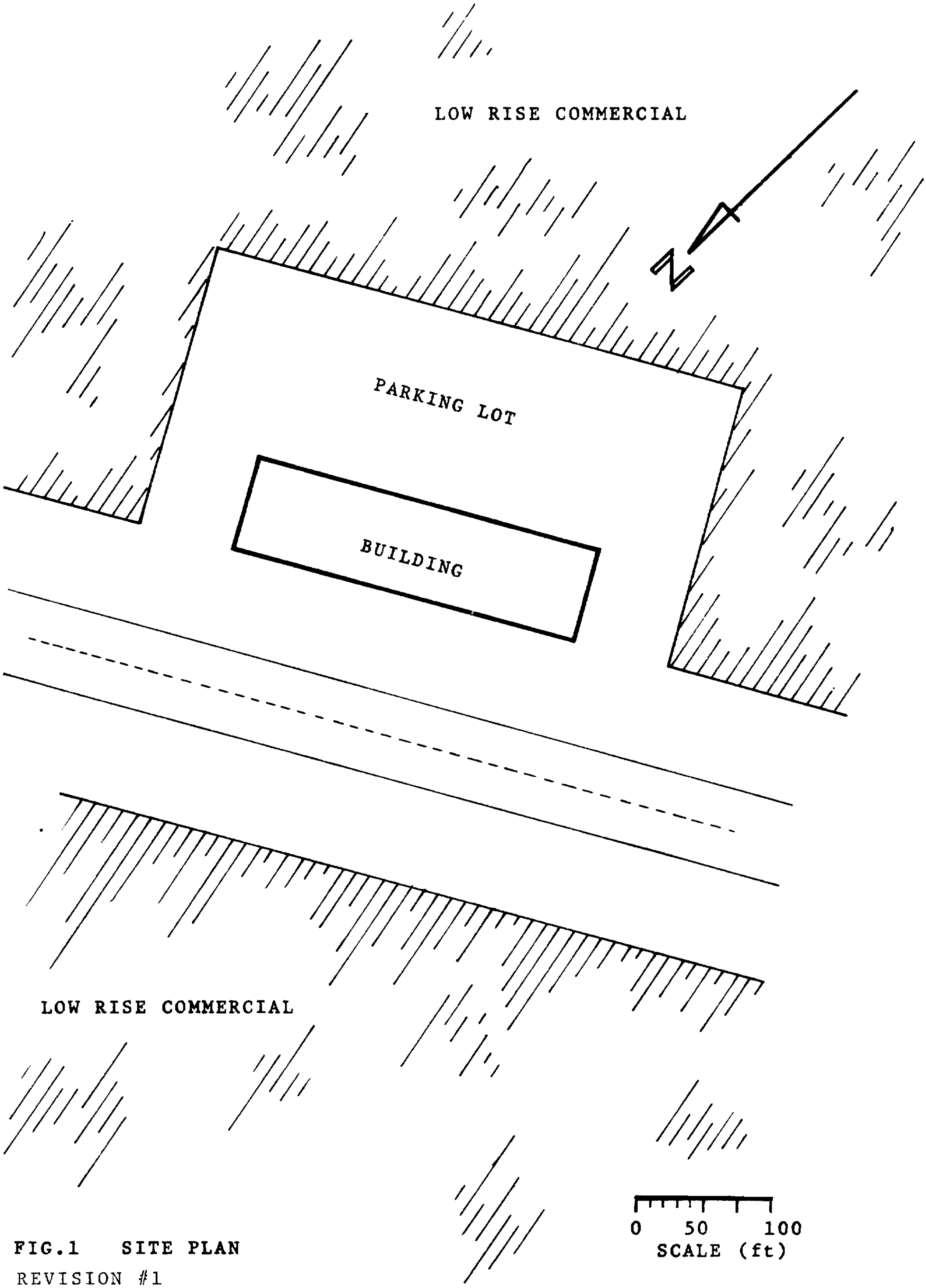


FIG.1 SITE PLAN

REVISION #1
DATE: 3 APRIL '78

CORRECTION/CLARIFICATION SHEET #3 20 April 1978.

The following is a list of corrections and clarifications as per our telephone conversation earlier this week.

CORRECTION/CLARIFICATION

1. CLARIFICATION It is intended that there be no mechanical environmental control of the equipment penthouse.

2. Appendix B Summary of Work — CLARIFICATION This form does not preclude the use of the SL2 program. For those consultants who intend to use SL2 it would be useful to add to the summary form the time spent on same.

3. CLARIFICATION All areas as defined in the specification should be conditioned by VAV systems with terminal re-heat where necessary (e.g., perimeter zones, lobby). Do not consider "supplementary heating" systems.

4. Clause 3.2.8 — CORRECTION Reduce "ambient wet-bulb temperatures" in table for cooling tower performance by 10^{o}F, i.e.,

Ambient Wet Bulb Temperature (°F)	% Capacity of Tower	
	Fan Operating	Fan Off
62°F	151	23
65°F	127	19
68°F	100	15
70°F	81	12

5. Clause 3.1.2 — CLARIFICATION The RY for Vancouver is 1959, January 1st is thus a Thursday

6. Figs. 2, 3 & 4 — CAUTION DO NOT SCALE FROM THESE DRAWINGS AS THEY ARE NOT TO SCALE. All dimensions are given in the specification. It should not be necessary to scale anything from the drawings. USE ONLY GIVEN DIMENSIONS.

7. Clause 3.2.1 — CLARIFICATION The intent of the last paragraph is that the total air supplied to all the spaces is equal to the total air extracted from them.

   The bracketed statement (see item 4.2.2) has no meaning and it should be deleted.

8. Clause 3.2.2 — CLARIFICATION It is intended that the toilet exhaust fan operates as per the schedule in 3.3.1, i.e., on 5 days per week from 7:00 a.m. to 5:00 p.m.

9. Clause 3.3.1 — CLARIFICATION There are no holidays throughout the year.

10. Clause 3.2.5 — CLARIFICATION It is intended that the chillers share the load equally after the first machine has reached its rated capacity.

11. Table 2.1 — CLARIFICATION Note thermal conductivity values are expressed in Btu/hr.ft/^{o}F and not in terms of per inch thickness as is commonly used.

12. Table 2.2 — CORRECTION Note the absorptance and transmittance values are under the incorrect column.

    For absorptance read transmittance and for transmittance read absorptance

    The values are

TRANSMITTANCE	ABSORPTANCE
- 0.047467403	0.1548285
1.547883000	1.75132940
- 1.270666100	-2.18134880
- 1.030198100	-1.42009740
2.292256400	4.19509120
- 1.002260200	-2.04779150

13. Clause 2.2.14

CLARIFICATION Assume that the "Adjustment Factor" (as per ASHRAE definition) for window sashes is 1.0, i.e., U value for the window (glass and frame) is equal to the U values as calculated for the glass alone.

14. Input Data Check Sheet

CORRECTION For "Occupancy Peak Sensible Load" read Occupancy Peak Load (i.e., Sensible + Latent).

15. Clause 3.6

CLARIFICATION It is the intent of this clause that the hot and cold water pumps operate on the schedule of 3.3.1 (7:00 a.m. to 5:00 p.m. 5 days/week).

CORRECTION/CLARIFICATION SHEET #4 25 APRIL 1978

1. item 5 correction/clarification sheet #1

CORRECTION For clarification of the term "Flow Coefficient" we referenced ASHRAE 1977 Handbook of Fundamentals, Chapter 21. There is a printing error in this chapter, namely Eq. (6) page 21.5 should read as follows:

$$Q = CS \left[0.52 \gamma P \frac{(T_i - T_o)}{T_i T_o} \right]^n \frac{(BH)^{n+1}}{n+1}$$

The square brackets were omitted in the text.

2. Section 5 "Input Data Check Sheet"

CLARIFICATION We require that this sheet contain the information for the whole building, i.e., one sheet and not individual sheets for each thermal block.

3.

CLARIFICATION Air supply rates should be determined from design day cooling load calculations for the individual thermal blocks. The design day values for Vancouver can be assumed to be 78°F dry bulb, 66°F wet bulb.

4.

CORRECTION Because there is some dispute over the suitability of certain "fan operating keys" we require that you use the following input:

card 5A col 40 key 3
card 5A col 73 key 3