COMPARISON OF COMPUTER-AIDED DESIGN HEATING CAPACITY AND INSTALLED EQUIPMENT HEATING CAPACITY FOR A DINING HALL FACILITY

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by

Courtney Craig Kleven

A thesis submitted in partial fulfillment
of the requirements for the degree of

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CHAPTER I

INTRODUCTION

The uncertainty of the future supply of usable energy has created an increasing awareness of the need for its more efficient use. In the United States, approximately 25% of the total energy consumption is used in residential and commercial buildings (1). The major portion of that energy consumption is environmental control for human comfort.

It has been projected that through increased emphasis on energy conservation in the design of new buildings, and through proper retrofit of existing buildings, a 25% energy savings in the residential and commercial building sector could be accomplished over the next 8 years. The net reduction could result in an equivalent savings of 3 million barrels of oil per day (2).

The opportunity to realize part of that savings exists with each Heating, Ventilating and Air Conditioning (HVAC) system under design and review. It therefore becomes an obligation of each system designer to employ the most up-to-date methods available to fully analyze the requirements of the proposed system and design for efficiency and optimum performance.

This analysis of the requirements for heating and ventilating a building stems from a basic interest in HVAC systems, access to new design standards, professional guidance, and the availability of computer programs. The Dining Hall under study has been built and is in operation. The choice of this building for study was a combination of recent design, accessibility of plans and design information, and the high level of internal heat gains associated with heavy occupancy and food services.

The purpose of this study is to compare the installed heating system capacity with the computer-predicted thermal requirements of the building. Certain design criteria, primarily ventilation quantities and sources, have been changed in an effort to decrease the required heating load of the building. With the revised criteria and the much more detailed heat transfer calculations readily available by means of the computer programs, a more economic and efficient selection of the heating and ventilating system equipment should be possible.

CHAPTER II

UWENCON/NBSLD PROGRAM

The computer program utilized for the study of the heating and ventilating requirements of the Dining Hall is on file at the University of Washington Academic Computer Center under the program name UWENCON. It was placed on file by Dr. C. J. Kippenhan of the Mechanical Engineering Department and Prof. D. L. Bonsteel of the Department of Architecture. It is based primarily on the program NBSLD developed by Dr. T. Kusuda at the National Bureau of Standards, U. S. Department of Commerce, Washington, D.C. (3).

The program calculates the net heat exchange of a building, or a space within a building, due to solar and sky radiation incidence upon exterior surfaces, heat conduction through exterior walls, roofs, and floors, heat convection due to outside air admitted to the space through the ventilation system and infiltration, and the internal heat generation of occupants, lighting, and equipment within the space. Loads are calculated as both sensible and latent heat requirements, including the required addition or extraction of moisture as required for maintaining a specified relative humidity.

Input to the program consists of data in three general categories: Operating Schedule Data, Weather Data, and Building Data. A simplified logic diagram for the UWENCON program is shown in Figure 1.

Operating Schedule Data is specified as hourly fractions of maximum values for the number of occupants, lighting level in watts, and equipment heat generation in watts. The occupancy level is used to calculate sensible and latent heat gains internal to the space. The lighting and equipment values are also used for internal heat gains, and include an input to modify the fraction of heat generation absorbed by radiation into the wall, roof/ceiling and floor surfaces.

Weather Data is submitted to the program in the form of Dry Bulb temperature, Wet Bulb temperature, Dew Point temperature, Barometric Pressue, Wind Speed, Cloud Cover and Type, each given as hourly readings on tape produced from U.S. Weather Bureau magnetic tape recordings for the dates desired for calculations.

Building Data is submitted for location, building orientation, interior/exterior surface and glass areas, "sandwich" wall layer properties, design air circulation rates, supply air temperature desired, and "fresh" air change rates. This data can be changed to evaluate the heating or cooling requirements as a function of various construction details, insulation values, building orientations, and air flow rates.

Subroutines of the UWENCON/NBSLD program utilize the input data to calculate the various parameters required for solving

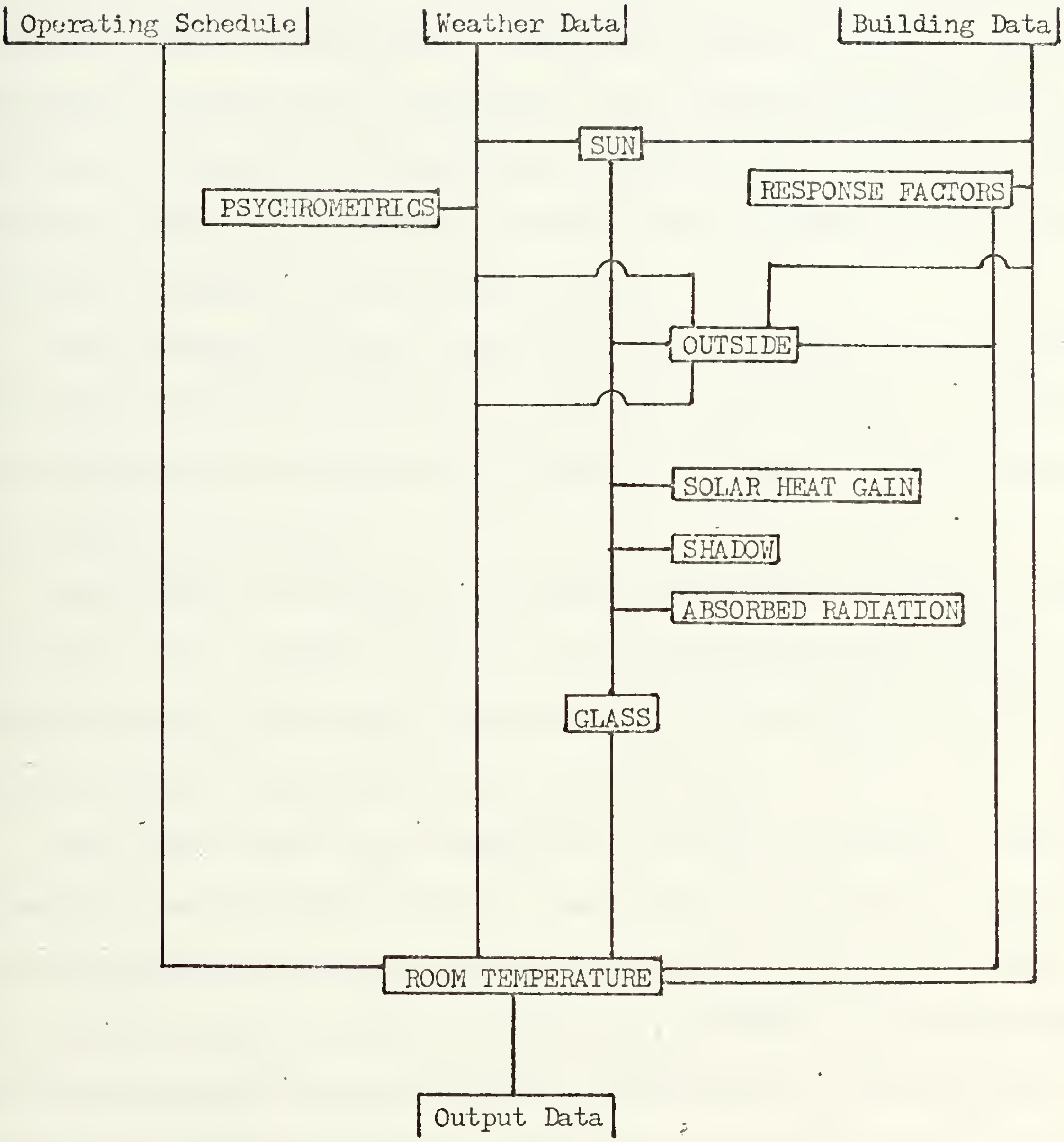

Figure 1. UWENCON/NBSLD Program Logic

the heat transfer relations necessary to obtain the desired heating and cooling load results. The subroutine SUN calculates net incident solar radiation for the orientation, location, date, cloud cover, time, and exterior surface data specified in the input statements. The PSYCHROMETRICS subroutines utilize the temperature, humidity and barometric pressure input data from the weather tape to calculate the outside air enthalpy and humidity ratio.

The RESPONSE FACTORS subroutine utilizes the wall construction details layer-by-layer to evaluate the thermal lag, damping, and heat storage capacities of the slab bounded by the exterior and interior surfaces.

The OUTSIDE subroutine utilizes the solar incidence, radiation from the building surface, convective heat loss, and transient heat conduction relationships to determine the exterior surface temperatures of the building.

The SOLAR HEAT GAIN, ABSORBED RADIATION and GLASS subroutines utilize the SUN output to calculate the amount of heat gain transmitted through the glass surfaces of the building for a basic double strength single pane window. Modifications are accomplished through shading coefficients. The orientation of the window surfaces, including attached shading fins and overhangs, are taken into account in subroutine SHADOW to accurately predict the total solar heat gain through the glass.

The ROOM TEMPERATURE subroutine takes the input from all other subroutines and performs the heat balance for the space.

Internal heat gains from the Operating Schedule data are used for internal heat gains and the Weather Data and PSYCHROMETRICS data are used for the energy requirements to condition the air from the ambient conditions to the supply conditions. Solar heat gains through the glass surfaces, RESPONSE FACTORS data, and Building Data of wall surface areas and configurations are used to compute the interchange of heat by conduction, radiation and convection of the interior surfaces. Shape factors are used for the radiant interchange of the interior surfaces as given by the surface areas and configurations.

The Output Data of the program is dependent upon the method of calculations desired. There are two basic methods available for calculation; the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) steady-state Design Day method, whereby the design outdoor temperature is specified and used for single temperature calculations, and the dynamic procedure utilizing actual weather data for calculations on an hourly basis.

Two modes of calculation are available in the UWENCON program for the dynamic calculation procedures. A constant interior temperature mode may be specified, with the heating or cooling loads calculated to maintain the specified room temperature. The other mode of calculation available is the "floating" temperature mode. For these calculations the heating and cooling capacity of the HVAC system is set equal to zero, equivalent to only supply and exhaust air flow equipment.

The resulting room temperature and relative humidity are then calculated.

Actual tabulation of the output data from UWENCON includes the following quantities of design and evaluation interest:

- Response Factors for each Construction
- Thermal Conductance for each Construction
- Solar Energy Absorbed by Opaque Surfaces
- Glass Solar Transmission plus Convection
- Date of Weather Data Utilized
- Hourly Values For:
    - Outside Dry Bulb Temperature
    - Outside Web Bulb Temperature
    - Inside Dry Bulb Temperature
    - Sensible Heat Load
    - Latent Heat Load
    - Supply Air Sensible Heat Capacity
    - Supply Air Latent Heat Capacity
    - Supply Air Humidity Ratio
    - Moisture Addition by Occupants
    - Infiltration Air Flow Rate

The original program, NBSLD, has two additional calculation modes not presently operable in UWENCON. These are both "Dead Band" modes, with upper and lower limits specified for room temperatures. In one mode the heating and/or cooling load is calculated to keep the interior conditions within the "Dead Band." The other mode calculates the same loads up to a specified capacity for the heating and cooling equipment. Any loads in excess of the specified system capacity cause the temperature to drift outside the "Dead Band." Room temperatures and relative humidity values resulting from the system overload are then calculated as output.

The programs, with their various modes of calculation and output can be utilized for heating or cooling applications, or applications requiring both capabilities. Application of the

programs for pre-design analysis can be utilized to determine system capacity and energy consumption impacts of various design alternatives.

The dynamic method for constant interior temperature mode was utilized for this study, as the required heating system capacity was the quantity desired.

CHAPTER III

APPLICATION

The dining hall selected for this study was built in 1976 and is presently in operation, as part of the Trident submarine facility at the Naval Submarine Base, Bangor, Washington. The floor plan of the building is as shown in Figure 2.

The building does not warrant air conditioning under present Department of Defense criteria, so the study was generally based upon the heating and ventilating requirements for the building in the winter season. The ASHRAE 97 1/2% winter design conditions for the Bangor area are listed as 26°F ambient temperature and a 15°F temperature range (4). The 26°F ambient temperature was used by the designer for static heat loss and ventilation heat gain requirements. The weather tape utilized for the computer predictions included a day (18 December, 1964) with an average daily temperature of 26°F. Room temperature specified was 68°F for a constant thermostat setting.

The building design configuration was altered slightly by modeling for the computer. For computer calculations of radiant exchange, the area under consideration must be a rectangular parallelepiped. The areas for study were modeled as

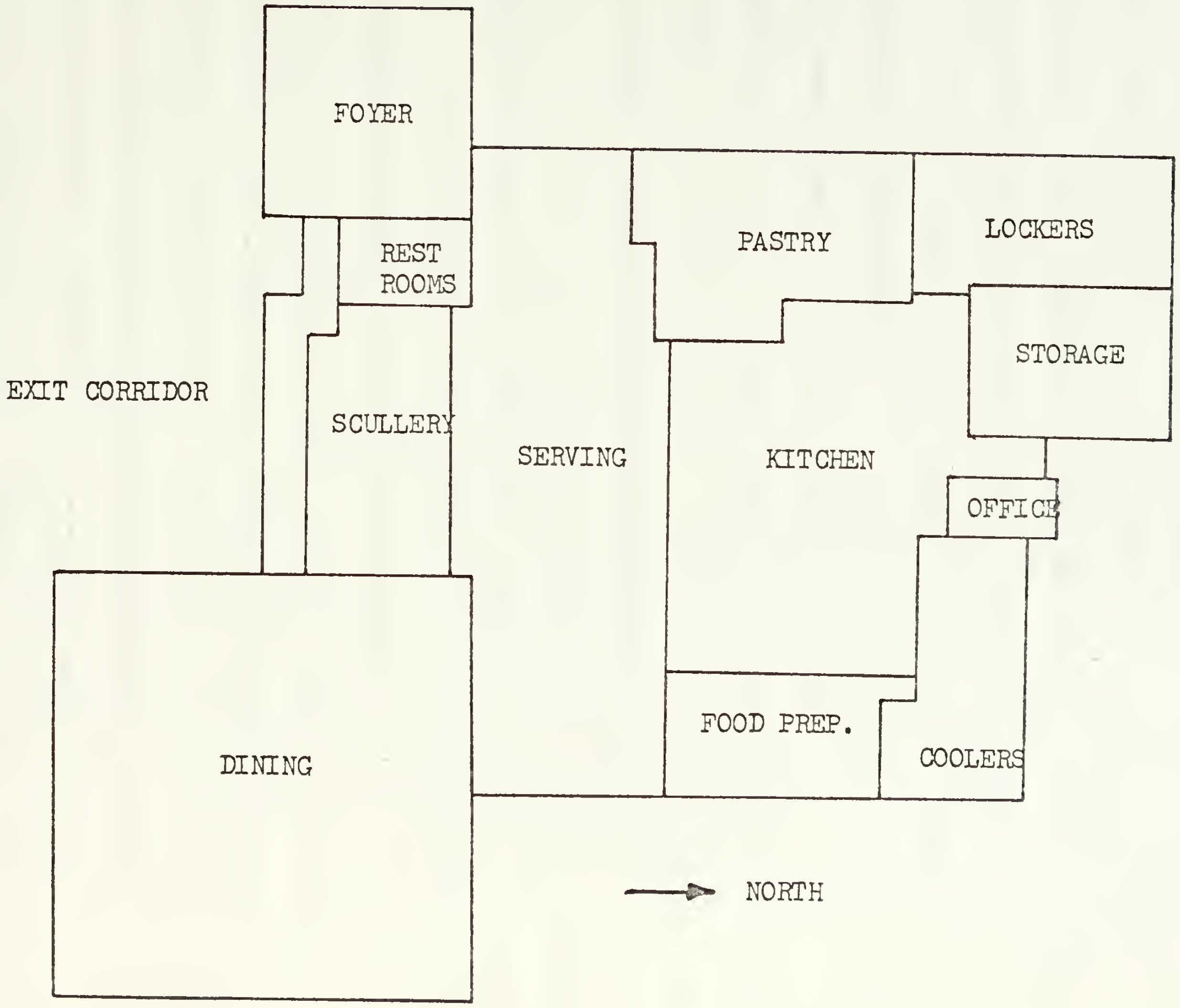

Figure 2. Floor Plan

rectangular parallelepipeds, with the net floor, roof, and exterior wall surface areas maintained as they exist, as they are the heat loss surfaces in each area. A floor plan showing the areas as modeled is shown in Figure 3.

The installed ventilation system for the building was then analyzed. Air supply and exhaust registers within each space were identified and the actual air flow rates were reviewed. The air change periods specified in the original design required approximately 30,000 cfm of outside air for the building (see Appendix for air change periods).

Revision of the air flow rates and sources was undertaken as an energy conservation measure. The Kitchen, Serving, and Scullery Areas require ventilation primarily to exhaust the moisture, heat, and odors caused by their food service functions. The Dining Area required ventilation for heating and the removal of odors. It was decided that outside air quantities could be significantly reduced by retaining the supply ducts in the Dining Area and providing for air transfer into the Kitchen, Serving and Scullery Areas where exhaust ducts are located. The outside air introduced into the Dining Area thus served both purposes, and the outside air could be greatly reduced into the food service areas. Similar air transfers were included in other areas, resulting in a net reduction of the outside air requirement from the approximately 30,000 cfm of the original design to approximately 13,000 cfm for the computer model calculations.

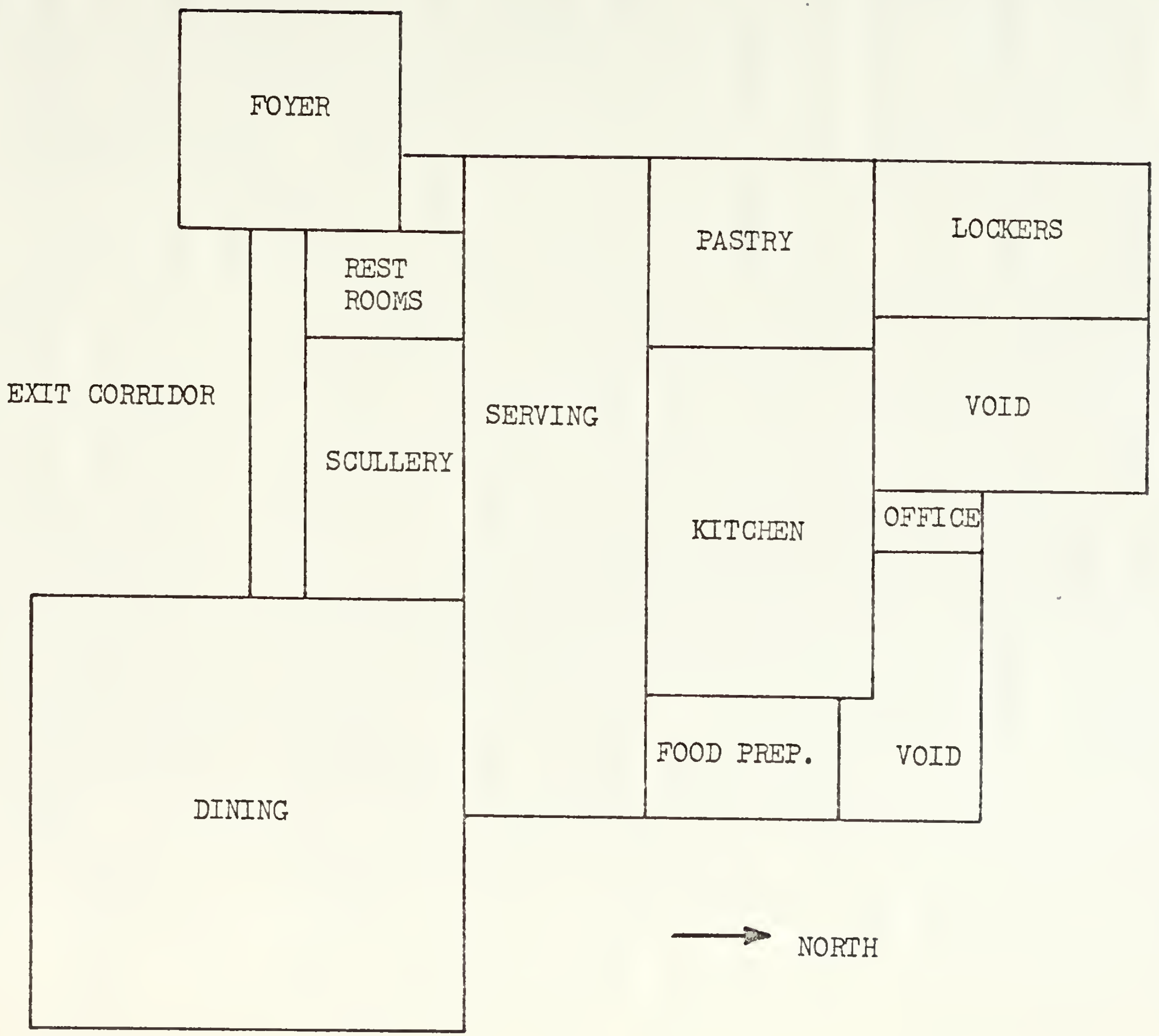

Figure 3. Floor Plan - Model

The outside air requirements were checked against the recommendations of ASHRAE Standard 90-75, "Energy Conservation in New Building Design," and ASHRAE Standard 62-73, "Standards for Natural and Mechanical Ventilation." Comparisons on both an occupant standard (cfm per person), and an area basis (cfm per square foot of floor) revealed that minimum standards were met and generally exceeded by the revision.

Each of the building areas was then modeled for the computer calculations. Roof, wall, and floor materials data, were given to the computer in layer-by-layer format to calculate thermal response factors, heat storage capacity, and thermal conductance of each type of surface. For those areas with drop accoustical ceilings, a thermal conductance value was specified for heat transfer calculations in the air space above similar to an attic. Building exterior walls were identified as heat loss surfaces, while interior walls were identified for radiant heat exchange and heat storage capacity as internal mass. Window areas, orientations, conductances and shading were specified.

Construction details were determined from the design drawings for roof, wall, and floor constructions. Generally, the construction of exterior surfaces was as follows:

Roof:	4-ply Built-up Roofing w/slag coat 2" Rigid Polyurethane Insulation 1/2" Plywood 2" Wood Tongue and Groove Decking

Exterior Walls: 8" Architectural Poured-in-Place Concrete
1 1/2" Semi-Rigid Polyurethane Insulation
1/2" Gypsum Board

Interior Walls: 5/8" Gypsum Board
3" Insulation (Accoustical) or Void
5/8" Gypsum Board

Windows: Double-Pane, Heat Absorbing
Precast Sunshades

Ceiling: 5/8" Gypsum Board on Steel Framing
3/4" Accoustical Tile

Floor: 1.5" Quarry Tile in Mortar Bed
4.5" Concrete (Concrete Joist Construction)
2" Spray Insulation
Cold Storage Area Below (Unheated)
or
1.5" Quarry Tile in Mortar Bed
4" Concrete slab
1.5" Semi-Rigid Polyurethane Insulation on Grade

Internal heat gains were generated by three sources; lights, occupants, and equipment. The lighting gains were modeled by adding the total of the fixtures' wattage and converting to a watts per square foot value based on the floor area. Occupancy level was estimated based upon function of the room and equipment (cooks present) and an estimate of dining occupants likely to be moving through or seated at a maximum period. Equipment levels were estimated by utilizing the equipment and electrical schedules, steam condensate values, and motor horsepower. Conversion factors were used to convert to an equivalent heat generation value in watts per square foot.

Hourly schedules for lights, occupancy, and equipment were then estimated based upon cooks starting at 0500, 1000,

and 1600, with meals being served from 0600-0800, 1100-1300 and 1700-1900. After 2000 most activity and heat gains were assumed minimized until 0500 the following morning.

Pertinent details on modeling for each area are given in the following section.

CHAPTER IV

ROOM/AREA MODELS

The building was modeled as 11 independent areas as was shown in Figure 3. Details on the modeling of each area are as follows:

Foyer:

Dimensions: 30' x 30' x 14'

Exterior Surfaces: Roof, South Wall, West Wall, North Wall (partial), East Wall (partial), Floor

Floor: Concrete Joist Construction, Crawl Space

Glass: South Wall, West Wall, U = .8, Shading

Lights: 4500 Watts Incandescent, 5 Watts/sf

Occupancy: 8 (maximum)

Equipment: None

Ventilation: 300 cfm, Outside Air

Restrooms:

Dimensions: 21' x 21' x 8'

Exterior Surfaces: Roof, Floor

Floor: Concrete Slab on Grade

Lights: 620 Watts Fluorescent, 1.5 Watts/sf

Occupancy: 4 (maximum)

Equipment: None

Ventilation: 300 cfm from Corridor

Serving Area:

Dimensions: 91' x 24' x 8'

Exterior Surfaces: Roof, West Wall, East Wall, Floor

Floor: Concrete Slab on Grade

Lights: 24,320 Watts Incandescent, 11. Watts/sf

Occupancy: 20 (maximum)

Equipment 380 KW, 63 KW Maximum Usage, 29 Watts/sf

Ventilation: 1000 cfm Outside Air, 6100 cfm Exhaust

Dining Area:

Dimensions: 60' x 60' x 14'

Exterior Surfaces: Roof, South Wall, West Wall (Partial), North Wall (partial), East Wall, Floor

Floor: Concrete Joist Construction, Crawl Space

Glass: South Wall, East Wall, U = .8, Shading

Lights: 7500 Watts Incandescent, 2.1 Watts/sf

Occupancy: 200 (maximum)

Equipment: 14,500 Watts (maximum), 4 Watts/sf

Ventilation: 6600 cfm, Outside Air

Exit Corridor:

Dimensions: 58' x 8' x 8'

Exterior Surfaces: Roof, South Wall, Floor

Floor: Concrete Slab on Grade

Glass: South Wall, U = .8, Shading

Lights: 3000 Watts Fluorescent, 6.5 Watts/sf

Equipment: None

Ventilation 200 cfm Outside Air

Pastry and Utensil Wash Area:

Dimensions: 27' x 32' x 8'

Exterior Surfaces: Roof, West Wall, Floor

Floor: Concrete Slab on Grade

Glass: None

Lights: 1120 Watts Fluorescent, 1.3 Watts/sf

Occupancy: 2 (maximum)

Equipment: 76 KW, 45 KW Maximum Usage, 52 Watts/sf

Ventilation: 1200 cfm Outside Air

Locker Rooms:

Dimensions: 30' x 22' x 8'

Exterior Surfaces: Roof, West Wall, North Wall, Floor

Floor: Concrete Slab on Grade

Glass: 3' x 9' Window, U = .9

Lights: 1480 Watts Fluorescent, 2.3 Watts/sf

Occupancy: 6 (maximum)

Equipment: None

Ventilation: 100 cfm Outside Air, 300 cfm Exhaust

Kitchen:

Dimensions: 51' x 28' x 8'

Exterior Surfaces: Roof, Floor

Floor: Concrete Joist Construction, Crawl Space

Glass: None

Lights: 2560 Watts Fluorescent, 1.8 Watts/sf

Occupancy: 6 (maximum continuous)

Equipment: 270KW, 101 KW Maximum Usage, 70 Watts/sf

Ventilation: 3000 cfm Outside Air, 2000 cfm from Dining Area, Exhaust

Scullery:

Dimensions: 33' x 20' x 8'

Exterior Surfaces: Roof, Floor

Floor: Concrete Joist Construction, Crawl Space

Glass: None

Lights: 1920 Watts Fluorescent, 2.9 Watts/sf

Equipment: 21 KW, 32 Watts/sf

Ventilation: 1500 cfm From Dining Area, Exhaust, 1500 cfm Auxiliary Exhaust Fan

Office:

Dimensions: 12' x 16' x 8'

Exterior Surfaces: Roof, North Wall, Floor

Floor: Concrete Joist Construction, Crawl Space

Glass: None

Lights: 1000 Watts Fluorescent, 5.2 Watts/sf

Occupancy: 1

Ventilation: 45 cfm Outside Air

Food Preparation:

Dimensions: 24' x 25' x 8'

Exterior Surfaces: Roof, East Wall, Floor

Floor: Concrete Joist Construction, Crawl Space

Glass: None

Lights: 1600 Watts Fluorescent, 2.7 Watts/sf

Occupancy: 2 (maximum)

Equipment: 4700 Watts, 7.8 Watts/sf

Ventilation: 500 cfm Outside Air

The two areas labeled VOID on Figure 3 account for the Walk-in-Cooler Areas and the Dry Storage Room. The Coolers are Pre-Fabricated Units with the mechanical equipment located on the roof, and the Dry Storage Area is constructed of concrete and insulated. They are not considered as heat transfer areas for this model of the building.

CHAPTER V

COMPUTER RESULTS

The results of the computer calculations for each area included hourly values for the sensible and latent heat requirements, humidity ratio, occupants moisture addition, room temperature and outdoor ambient temperature. This study is directed at the requirements for the heating and ventilating system for winter operation, therefore, the sensible heat requirements are of primary interest.

Sensible heat requirements for the areas generally fall into two classifications; Continuous heating requirements and Intermittent heating requirements. Continuous heating was required for the Foyer, Dining, Corridor, Locker, Office, and Food Preparation Areas. This is an expected result, as equipment heat generation in these areas would not offset the heat losses of ventilation air and exterior surface areas.

A plot of sensible heat requirements for the Exit Corridor as a function of time is shown in Figure 4.

The plot shows the peak sensible heat requirement of 14,000 BTU/HR occurring at approximately 0200. The time period 0500 to 2100 illustrates the greatly decreased heat requirements during the occupied periods as a result of internal heat generation (lights and occupants) and net solar heat gain through the roof and glass areas of the south wall.

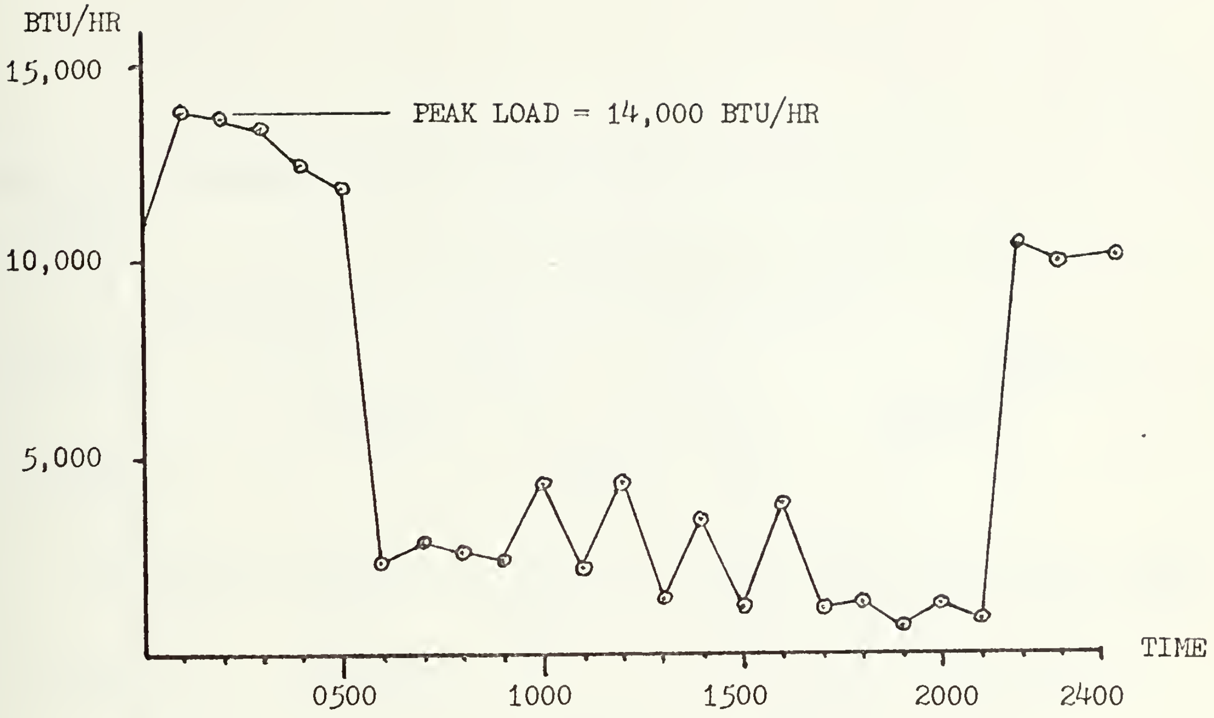

Figure 4. Corridor Sensible Heat Load
vs.
Time

Intermittent heating loads were predicted by the computer calculations for the Rest Rooms, Serving, Pastry, and Kitchen Areas. A plot of sensible heat requirements for the Kitchen Area as a function of time is shown in Figure 5.

The plot points out the major impact of internal heat generation for the occupied and food preparation periods. The effects of equipment usage for meal preparation is evident for the breakfast, lunch and dinner periods. For the dinner period (1600-1800) internal heat generation exceeded the heat loss due to ventilation and exterior surfaces. During this period of time, the excess heat would cause the room temperature to rise

above the specified 68° F thermostat setting.

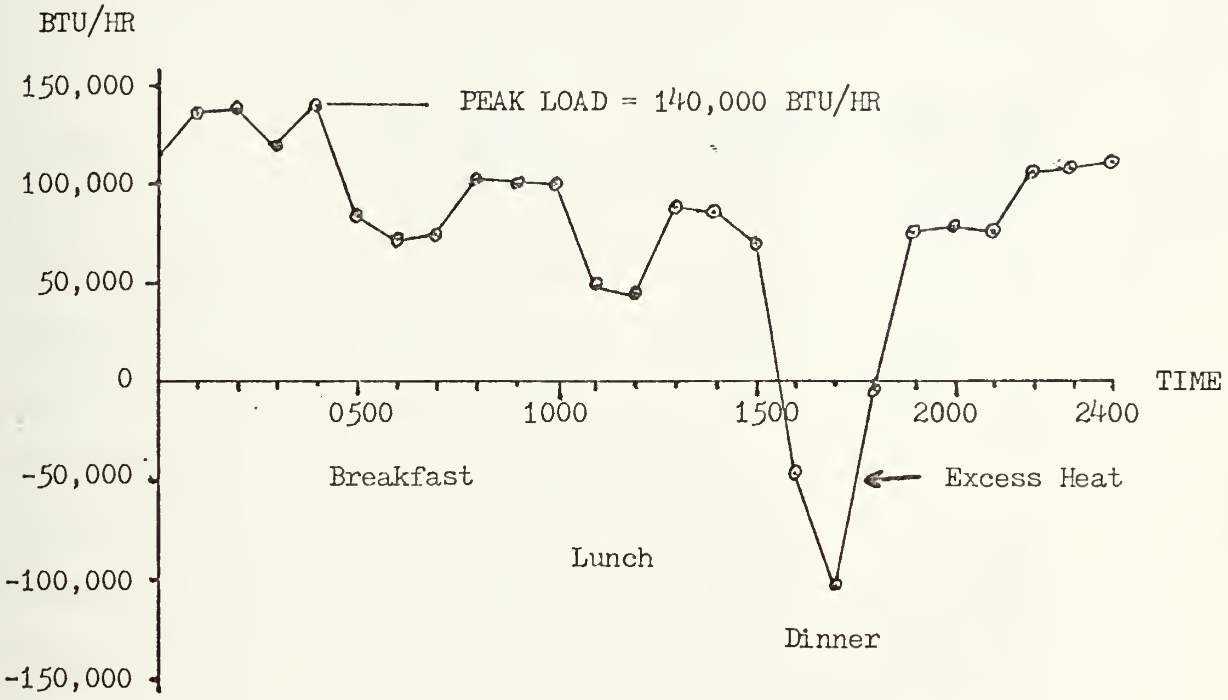

Figure 5. Kitchen Sensible Heat Load vs. Time

The maximum sensible heat requirements for each area (peak load) were obtained from the computer calculations. Table 1 illustrates the period of time heat was required (or Continuous), the hour of maximum heat load, and the peak sensible heat load for that hour.

The results shown in Table 1 indicate that the building heating system capacity should be designed to supply a total of 655,300 BTU/HR for the air flow rate specified in the author's revised design, (13,000 cfm outside air), and that the peak load would occur at approximately 0400.

TABLE 1: AREA PEAK SENSIBLE HEATING REQUIREMENTS

Area	Time Heat Required	Peak Load Time	Peak Load BTU/HR
Foyer	Continuous	0400	20,000
Rest Rooms	2400 - 0600	0400	800
Serving	2100 - 0500	0200	60,000
Dining	Continuous	0300	320,000
Corridor	Continuous	0200	14,000
Pastry	0800 - 0500	0400	58,000
Lockers	Continuous	0400	8,000
Kitchen	1800 - 1500	0400	140,000
Scullery	None	--	--
Office	Continuous	0400	4,500
Food Preparation	Continuous	0300	30,000
TOTAL		0400	655,300

CHAPTER VI

APPLICATION OF RESULTS

The peak heat loads shown for each area in Table 1 are the total sensible heat requirements to maintain the area at the specified 68° F temperature. The building was built with a recuperative heat recovery system, consisting of a recovery coil located in the exhaust air plenum, a preheat coil in the air intake plenum, and interconnecting piping and pumps for liquid flow through the system. The specifications for the system require delivery of 70% of the available exhaust air energy to the supply air stream. This system reduces the required heat addition to the building by the amount of energy it recovers from the exhaust air and delivers to the supply air.

The energy recovery from the exhaust air stream can be calculated as follows:

Exhaust Air Temperature (Te) = 68° F (Room Temperature)

Intake Air Temperature (Ti) = 20° F (Outside Temperature at Peak Load)

Air Flow Rate = 13,000 cfm (Revised Design)

Total Energy Available = (Mass Flow x Specific Heat) x (Temperature Differential)

$$= (1.08 \ \frac{\text{Btu}}{\text{hr}} - \text{cfm} - {}^{\circ}\text{F}) \times (\text{Volume Flow Rate, cfm}) \times (\text{Te}-\text{Ti})$$

$$= 673{,}900 \ \text{Btu/hr}$$

$$\text{Recovered Energy} = .70 \ (673{,}900 \ \frac{\text{Btu}}{\text{hr}}) = 471{,}730 \ \text{Btu/hr}$$

The actual required steam coil heat addition for the building is therefore:

Actual coil total = (Building Total) - (Heat Recovery)

= 655,300 - 471,730

= 183,570 Btu/hr

The ratio of actual required heating coil capacity to total required heat addition is therefore:

$$\frac{\text{Coil Capacity}}{\text{Total Heat Addition}} = \frac{183{,}570 \text{ Btu/hr}}{655{,}300 \text{ Btu/hr}} = .28$$

Actual required heating coil capacity for each area can then be calculated by the relationship:

Coil Capacity = (.28) x (Peak Load Requirement)

The peak load requirements from Table 1 are then used to determine the required coil capacities, as are shown in Table 2.

TABLE 2: COMPUTER DESIGN COIL CAPACITY

Area	Peak Load BTU/HR	Required Coil Capacity BTU/HR
Foyer	20,000	5,600
Rest Rooms	800	300
Serving	60,000	17,000
Dining	320,000	90,000
Corridor	14,000	4,000
Pastry	58,000	16,300
Lockers	8,000	2,300
Kitchen	140,000	40,000
Scullery	0	0
Office	4,500	1,300
Food Preparation	30,000	8,500
TOTAL	655,300 BTU/HR	185,300 BTU/HR

CHAPTER VII

DESIGN COMPARISONS

The original design for the building was performed by the ASHRAE steady-state Design Day method. Details of the calculations are included in the Appendix.

The design method of this study included dynamic calculations by means of the computer programs. This procedure accounts for internal heat generations as actually scheduled, for solar heat gain as directly computed and for thermal storage effects of the building mass. This procedure was thus expected to reveal lower energy requirements for the building. The potential for additional energy conservation without adverse affect on the thermal comfort and function of the building was recognized by the author. The outside air reduction and multiple use of the ventilation air within the building were utilized to realize these energy savings for the Computer Design. Comparisons of the design air flow and coil capacities for each Area and the Building Total are shown in Table 3.

The vast difference in total coil capacities for the building (1,125,600 BTU/HR by Original Design and 185,000 BTU/HR by Computer Design) requires further explanation. The outside air flow has a significant impact upon the results. The energy required to heat the outside air to room temperature for the Original Design can be approximated by:

TABLE 3: AIR FLOW AND COIL CAPACITY COMPARISON

AREA	ORIGINAL DESIGN Total Ventilation cfm	 Outside Air cfm	 Air Changes per Hour	 Coil Capacity BTU/HR	COMPUTER DESIGN Total Ventilation cfm	 Outside Air cfm	 Air Changes per Hour	 Coil Capacity BTU/HR
Foyer	900	900	6	63,000	300	300	1.5	5,600
Rest Rooms	600	0	6	23,000	300	0	5	300
Serving	5,080	5,080	15	190,000	6,100	1,000	20	17,000
Dining	6,600	6,600	18	283,000	6,600	6,600	8	90,000
Corridor	600	600	12	25,300	200	200	3	4,000
Pastry	4,000	4,000	15	112,000	1,200	1,200	5.8	16,300
Locker	910	910	15	24,500	300	100	3.5	2,300
Kitchen	11,250	11,250	30	376,000	5,000	3,000	26	40,000
Scullery	2,700	0	30	0	1,500	0	15	1.0
Office	160	160	6	2,800	45	45	2	1,300
Food Prep.	620	460	6	26,000	500	500	6	8,500
Total		29,960 cfm		1,125,600 BTU/HR		12,945 cfm		185,300 BTU/HR

Total Energy = (1.08) x (Volume Flow Rate) x (Temperature Rise)

= (1.08) x 29,960) x (68° - 20°)

= 1,533,126 BTU/HR

Assuming that the Heat Recovery Systems would recycle 70% of this energy, the actual coil capacity dedicated to heating the outside air to room temperature would be:

Capacity = .30 (1,153,126)

= 345,938 BTU/HR

The energy required to heat the outside air to room temperature for the Computer Design can be approximated similarly:

Total Energy = (1.08) x (Volume Flow Rate) x (Temperature Rise)

= (1.08) x (12,945) x (68-20)

= 671,069 BTU/HR

Assuming the same 70% Heat Recovery System performance, the actual coil capacity dedicated to heating the outside air to room temperature would be:

Capacity = .30 (671,069)

= 201,320 BTU/HR

The difference in coil capacities required for heating the outside air to room temperature would then be:

Coil Capacity Reduction = (345,938 - 201,320)

= 144,618 BTU/HR

This reduction in required capacity of 144,618 BTU/HR is the direct result of revised outside air flow requirements and constitutes a direct energy savings at the peak design load for the building. The impact of this reduced outside air flow upon

thermal comfort and functional use of the areas should also be examined, as the primary aim of energy conservation is to reduce energy consumption without adverse affects. Inadequate ventilation in this building would be considered an adverse effect, and the Computer Design ventilation figures in Table 3 warrant a close review.

The Serving and Kitchen Areas have the largest revisions from the Original Design ventilation. As was mentioned earlier, the transfer of air from the Dining Room into the Serving Area was revised for energy conservation. The primary purpose for ventilating the Serving Area is to carry away the excess heat and odors produced by cooking and serving food. The ventilation air through the Serving Area was actually increased from 5080 cfm in the Original Design to 6100 in the revised Computer Design. The outside air quantity was reduced from 5080 cfm to 1000 cfm. The 6100 cfm of ventilation air for that area in the Computer Design study was thus only 1000 cfm outside air, and the 5100 cfm would be air transferred into the Serving Area from the Dining Area.

The Kitchen Area Original Design had 11,250 cfm of outside air being admitted and exhausted. The air quantity was based upon all major heat sources (ovens and steam kettles) being in full operation simultaneously. This exhaust air requirement was used as the continuous ventilation flow rate. For the revised Computer Design it was assumed that the ovens and steam kettles would not all be placed in full operation simultaneously, but that the maximum ventilation should be sized for a more

reasonable expectation of 50% total capacity operation. This resulted in an exhaust requirement of 5000 cfm. It was felt that 3000 cfm of outside air would provide sufficient odor control, and the additional 2000 cfm for exhaust air would be transferred from the Dining and Serving Areas. The Air Changes figures listed in Table 3 are based upon the Total Ventilation quantities, and meet or exceed the ASHRAE recommendations for ensuring adequate ventilation. Other Ventilation rates were revised based upon similar reasoning and checked against ASHRAE standards. The net reduction of energy consumption by air flow is therefore a result of elimination of excess ventilation rather than a decrease in the thermal comfort or habitability of the building.

The difference in design heating capacity remaining after the outside air flow reduction has been considered is approximately 795,700 BTU/HR. This figure constitutes the difference in design capacity resulting from dynamic heat transfer calculations by the computer including the effects of variable outside temperatures, internal heat generation, thermal energy storage of internal mass, and the energy balance calculations performed for the Heat Recovery System. This 70% reduction in system capacity represents the potential savings in installed capacity had this building been designed by dynamic heat transfer calculations available in computer programs instead of by the Design Day method.

CHAPTER VIII

CONCLUSIONS

The heating capacity of the installed equipment is greater than the required heating capacity predicted by this study by a factor of approximately 3.4, based on maintaining the ventilation quantities as originally designed. Reduction of the outside air requirements as proposed in this study would indicate an installed capacity greater than required by a factor of 6. System design capacity cut by that large a factor may raise doubts concerning the validity of the computer program utilized.

The original program NBSLD was tested for validity by the National Bureau of Standards prior to its circulation. In 1974 a four bedroom townhouse was constructed inside a large environmental test chamber to accurately measure required heating and ventilating system performance in response to controlled dynamic external environments. It was found that the computer program NBSLD accurately predicted the systems and building performance; in most instances experimental results were predicted within 5% by the computer calculations.(5) Based on this documentation it is felt the computer predictions for the peak heating requirements of the Dining Hall under study are valid and correct within an acceptable degree of accuracy.

The results indicate there are great benefits of applying dynamic calculation procedures to building heat load estimating.

The extra investment in effort and money involved in the initial implementation of the computer programs will be quickly repaid in subsequent design efforts. Greater benefits are realized by the eventual owners of the facility in reduced first costs and decreased operation and maintenance costs for systems operating closer to optimum efficiency.

The computer programs enable the systems designer to evaluate the impact of design parameters on first cost and energy consumption. With that information readily available, design work can be tailored to minimizing over-all costs of building ownership, as opposed to the minimum first cost often evaluated.

Dynamic methods for accurately predicting thermal requirements for buildings are available and should be utilized. Design procedures can be utilized to optimize system performance and minimize energy consumption for environmental comfort. Through proper application of the available technology, the projected 25% savings in energy consumption is attainable within the next decade.

CHAPTER IX

DISCUSSION

The results of this study indicate that many of the food service areas generate heat at far greater rates than the building heat loss. For the occupied and service periods of the day, the excess heat generation could be utilized via the recovery system to supply heat to adjacent buildings. No actual calculations or cost estimates have been made, but an economic energy conservation possibility does exist.

The importance of energy conservation becomes greater each year. In each building design, the owner and his design agent should review the life-cycle costing of the building as a design function, as HVAC system sizes and equipment can have a significant impact on the annual operating costs of a building. By optimum equipment selection and decreasing the outside air requirements savings are possible which far exceed the additional design expense.

Dynamic HVAC load estimating procedures are available and should be required for all major new building designs. Through these procedures the actual dynamic requirements of a building can be accurately predicted during the initial design phases. The effects of ventilation air flow, insulation, and internal heat generation can be analyzed to select equipment and materials for more efficient energy consumption.

Every designer of new mechanical equipment installations should be aware of the alternatives related to energy consumption and analyze the design for operating costs and energy consumption. Designs based solely on first costs are not in the best interests of the client, nor are they the product of truly professional design efforts.

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APPENDIX

CONSULTANT'S DESIGN CALCULATIONS

Mechanical design calculations were included in the architectural firm's early submissions under the design contract for the building. The sizing of the heating system components was performed by steady-state heat loss calculations for the construction details specified and a design temperature recommended by ASHRAE in the 1972 edition of FUNDAMENTALS for that location. The building was treated as a shell, with heat loss calculations made for the various areas or zones based upon the exterior surface areas included within each zone. Internal heat gains from lights, occupants and equipment were not included in the capacity determinations, and solar heat gain and radiant exchange were accounted for only in the selection of the exterior surface/air interface resistance used to compute a representative "U" factor for the surface under consideration.

Calculations by the designer were as follows:

Design condition: 26°F ambient temperature
70°F interior temperature
Temperature differential = (70°-26°)
= 44°

Roof Loss:

Surface	Resistance
Outside surface	0.17
Built-up roofing	0.21
Insulation (approx. 4")	14.22
1/2 plywood	0.62
2 x 6 T & G decking	1.89
1/2 Gyp. DW	.32
3/4 Acc. Tile	1.89
Inside surface	0.68
TOTAL	19.60

U = 1/R = 1/19.6 = .05 Btu/hr-ft^2-°F

Heat Loss/Area = .05(44) = 2.2

Use 2.0 Btu/hr-ft^2 Roof Area

Glass Loss:

U = 1.13

Heat Loss/Area = 1.13(44) = 49.7

Use 50 Btu/hr-ft^2 Glass Area

Skylight/Clarestory Windows - use 50 Btu/hr-ft^2 as above

Exterior Wall Loss:

Surface	Resistance
Outside surface	0.17
Concrete - 6"	0.66
Insulation - 1"	4.34
1/2 Gyp. DW	0.45
Inside surface	0.68
TOTAL	6.30

U = 1/R = 1/6.30 = 0.151

Heat Loss/Area = 0.15(44) = 6.6

Use 7.0 Btu/hr-ft^2 Wall Area

Floor Loss:

Slab-on-grade over insulation:

Use U = 90 Btu/hr-lineal foot edge loss

Slab-exposed below

Surface	Resistance
Top surface (still air)	0.61
Tile	.05
Concrete - 6" Lt. Wt.	5.40
Insulation - 1"	2.78
Outside surface	0.17
TOTAL	9.01

U = 1/R = 1/9.01 = 1.11

Heat Loss/Area = 1.11(44) = 4.8

Use 5.0 Btu/hr-ft^2 Floor Area

From these representative "U" values for Heat Loss per Unit Area, the expected heat loss for each room was estimated. The amount of exterior surface area of each type was multiplied by its "U" value, and the total heat loss for all exterior surfaces in the room was estimated.

Calculations for the surface heat loss for each room are represented as follows:

Room	Surface	Area	U	Heat Loss
FOYER	Walls	880		
	Glass	290	50	14,500
	Wall-Glass	590	7	4,130
	Roof	770	2	1,540
	Skylight	130	50	6,506
	Edge loss	88/lf	90/lf	7,920
			Total =	34,590 Btu/hr

Room	Surface	Area	U	Heat Loss
SERVING LINE	Walls	280		
	Glass	55	50	2,750
	Wall-Glass	225	7	1,575
	Roof	1500	2	3,000
	Edge loss	22/lf	90/lf	1,990
	Floor	480	5	2,200
				Total = 12,515 Btu/hr
CONDIMENT	Walls	280		
	Glass	75	50	3,750
	Wall-Glass	205	7	1,435
	Roof	960	2	1,920
	Edge	22	90	1,980
	Floor	960	5	4,800
				Total = 13,885 Btu/hr
DINING	Walls	1580		
	Glass	420	50	2,100
	Wall-Glass	1160	7	8,120
	Roof	3600	2	7,200
	Edge	160/lf	90/lf	10,400
	Floor	3200	5	16,000
				Total = 62,720
CORRIDOR	Walls	580		
	Glass	145	50	7,250
	Wall-Glass	435	7	3,045
	Roof	350	2	700
	Edge	65	90	5,350
	Floor	350	5	1,750
				Total = 18,595
SCULLERY	Roof	685	2	1,370
	Floor	685	5	3,425
				Total = 4,795
PASTRY	Walls	135	7	945
	Roof	380	2	760
	Edge	17	90	1,530
				Total = 3,235
UTENSIL	Walls	104	7	728
	Roof	275	2	550
	Edge	13	90	1,170
				Total = 2,448

Room	Surface	Area	U	Heat Loss
WOMEN	Walls	96		
	Glass	18	50	900
	Wall-Glass	78	2	546
	Roof	200	7	400
	Edge	12	90	1,080
				Total = 2,926 Btu/hr
MEN	Walls	72		
	Glass	18	50	900
	Wall-Glass	54	2	378
	Roof	205	7	410
	Edge	9	90	810
				Total = 2,498 Btu/hr
DRY STORAGE	Walls	135	7	945
	Roof	460	2	920
	Edge	17	90	1,530
				Total = 3,395 Btu/hr
OFFICE	Walls	120		
	Glass	20	50	1,000
	Wall-Glass	100	2	200
	Roof	145	7	290
	Edge	18	90	1,720
	Floor	145	5	725
				Total = 4,435 Btu/hr
MEAT PREPARATION	Roof	200	2	400
	Floor	200	5	1,000
				Total = 1,400 Btu/hr
VEGETABLE PREPARATION	Walls	160	7	1,120
	Roof	375	2	750
	Floor	375	5	2,175
	Edge	20/lf	90/lf	1,800
				Total = 5,845 Btu/hr
KITCHEN	Walls	51		
	Glass	21	50	1,050
	Wall-Glass	30	7	210
	Roof	1400	2	2,800
	Edge	8	90	720
	Floor	1400	5	7,000
				Total = 11,780 Btu/hr

Room	Surface	Area	U	Heat Loss
LOCKER	Walls	216		
	Glass	18	50	900
	Wall-Glass	198	7	1,386
	Roof	145	2	290
	Edge	27	90	2,430
			Total =	5,006

Total heat loss through surfaces = 190,068 Btu/hr

Design ventilation quantities were then completed for each room based upon the desired design air change rate. Ventilation calculations are listed as follows:

Room	Volume, ft^3	Air Change Period	CFM Required
Foyer	9,000	6 minutes	900
Hall	720	6 minutes	75
Vestibule	128	2 CFM/ft^2	35
Women	880	2 CFM/ft^2	220
Vestibule	128	2 CFM/ft^2	35
Men	880	2 CFM/ft^2	220
Hall	600	5 minutes	120
Corridor	1,760	5 minutes	350
Scullery	5,430	2 minutes	2,715
Dining	36,000	5.5 minutes	6,600
Office	680	10 minutes	70
Serving	12,280	4 minutes	3,070
Alcove	760	10 minutes	75
Hall	680	10 minutes	70
Janitor	360	2 CFM/ft^2	90
Condiments	7,680	4 minutes	1,920
Pastry	3,400	4 minutes	850
Utensil	2,200	4 minutes	550
Janitor	280	2 CFM/ft^2	70
Kitchen	12,755	2 minutes	6,375
Meat Prep.	1,600	10 minutes	160
Veg. Prep.	3,000	10 minutes	300
Women	1,600	2 CFM/ft^2	400
Men	1,640	2 CFM/ft^2	410
Locker	1,160	2 CFM/ft^2	290
Hall	760	10 minutes	75
Toilet	240	2 CFM/ft^2	60
Office	1,200	10 minutes	120

The building was then separated into zones for air supply duct and heating coil sizing. Upon zone determination, the required heat addition to offset losses through the building and bring the outside air to the supply temperature dictated the steam flow required by the coil.

It should be noted at this point that an assumption was made for calculations. The assumption that the heat recovery system would add recycle sufficient heat to increase the outside air temperature from the 26°F ambient to an inlet condition at the steam coil of 45°F. The steam coil would then be sized to raise the air temperature to the required supply temperature.

Zone selection, air flow rates, supply air and steam heat addition calculations were as follows:

Steam Coil	Zone	CFM	Sensible Heat
SC-1	Serving & Condiments	5000	26,400

Supply - Room Temp. = 26,400/(1.08)(5000) = 5°F

Supply Temperature = 75° + 5° = 80°F

Coil Heat Addition = (80-45)(1.08)(5000) = 190,000 Btu/hr

Steam Condensate = 190,000/1,000 = 190 lb/hr

Similar calculations were made for the other zones. Listed below are the results of those calculations:

Coil	Zone	CFM	Building Heat Loss	Total Heat Addition
SC-1	Serving & Condiments	5,000	26,400	190,000
SC-2	Dining	6,600	62,720	283,040
SC-3	Foyer	900	34,000	63,000
SC-4	Exit Area	600	18,595	25,300
SC-5	Kitchen	11,250	11,780	376,000
SC-6	Preparation & Office	620	6,245	28,800
SC-7	Lockers & Toilets	1,100	10,430	47,500
SC-8	Pastry	3,500	8,163	112,000

System Total Design Capacity = 1,125,640 Btu/hr

UWENCON

The program UWENCON is utilized for air conditioning student projects in ME 425, "Air Conditioning," as taught by Dr. Kippenham of the M. E. Department at the University of Washington.

Pertinent details on the format for data input could be obtained from him. Control cards required to utilize the program are as follows:

```
Job Card
Account Card
ATTACH (TAPE 7, WEATHER, ID = SEGOATA)
ATTACH (UWENLIB, ID = SEGLIB)
RFL.
LOSET (LIB = UWENLIB)
SEG LOAD
UWENCON
7/8/9
Segload Deck
7/8/9
Data Deck
6/7/8/9
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Thesis
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Comparison of
computer-aided design
heating capacity and
installed equipment
heating capacity for a
dining hall facility.