CANADA'S GREEN PLAN
LE PLAN VERT DU CANADA

PERSONAL CONTROL AND 100% OUTSIDE-AIR VENTILATION FOR OFFICE BUILDING

PREPARED FOR:

Energy Efficiency Division
Energy Technology Branch/CANMET
Department of Natural Resources Canada
Ottawa, Ontario
DSS Contract No. 23440-92-9434/01-SQ
March 31, 1993

PREPARED BY:

Engineering Interface Limited.
Suite 200 -2 Sheppard Avenue East
North York, Ontario, M2N 5Y7

SCIENTIFIC AUTHORITY:

Ian Morrison, P. Eng.
Energy Efficiency Division
Energy Technology Branch/CANMET
Department of Natural Resources Canada
580 Booth Street
Ottawa, Ontario,
K1A 0E4

March 23, 1995

CITATION

Engineering Interface Limited. *Personal Control and 100% Outside-Air Ventilation for Office Buildings.* DSS Contract No. 23440-92-9434/01-SQ. Efficiency and Alternative Energy Technology Branch, CANMET, Energy, Mines and Resources Canada, Ottawa, Ontario, 1991 (83 pp.)

Copies of this report may be obtained through the following:

Efficiency and Alternative Energy Technology Branch
CANMET
Energy, Mines and Resources Canada
580 Booth Street, 9th Floor
Ottawa, Ont.
K1A 0E4

or

Document Delivery Service
Library and Documentation Services Division
CANMET
Energy, Mines and Resources Canada
562 Booth Street
Ottawa, Ontario
K1A 0G1

DISCLAIMER

NOTE

Funding for this project was provided by the Government of Canada under the Green Plan.

Catalogue No. M91/7/233-1993E
ISBN. 0-662-20667-3

PREFACE

This work was performed for CANMET's Buildings Group as part of its commercial-buildings research activities. These activities are distinct from but complementary to the Buildings Group's Advanced Commercial Buildings Program (C-2000).

C-2000 is a small-scale pilot program to demonstrate that commercial buildings can be more energy efficient, have better indoor environments, and have fewer adverse effects on the environment. It is also a vehicle to field test and accelerate the adoption of emerging technologies. C-2000 will result in the construction of a small number of high-performance buildings; the buildings will be monitored and the results will be transferred to industry.

The goal of the study reported here was to determine the energy and cost implications of ventilating office buildings exclusively with fresh air -- no air recirculation -- and of providng occupants with task ventilation to allow them individual control over the delivery and temperature of their ventilation air. These measures may improve indoor-air quality and thermal comfort -- both goals of the C-2000 program.

For more information on this project, contact CANMET's Ian Morrison, P. Eng., the project manager, at (613) 943-2262. For further information about C-2000 or the Buildings Group's other commercial-building research activities, contact Nils Larsson, MRAIC, the C-2000 Program Manager, at (613) 943-2263.

Introduction

Ces travaux ont été réalisés pour le compte du Groupe du bâtiment de CANMET, dans le cadre de ses activités de recherche concernant les bâtiments commerciaux. Bien qu'elles soient distinctes, ces activités viennent compléter le Programme des bâtiments commerciaux performants (C-2000) du Groupe.

Le Programme C-2000 est un programme pilote à petite échelle dont l'objectif est de prouver que les édifices commerciaux peuvent offrir un rendement énergétique accru et un meilleur environnement intérieur, tout en ayant moins d'effets néfastes sur l'environnement. Il permet également de faire l'essai de nouvelles technologies et de hâter leur application. Dans le cadre du Programme C-2000, on construira un petit nombre d'édifices à haut rendement; ceux-ci seront évalués, puis les résultats obtenus seront transférés à l'industrie.

L'objectif de la présente étude était de déterminer la quantité d'énergie et les investissements nécessaires pour ventiler des édifices commerciaux uniquement avec de l'air frais - aucune recirculation d'air - et pour permettre aux occupants de contrôler la distribution et la température de l'air de ventilation. Ces travaux pourraient entraîner une amélioration de la qualité de l'air intérieur et du confort thermique, deux objectifs du Programme C-2000.

Pour obtenir des précisions sur le projet, téléphonez à Ian Morrison, ing. et gestionnaires de projet à CANMET, au (613) 943-2262. Si vous désirez plus de renseignements au sujet du Programme C-2000 ou d'autres activités de recherche du Groupe du bâtiment relatives aux édifices commerciaux, communiquez avec Nils Larsson, MIRAC et gestionnaire du Programme C-2000, au (613) 943-2263.

ACKNOWLEDGEMENT

Engineering Interface Limited would like to express appreciation for the assistance in preparing this document to

Ian D. Morrison, P.Eng. CANMET

Nils Larsson, O.A.A., M.R.A.I.C., CANMET

Mark Riley, CANMET

TABLE OF CONTENTS

ILLUSTRATIONS

APPENDICES

1.0 EXECUTIVE SUMMARY

CANMET is seeking ways to improve the indoor environment while saving energy in buildings. Eliminating air recirculation, by ventilating office buildings with 100% outside air, may improve indoor-air quality. Giving each occupant control over the delivery pattern and temperature of ventilation air may enhance their thermal comfort and productivity; a novel air-delivery system, called the McGill Jet, has been developed for this purpose. Both these measures can potentially improve the indoor environment; however, their energy and cost consequences are unknown.

There were two purposes for this study. The first was to determine the energy and cost impact of using 100% outside air to ventilate office buildings; the second was to determine the energy and cost impact of providing occupants with McGill Jets to allow them to control their ventilation air.

It was not known whether the economics of a 100% outdoor-air system would depend upon a special envelope with energy conservation enhancements. Therefore, analyses were conducted to determine whether envelope improvements were required to make 100% outdoor-air ventilation feasible.

Analyses were also conducted to determine whether there would be an initial cost or energy penalty for lowering the HVAC supply-air temperature from the conventional 55F (12.5°C) to 45F (7°C); this change could improve comfort by lowering summer humidity levels and is complimentary to 100% outdoor-air ventilation because it reduces the volume of air required for cooling.

These objectives were met by analyzing a hypothetical 300,000 ft^2 (27,907 m^2) office building in Toronto, Edmonton, and Vancouver. Energy use and cost was simulated with a computer by Ross F. Meriwether, Consultant; the building's initial costs were estimated by a team of Toronto architects and contractors.

The following conclusions were drawn:

- Office buildings can be ventilated with 100% outdoor air without increasing energy costs and with only a small and acceptable increase in the building's initial cost by using HVAC systems with desiccant-coated rotary heat exchangers.
- McGill Jets can be provided to every occupant without increasing the building's first cost and without increasing energy costs.

- Increasing the building envelope's thermal resistance is not necessary for 100% outdoor-air ventilation. Increasing wall and glazing thermal resistance does reduce energy use but is not cost effective. Glazings that admit less solar energy reduce the building's initial cost and energy costs but are not necessary for 100% outdoor-air ventilation.

- Reducing the HVAC's supply-air temperature from 55F (12.5°C) to 45F (7°C) reduces the building's initial cost but does not affect energy cost.

1.0 SOMMAIRE

CANMET favorise la recherche de moyens qui permettraient l'amélioration de l'environnement intérieur des bâtiments commerciaux et, du fait même, la réalisation d'économies d'énergie. L'élimination de la ventilation de retour, en utilisant entièrement l'air extérieur pour la ventilation d'alimentation, peut améliorer la qualité de l'air intérieur du bâtiment. Un système de ventilation qui permet aux occupants de régler eux-mêmes la température, le débit et la direction de l'air de ventilation peut augmenter le bien-être thermique et la productivité des occupants. Le "McGill Jet", un nouveau système de ventilation d'alimentation, a été développé dans ce but. Ces deux méthodes peuvent améliorer l'environnement intérieur, mais les coûts d'investissement et de fonctionnement ne sont pas bien connus.

Les objectifs de l'étude sont nommés ci-dessous.

- Déterminer le coût d'un système de ventilation d'alimentation d'air extérieur (100 %) pour bâtiments commerciaux.
- Déterminer le coût d'un système de ventilation d'alimentation qui munit chaque occupant d'un "McGill Jet".

Il était également important de déterminer si l'amélioration de l'enveloppe thermique aura un effet notable sur le coût de base et sur les économies d'énergie d'un système de ventilation qui utilise l'air extérieur.

En dernier lieu, l'analyse a été fait pour déterminer le coût de base et les économies d'énergie d'un système de ventilation qui règle la température de l'air à 7°C (45 °F) au lieu de 12,5°C (55°F).

Pour atteindre les objectifs désignés, un bâtiment commercial type de 27 907m^2 (300 000 pi.c.) a été analysé dans les trois villes canadiennes de Toronto, Edmonton et Vancouver. Les frais d'énergie ont été simulés par Ross Meriwether, conseiller en énergie, et les coûts de base des systèmes ont été estimés par une équipe d'architectes et d'entrepreneurs de Toronto.

L'étude a déterminé que :

- les systèmes qui utilisent les échangeurs de chaleur de type rotatif peuvent être installés pour fournir de l'air extérieur à 100 %, sans augmentation de frais d'énergie et avec peu d'augmentation de coûts de base;

- chaque occupant peut disposer d'un "McGill Jet" sans augmentation de coût de base, avec des frais d'énergie comparables aux systèmes classiques;

- l'amélioration de l'enveloppe thermique n'est pas nécessaire pour le système de ventilation à l'air extérieur (100 %). L'amélioration des coefficients thermiques de vitrage et de mur diminuent les frais d'énergie, mais ces mesures s'avèrent trop dispendieuses. L'utilisation de vitrage qui réduit le transfert d'énergie solaire baisse le coût de base et les frais d'énergie, sans être nécessaire pour le système de ventilation à 100 % d'air extérieur;

- l'approvisionnement de l'air à 7°C au lieu de 12,5°C baisse le coût de base. Les frais d'énergie avec ce système sont comparables à ceux d'un système classique.

2.0 REASONS FOR STUDY

In the last 20 years the occupants of office buildings have become more concerned with indoor-air quality (IAQ). Some buildings have become so controversial in terms of IAQ that they have suffered the label of "sick building syndrome (SBS)." One California legal firm (1) claims over 100 cases of litigation. Studies done by a McGill University Air Quality Team (2) have found that some 50% of office occupants find reason to criticize the IAQ in their buildings. At one time this criticism was directed at the poor controllability of the air conditioning system. Today, criticism occurs even when the HVAC systems are maintained within ideal boundaries of temperature, relative humidity, noise and draft.

Some feel the problems have arisen through the introduction of building fabrics which outgas contaminants, through carpets which breed micro organisms in wet spots, through wood furnishings which contain formaldehyde and through office equipment which releases an assortment of volatile organic compounds.

Others claim that the introduction of variable air volume as a means of temperature control has caused SBS by reducing air motion to the extent that occupants feel they are in "dead air" with all of the supply air short circuiting from supply to return air diffusers overhead.

Some, who note that many studies fail to isolate any pollutants above threshold limits, think the problem is psychosomatic and would be corrected if individuals had more independent control of temperature and air motion.

All feel that increasing the outdoor air supply will dilute contaminants and improve conditions. The American Heating, Air Conditioning and Refrigeration Society has raised its minimum office ventilation quota from 10 cfm (5 l/s)/person to 20 cfm(10 l/s)/person in Standard 62-89. At the same time, ASHRAE has dropped the limit for carbon dioxide content in offices from 2500 ppm to 1000 ppm.

Owners have, on their own, decided that ventilation is so important that they will exceed the ASHRAE guidelines. Ontario Hydro plans a minimum of 28 cfm (13 l/s)/person in its new North York headquarters building. The Shipp Corporation adopted a ventilation ratio of 36 cfm (17 l/s)/person for its latest Toronto office. The Ontario Department of Labour claims, in the course of responding to 2,500 complaints, that reducing the CO_2 content to 600 ppm improves results. This corresponds to 50 cfm (24 l/s)/person of outdoor air.

It is clear the current trend in thinking perceives that more ventilation corresponds to less office pollution and fewer occupant complaints. The major factor preventing this is the initial and operating cost of heating and cooling equipment to support premium ventilation.

Heat exchangers, which draw upon exhaust air to heat incoming air, can help in the pursuit of greater ventilation. However, they need a temperature difference to accomplish heat exchange. This is available and quite effective for winter ventilation but less effective in summer when there is less temperature differential. For cooling, the maximum temperature difference between inside and outside air is 15F (8°C). Unfortunately, the significant cooling requirement for ventilation air in summer is latent. Until recently, heat exchangers of all types have been unable to exchange latent heat. However, the introduction of the "enthalpy wheel," a rotary heat exchanger with a desiccant media coating has overcome the barrier. The desiccant coating serves to subtract moisture from incoming ventilation air in summer and transfer it to the exhaust air stream. In fact, the efficiency of such equipment is claimed to be 80% for both sensible and latent heat.(3)

The significance of this development for commercial real estate has thus far been overlooked. Somehow, designers have remained unaware that 80% overall heat exchange means that the 20 cfm/person ventilation quota can now be raised to 100 cfm(47 l/s)/person without increasing the size of chillers, pumps and piping. A parallel conclusion is that 100 cfm(47 l/s)/person is enough to air condition typical office space. So, why shouldn't systems use 100% outside air if the enthalpy wheel can be worked into the initial cost equation? See Figure 1 for an energy comparison between 100% outside air and minimum outside air at maximum design.

This study has been carried out to test the impact of 100% outside air systems on energy and the building's initial cost.

A secondary purpose of this study is to determine whether envelope improvements are required to reduce the volume of ventilation air needed to heat and cool perimeter zones to make the 100% outdoor-air system feasible.

The other main purpose of this study is to examine the initial and energy cost of providing every building occupant with a personal supply of air which can be regulated as to volume and direction.

The personal control in this case is the McGill jet, an air outlet designed in consortium with McGill University in a Canadian Centres of Excellence Program. The McGill jet is a vertical air discharge outlet with the capability of swivelling 22 1/2 degrees away from vertical in any direction. It is a 4 inch (100 mm) diameter moulded fiberglas unit capable of supplying up to 150 CFM (70 l/s). The McGill jet mounts in the plane of the false ceiling tile. It is connected to typical ring main type supply air ductwork with insulated metal flex hose. Each flex runout contains a damper controlled by a 4 volt DC motor. This, in turn, is controlled by a ceiling mounted thermostat regulated by a TV type remote controller. See Figure 2. One or more jets will be located adjacent to each occupant. Single air supplies will be adequate for interior zones while dual outlets may be required for perimeter occupants in order to provide the cooling to counteract solar heat gain.

This type of air distribution is thought to enhance a concept known as "displacement ventilation." The supply air jets blow down in 5% of the office area while the exhaust air then rises in a horizontal plane in the other 95%. The air is then drawn away at the ceiling. This form of air distribution ventilates the <u>whole</u> office space while gathering pollutants en route and sweeping them away in a single pass. Another aspect of displacement ventilation is that the upward moving exhaust air absorbs internal heat gain. Thus, the air may be 78F(25.5°C) at the ceiling while controlling the occupant plane at 75F(24°C). Such a rise in temperature increases the difference in temperature between supply and exhaust air and reduces the required air volume commensurately.

3.0 BUILDING MODELS

A hypothetical 20 storey office building of 300,000ft^2 (27,907m^2) was analyzed to determine the feasibility of:-

- 100% outdoor air ventilation
- the McGill jet personal control
- 45F (7°C) supply air temperature (known as low temperature air - (LTA)
- envelope upgrades.

Four distinct configurations were analyzed:-

- a base system with 55F (12 1/2°C) supply air
- an LTA system with 45F (7°C) supply air
- an LTA system with 100% outside air
- an LTA system with 100% outside air and McGill jets

The four HVAC systems and the analyses performed are described in this section.

3.1 The Building

The building is described in Figure 3. It is typical of those which have been built recently in Canadian urban areas. To meet current architectural styles it will have 50% window glass in the envelope. The glass will be "low E" type R-3 (RSI 0.53) while the walls will have an insulation value of R-10 (RSI 1.78).

The floor plan is shown in Figure 4. It is divided by an imaginary line, 12 1/2 ft. (3.8 m) in from the outside wall into perimeter and interior space.

Other design factors, assumptions and instructions for energy analysis are shown in Figure 5. The required sensitivity runs for three cities and other building factors are shown in Figure 6.

3.2 The Base Design

The base HVAC system for the study employs a variable air volume system with separate supply air zones for the interior and perimeter space. Earlier VAV designs used a single supply air temperature but suffered from the cost of the parasitic heat needed to elevate the low supply air temperature needed for the interior zone to that required for the perimeter zone during heating seasons. The two zone system suffers less from this problem and is therefore a better candidate to be compared with ones using 100% outside air.

The base system employs 24 fan driven air terminals on each floor. See Figure 7. This provides a separate temperature control every 25 ft. (7.6m) on average for the perimeter and every 1930ft^2 (180m^2) on average for the interior. This allows separate temperature control for every second person on average at the perimeter and every tenth person on average in the interior.

Air is supplied and returned through conventional light air diffusers in the ceiling. With this type of air distribution complaints have arisen when the change rate of total fresh air and return air is less than four an hour. For this reason fan driven air terminals are used to assure that minimum level of air change with either 45F (7°C) or 55F (12.5°C) air supply.

Heating for the base system is provided by heating coils in the air terminals. These are supplied with hot water from two gas-fired boilers. Two centrifugal chillers are used for chilled water generation. Separate air handling systems are used for supply to perimeter and interior zones. See Appendices B4 through B8 for piping arrangements.

The base system is arranged for a full airside economizer cycle. The air handling units, chillers, gas-fired boilers, water tower and pumps are located in the penthouse as shown in Figures 8 and 9.

The base system was analyzed for energy in Toronto, Edmonton and Vancouver. It was then rerun in Toronto with envelope upgrades as follows:-

- R-10 (RSI 1.78) wall to R-20 (RSI 3.6)
- R-3 (RSI 0.53) glass to R-8 (RSI 1.4)
- 0.33 glass shading coefficient to 0.16
- all of the above improvements.

The insulation values of wall and glass had no significant effect on the chiller and air handling systems but the lower glass shading coefficient reduced the chiller capacity by 20% and allowed the use of smaller supply ducts as shown in Figure 10.

3.3 The LTA Design

This resembles the base system. The supply air systems are smaller as shown in Figure 11 and the fans use less energy. The chiller uses more energy, however, in order to generate water cold enough to produce the 45F (7°C) supply air.

The LTA approach is gaining popularity among designers. This is not just because it saves space and reduces initial cost as will be shown later, but because it assures a more comfortable relative humidity on muggy days. On cloudy days with high dewpoint, the 55F (7°C) air supply systems must either add parasitic reheat energy or suffer a rising relative humidity, from 50% to 70%. LTA systems will also suffer a rise in RH but this will be from a base of 40% RH to a more acceptable 60% RH. In the long run LTA systems will be advocated more for enhanced comfort than the cost or space saving potential.

3.4 The LTA System with 100% Outside Air

This is similar to the LTA design except that rotary air heat exchangers have been added together with arrangements to supply only 100% outside air. The heat exchangers are equipped with a chemical additive on the media which provides 80% transfer of both sensible and latent heat between outside supply and building exhaust air. The rotary units are limited to 12 feet (3.7m) in diameter. For this reason four units are required to supply perimeter air and two units are required to supply interior air. The air handling equipment will be arranged in the penthouse as shown in Figures 12 and 13.

3.5 The LTA System with 100% Outside Air and McGill Jets

This system resembles LTA with 100% outside air but substitutes the McGill jet for the light air diffusers. The number of temperature controls is now increased from 480 to 1800. See Figure 14 for the duct layout.

Heating in the perimeter zone will involve a 250 Watt electric heating element in the runout to each jet. While this provides a personal temperature control for heating, the electric heater is responsible for only 25% of the heating required at maximum design. When all electric heaters are engaged on any one building exposure a central heating coil based on gas energy will elevate the supply air from 45F (7°C) to as high as 100F (37½°C). The electric heaters then add approximately 25F (14°C) to the final supply temperature. The majority of heating in this design is gas sourced.

In case some floors on the south side in winter are sunlit while others are in shade, an arrangement has been made to draw upon the 45F (7°C) supply air feeding the interior to supply the sunlit perimeter zones. The interior supply system is oversized for this purpose.

Two sub systems were studied. The first used the highly reflective window glass with reduced duct sizes as shown in Figure 15. The second used either wallfin or ceiling radiant panels for heating in place of the duct heaters and central heating coil. In this case the heating is controlled by exposure with water scheduled to heat the perimeter space to 78F (25½°C). Individual control is then obtained by using the 45F (7°C) perimeter supply air to "cool back" to the desired temperature. This variation was studied to avoid electric heating cost and the duct crossover between interior and perimeter supply air systems.

The systems with the McGill jet take advantage of the displacement ventilation principle wherein the temperature at the false ceiling is likely to be 3F (1.7°C) higher than the controlled temperature at the desk. This enables these systems to operate with about 10% less supply air. The total air supply can be as low as two air changes per hour versus the minimum of four air changes per hour available from the fan driven terminals in the conventional air distribution. Four air changes for total air circulation has been regarded as a minimum in the past since none of the conventional air supply is driven directly into the working zone. The McGill jet overcomes this and is expected to provide better results with displacement ventilation than four air changes will with conventional air distribution.

Air jets are not new in Canadian offices. One major office complex in Toronto has just completed a renovation from light air diffusers to vertical air jets. The jets in that complex do not have individual temperature control but they are given credit by occupants for superior air distribution.[4]

In all 100% outside air schemes the washroom fans have been deleted. Instead, some of the office exhaust air has been drawn through the washrooms to upgrade their air circulation from a four to a one minute air change. Washroom air is prevented from recirculating at the rotary heat exchanger by maintaining a superior pressure on the fresh air side of the wheel.

All schemes have dampered bypasses with the capability of 100% recirculation. This is used on the 100% outside air schemes only to maintain intermittent heat in the building during unoccupied periods.

Further details of design are included in Appendix B. This data includes CFM (l/s) allocation to systems, motor sizes, pump capacities, circuit diagrams for heating and cooling, temperature traverses for the systems operating during the summer peak, typical instructions to subcontract estimators, enclosure details for the base and well insulated scenarios and a confirmation of budget costing on the building enclosure from the general contractor.

3.6 The Potential for Cool Storage

Low temperature air at 45F (7°C) has been generated with 40F (4½°C) water with eight row cooling coils at 300 fpm (0.47 m/s) face velocity. LTA is often associated with cool storage using 39F (4°C) water from a chiller or ice bank. Previous studies with roof mounted storage for a building of this size, with Toronto electric rates, found simple paybacks of four years for water storage and seven years for ice storage.[5] Ice storage is not necessary to generate the low air temperatures required for LTA. In this study the cooling coils are sized to provide LTA with 40F (3½°C) water from conventional chillers.

4.0 CHARACTERISTICS OF THE McGILL JET

4.1 Objectives

1. Provide a personal microclimate within the confines of standard dwarf office partitions. This involves both temperature and air pattern control.

2. Provide improved air movement within the working zone to dilute and carry away contaminants generated by occupants, furnishings and equipment.

3. Provide a ventilation displacement system. This involves a steadily rising plane of air from the floor to the ceiling to absorb internal heat gain and carry away pollutants. The downward airflow of the jets involves some 5% of the floor space. This generates gradual upward airflow in the remaining 95%.

4.2 Components See Figure 16

1. The Take Off
   This consists of a duct fitting connecting to the main supply duct with a damper operated by a 4 volt direct current motor.

2. The Thermostatic Control Unit
   This incorporates a temperature sensor and thermostat together with a numeric display of temperature from 20°C to 25°C. Ordinarily, the figures reveal the thermostat setting but they can be used also to display the actual temperature. A series of LED dots reveal the extent of the damper opening.

3. The Remote
   This is a small hand held battery operated device which can be used to reset the thermostat or reveal the space temperature.

4. The Jet
   This is an air outlet located in the plane of the false ceiling. The jet is housed in a frame which attaches to the false ceiling structures and allows the jet to swivel in any direction up to 22½ degrees from vertical.

4.3 Operating Criteria

1. Degree of Temperature Control
   A master thermostat should be used to control the average air temperature on each office floor at 23°C. This is a temperature preferred by most occupants. This control will be effected by varying the base supply air temperature.

   The damper control in the jet can then be expected to vary the microclimate in the work stations by up to 1°C from the general office setting.

2. Variation in Supply Duct Pressure
   The pressure in most supply ducts will vary from 1/2" W.G. to 1 1/2" W.G. (125 to 375 pascal), depending upon closeness to the fan or supply duct riser. Within this range the damper may be set to a maximum opening which prevents jets at higher duct pressure from robbing air from these at lower duct pressure.

3. Adjustment for Temperature Stratification
   With displacement ventilation the temperature at the ceiling may be higher by up to 2°C than that at the desk. An offset adjustment is provided in the thermostatic control unit to compensate for this difference.

   It is also likely that air on the floor will be 2°C cooler than air at desk level because of the means of air distribution. This is unlikely to be noticed unless the air temperature drops below 20°C. This has not been the case in testing even with supply air at 7°C.

4. Jet Location
   The jet should be located so that it does not blow air directly down on an occupant's head. In most cases it is satisfactory if the jet is situated one metre horizontally away from the occupant.

4.4 Cost

At the present time, with hand assembly of the jet and the circuit board in the eye-in-the sky, an installation can be made for approximately $1500. In the future, with addition of a microprocessor and a specially moulded air outlet, the selling price of a complete installation is expected to drop to $750 based on an installation of 1000 or more units.

For new buildings, cost will be comparable to or lower than the cost of conventional fan driven air terminals and light air outlets.

Recent research at Renseslar Technical Institute, reported in the ASHRAE Journal July 1992, finds personal control to increase office worker efficiency by an average of 2%. Such an increase would pay for the McGill jet in one year.

Patents have been sought for the McGill Jet Concept including the use of a remote control.

5.0 ENERGY SIMULATION AND ENERGY COSTING RESULTS

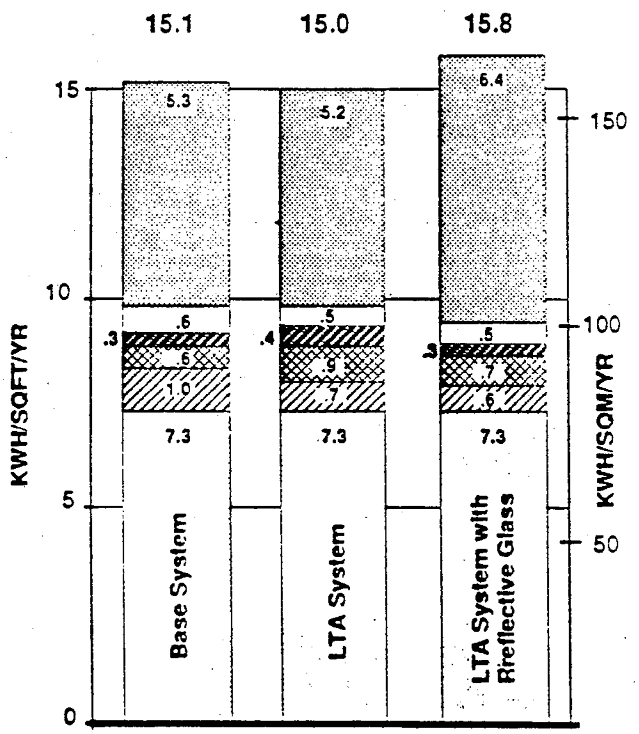
The energy analysis has been sublet to Ross F. Meriwether, consulting engineers, San Antonio, Texas.

The idea that 100% outside air can be energy conserving is not likely to be accepted easily by HVAC designers. Maximum credibility can be contributed by Mr. Meriwether for this purpose because his reputation has been established within ASHRAE and within the Canadian Government where his programs have been used for almost 20 years.

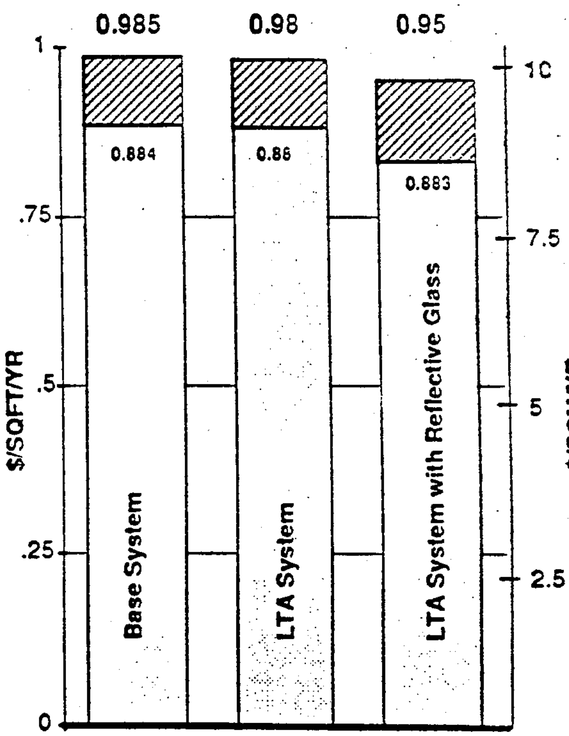
A summary of the Meriwether results is included in Appendix A.

5.1 COMPARISON OF BASE SYSTEM WITH LTA SYSTEM

There was a direct trade off between fan and chiller energy as shown in the bar graphs below. While the fans are smaller for LTA, the chillers must operate at 0.71 kW/ton vs 0.65 kW/ton for the base system. There is also a small trade off between the energy for gas heat and accessories including pumps and domestic water heating. Chiller energy includes tower fan energy. No allowance is made for elevators, security lighting and other miscellaneous loads. Energy costs for Toronto, Edmonton and Vancouver are based on 1992 Toronto rates.



ENERGY COMPARISON



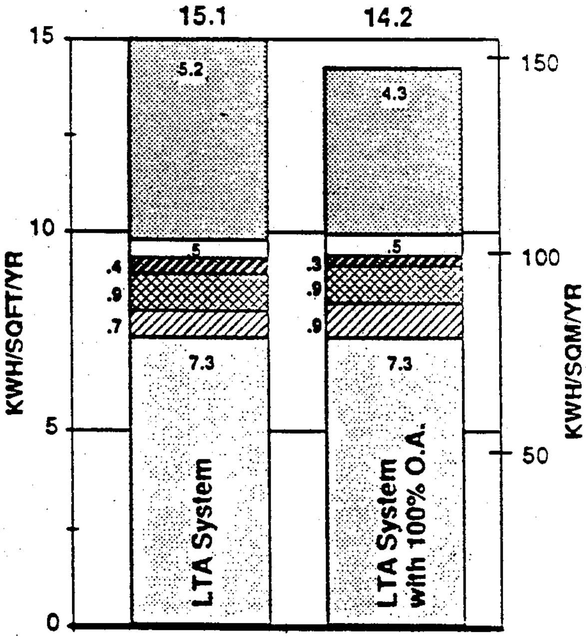
COST COMPARISON

5.2 LTA SYSTEM VS LTA SYSTEM WITH 100% OUTSIDE AIR

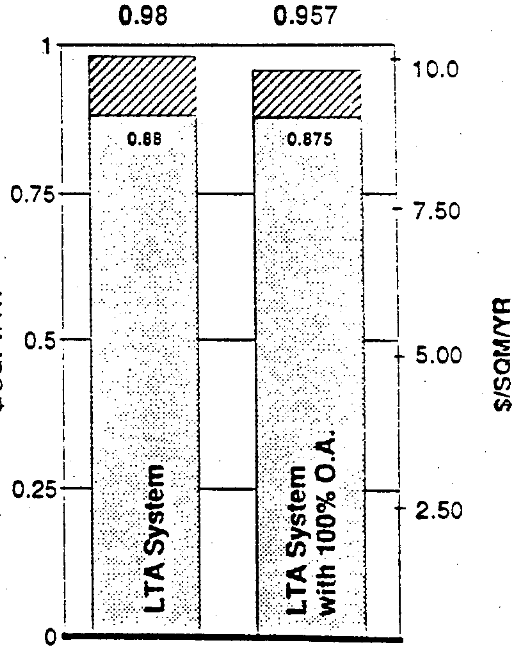
The LTA system with 100% outside air uses more fan energy than the LTA system to overcome the air resistance of the heat exchangers but less overall energy. Heating will never be necessary for interior air supply even if all the ventilation air is delivered to the interior zone. A complete 80% heat exchange raises air from -5F (-20.5°C) to 59F (15°C) which is too high for delivery to the interior. In such circumstances the rotational speed of the heat exchangers will be slowed thermostatically to reduce the air delivery temperature.

The accessories shown on the graph include domestic water heating, and electricity for special effects such as exterior lighting and water displays.

The comparison in energy and cost is shown below.



ENERGY COMPARISON



COST COMPARISON

LEGEND:

░ *Lites Plugs*
▨ *Fans*
▩ *Chillers*
▨ *Acc's*
☐ *Humidity*
░ *Gas Heat*

LEGEND:

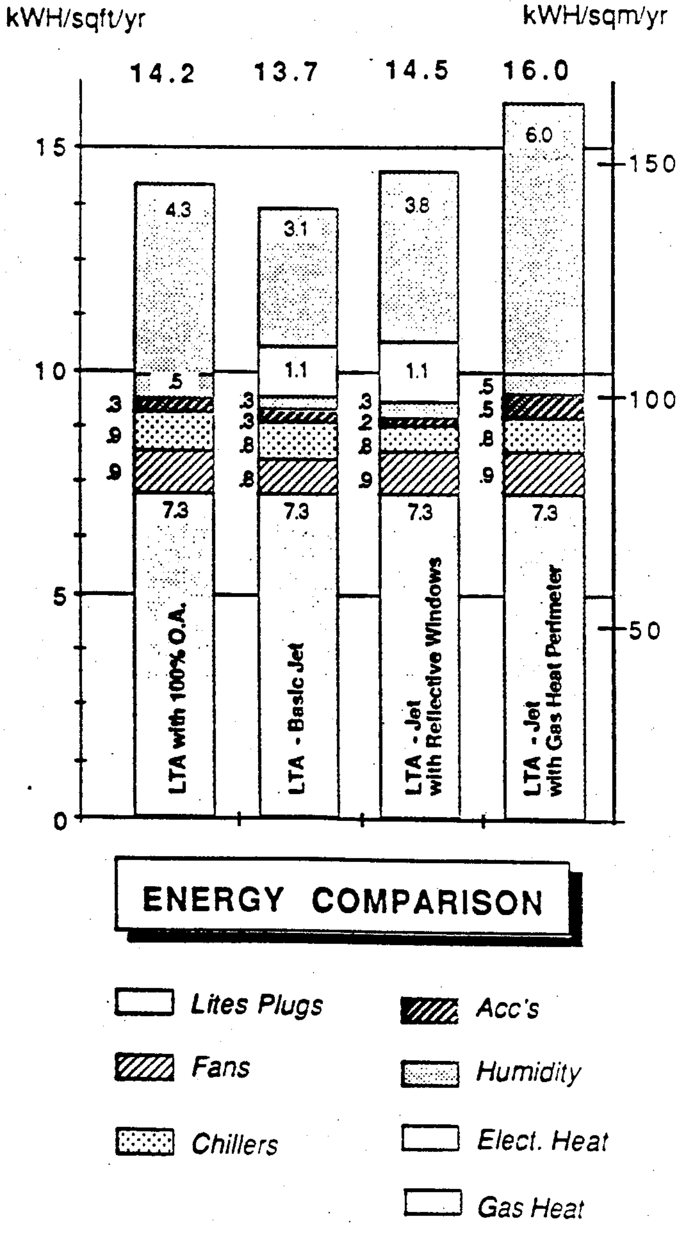
☐ *Electricity*
▨ *Gas*

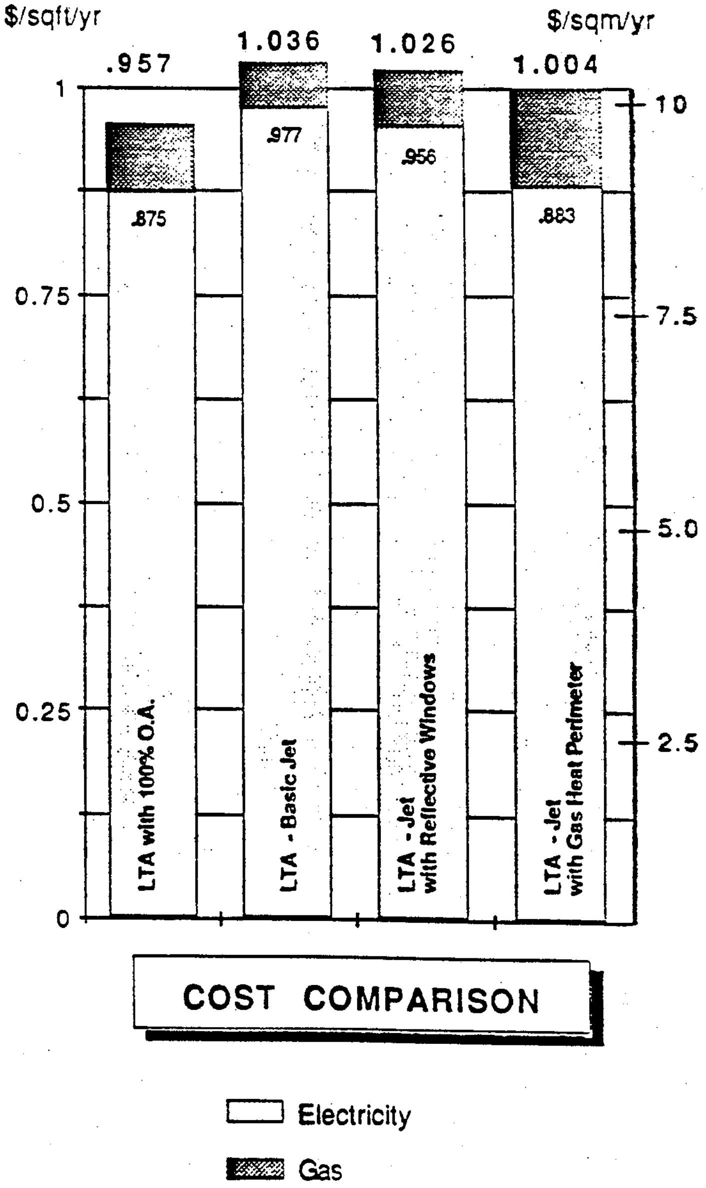
5.3 LTA SYSTEM with 100% OUTSIDE AIR vs LTA SYSTEM WITH 100% OUTSIDE AIR & McGill JETS

Three scenarios are involved with the McGill jet, the basic jet, the basic jet with reflective windows and the basic jet with a total gas heat perimeter.

The reflective windows, which saved so much on cooling, provide a barrier to solar heat gain in winter and thus increases the heating requirement.

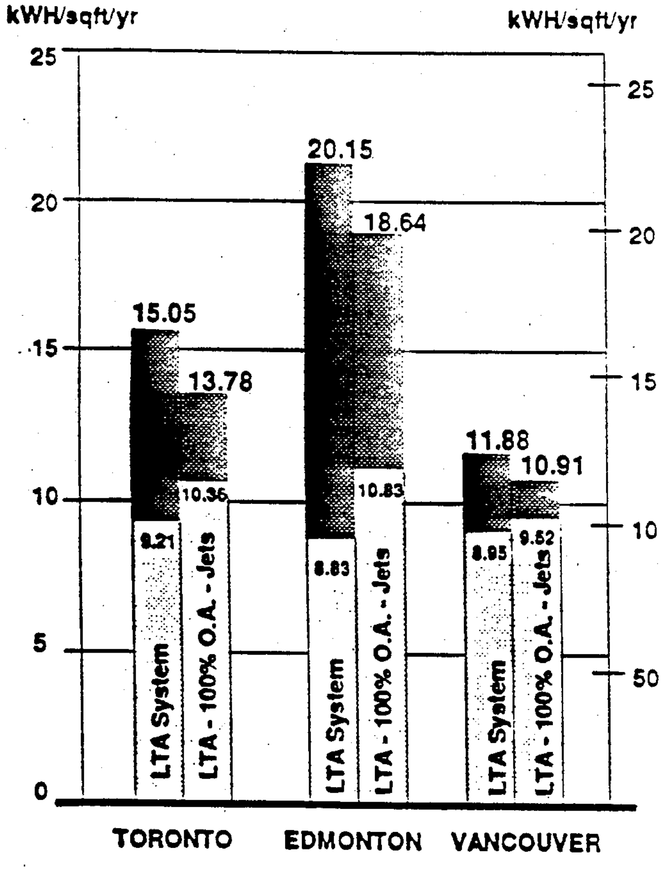
The gas perimeter reduces heating cost by eliminating expensive electric heat but it uses more gas energy to create the necessary overheated condition to allow the jets to cool bac to the occupant temperature set points.


ENERGY COMPARISON

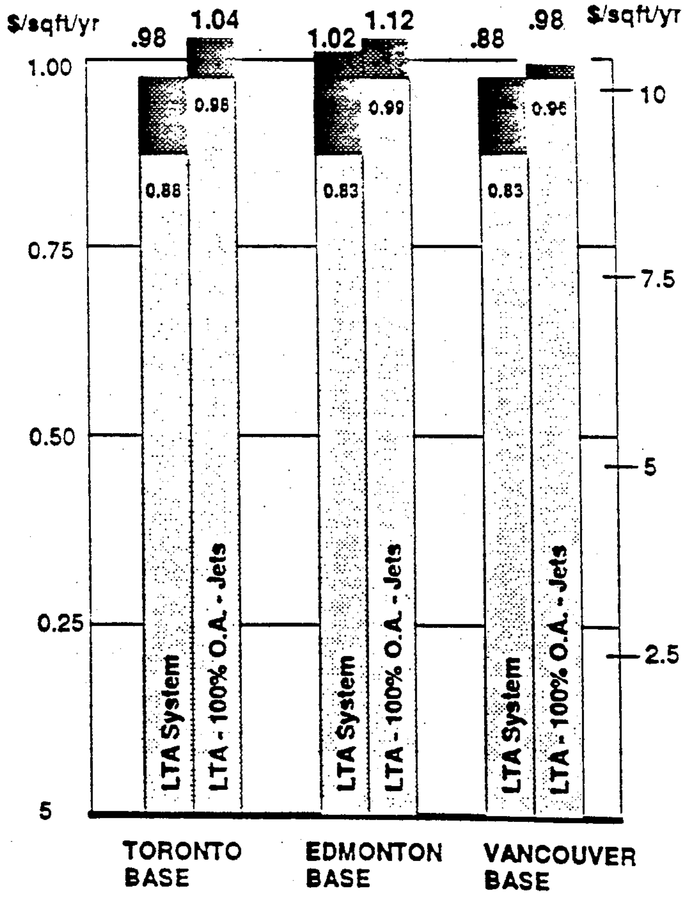

COST COMPARISON

5.4 VARIATIONS FOR LOCATION

The graphs below compare the LTA system with the LTA 100% Outside Air - McGill jet in Toronto, Edmonton and Vancouver. In all cases the system with 100% outside air and jets uses less energy. However, the cost is higher because of the use of electric heat.



ENERGY COMPARISON



COST COMPARISON

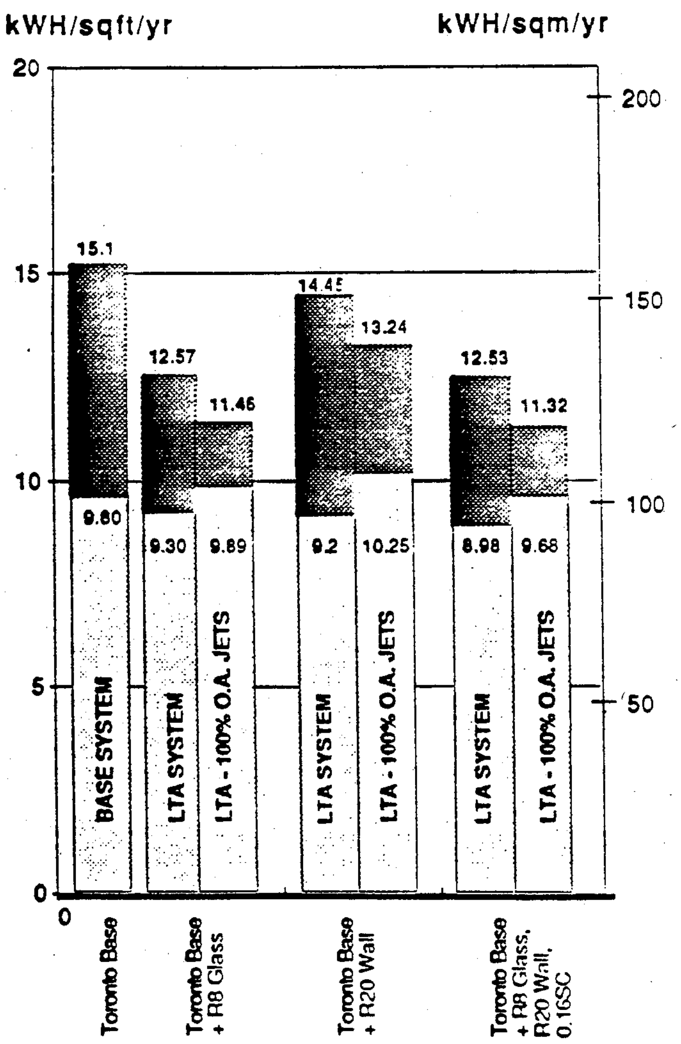
☐ Electricity

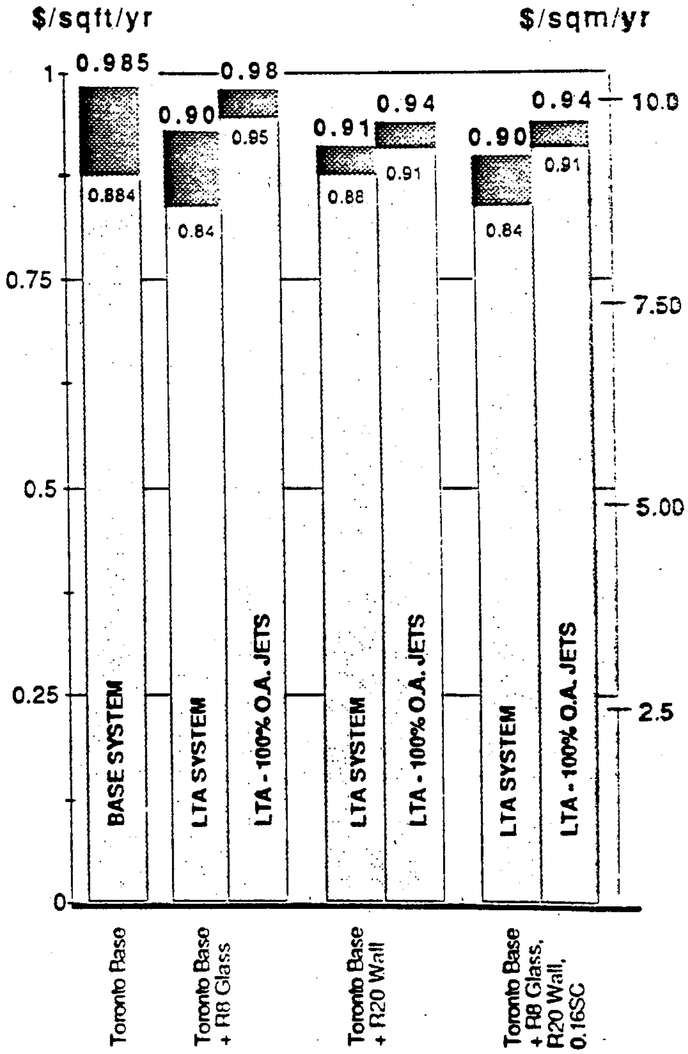
▨ Fuel (includes electric heat)

5.5 VARIATIONS FOR BUILDING ENCLOSURE

The variation for a heavy glass shading coefficient has already been shown. The variation in energy and energy cost are shown below for:

- R-8 (RSI 1.4) glass vs R-3 (RSI 0.53)
- R-20 (RSI 3.6) wall vs R-10 (RSI 1.8)
- Highly reflecting glass as well as upgraded wall and glass insulation





▭ Electricity
▨ Gas

ENERGY COMPARISON

COST COMPARISON

6.0 INITIAL COST COMPARISONS

6.1 Initial Cost Comparisons

The costing study was sublet to Shore Tilbe Henschel Irwin and Peters, Architects and Engineers, Jackson Lewis General Contractors and S.I. Guttman Mechanical Contractors.

S.I. Guttman, in turn, sublet some of the costing on mechanical and electrical trades to Ontario Electric, Duffy Sheet Metal, Landis and Gyr Controls and Clark System Balancing.

Meetings were held and drawings exchanged to ensure that all parties would be interfacing their costing accurately.

Pricing for chillers, fans, coils and wallfin was solicited from the Trane Co. Costs on rotary heat exchangers and air terminals were taken from Airex Ltd.

The summary of all the costing is shown on Figure 17.

The costing of the McGill University air jet was based on estimates secured in the manufacture of prototypes and projections for future cost when orders of 1000 or more are received. The components and costs are shown below:

		Order of 12 units for Prototype	Projected Cost for 1000 Units	Projected Selling Price for 100 Units
1.	Air Jet in mounting frame suitable for attachment in ceiling grid	$75	$40	$ 75
2.	Thermostatic Control Unit	$ 850 for interior $1100 for perimeter	$125 (based on computer chip)	$250
3.	Duct take off incl. 4 volt DC motor & damper	$75	$40	$ 75
4.	250 Watt electric heater for perimeter zones	$250	$150	$275
5.	Remote operator	$100	$ 15	$ 30

Costs on the building envelope were obtained with the help of sketches prepared by Shore Tilbe Architects and with costing by Jackson Lewis. See Appendix B.

Costing was as follows:

R-20 wall $60{,}000\ ft^2 (5581 m^2) \times \$16.50/ft^2 (\$177.38/m^2)$ = $990,000
R-10 wall $60{,}000\ ft^2 (5581 m^2) \times \$15.50/ft^2 (\$166.63/m^2)$ = $930,000

Premium for better insulation: $ 60,000

R-8 glass $60{,}000\ ft^2 (5581 m^2) \times \$25.00/ft^2 (\$268.75/m^2)$ = $1,500,000
R-3 (low E) glass $60{,}000\ ft^2 (5581 m^2) \times \$18.00/ft^2 (\$193.50/m^2)$ = $1,089,000

Premium for better insulation: $ 420,000

Premium cost for shading coefficient of 0.16
= $60{,}000\ ft^2 (5581 m^2) \times \$1.50/ft^2 (\$16.13/m^2)$ = $ 90,000

7.0 CONCLUSIONS

The following comments can be made with respect to the study.

7.1 The Feasibility of Low Temperature Air Supply

Reducing the supply air temperature from 55F (12½°C) to 45F (7°C) decreased the total supply air from 188,500 CFM (88,595 l/s) to 121,200 CFM (56,960 l/s). Although the cooling capacity rose from 492 tons to 502 tons for LTA, the overall energy remained equal. The initial cost was estimated as follows:

Base System	$4,365,974
LTA System	3,926,090
Saving	$ 439,884

To the cost saving of 10% should be added the additional comfort which results from the systems ability to maintain comfortable relative humidity without reheat even in muggy weather. A number of testimonials are being received from building occupants using LTA systems. They claim that the lower relative humidity (at 40%) makes the air seem fresher!

The LTA system is destined to be the one of choice in future office air conditioning.

7.2 Feasibility of 100% Outside Air

There is a premium for the LTA system with 100% outside air.

	Initial Cost
LTA System with 100% outside air	$4,226,160
LTA System	3,926,090
Premium Cost	$ 300,070

On the other hand the heat exchangers provide an energy saving in sensible and humidification heat despite the fan energy required to overcome their air resistance.

System	Electricity Cost $/Yr	Fuel Cost $/Yr	Total Cost $/Yr
LTA System	264,000	30,000	294,000
LTA System with 100% OA	262,500	24,600	287,100
Saving	1,500	5,400	6,900

The saving is not conducive to investing in 100% outside air for energy alone, but a builder who is prepared to spend $30,000,000 to build the office will be tempted to spend 1% more to be able to market the all-fresh-air concept.

The feasibility of 100% outside air systems will be increased by using LTA.

7.3 Feasibility of the McGill Jet

There is a significant saving in the elimination of the fan driven terminals from the base system. This allows the McGill jet concept to compare favourably in cost even with the addition of the heat exchangers for 100% outside air.

For the base system glazing the costs are as follows:

System	First Cost $	Electricity Cost $/Yr	Fuel Cost $/Yr	Total Energy Cost $/Yr
Base System	4,365,974	265,200	30,300	295,500
LTA System with 100% OA and jets	3,560,638	293,100	17,700	310,800
Difference	805,336	-27,900	12,600	-15,300

From this it is seen that the electric heaters are taking on 40% of the heating load and driving up the overall energy cost even though the jet system uses fewer equivalent kWh/yr.

If the all-gas-heating alternative is adapted with the jet concept the saving for the system is reduced to $577,000 but the energy cost is still higher by $5700/yr because of the extra heat required to facilitate the individual temperature control of perimeter offices.

7.4 Low Shading Coefficient Glass, Pro or Con

The low shading coefficient reduced the initial cost of the chiller and air handling system by $361,300 in the conventional system and $243,000 in the 100% Outside Air LTA system.

Judged alongside the premium cost of $90,000 this makes sense as long as the architect and owner are pleased with the appearance.

The energy use rose 0.74 kWh/ft^2/yr (7.96 kWh/m^2/yr) because the reflectivity of the wall reduced solar heat gain in winter more than it helped cooling energy in summer. Owing to the high electric demand rate used in Toronto, however, the saving in chiller cost overcame the increase in heating cost by 1¢/ft^2/yr (11¢/m^2/yr) or $3,000/yr.

In summary, the highly reflective glass is economically sound. Its feasibility does not depend on either ventilation rate or wall insulation. Architectural approval for the reflectivity must take into account exterior aesthetics as well as the reduction of natural daylight for occupants and the opportunity of using this to reduce lighting energy cost.

7.5 Impact of Increasing Envelope Insulation

The R-20 wall reduced energy by 0.54 kWh/ft^2/yr (5.81 kWh/m^2/yr) equal to 1½¢/ft^2/yr (16¢/m^2/yr) or $4,500/yr. This does not relate well to the cost of $60,000 and cannot be justified. The simple payback is 13.3 years.

The R-8 glass reduces energy by 2.32 kWh/ft^2/yr (24.94 kWh/m^2/yr) equal to 6¢ft^2/yr. (64.5¢/m^{2}yr) or $18,000/yr. This does not relate well to the extra cost of the glass at $420,000 and cannot be justified. The simple payback is 23.3 years.

In summary, heavier enclosure insulation is not economic for buildings which tend to be self heating. This conclusion is not affected by the choice of ventilation rate or the means of air distribution.

8.0 RECOMMENDATIONS

1) Visit sites where enthalpy wheels are operating and verify the catalogue ratings and claimed ease of maintenance.

2) Consider designing the next office building with Low Temperature Air and 100% outside air.

3) Install the McGill jet as a retrofit in locations where occupants complain of lack of temperature control and air motion, conduct field trials and, carry out questionnaires to verify the improvement in personnel acceptance.

4) Monitor energy consumption of McGill Jet, 100% OA, and LTA systems to confirm simulated results.

5) Given acceptance of the personally controlled jet, use this feature in connection with 100% outside air on the next office building.

BIBLIOGRAPHY

1) Legal Firm: Simke, Chodos, Silberfeld & Anteau
Los Angeles, California

2) The New England Medical Journal March 1993
"The Effect of Varying Levels of Outside Air Supply on Sick Building Syndrome"
Interventions for Sick Building Syndrome"
R.I. Menzies, J.P. Farant, I. Hanley, R.M. Tamblyn

3) Carnes Energy Recovery Wheel Design Manual.
Catalogue HW-01G November 1989. Phone 608-845-6411.
Efficiencies vary from 70% to 82% based on face velocity. 80% was used in this report.

4) Commerce Court.

5) Study by Engineering Interface for Ontario Hydro In 1992 on the economics of ice and chilled water storage for four office buildings of 25,000 ft^2 (2325 m^2), 50,000 ft^2 (4650 m^2), and 150,000 ft^2 (13,950 m^2), and 350,000 ft^2 (32,560 m^2).

6) The Space Pak system. This is a proprietary system that avoids the usual cutting and patching of plaster in older residences by snaking flexible tubes through stud partitions and between floor joists. The air supplied to the rooms at 45F (7°C) through two inch diameter vertical jets. Despite the low air temp and 2000 fpm (10 m/s) outlet velocity, the jets have caused no discomfort to persons sitting four feet or more, horizontally, away from the jets.

Figure 1

COMPARISON BETWEEN CONVENTIONAL AND 100% OUTSIDE SYSTEM

LTA System vs LTA - 100% O.A. Jets

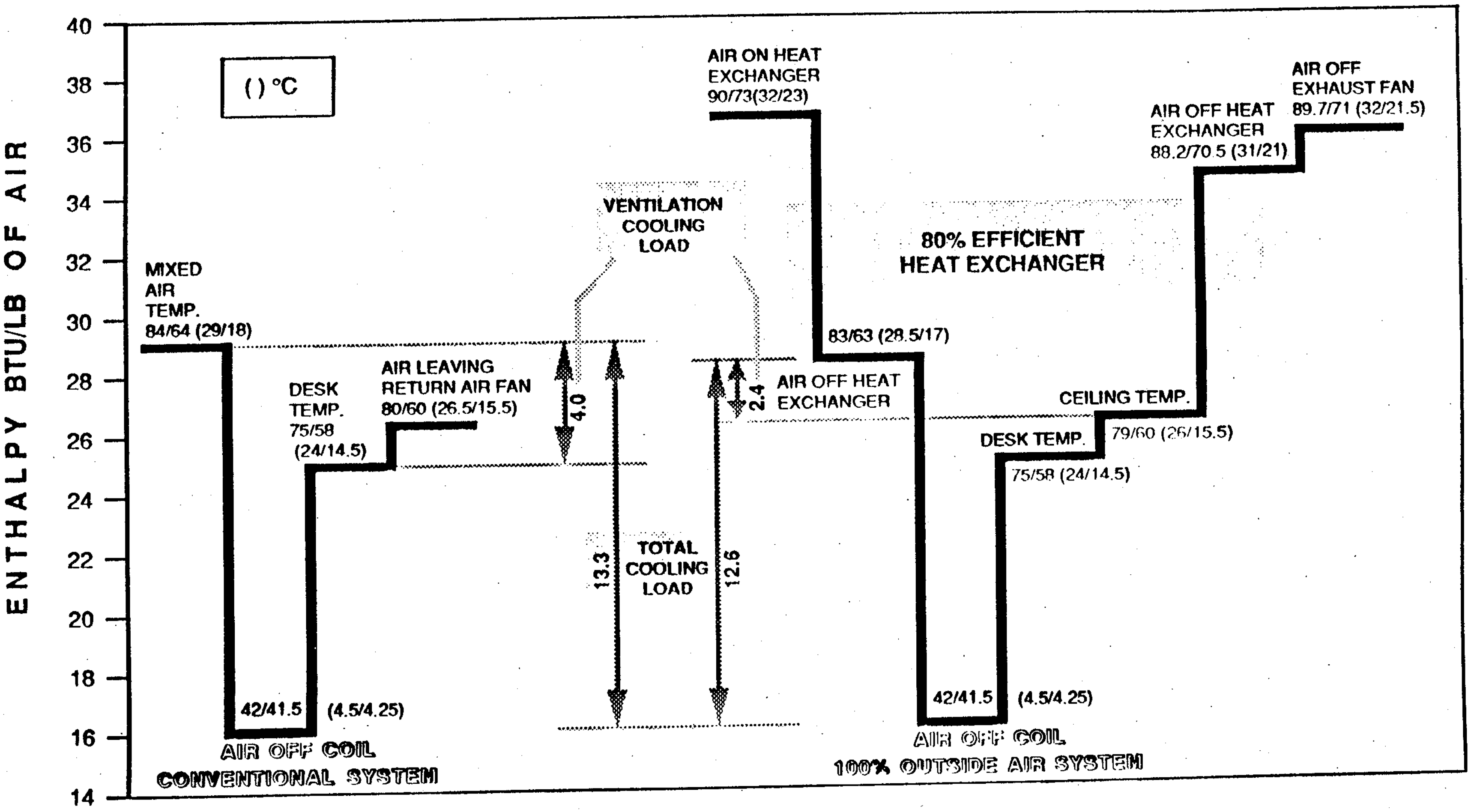


FIGURE 2

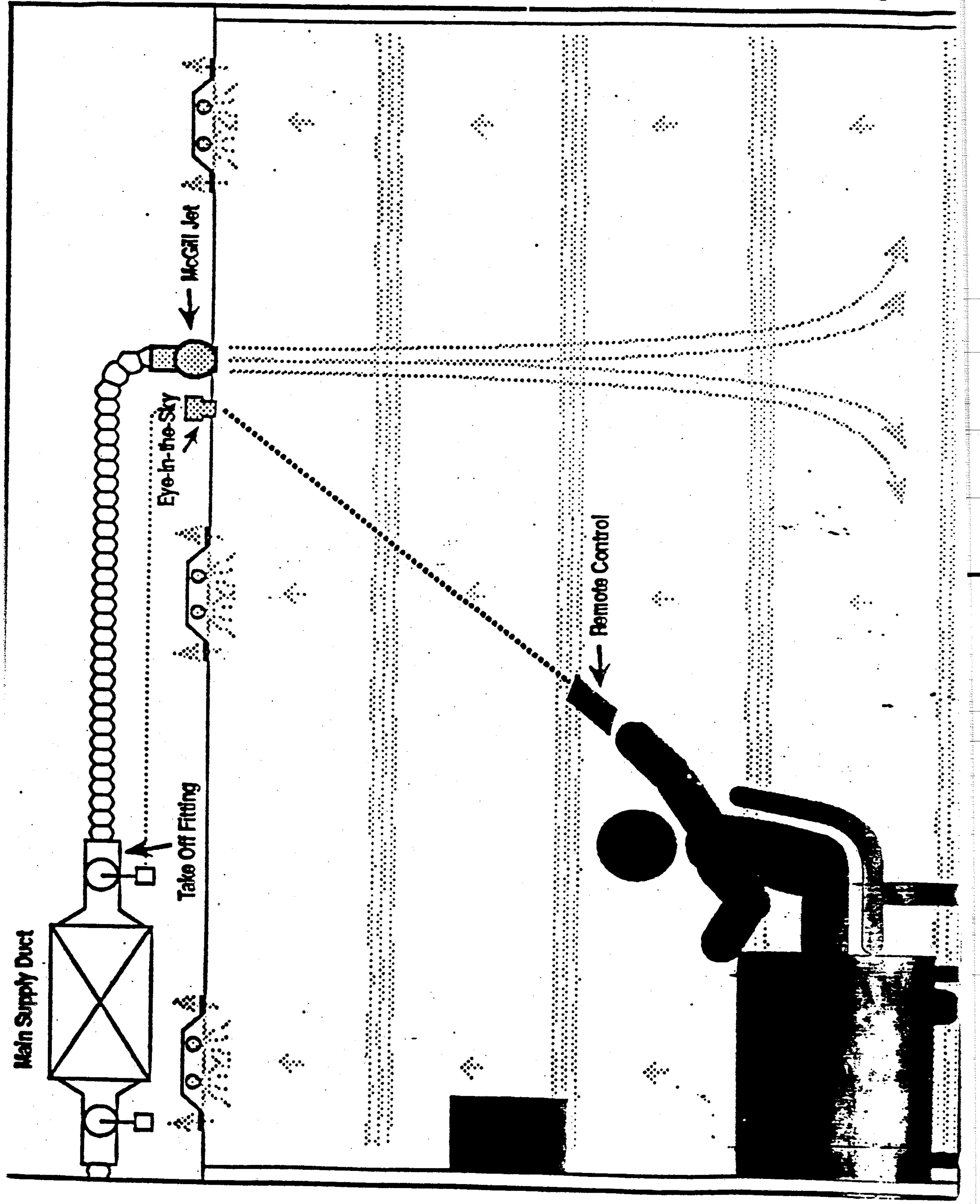
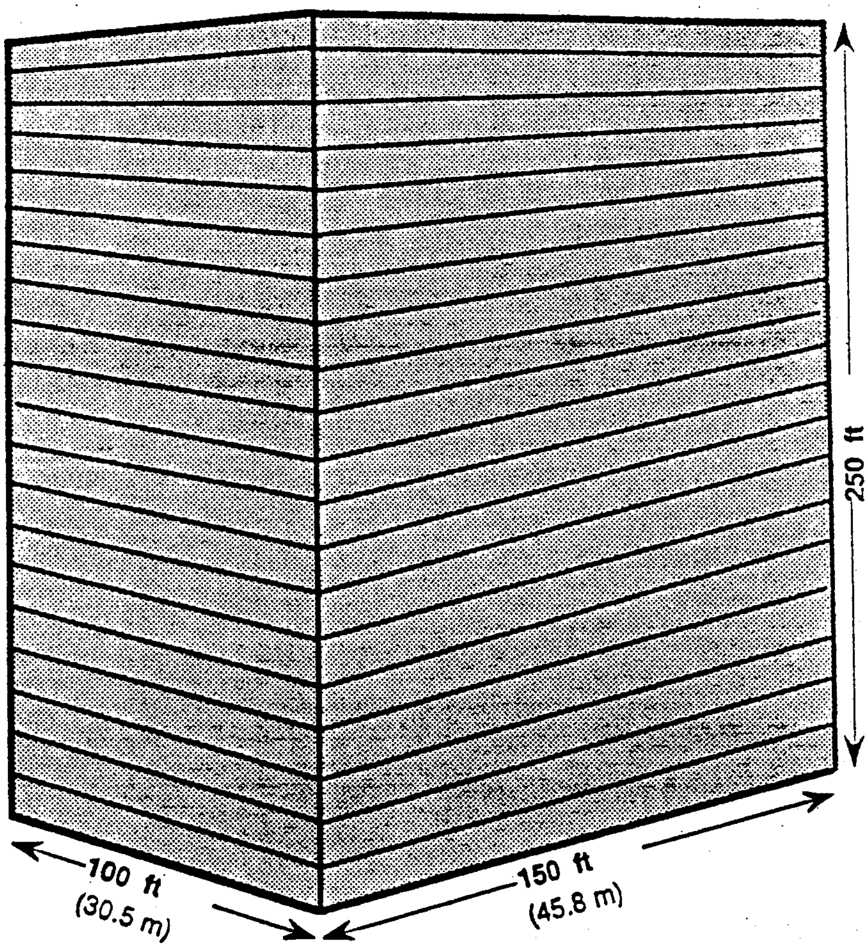

Main Supply Duct
Take Off Fitting
Eye-In-the-Sky
McGill Jet
Remote Control

Figure 3

20 Storey Prototype Building

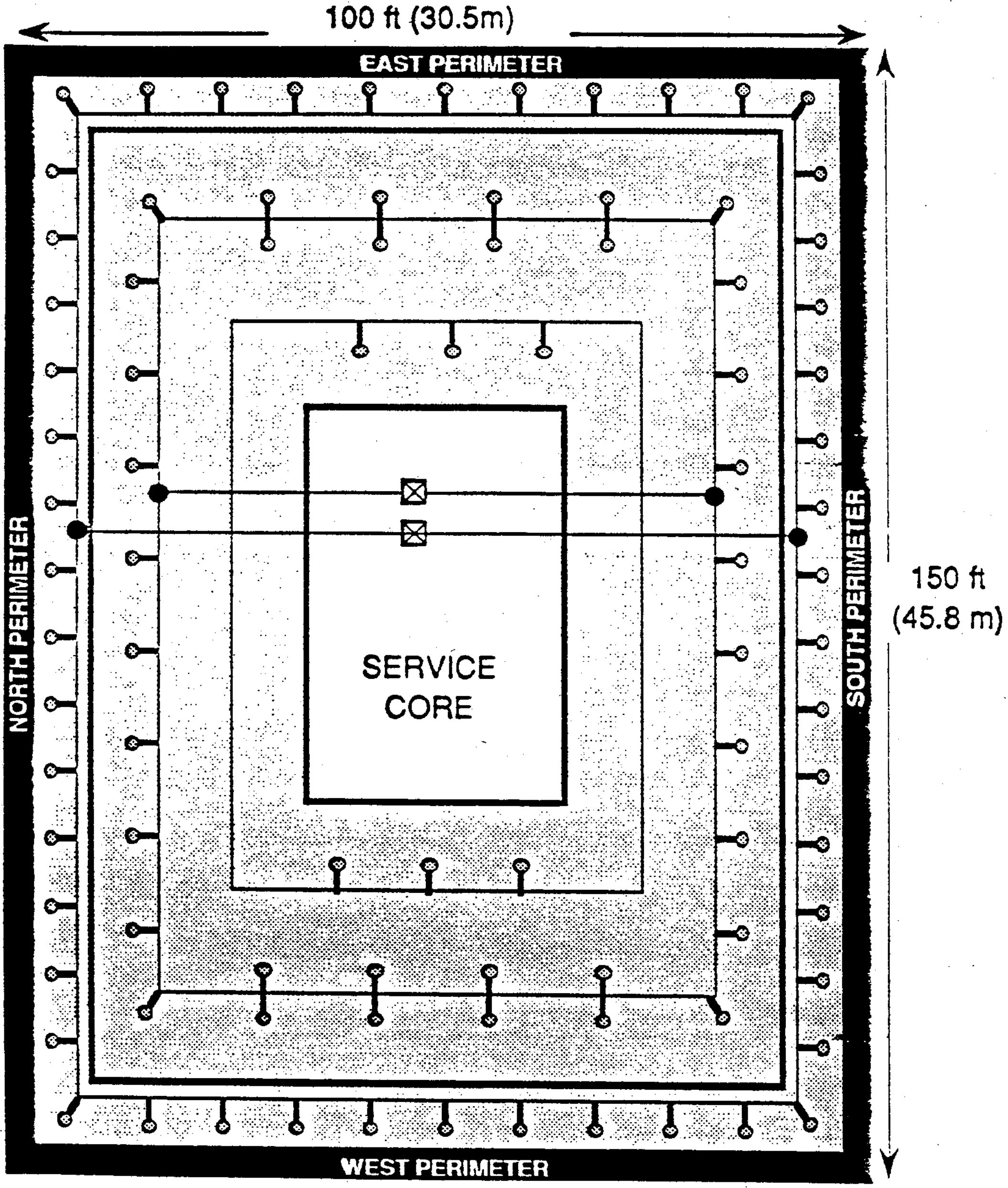


ENVELOPE SUMMARY

• WALL AREA:	62,500 Sq.ft.	(5,814 sq.m.)
• GLASS AREA	62,500 Sq.ft.	(5,814 sq.m.)
• ROOF AREA	15,000 Sq.ft.	(1,395 sq.m.)
TOTAL ENVELOPE	**140,000 Sq.ft.**	**(13,023 sq.m.)**

Figure 4

Typical Floor Plan



AREA SUMMARY		
• INTERIOR	7,724 SQ. FT.	(718.5 SQ.M.)
• NORTH PERIMETER	1,719 SQ. FT.	(159.9 SQ.M.)
• EAST PERIMETER	1,094 SQ. FT.	(101.8 SQ.M.)
• SOUTH PERIMETER	1,719 SQ. FT.	(159.9 SQ.M.)
• WEST PERIMETER	1,094 SQ. FT.	(101.8 SQ.M.)
• TOTAL AIR CONDITIONED	13,350 SQ. FT.	(1241.9 SQ.M.)
• SERVICE CORE	1,650 SQ. FT.	(153.5 SQ.M.)
TOTAL AREA	15,000 SQ. FT.	(1395.3 SQ.M.)

FIGURE 5

BASE BUILDING DESIGN

CONFIGURATION	20 Floors 150 ft x 100 ft, long wall south See Fig. 1
FLOOR AREA	See Fig. 2
HEAT TRANSFER COEFFICIENTS	Wall 0.1 Btu/ft^2/Hr/°F .57W (m^{2}K) Roof 0.1 Btu/ft^2/Hr/°F .57W (m^{2}K) Glass 0.3 Btu/ft^2/Hr/°F 1.7W (m^{2}K)
WINDOWS	50% of wall area Low E glass Shading coefficient - 0.33
WEATHER	Toronto, 315 Bloor St. W.
LIGHTS	1.5 Watts/ft2 (16.1W/m2) 30% of heat to false ceiling 7:30 a.m. to 10:30 p.m. weekdays 9:00 a.m. to 2:00 p.m. Saturdays Other times (incl. 10 holidays) 10% emergency lighting
PLUG LOAD	0.5 Watts/ft^2 occupied hours (as above) (5.4 W/m^2) 0.2 Watts/ft^2 unoccupied hours (2.15W/m^2)
OUTDOOR DESIGN	Summer 90F DB (32°C DB) 73F WB (23°C WB) Winter -5 DB (-20.5°C)
INDOOR DESIGN	Summer 75F DB (24°C) Humidity - variable Winter 72F DB (22°C) 30% RH
SETBACK TEMPERATURES	±7F from design (±4°C)
OCCUPANCY	1 person/200ft^2 (1/18.6m^2) 67/floor 10% 7 am - 8 am) 40% 8 am - 9 am) 100% 9 am - 5 pm) Weekdays 50% 5 pm - 6 pm) 10% Saturdays
SYSTEM SCHEDULE	(6 am - 6 pm Weekdays (8 am - 2 pm Saturdays (OFF at other times except cycled to maintain setback temps. (early startup when necessary to avoid peak loads

FIGURE 5 (CONTD)

VENTILATION	Minimum 20 CFM O.A.(9.4 l/s)/person except unoccupied periods Up to 100% O.A. when helpful in reducing cooling requirements
INFILTRATION	Worst condition is 0.15 CFM/ft^2(0.76 l/s/m^2) on north wall
SUPPLY AIR TEMP	45F off cooling coil (7°C) 2F rise in ducts (1°C)
HUMIDIFIER	Sprayed coil
HEAT	By hot water reheat coils Natural gas @ 75% efficiency $5.00/MCF (17.5¢/m^3)
ELECTRICITY	$13.79/kW (The 1992 Toronto rate) 4.48¢/kWh
FANS	Main supply - 4 1/2" S.P. (13.5 kpa) 70% efficiency Air terminals - 3/4" S.P. (2.25 kpa) based on enough circulation to provide 57F (14°C) air to space.
PUMPS	Chilled Water 60 Ft Head (179 kpa) Hot Water 100 Ft Head 50 ft for syst 5/6 (150 kpa) Condensing Water 50 Ft Head (299 kpa) Spray Water 25 Ft Head (75 kpa) (operated when demanded by humidistat) 70% efficiency Constant flow
WATER RANGES AT MAXIMUM DESIGN	Chilled water 40F to 56F (4.5°C to 13.5°C) Hot water 180F to 160F (82°C to 71°C) Condensing Water 85F to 95F (29.5°C to 35°C)
CHILLER	0.7 kW/ton at design condition (0.2 kW/kW) Head temp. can vary downward at reduced wetbulb 1 kW for 188 max kW
TOWER	Fans 1 BHP for 40 MAX tons with constant energy input
MINIMUM AIRFLOW AT AIR TERMINALS	0.1 CFM/ft^2 (0.5 l/s/m^2)
SENSITIVITY ANALYSIS	Location Rerun base design in • Edmonton • Vancouver
BUILDING ENVELOPE	Rerun base design for • Walls R20 (R3.5) • Roof R20 (R3.5) • Glass R-8 (R1.4) • SC - 0.16 • All of the above

FIGURE 5 (CONTD)

Then, the air supply to suit the north zone will be as high as 120F (49°C) while the south zone needs cooling.

The solution is to add 20,000 CFM (9400 l/s) capacity to the interior fan which always supplies 45F (7°C) air.

On each floor there will be a bypass damper which will make available 1000 CFM (470 l/s) to any south zone in direct sunlight.

The cost of this extra fan/coil capacity, supply duct trunk and automation will be added to the budget for the zero complaint solutions.

As the south zone temperature rises the electric heat will shut off automatically. When a sensor notes the electrical heater load falling to zero on any south zone the controls will immediately cause the 45F (7°C) bypass to open from the interior zone and the airflow to revert from 52,000 CFM (24,440 l/s) (2600 CFM/floor(1222 l/s)) to that required to handle the cooling load.

Note, when the electric heaters go on and the heating requirement grows, the jet terminals need more than minimum airflow to deliver adequate heat. With R-8 (R-1.4) glass this airflow speed up for maximum heating may not be required.

SENSITIVITY RUNS WITH ZERO COMPLAINT

Try system with	R-20 wall/roof (R-3.7) R-8 glass (R-1.4) R-0.16 shading coefficient

All of the above rerun with gas heat brought on when 50% of the electric heat is used.

Rerun Vancouver and Edmonton with the base system.

Rerun with standard air terminals and diffusers. In this case the system heating coil and electric heaters will be deleted in favour of fan driven air terminals with gas-fired water reheat.

Note that more primary air is required because the return air temperatures are lower.

FIGURE 5 (CONTD)

TYPE SYSTEM

Rerun with 55F (12.5°C) air supply instead of 45F (7°C)
Fan driven terminals will still be used.

BUILDING

Same as before.
Note different air handling capacities when window shading coefficient is dropped from 0.33 to 0.16 See Appendix B-1
See sketches of system configuration. Figs. 3,4 and Fig. 7 to 15

HEATING

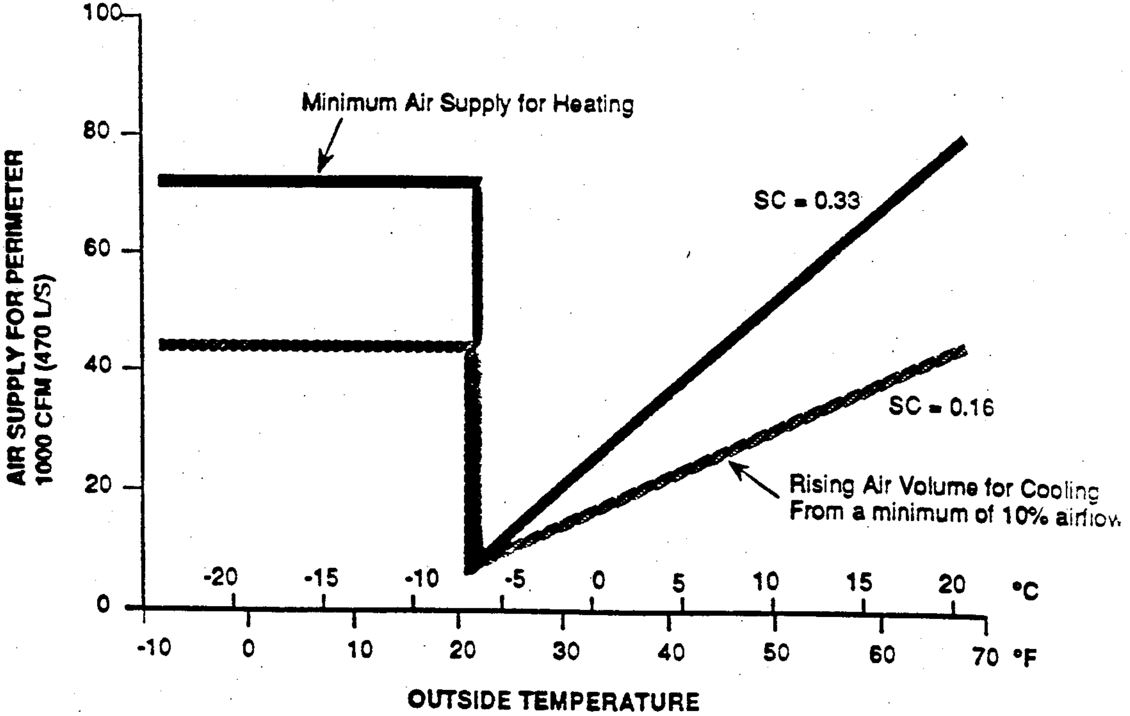
Each perimeter terminal (1000 in all) is provided with a 250 Watt electric heater which is operated thermostatically (off-on). Maximum electrical heating load is 250 x 1000 or 250 kW.

When a meter registers 75% of this load, the heating coil (gas-fired hot water) will add heat to the perimeter air supply to minimize electric input to heating.

During unoccupied periods the system will cycle on 100% return air. The electric heat will be turned off and the hot water coil will respond to return air temperature or the average of selected perimeter zone thermostats.

During occupied periods the heat exchangers will operate on a varispeed rotation control to respond to a discharge air controller set for 45F (7°C).

When the perimeter zone has a heating requirement, the perimeter fan will operate at 52000 CFM (24,440 l/s) (irrespective of shading coefficient) and the heat exchanger will operate at 80% (top) efficiency.



There is an obvious problem when the sun is shining strongly on a winter day at -5F (-20°C) and the wind blowing strongly against the north wall.

FIGURE 6

ENERGY SENSITIVITY ANALYSIS AND PROGRAMMING REQUIREMENTS

	Col. 1 Base	Col.2 Increase Wall from R10 to R20 (1.8 to 3.7)	Col. 3 Increase Glass from R3 to R8 (0.5 to 1.4)	Col. 4 Decrease Glass Shading Coef. from 0.33 to 0.16	Col. 5 Combine Cols 2,3,&4	Col.6 Increase Air Off Fan Temp from 45F to 55F (7°C to 13°C)	Col. 7 Add Ht.Exch. and use 100% Outside Air	Col.8 50% vs 75% Electric Heat
BASE DESIGN Using Light/Air Diffusers								
Toronto	X	X	X	X	X	X	X	-
Edmonton	X	-	-	-	-	-	-	-
Vancouver	X	-	-	-	-	-	-	-
ZERO COMPLAINT DESIGN Using Personal Control Jets								
Toronto	X	X	X	X	X	X	-	X
Edmonton	X	-	-	-	-	-	-	-
Vancouver	X	-	-	-	-	-	-	-
ENERGY BREAKDOWN	kW MAX	kWh/yr						
Lights	X	X						
Plugs	X	X						
Fans/Pumps	X	X						
Chillers	X	X						
Tower	X	X						
Boilers								

FIGURE 6

ENERGY SENSITIVITY ANALYSIS AND PROGRAMMING REQUIREMENTS

	Col. 1 Base	Col.2 Increase Wall from R10 to R20 (1.8 to 3.7)	Col. 3 Increase Glass from R3 to R8 (0.5 to 1.4)	Col. 4 Decrease Glass Shading Coef. from 0.33 to 0.16	Col. 5 Combine Cols 2,3,&4	Col.6 Increase Air Off Fan Temp from 45F to 55F (7°C to 13°C)	Col. 7 Add Ht.Exch. and use 100% Outside Air	Col.8 50% vs 75% Electric Heat

COOLING BREAKDOWN

NOTE MAXIMUM COOLING LOAD (CONTINUOUS OPERATION NO PULL DOWN LOAD) FOR EACH RUN

HEATING BREAKDOWN

BTU/YR. (GJ/yr)GAS (SEPARATE HEATING & HUMIDIFICATION ENERGY) FOR EACH RUN
BTU/YR. ELECTRIC (SEPARATE HEATING FROM OTHER)

ENERGY COST

MONTHLY TOTALS FOR GAS AND ELECTRIC FOR EACH RUN

Figure 7

Base Building Duct Layout for Typical Floor

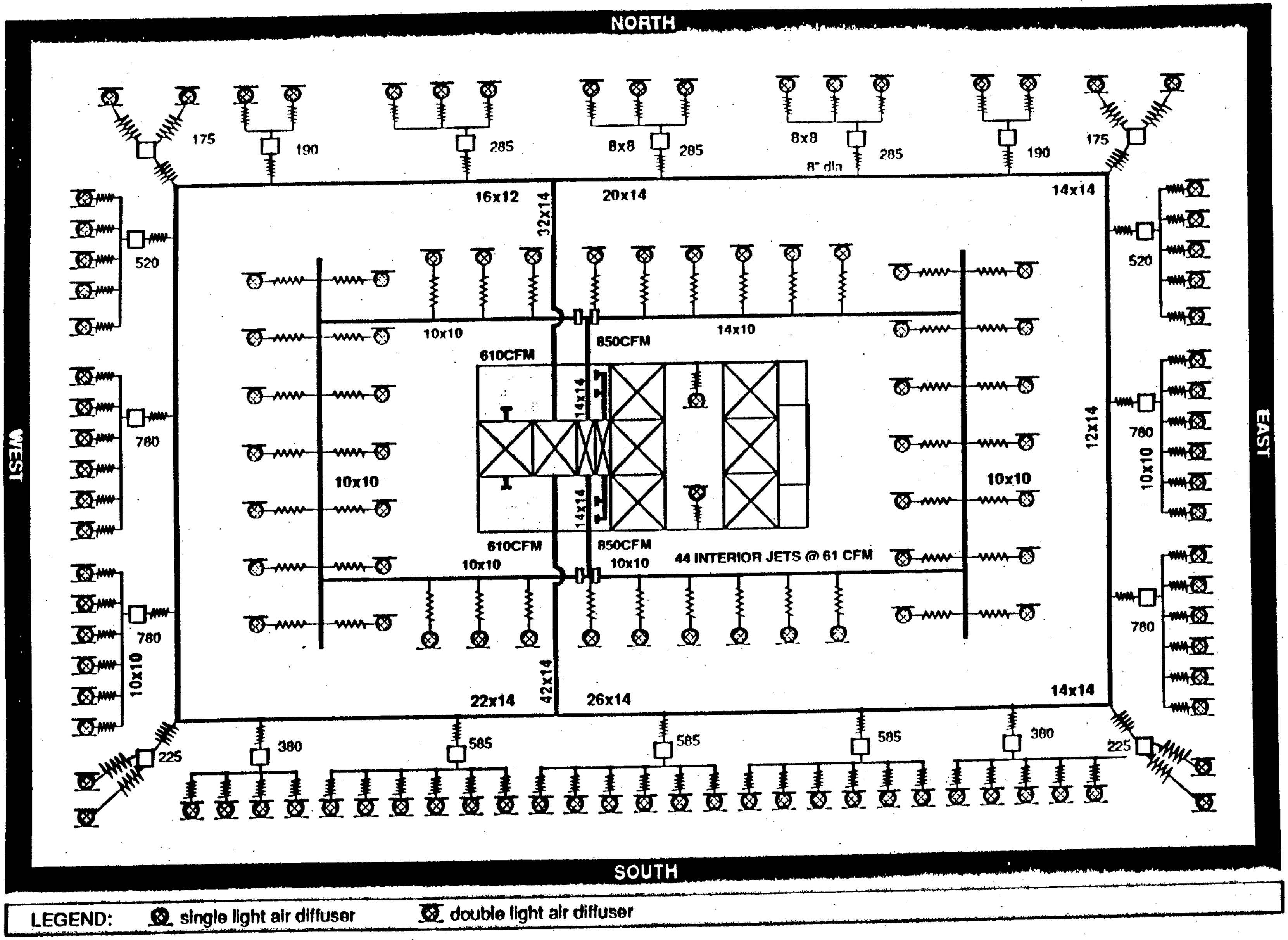


Figure 8

Penthouse Layout

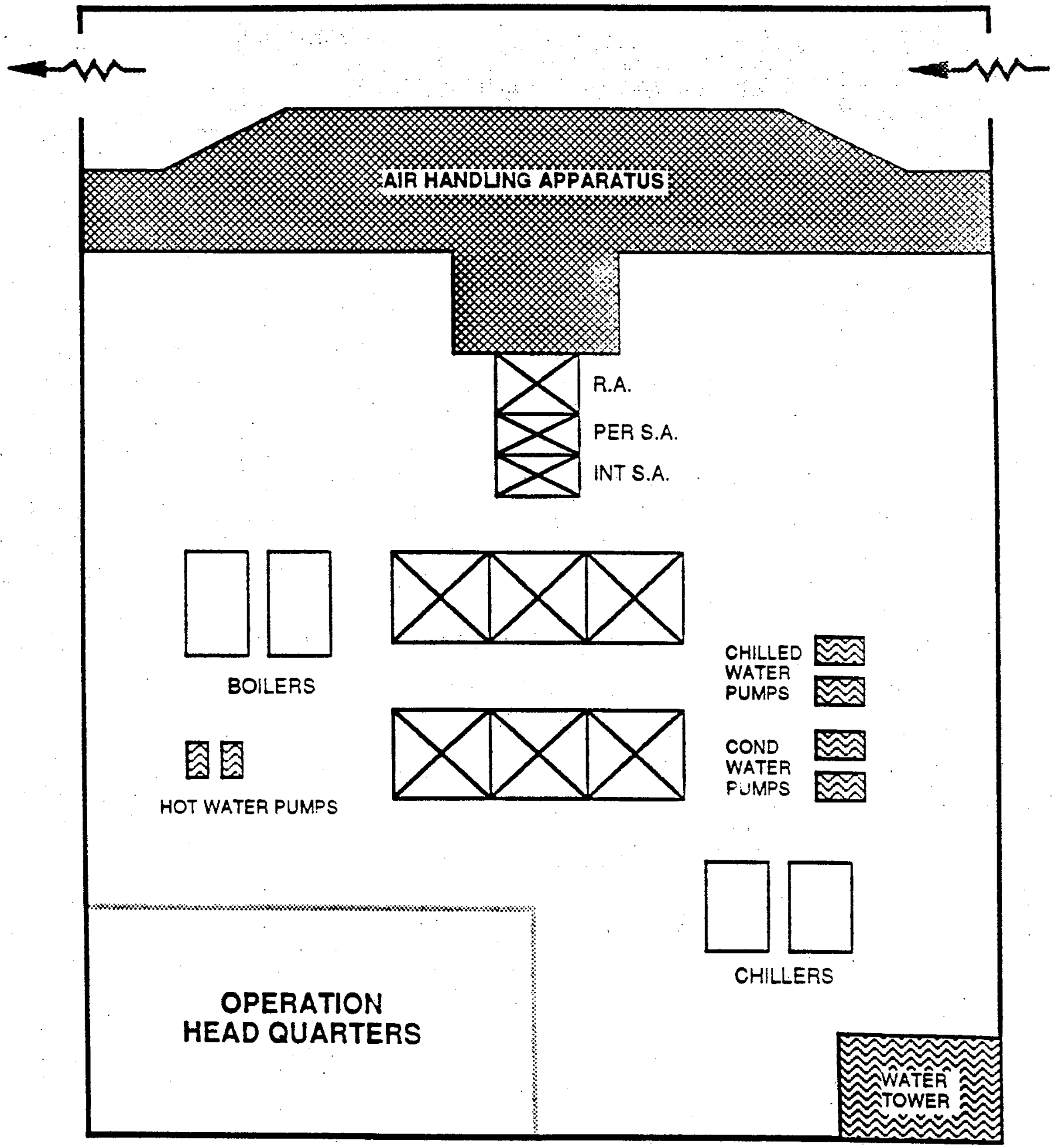


Figure 9
Penthouse Floor Plan for Base Building Design

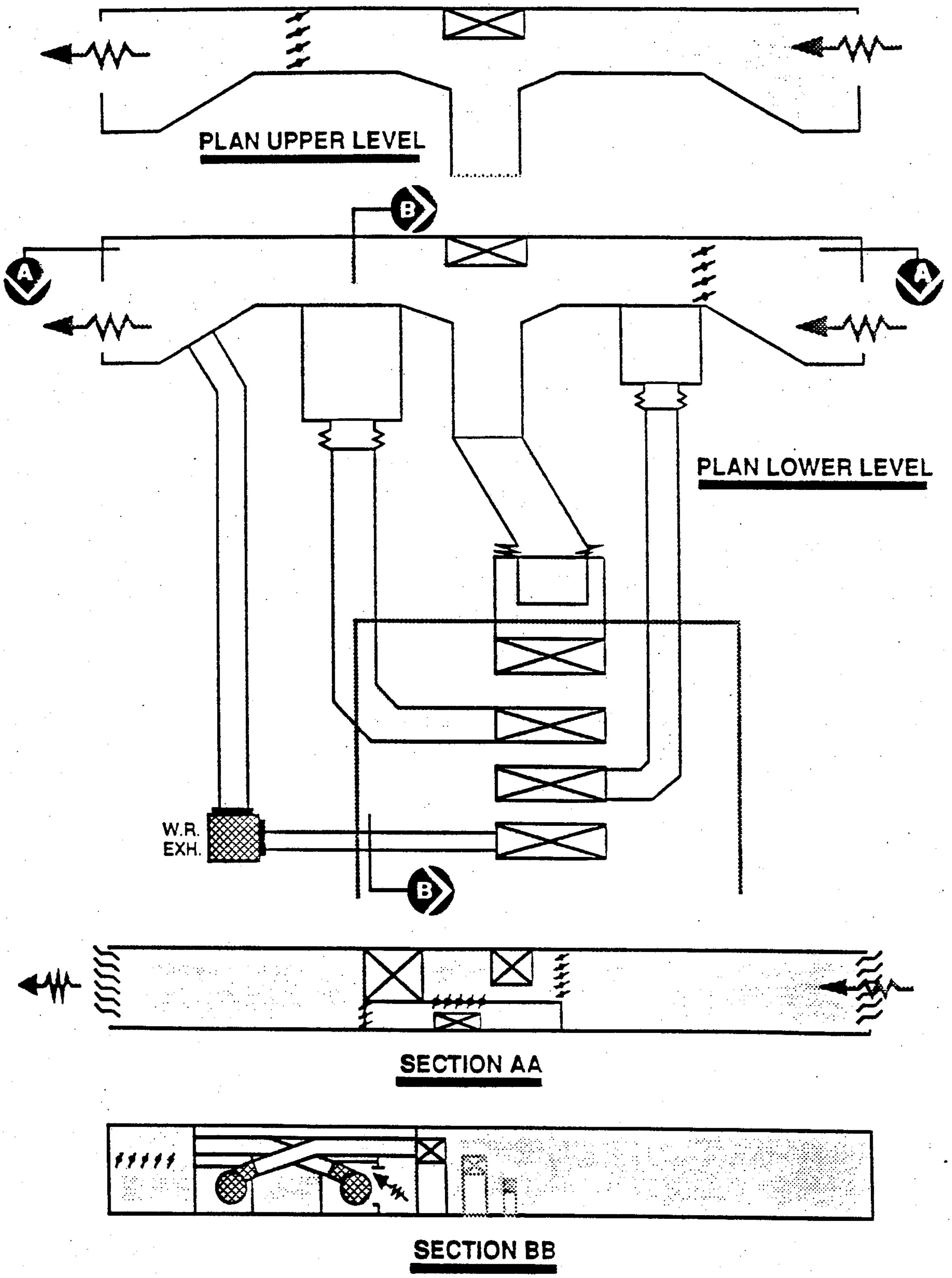


Figure 10

Duct Layout for Base Building with LTA

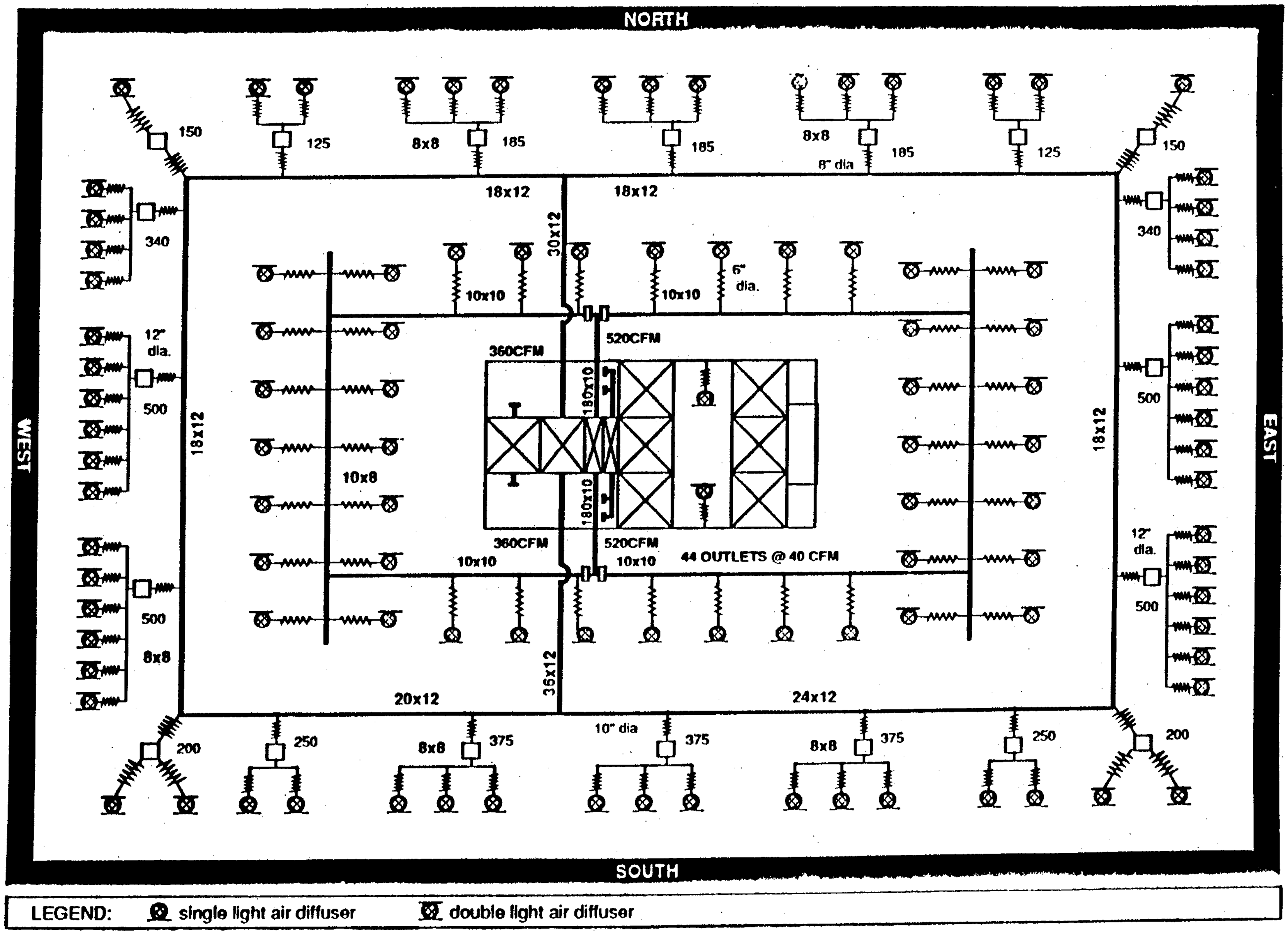


Figure 11

Duct Layout for Base Building wiht LTA and Reflective Glass

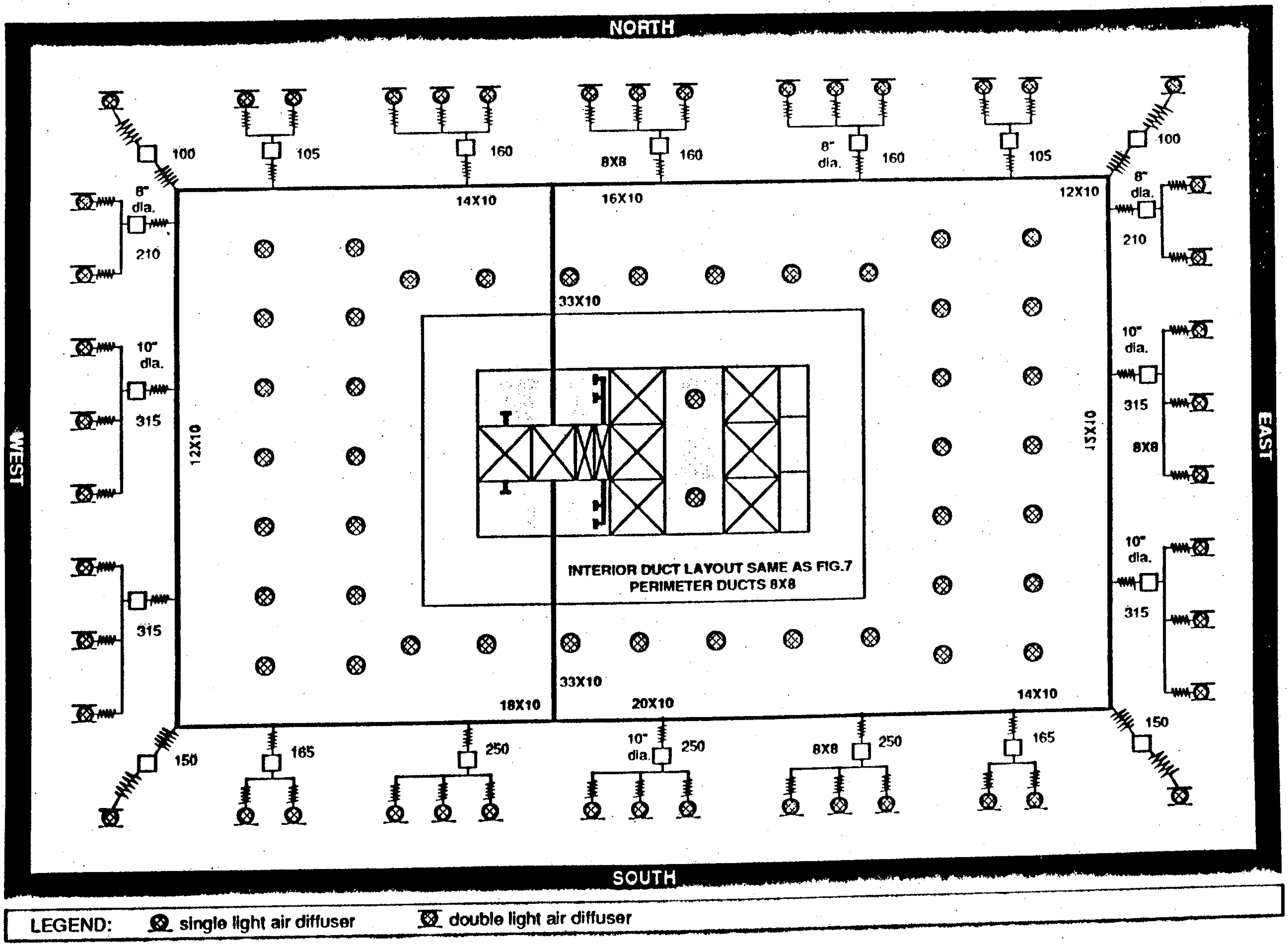
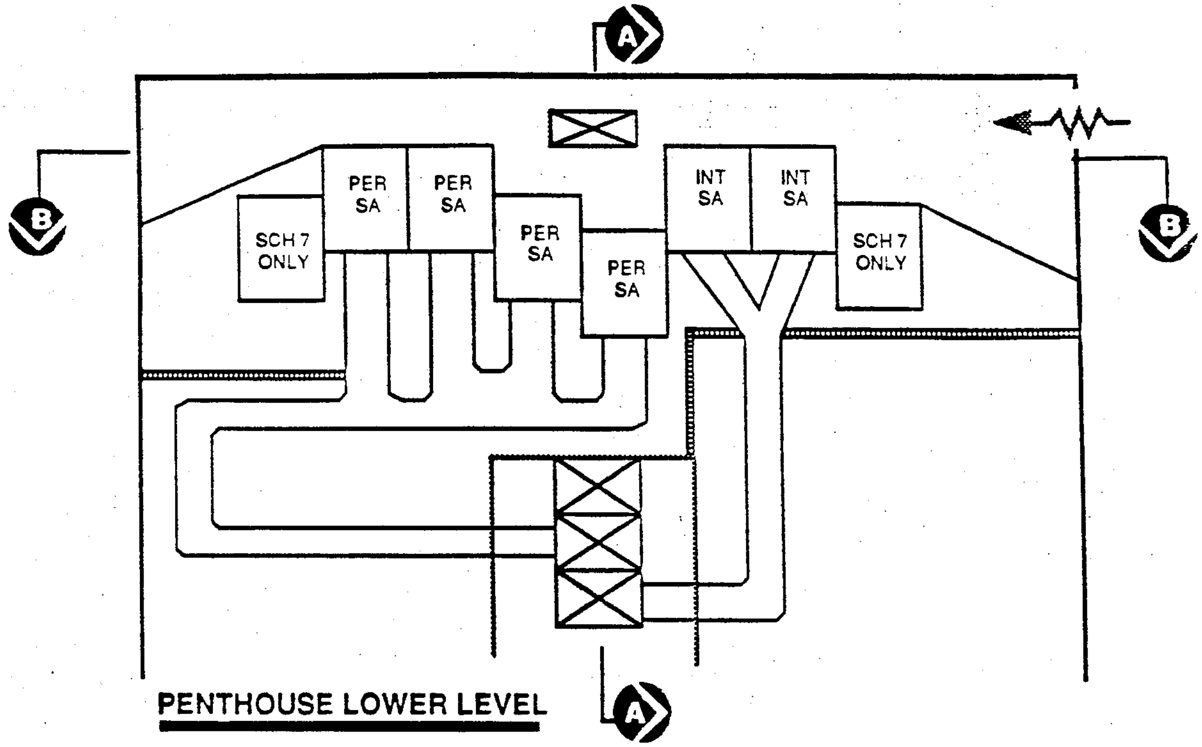
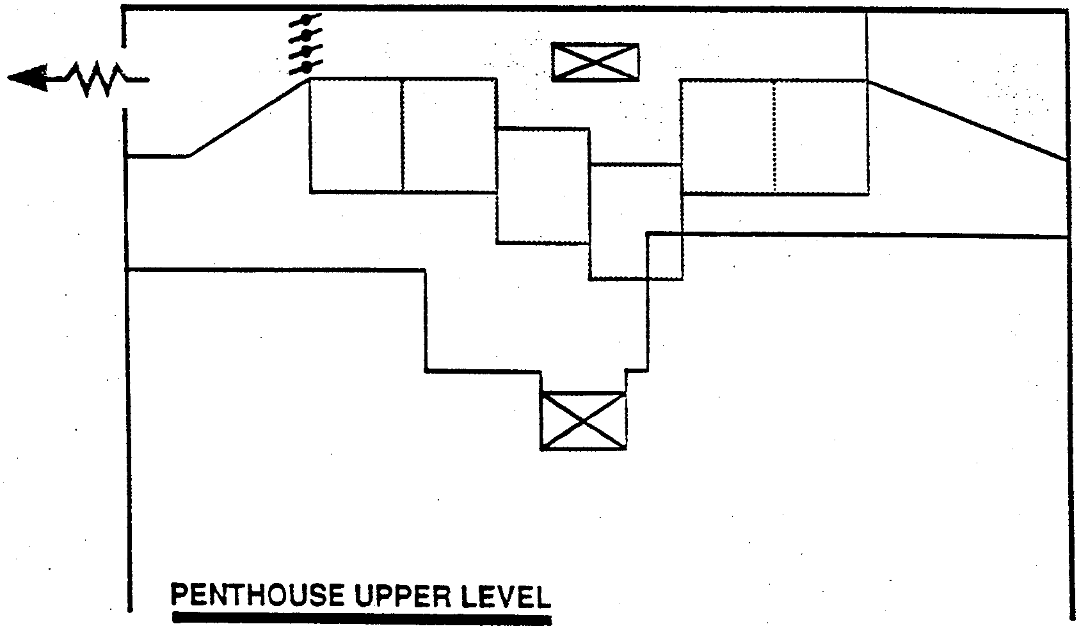


Figure 12

Penthouse Layout for 100% Outside Air Systems



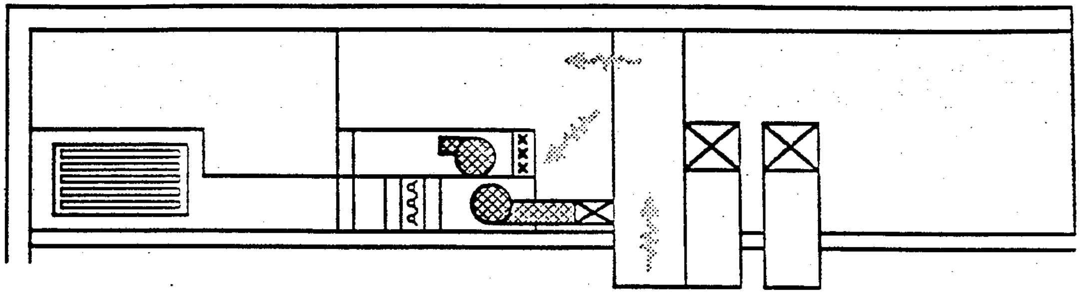
PENTHOUSE LOWER LEVEL



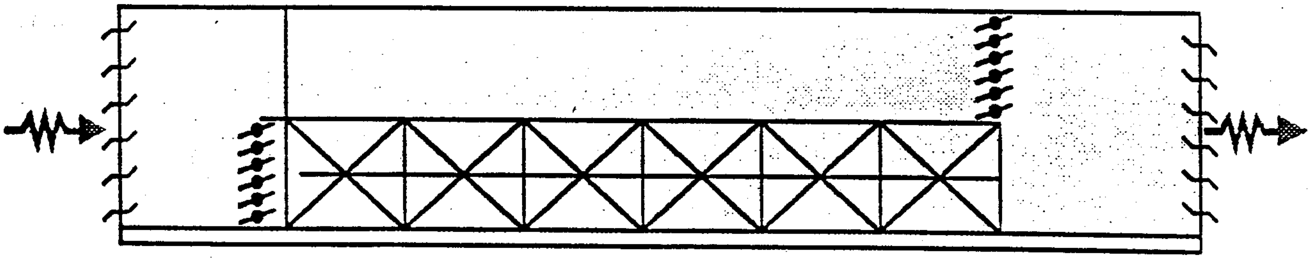
PENTHOUSE UPPER LEVEL

Figure 13

Sections for Figure 12



SECTION AA



SECTION BB

Figure 14
Duct Layout for McGill Jets

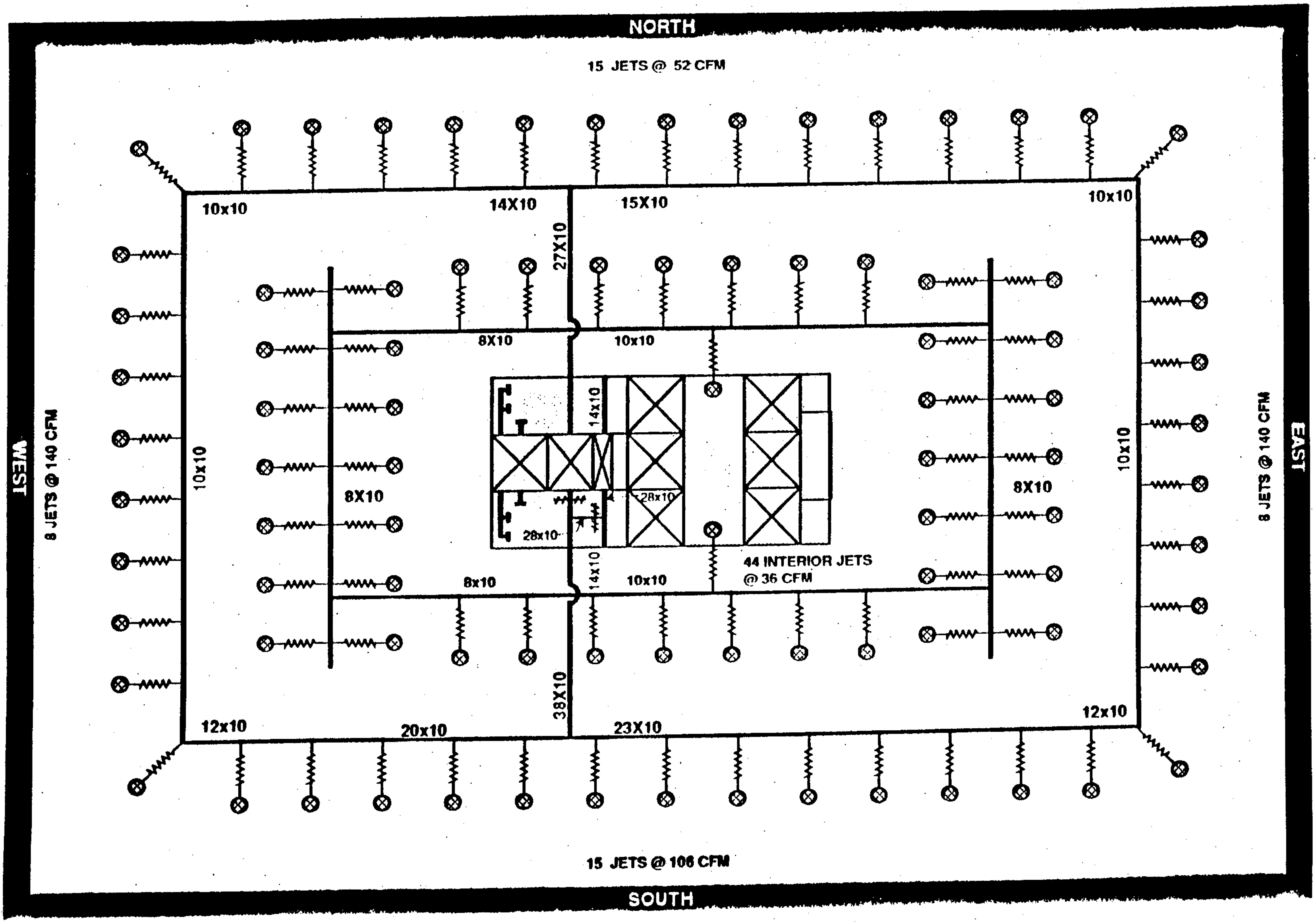
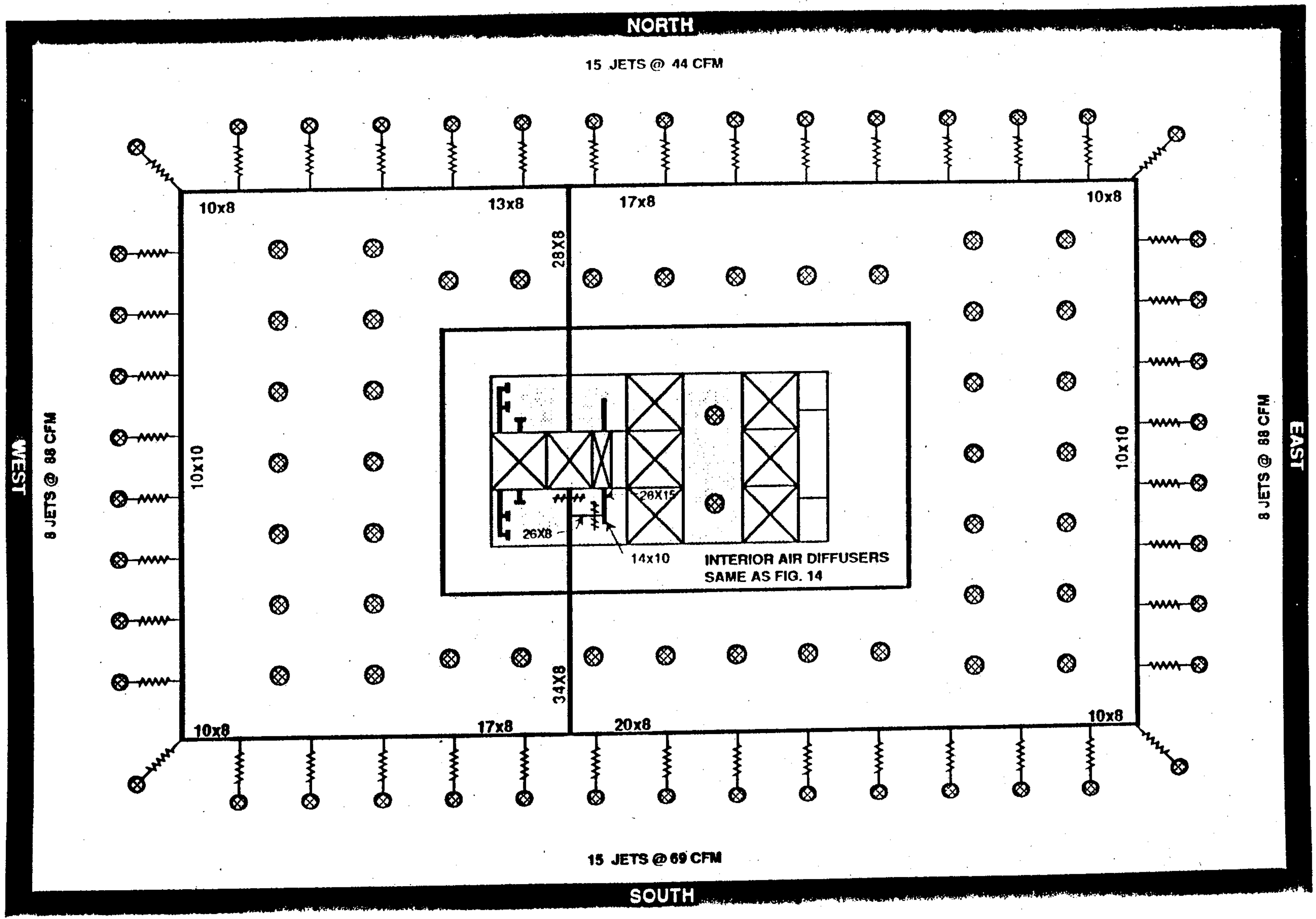
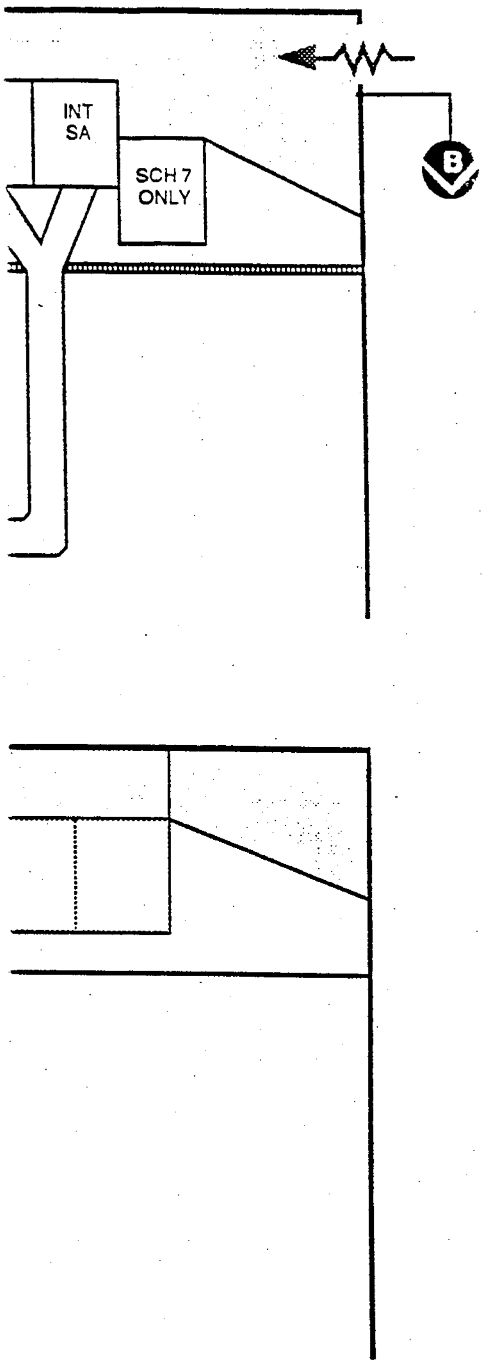


Figure 15

Duct Layout for McGill Jets with Reflective Glass



Systems


INT SA
SCH 7 ONLY
B

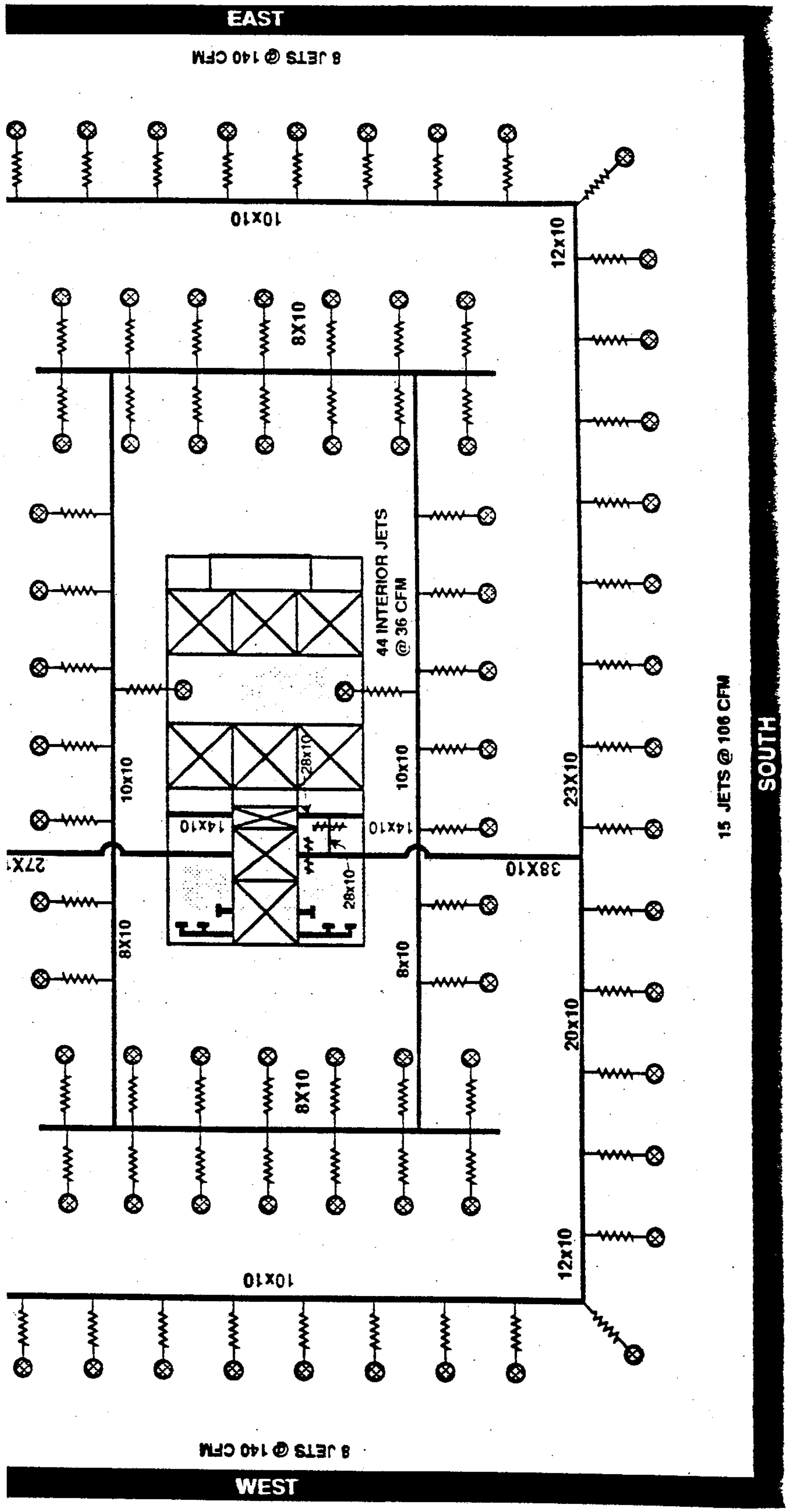

EAST
8 JETS @ 140 CFM
10x10
12x10
8X10
44 INTERIOR JETS @ 36 CFM
10x10
28x10
14x10
14x10
27X1
38X10
28x10
23X10
8X10
8x10
8X10
20x10
12x10
10x10
15 JETS @ 106 CFM
SOUTH
8 JETS @ 140 CFM
WEST

Figure 17

Costing Summary

Item	Base System	LTA System	LTA with reflective glass	LTA with 100% OA	LTA with 100% OA-Jets	LTA with 100% OA Jets with reflective glass	LTA 100% OA Jets with Wall-fin Perimeter
Sheet Metal							
On Floor Ducts	903,250	770,942	658,116	770,942	406,762	391,697	391,697
Duct Riser	183,593	150,202	125,907	150,202	144,986	132,151	132,151
Penthouse ducts & Plenums	83,573	77,392	69,359	92,242	90,372	85,321	85,321
Fans	129,217	83,732	65,186	77,154	82,808	56,188	56,188
Air Terminals	525,360	525,360	525,360	525,360	---	---	---
Misc. Equipment	84,568	73,612	65,032	83,732	82,434	71,896	71,896
Heat Exchangers	---	---	---	132,759	116,622	91,344	91,344
1800 Jet Fittings	---	---	---	---	135,000	135,000	135,000
1800 Damper Fittings	---	---	---	---	135,000	135,000	135,000
1800 Thermostatic Control Unit	---	---	---	---	450,000	450,000	450,000
1000 Elec. Heaters	---	---	---	---	275,000	275,000	---
1800 Remote Actuators	---	---	---	---	54,000	54,000	54,000
Subtotal	1,909,561	1,681,240	1,508,960	1,832,390	1,972,984	1,877,597	1,602,597
Insulation							
Ductwork	279,013	246,850	210,782	251,170	190,454	179,764	190,454
Piping	149,300	149,300	121,000	153,200	71,700	65,400	149,300
Sub Total	428,313	396,150	331,782	404,370	262,154	245,164	339,754
Electrical							
Base Electric	42,100	29,700	35,400	61,400	100,500	96,600	100,500
Heater Wiring	---	---	---	---	75,000	75,000	---
Subtotal	42,100	29,700	35,400	61,400	175,500	171,600	100,500

Figure 17

Costing Summary

Item	Base System	LTA System	LTA with reflective glass	LTA with 100% OA	LTA with 100% OA-Jets	LTA with 100% OA Jets with reflective glass	LTA 100% OA Jets with Wall-fin Perimeter
Automation							
Central Computer	20,000	20,000	20,00	20,000	20,000	20,000	20,000
Floor Controls	170,000	170,000	170,000	170,000	---	---	---
DDC Equipment	55,000	55,000	55,000	80,000	115,000	115,000	80,000
Engineering	80,000	80,000	80,000	90,000	45,000	45,000	45,000
Labour	225,000	225,000	225,000	240,000	120,000	120,000	120,000
Subtotal	550,000	550,000	550,000	600,000	300,000	300,000	265,000
System Balancing							
Air Balance	35,000	35,000	35,000	35,000	35,000	35,000	35,000
Water Balance	30,000	30,000	30,000	30,000	15,000	15,000	30,000
Subtotal	65,000	65,000	65,000	65,000	50,000	50,000	65,000
Piping							
Risers	140,000	140,000	140,000	140,000	---	---	140,000
Ring Mains	73,000	73,000	73,000	73,000	---	---	73,000
Radiation	92,000	92,000	92,000	92,000	---	---	—
Coils	41,000	41,000	30,000	53,000	53,000	53,000	53,000
Wallfin	---	---	---	---	---	---	350,000
Penthouse	49,000	49,000	49,000	49,000	49,000	49,000	49,000
Chilled Water	22,000	22,000	22,000	22,000	22,000	22,000	22,000
Cond. Water	36,000	36,000	36,000	36,000	36,000	32,000	36,000
Subtotal	453,000	453,000	442,000	465,000	160,000	156,000	723,000
Equipment							
Chillers	175,000	168,000	131,000	208,000	177,000	130,000	177,000
Air Handling	448,000	288,000	223,000	278,000	247,000	195,000	247,000

Figure 17

Costing Summary

Item	Base System	LTA System	LTA with reflective glass	LTA with 100% OA	LTA with 100% OA-Jets	LTA with 100% OA Jets with reflective glass	LTA 100% OA Jets with Wall-fin Perimeter
Cooling Tower	65,000	65,000	50,000	75,000	65,000	50,000	65,000
Heating Coils	30,000	30,000	30,000	30,000	---	---	---
Boilers	68,000	68,000	68,000	68,000	35,000	35,000	68,000
Pumps	71,000	71,000	69,000	75,000	72,000	63,000	72,000
Isolation	15,000	15,000	15,000	18,000	18,000	18,000	18,000
Expansion Tanks	18,000	18,000	18,000	18,000	10,000	10,000	18,000
Water Treat	18,000	18,000	18,000	18,000	12,000	12,000	18,000
Expansion Joints	10,000	10,000	10,000	10,000	4,000	4,000	10,000
Subtotal	918,000	751,000	632,000	798,000	640,000	517,000	693,000
Grand Total	4,365,974	3,926,090	3,565,142	4,226,160	3,560,638	3,317,361	3,788,851

ross f. meriwether/consulting engineering

3315 outrider san antonio texas 78247-4405 phone (512) 490-7081

computer analysis of building energy systems

September 4, 1992

Mr. Robert T. Tamblyn
Engineering Interface Limited
Suite 200, 2 Sheppard Ave. East
North York, Ontario, CANADA
M2N 5Y7

Bob, I have finally finished all of the comparison runs for the 100% O/A study. The enclosed summary charts include the base cases for the three cities that I previously sent you plus the six new cases. I changed the typo (which should have been 3,970 instead of 3,790) in the chart on the relative effects of infiltration and humidification. Otherwise, that chart is the same as last time.

As I mentioned on the phone, the base cases from the "2nd Pass Comparison Chart" have been changed slightly to accommodate two boilers instead of one, with a rated (peak) efficiency of 82% instead of 80%. This raised the seasonal efficiency for the boilers in Toronto to 67% for the conventional case, and 63% for the 100% O/A case (base conditions). The sizing and peak efficiencies now being used for boilers and chillers are:

Boilers sized at 2/3 of peak requirement, 82% max efficiency
Chillers sized at 1/2 of peak reqmt, .73 kw/ton for 45F, .65 kw/ton for 55F

To repeat the info from the July 24th letter so you won't have to look it up, the seven cases are identified as the 4th character of the run ID (such as ETB1P, or PTC3), with the seven cases being:

1 - the Base case, with SCg=0.33, Ug=0.33, Uw=0.1, Supply Air Temp=45F
2 - SCg changed to 0.16
3 - Ug changed to 0.125
4 - Uw changed to 0.05
5 - all three of the above changes
6 - original conditions except Supply Air Temp=55F
7 - 100% O/A and heat wheel used with air terminals at 45F

For Case 1, the conventional system and the 100% O/A jet system were run for Toronto, Edmonton, and Vancouver. For Case 2 through Case 6, the conventional system and the 100% O/A jet system were run for Toronto only. For Case 7, only the modified conventional system was run for Toronto.

As before, the enclosed disk contains all of the print files for all of the runs. The run types have been separated for convenience:

EREPRN has all of the building and airside models. The interior from Case 1 (such as ETB1I.PRN, or ETO1I.PRN) was the same for Cases 2 through 5, since only perimeter characteristics were changed. The interior was re-run for Cases 6 and 7.

TCRPRN has all of the summations of the perimeter and interior for each case (such as TTB1.PRN, or TT03.PRN).

EECPRN has all of the mechanical plant models (such as PTC1.PRN), with the "C" indicating that it is a combination of the conventional (the "B" in TTB1) and the 100% O/A (the "O" in TT01).

MUCPRN has all of the utility cost calculations. The first six runs are combined in UAC1.PRN, the next 10 runs are combined in UAC2.PRN, and the last run (the single case 7 run) is in UAC7.PRN.

I have enclosed a listing of the compressed files and the individual print files within each compressed file. To unload the print files, just mount the disk in drive A, and enter the command corresponding to the compressed filename, such as:

```
A:MUCPRN
```

which will uncompress all of the utility cost printouts.

If you wanted to get only one specific print file from a compressed file, just follow the compressed filename with the desired print filename, such as:

```
A:EECPRN PTC1.PRN   or   A:EREPRN ET01P.PRN
```

Since there are a lot of print files for all of these cases, I am sure you will want to be very selective in what you print. Your staff might get a little testy if you tie up the printer for two or three days. If you have any questions about getting to the desired print file, or any questions on interpreting results, just call.

Regards,

Ross F. Meriwether

COOLING/HEATING PEAKS AND CONSUMPTIONS

System	Actual Peak Cool Tons	Actual Peak Heat MBH	Total Cool Ton-hrs	Total Heat MMBtu
Conv,Case 1,Toronto	598	5,429	375,320	4,027
100% O/A #1,Toronto	537	4,452*	323,658	3,330*
Conv,Case 1,Edmonton	503	7,784	227,438	8,163
100% O/A #1,Edmonton	476	6,579*	194,159	7,245*
Conv,Case 1,Vancouver	465	4,093	300,864	1,776
100% O/A #1,Vancouver	436	2,934*	257,686	1,256*
Conv,Case 2,SCg=.16	513	5,429	295,016	4,957
100% O/A #2,SCg=.16	438	4,422*	244,661	4,148*
Conv,Case 3,Ug=.125	580	4,343	424,816	1,990
100% O/A #3,Ug=.125	531	3,103*	383,919	1,401*
Conv,Case 4,Uw=.05	592	5,201	379,870	3,573
100% O/A #4,Uw=.05	531	4,195*	329,415	2,900*
Conv,Case 5,SCg,Ug,Uw	498	4,115	341,557	2,247
100% O/A #5,SCg,Ug,Uw	429	2,814*	298,127	1,594*
Conv,Case 6,55F	590	5,335	303,515	3,997
100% O/A #6,55F	484	4,466*	258,411	3,317*
Conv,Case 7,100% O/A	593	3,760	369,900	3,364

* Note: These heating values are BEFORE converting the heating coils at the jets to electric resistance heating.

COMPARISON OF CONVENTIONAL SYSTEM TO 100% O/A JET SYSTEM

System	Energy Cost $	Gas Cost $	Elec Cost $	Max Dmd KW	Total Elec K-KWH	Total Gas MCF	Scheme
Conv,Case 1,Toronto	293,818	29,895	263,923	1,166	2,762	5,978	1
100% O/A #1,Toronto	311,099	17,635	292,464	1,129	3,112	3,526	5
Conv,Case 1,Edmonton	305,562	57,930	247,632	1,050	2,649	11,586	1E
100% O/A #1,Edmonton	336,769	39,995	296,774	1,061	3,250	8,000	5E
Conv,Case 1,Vancouver	264,171	15,015	249,156	1,007	2,684	3,002	1v
100% O/A #1,Vancouver	278,998	7,0950	271,903	1,018	2,855	1,419	5v
Conv,Case 2,SCg=.16	285,241	35,630	249,611	1,069	2,677	7,126	2
100% O/A #2,SCg=.16	307,970	21,100	286,870	1,017	3,119	4,219	6
Conv,Case 3,Ug=.125	282,001	16,750	265,251	1,136	2,790	3,351	1a
100% O/A #3,Ug=.125	293,150	8,0355	285,115	1,125	2,967	1,606	5a
Conv,Case 4,Uw=.05	290,221	26,860	263,361	1,160	2,761	5,372	1w
100% O/A #4,Uw=.05	306,263	15,300	290,963	1,122	3,075	3,060	5w
Conv,Case 5,SCg,Ug,Uw	269,779	18,160	251,619	1,045	2,694	3,631	1aw
100% O/A #5,SCg,Ug,Uw	280,804	8,4105	272,394	1,007	2,904	1,682	5aw
Conv,Case 6,55F	295,548	30,215	265,333	1,160	2,770	6,044	3
100% O/A #6,55F	310,728	17,540	293,188	1,068	3,101	3,507	7
Conv,Case 7,100% O/A	287,006	24,605	262,401	1,146	2,745	4,920	4

TOTAL ANNUAL ELECTRIC USAGE IN KWH

System	Lights & Plugs	All Fans	Chlrs	Cool Accs	Heat Accs	Elec Heat
Conv,Case 1,Toronto	2,194,186	205,173	256,102	74,129	32,638	0
100% O/A #1,Toronto	"	273,953	224,856	68,767	20,158	329,741
Conv,Case 1,Edmonton	"	200,496	149,233	42,050	63,496	0
100% O/A #1,Edmonton	"	333,054	131,338	40,972	43,282	507,656
Conv,Case 1,Vancouver	"	194,854	208,386	69,540	17,124	0
100% O/A #1,Vancouver	"	221,480	185,899	67,805	6,201	179,506
Conv,Case 2,SCg=.16	"	179,750	204,605	61,639	36,829	0
100% O/A #2,SCg=.16	"	262,256	171,338	53,387	22,092	415,427
Conv,Case 3,Ug=.125	"	218,879	281,046	75,251	20,360	0
100% O/A #3,Ug=.125	"	258,820	257,968	72,918	6,685	175,970
Conv,Case 4,Uw=.05	"	205,641	258,205	73,634	29,710	0
100% O/A #4,Uw=.05	"	266,728	227,901	68,790	15,115	301,897
Conv,Case 5,SCg,Ug,Uw	"	187,363	228,869	62,859	20,551	0
100% O/A #5,SCg,Ug,Uw	"	230,402	200,862	55,680	6,871	215,604
Conv,Case 6,55F	"	300,203	182,649	57,276	35,366	0
100% O/A #6,55F	"	353,990	157,718	49,245	17,658	327,780
Conv,Case 7,100% O/A	"	203,447	252,412	73,919	21,224	0

date 920904

RELATIVE EFFECTS OF INFILTRATION AND HUMIDIFICATION ON TOTAL HEATING LOAD

System	Orig Heat MMBtu	Orig Cool K T-Hr	Chng Heat w/No Infil MMBtu	Chng Cool w/No Infil K Thr	Chng Heat w/Ext Humid MMBtu	Total Extnl Humid Load MMBtu	Chng Cool w/Ext Humid K Thr
Conv,Case 1,Tor,Perim	3,970	198	-1,760	+18	-180	188	+1
Conv,Case 1,Tor,Inter	57	177			-39	323	+3
100% O/A,#1,Tor,Perim	3,330	160	-1,754	+24	-221	246	0
100% O/A,#1,Tor,Inter	0	164			0	213	+2
Conv,Case 1,Edm,Perim	7,902	126	-3,151	+19	-341	378	+4
Conv,Case 1,Edm,Inter	262	102			-149	556	+6
100% O/A,#1,Edm,Perim	7,245	98	-3,414	+25	-560	569	+2
100% O/A,#1,Edm,Inter	0	96			0	366	+5
Conv,Case 1,Van,Perim	1,765	145	-892	+27	-36	42	+1
Conv,Case 1,Van,Inter	11	155			-6	83	+1
100% O/A,#1,Van,Perim	1,256	110	-730	+31	-37	46	0
100% O/A,#1,Van,Inter	0	148			0	41	+1

date 920904

Bob:

The top line is the new case (I called it Case #X), and the second line is the original 100% O/A Case #1 for Toronto (it was also the second line in each set of the previous charts you received).

When preparing the plant inputs for the new run, I discovered that I had used the TOTAL peak heating (including the 640 MBH of electric heat) to size the heating system pumps for the original 100% O/A case. This resulted in a slight oversizing of the pumps (15%), so to make this comparison apples to apples, I re-ran the original case with the correct boiler pump size (10.3 KW instead of 12.0 KW).

This changed some of the figures for the 100% O/A Case #1 in the previous chart slightly. To help you see how much the revised original changed, I have faxed two copies of the comparison chart: one "clean" copy, and one copy with the original figures marked underneath the revised run figures. You probably ought to use these new figures in any reference to the 100% O/A Case #1 for consistency.

date 920911

COMPARISON OF 100% O/A ALL GAS HEAT TO ORIG 100% O/A WITH ELEC HEAT AT PERIM

System	Energy Cost $	Gas Cost $	Elec Cost $	Max Dmd KW	Total Elec K-KWH	Total Gas MCF	Scheme
100% O/A #X,All Gas	301,202	36,270	264,942	1,129	2,814	7,257	5X
100% O/A #1,Elec Perim	310,766	17,530	293,236	1,129	3,109	3,506	5

COOLING/HEATING PEAKS AND CONSUMPTIONS

System	Actual Peak Cool Tons	Actual Peak Heat MBH	Total Cool Ton-hrs	Total Heat MMBtu	
100% O/A #X,All Gas	537	4,452	329,804	3,618	5X
100% O/A #1,Elec Perim	537	4,452*	323,658	3,330*	5

* Note: These heating values are BEFORE converting the heating coils at the jets to electric resistance heating.

TOTAL ANNUAL ELECTRIC USAGE IN KWH

System	Lights & Plugs	All Fans	Chlrs	Cool Accs	Heat Accs	Elec Heat	
100% O/A #X,All Gas	2,194,186	273,953	228,106	69,112	77,997	0	5X
100% O/A #1,Elec Perim	"	273,953	224,856	68,767	17,524	329,741	5

date 920911

COMPARISON OF 100% O/A ALL GAS HEAT TO ORIG 100% O/A WITH ELEC HEAT AT PERIM

System	Energy Cost $	Gas Cost $	Elec Cost $	Max Dmd KW	Total Elec K-KWH	Total Gas MCF
100% O/A #X,All Gas	301,202	36,270	264,942	1,129	2,814	7,257
100% O/A #1,Elec Perim	310,766	17,530	293,236	1,129	3,109	3,506
	311,099	17,635	292,464*	1,129	3,112	3,526

*This was a TYPO. It should have been 293,464 so the new figure is really down slightly

COOLING/HEATING PEAKS AND CONSUMPTIONS

System	Actual Peak Cool Tons	Actual Peak Heat MBH	Total Cool Ton-hrs	Total Heat MMBtu
100% O/A #X,All Gas	537	4,452	329,804	3,618
100% O/A #1,Elec Perim	537	4,452*	323,658	3,330*

no change

* Note: These heating values are BEFORE converting the heating coils at the jets to electric resistance heating.

TOTAL ANNUAL ELECTRIC USAGE IN KWH

System	Lights & Plugs	All Fans	Chlrs	Cool Accs	Heat Accs	Elec Heat
100% O/A #X,All Gas	2,194,186	273,953	228,106	69,112	77,997	0
100% O/A #1,Elec Perim	"	273,953	224,856	68,767	17,524	329,741
					20,158	

date 920911

```
OUTPUT FILE FOR MUC PROGRAM: 100% O/A CASE X (ALL GAS HEAT) & ORIG 100% O/A CASE #1, TORONTO

             GAS      GAS     ELEC       ELEC  AUX FUEL  AUX FUEL  COOLING    COOLING  TOT STM    TOT STM
          DEMAND  CONSUMP   DEMAND    CONSUMP   CONSUMP             DEMAND    CONSUMP   DEMAND    CONSUMP
SYS  MO      MCF      MCF       KW        KWH      UNIT     HOURS     TONS    TON-HRS      MBH       MBTU

SYSTEM X1  100% O/A ALL GAS

X1    1     74.8   1435.7     705.    223917.        0.        0.       0.         0.    4452.    989845.
X1    2     79.6   1153.4     684.    196806.        0.        0.       6.        12.    4452.    765655.
X1    3     44.9    816.4     696.    214796.        0.        0.      84.      2055.    4324.    422994.
X1    4     19.5    446.3     750.    221493.        0.        0.     181.      7026.    1536.    104056.
X1    5     21.2    430.2     747.    230824.        0.        0.     170.     12209.    2183.     78853.
X1    6     15.4    198.5    1004.    242939.        0.        0.     446.     50799.     197.     18570.
X1    7     14.4    134.8    1129.    291765.        0.        0.     537.     90070.     207.      9620.
X1    8     10.0    137.4    1053.    280874.        0.        0.     487.     79499.     158.     11441.
X1    9     14.6    184.5    1013.    248847.        0.        0.     456.     60455.     187.     17044.
X1   10     21.9    411.1     968.    240200.        0.        0.     414.     26876.    2078.     90952.
X1   11     38.3    736.2     662.    209638.        0.        0.      42.       684.    4117.    351605.
X1   12     61.3   1172.1     661.    211490.        0.        0.      23.       120.    4363.    756934.

SYSTEM 12  100% O/A #1 W/JETS,TOR,45F

12    1     59.9    965.2     891.    314928.        0.        0.       0.         0.    3812.    697785.
12    2     61.7    742.3     891.    268040.        0.        0.       6.        12.    3812.    531454.
12    3     27.1    387.6     832.    254798.        0.        0.      80.      1983.    3812.    250003.
12    4      8.6     68.9     855.    218190.        0.        0.     101.      6218.    2374.     15270.
12    5     11.2     65.4     799.    227067.        0.        0.     170.     11700.    2865.     11588.
12    6      1.8     43.9    1004.    238458.        0.        0.     446.     49388.       0.         0.
12    7      1.8     46.4    1129.    289165.        0.        0.     537.     89394.       0.         0.
12    8      1.8     46.7    1053.    278220.        0.        0.     487.     78750.       0.         0.
12    9      1.8     43.6    1011.    244686.        0.        0.     455.     59420.       0.         0.
12   10     11.5     77.4     975.    236664.        0.        0.     434.     25989.    3102.     22197.
12   11     21.3    314.2     851.    245939.        0.        0.      42.       684.    3812.    192429.
12   12     44.4    704.5     873.    292870.        0.        0.      23.       120.    3812.    483380.


ANNUAL VALUES FOR ALL SYSTEMS  (NOT INCLUDED ON OUTPUT FILE FOR MUC)

X1 ANN      79.6   7256.5    1129.   2813587.        0.        0.     537.    329804.    4452.   3617569.
12 ANN      61.7   3506.1    1129.   3109024.        0.        0.     537.    323658.    3812.   2204107.
```

100% O/A CASE X (ALL GAS HEAT) & ORIG 100% O/A CASE #1, TORONTO Scenario 5x 9/11/1992

SYS	NO	ENGINE ENERGY MMBTU*	BOILER ENERGY MMBTU*	PROCESS ENERGY MMBTU*	ELECTRIC BASE KWH	ELECTRIC HTNG ACC KWH	ELECTRIC CLNG ACC KWH	ELECTRIC GENR ACC KWH	ELECTRIC OVRL ACC KWH	ELECTRIC HEATING KWH	ELECTRIC COOLING KWH	ELECTRIC PROCESS KWH	GAS/STM COOLING MBTU
SYSTEM X1 100% O/A ALL GAS													
X1	1	0.	1389.	46.	214854.	9063.	0.	0.	0.	0.	0.	0.	0.
X1	2	0.	1112.	41.	188479.	8182.	86.	0.	0.	0.	59.	0.	0.
X1	3	0.	771.	46.	201838.	8820.	1626.	0.	0.	0.	2513.	0.	0.
X1	4	0.	401.	46.	201320.	7767.	4801.	0.	0.	0.	7605.	0.	0.
X1	5	0.	384.	46.	203658.	7959.	7012.	0.	0.	0.	12194.	0.	0.
X1	6	0.	155.	44.	195657.	3607.	9874.	0.	0.	0.	33801.	0.	0.
X1	7	0.	88.	46.	216254.	2151.	13646.	0.	0.	0.	59714.	0.	0.
X1	8	0.	91.	47.	214244.	2166.	12810.	0.	0.	0.	51655.	0.	0.
X1	9	0.	141.	44.	195922.	3292.	10534.	0.	0.	0.	39098.	0.	0.
X1	10	0.	365.	46.	205842.	7167.	7303.	0.	0.	0.	19888.	0.	0.
X1	11	0.	691.	45.	198398.	8772.	1170.	0.	0.	0.	1298.	0.	0.
X1	12	0.	1128.	44.	201907.	9052.	250.	0.	0.	0.	282.	0.	0.
X1	ANN	0.	6715.	541.	2438373.	77997.	69112.	0.	0.	0.	228106.	0.	0.
YSTEM 12 100% O/A #1 W/JETS,TOR,45F													
12	1	0.	919.	46.	310436.	4492.	0.	0.	0.	0.	0.	0.	0.
12	2	0.	701.	41.	264347.	3548.	86.	0.	0.	0.	59.	0.	0.
12	3	0.	342.	46.	248584.	2110.	1625.	0.	0.	0.	2479.	0.	0.
12	4	0.	23.	46.	205865.	341.	4771.	0.	0.	0.	7213.	0.	0.
12	5	0.	19.	46.	207793.	310.	7004.	0.	0.	0.	11960.	0.	0.
12	6	0.	0.	44.	195358.	127.	9851.	0.	0.	0.	33122.	0.	0.
12	7	0.	0.	46.	216050.	135.	13621.	0.	0.	0.	59360.	0.	0.
12	8	0.	0.	47.	214066.	138.	12756.	0.	0.	0.	51261.	0.	0.
12	9	0.	0.	44.	195680.	124.	10404.	0.	0.	0.	38478.	0.	0.
12	10	0.	31.	46.	209759.	331.	7230.	0.	0.	0.	19344.	0.	0.
12	11	0.	269.	45.	241598.	1873.	1170.	0.	0.	0.	1298.	0.	0.
12	12	0.	660.	44.	288342.	3997.	250.	0.	0.	0.	282.	0.	0.
12	ANN	0.	2965.	541.	2797879.	17524.	68767.	0.	0.	0.	224856.	0.	0.

* GAS AND AUXILIARY FUEL COMBINED

```
MONTHLY AND ANNUAL UTILITY COST FOR

 100% O/A CASE #X (ALL GAS HEAT) & ORIG 100% O/A CASE #1                                    9/11/1992

                AVER    UNIT              AVER    UNIT
     ELECTRIC   RATE    COST       GAS    RATE    COST
      COST,$   C/KWH  $/SQFT   COST,$   $/MCF  $/SQFT

YSTEM X1     100% O/A X (ALL GAS)

 JAN    19753.  8.822   0.074     7180.    5.00   0.027
 FEB    18249.  9.273   0.068     5765.    5.00   0.022
 MAR    19221.  8.948   0.072     4080.    5.00   0.015
 APR    20265.  9.149   0.076     2230.    5.00   0.008
 MAY    20642.  8.943   0.077     2150.    5.00   0.008
 JUN    24729. 10.179   0.093      990.    5.00   0.004
 JUL    28640.  9.816   0.107      675.    5.00   0.003
 AUG    27104.  9.650   0.102      685.    5.00   0.003
 SEP    25118. 10.094   0.094      920.    5.00   0.003
 OCT    24110. 10.037   0.090     2055.    5.00   0.008
 NOV    18521.  8.835   0.069     3680.    5.00   0.014
 DEC    18590.  8.790   0.070     5860.    5.00   0.022

 NN    264942.  9.417   0.992    36270.    5.00   0.136


 YSTEM 12     100% O/A 1,TOR,45F

 JAN    26396.  8.381   0.099     4825.    5.00   0.018
 EB     24295.  9.064   0.091     3710.    5.00   0.014
 AR     22888.  8.983   0.086     1940.    5.00   0.007
 APR    21565.  9.884   0.081      345.    5.00   0.001
 AY     21191.  9.332   0.079      325.    5.00   0.001
 UN     24528. 10.286   0.092      220.    5.00   0.001
 JUL    28524.  9.864   0.107      230.    5.00   0.001
 UG     26985.  9.699   0.101      235.    5.00   0.001
 EP     24904. 10.178   0.093      220.    5.00   0.001
 OCT    24048. 10.161   0.090      385.    5.00   0.001
 NOV    22753.  9.252   0.085     1570.    5.00   0.006
 EC     25159.  8.591   0.094     3525.    5.00   0.013

ANN    293236.  9.432   1.098    17530.    5.00   0.066


TOTAL UTILITY COST

 NUM   NAME                              ANN $

 X1    100% O/A X (ALL GAS)            301212.
 .2    100% O/A 1,TOR,45F              310766.


 NUM       JAN $    FEB $    MAR $    APR $    MAY $    JUN $    JUL $    AUG $    SEP $    OCT $    NOV $    DEC $

 X1       26933.   24014.   23301.   22495.   22792.   25719.   29315.   27789.   26038.   26165.   22201.   24450.
 12       31221.   28005.   24828.   21910.   21516.   24748.   28754.   27220.   25124.   24433.   24323.   28684.
```

APPENDIX B-1

AIR VOLUME REQUIREMENTS

				CFM OVERALL			CFM/FLOOR			CFM/ZONE				
System	Supply Air Temp F	Shad-ing Coeff	Heat Exch.	SUPPLY AIR PER	SUPPLY AIR INT	Return Air	SUPPLY AIR PER	SUPPLY AIR INT	Return Air	SOUTH	EAST	WEST	NORTH	INT
Base System	55	0.33	NO	138,000	50,500	168,500	6,900	2,525	8,425	195	260	96	260	61
LTA System	45	0.33	NO	88,700	32,500	101,200	4,435	1,625	5,060	125	167	62	167	40
LTA Reflective Glass	45	0.16	NO	61,400	32,500	73,900	3,070	1,625	3,695	82	103	52	103	40
LTA 100%OA	45	0.33	YES	88,700	32,500	101,200	4,435	1,625	5,060	125	167	62	167	40
LTA 100%OA Jets	45	0.33	YES	75,000	[1] 30,000	105,000	3,750	1,500	5,250	106	142	52	142	36
LTA 100%OA Jets Reflective Glass	45	0.16	YES	52,000	[2] 30,000	82,000	2,600	1,500	4,100	69	88	44	88	36
LTA 100%OA Jets Gas Heat Perimeter	55	0.33	YES	116,700	[3] 46,700	163,400	5,835	2,335	8,170	152	203	75	203	53

NOTES:

[1] This fan will be increased in size from 30,000 cfm to 50,000 cfm to provide cool air to the south zone on sunny winter days.

[2] This fan will be increased in size from 30,000 cfm to 42,000 cfm to provide cool air to the south zone on sunny winter days.

[3] This fan will be increased in size from 46,700 cfm to 75,000 cfm to provide cool air to the south zone on sunny winter days.

APPENDIX B-2

MOTOR SIZING

Item		Base System	LTA	LTA Reflective Glass	LTA 100% O.A.	LTA-100% O.A. Jets	LTA-100% O.A. Jets Reflective Glass	LTA-100% O.A. Jets Gas Heat Perimeter
Carnes Wheels Total Area (ft^2) Perimeter		-	-	-	4 @ 92.2	{2 @ 92.2 {2 @ 64.4	{2 @ 76.6 {1 @ 64.4	5 @ 92.2
Interior		-	-	-	2 @ 64.4	2 @ 92.2	2 @ 64.4	3 @ 92.2
Supply Fans Perimeter	cfm	1 @ 138,000	1 @ 88,700	1 @ 61,400	4 @ 22,200	{2 @ 22,100 {2 @ 15,400	{2 @ 18,300 {1 @ 15,400	5 @ 23,300
	SP	4"	4"	4"	5 ½"	5 ½"	5 ½"	5 ½"
	BHP	155	89	155	4 @ 22	{2 @ 31 {2 @ 21	{2 @ 25 {1 @ 21	5 @ 32
	Motor Size	200	60	200	4 @ 25	{2 @ 40 {2 @ 30	{3 @ 25	5 @ 40
Interior	cfm	1 @ 50,500	1 @ 32,500	1 @ 32,500	2 @ 16,250	2 @ 15,000	2 @ 15,000	3 @ 15,600
	SP	4"	4"	4"	5 ½"	5 ½"	5 ½"	5 ½"
	BHP	57	33	33	2 @ 16	2 @ 21	2 @ 21	3 @ 21
	Motor Size	60	40	40	2 @ 20	2 @ 25	2 @ 25	3 @ 25
Return Fan	cfm	1 @ 168,500	1 @ 101,200	1 @ 73,900	{2 @ 16,250 {2 @ 22,200	{2 @ 30,900 {2 @ 21,600	{1 @ 15,400 {2 @ 18,300	{3 @ 15,600 {5 @ 23,300
	SP	1 ½"	1 ½"	1 ½"	2 ½"	2 ½"	2 ½"	2 ½"
	BHP	1 @ 63	1 @ 38	1 @ 28	{2 @ 10 {2 @ 14	{2 @ 19 {2 @ 13	{1 @ 9 {2 @ 11	{3 @ 9 {5 @ 14
	Motor Size	1 @ 75	1 @ 40	1 @ 30	{2 @ 10 {2 @ 15	{2 @ 20 {2 @ 15	{1 @ 10 {2 @ 15	{3 @ 10 {5 @ 15
Filters - 40% NBS		Supply Air only	Supply Air only	Supply Air only	Supply & Return	Supply & Return	Supply & Return	Supply & Return

APPENDIX B-2

MOTOR SIZING

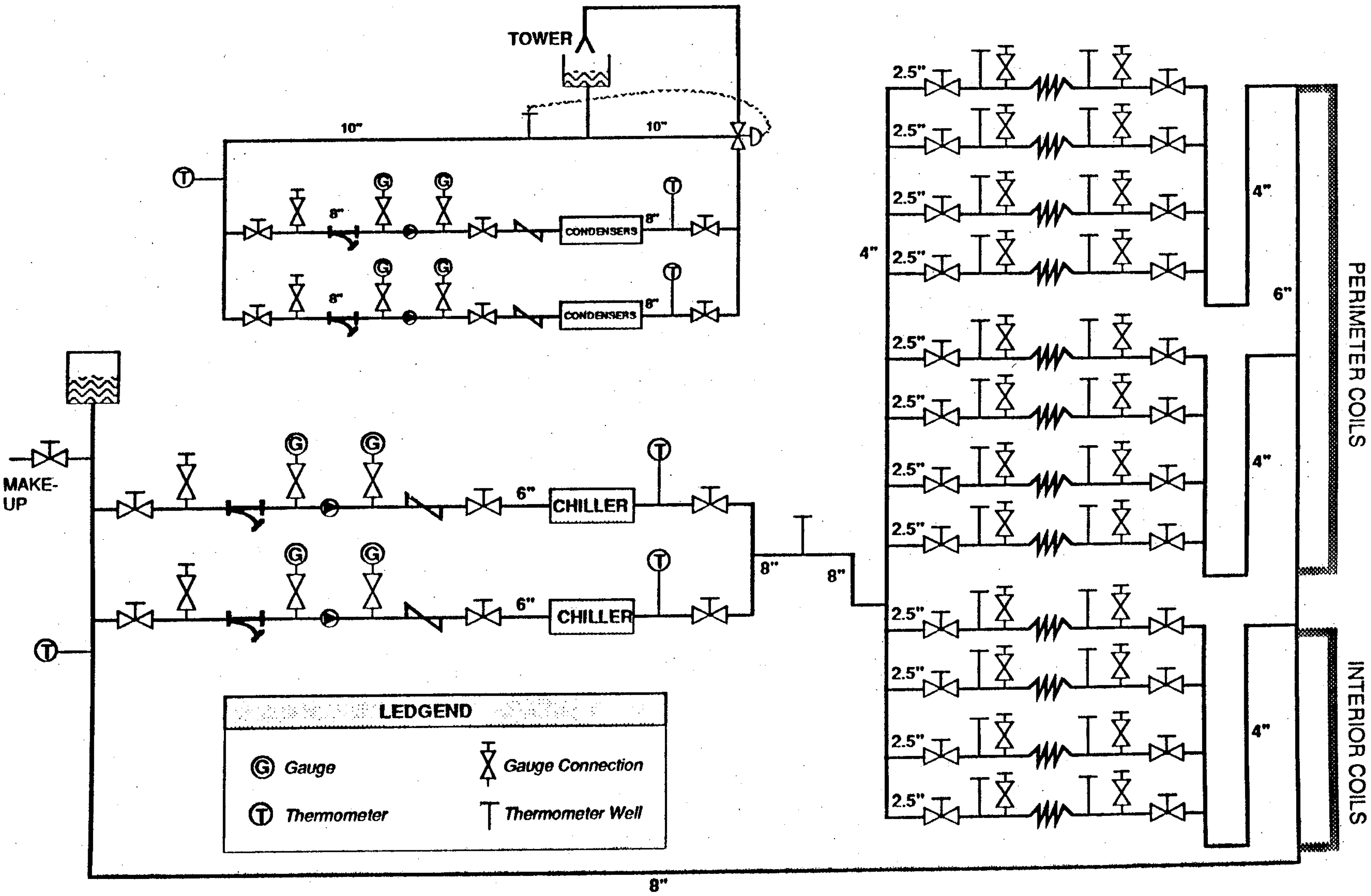
Item	Base System	LTA	LTA Reflective Glass	LTA 100% O.A.	LTA-100% O.A. Jets	LTA-100% O.A. Jets Reflect-ive Glass	LTA-100% O.A. Jets Gas Heat Perimeter
Cooling Coils (ft^2) (6 row 14 fins/inch)							
Perimeter	276	178	123	4 @ 45	{2 @ 45 {2 @ 31	{2 @ 37 {1 @ 31	5 @ 47
Interior	101	65	65	2 @ 33	2 @ 31	2 @ 31	5 @ 31
Heating Coils (2 row 8 fins/inch)							
Perimeter	276	178	123	4 @ 45	{2 @ 45 {2 @ 31	{2 @ 37 {1 @ 31	5 @ 47
Sprays	One	One	One	Four	Four	Three	Five

APPENDIX B-3

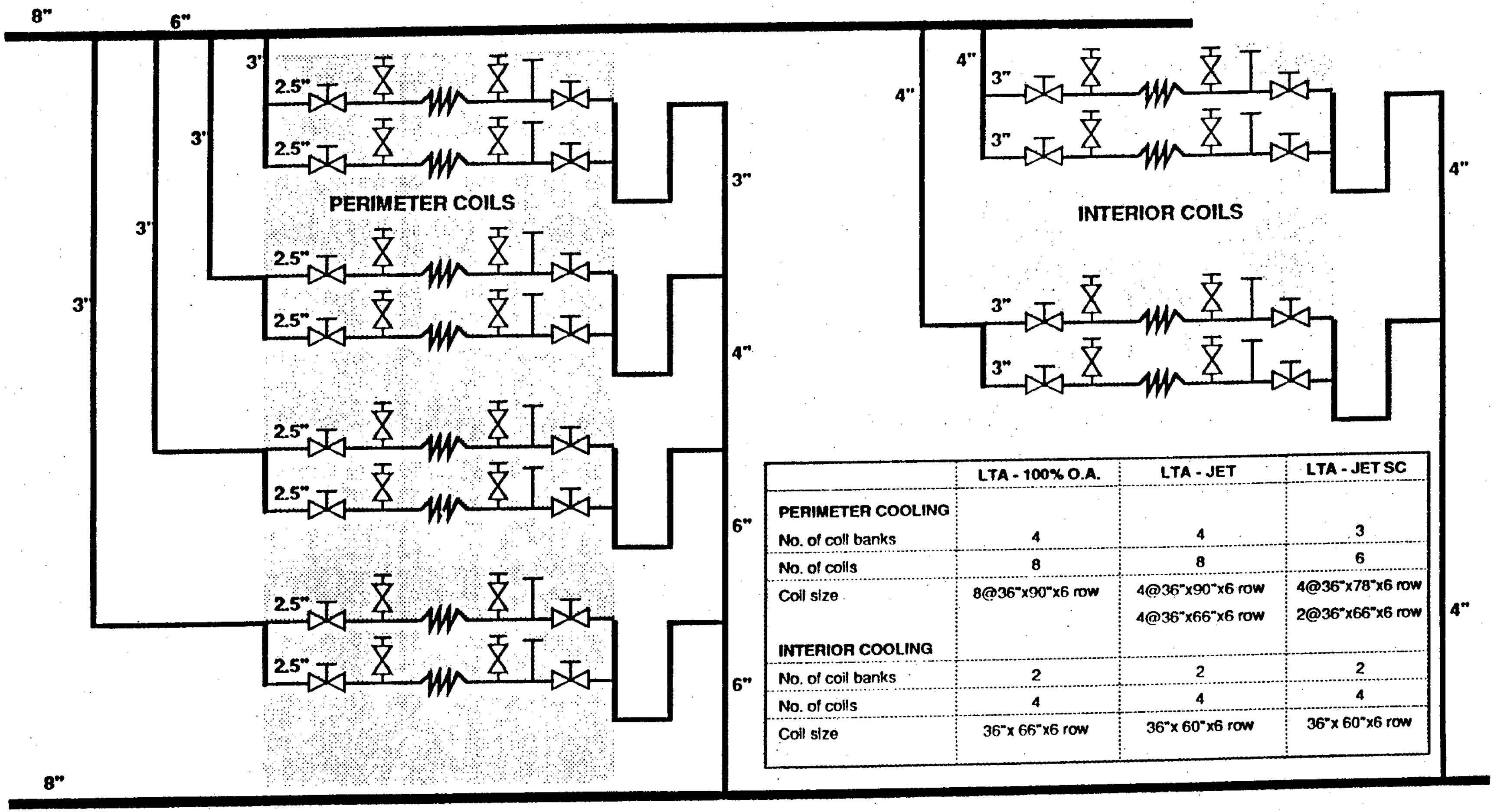
PUMPS

	Base System	LTA System	LTA Reflective Glass	LTA 100% O.A.	LTA 100% O.A. Jets	LTA 100% O.A. Jets Reflective Glass
TONS	492	502	428	514	471	383
Ch.W GPM	738	753	642	771	706	575
Ft. Head	60	60	60	60	60	60
BHP actual	15.8	16.1	13.8	16.5	15.1	12.3
nominal	20	20	15	20	20	15
Armstrong Cat. #	6G	6G	6G	6G	6G	6G
Cond.W. GPM	1476	1506	1284	1542	1413	1149
Ft. Head	50	50	50	50	50	50
BHP actual	26.4	26.9	22.9	27.5	25.2	20.5
nominal	30	30	25	30	30	25
Armstrong Cat. #	All 10 x 10 @ 1150 RPM					6G
Primary Hot Water GPM	600	600	600	600	550	550
Ft. Head	25	25	25	25	25	25
BHP actual	5.4	5.4	5.4	5.4	4.9	4.9
nominal	7.5	7.5	7.5	7.5	7.5	7.5
Armstrong Cat. #	All Series 4300 6 x 6 @ 1200 RPM Curve E 1563					
Secondary Hot Water GPM	600	600	600	600	550	550
Ft. Head	100	100	100	100	50	50
BHP actual	21.4	21.4	21.4	21.4	9.8	9.8
nominal	25	25	25	25	15	15
Armstrong Cat. #	All 4300 Series 5 x 5 Curve E 1558					
Sprays GPM	30	30	30	30	30	30
Ft. Head	30	30	30	30	30	30
BHP actual	0.3	0.3	0.3	0.3	0.3	0.3
nominal	1/2	1/2	1/2	1/2	1/2	1/2
Armstrong Cat. E	H63	H63	H63	H63	H63	H63

APPENDIX B-4
Chilled Water Piping Schematic for Systems Using Conventional Air Distribution



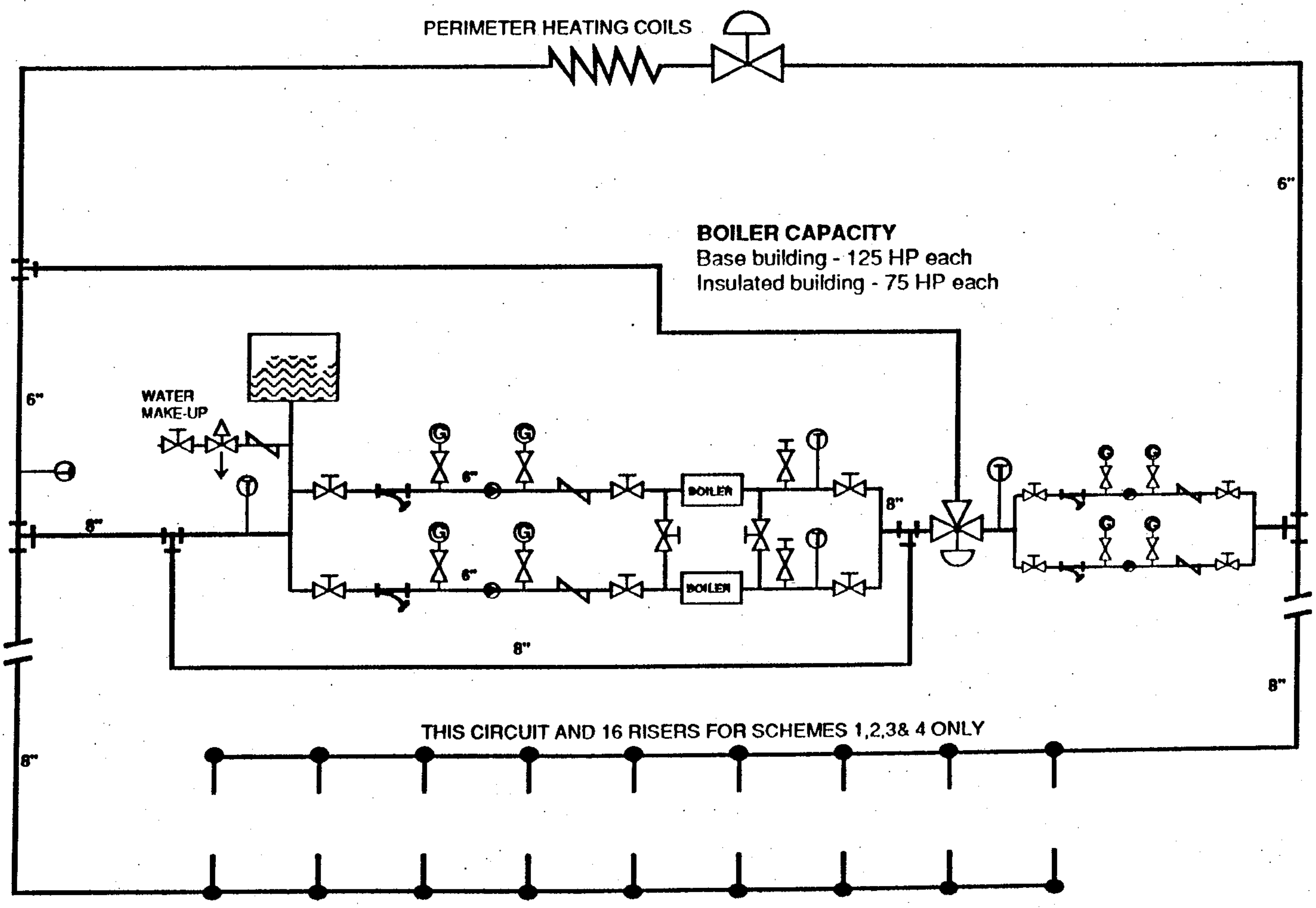
APPENDIX B-5
Cooling Coil Connections for Systems Using McGill Jets



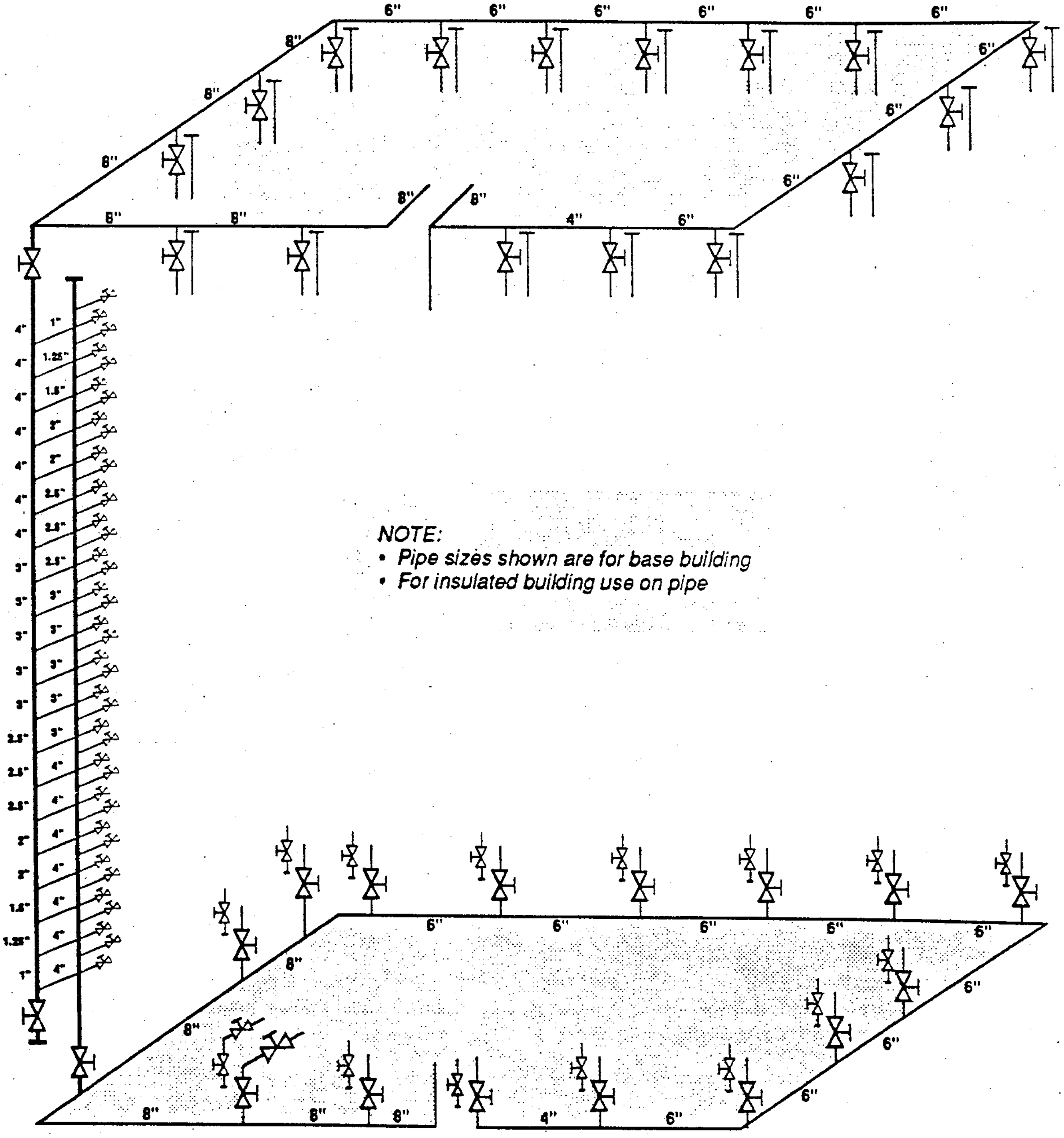
	LTA - 100% O.A.	LTA - JET	LTA - JET SC
PERIMETER COOLING			
No. of coil banks	4	4	3
No. of coils	8	8	6
Coil size	8@36"x90"x6 row	4@36"x90"x6 row 4@36"x66"x6 row	4@36"x78"x6 row 2@36"x66"x6 row
INTERIOR COOLING			
No. of coil banks	2	2	2
No. of coils	4	4	4
Coil size	36"x 66"x6 row	36"x 60"x6 row	36"x 60"x6 row

NOTE:
1. *Heating for the perimeter will be 2 rows deep, 8 fins/inch with same face area as cooling coils*
2. *No heating coils for interior systems*
3. *Cooling coils will be 14 fins/inch*

APPENDIX B-6
Heating Piping Schematic for All Systems Using Perimeter Gas Heat

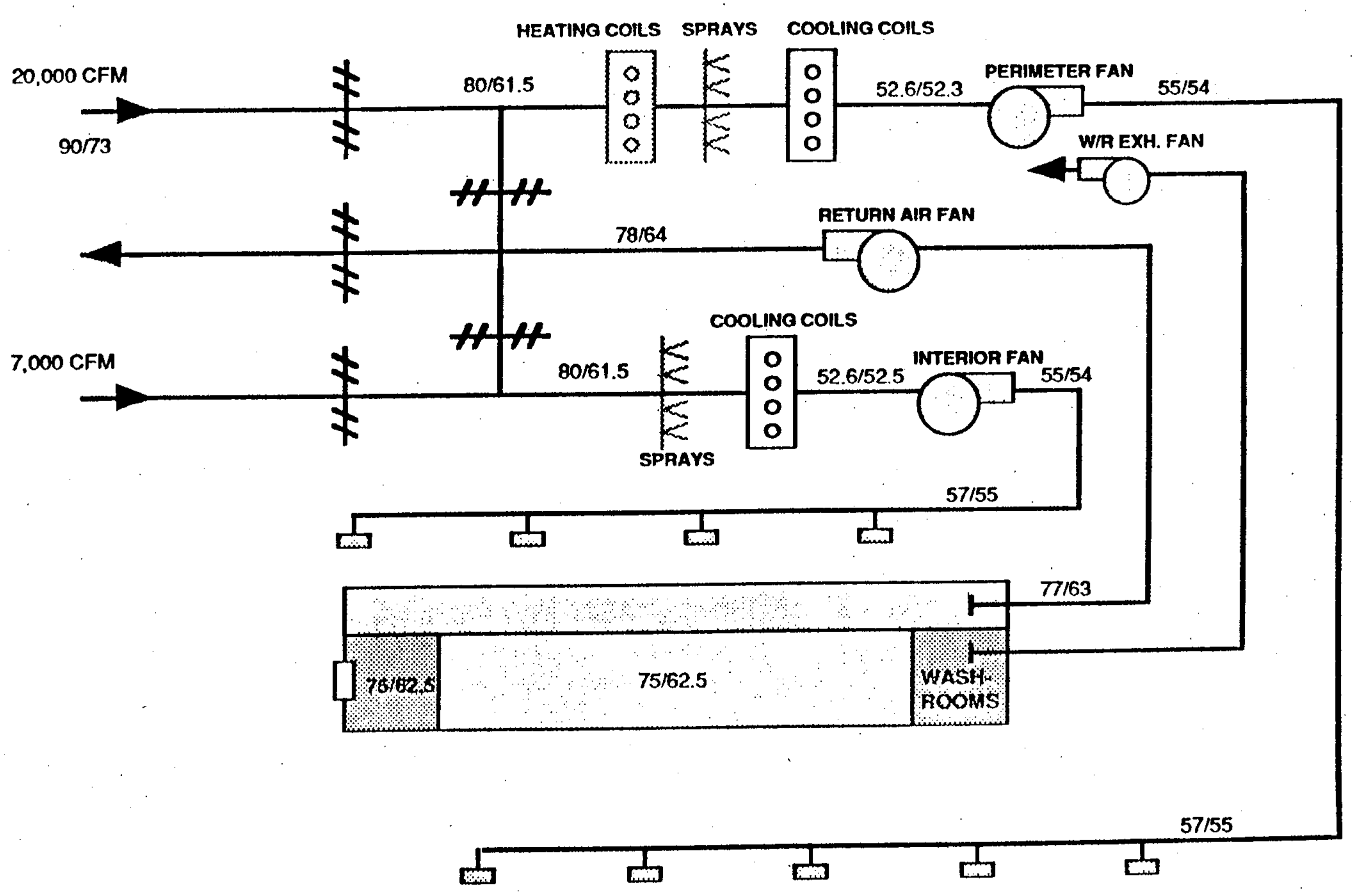


APPENDIX B-7 - HEATING RISER DIAGRAM
Schematic for All Systems Using Perimeter Gas Heat

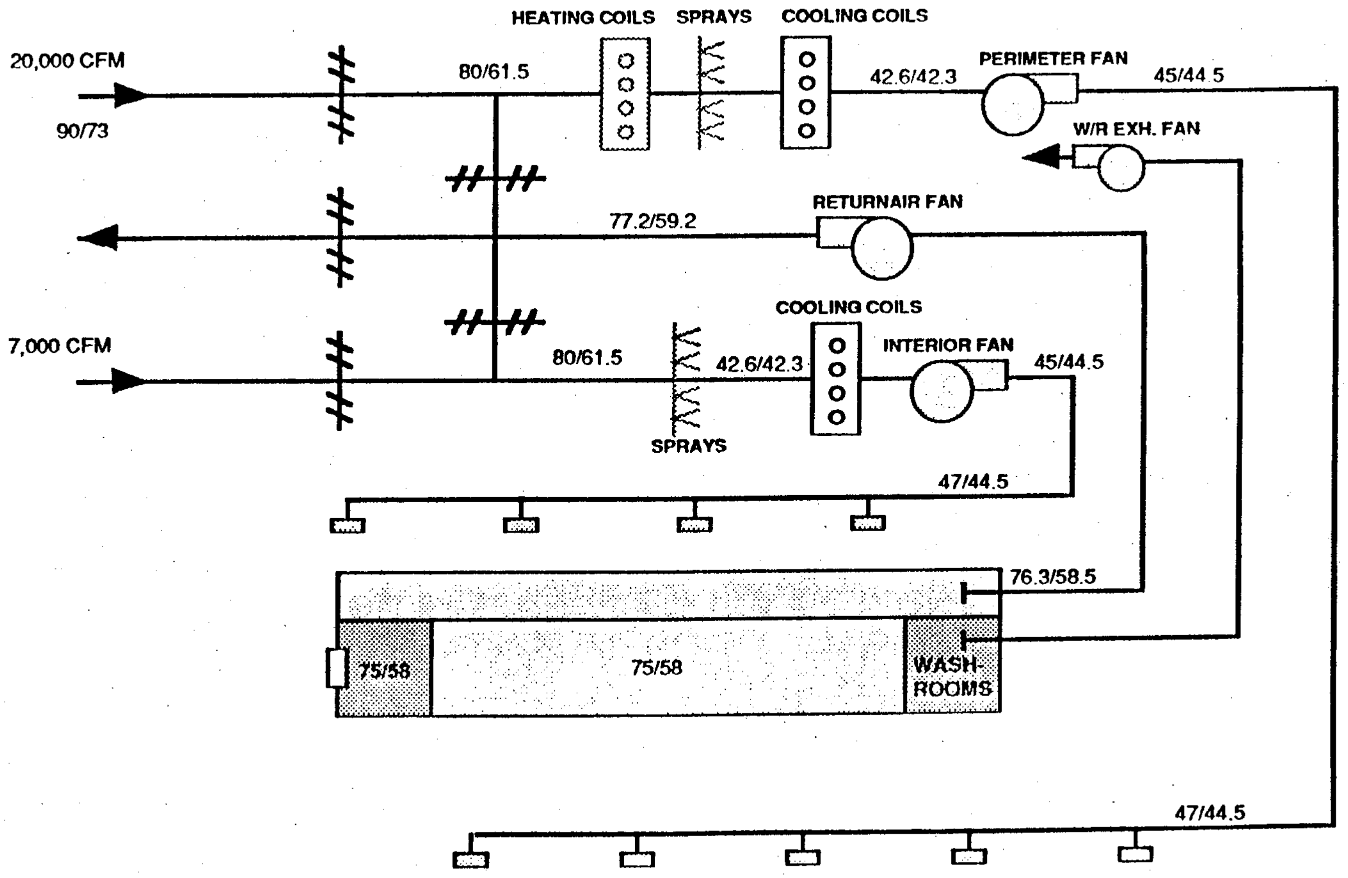


NOTE:
- Pipe sizes shown are for base building
- For insulated building use on pipe

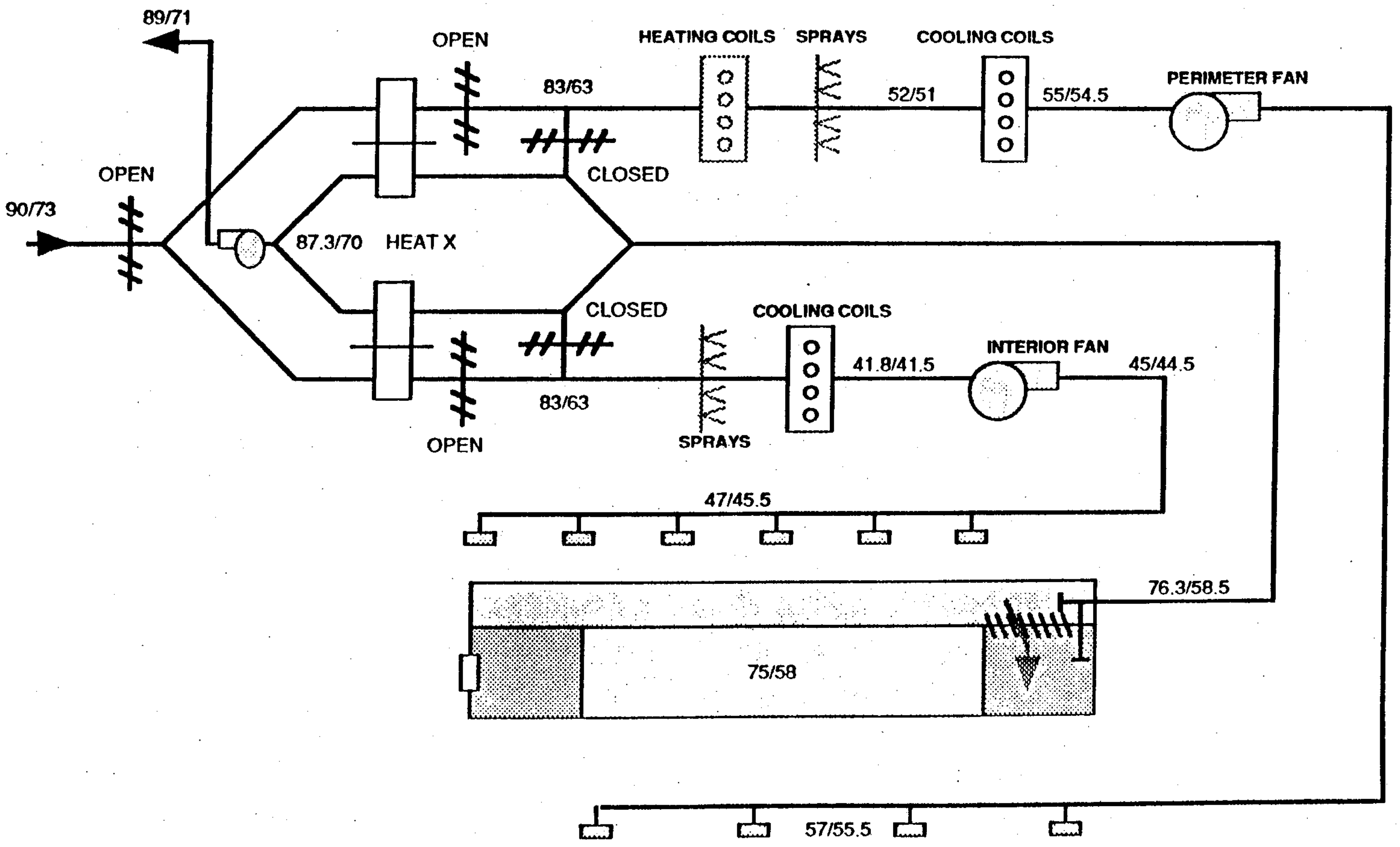
APPENDIX B-8
TEMPERATURE TRAVERSE - Base System (Summer Peak)



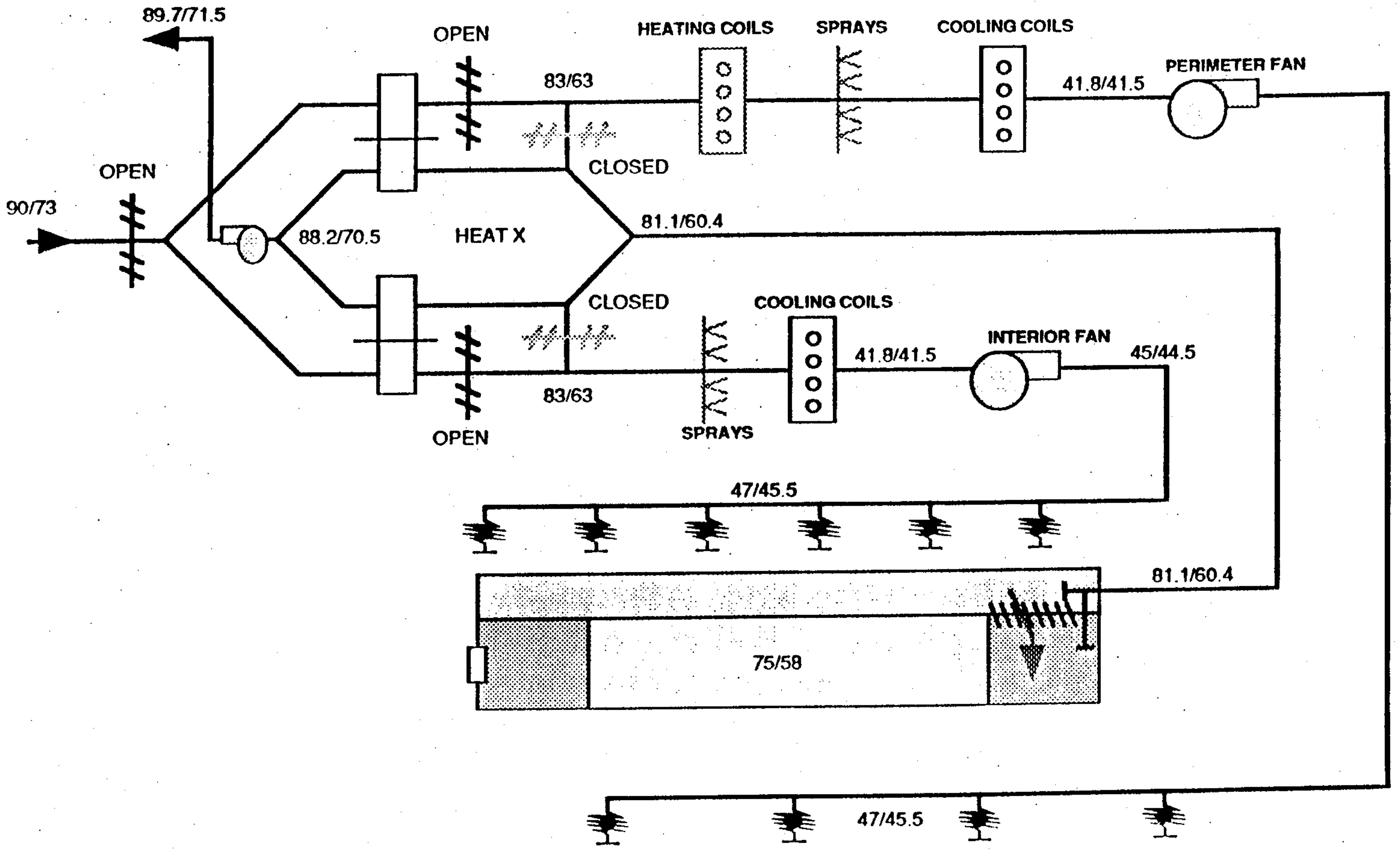
APPENDIX B-9
TEMPERATURE TRAVERSE - LTA Systems (Summer Peak)



APPENDIX B-10
TEMPERATURE TRAVERSE for LTA with 100% Outside Air (Summer Peak)



APPENDIX B-11
TEMPERATURE TRAVERSE for McGill Jet System (Summer Peak)



APPENDIX B-12

INSTRUCTION TO CONTROL SUB CONTRACTOR

DDC

AUTOMATION CONCEPTS

Building has 20 typical storeys with major equipment and control HQ located in the penthouse.

Conventional System

HVAC is variable volume with cfm as shown.

Auto dampers are sizes for 1000 fpm. (5.1 m/s)

Fan driven VAV terminals are of sizes and numbers indicated.

Perimeter terminals have reheat coils which are to be controlled in conjunction with the primary air inlet dampers.

Air supply to interior is to be 47F (8°C) (45F (7°C) off the cooling coil) year round.

Air supply to the perimeter terminals will be raised to room temperature if all perimeter zones are in a heating mode.

Heating for unoccupied periods will be accomplished by cycling fan driven perimeter terminals to suit a setback (65F±) (18.5°C) temperature.

Cooling will be cycled automatically during unoccupied periods (by starting central fans, chillers, pumps, tower, etc.) to h old a maximum temperature of 82F± (28°C).

Spray type humidifier will maintain building at 30% RH for occupied periods.

100% air type economizer will operate from an enthalpy control.

Central automation is required to start/stop/log fans, pumps, chillers, tower, boiler on preset schedules.

Remote temperature control is required for discharge air temperature, mixed air temperature, chilled water supply, condensing water supply (provide 3-way tower valve and two-speed fan control), outside air ratio, radiation temperature control (3-way valve).

Temperature indication is required for water on/off, cooling and heating coils, chillers (2), boilers (2), tower, radiation plus supply air, return air, mixed air, air on/off heat exchangers (both sides).

A temperature controller will be used to vary the speed of the heat exchanger wheels for Scheme 4.

Control valves are required for all heating and cooling valves.

Minimum outside air will be 27,700 cfm. (13,019 l/s)

Supply and return fans will be varispeed with volume controlled by discharge pressure.

APPENDIX B-12 (CONTD)

100% Outside Air System

Air will be supplied through personally controlled jets.

Interior air will be maintained at 45F(7°C) supply (off coil) for occupied periods. System will be stopped for unoccupied periods.

Perimeter air will be supplied at 45F(7°C) (off coil) for occupied periods. The volume of air will be varied at the runout dampers to correspond to cooling load. 15 cfm (7 l/s) will be provided as a minimum on each runout. When any zone requires heating, a 250 Watt heater element will be energized while, at the same time, the damper will open to admit 35 cfm (16.5 l/s). When 75% of the elements are activated, the hot water coil will raise the supply air temperature to prevent more electric heat being used.

If the south zone is calling for cooling on any floor (e.g., all electric heaters are off) when other zones are calling for heating, a set of bypass dampers will open on each floor to admit cold air from the interior zone supply.

Humidity will be maintained at 30% by a spray type humidifier.

The heat exchange wheels will be slowed to reduce efficiency in order to prevent the air being supplied at more than 45F (7°C). Before the heating coil in the perimeter system is activated, however, the perimeter heat wheels will be speeded up to gain the highest possible leaving air temperature.

The return air and perimeter air fan will be cycled at night on 100% return air to maintain 65F± (18.5°C) in several key zones. Electric heat will be turned off at this time and all heating will be done by the hot water coil.

Supply and return fans are varispeed with speed controlled by discharge pressure controllers.

Instrumentation will be similar to conventional system.

APPENDIX B-13

INSTRUCTIONS TO SYSTEM BALANCE SUB CONTRACTOR

Conventional System

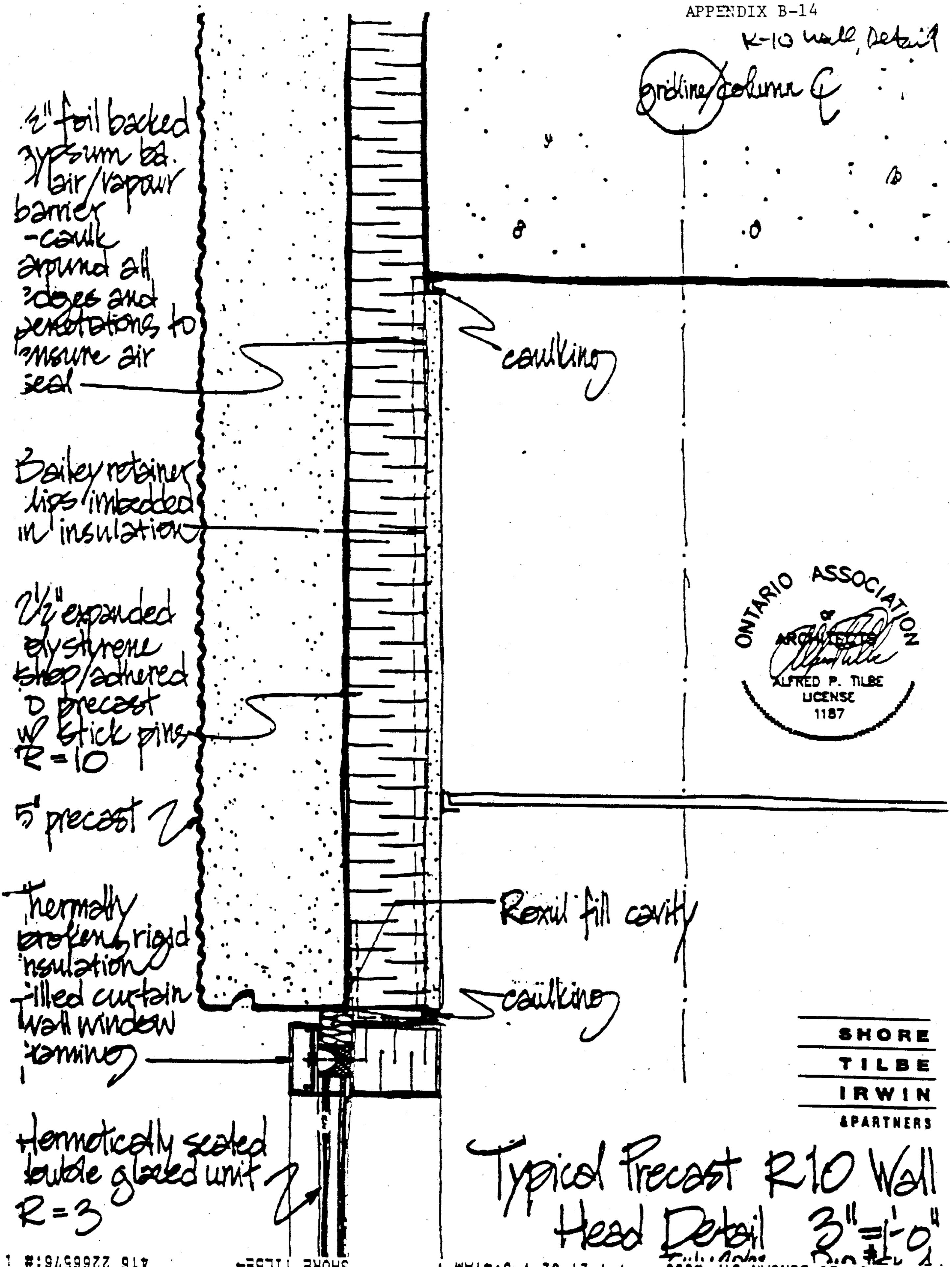
1. Verify and adjust, if necessary, fans to design maximum cfm.
2. Check tracking of supply and return fans to verify that neutral pressure plane is being held at mid-building height.
3. Verify and adjust, if necessary, all air terminals to design maximum cfm.
4. Verify that thermostats respond correctly on each air terminal, (cooling and heating), each coil, each heat exchange wheel. Verify chilled and condensing water controls.
5. Verify humidity and economizer controls.
6. Verify instrument readings, thermostats and controllers.

100% Outside Air System

1. Verify and adjust, if necessary, fans to design maximum cfm.
2. Check tracking of supply and return fans to verify that neutral pressure plane is being held at mid-building height.
3. Verify that thermostats respond correctly on each air terminal, (cooling and heating), each coil, each heat exchange wheel. Verify chilled and condensing water controls.
4. Verify humidity and economizer controls.
5. Verify instrument readings, thermostats and controllers.
6. Adjust and verify flow settings for each jet as follows:-
    - set damper for maximum flow on cooling
    - set damper for minimum flow on heating
7. Verify that each electric heater turns on and note discharge air temperature.

APPENDIX B-14

R-10 wall, Detail

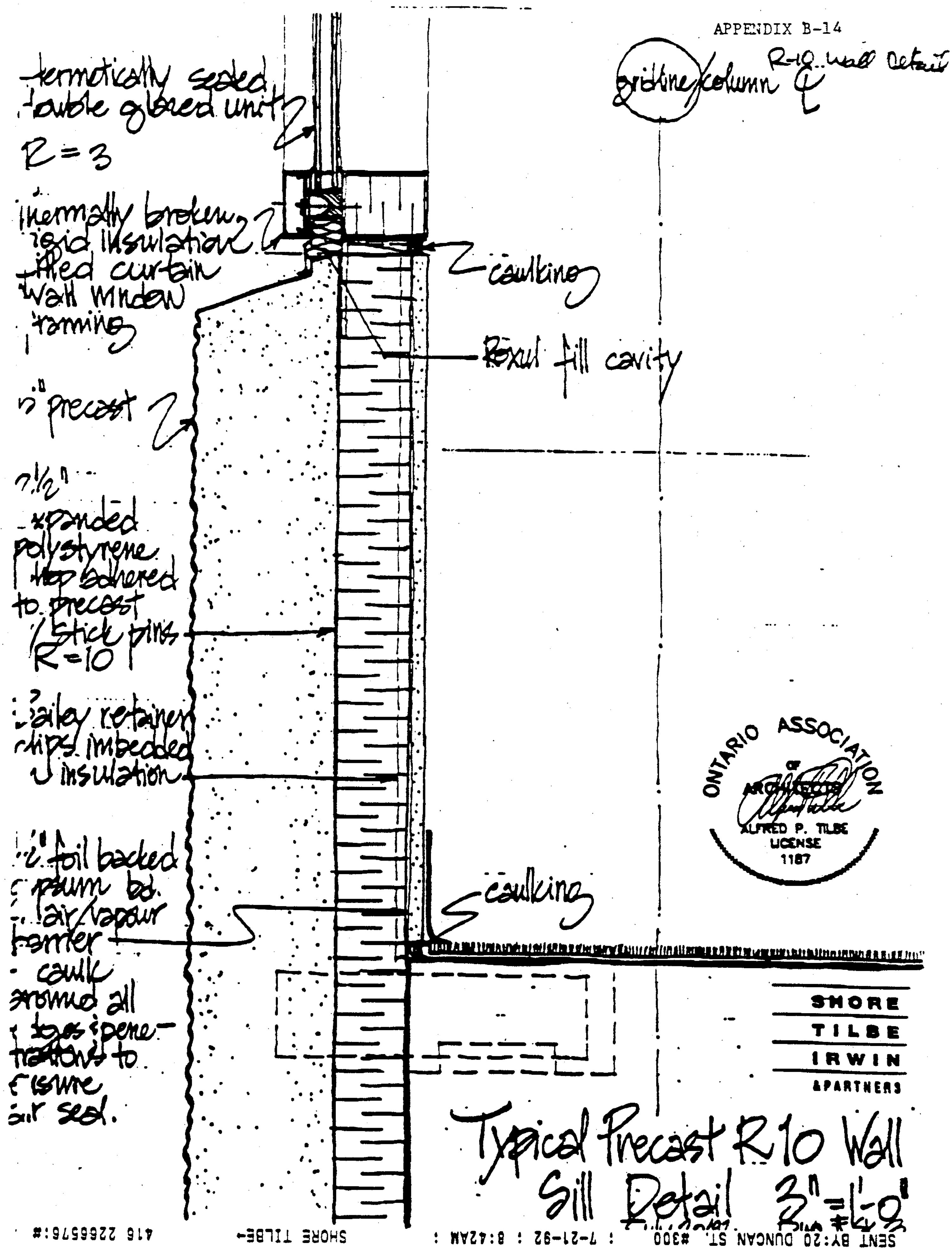


ONTARIO ASSOCIATION OF ARCHITECTS
ALFRED P. TILBE
LICENSE
1187

SHORE
TILBE
IRWIN
&PARTNERS

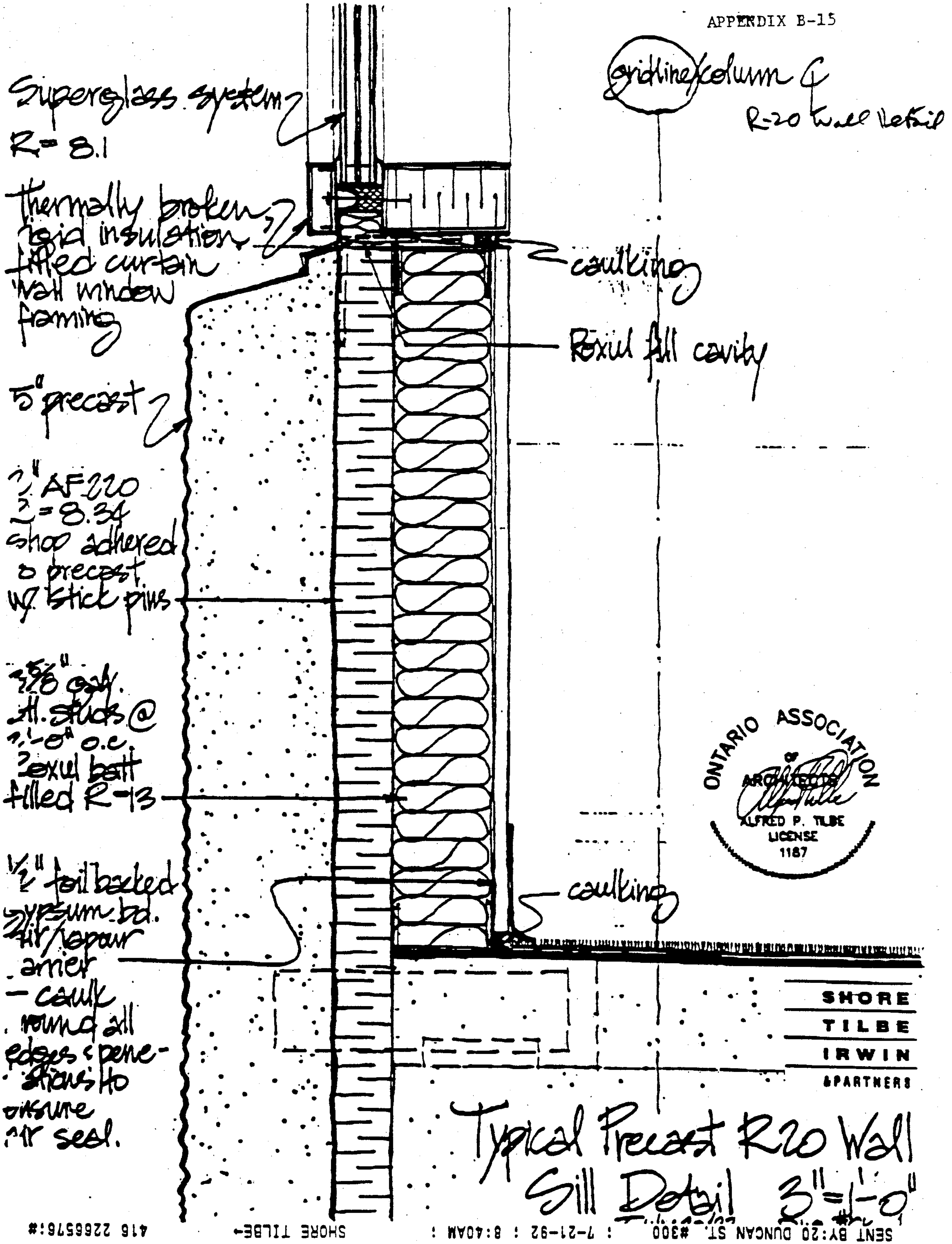
Typical Precast R10 Wall Head Detail 3"=1'-0"

APPENDIX B-14



Typical Precast R10 Wall Sill Detail 3"=1'-0"

SENT BY:20 DUNCAN ST. #300 : 7-21-92 : 8:42AM : SHORE TILBE→ 416 2265576:#

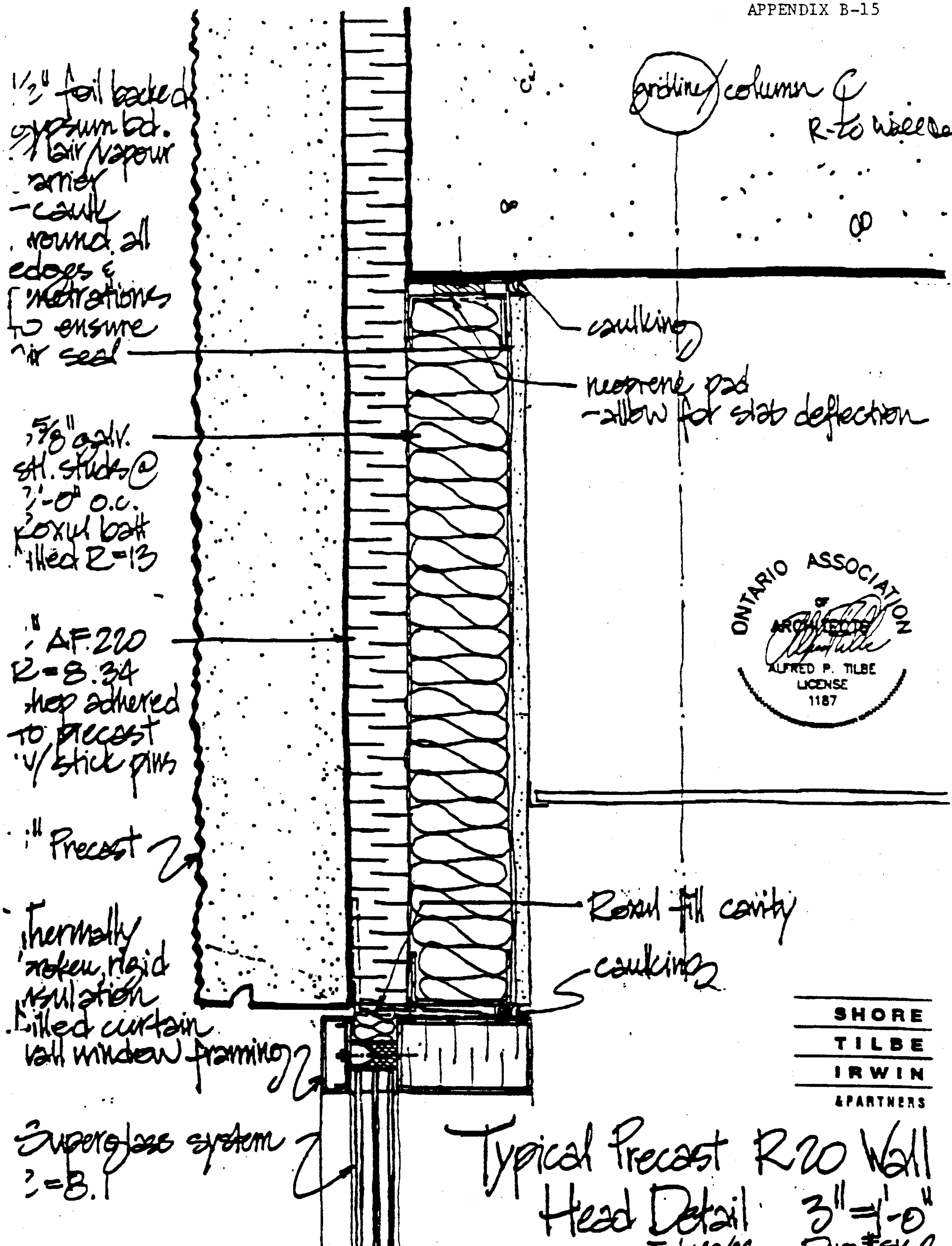


ONTARIO ASSOCIATION OF ARCHITECTS
ALFRED P. TILBE
LICENSE
1187

SHORE
TILBE
IRWIN
& PARTNERS

Typical Precast R20 Wall Sill Detail 3"=1'-0"

SENT BY:20 DUNCAN ST. #300 : 7-21-92 : 8:40AM : SHORE TILBE→ 416 2265576:#



ONTARIO ASSOCIATION OF ARCHITECTS
ALFRED P. TILBE
LICENSE
1187

SHORE
TILBE
IRWIN
&PARTNERS

Typical Precast R20 Wall Head Detail 3"=1'-0"

July 20/92 Dwg #SK 2.

SENT BY:20 DUNCAN ST. #300 : 7-21-92 : 8:41AM : SHORE TILBE→ 416 2265576:#

General Contractor's Estimates on
Bldg Enclosure.

Jackson
Lewis

July 24, 1992

SHORE TILBE IRWIN & PARTNERS
20 Duncan Street, Ste. 300
Toronto, Ontario.
M5H 3G8

Attention: Mr. Thomas Tampold

Dear Tom:

RE: PRICING STUDY ON WALL SYSTEMS

Pursuant to your request, we have carried out pricing exercises on the two wall scenarios based upon the sketches forwarded us on July 20, 1992. We would wish to caution that our pricing is based upon the simplest building possible, a square without relief except some allowance at Ground Floor. Our assumptions were as per the attached Budgetary Purpose Assumptions and were based upon a ratio of:

41.12% Glass On Typical Floors
AND
58.88% Precast

Under these scenarios and ratios, the typical floor wall enclosure is $381,340 more expensive in the higher R value systems.

We should also caution that pricing is based upon current market conditions and could vary greatly with appreciable delays.

Attached are all of the calculations and figures derived from our study.

Should further be required, please call.

Yours very truly,
THE JACKSON-LEWIS COMPANY INC.

C.W. Washer
C. W. Washer
President

CWW:rob
Encl:

JULY 14, 1992

BUDGET PRICING
WALL SYSTEMS

For Budgetary Purposes assume:

a)	20 Storey Tower	15,000 S.F./Floor
	Gross Floor Area	300,000 S.F.
b)	Say Building	122.5' x 122.5' Square in shape.
c)	Floor to Floor height	14' Ground to 2nd.
d)	Typical 2 thru 19	12'0"
e)	20th Floor	13'0"
f)	Windows typical strip	5'0" in height.
g)	Assume 2' Parapet above roof line.	
h)	Assume Penthouse cladding not pertinent.	
i)	Assume glass & ground floor cladding would be same either scheme.	

Quantities for Pricing:

1. Allow ground floor:
   - Glass 2400 S.F.
   - Precast 4400 S.F. + 10% for Cols. etc. = 5,000 S.F.

2. Upper floors:

• Glass	5' x 490 x 19	=	46,550 S.F.
• Precast	7' x 490 x 18	=	61,740 S.F. TYP
	10' x 490 x 1	=	4,900 S.F. 20th and Roof
• Interior Drywall Typical Floors:			
	6.2'x 490 x 18	=	54,684
	7.2'x 490 x 1	=	3,528
			58,212 S.F.

All units exclusive of G.S.T. and based upon mid 1992 Market Conditions:

Pricing - Scenario I:

•	Ground Floor glass and Entrances	2,400 S.F. + 8 doors	=	100,000
•	Precast	5,000 S.F.	=	100,000
	TOTAL GROUND FLOOR			$200,000
	Typical Upper Floors R20 wall with R8 Window			
•	Precast Concrete & Insulation	66,640 S.F. x 14.00	=	932,960
•	Glass & Glazing Superglass	46,550 S.F. x 25.00	=	1,164,750
•	Interior Drywall, Insul. & Caulk.	58,212 S.F. x 2.50	=	145,530
	TOTAL			$2,443,240
	Add for Mirror Glass			$70,000

Pricing - Scenario II

•	Ground Floor as above		=	200,000
	Typical Upper floors R10 and R3 Window			
•	Precast Concrete & Insulation with Bailey Inserts	(66,640 S.F.)x 14.40	=	960,000
•	Glass & Glazing - Strip Std.	46,550 S.F. x 18.00	=	837,900
•	Interior Drywall & Caulk	58,212 S.F. x 1.10	=	64,000
	TOTAL			$2,061,900
	Add for Mirror Glass			$70,000

Continued on Page 2

Jackson
Lewis

Pricing - Scenario II....(Cont'd)

∴ **Cost Per Gross S.F. of Building for Exterior Wall Cladding would be:**

SCENARIO I $\frac{\$2,443,240}{300,000}$ = **$8.144 / S.F.**

SCENARIO I with Mirrored Glass $\frac{\$2,513,240}{300,000}$ = **$8.377 / S.F.**

SCENARIO II $\frac{\$2,061,900}{300,000}$ = **$6.873 / S.F.**

SCENARIO II with Mirrored Glass $\frac{\$2,131,900}{300,000}$ = **$7.106 / S.F.**

●●●●●●●●●●●●●●●●●●●●

Jackson
Lewis