CANADA'S GREEN PLAN
LE PLAN VERT DU CANADA

DESIGN AND ANALYSIS OF PRELIMINARY C-2000 MULTI-RESIDENTIAL BUILDING

PREPARED FOR:

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Energy Technology Branch/CANMET
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NOTE

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Preface

This work was performed for CANMET's Buildings Group as part of its commercial-buildings research activities. These activities are distinct from but complimentary 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 purpose of this project was to apply the ASHRAE 90.1 Standard to a multi-unit residential building and to examine what additional technical criteria could be incorporated into the C-2000 Program. In addition, the project determined how a building developer and the design team responded to the preliminary technical criteria for C-2000 buildings. Based on these responses, recommendations were made to improve the development of the technical criteria.

For more information on the project, contact CANMET's Robin Sinha, P.Eng., the project manager, at (613) 943-2260. 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.

Table of Contents

Table of Contents Cont'd

List of Figures

EXECUTIVE SUMMARY

Presently, energy consumption in buildings represents over one third of the total energy consumed in Canada each year. The production of this energy results in the release of greenhouse gases and the production of radioactive waste. In addition, environmental damage is incurred through the consumption and pollution of water, the emission of ozone depleting substances, and the production of both construction and residential waste.

In response to these issues, Canmet, the research and development arm of Energy Mines and Resources, is implementing an Advanced Commercial Building Program referred to as the C-2000 Program.

Specifically, the Program is intended to result in the construction of office, multi-unit residential, retail and service buildings that will:

- consume significantly less energy than current construction,
- reduce adverse environmental impacts,
- create a more comfortable and healthy indoor environment, and
- reach a higher level of functional performance.

The purpose of this project was to apply the ASHRAE 90.1 Standard to a multi-unit residential building and to examine what additional technical criteria could be incorporated into the C-2000 Program. In addition, the project determined how a building developer and design team responded to the preliminary technical criteria for C-2000 buildings. Based on these responses, recommendations were made to improve the development of the technical criteria.

The results of this study will provide a basis for the next step in the C-2000 Program, which is the development of technical criteria such as performance targets, prescriptive requirements and verification.

The C-2000 design upgrades recommended for the multi-unit residential building studied in this project include:

- an airtight envelope,
- heat recovery,
- lighting control strategies,
- air distribution through dedicated ducting,
- humidifier controls,
- reducing odour and sound transmission between suites,
- reducing thermal bridging,
- water conserving appliances and fixtures,

- eliminating the use of CFCs and minimizing the use of HCFCs,
- implementing a recycling program for tenants, and
- using recycled material in the construction of the building.

For the multi-residential co-op building in this study, an energy savings of 9,442,482 MJ or 46.2% of the base ASHRAE 90.1 energy consumption was achieved through the C-2000 upgrades. Assuming $0.09/kWh of electricity and $0.17/M3 for natural gas, the annual operating costs for this building is reduced by approximately $136,530.

The costs of the upgrades beyond ASHRAE 90.1 is approximately $860,000 for all energy, environmental and indoor environmental upgrades. Assuming no changes in the energy costs, this translates into a 6.3 year simple payback. The payback period could be reduced by eliminating some of the less cost-effective measures, although this will reduce the energy efficiency and/or the quality of the indoor environment.

Water consumption of the C-2000 design can be reduced by 20.8 million litres annually from the initial design of the building.

The use of ozone depleting substances in the construction and operation of the building will be eliminated from the C-2000 design with the exception of refrigerators.

RÉSUMÉ

À l'heure actuelle, les immeubles consomment le tiers de toute l'énergie utilisée au Canada chaque année. La production de cette énergie génère des gaz à effet de serre et des déchets radioactifs. En outre, la consommation et la pollution de l'eau, les émissions de substances qui détruisent la couche d'ozone ainsi que la production de déchets domestiques et de construction causent des dommages à l'environnement.

En réponse à cette situation, CANMET, l'organisme de recherche et de développement d'Énergie, Mines et Ressources, met en place le Programme des bâtiments commerciaux performants, le Programme C-2000.

L'objectif du Programme est de construire des immeubles à bureaux et à logements multiples, des bâtiments de service ainsi que des immeubles destinés au commerce de détail dotés des caractéristiques suivantes :

- consommation d'énergie considérablement moindre que les constructions actuelles;
- diminution des effets nuisibles sur l'environnement;
- environnement intérieur plus sain et plus confortable;
- rendement plus élevé.

Le projet avait pour but d'appliquer la norme ASHRAE 90.1 à un immeuble à logements multiples et d'étudier les critères techniques supplémentaires qui pourraient être incorporés au Programme C-2000. Le projet a également permis de sonder l'opinion d'un promoteur et d'une équipe de conception en ce qui concerne les critères techniques préliminaires. Partant de leurs commentaires, on a formulé des recommandations en vue d'améliorer les critères.

Les résultats de cette étude serviront de point de départ à la prochaine étape du Programme C-2000, soit l'élaboration de critères techniques tels des objectifs de rendement, des normes obligatoires et des modalités de vérification.

Voici quelques-uns des domaines qui ont fait l'objet de recommandations dans le cadre du projet d'amélioration d'un immeuble à logements multiples :

- enveloppe étanche à l'air
- récupération de la chaleur
- techniques de contrôle de l'éclairage
- distribution de l'air par des conduits spécialisés commandes de l'humidificateur
- réduction de la transmission des bruits et des odeurs d'une pièce à l'autre
- réduction des ponts thermiques
- appareils de conservation de l'eau
- élimination de l'utilisation des CFC et des HCFC
- mise en place d'un programme de recyclage à l'intention des locataires
- utilisation de matériaux recyclés pour la construction de l'immeuble.

Les améliorations qui ont été apportées à la coopérative de logements en respectant les critères C-2000 ont permis de réaliser des économies d'énergie de 9 442 482 MJ, ce qui représente 46,2 p. 100 de la consommation d'énergie correspondant à la norme de base ASHRAE 90.1. En supposant que le coût de l'électricité soit de 0,09 \$/kWh et celui du gaz naturel de 0,17 \$/m^3, la réduction annuelle des coûts d'exploitation de l'immeuble s'élève à quelque 136 530 \$.

Le coût de toutes les améliorations liées à la consommation d'énergie, à la protection de l'environnement et au confort à l'intérieur de l'immeuble, qui visent à dépasser la norme ASHRAE 90.1, s'élève à 860 000 $ environ. Si l'on suppose que le coût de l'énergie ne changera pas, la période de remboursement sera de 6,3 ans. Cette période pourrait être réduite en éliminant certaines améliorations moins rentables, mais cela diminuerait l'efficacité énergétique de l'immeuble ou le confort à l'intérieur de celui-ci.

En modifiant la conception d'origine de l'immeuble suivant les critères C-2000, on peut réduire la consommation d'eau de 20,8 millions de litres par année.

La réfection de l'immeuble en fonction des critères C-2000 permettra d'éliminer l'utilisation de toutes les substances qui entraînent la destruction de la couche d'ozone, sauf pour ce qui est des réfrigérateurs.

1.0 INTRODUCTION

Presently, energy consumption in buildings represents over one third of the total energy consumed in Canada each year. The production of this energy results in the release of greenhouse gases and the production of radioactive waste. In addition to the detrimental effects of the energy consumed by buildings, environmental damage is also created through the consumption and pollution of water, the emission of ozone depleting substances, and the production of both construction and residential waste.

Over the last ten years in Canada, energy consumption in low-rise, residential buildings has been targeted by such efforts as the R-2000 Program. This program has been successful in dramatically reducing the overall energy consumption in buildings while, at the same time, making significant improvements in the areas of indoor air quality, building longevity, and occupant comfort. Acting as a catalyst for improvements to the building code, the R-2000 Program has resulted in the construction of higher quality, single-family homes regardless of whether or not they are built and certified to R-2000 standards.

Large residential and commercial buildings in this country are in serious need of a similar effort to improve their efficiency, environmental sensitivity, indoor air quality and durability. Although most large, residential or commercial buildings have less exposed surface area per unit of interior floor area than single-family dwellings, they consume significantly more energy. Multi-residential housing is often criticized for providing lower standards of comfort, have lower standards of indoor air quality, contain more physical defects, and contribute significantly more to environmental damage than low rise residential homes.

To some degree the American Society for Heating, Refrigeration and Air-Conditioning Engineers addressed the problem of inefficient buildings through the ASHRAE/IES 90.1 Standard. This standard was developed as a means of reducing energy consumption and peak electrical demand through existing technologies. However, this standard does not address the problems of indoor air quality and environmental damage.

In response to these issues, Canmet, the research and development arm of Energy Mines and Resources is implementing an Advanced Commercial Building Program referred to as the C-2000 Program.

Specifically, the Program is intended to result in the construction of office, multi-unit residential, retail and service buildings that will:

- Consume significantly less energy than current construction,
- reduce adverse environmental impacts,
- create a more comfortable and healthy indoor environment, and
- reach a higher level of functional performance

The purpose of this project was to apply the ASHRAE 90.1 Standard to a Multi-unit residential building and examine what additional technical criteria could be incorporated into the C-2000 Program. In addition, the project determined how a building developer and design team respond to the preliminary technical criteria for C-2000 buildings. Based on these responses, recommendations have been made to improve the development of the technical criteria.

The results of this study will provide a basis for the next step in the C-2000 Program which is the development of technical criteria such as performance targets, prescriptive requirements and verification.

2.0 SCOPE OF WORK

A 15-story, 174-unit co-op apartment building located in Toronto was selected for this project. Options for significantly upgrading the building at the design stage in cooperation with the established design team were reviewed. The process was documented with particular emphasis on the objections and concerns raised by the various members of the design team. The study is subdivided into three of the four primary areas identified by C-2000. These are; energy, indoor air quality and the environment.

It was determined that functional issues would not be discussed in this report. Issues such as wheelchair access are already required by the building code. Other functional issues are highly dependent on the use of the building and are not discussed in this report.

The tasks associated with defining the C-2000 criteria for each of these three areas is described below.

Energy

- Upgrade initial design of building to ASHRAE 90.1 Standard, and identify areas of Standard that can be enhanced by the C-2000 Program.

- Produce recommendations for reducing the energy consumed by the study building 30 to 50 percent of the ASHRAE 90.1 levels.

- Determine preliminary costing information of energy upgrades.

- Determine energy savings resulting from energy upgrades, and prioritize potential upgrades with respect to cost effectiveness.

- provide initial recommendations on appropriate performance levels for C-2000 in multi-unit residential buildings

Indoor Air Quality

- Produce recommendations for improving the occupant comfort and indoor air quality.

- Determine preliminary costing information of energy upgrades.

- Prioritize potential upgrades with respect to cost effectiveness.

Environmental Issues

- Produce recommendations for upgrading the environmental aspects of the building, including; reduction in construction waste, water consumption and the use of environmentally harmful chemicals.

- Determine preliminary costing information of environmental upgrades.

- Prioritize potential environmental upgrades with respect to cost effectiveness.

3.0 BUILDING BACKGROUND

The process of developing a C-2000 design for the multi-residential building was to upgrade the initial design to meet the requirements of the ASHRAE 90.1 Standard. Additional technical criteria were then incorporated into the C-2000 to enhance the ASHRAE 90.1 design.

3.1 Building Description

The building studied in this report is a 174 unit co-operative building in Toronto with some commercial space on the ground and first floors. The building description is as follows:

Floor area:	16,000 m^2 (172,000 ft^2) residential space 1,790 m^2 (19,300 ft^2) commercial space
Wall area	7,890 m^2 (84,900 ft^2)wall area (average RSI-2.64 brick facing and concrete block)
Glass area	1,895 m^2 (20,400 ft^2) glass area (RSI-0.3, SC = 0.88) Double glazed windows /thermally broken aluminium frames.
Heating system	255 water source heat pumps (closed loop) located in suites, common rooms and commercial space. 5 central low temperature hot water boilers (gas fired) warming heat pump water loop. 2 make up air units (gas fired duct furnace) preheating fresh air to commercial and residential areas. Minimal electric unit heaters.
Cooling System	255 water source heat pumps (closed loop) located in suites, common rooms and commercial space. 2 evaporative coolers removing heat from heat pump loop.
DHW System	Circulating water system 2 gas fired DHW boilers 2,270 L storage tank insulated to RSI-2.2 (R-12.5)
Ventilation System	Fresh air supplied to corridors by make-up air units. Air passes from corridors to suites via cracks in doors. Exhaust air directly vented outdoors through kitchen and bathroom exhaust fans (manually operated).

Sample floor plans of the building can be seen on the following page. These floor plans are the ground floor, the 10th floor (a typical suite layout) and the common space on the 15th floor.

At the time that the building had been chosen for the C-2000 project, the preliminary designs had already been completed. Other than a few details such as pipe sizes, electrical power distribution and certain lighting systems the design had been completed. The building did not meet the ASHRAE 90.1 requirements and significant upgrades were necessary.

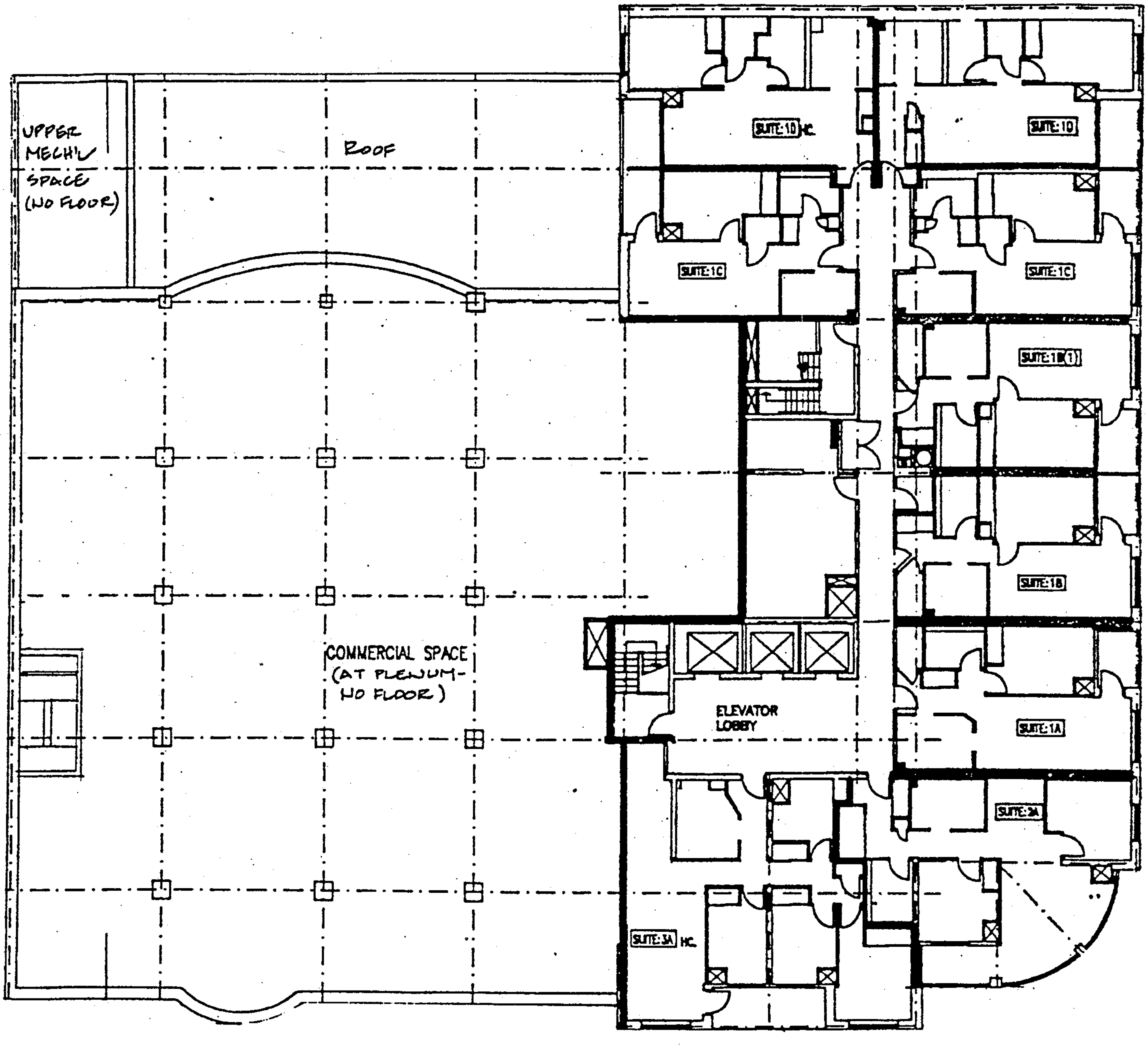


Figure 1: Floor Plan of 2nd storey residential and commercial space

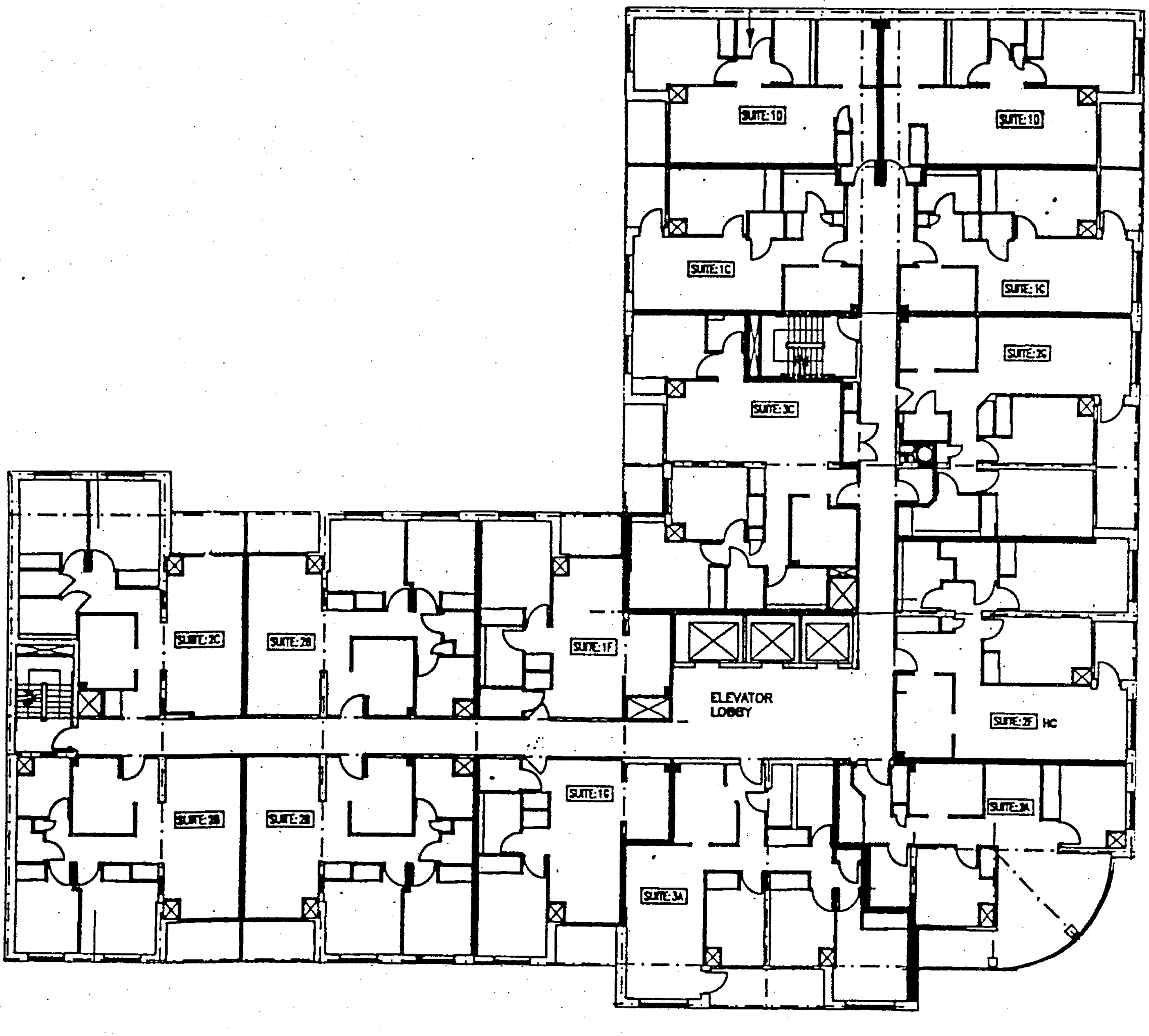
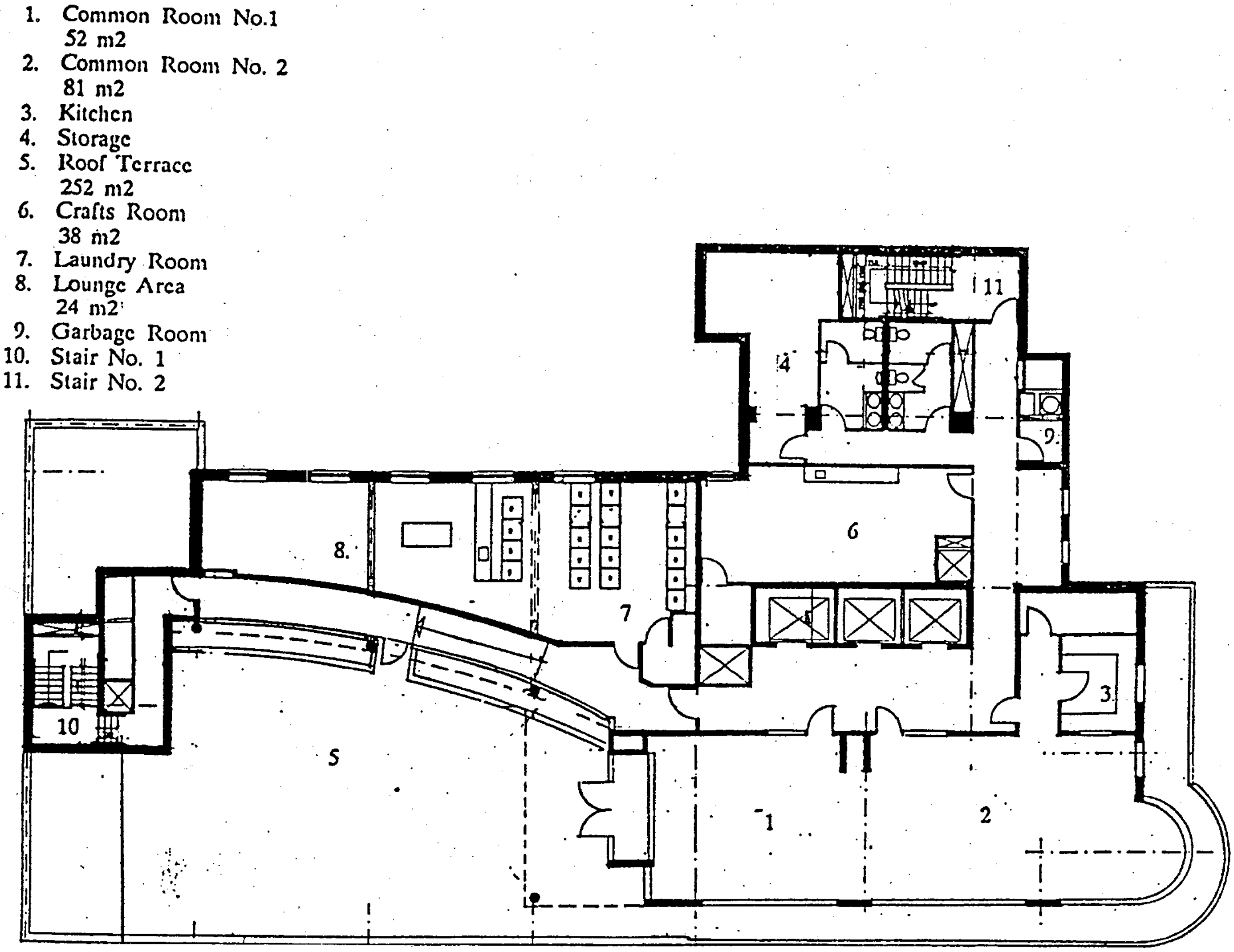


Figure 2: Floor Plan of 4th to 10th storey residential space



1. Common Room No.1
   52 m2
2. Common Room No. 2
   81 m2
3. Kitchen
4. Storage
5. Roof Terrace
   252 m2
6. Crafts Room
   38 m2
7. Laundry Room
8. Lounge Area
   24 m2
9. Garbage Room
10. Stair No. 1
11. Stair No. 2

Figure 3: Floor Plan of 15th Storey Common Space

3.2 Motivation for Owner's Interest in C-2000

The building is being developed by the Co-operative Housing Federation of Toronto (CHFT), and for the most part it was the project manager from the CHFT that drove the improvements to the building. There were three reasons for the Co-op committee's interest in the C-2000 Project:

- Toronto's city planning department required the design to meet or surpass the ASHRAE 90.1 Standard in order to obtain a building permit;
- the Ontario Hydro incentives would greatly help offset the costs of the improvements and reduce the payback to a reasonable time, and
- the co-op committee was committed to building an environmentally responsible building.

3.3 Design Team

The architectural firm leading the design team was a large Toronto based firm. This firm has won a number of design awards, but is not specifically noted as a leader in the areas of energy efficiency or environmental design. Engineering consultants on the project were traditional civil/mechanical/electrical firms, again with no particular expertise in energy-efficient construction.

The Architect, however, saw the process of upgrading the building as a series of further complications that would increase design costs, and would potentially delay the construction of the building. Clearly, there was not an understanding on the part of the design team of many of the basic issues.

The initial issues addressed were the requirements of the ASHRAE 90.1 Standard, including:

- envelope RSI values,
- lighting levels, and
- equipment efficiencies.

Also discussed at the early stages were several basic building science issues and occupant health concerns. These included:

- air barrier detailing,
- thermal bridging,
- window installation details, and
- ventilation.

A lack of understanding of most of these issues was demonstrated by the design team. The lighting requirements of ASHRAE 90.1 were dismissed as impossible to achieve by the electrical designers. The air barrier system in the original design was to be the interior drywall despite the HVAC ducting running on the exterior of this element. The requirement for a continuous air barrier was not addressed in the design drawing, except by "specifying" a continuous air barrier in the specifications. The substantial thermal bridging problems in the original design were considered too expensive to correct in a social housing building. The issue of ventilation was addressed with operable windows in the suites.

As is common in commercial building design and construction, the design team was selected with little or no regard for their capabilities in the areas addressed by the C-2000 program. Consequently, little attention is given to energy efficiency, occupant comfort or environmental damage in either the design or construction of the building.

4.0 Analysis Approach

The ASHRAE/IES 90.1 Standard has been developed as a means of setting minimum requirements for the energy-efficient design of new buildings other than single-family residences. The standard addresses issues such as lighting, electrical systems, mechanical equipment, and building envelope. However, it was created with the intent of not constraining buildings with unrealistic requirements. Consequently, there is significant potential for improvement in the C-2000 Program using the ASHRAE 90.1 Standard as a basis.

The approach presented to the design team was to first upgrade the building to the requirements of ASHRAE 90.1 and than consider bringing the building up to what could be considered a C-2000 pre-prototype. The three areas of C-2000 examined by Buchan, Lawton, Parent Ltd. in this project were energy, indoor air quality and environmental damage.

It was determined that the C-2000 energy issues would include:

- Building Envelope
  - Insulation levels of walls, roof and floors
  - Thermal bridging
  - Windows & doors
  - Infiltration

- HVAC System
  - Equipment efficiencies
  - Central HVAC systems
  - Thermal storage
  - Heat recovery for ventilation air
  - Timer control setback of ventilation air
  - CO sensors in garage controlling exhaust fans
  - Temperature setback in common areas

- DHW Upgrades
  - Water conserving fixtures and appliances
  - Temperature setback
  - Waste heat recovery

- Lighting Systems and Controls
  - T8/electronic ballasts in garage
  - Occupancy sensors
  - Daylighting
  - Compact fluorescents in suites

- Appliances
    - Maximum energuide ratings

- Electrical Systems
    - High efficiency motors
    - High efficiency transformers
    - hydronic ramp heaters

- Energy Management and Central Monitoring System
    - Central Control system

The C-2000 indoor climate issues are:

- Ventilation
    - Air flows
    - Distribution system

- Humidity levels
    - Central humidification and controls

- Thermal Comfort
    - Thermal bridging
    - Infiltration

- Ambient Light Levels
    - Providing acceptable light levels
    - Quality of light
    - Daylighting

- Noise Control
    - Minimum sound transmission levels
    - Acoustic sealants

The C-2000 external environment issues include;

- Water consumption
    - Low consumption fixtures, appliances and toilets
    - Minimizing air conditioning loads (evaporative cooler)
    - Low maintenance landscaping
    - rainwater storage

CFC/HCFCs
    Minimum ODP (Ozone Depletion Potential)
    CFC/HCFC elimination in insulation products
    Minimizing CFC/HCFCs in mechanical equipment

Solid waste reduction
    Recycling construction and residential waste
    Use of recycled construction materials

Although this list of C-2000 issues is not exhaustive, based on the design of the building in this study these were considered to be the priorities for C-2000.

5.0 ANALYSIS OF ENERGY OPTION FOR C-2000

The energy requirements of the pre-prototype C-2000 building are based on the ASHRAE 90.1 Standard. It is hoped that the C-2000 design will require 50 to 70% of the annual energy required by the ASHRAE 90.1 design. This section of the report will examine the upgrades required and the difficulties involved with meeting the ASHRAE 90.1 requirements. The energy issues addressed by the ASHRAE 90.1 Standard are outlined below.

- Building Envelope
    - Insulation levels of walls, roof and floors
    - Thermal bridging
    - Windows & doors
    - Infiltration
- HVAC System
    - Equipment efficiencies
    - Central HVAC systems/thermal storage
    - Heat recovery for ventilation air
    - Timer control setback of ventilation air
    - CO sensors in garage controlling exhaust fans
    - Temperature setback in common areas
- DHW Upgrades
    - Water conserving fixtures and appliances
    - Temperature setback
    - Waste heat recovery
- Lighting Systems and Controls
    - T8/electronic ballasts in garage
    - Occupancy sensors
    - Daylighting
    - Compact fluorescents in suites
- Appliances
    - Maximum energuide ratings
- Electrical Systems
    - High efficiency motors/ High efficiency transformers
    - hydronic ramp heaters
- Energy Management and Central Monitoring System
    - Central Control system

5.1 Upgrading the building to ASHRAE 90.1 Design

The approach presented to the design team was to first upgrade the building to the requirements of ASHRAE 90.1 and than consider bringing the building up to what could be considered a C-2000 pre-prototype. This section compares the initial design of the building with the National Building Code requirements and then examines the upgrades required to bring the initial design of the building to ASHRAE 90.1 levels.

5.1.1 Building Envelope

There are no minimum insulation levels required by the National Building Code for commercial buildings. The National Building Code sets minimum insulation levels only for low rise residential buildings.

The original design of the building envelope was within the parameters normally found with this type of building. The insulation levels of the initial design and the ASHRAE levels shown in Table 1.

Table 1: Insulation Levels of Initial Design and ASHRAE Design.

	Envelope R-values in Initial Design		ASHRAE Requirements
Component	***Nominal R-Value***	***R-Value of Wall Assembly***	***R-Value of Wall Assembly***
Wall	RSI-3.52 (R-20)	RSI-2.64(R-15)	RSI-1.48(R-8.4)**
Roof	RSI-2.11 (R-12)	RSI-2.11 (R-12)	RSI-3.52 (R-20)
Slab above unheated garage	RSI-1.53 (R-8.7)	RSI-1.53 (R-8.7)	RSI-4.40 (R-25)
Windows	RSI-0.30 (R-1.7)	RSI-0.30 (R-1.7)	RSI-.23 (R-1.3)**
Doors	RSI-0.70 (R-4.0)	RSI-0.70 (R-4.0)	Treated as portion of wall

** Based on the system performance analysis of the ASHRAE 90.1 design. This method of analysis allows energy trade-offs between components of the envelope (ie: less window area, deeper overhang shading and larger thermal resistance of windows results in lower wall RSI requirements).

The effects of thermal bridging from wall material (studs), building sections (balcony slabs) and walls with lower insulation levels (shear walls) reduced the nominally RSI-3.52 (thermal resistance of insulation) walls of the building to an effective resistance (thermal resistance of wall assembly) of RSI-2.64. A typical RSI-3.52 wall consisted of 90mm of batt insulation and 32mm of rigid insulation. The R-value of the batt insulation was significantly compromised by the metal studs, and the RSI-value of the wall reduced to RSI-3.18. Balcony slabs and parapets were not thermally isolated from the interior structure of the building. This deficiency would create a fin effect removing significant amounts of heat from the building. In addition, many shear walls were inadequately insulated. The RSI-value of the shear wall assemblies was between RSI-1.41 or RSI-1.76. The lower insulation in the shear walls also reduced the average RSI-value of the building envelope.

For the effective thermal resistance of a wall, the ASHRAE 90.1 Standard addresses the problem of thermal bridging since the requirements are based on the insulation levels of the wall assembly. However, any amount of thermal bridging is acceptable as long as the overall RSI values are attained, and the moisture damage or thermal discomfort resulting from thermal bridging are ignored.

The insulation of the roof and the floor slab were inadequate for the ASHRAE 90.1 requirements. As shown in Table 1, insulation was added in the ASHRAE 90.1 design. As with the wall insulation, thermal bridging through channels and beams reduced the effective thermal resistance of the floor above the unheated garage.

The thermally broken aluminium windows specified in the initial design were sufficient to meet the requirements of the ASHRAE 90.1 Standard. There is no requirement in the ASHRAE 90.1 Standard for minimum door R-value.

Similar discontinuities to those found in the wall insulation were encountered with the building's air barrier. The air barrier was not continuous and consequently portions of the building envelope would allow significant amounts of infiltration. The air barrier in the initial design would not provide an effective barrier against infiltration and exfiltration as required by the National Building Code

Infiltration is not significantly addressed in the ASHRAE 90.1 Standard other than the requirement of caulking of envelope joints and penetrations. Consequently, the poor air barrier detailing in the initial design still meets the requirements of the ASHRAE Standard.

The architects had a difficulty accepting these deficiencies in their design. A fundamental understanding of heat transfer, building science and building code requirements was missing. With the insistence of the client driving the process, it was possible to have changes to the final drawings made that would reduce the thermal bridging and provide an effective, continuous air barrier.

5.1.2 HVAC

Heating

The initial design of the heating system included:

- 5 Low temperature hot water boilers & 255 water source heat pumps.
- 2 Make up air units (direct fired gas furnace).
- Minimal electric unit heaters for storage and mechanical rooms.

There are no requirements in the National Building Code pertaining to the efficiency or design loads of commercial buildings. The equipment efficiencies of HVAC equipment in the initial design, and the ASHRAE 90.1 design are shown in Table 2.

Table 2: Efficiencies of Heating & Cooling Equipment for Both the Initial Design and the ASHRAE Design

Equipment	*Rating*	*Initial Design*	*ASHRAE 90.1 Requirements*
Low Temp. Boilers	Efficiency (%)	83%	80%
Heat Pumps cooling (29.4 EWT)	EER	9.8 to 12.5	9.3
Heat Pumps heating (21.1 EWT)	COP	3.8 to 4.2	3.8
Make-up Air Heaters	Efficiency (%)	77%	80%
Electric heaters	Efficiency (%)	100%	N/A

In addition to the equipment efficiency requirements, ASHRAE 90.1 has a series of prescriptive criteria pertaining to the HVAC system of the building. Some of these requirements applicable to the building in this study are as follows:

- Equipment must be sized using the procedure outlined in the ASHRAE Fundamentals Handbook.
- Separate zones must have individual thermostatic controls with a setpoint range between 55 and 85F.
- Minimum insulation levels for HVAC piping and air handling ducts (based on size and temperature difference).
- Economizer controls.
- Flue dampers for gas fired equipment.

With the exception of the make-up air (MUA) systems, the HVAC equipment specified in the initial design met the required efficiencies of the ASHRAE 90.1 Standard. The manufacturer of the make-up air systems was changed because they could not produce equipment meeting the required efficiencies. The efficiency of the initial MUA units was 77%, and the new units had an efficiency of 80%. In addition, flue dampers were added to all the hot water boilers to prevent back-drafts through the flues.

Insulation on heating and cooling ducts reduces heat transfer between the air flowing through the ducts and the building space. Duct insulation is not required by the National Building Code, and insulation levels had not yet been specified in the initial design. ASHRAE 90.1 requires that the warm and cold air ducts be insulated to RSI-0.58 (R-3.3). The ducts in this category include the distribution ducts in the suites, commercial space, offices and common areas (distributing air from heat pumps).

The difficulty with the high efficiency requirements is obtaining the required information from the manufacturer. In most cases the local suppliers of the equipment were either unwilling or unable to provide up to date efficiency specifications. A significant amount of time was spent looking for efficiency information. A portion of the C-2000 Program will need to address this potential difficulty.

The upgrades to the heating system necessary for the building to meet the ASHRAE 90.1 requirements are listed below.

- Replace make-up air units in initial design (> 80% efficient).
- Insulate all heat pump duct run-outs
- Provide flue dampers for all gas fired equipment in conditioned space

Cooling

The cooling system in the initial design consists of 2 cooling towers & 255 water cooled heat pumps. As with the heating equipment, there are no minimum efficiencies in the Building Code. The efficiencies of the initial design and required by the ASHRAE 90.1 Standard for the heat pumps are listed in Table 2. No requirements are imposed on the cooling tower by the Building Code or the ASHRAE 90.1 Standard. ASHRAE's prescriptive criteria listed in the heating section also applies to cooling systems.

With the exception of the duct insulation requirements discussed in the previous section, no upgrades were required to the cooling system for the building to meet the ASHRAE 90.1 Standard.

Ventilation

The ventilation system of the initial design consisted of an individual exhaust fan exhausting directly to the outdoors in each suite's bathroom and kitchen. Two make up air ducts provided fresh air to each corridor. Make up air is provided to individual units through undercuts in the entrance doors to the suites. The installed capacity of the ventilation system was 8,500 l/s (18,000 cfm) for the 174 apartments (49 l/s per suite). This design meets all the requirements of the building code.

The Building Code requires that 7.5 l/s (15.9 cfm) of mechanical ventilation is provided for each unit. ASHRAE 90.1 does not propose any new concepts for ventilation. For ventilation rates, the ASHRAE 62 Standard is referenced and does not discuss distribution of ventilation air..

Although methods of providing ventilation are not part of the ASHRAE 90.1 Standard, the subject of improving the ventilation system was examined at one of the design meetings. As previously mentioned, the initial system consisted of make-up air entering the suites from the pressurized corridor through cracks in the doors. The air would leave the suites through kitchen and bathroom exhaust fans if they were operating. If the exhaust fans were not operating, as is usually the case, the suite would be pressurized forcing air through cracks in the exterior envelope. Forcing warm moist air through the envelope would eventually lead to moisture problems in the building envelope due to condensation. The design leader did not feel that this was an issue because "they had always built buildings like that". In addition operable windows were provided should the occupants feel they required additional ventilation.

5.1.3 Domestic Hot Water

The National Building Code does not specify minimum levels of insulation for the domestic hot water piping, or minimum flow rates of fixtures such as showers or faucets.

The insulation levels required by the ASHRAE 90.1 Standard are RSI-0.63 (R-3.6) for pipe diameters less than 2 inches. The initial design of the building had not specified the insulation levels for domestic hot water piping, or fixture flow rates. However, there was little difficulty in convincing the design team to upgrade the DHW insulation levels to the ASHRAE 90.1 requirement.

The ASHRAE 90.1 Standard requires that circulating DHW systems must be controlled by a timer, so that the pump can be shut down during times when hot water is not required by occupants. This will reduce the significant amounts of heat lost through the pipes because the pipes are maintained at design temperatures. If this system is used, the water in the pipes will approach room temperature. A tenant wishing to use hot water at this time will be required to run the water until the cold water in the pipe is completely replaced by hot water. In a 15 storey apartment building, this would a significant waste of water. This requirement was considered by the design team to be an inappropriate for an apartment building, where the hot water circulation system could not be shut down at night, because tenants working irregular hours would be inconvenienced. To some degree, their complaints are valid. The group was convinced that a programmable timer control connected to the circulating pumps would not incur significant capital costs. The tenants as a group could then chose if the central circulating pump would actually need to be shut down at night. This will meet the ASHRAE 90.1 objectives.

The addition of low-flow shower heads (3.0 gpm) and flue dampers on all DHW boilers was readily accepted due to their simplicity, low cost, and energy savings potential.

The upgrades to the domestic hot water system of the initial design include the following;

- The DHW piping was insulated to RSI-0.63.
- A timer control was installed on the central circulation pump.
- Low flow shower heads were included in design.
- Flue dampers were added to the hot water boilers.

5.1.4 Lighting and Lighting System Controls

The National Building Code does set minimum lighting levels for various types of occupancies, but does not address the issue of lighting power requirements. In the design of the ASHRAE 90.1 Standard, the minimum lighting levels in the code were strictly observed. The connected lighting load of the initial design is shown in Table 3 along with the ASHRAE 90.1 allowance for the same spaces.

Table 3: Lighting Load of Initial Design and ASHRAE Design

Space	Floor Area (m^2)	Initial Design (W) **	ASHRAE Design (W)
Commercial space	2,681	40,032	40,032
Parking ramp	169	1,820	1,820
Mech./storage /garbage rooms	348	1,395	1,080
Corridors/stairs	1,280	27,993	12,672
Offices/board rm.	197	1,706	1,402
Lobbies/lounges	1,171	7,767	6,822
Garage	5,138	18,135	18,135
Total	**10,984**	**103,249**	**86,118**

** Commercial, parking ramp had no lighting in the initial design. Other spaces undefined were assumed to be the same as the ASHRAE 90.1 levels.

Suite Requirements

Individual apartments are not subject to any lighting power restrictions under the ASHRAE 90.1 Standard, yet they represent over 60 percent of the installed lighting load for this building. In the initial and ASHRAE 90.1 design of this building incandescent lamps were used in the suites.

Common Area Requirements

The attitude of the designers, with respect to the lighting budget, was that the required power levels were not achievable at a reasonable cost.

The lighting power allowance portion of the ASHRAE Standard is simple to apply in spaces with known occupancy requirements. However, difficulties can arise with speculative portions of the building. In the case of the building being studied, the commercial (office area) portion of the building had been rented, but the interior layout had not been defined by the tenant. Builders often feel uneasy about limiting a tenant's lighting power. The common fear is that tenants will be reluctant to rent spaces with restrictions placed on the amount of light they can use. However, the design team was convinced that the power density allowance could be modified once the tenant had finalized the layout, and adequate lighting could be provided. Consequently, an allowance of 1.8 W/ft^2 was given to the commercial space.

The lighting levels in the corridors and the stairwells of the initial design far exceeded the 10 foot-candles at floor level required by the Ministry of Housing. In addition, the original systems would have created uneven and harsh lighting.

The most significant lighting modification in the ASHRAE 90.1 upgrade involved replacing the two, 4-foot T12 fluorescent lamp fixtures in the corridors and the stairwells with one, 4 foot T8 lamp/electronic ballast in the corridor and compact fluorescents in the stairwells. This modification reduced the connected lighting load, reduced the light levels to 10 foot candles and provided more even illumination.

The ASHRAE Standard encourages the use of occupancy sensors and daylighting controls through power credits for the use of lighting controls, but lighting controls are not required and often avoided by electrical designers. The use of any automated lighting controls met great resistance from the design team with the exception of the photocells on the exterior lights. Designers are reluctant to use automatic lighting systems because of the possibility of occupant dissatisfaction, and malfunctions.

5.1.5 Appliances

The are no efficiency requirements or minimum Energuide ratings specified by the Building Code or the ASHRAE 90.1 Standard. Consequently, no specifications were made in either the initial building design, or in the ASHRAE upgrades.

The energuide ratings of equipment used in the initial design and the ASHRAE 90.1 design can be seen in Table 14.

5.1.6 Electrical Systems

There are no requirements in the National Building Code for either the subdivision of electrical feeders or the efficiency of electrical equipment.

Feeder Subdivision

No electrical power schematic was available for the initial design of the building. This schematic was required to show the proper power feeder distribution and the electrical cabinets required to allow check metering.

The ASHRAE 90.1 Standard requires that power feeders for lights & receptacles, HVAC equipment, service hot water, elevators and occupant equipment (stoves etc.) be separated. In addition, an electrical cabinet is required for each feeder to allow for a portable check metering to measure the load.

The separation of power feeders according to the ASHRAE 90.1 Standard directly conflicts with individual tenant metering, since suite heat pumps and suite lighting feeders must be separated. This essentially eliminates the possibility of individual metering which is considered to be a method of limiting electricity consumed by tenants. It was decided to keep the individual suite metering since it was the most logical and energy efficient choice. This section adversely affected the integrity of the standard in the eyes of the design team.

High Efficiency Motors

No high-efficiency motors were specified in the initial design of the building. For this project, high efficiency motors are defined as meeting Ontario Hydro's high efficiency motor requirements. Although The ASHRAE 90.1 Standard specifies what a high efficiency motor is, Ontario Hydro's requirements are more stringent, more detailed and required by Ontario Hydro's New Building Construction Program (Ontario Hydro incentive program based on ASHRAE 90.1 Standard).

According to the ASHRAE Standard all polyphase motors greater than 1 HP and operating more than 500 hours per year must be high efficiency motors. But this portion of the Standard is modified by Ontario Hydro and does not apply to motors in package equipment (ie: make-up air units). Almost all mechanical equipment using fans, pumps or blowers can be specified to contain high efficiency motors. In addition, since ASHRAE 90.1 applies only to spaces consuming more than 1.1 W/ft^2, garage exhaust fans in this building are exempt from the energy efficient motor requirements.

To meet the requirements of the ASHRAE/IES 90.1 New Building Construction Program, it was necessary to specify high-efficiency motors for the water circulation pumps. But not for the garage exhaust fans, make-up air units, and other packaged systems.

5.1.7 Energy Management/Central Monitoring Systems EMS/CMS)

The initial design of the building had no EMS/CMS systems.

The ASHRAE 90.1 Standard requires that all buildings over 3,715 m^2 require a CMS system. This was modified by the Ontario Hydro's New Building Construction Program (Ontario Hydro's incentive program based on the ASHRAE 90.1 Standard). Ontario Hydro requires that all buildings larger than 18,600 m^2 (200,000 ft^2) contain a CMS system.

The philosophy of the EMS/CMS system is to provide a central location from which any automated controls such as timers can be operated, and energy consumption can be monitored.

This was a very unpopular issue with the mechanical designers. A CMS system was considered to be prohibitively expensive, with no substantial energy savings. The perceived high cost of these requirements is an issue which is difficult to change. In fact, the energy management issues in ASHRAE 90.1 require the capability for monitoring, but do not require that costly monitoring equipment be installed. It is assumed that the utilities can monitor the equipment if they so desire. The central monitoring system would, in the case of a multi-residential buildings, essentially be a processor controlling and monitoring the equipment from a central location rather than a remote one. The greatest cost of these systems would be the wiring, and the central processor. Because of the widely varied requirements of tenants in a multi-unit residential building, it is unlikely that significant energy savings would result from the installation of a CMS/EMS.

The building under study was below the 18,600 ft^2 limit and it did not require a CMS system. If it had, it is very likely that the ASHRAE application would not have been completed, despite the incentives. No EMS/CMS was included in the ASHRAE 90.1 design.

5.2 Summary of ASHRAE 90.1 Performance

The ASHRAE 90.1 Upgrades to the building are summarized below.

Envelope

- Insulate roof to RSI-3.52
- Insulate floor above garage to RSI-4.40

HVAC Equipment

- Replace make-up air units in initial design (> 80% efficient).
- Insulate all heat pump duct run-outs
- Provide flue dampers for all gas fired equipment in conditioned space
- Increase ventilation levels to ASHRAE-62 Standard

Domestic Hot Water

- The DHW piping was insulated to RSI-0.63.
- A timer control was installed on the central circulation pump.
- Low flow shower heads were included in design.
- Flue dampers were added to the hot water boilers.

Lighting

- Reduce interior lighting load of building to 86,120 Watts (a 17,130 Watt reduction).

Appliances

- No change.

Electrical System

- Subdivide power feeders according to usage category.
- Provide electrical cabinet for subdivided feeders.
- High efficiency motors of domestic water circulation pumps.

EMS/CMS

- No change.

Once the ASHRAE upgrades were completed, the building's energy consumption was modeled using ASEAM 3.1. It was found that the building consumed 20,409,000 MJ of energy over one year. Table 4 shows the breakdown of the energy consumption for the initial design of the building and the ASHRAE design. It should be noted that the increase in gas consumption in the ASHRAE 90.1 design resulted from the decreased electrical power required in the corridors. The energy efficient lights gave off less heat to the corridors, consequently the heating requirements of the gas make-up air heaters increased to compensate.

Figure 4 compares the energy consumption broken down by component for the two designs. The ASHRAE 90.1 design is only marginally more energy efficient than the initial design of the building. The areas of decreased energy consumption were lighting, pumps & fans and cooling. The heating requirements for the building increased slightly due to the lower lighting power heating the building.

The results shown in Figure 4 demonstrate that unless significant reductions are made in the building's heating load, substantial reductions in energy consumption are not possible. Infiltration, walls and windows represent almost the entire heating energy required by building (Table 7), yet no improvements to these systems was required in the ASHRAE 90.1 design. Other significant areas of energy consumption for this building are lighting (suites and garage 67% of connected load is not covered by the ASHRAE 90.1 Standard), domestic hot water(insulated pipes and low flow showers required by ASHRAE 90.1) and equipment (not covered by ASHRAE 90.1).

Table 4: Energy Consumption of Initial Design and ASHRAE 90.1 Building

	Electricity Demand (kWh)	Gas Demand (M^3)	Total Energy Consumed (MJ)
Initial design	2,773,176	298,854	20,978,464
ASHRAE 90.1 design	2,544,309	305,218	20,409,186

The winter and summer electrical peak load for the ASHRAE 90.1 Building were 1,346.7 kW and 1848.8 kW respectively.

The values for peak electricity consumption are derived from the peak heating and cooling requirements calculated by ASEAM 3.1. The peak lighting and appliance loads in the suites are calculated assuming 80 and 85% percent of the full load values respectively. All fans and pumps, as well as lighting in common areas, are considered to be 100 percent on for the peak power consumption. The summer and winter peak loads are calculated below in Table 5 for the ASHRAE 90.1 design.

Table 5: Peak Electrical Load Calculation for the ASHRAE Design

Electricity Load	Winter Peak (kW)	Summer Peak (kW)
Heating Load (COP = 3.55)	361.0	N/A
Cooling Load (COP = 3.55)	N/A	771.0
Suite Lighting (80%)	120.4	120.4
Suite Appliances (85%)	689.9	689.9
Office Equip + Lights	5.9	5.9
Commercial Space	47.2	47.2
Common Equip & Lights*	134.5	134.5
Cooling Tower	N/A	28.6
Fans + Pumps	87.9	51.3
Total Peak Power	1,346.7	1,848.8

* The parking garage, corridor, and exterior lights are on 100 per cent of the time; the remaining common area lighting is on 80 per cent of the time; and equipment in the common area is assumed to be on 80 percent during peak hours.

Table 6 and 7 show the design heat losses and gains respectively for both the initial design and the ASHRAE 90.1 Building designs. Figure 4 illustrates the breakdown of the annual energy consumed by the base case and the ASHRAE 90.1 design.

Table 6: Cooling Load by Component for Initial and ASHRAE Design

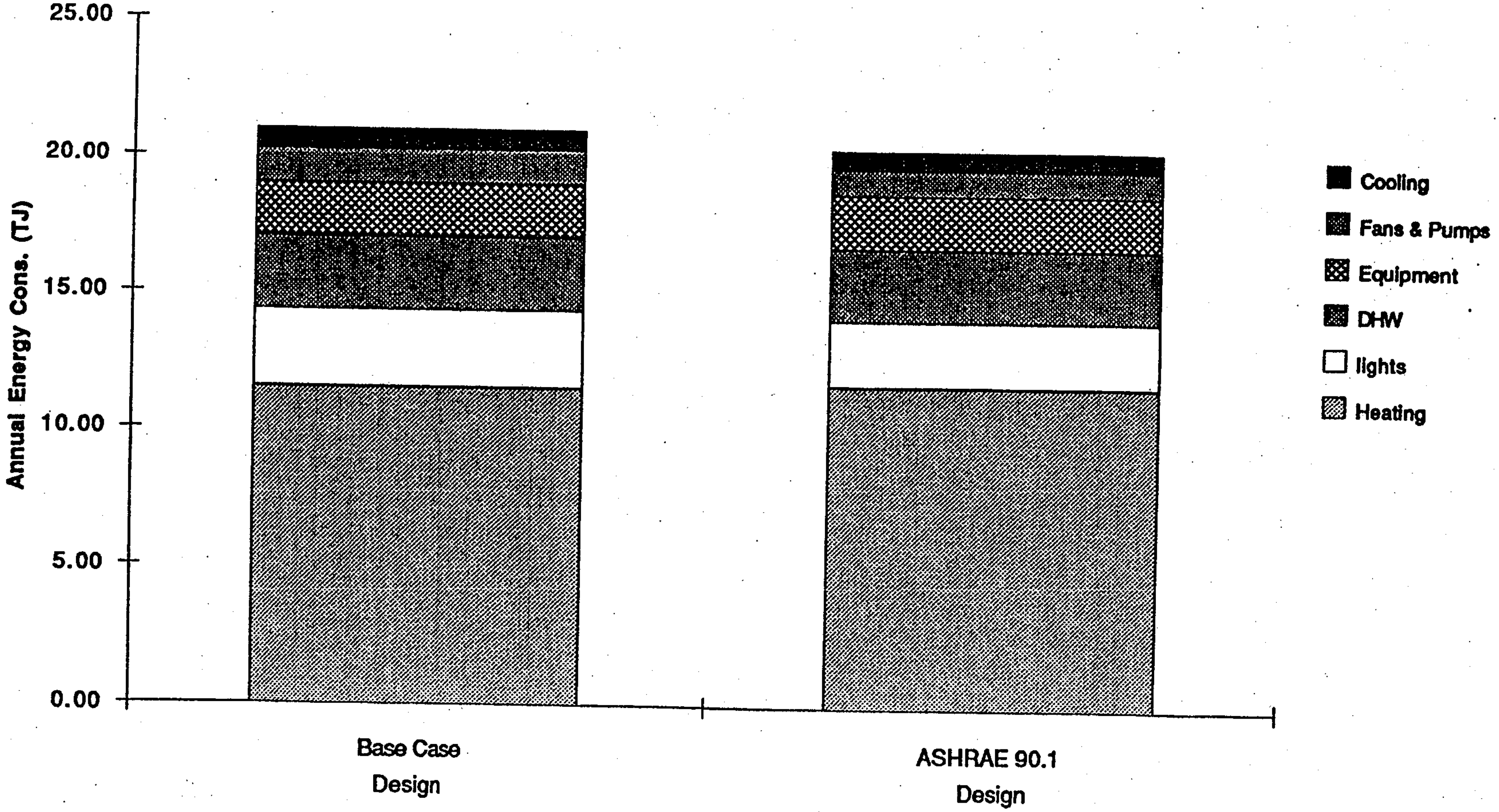
	Design Cooling Load @ T_{design} = 31C (kW)	
Cooling Load Component	**Cooling Load of Initial Design (kW)**	**Cooling Load of ASHRAE 90.1 Design (kW)**
Roof	12.6	8.7
Wall	72.5	72.5
Door	9.7	9.7
Windows	1,361.9	1,361.9
Basement	0.8	0.2
Occupants	41.0	41.0
Lights	225.8	210.6
Equipment	874.8	874.8
Infiltration	151.4	151.4
Total	**2,750.5**	**2731.7**

Table 7: Heating Load by Component for Initial and ASHRAE Design

	Design Heating Load @ T_{design} = -15C (kW)	
Heating Load Component	**Heating Load of Initial Design (kW)**	**Heating Load of ASHRAE 90.1 Design (kW)**
Roof	41.7	25.1
Wall	219.0	219.0
Door	27.5	27.5
Windows	234.1	234.1
Basement	5.0	1.8
Infiltration	913.6	913.6
Total	**1,440.9**	**1422.8**

Figure 4: Annual Energy Consumption By Component

Initial Design and ASHRAE Design



5.3 C-2000 ENERGY PERFORMANCE ISSUES

Based on the preliminary outline of the C-2000 project, there are two main energy goals of this project. The first is to reduce energy consumption by 30 per cent to 50 per cent of an ASHRAE 90.1 building, and the second is to reduce peak electricity demands in summer and winter. To accomplish both goals, upgrades to the electrical/lighting systems, building envelope, and mechanical systems will be required.

Individual envelope upgrades are examined in isolation. The combination of upgrades was determined by performing all the upgrades on the building design and simulation this design with ASEAM 3.1. The combined upgrades do not necessarily equal the sum of the individual upgrades. The final C-2000 energy consumption and peak electrical demand are determined by incorporating all the C-2000 upgrades into the building design.

5.3.1 Building Envelope

Walls

ASHRAE 90.1 has very modest requirements for the insulation levels in the building's walls. Using the system component analysis, the minimum insulation value of the wall is RSI-1.5 R-(8.4). This level of insulation is significantly lower than is used in most new Canadian buildings, and consequently there is significant room for improvement in the C-2000 Program. In the construction of a new building, it would be simple and cost effective to upgrade the insulation to an effective RSI-3.52 (R-20). According to simulations performed on ASEAM 3.1, this would result in a 1,310,600 MJ (6.5 percent) reduction in the annual energy consumed by the building.

Windows

The co-op building was designed with conventional double glazed aluminium windows with a thermal break. These windows were more than sufficient for the building to pass the ASHRAE 90.1 requirements. These windows were upgraded to vinyl Low-E argon windows in the C-2000 design. The high efficiency window industry is well developed, and dependable. Since these windows are the same dimensions as traditional windows, the implementation of this technology will be simple. It was found that the use of high efficiency windows resulted in a 533,100 (2.6 percent) energy reduction for the entire building, and a significant reduction in the peak cooling requirements.

Roof

The roof insulation required by the ASHRAE Standard as previously discussed is RSI-3.52 (R-20). Although the roof heat loss through of the ASHRAE 90.1 design determined in Section 5.2 is relatively small, on a unit area basis it is still significant and warrants improvement beyond ASHRAE 90.1. The C-2000 version of the building was designed with an RSI-7.04 (R-40) roof. The ceiling below the mechanical penthouse was also assumed to be RSI-7.04 (R-40). It would be of no advantage to increase the insulation of the penthouse ceiling since the ventilation rates are large and the heating is nominal in this space. As with the increasing the wall insulation, the procedures are well known by the building community and the materials are readily available. The building's energy load was decreased by 122,700 MJ or 0.6 percent of the ASHRAE building's annual energy load.

Exposed Floors

The initial building design consisted of RSI-1.6 (R-8.7) floors above the unheated garage. The thermal resistance of the floor between the unheated garage and the first floor is required to be RSI-4.4 (R-25) according to the ASHRAE 90.1 Standard. By increasing the insulation to RSI-5.28 (R-30) there would be negligible savings. The ASHRAE 90.1 slab requirements are sufficient for the C-2000 program.

Infiltration

Infiltration is an issue that is not sufficiently detailed in the ASHRAE 90.1 Standard. Studies performed on high-rise apartment buildings by CMHC suggest that typical buildings allow between 1.42 and 2.29 L/s/m^2 (0.28 - 0.45 cfm/ft^2) of wall area at 25 Pa pressure difference. It will be assumed that the infiltration rate for the co-op building is average of these field measurements, or 1.88 L/s/m^2 (0.37 cfm/ft^2) at an average 25 Pa pressure difference over the building envelope.

A logical assumption for the C-2000 Program is that air infiltration can be reduced to R-2000 levels. It is possible that further reductions can be realized through improvements to the R-2000 construction techniques, but for this study R-2000 construction is sufficient. The R-2000 infiltration rate is 1.5 AC/hr at 50 Pa. Assuming an average house is 24,000 ft^3 with 2,000 ft^2 wall area, the infiltration rate per wall area is approximately 1.52 L/s/m^2 (0.3 cfm/ft^2) at 50 Pa, and 0.96 L/s/m^2 (0.19 cfm/ft^2) of envelope area at the 25 Pascals expected in the 15 story building.

The following formula was used to convert an air leakage rate at a specific pressure difference to different pressure difference.

$$Q_{25} = Q_{50}(25Pa/50Pa)^n \qquad \text{where } n=0.65$$

The improvements necessary to reduce natural air infiltration to R-2000 levels are relatively small when compared to the energy savings. The procedures for reducing air infiltration has been well developed through the R-2000 Program, and can easily by applied to commercial buildings. The simulation results for the building at R-2000 infiltration levels indicated that a reduction in the building's energy consumption of 3,735,400 MJ (18.5 percent of the ASHRAE building) can be realized.

The reduction in infiltration rates will be highly dependent on the average pressure difference assumed to be acting over the face of the building. For the building in this study, the pressure difference between indoor and outdoor air building envelope was determined to be 25 Pascals.

Increasing the tightness of interior partition walls is an issue of air quality and noise reduction. This topic will be covered in the Indoor Environment Section.

Doors

No discussion is made about doors in the ASHRAE 90.1 Standard. They are treated as part of the wall area with lower insulation value. The doors in the initial design were RSI-0.31. In the C-2000 design, the doors will be insulated to RSI- 0.88, and will be assumed to be tight (8 cm^2 of leakage area/m2 of door @ 25 Pa pressure difference). The improved air tightness of the doors was included in the examination of infiltration.

Compliance and Verification of C-2000 Envelope Criteria

The requirements for the building envelope are simple to apply as well as to enforce. The required insulation levels and proper air barrier detailing can be enforced by a plans evaluation and the infiltration rates can be verified by pressurizing the building. There are two possible methods of performing the pressure tests on the building:

- Each unit must have airtight interior walls, so each unit must meet the infiltration requirements individually. The blower can then be placed in the corridor door to depressurize the suite. Two or three units could be randomly chosen for testing.

- The second option is to depressurize the entire building using the ventilation system. This would be a more difficult test to perform, due to the size of some residential buildings. However, the results would represent the entire building as opposed to individual apartment tests. Also, the interior walls of the suites would only have to be airtight enough to prevent the transmission of odours.

It is recommended that the second test be used to verify the air leakage rates due to cost (internal walls not as airtight as exterior walls). Inspections will be required to examine the air barrier between suites to limit the transmission of odours.

Windows will be subject to a minimum energy rating according to the CSA-A440.2 window standard.

The combination of envelope upgrades will reduce the building's energy consumption by 6,143,600 MJ or 30.4 percent. The additional cost of the envelope upgrades is approximately $285,384.

Table 8: Energy Savings From C-2000 Envelope Upgrades

Envelope Upgrade	*Energy Savings (MJ)*	*Energy Savings (% ASHRAE)*	*Peak Electricity Reduction*		*Cost ($)*
			Summer	Winter	
R-20 Walls	1,310,650	6.5	7.4	25.2	112,165
High Eff. Windows	533,121	2.6	98.3	10.2	101,815
R-40 Roof	122,669	0.6	0.6	5.1	43,404
R-2000 Infiltration	3,735,389	18.5	18.6	79.2	20,000
Eff. Doors	152,662	0.8	0.7	6.2	8,000
Combination of Envelope upgrades	**6,143,627**	**30.4**	**127.6**	**130.3**	**285,384**

Individual envelope upgrades are examined in isolation. The combination of upgrades was determined by performing all the upgrades on the building design and simulation this design with ASEAM 3.1. The combined upgrades do not necessarily equal the sum of the individual upgrades.

5.3.2 HVAC Equipment and Systems

In searching for high efficiency equipment that could be incorporated into the C-2000 design for this building, it was found that only marginal improvements could be made beyond the ASHRAE 90.1 equipment efficiencies for conventional systems. However, alternative systems such as waste heat recovery would improve the efficiency of the HVAC equipment. If the individual heat pump systems are replaced with a central chiller and boiler hydronic system, heat recovery from the chiller to heat domestic hot water could be used to improve the efficiency of the HVAC system.

Heating

As discussed previously, the heating system in the ASHRAE 90.1 design consists of water source heat pumps. In the context of a C-2000 building, there are several benefits to replacing the heat pumps with a central boiler/chiller and fan coil units. Because of the complexity of heat pumps and the number required to heat and cool the building maintenance resulting in poor operating efficiencies. Since the new system will consist of a central system, it can be regularly maintained to keep it's design efficiency. The use of a central boiler will also reduce the winter peak electric demand of the building.

The apartment heat pumps will be replaced by fan coil units with water meters to monitor individual energy consumption. Metering is important for the central heating system, since tenants have a tendency to use more energy when they are not paying for what they consume. The cost of individual heat pumps will be approximately the cost of fan coil units with water meters. The increase in capital cost for this system will result from providing two high temperature boilers instead of one low temperature boiler, and providing a central chiller.

The energy consumption resulting from the central boiler/chiller system is an increase of 1,333,000 MJ or 6.6% of the ASHRAE 90.1 design (accounts for both central boiler and central chiller). However, the winter electrical demand will be reduced by 361 kW.

Cooling

The ASHRAE 90.1 design consisted of heat pumps and two evaporative coolers. Replacing this system with a central chiller and fan coil units will allow; proper maintenance to maintain the operating efficiency, lower capital costs, heat recovery from the compressor, and the elimination of HCFCs used in heat pumps.

By converting the cooling system to a central chiller, a heat recovery system can be installed to preheat domestic hot water during the summer cooling season. These systems are not uncommon on large chillers, and many chiller manufacturers build heat recovery systems into their chillers at the customers request. Since these systems are integrated with the chiller at the manufacturing stage, the additional costs are reasonable, and the systems are dependable. This system will be discussed further in the domestic hot water section.

Training will be required for the buildings maintenance staff as to the proper care of the chiller to ensure high efficiencies.

The use of thermal storage is recommended in the ASHRAE 90.1 Standard, but is not required. Insulated water storage tanks will be used to store chilled water for use during peak cooling hours in the summer. By using two 2,500 litre tanks, the peak cooling required from the chiller can be reduced by approximately 15 percent. In addition to the reduced capital cost (a smaller chiller will be required to meet the peak loads), the peak summer electricity demand will also be reduced by 15 percent of the cooling load or 115 kW.

There will be some standby losses, but they can be minimized by charging up the chilled water supply shortly before it is required. In other words, the chiller can begin using its excess capacity to provide chilled water for the storage tanks in the mornings, so during peak cooling requirements in the afternoon the supply of chilled water can be circulated through the fan coil units. The building energy consumption will increase by 20,184 MJ or 0.1 percent.

Ventilation Equipment

The make-up air systems being installed in apartment buildings today offer significant potential for energy savings. A typical system consists of preheated outdoor air being continuously supplied to corridors and common areas. Door cracks allow the air to pass from the corridor to the suites. The air is then exhausted with no heat recovery by kitchen and bathroom fans. The system is usually poorly balanced so that air is being forced through the building envelope creating moisture problems and drafts. In addition, the exhaust fans are incorrectly sized due to the stack effect, resulting in insufficient ventilation on lower floors. The unheated garage ventilation systems consists of supply/exhaust fans that may or may not be operating constantly. In the case of the co-op building in this study, they garage fans are operating continuously.

The make-up air system in the initial and the ASHRAE 90.1 design include two separate units. The commercial unit supplies 3,700 cfm of fresh air to the commercial space, and the residential units supplies 18,000 cfm of fresh air to the residential corridors and common areas.

The proposed C-2000 modifications to the ventilation system include the addition of supply/exhaust setback, air ducts between suites and apartments (discussed in Section 6.1), heat recovery, carbon monoxide/dioxide sensors controlling the garage fans and some form of certified mechanical installers to ensure successful commissioning of the building.

During times of low occupancy or low ventilation requirements such as offices at night, the ventilation requirements for a space can be significantly lower than the design levels. The air flow in the ventilation system can be set back when supply and exhaust air requirements are lower than design conditions. Times when ventilation could be reduced would include late morning, afternoon and night in the residential space and at night for the commercial and office space. The acceptability of this type of ventilation may need more investigation for residential buildings. The proposed schedules for the residential and commercial space is shown below in Tables 9 and 10.

Table 9: Residential Make-up Air Schedule

Time of Day	*CFM (outdoor)*	*% Full Motor Load*	*Required Motor Power - HP (output)*
6 am - 9 am	18,000	100%	10.0
9 am - 11 am	12,600	34%	3.4
11 am - 1 pm	16,200	73%	7.3
1 pm - 4 pm	12,600	34%	3.4
4 pm - 9 pm	18,000	100%	10.0
9 pm - 11 pm	12,600	34%	3.4
11 pm - 6 pm	3,600	10%	1.0

Table 10: Commercial Make-up Air Schedule

Time of Day	*CFM (fresh+Total) **	*% Full Motor Load*	*Required Motor Power - HP (output)*
6 am - 7 pm	2,700 + 18,000	100%	10.0
7 pm - 6 am	500 + 16,750	75%	7.5

* The ventilation air being supplied to the commercial space consists of approximately 15% outdoor air, while the remainder is recirculated indoor air. The outdoor air supply will be reduced to a nominal level at night, and the recirculated air will be reduced because the thermostat setback at night reduces the amount of air required to circulate heat.

By following the schedule in Tables 9 and 10, fresh air will be provided when it is required, and when it is not, the reduction in outside air will reduce the building's heating/cooling load and motor power load. The energy saving associated with using these schedules will be 1,432,400 MJ (7.1 percent).

Heat lost from exhaust air can be greatly reduced by replacing the commercial and residential make-up air units with heat recovery ventilators (HRVs). The proposed system would preheat outdoor air in the winter, and to a lesser degree pre-cool outdoor air in the summer. Not only will this reduce the energy consumed by the building, but summer comfort will be improved in areas not serviced by heat pumps, such as corridors and storage areas.

The efficiency of the HRV is approximately 66 percent of the maximum heat transfer in the winter, and 20 percent in the summer. It is difficult to set a minimum effectiveness for an HRV for C-2000 building, since it is highly dependent on operating conditions such as indoor and outdoor temperatures, and air flows. However, a well balanced system at design temperatures in Toronto should be operating with an effectiveness greater than 60 percent. With a balanced flow at design winter conditions (-18°C), this would raise the supply air temperature to 8 °C. At summer design conditions ($T_o = 31$ °C) the entering air temperature would be 29.8 °C.

A heat recovery system will greatly reduce both the summer and winter peak electricity demand, and reduce the energy annually consumed by the building. Since there will be no exhaust fans directly exhausting outside, there is will be no potential for exhaust fans on lower floors to be inadequate to overcome the stack effect. Which normally results in poor ventilation, and potential moisture problems.

HRV systems are a well developed technology that have proven their dependability in the R-2000 program. The additional cost of the HRV would be offset by the elimination of the make-up air heaters used in the initial design to pre-heat the fresh air. The A heat recovery system in both the residential and commercial portion of the building will save 2,197,600 MJ (10.8 percent)

Garage supply and exhaust fans often operate continuously in unheated garages. This excess ventilation results in a waste of electricity caused by the continuous operation of the fans, and an unnecessarily cold garage causing discomfort to occupants going to and from their cars. The installation of carbon monoxide sensors controlling the operation of supply and exhaust fans will reduce the energy consumed by the garage fans and provide a more comfortable temperature in the garage. The sensors required for this upgrade are relatively inexpensive and dependable. It is assumed that the CO sensors will reduce the operating time of the fans by 50%, resulting in a savings of 173,600 MJ (0.9 percent).

The combination of the upgrades to the HVAC system in the C-2000 building will result in an energy savings of 1,803,400 MJ. The cost of the improvements are $70,800.

Table 11: Energy Savings From C-2000 HVAC System Upgrades

HVAC System Upgrade	Energy Savings (MJ)	Energy Savings (% ASHRAE 90.1)	Peak Electricity Reduction (kW)		Cost ($)
			Summer	Winter	
HRVs	2,197,605	10.8	4.0	11.4	85,500
Ventilation Setback	1,432,385	7.1			3,500
CO sensors	173,569	0.9	1.8	1.8	12,000
Temp. Setback	94,856	0.5			1,500
Central Chiller & Boiler	- 1,332,570*	- 6.6	- 36.5**	361.0	3,500
Thermal Cool Storage	- 20,184*	- 0.1	115.0	0.0	- 35,200***
Combination of HVAC upgrades	**1,803,430**	**8.8**	**83.3**	**374.2**	**70,800**

* The negative energy savings represent increases in the energy and summer electrical power consumed by the building. However, the additional operating costs of this equipment is offset by lower maintenance costs and lower peak electrical requirements.

** The negative peak electricity reduction represents an increase in the summer electrical power consumed by the building.

*** The negative additional cost of the thermal cool storage option resulted from a smaller chiller required meet the cooling load.

5.3.3 Domestic Hot Water Equipment

Energy required to heat the domestic hot water consumed in the building represents almost 15 percent of the annual energy consumed in the building. This energy can be reduced through the use of water conserving fixtures, night setback of the hot water temperature, and the preheat of city water before it enters the boiler.

Reducing Consumption

Water conserving shower heads can reduce the flow of water to between 5.7 and 9.5 litres per minute from the 11.4 l/m required by ASHRAE 90.1. As shown in the water conservation section, the cost of the lowest flow shower (5.7l/m) heads are not significantly more than the 11.4 l/m shower heads. However, if the shower head flow rate is too low, occupant satisfaction may become a problem. For these reasons, the C-2000 design the shower heads should be 9.5 l/m.

The ASHRAE Standard does not require faucets to be of low flow design, however faucet aerators are inexpensive and simple to install and can reduce the water consumption of a unit by 60 litres per day.

The energy savings will by 511,200 MJ per year or 2.5% of the energy consumed by the ASHRAE 90.1 design of the building.

Temperature Setback

The ASHRAE Standard requires the installation of timer controls on the domestic hot water circulation pump to reduce pipe losses. As discussed in Section 5.1.3, this is not a practical control strategy in a residential building, since occupants requiring water at night will be required to run the taps or showers until the cold water in the pipe is completely replaced by hot water. In addition, the pump may be required to provide the pressure necessary for domestic water to reach the upper levels of the building.

In lieu of the pump timer required by the ASHRAE 90.1 Standard to reduce pipe losses during night hours, the boiler water temperature could be reduced from 140 F to 130 F without disrupting the occupants comfort. Lowering the temperature below this level could cause health problems such as legionnaires disease, and is not recommended. The energy savings will result from the lower temperature of the water being consumed, and lower pipe losses in the circulating system.

Temperature setback would reduce the building's energy consumption by 125,500 MJ (0.6% of the ASHRAE 90.1 design).

It is unlikely that further increases in pipe insulation would be helpful for the C-2000 design, since the return would most likely be small compared to the additional cost. However, this should be confirmed through further study.

Waste Heat Recovery

The ASHRAE Standard recommends that waste heat recovery and solar energy be examined for the preheating of domestic hot water. Since waste heat recovery is only a suggestion of ASHRAE 90.1 it is unlikely that it will be incorporated into many buildings.

In a large buildings there is an opportunity of preheating domestic hot water at no energy cost. This can be done through solar energy, waste heat recovery from the central chiller during the cooling season, or grey water heat recovery. With the large amount of domestic hot water used in these buildings, preheating of 10 degree Celsius city water can result in significant energy savings. Due to the wide variety of buildings being encompassed in the C-2000 program, it is not possible to recommend one method of preheating hot water. However, one form of domestic hot water preheating should be required for all C-2000 buildings.

For this building, grey water and chiller waste heat (in cooling season) is used to preheat water before it enters the gas fired boilers. The heat transfer will be done through the use of a heat exchanger with bypass controls. In the summer, only waste heat from the chiller and in the winter only grey water will be used.

Waste heat recovery will reduce the building's energy requirements by 377,500 MJ per year (1.9% of the ASHRAE 90.1 design).

Another possibility of waste heat recovery is the use of dryer exhaust to preheat laundry water. However, this requires further investigation.

The result of the domestic hot water upgrades is an energy savings of 922,600 MJ at a cost of $17,150.

Because solar energy and waste heat recovery are not common in building designs, these measures will encounter resistance from the building community. Because of the lack of standards for this type of systems, it is recommended that installers require certification, or engineers be required to inspect the designs and the system.

Table 12: Energy Savings From C-2000 DHW System Upgrades

Domestic Hot Water Upgrade	Energy Savings (MJ)	Energy Savings (% ASHRAE 90.1)	Peak Electricity Reduction (kW)		Cost ($)
			Summer	Winter	
Consumption Reduction	511,225	2.5	Gas	Gas	7,150
Temp. Setback	125,471	0.6	Gas	Gas	3,500
Preheat	377,514	1.9	Gas	Gas	6,500
Combined DHW System Upgrades	**922,613**	**4.5**	**Gas**	**Gas**	**17,150**

5.3.4 Lighting and Lighting Controls

It is unlikely that the lighting power could be reduced beyond ASHRAE 90.1 requirements for common areas of residential buildings. The ASHRAE 90.1 power allowance for the corridors and stairwells is insufficient to meet the lighting levels required by the National Building Code (10 footcandles at floor level). With T-8 lamps and compact fluorescents in the corridors, power allowances from other areas of the building were required to offset the lighting power in the corridors. It should be noted that certain spaces such as office areas can attain lighting power levels significantly lower than the ASHRAE requirements.

Innovative lighting controls such as daylighting and occupancy sensors are recommended by the ASHRAE 90.1 Standard, but are not required.

Common Areas

Because the ASHRAE Standard applies only to spaces consuming more than 1.1 W/ft^2, unheated spaces are generally not controlled by the Standard. For the building in this study, this would apply to the unheated garage. It has been designed with 195, 2 to 4 ft T12 fluorescent fixtures. Since the garage lighting is on 24 hours a day, any reduction in the garage lighting power will significantly reduce the peak electricity demands as well as the annual energy consumption. By replacing the garage fixtures from the initial/ASHRAE 90.1 design with 72 W T8/electronic ballasts, the electricity peak would be reduced by 4.1 kW, and 35,900 kWh per year would be saved.

Another possibility for energy conservation and peak electricity reduction is the use of occupancy sensors in the corridors. The majority of the time corridor lights are on when the space is unoccupied. Since corridor lighting represents a significant portion of the lighting power in the building, a great deal of energy conservation is possible. The corridors require 8.5 kW of power, although they are not occupied more than 40 percent on the day. Reducing the hours of operation by just 50 per cent would save 37,200 kWh of energy and would reduce the peak electricity demand by approximately 1.5 kW, assuming 85 per cent of the corridor lights were on during peak hours.

Approximately 3,700 ft^2 of the building's perimeter area is available for daylighting controls. The use of daylighting will lower the building's lighting and cooling loads without reducing the ambient light level of the space. The obstacle to the successful implementation of daylighting controls in a building is the industry's resistance. Most builders do not like control systems because of the potential for malfunctions.

The perimeter area is taken to be a maximum of 15 feet from the outside wall, and includes commercial space, office space, and 15th floor common areas. For the calculation of the lighting energy saved, it was assumed that the windows were all north facing to account for shading from other buildings in the area. It was also assumed that the lamps in these areas could be continuously dimmed. The peak electrical savings resulting from daylighting will be 5.9 kW during the summer, due to cooling load reductions. The energy savings will be 19,445 kWh (70,000 MJ)

Suites

Because the suite lighting represents more than 60 percent of the lighting load in most residential buildings, compact fluorescents should be considered to reduced the lighting power of residential space.

Because fluorescent lamps are believed to provide poor colour rendition, and compact fluorescents sometimes flicker before turning on, it would most likely be unacceptable to equip the living spaces of the suites with fluorescent lamps. But, entrance areas, kitchens and bathrooms and corridors could be fitted with compact fluorescent fixtures with little or no occupant dissatisfaction. This would reduce the connected lighting load of the building by 60 kW.

Outside

The ASHRAE 90.1 lighting design provided high pressure sodium lamps for all exits, garage entrance and roof terraces. The main commercial and residential entrances were equipped with incandescent lamps since they provide higher quality lighting.

It is fairly difficult to provide adequate outdoor lighting given the ASHRAE 90.1 outdoor lighting power allowance. Unless an acceptable alternative to incandescent lamps are available for the main entrances, little can be done to reduce the exterior lighting power beyond ASHRAE 90.1 levels. For security reasons it would not be recommended to reduce the illumination levels further in other areas (exits, terraces etc.), consequently, the ASHRAE 90.1 lighting allowance is recommended for the C-2000 design.

All outdoor lighting must be controlled by a photocell or a timer according to the ASHRAE Standard. Consequently, no additional lighting controls are required for exterior lighting.

Summary of Lighting Upgrades

Further investigation is required into the lighting quality of external lights and an energy efficient/high quality alternative to incandescent lamps. The study should also investigate occupant and owner satisfaction.

The combination of lighting upgrades resulted in an annual energy reduction of 421,652 MJ, as well as summer and winter peak electricity reductions of 60 and 54 kW respectively. The additional cost of the lighting upgrades is $65,750.

Table 13: Energy Savings from C-2000 Lighting Upgrades

Lighting Upgrade	Energy Savings (MJ)	Energy Savings (% ASHRAE)	Peak Electrical Reduction (kW)		Cost ($)
			Summer	Winter	
T-8's in Garage	127,134	0.5	4.1	4.1	29,250
O/S in Corridors	131,738	0.6	1.5	1.5	7,500
CFL in Suites	92,780	0.5	48.4	48.4	21,250
Daylighting	70,000	0.3	5.9	N/A	7,750
Combination of Lighting Upgrades	**421,652**	**2.1**	**59.9**	**54.0**	**65,750**

5.3.5 Appliances

High efficiency appliances such as refrigerators and stoves offer a significant energy savings and peak load reduction potential. For the C-2000 design, it was assumed that the appliances would be upgraded from an average name brand appliance to the most efficient name brand appliance, according to the 1991 Energuide ratings. Consequently, the appliances chosen for the C-2000 design are by no means the most energy efficient models available. Table 14 illustrates the Energuide ratings for appliances used in the ASHRAE 90.1 building and the C-2000 building.

Table 14: Energuide Ratings of C-2000 Appliances

Appliance	Quantity	Energuide Rating (kWh/month)	
		ASHRAE 90.1	C-2000
Refrigerator	176	67	64
Stove	176	100	80
Washer*	10	300	255
Dryer*	10	240	207

* Washer and dryers are community appliances, and are assumed to be used 3 times as much as individual units

Table 15: Energy Savings from C-2000 Appliance Upgrades

Appliance Upgrade	Energy Savings (MJ)	Energy Savings (% ASHRAE)	Peak Electrical Reduction (kW)		Incremental Cost ($)
			Summer	Winter	
High-Efficiency Appliances	193,485	1.0	102.9	57.7	32,200

5.3.6 Electrical Systems

Subdivision of Electrical Feeders

Since the ASHRAE 90.1 Standard does not require individual tenant metering, this should be a requirement of the C-2000 Program. If tenants are not paying for the energy they used, significant amounts of energy will be wasted.

High efficiency motors

All motors in the ASHRAE 90.1 design over 1 horse power are required to meet Ontario Hydro's high efficiency requirements. For this project, high efficiency motors are defined by Ontario Hydro's high efficiency levels. The Ontario Hydro New building Construction Program based on the ASHRAE 90.1 Standard modified the ASHRAE motor efficiencies to match the Ontario Hydro's requirements. As discussed in Section 5.1.6, high efficiency motors are not required for the garage exhaust fans and packaged equipment.

It would be recommended that all motors in the C-2000 building meet the high-efficiency motor specifications of Ontario Hydro. In the case of the building in this study, the garage supply and exhaust fans, the make-up air systems, and the HRVs would all be required to have energy-efficient motors.

High efficiency motors are commonly used, and can be specified for most package equipment. There should be no barriers in implementing the high efficiency motor requirement. A simple motor list provided by the building and an inspection will provide verification.

High efficiency motors in the make-up air units and the garage exhaust fans would reduce the energy consumption of the building by 11,200 kWh's (40,330 MJ) or 0.2 percent of the building's annual energy consumption

Transformers

The ASHRAE 90.1 requirement for transformers is that they are correctly sized for the building load. High efficiency transformers are not required.

The transformers specified for the ASHRAE 90.1 building have full load efficiencies of 97.5 percent. For the C-2000 design, high efficiency transformers with 98.5 percent full load efficiencies is recommended.

A high efficiency transformer would reduce the energy consumption of the building by 12,650 kWh's (45,550 MJ) or 0.2 percent of the annual energy consumption.

One drawback to high efficiency transformers is the lack of information provided by manufacturers.

Ramp Heaters

The electric ramp heaters offer a potential for reducing peak electrical demand. Instead of directly heating the ramp with electric resistance heaters in the asphalt, a water glycol loop can be used to remove ice from the ramps. A gas heater with a small storage tank will provide the energy for ramp heating. Some energy will be lost due to standby losses in the tank, but the over 70 kW required for ramp heating will not be used during peak electrical hours. Although the building's energy consumption will increase slightly, some financial benefits will be achieved due to the significantly lower energy cost.

Hydronic ramp heating is a method of reducing peak electrical demand, provides little energy savings and consequently little financial return for the building owner. This system is approximately $3,500 more expensive than electric resistance ramp heating. It is important to note that peak reduction upgrades will be an unwelcome portion of the C-2000 energy requirements until a dual rate system makes demand reduction more attractive.

A hydronic ramp heater will increase the energy consumption of the building by 32,070 MJ or 0.1 percent of the building's energy consumption. However, the peak electrical demand will be reduced by 70.7 kW in the winter.

Summary of electrical upgrades

The electrical upgrades will result in an annual energy savings of 81,600 MJ and a summer and winter peak electricity reduction of 10.7 and 78.2 kW respectively. The cost of these upgrades is approximately $25,700 above the ASHRAE Building.

Table 16: Energy Savings from C-2000 Electrical Upgrades

Electrical Upgrade	***Energy Savings (MJ)***	***Energy Savings (% ASHRAE)***	***Peak Electrical Reduction (kW)***		***Cost ($)***
			Summer	Winter	
High-Efficiency Motors	40,329	0.2	1.3	1.3	1,100
High-Efficiency Transformers	45,552	0.2	9.6	7.0	21,100
Hydronic Ramp Heaters	- 32,070	0.1	N/A	70.7	3,500
Combination of electrical Upgrades	**81,637**	**0.4**	**10.7**	**78.2**	**25,700**

5.3.7 Energy Management and Control

It is recommended that the central energy management system be optional in residential buildings, not mandatory. The reasoning for this is that the electrical and mechanical systems in most residential buildings are not complicated enough to warrant the use of central computer. There are very few timer controls in a residential building due to the varied schedule of the residents. Since there is no simultaneous heating and cooling and free cooling is unlikely, complicated interconnect controls are also not required.

5.4 C-2000 Energy Performance Analysis

By combining the energy upgrades discussed in section 5.3, it was possible to develop a design for the preliminary C-2000 building. It was determined that the 30 to 50 percent annual energy reduction beyond the ASHRAE 90.1 building design is feasible. The exact amount of the reduction depends heavily on the infiltration rate, and the mechanical equipment in the ASHRAE 90.1 design. The C-2000 Energy upgrades beyond the ASHRAE 90.1 design are summarized below.

Envelope

- Increase effective thermal resistance of walls from RSI 2.64 to RSI 3.52.
- Replace thermally broken aluminium window frames conventional glass windows with Low-E argon windows.
- Increase effective thermal resistance of roof from RSI-3.52 to RSI-7.04.
- Reduce infiltration to equivalent R-2000 levels (0.96 L/s/m^2).
- Set minimum thermal resistance of doors to RSI-0.88.

HVAC Equipment

- Replace closed loop water source heat pump system with central chiller/boiler and individual fan coil units.
- Install thermal cool storage system.
- Provide ventilation setback in both residential and commercial portions of building.
- Replace residential and commercial make-up air heaters with heat recovery ventilators.
- Install CO sensors on garage exhaust fans.
- Setback temperatures in commercial space and offices.

Domestic Hot Water

- Reduce shower flow rates from 11.4 l/m to 9.5 l/m.
- replace conventional faucets with those consuming less than 9.5 l/m.
- Water temperature setback.
- Waste heat recovery from chiller/grey water.

Lighting

- Replace conventional fluorescent lights with T-8/electronic ballasts.
- Occupancy sensors in corridor.
- Compact fluorescent lights in some areas of suites.
- Daylighting in commercial space, offices and common rooms (where possible).

Appliances

- Maximum allowable energuide ratings

Electrical Systems

- High efficiency motors throughout building (according to Ontario Hydro efficiency levels).
- High efficiency transformers.
- Hydronic ramp heaters instead of electric resistance heaters

EMS/CMS

- None.

For the co-operative building being examined in this project, the energy consumed annually by the final C-2000 design is 10,966,704 MJ. This is a reduction of 9,442,482 MJ or 46.2% of the ASHRAE 90.1 energy consumption.

The peak summer electrical demand has been reduced to 1635 kW. This is a reduction of 251.6 kW or 13% of the ASHRAE 90.1 summer electrical demand. The winter peak electrical demand has been reduced to 795.8 kW. This is a reduction of 578.3 kW, or 42% of the winter peak electrical demand of the ASHRAE 90.1 building.

Table 17: Energy Consumption of ASHRAE 90.1 and C-2000 Designs

Electricity Demand	*Gas Demand*	*Total Energy Cons.*
2,544,309 kWh	305,218 M^3	20,409,186 MJ
1,283,783 kWh	169,428 M^3	10,966,704 MJ

The additional cost of the C-2000 energy upgrades is approximately $497,000. The annual reduction in energy costs are approximately $136,530.

Figure 5: Annual Energy Consumption By Component

Initial, ASHRAE 90.1 and C-2000 Designs

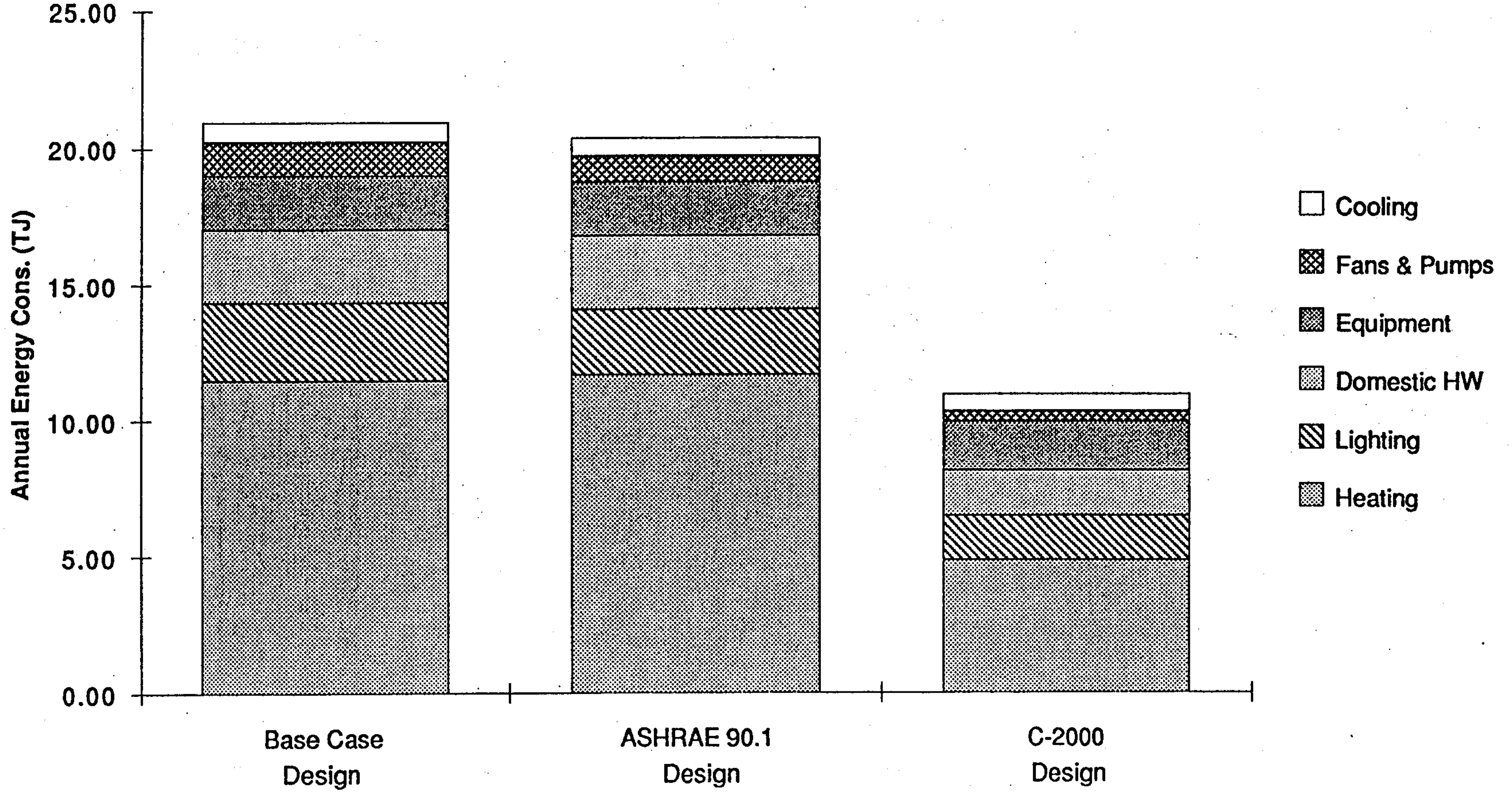


Figure 6: Annual Energy and Peak Electrical Reductions of C-2000 Upgrades

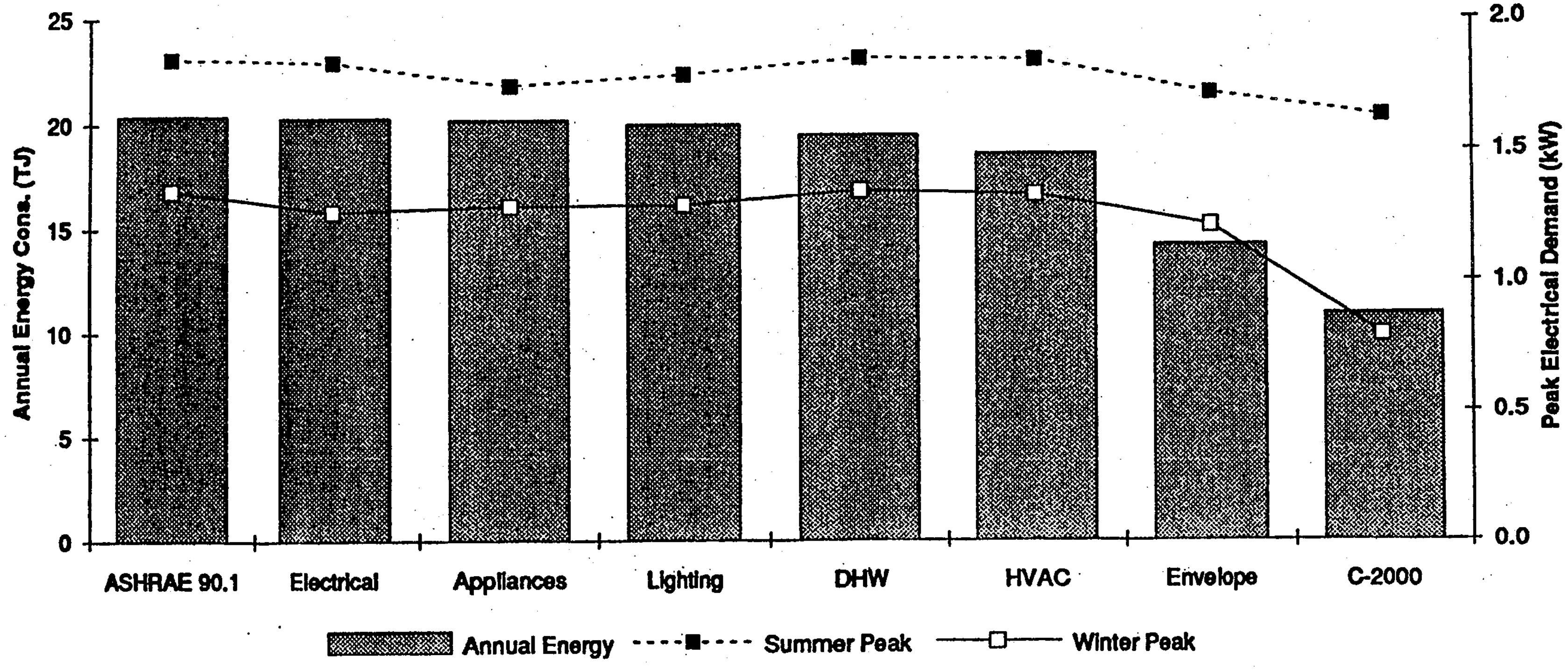


Figure 7: Cooling Load By Component

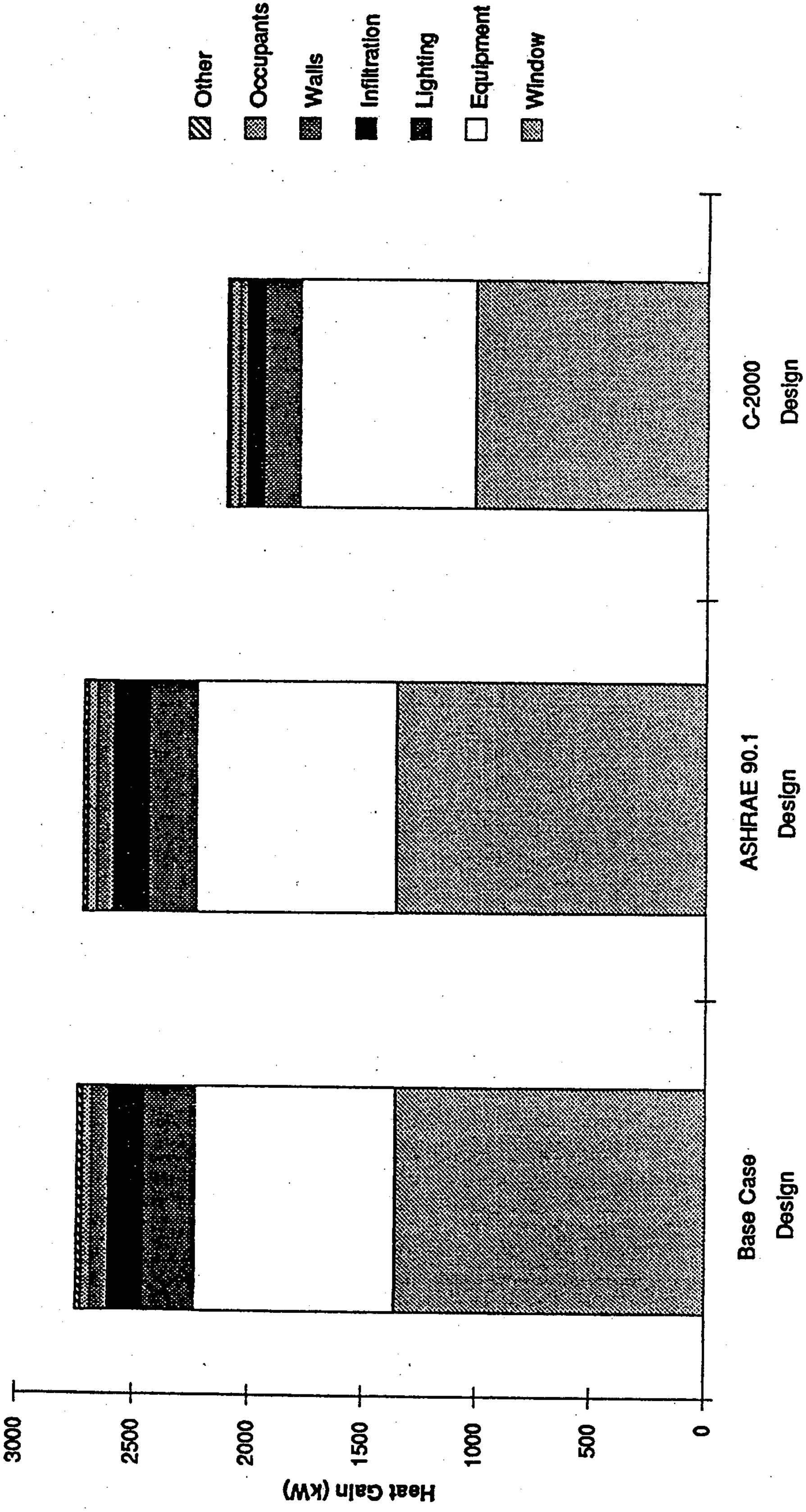


Figure 8: Heating Load By Component

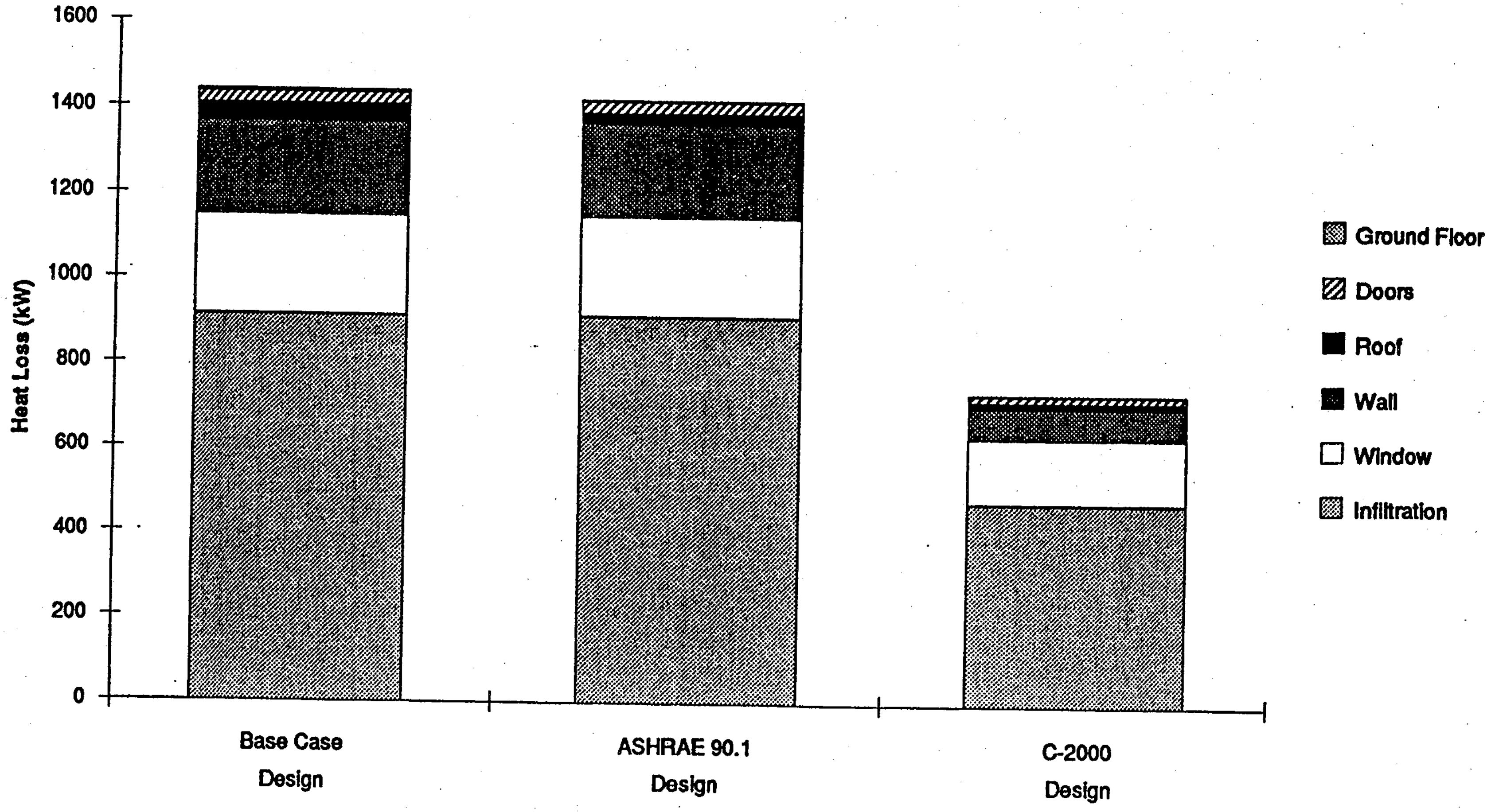


Table 18: Cooling Load By Component (Data from Figure 7)

	Design Cooling Load @ T_{design} = 31C (kW)		
Cooling Load	**Base Case Design**	**ASHRAE 90.1 Design**	**C-2000 Design**
Windows	1,362	1,362	1018
Equipment	875	875	773
Lighting	226	211	158
Infiltration	151	151	81
Walls	72	72.5	32
Occupants	41	41	41
Roof, Ground floor & Doors	23	19	13
Total	**2750**	**2732**	**2116**

Table 19: Heating Load By Component (Data from Figure 8)

	Design Heating Load @ T_{design} = -15C (kW)		
Heating Load	**Base Case Design**	**ASHRAE 90.1 Design**	**C-2000 Design**
Infiltration	914	914	478
Windows	234	234	156
Walls	219	219	75
Roof	42	25	12
Doors	28	28	16
Ground Floor	5	2	2
Total	**1442**	**1422**	**739**

6.0 C-2000 INDOOR ENVIRONMENT ISSUES

6.1 Ventilation

The building as originally designed gave no specific consideration to the issue of indoor air quality. The ventilation system consists of make-up air entering the suites through cracks in the corridor doors. The air would leave the suites through kitchen and bathroom exhaust fans if they were operating. If the exhaust fans were not operating, as is usually the case, the suite would be pressurized forcing air through cracks in the exterior envelope. Forcing warm moist air through the envelope would eventually lead to moisture problems in the building envelope due to condensation. The design leader did not feel that this was an issue because "they had always built building like that." In addition, operable windows were provided should the occupants feel they required additional ventilation.

The installed capacity of the ventilation systems was essentially that required by the building code.

It is recommended that the ventilation system operate full time. Although the system will be setback as discussed in section 5.3.2, it will continue to provide ventilation. The design ventilation load will be based on the ASHRAE 62-1989 Standard. The ventilation air will pass from the corridors to the suites via a air duct system that ties into the fan coil unit of each unit. The fan coil system will heat the air and distribute it to various rooms. The air will continue to be exhausted through the kitchen and the bathroom via the central heat recovery ventilator.

Because the C-2000 ventilation system between the corridor and the suites ties into the fan coil units installation will not be difficult. The result of proper ventilation levels will result in a significantly improved indoor air quality.

The barriers to the implementation of the ventilation requirements of the C-2000 Standard will be due to lack of training and resistance from the HVAC industry. Issues such as the stack effect and proper ventilation are rarely addressed by mechanical designers when designing the HVAC systems in typical apartment buildings.

To comply with the C-2000 Program, it should be required that the mechanical designers provide calculations in the sizing of ventilation/exhaust fans and air flow rates.

6.2 Humidity Levels

No means of humidity control were included in the initial design of the building. However, the fan coil units would provide dehumidification during the cooling months.

To eliminate problems caused by dry air, a humidifier system will be placed in the make-up air ducts. The relative humidity of the incoming air should be limited to the range of 30 to 50 percent. This system will consist of mechanical atomizers for humidification in the central supply air ducts leaving the HRV's. The system will be controlled by humidity sensors downstream from the point of humidification.

Through relatively inexpensive technology significant improvement can be made to the humidity levels of this building during the winter. It is unlikely that there will be any difficulty in implementing the humidity control requirement. The fan coil units in the suites would continue to dehumidify the air during summer.

Because this upgrade consists of existing technology, training is not required design purposes. Training will be required for maintenance staff to keep the system operating effectively. Compliance of the humidity controls can be confirmed through inspection.

6.3 Thermal Comfort

Thermal comfort will have a significant effect on the quality of the indoor environment. There are two sources of thermal discomfort in apartment buildings, these being drafts and "cold spots" created by thermal bridging through the envelope.

The initial design of the building did not address the serious issue of thermal bridging through poorly insulated shear walls, windows with low thermal resistance and from balcony ledges. In addition, the air barrier was not continuous, which would result significant amounts of draft.

The ASHRAE 90.1 Standard addresses the issue of thermal bridging on the effective thermal resistance of the wall. But ASHRAE 90.1 does not address local issues resulting from thermal bridging through the building envelope such as cold spots. These cold spots can result in condensation which will lead to moisture damage and thermal discomfort for the occupants of the space.

The elimination of thermal bridging in the C-2000 building will provide a building which is free from thermal discomfort and less moisture damage. The use of air-tight, high thermal resistance windows will also reduce cold spots commonly associated with windows. The requirement of a continuous air barrier in the C-2000 design would significantly reduce the amount of drafts in the building.

As previously discussed, the elimination of thermal bridging and infiltration can be accomplished through existing technology and design practices. The result would be a significant improvement in thermal comfort.

Because there is presently a lack of training on the part of many architects and a lack of any requirements for improvement, there are large barriers to the elimination of thermal discomfort in high rise apartments.

Training of designers in the building industry and explicit requirements required in the building design are required for successful implementation of this C-2000 requirement. Compliance can be performed through plans evaluation, site inspections and air leakage tests.

6.4 Low Emitting Materials

Another method of improving air quality is eliminating materials that release toxic substances into the indoor environment such as formaldehyde released from carpets. It is unlikely that these materials can be cost effectively removed from the occupied space. Since the space will be well ventilated, this issue is not expected to be a significant problem for the occupants of the C-2000 building.

The issue of off gassing of contaminants from building materials must be addressed as a manufacturing concern so that suitable materials are made available for future C-2000 buildings. Development of these products is progressing very slowly, and protocols and emission standards for materials should be developed as part of the C-2000 Program to promote research in these areas.

6.5 Ambient Light Levels and Light Quality

In attempting to reduce the lighting energy consumed, often the ambient light levels of spaces are compromised. The C-2000 design will strictly adhere to the lighting levels required by the building code.

Efforts to reduce the amount of energy consumed by lights should not eliminate the need to provide adequate lighting for the tasks being performed by occupants of the space. These minimum illumination levels can be determined from the building code, or from the Illumination Engineers Society (IES) handbook. The required illumination levels must be met in any lighting design. The energy savings should come from designing a lighting systems that provides the minimum illumination levels for the least amount of energy.

In addition to the level of light in the space, some special cases will require higher quality of light. For example, retail stores would not accept T8 fluorescent lamps, since it will not compliment the merchandise. However this is accounted for in the ASHRAE 90.1 Standard's lighting allowance. A higher lighting density is given to retail stores so they may use some incandescent lights to provide a warm high quality light. This will also be a problem when attempting to introduce compact fluorescents in residential suites. For this reason the C-2000 co-op building was design with only partial compact fluorescents in the residential space. It is assumed that the occupants will wish to use incandescent lights in places such as dining and living rooms.

When the lighting design is being performed, a great deal of attention should be given to the occupants of the space. Poor light levels and light quality can result in significant occupant dissatisfaction, and would greatly hamper the acceptance of the C-2000 program.

Calculations of light levels should be required for compliance of the minimum light levels in the building.

Daylighting will also be examined as a means of providing natural light to certain spaces. The spaces will include the commercial area and the large common rooms on the 15th storey. The light levels required by the building code will still be required by the daylighting controls.

6.6 Noise Control

The noise control criteria will based on the present requirements of the building code for noise transmittance through walls. The transmission of sound between individual suites is measured by the sound transmission class (STC) of the wall. This number represents the amount of sound absorbed by a particular wall. The C-2000 design will improve upon the requirements of the building code.

Because of the high density of people in multi-residential buildings, noise can greatly affect the quality of the occupants environment. Loud noises from other apartments and outside the apartment can become a constant irritation. The present building code requires an STC rating of 50 between dwellings and 55 for walls between a dwelling and the elevator shaft or garbage chute. In the initial design STC values ranged from 50 between dwellings to 58 between dwellings and corridors.

To improve the living quality of the occupants, it is recommended that the STC requirements be increased for residential buildings in the C-2000 program. The STC rating between dwelling units and between dwelling units and common areas (including commercial space) should be increased to 60. For walls between dwellings and elevators or garbage chutes, the STC requirements should be increased to 65. The reduced sound transmission in the walls can be obtained through increased amounts of sound attenuation blankets which cost approximately \$0.95/ft^2.

Electrical outlets, the junctions between intersecting walls and floors, and any other openings should be sealed with acoustical sealant. If this is not performed, the sound will pass through these locations negating the benefits of increased STC ratings in the walls.

To ensure that these requirements are met by C-2000 buildings, either a inspection will be required during the construction of the walls, or spot checks will be required upon completion of the building. The use of inspections would be preferable to final sound tests due to the cost of the testing equipment and the difficulty of correction after completion of the building.

6.7 Odour Control

A common problem in multi-residential buildings is the transmission of odours from apartment to apartment. The main source of this problem is due to odours traveling through common corridor space. The ventilation system in the C-2000 building will eliminate this portion of odour transmission between apartments. Fresh outdoor air will be entering the suites from the corridors and will be exhausted from the suites. Since the exhaust system will be operating constantly, it will be difficult for the odours to escape into the corridor.

The other source of odour control between the residential suites is through cracks in floors and walls. This form of odour transmission is often driven by the stack effect forcing warm air up through the building. This can be eliminated by reducing the air leakage between suites. A minimum air leakage can be specified for individual suites (not as stringent as the requirements for the exterior envelope) which will permit depressurization tests to be used for verification.

The combination of pressurized corridors and tighter interior walls will prevent odours from passing between residential suites.

6.8 Summary of Indoor Environment Issues

The additional cost of implementing the indoor environment upgrades is $221,600. This includes the cost of sound attenuation blankets, providing tighter interior walls, and for central humidification. Any indoor air quality improvements previously addressed in the energy performance sections, are not included in the indoor environment costs.

Although the quality and longevity of the building will be greatly improved through the indoor environment upgrades the financial savings are relatively small in comparison to the energy efficiency upgrades. Unless tenants and owners realized the value of a healthy indoor environment, these upgrades will be difficult to justify financially.

7.0 C-2000 ENVIRONMENTAL ISSUES

7.1 Water Conservation Measures

Canada has one of the largest supplies of fresh water representing 20% of the world's resources. The demand for water in Canada has increased 4 1/2 times since the mid 1960's. To reduce the strains on countries water resources, as well as to reduce the high costs of municipal waste water treatment, water must be used more efficiently. The need for water efficiency has been recognized and incorporated into the C-2000 building design discussed in this study.

Clothes Washers

Common area washing machines equipped with water level controls. Reducing the water consumed by the washing machines will save approximately 19 litres per day for each washing machine. This will result in a 190 litres/day reduction in water consumption. The specification of horizontal axis washing machines, which consume less water than upright machines is one possibility of reducing water consumption.

The project will not be provided with dishwashers or in-suite laundry facilities to reduce water and energy consumption.

Faucets

The flow rates on the faucets were not specified in the initial drawings, and it is assumed that they will be typical faucets with a flow of 13 litres per minute.

All kitchen and bathroom sinks will be provided with faucet aerators that reduce the flow to 8 litres per minute. Two people would operate their bathroom and kitchen faucets approximately 12 minutes per day. The aerators would result in a 60 litre saving per day for each suite.

Shower heads

No shower flow was specified in the initial design of the building. Typical shower flow rates are approximately 15.2 l/m.

Low flow showers were incorporated into the ASHRAE Design as required by the standard. ASHRAE 90.1 limits the shower flow rate of less than 11.4 l/min (3 gpm)

Shower heads will limit flow to 9.5 l/min (2.5 gpm) (Ontario Hydro recommendations.). Assuming the showers in each unit operate 20 minutes per day, this measure will reduce each unit's water consumption by 114 litres per day less than a typical shower.

Toilets

The initial design of the building did not specify the flow rate of the toilets. It is assumed that typical toilets would be installed, and that the flow rate would be 20 litres/flush.

Water closets in the C-2000 design will be a low flow type with a maximum of 7.4 litres per flush(2.0 gallons). Most toilet manufacturers produce a line of low flow toilets, consequently the installation of these fixtures will not present a difficulty.

The low flow toilets will save approximately 176 litres per day for each unit (30,700 litres per day for the building) assuming 14 flushes per day . Because the toilets upgrades will represent a cost increase to the developer with no return, there will be some resistance in the implementation of low flow toilets. Since toilet manufactures readily supply the flow rates of their equipment, verification will be as simple as presentation of the toilet specifications to the inspector.

Common area men's washrooms will be provided with urinals with a maximum of 2 litres per flush. Low flow urinals will reduce the daily water consumption of the building by approximately 38 litres per day each.

Outdoors

Water used for the evaporative cooling tower will be minimized by minimizing air conditioning loads. These measures will limit energy consumption and water uses for air conditioning system operation. It is expected that the cooling load will be reduced by 20 percent, reducing the water requirements by 10,600 litres per day from an original 53,000 litres gallons per day.

All landscaping will be of a low maintenance low water-consuming type. No lawn areas are planned. The approximately 100 square metres of exterior planters will require approximately 0.5 hours of watering every 2 days. All trees will be planted in a mulched bed for increased water retention. This will help to minimize demand for water on the exterior of the building. It is expected that landscaping will require 37,800 litres of water during the summer season.

7.1.3 Waste Water Treatment

Existing municipal codes make the treatment and re-use of grey water prohibitive. In many situations, treated grey water cannot even be used for watering landscaped areas. The C-2000 program should examine the existing municipal codes and present water treatment systems in hopes of modifying the use of grey water as seen by building codes.

7.1.4 Rainwater Storage

Since grey water cannot be used in watering the landscaped areas, some rain water could be cost effectively stored for future watering. Because of the small amount of landscaped area, the water storage requirements would be modest. It is expected that using rain water for landscaping purposes will eliminate the use of approximately 7,600 litres per year (summer season only).

7.1.4 Water conservation policies

The following procedures are being recommended for the minimization of water consumption in the operation of the building:

- provision of a "kit" of information to new members, one component of which will address water and energy conservation,
- annual unit inspections which will include the review of fixtures and faucets for worn washers, seals and other mechanisms which limit water flow,
- weekly common area inspections for purposes which will include the detecting and correcting of pipe leaks,
- tracking and posting the water and energy consumption of the building to keep members informed as to the progress of the consumption measures.

Summary of Water Conservation Measures

In accordance with conventional calculation procedures, it is anticipated that the peak demand for water will be 1,200 litres per minute (lpm) comprised of 1,125 lpm design fixture load and 75 lpm used by the cooling towers.

The additional cost to the project resulting from the water conservation measures (excluding those discussed in hot water reduction) is approximately $26,100. For

174 units and 10 washing machines, the water conservation measures will reduce the daily water requirements by 53,500 litres per day (excluding cooling tower and landscaping requirements) or 20.8 million litres per year (including cooling tower and landscaping requirements).

7.2 Elimination of Ozone Depleting Chemicals

Because of its resistance to dissociation, CFCs released into the atmosphere rises into the stratosphere to be broken down by UV rays. The chlorine then begins to attack the ozone thinning it and thus allowing increased levels of UV rays to reach the earth. Excessive levels of UV rays can result in skin cancer, eye cataracts, weaken the immune systems of animals and damage plant life including farm crops required to sustain humans.

There are four significant ozone depleting substances associated with buildings. These are CFC-11 used in low pressure chillers, HCFC-123 being used as a CFC-11 replacement, CFC-12 which has been the refrigerant used in medium to high pressure chillers, HFC-134a which is the replacement refrigerant for CFC-12 in medium pressure chillers, and HCFC-22 which is used in most refrigerators and heat pumps and air conditioners as well as some centrifugal chillers. When comparing the above substances an ozone depletion potential (ODP) will be used for which the reference of 1 is given to CFC-11. Table 18 illustrates the adverse affects the above refrigerants have on the ozone layer.

Table 20: Ozone Depletion Factors (ODP)

Refrigerant	Common Use	ODP(CFC-11 = 1)
CFC-11 *	Low pressure chiller	1.0
CFC-12 *	Med/high pressure chiller	1.0
HCFC-123	Low pressure chiller	0.02
HCFC - 22	Refrigerators & Heat Pumps	0.05
HFC - 134a	Medium pressure chillers	0.0

* These refrigerants will be banned in Canada as of Jan. 1, 1996. With the exception of recycled refrigerant they will no longer be sold.

7.2.1 CFC/HCFC Reduction in Insulation

In mid 1993 CFCs will be eliminated from manufactured insulation materials. HCFCs are replacing CFCs as the blowing agent used to make rigid insulation, and in the case of some expanded polystyrene boards water is used instead of

CFCs or HCFCs. Sprayed foam insulation can still be obtained with either CFC, HCFC or CO^2 as the blowing agent.

Polystyrene board with water as the blowing agent can be produced for approximately the same cost as convention boardstock. Icynene foam insulation is applied with $C0_2$ as the blowing agent eliminating all CFCs and HCFCs. The only drawback to Icynene is that it must be applied by licensed installers.

All CFCs and HCFCs can be eliminated from insulation products in commercial buildings. Therefore, the C-2000 Program should not allow any ozone depleting substances in insulation materials.

7.2.2 CFC/HCFC Reduction in Equipment

The initial design of the building included the use of 255 water source heat pumps. At present the only available refrigerant for heat pumps is HCFC-22, consequently any design specifying heat pumps will require the use of ozone depleting substances. In addition since such a large number of individual system will be operating, the chances of refrigerant leakage is significant.

To eliminate the HCFCs in the HVAC system of this building, two positive pressure centrifugal chillers will provide central cooling for the residential and commercial portions of the building. The refrigeration cycle of a positive pressure chiller is above atmospheric pressure which prevents air from leaking into the refrigerant. The centrifugal chiller would be easier to maintain as well as to locate and contain any leaks due to its central location. Since HFC-134a is not toxic and has zero ODP this system is the best choice for the C-2000 building.

These new chiller have been gaining popularity in the last several years due to the impending ban on CFCs in Canada. Although some provinces have strict regulations concerning positive pressure chillers, these regulations are being updated to reflect advances in chiller equipment and to allow easier access to ozone friendly cooling equipment. These elimination of ozone depleting refrigerants can easily be confirmed by an inspection of the equipment, and providing manufacturers specification of the equipment.

7.2.3 Summary CFC/HCFC Reduction Measures

The only CFCs or HCFCs remaining in the building will be the HCFC-22 in the residential refrigerators. Since the ODP of HCFC-22 is 0.05, the maximum ozone depletion potential allowed in C-2000 buildings is 0.05. At the present time, the only feasible substitutes for HCFC-22 refrigerators would be absorption refrigerators. This would be an impractical substitute due to the low COP of these fridges as well as the unavailability of absorption refrigerators in the size required for residential apartments. The C-2000 program should require non HCFC-22 refrigerators as soon as it is technically feasible, but in the meantime, standard energy efficient refrigerators will be used in this building.

7.3 Waste Reduction

7.3.1 Construction Waste

Elimination of Waste

Recycling bins will be required on site for metals, cardboard, and wood waste. This will allow recyclable materials to be separated from the waste stream at the construction site. Some of the wood will be chipped and used for landscaping treatment.

Drywall material is already required to be recycled by Toronto by-laws and will no requirements under the C-2000 Program.

Brick and concrete waste will be crushed and used in the parking garage as a pavement sub-base.

Use of Recycled Materials

Recycled building materials are becoming available to commercial developers and these materials will be incorporated into the C-2000 building. These materials are drywall and roofing tiles, batt insulation and aggregate. The cost of these materials will dictate the extent to which they are adapted by the building community. It is expected that the use of recycled materials will increase the cost of the building by $115,000.

7.3.2 Domestic Waste

No plans were included in the initial design of the building to provide recycling of residential waste.

To encourage waste reduction by the tenants, The C-2000 design of the building included a recycling area in the garbage rooms of each floor. Locating the recycling area on each floor will mean no extra labour required for tenants to recycle their garbage. A bin will be provided for cans, coloured glass, clear glass, plastic pop bottles and compost. The acceptability of compost collection will require further examination for its acceptability under health regulations.

These measures are simple to implement and will not incur significant costs to the project. The cost of recycling the waste will be significantly offset by the reduction in waste removal costs. With rising tipping fees in Southern Ontario, recycling waste may become cost effective. It is estimated that as much as 30 percent of residential waste can be recycled using blue boxes and composting.

To prevent problems with odours from the recycling area, a separate exhaust system is required for each garbage room. Since all the rooms are directly above one another, it will be simple to tie these systems into the central heat recovery system. It will also be required that the recycled garbage be removed regularly to a central garbage room to prevent excessive smells and health concerns. Since waste will be stored in these rooms, a 1 hour fire rating is required for these walls.

This program will require training of the residents as to what can and cannot be recycled. In addition the maintenance staff of the building will requiring some training on how to probably care for the recycled waste to prevent health problems in the building. Compliance can be insured through inspection of the recycling/garbage room.

7.3.3 Summary of Waste Reduction Measures

The waste reduction measures of the C-2000 Program will attempt to reduce construction waste, residential waste. In addition, the C-2000 program will require the use of recycled building materials.

Inspections will be required to verify that recycling systems are present. However, training of both construction personnel and residents will be required to insure the system is used correctly. Information will also be required to indicate which recycled materials are available to the building industry. This information could take the form of a "recycled material" newsletter which could be updated semi-annually.

7.4 Summary of Environmental Upgrades

The additional cost of implementing the environmental upgrades is $141,400. This includes the cost of water conservation, recycled building materials and recycling domestic waste. The environmental costs do not include any environmental upgrades addressed in the energy performance section. As with the indoor environment upgrades, the C-2000 environmental costs will be difficult to justify because of the low financial return.

8.0 DISCUSSION

For the multi-residential co-op building in this study, an energy savings of 9,442,482 MJ or 46.2% of the base ASHRAE 90.1 energy consumption. Assuming $0.09/kWh of electricity and $0.17/M3 for natural gas, the annual operating costs for this building is reduced by approximately $136,530.

The costs of the upgrades beyond ASHRAE 90.1 is approximately $860,000 for all the energy, environmental and indoor environmental upgrades. Assuming no changes in the energy costs, this translates into a 6.3 year simple payback. The payback period could be reduced by eliminating some of the less cost effective measures, although this will reduce the energy savings or the quality of the indoor environment.

Water consumption of the C-2000 design can be reduced by 20.8 million litres annually from the initial design of the building.

The use of ozone depleting substances in the construction and use of the building will be eliminated from the C-2000 design with the exception of refrigerators.

The quality of the indoor environment can be greatly improved by increasing the ventilation, and by reducing odour and sound transmission.

9.0 PRELIMINARY C-2000 CRITERIA

A list of prescriptive requirements for C-2000 buildings has been developed from this report. It is recommended that Residential C-2000 buildings meet the following prescriptive requirements in addition to meeting the ASHRAE 90.1 Standard.

Envelope

- Effective thermal resistance of walls greater than RSI-3.52 (R-20), including thermal bridging.
- All windows must be Low-E/inert gas with a minimum thermal resistance of RSI-0.31 and a shading coefficient of 0.68.
- The effective thermal resistance for all roofs of heated spaces must be greater than RSI-7.04.
- Infiltration must be less than 0.96 L/s per m2 of wall area at 25 Pa pressure difference.
- Floors and walls adjacent to unheated spaces must meet the ASHRAE 90.1 Requirements.

Training in the area of thermal bridging (basic heat transfer) and air barrier design and installation will be required to implement these envelope upgrades. Commercial air leakage testing standards will be required to verify the air tightness of C-2000 buildings.

HVAC Equipment

- All HVAC equipment must meet the ASHRAE 90.1 Efficiency Requirements.
- Heating and cooling must be done with a central gas fired boiler and a central chiller. Fan coil units shall be used to heat/cool individual spaces, and water meters are required to monitor the consumption of tenants.
- Thermal cool storage is required for electric chillers to lower peak electrical demands.

- Ventilation system must be set back during periods of lower demand. The amount of setback will be dependent on the occupants and activities in of each space.

- Heat recovery is required on all ventilation systems with a minimum effectiveness of 65% during winter design conditions and balanced air flows.

- Temperature setback is required for all common spaces and office areas.

- Carbon monoxide sensors are required for the control of all garage exhaust fans.

Training will be required for minimum ventilation levels. A standard outlining the acceptable levels of ventilation reduction during off-peak hours will be required for the C-2000 Program.

Domestic Hot Water

- Water flow of shower heads must be less the 9.5 l/min (2.5 gal per min)

- Aerators are required on all faucets limiting the flow to 8 l/min (2.1 gal per min).

- Temperature setback will be used to minimize pipe losses when a timer control on a circulating system is not practical.

- Waste heat recovery from central chiller and grey water or solar preheating of domestic hot water is required in all C-2000 buildings.

Significant training will be required for mechanical designers in the area of waste heat recovery. Engineers unfamiliar with the process will be reluctant to implement heat recovery systems.

Lighting

- The connected lighting power must be less than the allowance provided by the ASHRAE 90.1 Standard.

- Parking Garages and all other interior spaces not covered by the ASHRAE 90.1 Standard require T8 lamps with electric ballasts.

- Occupancy Sensors are required in corridors leading to the suites.

- 40 percent of the suite lighting must be provided by compact fluorescents.
- Daylighting controls are required for office areas and common rooms where there is sufficient window area.

Training of lighting designers in the areas of new control systems and design strategies that reduce lighting power without compromising the light levels will be required.

Appliances

- Appliances must meet the maximum energuide ratings of the C-2000 design listed in Table 14.

Electrical Systems

- All residential tenants must be metered individually.
- All motors greater than 1 HP must meet Ontario Hydro's high efficiency levels.
- All transformers must be high efficiency. The minimum efficiency levels will be highly dependent on the size of the transformer.
- Ramp heating must not be provided by electric resistance heaters.

New high efficiency motor standards should be developed for the C-2000 Program. Neither the ASHRAE 90.1 or Ontario Hydro's motor requirements are entirely adequate for C-2000 buildings.

Indoor environment

- Provisions must be made to minimize thermal bridging through balcony slabs and shear walls. These provisions include insulation on the underside of floor slabs adjacent to balconies, thermal breaks between balconies and floor slabs (when the balcony can be externally supported), and minimum R-values for walls sections on an individual basis (ie: all exterior wall sections must have a thermal resistance of RSI-2.1 even if the effective wall resistance of the building meets the RSI-3.52 requirement).
- Ventilation air from corridor must be ducted to suite fan coil system.

- Ventilation rates must meet the ASHRAE 62-1989 requirements.

- Central humidification control is required for ventilation air.

- Lighting levels must meet IES handbook and National Building Code requirements.

- A minimum sound barrier of STC-60 between suites (including floors) and STC-65 between suites and corridors is required.

- A minimum air transfer requirement for individual suites will limit noise and odour transmission between suites. The optimum infiltration level has not been determined, however it will not be as stringent as the exterior envelope requirements.

A standard for the delivery of ventilation air will be required for residential buildings. This will identify the acceptable methods of supplying fresh air.

External Environment

- Washing machines must be equipped with water level controls

- Faucets, showers and toilets will limit water consumption to 8 l/min, 9.5 l/min and 7.4 l/flush respectively.

- All landscaping must have low water requirements.

- Rainwater storage is required to minimize water requirements of landscaping.

- No CFCs or HCFCs are permitted in the application or production of insulation.

- Mechanical equipment may not use CFCs.

- The only mechanical equipment permitted to use HCFCs are refrigerators.

- Recycling bins for metals, cardboard and wood are required on the construction site.

- Brick and concrete waste shall be crushed and used for pavement sub-base.

- Recycled dry-wall, batt insulation and aggregate shall be used in the construction of the C-2000 building. Minimum levels for recycled construction materials have not been defined.

- Recycling bins are required in all garbage rooms and must be properly maintained.

Training will be required for the development of the recycling portion of the C-2000 Project. In addition, a standard will be required for the use of recycled materials in C-2000 buildings.

10.0 CONCLUSIONS

Tighter air barriers, additional insulation, providing ventilation and DHW heat recovery, providing lighting control strategies and installing high-efficiency motors represent the greatest opportunities for reduction in the building's energy consumption.

It was determined that the C-2000 energy target of a 30 to 50 percent reduction beyond the ASHRAE 90.1 Standard would be possible.

The main obstacles to the C-2000 energy upgrades include lack of understanding of air barrier design, thermal bridging, ventilation requirements and energy efficient lighting systems.

It was determined that the indoor environment of the C-2000 Building could be most cost effectively improved by providing dedicated ducting for air distribution, a centralized exhaust system, humidifier controls, airtight walls between suites to reduce in odour transmissions, improved sound barriers between suites and thermal breaks in the exterior envelope.

Through implementation of the indoor environmental upgrades, a significant improvement in occupant comfort is possible.

The main obstacles to the implementation of the indoor environmental upgrades are the lack of low emitting construction materials and the small financial return for the building developer.

It was determined that the environmental impact of the C-2000 Building could be most cost effectively reduced by installing water conserving appliances and fixtures, eliminating the use of CFCs and minimizing the use of HCFCs, implementing a recycling program for tenants and using some recycled material in the construction of the building.

The major barriers to the implementation of the environmental upgrades is the scarcity of recycled building materials, lack of recycling in present construction practices and the low financial return resulting from these upgrades.