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The Design and Development of Two Energy and Environmentally Sustainable Prototype Office Buildings

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SYNOPSIS

The C-2000 program for advanced commercial buildings is an awards program to assist in the development of energy efficient and sustainable building technologies and design in Canada. The objectives of the C-2000 program are to develop energy efficient buildings using sustainable materials and technologies. The buildings must provide a high level of occupant comfort. The technology must be transferable to the current building industry and must meet market constraints. This paper presents a case study of the design and development of two C-2000 office buildings, in which innovative energy efficient ventilation strategies were implemented. The buildings are located in the Pacific Northwest in British Columbia and are projected to use between 30% - 50% of the energy used by a base building, performing to the ASHRAE/IES 90.1 Standards.

1.0 INTRODUCTION

The C-2000 program for advanced commercial buildings is an awards program to assist in the development of energy efficient and sustainable building technologies and design in Canada. The Bentall Crestwood Corporate Centre has two buildings as a single project under the C-2000 Awards Program. The Buildings are located in a campus style business park in Richmond, British Columbia and are referred to in this paper as Building 2 and Building 8.

The objectives of the C-2000 program are to develop energy efficient buildings using sustainable materials and technologies. The buildings must provide a high level of occupant comfort. The technology must be transferable to the current building industry and must meet market constraints.

In order to achieve the objectives of the C-2000 award program, the designers of the Bentall Crestwood Corporate Centre developed an innovative team approach, integrating all disciplines through all stages of the design. The design process was coupled with a computer modeling process to provide feedback on the effects of design decisions on energy demand and to provide a quantitative basis for measurement of performance measures. The design process progressed through a series of eight key steps; Orientation and Configuration Modeling, Envelope Design, Lighting and Power Design, Heating and Cooling Design, Ventilation Design, Building Materials Selection, Site Design and Commissioning/Quality Assurance. The design team; including architects, energy, mechanical, electrical and environmental consultants worked together to create two buildings that perform functionally, aesthetically and environmentally.

The Bentall Crestwood Corporate Centre buildings use between 30% - 50% of the energy used by a base building, performing to the ASHRAE/IES 90.1 Standards (ASHRAE/IES, 1990). The design team applied advanced window design, a self-balancing interior atrium space (volarium), advanced envelope technology, advanced and innovative systems design and window shading to achieve the energy objectives.

The Bentall Crestwood Corporate Centre buildings are thermally balanced, have good acoustic ratings, optimize daylighting, have operable windows and a once through fresh air system for ventilation. Interior ambient lighting is maintained at approximately 60 foot candles. In addition, a Commissioning/Quality Assurance process was designed specifically for the project to ensure that the buildings are properly designed, constructed, operated and maintained.

This paper presents a case study of the design and development of the two Bentall Crestwood Corporate Centre C-2000 office buildings focusing on the innovative energy efficient ventilation strategies.

2.0 VENTILATION STRATEGY FOR BENTALL CRESTWOOD CORPORATE CENTER C-2000 BUILDINGS

2.1 DESIGN PROCESS

The entire design team was involved from the beginning of the concept design phase. At this time, critical information regarding energy budgeting, client parameters, site restraints and basic technical information were exchanged. Each member of the group was made aware of every other members' concerns and ideas and contributed equally during the concept design process. The exchange of ideas between team members was facilitated by adding a series of eight meetings to the design process. The meetings were structured as follows:

Meeting 1:
- Entire team with client and funding partners.
- Discussion to resolve parameters for energy and environmental goals.
- Action to develop preliminary design goals.

Meeting 2:
- Entire design team.
- Discussion to refine preliminary design approach.
- Action to sketch basic configuration options responding to energy and environmental goals.

Meeting 3:
- Entire team including client, funding partners and experts.
- Discuss research information available as presented by guest experts in atrium design and daylighting design.
- Action to model basic configuration options.

Meeting 4:
- Architectural and energy team members.
- Review results of preliminary orientation, configuration and atrium options on DOE-2.1E.
- Action to refine modeling.

Meeting 5:
- Architectural and energy team members.
- Review results of refined modeling.
- Action to finish modeling all options.

Meeting 6:
- Architectural and client team members.
- Develop options for envelope treatment.
- Action to sketch detailed options.

Meeting 7:
- Architectural, energy and client team members.
- Select best orientation and configuration option.
- Action to input envelope design option values and model for selected configuration/orientation option.

Meeting 8:
- Entire design team.
- Review modeling results.
- Action to tabulate cost benefit analysis of various options and develop concept design approach for presentation.

The energy and environmental goals were outlined in these eight meetings. The team developed a slightly different approach to each of the two buildings. For Building 8, because the form was fixed due to owner site constraints, the design team chose to achieve C-2000 performance levels using high performance, but relatively non-exotic technologies applied in innovative and effective ways. The result is a building which can be easily reproduced by the design community at large without highly specialized resources or the assumption of a high level of risk. The design team took a much more adventurous and leading-edge approach to Building 2, relying on a super-performance envelope and a high degree of thermodynamic synergy to produce very low energy loads which can be met by extremely efficient, yet extremely simple mechanical systems.

2.2 CONCEPT DESIGN

For both buildings the objectives of the overall ventilation strategy were to:

1. Reduce the source level of volatile organic compounds in the interior spaces
2. Reduce the source level of indoor particulates.
3. Reduce the potential for indoor microbial contamination.
4. Provide alternatives to back up ventilation systems.
5. Reduce overall energy consumption.
6. Reduce the use of ozone depleting refrigerants.
7. Minimize the entry indoors of outdoor ambient pollutants such as carbon monoxide, oxides of nitrogen and particulates.

These seven objectives were to be met within the constraints of the owners' functional program. Constraints imposed upon the design of the ventilation systems included:

- Provision of outside air ventilation rates exceeding current standards (ASHRAE/ANSI, 62-1989).
- Maintenance of constant volume air flow to maximizing occupant comfort.
- Multiple zoning allowing a maximum of 1,000 ft^2/zone in the interior space and 500 ft^2/zone in the perimeter space.
- Flexibility to add further capacity and zoning to the HVAC system

- Cost efficient system design based on life-cycle costing balanced with a low capital cost.

In meeting these constraints the HVAC strategy for both Buildings 8 and 2 is predicated on the fundamental concept of maximum compartmentalization of HVAC functions. Meeting thermal and ventilation requirements on a highly local basis eliminates the intrinsic zone control (i.e. reheat), ventilation, and energy transport inefficiencies of conventional central HVAC systems while offering an extremely high level of individual zone control and flexibility.

2.3 DESIGN DEVELOPMENT

Options for ventilation were not modeled separately but formed an intrinsic part of the considerations for both buildings. As options were investigated throughout the design development, the following opportunities for improving the ventilation and energy efficiency of both buildings became apparent.

2.3.1 Operable Windows

The HVAC system for Building 2 is a low volume system based on the low heating and cooling loads the building is expected to generate. Operable windows were considered as a back up air supply system. The operable windows are tied to a simple interlock system that shuts the air supply off at one diffuser if a window is opened. Generally this is a cost effective and viable solution. The operable windows comprise approximately 10% of the general window area. However, operable windows were determined to not be an effective solution as back up ventilation for Building 8.

2.3.2 Volarium

For the internal space in Building 2 a "Volarium" was evaluated. The "Volarium" is a hybrid or modified atrium which is completely internal to the building envelope. For the purpose of ventilation, the volarium is intended to provide mixed air that has been marginally cooled or heated. The air supplied through the volarium may be freshened with specific plants that have been found to cleanse the air of specific toxins. If the volarium is not used for this purpose, the system may be reversed to exhaust the stale air from the building.

2.3.3 100% Direct-Ducted Fresh Air Systems

The design team explored direct-ducted 100% fresh air systems for both Buildings 8 and 2. The design supply of outside air is 30 cubic feet per minute (cfm) per person. Studies undertaken to determine the local relative humidity within buildings in the Pacific Northwest show that the relative humidity design goal of 50% is achievable in a low volume ventilation system without the use of a supplemental humidification.

2.3.4 Indoor Air Quality

The design team investigated the option of restricting the selection of materials for construction and interior finishing to those with minimal contaminant emission problems. Emissions of concern included off-gassing of harmful vapors (commonly found in carpet glues, wall vinyl and some paints) and particulates (from the fine breakdown of unstable materials such as insulation, cloth fabrics and carpets).

Locations of outside air intakes were evaluated to minimize the intake of carbon monoxide and other contaminants commonly found in outdoor air. Commissioning Specifications were written with the intent of eliminating the potential for microbial contamination.

2.4 HEATING, VENTILATION AND AIR CONDITIONING SYSTEMS

The ventilation system in Building 8 provides unmixed, outside air directly to a four-pipe heat/cool fan coil unit and ceiling diffuser system in each individual HVAC zone using a roof-mounted ventilation air handler with hot water pre-heat. The outside air is mixed with local return air in the fan coil and subsequently provided directly to the space. This positive ventilation delivery directly to the zone avoids the inherent loss of overall ventilation effectiveness associated with centralized variable air volume (VAV) systems. Combined with the constant volume air flow characteristics of the fan coil system, estimated net ventilation effectiveness is 0.90. Passive relief air dampers in the ceiling space to the outside wall at several locations on each floor provide system trim balancing in conjunction with mechanical washroom and other specialized exhaust (e.g. photocopy rooms, kitchens, etc.). The system is fully flexible to accommodate tenant improvements, and includes accessible exhaust risers for tenant connection.

Installed system capacity accommodates a net effective ventilation rate of up to 30 cfm per person for initial and periodic building flushout purposes, although the normal final operational rate is anticipated to be 20 cfm per person. Ongoing air quality monitoring may allow the rate to be reduced further. Gross fan coil air supply will provide a minimum zone air circulation rate of four air changes per hour.

Given the relatively simple ventilation configuration and the associated ease of maintenance (the most catastrophic failure would consist of a motor replacement which could be accomplished in a few hours), provision for backup ventilation was not considered economically justifiable.

Building 2 extends the ventilation concepts introduced for Building 8 even further by providing unmixed, outside air directly to overhead high induction room diffusers in a "once through" ventilation configuration. The ventilation air is tempered by zone heat/cool coils and is the sole primary diffuser supply. Secondary induction occurs at the room level, and there is subsequently no inter-room air mixing or no inter-room air recirculation. Estimated net ventilation effectiveness is 0.90. Relief and exhaust provisions are similar to Building 8, as are the installed and planned ventilation capacities of 30 and 20 cfm per person respectively. Effective induced room air movement will be validated through laboratory verification of individual products, but is not expected to be less than four air changes per hour. This system is also fully flexible with respect to accommodating tenant improvements. Backup ventilation for Building 2 will be provided by openable windows. Outside air filtration is minimum 50% dust spot efficiency for both buildings.

2.5 ENERGY EFFICIENCY

A preliminary energy efficiency plan was developed at the Concept Design phase of the project. Although a number of modifications to specific strategies had to be made as the analyses proceeded through Design Development, the initial premises and performance targets remained intact.

Simplicity, elegance, robustness, and cost-effectiveness were the key criteria for all strategies. Complex, highly exotic or specialized, or "fragile" technologies were avoided. The introspective question continuously asked by the design team was whether or not a proposed approach or technology would be likely to be embraced and reproduced by the mainstream building industry. If not, it was abandoned as unsuitable.

Reflecting this premise, Building 8 was developed using entirely mainstream and readily reproducible technologies applied in an effective and integrated manner. The resulting building, a visual twin to an existing adjacent building achieves the 50%-of-ASHRAE/IES 90.1 energy performance target with negligible projected net incremental capital cost compared to the baseline market building (less than 2%).

Building 2 was developed using slightly more advanced, (but not exotic) technologies with the objective of significantly exceeding the 50% of ASHRAE/IES target. At the present level of development, the building energy use approaches 30% of ASHRAE/IES 90.1.

DOE 2.1e (integrated with LBL Window 4.1) was used for all energy analyses. In addition to the Building 8 and Building 2 ASHRAE/IES Reference design models, two variations of a Building 8 "market" or baseline building were modeled for life-cycle costing purposes.

3.0 CONCLUDING COMMENTS

Early in the project, modelling of the energy demands for both buildings identified an important practical design consideration that carried through to the final design of the HVAC systems. Put simply, the design team determined that while the magnitude of envelope and electrical energy loads is clearly a cornerstone of building energy performance, the single most significant factor in the performance equation is often the response of the HVAC system to these loads. In this regard popular central mixed-air VAV systems do not perform well. They generally address multiple-zone load variations by supplying cooling air to meet the worst-zone cooling load, and then relying on VAV box shutdown combined with reheating to control overcooling in less critical areas. In practical reality, the minimum VAV box position is dictated by ventilation and/or air circulation requirements, and since this is often still well above what is required to meet the cooling load, the zone operates in reheat mode for extended periods of time. Most central VAV-reheat systems do in fact operate as constant volume reheat systems most of the year. The wider the zone thermal variances, the more severe the effect.

One solution to this problem is to compartmentalize HVAC systems as much as possible, minimizing the number of zones served by any one system. In this respect the HVAC systems for both Buildings 8 and 2 extend this practical concept to its logical conclusion by meeting heating and cooling loads at the zone, or "terminal" level. The resulting buildings use between 30% - 50% of the energy used by a base building, performing to the ASHRAE/IES 90.1 standards. To achieve this goal, the design team made use of advanced window design, an interior self-balancing atrium space (volarium), advanced envelope technology, advanced and innovative systems design and window shading.

4.0 REFERENCES

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