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# A COMPARISON OF CONVENTIONAL AND $CO_2$ DEMAND-CONTROLLED VENTILATION SYSTEMS

Giovanna Donnini

A Thesis

in the Centre

for Building Studies

Presented in Partial Fulfilment of the Requirements
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## ABSTRACT

A Comparison of Conventional and
$CO_2$ Demand-Controlled Ventilation Systems

Giovanna Donnini

The use of indoor carbon dioxide levels is a good method for controlling indoor air quality in office buildings, when there are no other pollutant sources present than the occupants. The measured $CO_2$ is used to determine the amount of outdoor air needed to purge air contaminants and to obtain the desired $CO_2$ indoors. Two floors of a commercial building in Montreal were used in the study. Since both floors were identical in architectural layout, type of work being done, and in population density, and since they had identical yet separate ventilation systems, one floor was used as a control, and the other was modified to include a $CO_2$ and supply temperature control system. The strategy complies with the requirements of the ventilation, indoor air quality, and thermal comfort standards. It also performs the ventilation service in an energy effective manner, with an annual saving of 12%, and a payback period of 0,4 years. Not only does it save energy, but it also does not compromise the indoor air quality and thermal comfort. Although most of the parameters measured satisfy the standards, the occupants' perception of their working environment does not reflect the measured results. The $CO_2$-controlled floor occupants complained more than the other floor, however, the measured results did not validate this difference, implying the influence of other global factors.

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Finally, I would like to dedicate this work to my parents, my family, and Martin.

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## NOMENCLATURE

| | |
|---|---|
| ach | air changes per hour |
| ADPI | Air Diffusion Performance index |
| AHU | Air Handling Unit |
| ASHRAE | American Society of Heating, Refrigerating, and Air-Conditioning Engineers |
| °C | degrees celsius |
| $c_{r,m}$ | temperature correction at a test position |
| $CO_2$ | carbon dioxide |
| CV | constant air volume system |
| DCV | Demand Controlled Ventilation |
| ETS | Environmental Tobacco Smoke |
| h | hour |
| HCHO | formaldehyde |
| IRSST | Institut de recherche en santé et en sécurité du travail |
| kWh | kiloWatts per hour |
| l/s | litres per second |
| l/s/person | litres per second per person |
| l/min | litres per minute |
| m | meters |
| m/s | meters per second |
| m/s/°C | meters per second per degree celsius |
| $m^3/hr$ | cubic meters per hour |
| $mg/m^3$ | milligrams per cubic meter |
| MMMF | Man Made Mineral Fibres |
| PMV | Predicted Mean Vote |
| PPD | Predicted Percentage of Dissatisfied |
| ppm | parts per million |
| PWC | Public Works Canada |
| Rh | relative humidity |
| RRQWE | Regulation Respecting the Quality of the Work Environment |
| s | seconds |
| SBS | Sick Building Syndrome |
| $SF_6$ | sulphur-hexafluoride |
| SIQ | Société immobilière du Québec |
| $t_a$ | air temperature at each point |
| $t_{ac1}$ to $t_{acn}$ | individual corrected test point temperature |
| $t_c$ | average test zone temperature |
| $T_{dp}, t_{dp}$ | dew point temperature |
| $T_o, t_o$ | operative temperature |
| $t_r$ | reference temperature |

| | |
|---|---|
| TLV | Threshold Limit Value |
| $v_a$ | air speed at each point |
| VOC | Volatile Organic Compound |
| WHO | World Health Organization |
| | |
| $\mu g/m^3$ | micrograms per cubic meter |
| $\Theta_n$ | effective draft temperature at test point n |

## PREFACE

Source control and an adequate supply of outdoor air are the two strategies used to achieve good indoor air quality. However, the more outdoor air that is supplied, the more energy is needed to heat/cool that outdoor air. Significant energy savings can be achieved if we were to supply the required outdoor air only when the need arose. This would ensure enough outdoor air to keep the indoor air quality acceptable, without over-ventilating. This is accomplished through the use of demand controlled ventilating (DCV) systems.(1) Strategy for DCV systems will depend on the type and function of the buildings in which they are located, and on the type of pollutant(s) present. In non-industrial buildings, demand for indoor air quality will depend mainly on occupancy load and human activities on the premises.

Pollution sources in indoor air are too numerous to count; from building materials to activities taking place in the building.(2) It would be highly impractical to monitor all possible contaminants in any given space. So only those most susceptible to being present in this particular office environment were monitored. For this reason, and since our instruments were not detecting any measurable amounts, ozone, carbon monoxide, nicotine, radon, and microbiological testing were dropped during the preliminary study.(3)

# CHAPTER 1

## 1. INTRODUCTION

Heating and cooling ventilation air requires a substantial amount of energy. In large buildings, it may amount to 40% of the total energy consumed by the building.(4) Thus, there is a strong incentive to minimize the amount of ventilation air used. A potential source of energy conservation exists within the commercial sector in business establishments that have a transient occupancy rate, yet operate ventilation systems at code-specified maximum occupancy levels, or as a function of exterior temperature. Commercial buildings are ventilated with outdoor air to replace the oxygen consumed and to dilute air contaminants created by occupants and their activities. The minimum amount of outdoor air that a ventilation system must be able to supply is specified by building codes in the design stage based on maximum occupancy conditions. However, energy is wasted through overventilation when a building is operated according to code and its occupancy rate is generally considerably below maximum capacity--as is often the case with transient occupancy establishments.

The density of workers and visitors can be quite variable. Building codes specify a minimum amount of outdoor air for ventilation of such buildings based on the maximum number of occupants for which the building was designed. This leads

to excessive use of outdoor air and wasted energy since the buildings operate most of the time with considerably less than the designed occupant load. Recognizing this unnecessary energy loss, building owners and operators have often closed the outdoor air dampers or the ventilating system without regard for the effect on occupant health, comfort, or productivity.

This project was undertaken to show that a carbon dioxide sensor that measures the occupant-generated carbon dioxide could be used to control the use of outdoor air in a more efficient manner. The solution to the problem of optimizing ventilation and energy usage is a closed-loop control system. A ventilating system under the control of a carbon dioxide sensor could provide outdoor air when needed but restrict its use when it is not needed. This kind of control should be particularly effective in buildings with a large and unpredictable variation in the number of building occupants.

A carbon dioxide-based ventilation system supplies outdoor air when the carbon dioxide levels in a room reach the control point, and restricts outdoor air when it is not needed.

This study was designed to measure indoor air contaminant levels, thermal comfort levels, subjective occupant response, and energy consumption for heating and cooling.

## 1.1 Literature Review

Demand controlled ventilation (DCV) systems are defined as systems where the outdoor air flow rate is controlled by a preset limit of a parameter, usually an airborne pollutant. For the office environment, it is applicable only when the dominant pollutants are generated by the occupants.(5)

Several conditions must exist for this technology to be applicable in office buildings:

1) the ventilation system must operate with variable outdoor air rates, otherwise such a control system is not possible;

2) the occupant density must be variable and unpredictable, otherwise other technologies are viable;

3) a large portion of the year must be spent in heating or cooling the outdoor air, otherwise the savings would be minimal;

4) the occupant density must reach high levels, since the control system would not be as efficient at low concentrations; and

5) the generation of non-occupant related pollutants must be minimal, especially since one is trying to control the ventilation with respect to occupancy, since the generation of other pollutants, say, offgassing from building materials, does not follow occupancy patterns.(5)

Considerable research has gone into DCV systems over the past 10 years. Up until 1983, most papers on DCV systems stressed energy savings and pay-back times, but it is indoor air quality that is being emphasized in more recent works.(1) Most of the work reviewed deals with demand control applications in public rooms, only some deal with offices, and very few with dwellings.

According to the literature, there is no doubt that $CO_2$ is the most reliable control contaminant.(4,6-17) This is true when no other large pollution sources, such as smokers, are present. It is an excellent surrogate measure for ventilation rate per person, and hence, the ideal indicator for indoor air quality.(1)

Therefore, much of the research focused primarily on $CO_2$ control.(4,10,18-23) However, some work has shown that $CO_2$ control alone can cause thermal comfort problems, especially during the summer.(24) It has also been shown that occupants report they feel warmer with $CO_2$ control, although air temperatures were unchanged.(19) Then again, other work has shown that occupants did not

mention any feelings of discomfort with either $CO_2$ control or constant outdoor air flow.(7,25) Other papers deal with $CO_2$ versus temperature control, with the temperature control being dominant.(13) It was shown that the temperature control is dominant when the outdoor temperature is above 10°C. When the temperature dropped, the $CO_2$ sensor called for more air first.

Some work has also been done using tobacco smoke, water vapour, and odour as controlling sensors.(1) None of these are as successful as the $CO_2$. Smoking does not reflect the occupant load in a room; it cannot be assumed that all occupants generate tobacco smoke in equal amounts and rates. Similarly, the relationship between the relative humidity, odour, and the occupant load in a room is very weak since moisture and odours are absorbed and desorbed by the building carpets, furniture, etc.

The level of carbon dioxide found in the exterior air has a direct impact on the control set point. The carbon dioxide concentration of the atmosphere is 320 to 350 ppm, depending on the degree of industrialization. The value has been shown to increase yearly due to the combustion of fossil fuels. Under normal circumstances, the $CO_2$ concentration in the environment does not vary more than 150 ppm.(1)

The $CO_2$ set point varied drastically throughout previous research work. Pneumatic controls, when one sets a lower and upper limit (from totally closed to fully opened dampers), were set from 850 to 3000 ppm for the lower limit, and from 1200 to 5000 ppm for the upper limit.(6,19,25,26) When the $CO_2$ only had one set point (open/close), the limit ranged from 500 to 1000 ppm.(7,10,14,17,21,23) However, very often, the set point was found to be too high; the $CO_2$ control never operated due to $CO_2$ levels detected being below the control limits.(19,25)

A DCV system can be operated automatically, or manually. It can consist of either a timer control, and/or a presence control, and/or a sensor control.(1) The experiments done with manual control did not show satisfactory results.(16) It was seen that the operator usually opened the outdoor air damper when the air quality in the room was already bad. Even the maximum outdoor air flow was not capable of reducing the $CO_2$ level at that point. Tests with occupancy or infra-red-presence sensors also failed to show good results.(9,16) The occupancy-counting device was unable to compensate for variations in the rate of natural infiltration.

Most of the $CO_2$ sensors were placed in the return or exhaust ducts, so the optimum location of the sensor was never questioned.(7,10,15,18,23) Only researchers who monitored in the actual occupied zones found that $CO_2$ levels

varied greatly.(6,10,22,23) However, none of the studies give recommendations for the placement of the sensors. The only cases where sensors were placed other than just in the exhaust ducts had sensors in the occupied zones, near thermostats, near return grilles, on walls.(25) One study actually suggested placing a sensor on every floor (for a multi-storey building), and choosing the highest reading for control.(10)

When choosing a location for the sensor, one should pay close attention to the air flow pattern.(23) If the sensor is placed where there is no air movement, or if there is too much of an air draft, the air flow pattern will directly influence the sensor signal, which will likely be very different from the real level in the actual working zone.

Most studies were performed to evaluate energy savings. The highest savings were noted in rooms where the variation in occupancy is very high and/or unpredictable.(1) When actual measurements were taken, saving in energy consumption reported ranged from 8 to 40%.(7,11,21,25) Savings of 30 to 60% were reported in studies where simulation or estimation was done.(15,20,22) One project actually reported a 70% reduction in running time, a 90% reduction in energy consumption (the $CO_2$ control was coupled with a heat recovery system), and a 20% reduction in maintenance.(26) Another study found it was possible to even reduce further the running time of 10 hours a day to only 22 minutes a

day.(24) The $CO_2$ control was even found to be more efficient than a heat recovery system, with an air flow reduction of 60% with $CO_2$ control.(18) Furthermore, the $CO_2$ control set point has a direct influence on the amount of savings achieved. Compared to a constant flow system, 40% savings were realized with a $CO_2$ set point of 700 ppm, and a 10% saving with 650 ppm.(7)

Pay-back periods have been reported to range from 1 to 6 years.(4,10,20,21,25,27)

The comparison of the $CO_2$ control-system and the normal mode has been done by alternating the control each week.(25) No one has done a simultaneous comparison between two identical systems.

Ventilation of indoor spaces with outdoor air is one of the main means one has of controlling contaminant levels in the indoor air. The carbon dioxide control system is designed to limit the carbon dioxide level produced by the occupants in a space. The $CO_2$ level also is used as a surrogate for other contaminants produced by people. If the use of outdoor air is to be restricted with the provision that the $CO_2$ level be held below a certain limit, there must be assurance that other contaminants are also controlled at concentrations below accepted limits.

## 1.2 Objectives and Methodology of the Present Study

From the review of the literature, it can be seen that experimental work on demand-controlled ventilation has concentrated only on the energy savings and pay-back times. The $CO_2$-control system was mainly used in public rooms. The lower limit set-point for pneumatic controls was 850 ppm and higher; which already is known to be an uncomfortable level for occupants.(28) The upper limit set-point was 1200 ppm and higher; which does not even ensure that the ASHRAE standard is satisfied.(29) The control sensors were placed in the return or exhaust ducts; the optimum placement was never questioned. The control system was compared to the normal mode of operation, but only sequentially, and not simultaneously.

The purpose of this study is to test a carbon dioxide-controlled ventilation system in a commercial building as a method of controlling indoor air quality, occupant comfort, and energy consumption.

The main objectives can be iterated as follows:

1) to verify the indoor air quality does not worsen with the $CO_2$-controlled system as compared to the outdoor temperature-controlled system;

2) to verify the thermal comfort does not worsen with the $CO_2$-controlled system as compared to the outdoor temperature-controlled system;

3) to verify the occupants do not perceive a deterioration in their working environment with the $CO_2$-controlled system as compared to the outdoor temperature-controlled system; and

4) to verify that the energy consumption lessens with the use of the $CO_2$-controlled system as compared to the outdoor temperature-controlled system.

The methodology adopted is experimental. The following study compares the indoor environment created by two different types of ventilation control systems in an eleven-storey office building, located along the St. Lawrence river, in

Montreal. Experiments were conducted during an entire year and consisted in the measurement of the physical parameters important for human comfort and health. Energy consumption was also monitored, as was occupant perception, since saving energy at the expense of occupant acceptance would be an unattractive compromise. The two systems were electrically operated: a conventional system was controlled by outdoor temperatures, and a demand-controlled system was regulated by indoor carbon dioxide concentration and supply temperature. The main objective was to compare the air quality, thermal comfort, energy demands, and occupant satisfaction resulting from the two different controls, in two separate floors of an office building, and to rate these results according to their respective criteria, since operation of a ventilating system should always keep all of the contaminants and thermal comfort parameters within acceptable limits.

Prior to the study, a walk-through survey was conducted during which monitoring sites were identified on the two floors pre-selected for the study. A ten-week intensive study followed to determine the building's dynamic response to various outdoor air levels.(30) It was found that the parameters tested were uniform throughout the zone, both horizontally and vertically. Therefore, the sampling was limited to desk-top level (in the vertical plane), and to geographic locations (in the horizontal plane). It was also found that all parameters tested were identical on both floors.(30)

The testing began in May 1990 and continued until April 1991.

As is the case in many commercial buildings, the office layout changed continuously. It was decided to keep the sampling stations fixed, even though a work-station was removed from it, since it represents reality.

Figure 1.1 shows the different sampling stations (from 1 to 10) for both floors. The sampling stations on each floor are directly above each other.

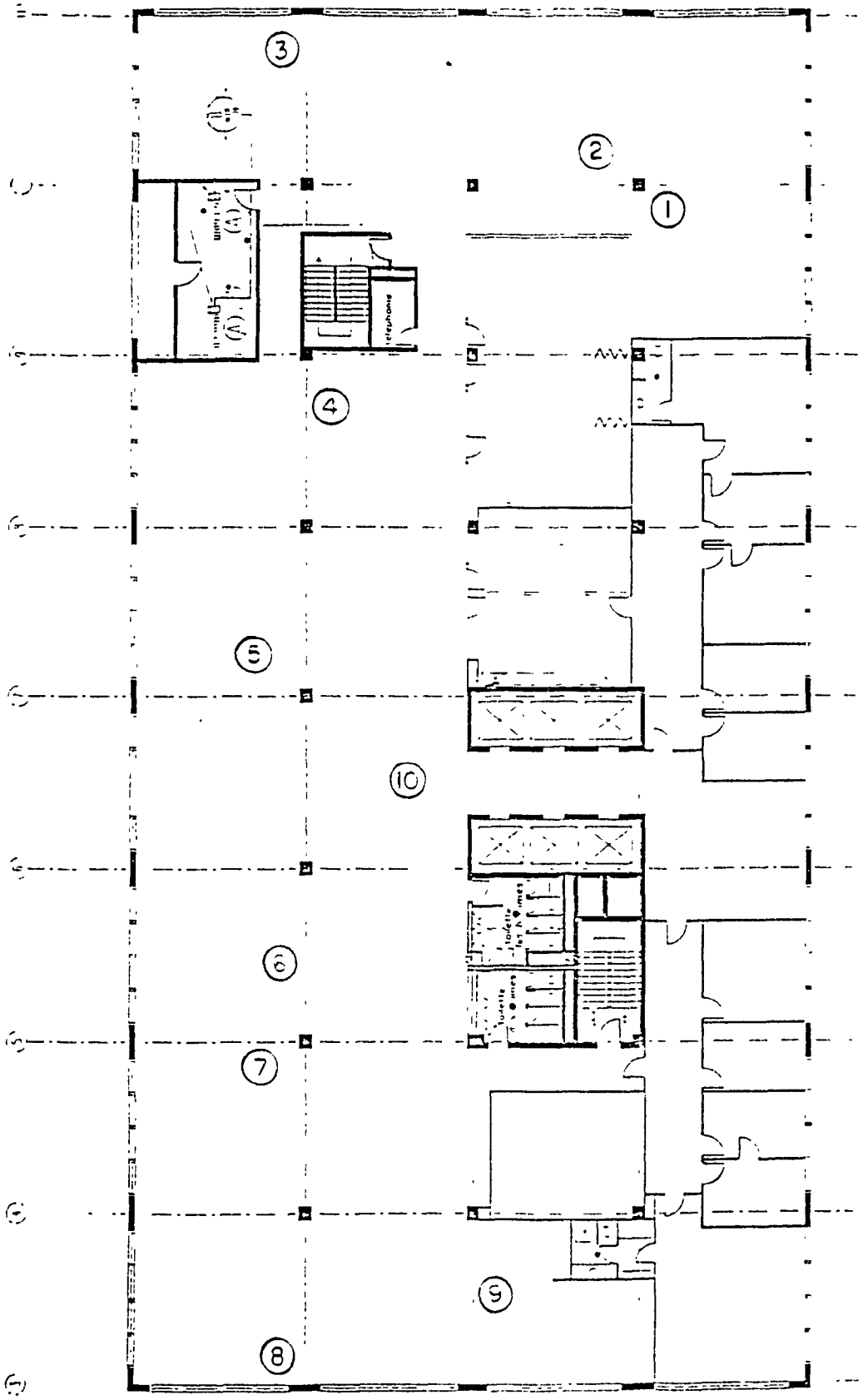



Figure 1.1 Sampling stations (from 1 to 10) of one floor

Actual test data was obtained over four seasons by comparing the carbon dioxide-based ventilation control system against normal code-specified ventilation control. The two methods were to be compared in terms of measured indoor air quality, measured thermal comfort, occupant subjective response, and measured energy consumption. Each scheduled test period consisted of one week per month, for 12 consecutive months. This plan was set up to evaluate system performance under different weather conditions. The testing was performed simultaneously on two floors of an office building--one floor operating under the normal mode, and the other floor operating under the carbon dioxide control mode. These two types of control were in operation throughout the total testing year (including the time between the scheduled test periods).

An indoor temperature control was installed by the building owner to override the $CO_2$-control system; to certify that the indoor temperature would not exceed the comfort limits.(30)

A set of relays was installed to enable the 8$^{th}$ floor system to be operated in a "$CO_2$ mode"; while the 9$^{th}$ floor system operated under the "normal mode". Under the $CO_2$ control the $CO_2$ state kept the outdoor air damper closed until the $CO_2$ level in the space reached the lower control point (600 ppm). The outdoor air dampers would open to a minimum when the $CO_2$ did reach 600 ppm. As the $CO_2$ increased further, so did the opening of the dampers, up to a maximum

opening when the $CO_2$ reached the upper limit of 1000 ppm. The lower limit of 600 ppm was chosen due to the recent findings that headaches start at this point.(28) The upper limit of 1000 ppm was chosen since it is the ASHRAE recommendation.(29) The code-specified amount of outdoor air was provided under the normal mode (i.e. based on temperature demand).

Instrumentation measured indoor $CO_2$ levels and the times the $CO_2$ controlled the dampers.

Outside and inside air temperature readings were used to control the dampers for the required outdoor airflow and adequate comfortable indoor environment under the normal mode operation.

The following parameters were measured for one week per month, for twelve consecutive months: indoor air quality parameters (carbon dioxide, formaldehyde, volatile organic compounds, particles, ventilation, and system performance); thermal comfort parameters (dry-bulb and operative temperature, relative humidity, air diffusion performance index, vertical temperature gradients, air velocity, and thermal comfort PMV and PPD); and occupant perception. The energy demand was monitored continuously throughout the 12 months, i.e. 365 days.

This study, then, will show the following:

1) it will be found that the indoor air quality does not deteriorate with the use of a $CO_2$-control system;

2) it will be found that the thermal comfort does not deteriorate with the use of a $CO_2$-control system;

3) it will be found that the occupants will complain more on the $CO_2$-controlled floor. However, it will be shown that this increase in complaints is not due to the control system, but to other global factors in the working environment; and

4) it will be found that the energy demand is decreased significantly with the use of a $CO_2$-control system.

## 1.3 Contributions and Summary

It will be shown that demand-controlled ventilation using indoor $CO_2$ as an indicator does not worsen indoor air quality and thermal comfort, when used in an office environment. The $CO_2$-control set-points must be low enough so that they satisfy the present air quality standards and comfort recommendations. The optimum sensor location would be at the critical work-station, however, placement in the return duct would also produce adequate results depending on the contaminant removal efficiency. It will be shown that occupants' complaints do not necessarily reflect the measured results. This project was unprecedented by the fact that the comparative testing was done simultaneously, and not sequentially.

# CHAPTER 2

## 2. PARAMETERS STUDIED AND THEIR STANDARDS

The parameters studied include indoor air quality (carbon dioxide, formaldehyde, volatile organic compounds, particles, and ventilation), thermal comfort (dry-bulb and operative temperature, relative humidity, air diffusion performance index, vertical temperature gradients, air velocity, and global thermal comfort), occupant perception, and energy demand. All of the results will be compared with the ASHRAE standards and the provincial regulations. Since it will be shown that the standards are respected on both floors, any statistical analysis would be redundant. It is not the difference between the two floors that is important, but that the ASHRAE limits are respected.

### 2.1 Indoor Air Quality Parameters and Standards

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) defines acceptable indoor air quality as: "air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction".(29) This definition stems from the fact

that contaminants in non-industrial workplaces, such as office buildings, rarely reach levels known to be harmful, although adverse health effects and complaints regarding discomfort are common. ASHRAE has established standards for indoor air that provide for the health and comfort of the majority of the occupants.(29)

The number of studies which have examined the various aspects of indoor air quality is unmeasurable. Among the most commonly studied contaminants are: carbon dioxide, formaldehyde, dust, and volatile organic compounds.(31,32) The objective of this study was not to find the source of each contaminant, but to compare their reaction when submitted under different environments.

## CARBON DIOXIDE

Carbon dioxide ($CO_2$) is a colourless, odourless gas formed as a result of burning carbon-containing substances. The primary sources of $CO_2$ in a non-industrial occupational setting are human respiration and smoking. By replacing oxygen, $CO_2$ acts as an asphyxiant and may cause headaches, loss of judgement, dizziness, drowsiness and rapid breathing at concentrations greater than 5000 ppm.(32) At concentrations greater than 1000 ppm, complaints of headaches, tiredness, eye, nose, and throat irritation are more prevalent, presumably because

of other contaminants also found in the air.(33) The current ASHRAE standard is set at 1000 ppm for continuous exposure.(29)

Several studies have examined $CO_2$ concentrations throughout the day in office settings and have confirmed a pattern with one peak in the late morning, from approximately 10:30 A.M. to 12:00 noon, and an even larger peak in late afternoon from 2:00 P.M. to 4:00 P.M..(34,35)

Normally, healthy people can tolerate an oxygen depletion, at sea level pressure, from 21% to about 16%. People can also tolerate an increase in the carbon dioxide content of the air they breathe from a background of 300 ppm to about 5000 ppm without serious effects. It has been found, however, that occupant-generated carbon dioxide is a reasonable surrogate for human body odour.(25) Chamber studies have shown that a steady-state $CO_2$ level of 1000 ppm has an associated odour level that about 20% of the visitors to a space can detect.(36,37)

Thus, it appears that 1000 ppm of $CO_2$ in the room air is about the maximum desired for a business establishment, where the productivity of workers is important.(25)

The time dependence of occupancy and $CO_2$ concentrations with the ventilation system in an all outdoor air mode as well as in a recirculation mode has been

investigated. It was illustrated that in the fresh air mode, $CO_2$ levels followed closely the patterns of occupancy. In the full recirculation mode, $CO_2$ levels did not respond as closely to occupancy and were almost twice as elevated as those in the all outdoor air mode.(38)

Carbon dioxide concentrations have been used as an indicator of indoor air quality by providing a measure of how well the ventilation system is diluting and removing air contaminants generated within a building.(31) In addition, $CO_2$ generated by expiration has been used as a tracer to quantitatively measure air recirculation and ventilation rates.(34,39,40)

The role that ventilation conditions play in controlling levels of gaseous contaminants has been investigated.(41) The particularly strong correlation coefficients detected with $CO_2$ and ventilation conditions reaffirm the use of $CO_2$ as a crude indicator for ventilation conditions.

The concentrations of $CO_2$ normally observed in buildings are not associated with any symptom, except the sensation of stale and stuffy air. Previous research has shown that occupants perceive differences in carbon dioxide levels when the normal concentration level is at 500 to 700 ppm and the $CO_2$ level rises to approximately 1600 to 1800 ppm. It is suggested that the threshold for subjective perception of carbon dioxide concentration falls between 1100 and 1600 ppm.

However, the results of a recent study indicate no subjective perception of carbon dioxide concentrations in the 800 to 1100 ppm range.(25)

ASHRAE sets the guideline at 1000 ppm. However, it is noted that this level is not considered a health risk, but it is a surrogate for human comfort with respect to odour.(29)

The Regulation Respecting the Quality of the Work Environment (RRQWE), the only standard legally enforceable in the province of Quebec, sets the average concentration limit at 5000 ppm for any work environment, whether it be industrial or not.(42)

## FORMALDEHYDE

Formaldehyde (HCHO) is a colourless gaseous organic compound with a characteristic odour. Human sensitivity to formaldehyde varies over a wide range. Recent research shows that some people can begin to detect formaldehyde at around 0,075 $mg/m^3$. Most people begin to detect formaldehyde at around 0,15 $mg/m^3$; sensitized occupants begin to experience irritation of the mucous membranes at less than 0,15 $mg/m^3$. A larger fraction of the population experiences some discomfort from formaldehyde at 0,75 $mg/m^3$.(25) This gas is

highly soluble in water and acts as an irritant to the mucous membranes of the eyes and upper respiratory tract when concentrations exceed 1,5 to 4,5 $mg/m^3$.(32,43) Formaldehyde is also a suspected carcinogen and despite epidemiological studies, which provide little convincing evidence of the carcinogenicity in humans, chronic exposures to levels above 1,5 $mg/m^3$ (which is also the threshold limit value) should be of concern.(25,29) Formaldehyde has been shown to cause cancer in laboratory animals at concentrations of 22,5 $mg/m^3$.(25) It may also be responsible for allergic disorders including asthma.(44)

There have been reported symptoms of ocular or pharyngeal discomfort and irritation in connection with high concentrations of formaldehyde in new buildings where insulating materials releasing formaldehyde had been used. Experiments carried out in climatic chambers confirm the important role of this pollutant.(45) Many annoyance- or health-related complaints are claimed to be due to new and freshly renovated buildings.(46) For example, workers which perform renovations or construct new buildings often complain of eye and throat irritation.(47) The concentration in new and freshly renovated buildings are on an average more than an order of magnitude higher than those found in older houses.(46) But, the problem is not exclusive to new construction. It seems that even used materials from a 7-year old building still emit low and constant concentrations.(48) From tests performed in environmental chambers (with controlled temperature, relative

humidity, and air exchange rates) on various materials including insulation, coverings, furnishings, textiles, and paints, formaldehyde was the compound most often found; with emission rates ranging from 0,046 to 9,89 grams per hour.(49)

Formaldehyde is a common pollutant found in the indoor environment. It is a substance used in bonding/laminating agents, adhesives, paper and textile products, and foam insulation. In office buildings, sources of formaldehyde include: urea-formaldehyde foam for insulation, particle board, plywood, new furniture and furnishings, carpets, draperies, carbonless copy paper, cigarette smoke, unvented combustion products, and a variety of products, mainly used for disinfection, cleaning and painting.(25,43)

The ASHRAE standard is currently set at 60 $\mu g/m^3$ from the Canadian Exposure Guidelines for Residential Indoor Air Quality as a target level for acceptable long-term exposure.(29,50)

Concentrations in the ambient atmosphere of buildings are rarely sufficient to cause symptoms.(51) It is possible, however, that low concentrations of this pollutant, potentiated by other factors, may become important.

The World Health Organization (WHO) has recently introduced a concentration limit of 0,1 $mg/m^3$ for indoor air, because this is considered the threshold of

irritation, whereas "significant increases in symptoms of irritation start at levels above 0,3 mg/$m^3$ in healthy subjects".(52)

The RRQWE sets the average concentration of 3000 $\mu$g/$m^3$ as the ceiling limit.(42)

## VOLATILE ORGANIC COMPOUNDS

Whether they come from building materials, furniture, household maintenance products (waxes, detergents, insecticides), personal hygiene products (cosmetics), do-it-yourself goods (resins), office materials (photocopier ink) or Environmental Tobacco Smoke (ETS), Volatile Organic Compounds (VOC's) may affect humans in different ways, and sometimes are also a source of odours.

No significant difference in the VOC concentration between rooms with and without complaints in the same building have been noted: the levels in the latter were even higher than those in the former.(53) On the other hand, there have been reported effects (detectable through subjective sensation, performance tests or fine clinical observations, like the tear film stability of the eye) in chamber experiments with total VOC concentrations equivalent to those found in new or refurbished buildings.(54,55)

It has been found, moreover, that the concentration of some VOC's was inversely proportional to the relative humidity, which would explain why some disorders can be more severe in winter than in summer.(56) The correlation was attributed to the effect of air humidity on the emission from materials. The effect of VOC dissolution in (and successive release from) the water adsorbed on material surfaces, particularly books and papers on open shelves and surfaces with high adsorption rates (carpets, fabrics, etc.) has been speculated; the complaint rate in fact correlated strongly with the amount of such surfaces in rooms, referred to as shelf factor and fleece factor, respectively.(57) In the same study, it was reported that very large variations of VOC concentrations in space and time occurred, depending on activities within the space.(58)

Somewhat higher concentrations of VOC's might be expected during the summer months, since during the winter, infiltration contributes to a greater extent than in the summer to the rate of air change, due to the greater indoor-outdoor temperature differences (provided the source strengths remain unchanged).(59)

Indoor air VOC concentrations tend to increase very quickly as ventilation decreases below a rate within the range of 0,6 to 1,2 ach, depending on the source strengths and sinks. The stronger the sources, and the larger the available sinks, the more ventilation is required.(60)

In a recent paper comparing the levels of VOC's in two preschools, one healthy and the other closed because of Sick Building Syndrome (SBS) problems, it was put forward that concentration gradients rather than absolute concentrations of VOC's may trigger SBS.(61)

The ASHRAE standard is based on the WHO Working Group Consensus of Concern about Indoor Air Pollutants at 1984 Levels of Knowledge. They refer to the American Conference of Governmental Industrial Hygienists (1983-1984) threshold limit values (TLV). ASHRAE recommends to use one-tenth of the TLV as the limit. So, the ASHRAE recommended value for stoddard solvent is 52,5 $mg/m^3$.(29,62) Stoddard solvent represents a mixture of various substances from the VOC group (including toluene, xylene, etc.) It is used in laboratory analyses as a measure of total hydrocarbons.

The RRQWE sets the average concentration limit at 575 $mg/m^3$ for stoddard solvent.(42)

PARTICLES

Outdoors, particles originate from the action of wind blowing over loose soil, from combustion emission and from various manufacturing processes. The concentration of particles in the indoor air tends to increase as more outdoor air is used when there is little or no smoking indoors. Reduction of outdoor air and a normal amount of smoking will cause the particulate concentration indoors to be greater.(25)

The distribution of particle sizes is strongly influenced by the source. Particles coming from outdoors, especially wind-driven dust, tend to be much larger than those generated indoors. Dust and pollen range from 1 to 100 micrometers in size. Tobacco smoke particles, on the other hand, range from 0,01 to 1,0 micrometers. Although the smallest particles may be more numerous, their total mass is generally smaller than the bigger particles. Also they are more easily airborne and enter deeper into the lungs.(25)

Dust in the indoor air consists of organic and inorganic particles, many of which can be classified as fibres. The total dust concentration in a room is dependent on ventilation, cleaning and activity levels, and the degree of tobacco smoking.

No correlation has yet been shown between SBS and total dust concentration. However, Man Made Mineral Fibres (MMMF) have been a matter of concern and there have been reports of a correlation between airborne MMMF and eye irritation and also between non-respirable MMMF on surfaces and skin irritation.(63) MMMF come mainly from acoustic ceilings: especially high concentrations were found in rooms with uncovered ceilings, but also where the fibres were bound by a water-soluble glue and exposed to water damage.(64) The non-respirable fibres are transferred from such surfaces to skin and eyes normally by direct hand contact. The airborne fibres are those most likely to be inhaled.

The ASHRAE standard is currently set at 40 $\mu g/m^3$ from the Canadian Exposure Guidelines for Residential Indoor Air Quality for acceptable long-term exposure.(29)

The RRQWE sets the average concentration of 10 $mg/m^3$ of total dust as the limit for nuisance particulates.(42)

## VENTILATION

In the typical commercial environment, some measure of exhaust air is recirculated and mixed with a portion of outside air. The concentration of any contaminant released at a constant rate will in general be a direct function of the dilution rate by outside air.(65)

Insufficient ventilation due to energy saving measures following the oil crisis has been claimed as one of the main causes for SBS symptoms. Minimum ventilation rates do nevertheless exist in many countries, but vary from country to country and, of course, from non-smoking to smoking conditions.

The latest information indicates that a rate of approximately 8 litres per second (nearly 30 $m^3$/hr) per person (sedentary activity) will be adequate for non-smoking areas in order to extract the bioeffluents of humans.(66) At this level a $CO_2$ concentration of 0,1% will be present and 20% of people entering the room will be dissatisfied with the environment. If a higher percentage of dissatisfied is accepted (25 to 30%), the ventilation rate can be proportionally reduced (3,8 to 5,4 l/s/person). In smoking areas the ventilation rate should be higher.(37,67)

Ventilation should not by itself cause problems such as draught or odour. Therefore, attention must be laid on accurate commissioning and maintenance

(cleaning) of the ventilating plants. Also recirculation of air which introduces contaminants to working areas should be avoided.

For office space, the ASHRAE standard is currently set at a minimum outdoor air requirement of 10 l/s/person; with an estimated maximum occupancy of 7 people/100 $m^2$.(29)

The RRQWE sets the outdoor air rate requirement at 2,4 l/s/person; with an occupancy rate of 10 people/100 $m^2$.(42)

## 2.2 Thermal Comfort Parameters and Standards

The environmental quality of a space is determined by the occupant's response to various environmental stimuli and his integration of these inputs into a comfort response. If one assumes that sufficient heating or cooling capacity is available to maintain the desired average temperature within a space, then a comfortable thermal environment will be completely dependent upon the distribution of treated air in the space. From a thermal standpoint, it is possible to have an average temperature (existing at some point in the space) which satisfies overall criteria for thermal balance. At the same time, there may be conditions which cause the local temperatures throughout the space to vary from this average or mean value.

The objective of a good air distribution system is to produce, within the occupied space, the proper combination of temperature, air motion, and relative humidity to keep the occupants comfortable.

## TEMPERATURE (DRY-BULB AND OPERATIVE)

The standards for maintaining a certain acceptable level of comfort and occupational activity fluctuate between 20 and 26°C, taking into account the clothing and the relative humidity.(68) However, there are indications that temperature should be kept in the lower part of the comfort range; a reduction in mental work capacity has been observed above 24°C.(69,70) In a recent study, a significant statistical relationship between room temperatures above 22°C and the appearance of SBS symptoms was observed.(71) Similar findings were found in offices as well as in homes.(72,73) Finally, higher temperatures will increase offgassing from materials.

The RRQWE states that for "light work performed while sitting: any mental work, precision work, reading or writing," the minimum temperature required is 20°C. However, the provincial regulation does not set a maximum temperature level for typical office work.(42)

ASHRAE is more demanding in its recommendations, as its temperature limits are coupled with relative humidity, to form a comfort zone, as follows:

-winter: $t_o$ = 19,5 - 23°C at $t_{dp}$ = 16,7°C

to

$t_o$ = 20,2 - 24,6°C at $t_{dp}$ = 1,7°C, and

-summer: $t_o$ = 22,6 - 26°C at $t_{dp}$ = 16,7°C

to

$t_o$ = 23,3 - 27,2°C at $t_{dp}$ = 1,7°C,

where $t_o$ = operative temperature, and

$t_{dp}$ = dew point temperature.(74)

Figure 2.1 shows these boundaries on a psychrometric chart.

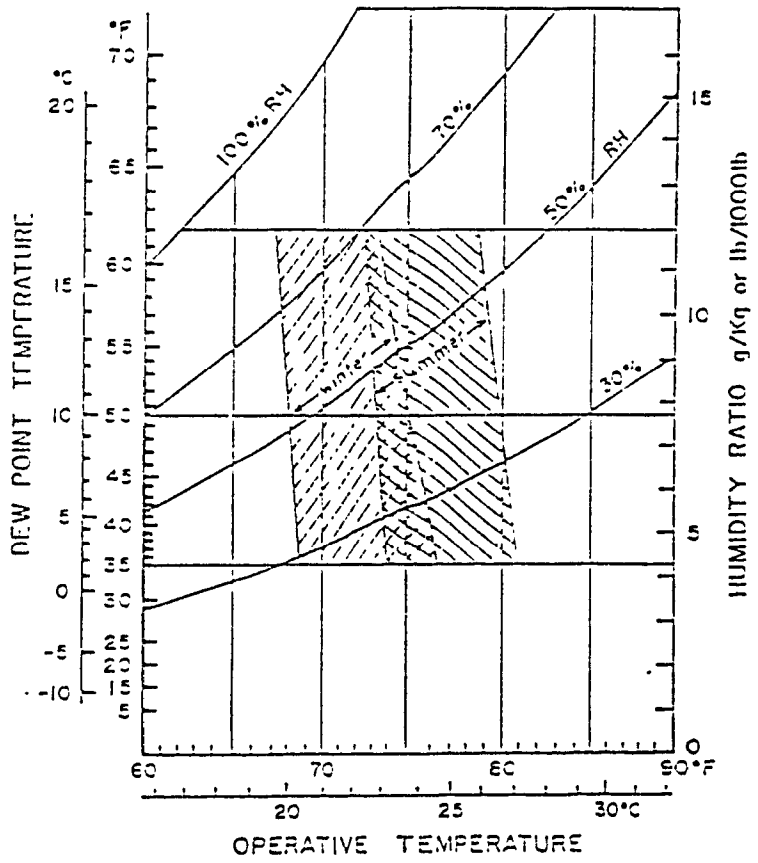



Figure 2.1 ASHRAE thermal comfort limits (74)

These limits are acceptable assuming the occupants are clothed in typical summer and winter clothing, at light, mainly sedentary, activity.(74)

RELATIVE HUMIDITY

There is no agreement on what constitutes the ideal range of relative humidity. The thermal effect of humidity on the comfort of sedentary persons is very small. It is known that high values (above 70%), particularly associated with high temperature, are uncomfortable and health may be threatened, at least through the development of surface condensation and mould growth. Moreover, high humidity may lead to structural damages in buildings, especially in cold climates.(74) Very low relative humidity (less than 20%) can cause, in some individuals, drying of the mucous membranes and of the skin.(75,76) However, it was shown that in 78-hour exposures to dry clean air (relative humidity of 9%) no signs or symptoms were found, even in people with high metabolic rates.(75) Also, raising the relative humidity above 50% in winter has not been shown to improve respiratory health.(74) Consequently it appears that the direct effect of low humidity on the prevalence of SBS can be considered unimportant, but indirect effects could play a role, including the buildup of static electricity and consequent electric discharges, offgassing of vapours following a significant humidity change or variation of the respirable suspended particulate matter.

The RRQWE states that for offices and commercial establishments, a minimum relative humidity of 20% must be maintained during office or business hours. However, similarly to temperature, the provincial regulation does not set a

maximum humidity level for typical office work.(42)

In zones occupied by sedentary or near sedentary people, ASHRAE states that the dew point temperature shall not be less than 1,7°C or greater than 16,7°C. These are the same comfort zone limits described in the previous section.(74)

## AIR DIFFUSION PERFORMANCE INDEX

The Air Diffusion Performance Index (ADPI) is a single number rating of the air diffusion performance of a system of diffusers, as installed, at a specified air delivery rate and space load. It is a means of determining the ability of an air distribution system to produce an acceptable thermal environment, based on air motion and air temperature distribution at specified zone heating or cooling loads.(77)

The purpose of a heating, ventilating, or air conditioning system is to create the proper combination of temperature, humidity and air motion which will provide comfort for the occupants of the conditioned room. The success or quality of the system largely depends on proper air distribution. Even though, on an average basis, the air conditioning system may have sufficient temperature and humidity control, there can be areas within the space which can be uncomfortable for the

occupants. Such discomfort may arise from excessive room air temperature variations--horizontally, vertically, or both--excessive air motion, or a combination of these factors, causing occupants to complain of drafts or stuffiness.(78)

The ADPI was measured for one week every month. The ANSI/ASHRAE 113P "Method of testing for room air diffusion" was used.(77)

Four test zones (two per floor) were selected as shown in Figure 1.1 (zone 1 includes stations 1 and 2; zone 2 includes stations 5, 6, and 7). A point in the centre of each test zone 1,1 m above the floor was selected as the reference temperature, $t_r$. The vertical test points ($t_a$, air temperature at each point and $v_a$, air speed at each point) were located at 0,1 m, 0,6 m, 1,1 m, and 1,7 m above the floor, and were a minimum of 0,6 m apart, horizontally. Each of these horizontal positions is considered a set.

All reference temperatures recorded are averaged to obtain the average temperature at the reference point during the test;

$$t_{r,avg} = ( t_{r,1} + t_{r,2} + \ldots + t_{r,m} )/m$$

where $t_{r,avg}$ = time averaged reference temperature, °C,
$t_{r,1}$ to $t_{r,m}$ = temperatures at the reference point, ($t_{r,max} - t_{r,min} < + 1,1$ °C), °C, and
m = number of test positions.

At each set of temperature readings (at a test position), the reference point temperature taken during that set is compared to the average reference temperature taken for the total zone, to determine a temperature correction factor to be applied to all test point temperatures at that test position;

$$c_{r,m} = t_{r,avg} - t_{r,m}$$

where $c_{r,m}$ = temperature correction at a test position (shall not exceed +/- 1,1°C), °C,
$t_{r,avg}$ = time averaged reference temperature, °C, and
$t_{r,m}$ = reference point temperature for each set of temperature readings at test position m, °C.

The set test position temperature correction factor is added to all corresponding test point temperatures. This corrects the test point temperature for any unavoidable swing in the reference temperature;

$$t_{acn} = t_{an} + c_{r,m}$$

where $t_{acn}$ = corrected temperature at test point n, °C,
$t_{an}$ = measured temperature at test point n, °C, and
$c_{r,m}$ = temperature correction at test position m, °C.

The individual corrected test point temperatures are averaged to obtain the average zone temperature;

$$t_c = ( t_{ac1} + t_{ac2} + ... + t_{acn} )/n$$

where $t_c$ = average test zone temperature, (between 20 and 26°C), °C,
$t_{ac1}$ to $t_{acn}$ = individual corrected test point temperature, °C, and
n = number of test points in test zone.

At each test point, the effective draft temperature is calculated as follows;

$$\Theta_n = t_{acn} - t_c - 8 ( v_n - 0,15 )$$

where $\Theta_n$ = effective draft temperature at test point n, °C,
$t_{acn}$ = corrected temperature at test point n, °C,
$t_c$ = average test zone temperature, °C, and
$v_n$ = air speed at test point n, m/s.

The Air Diffusion Performance Index is the percentage of test points where the effective draft temperature and velocity meet the criteria:

$- 1,7°C \leq \Theta \leq 1,1°C$, and

$v \leq 0,35$ m/s.

Approximately 30 test points were selected in the horizontal direction for each test zone. The area facing west was chosen for the afternoon testing period since the thermal load was the greatest at that time due to the sunshine. Consequently, the area facing east was tested in the morning.

To comply with the ASHRAE standard, the ADPI shall be equal to or greater than 80%.(77)

## VERTICAL TEMPERATURE GRADIENTS

Air temperature in enclosed space generally increases from floor to ceiling. If this increment is sufficiently large, local warm discomfort can occur at the head, and/or cold discomfort at the feet, although the body as a whole is thermally neutral. Therefore, to prevent local discomfort, ASHRAE states that the vertical air temperature difference within the occupied zone, measured at the 0,1 m and 1,7 m levels should not exceed 3°C.(74)

AIR VELOCITY

At low temperatures, it is important not to have high air velocities; to avoid local draft discomfort. However, at higher temperatures, air velocities should not be so high as to create displacement of loose paper, hair, and other light objects.(74)

ASHRAE states that within thermally acceptable temperature ranges, there is no minimum air movement that is necessary for thermal comfort. However, in winter, the average air movement shall not exceed 0,15 m/s. In the summer, the average air movement in the occupied zone shall not exceed 0,25 m/s. But a higher air movement can be acceptabie if coupled with a higher temperature; i.e. 0,275 m/s increase for each degree °C above 26°C, to a maximum of 28°C (corresponding velocity maximum of 0,8 m/s).

Public Works Canada recommends the levels shown in the following table:

Table 2.1 Air velocity recommendations (79)

| AIR VELOCITY (m/s) | AIR MOVEMENT | CONDITION FOR THE OCCUPANTS | SENSATION FOR THE OCCUPANTS |
|---|---|---|---|
| 0,00 to 0,05 | poor | mediocre | stagnant |
| 0,05 to 0,09 | marginal | mediocre | stagnant |
| 0,09 to 0,15 | good | satisfactory | comfortable |
| 0,15 to 0,25 | excellent | satisfactory | very comfortable |
| 0,25 and over | excessive | mediocre | uncomfortable drafts |

## GLOBAL THERMAL COMFORT (PMV AND PPD)

Human beings are said to be thermally comfortable when they cannot say whether they would prefer cooler or warmer surroundings. This condition is related to the equilibrium resulting from heat generated within the body and transferred to the environment by convection, radiation and evaporation of moisture. However, a thermal environment which will provide optimal thermal comfort is not always possible physically and financially.

To quantify the degree of discomfort, an index has been devised which gives the Predicted Mean Vote (PMV) of a large group of subjects.(80) The PMV scale ranges from -3 (cold) to +3 (hot), the optimum being 0 (neutral). Figure 2.2 below shows the relationship between the PMV and the Predicted Percentage of Dissatisfied (PPD).

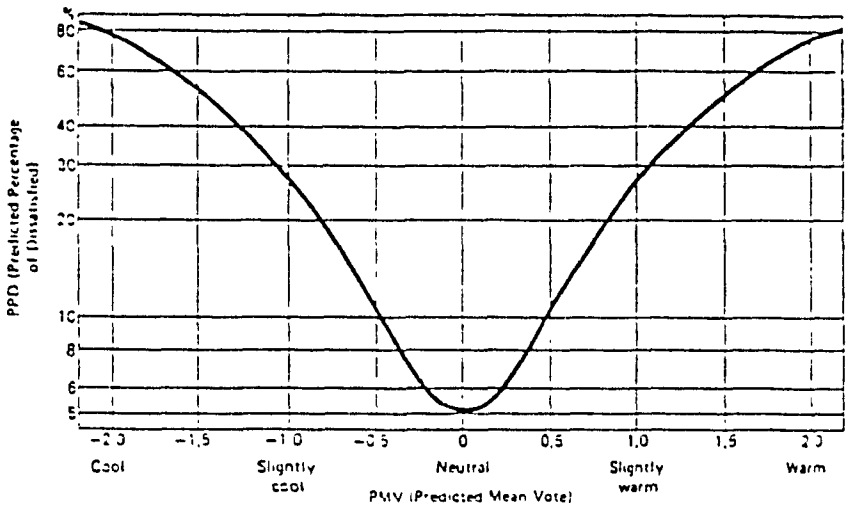



Figure 2.2 The relationship between PMV and PPD (80)

This figure is based on studies comprising a group of 1300 subjects. As can be seen, the lowest that can be expected is 5% PPD.

To comply with the ASHRAE standard, the PPD shall be equal to or less than 20%.(74)

## 2.3 Occupant Perception Parameters and Standards

As mentioned previously, ASHRAE defines acceptable indoor air quality as being

> "air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction."(29)

An acceptable thermal environment is further defined as follows: "an environment which at least 80% of the occupants would find thermally acceptable."(74)

Increased absenteism and relatively low productivity are two of the main characteristics of populations of buildings which have indoor environment problems. It has been estimated that the present average annual costs associated with any given building are about $ 20.00 per square meter for heating, ventilating, and air conditioning, and about $ 2000.00 per square meter for occupant salary.(81) It is readily apparent from these estimates that even modest loss in productivity can lead to significant financial losses.

It has been the initial reaction of a number of professionals confronted with repeated complaints of ill-defined discomfort to blame psychological factors, and all the more so since these symptoms appear to have no organic basis and women are the most frequently affected.

Many gases and vapours give rise to sensory discomfort from odour and irritation, which may be a disturbing factor, leading to anxiety and stress, especially when the sources are not identified.

An investigation carried out on 600 office workers in the USA showed that 20% of the employees experience symptoms of SBS and most of them were convinced that this reduces their working efficiency.(32)

In one study, measurements of the occupants' subjective response to their environment showed that seasonal variations interacted with the occupants' perceptions of the ventilation conditions and the associated carbon dioxide levels. Occupants in that study reported feeling more comfortable and generally cooler in the warm season than in the cold season regardless of the ventilation conditions.(25)

Various studies have been carried out testing patients either with a set of performance tests (memory, vigilance, reaction time) or in the form of a psychosociological survey evaluating how these complainants viewed their working conditions in air-conditioned environments.(56,82) The performance tests show no significant differences between symptomatic and control groups.

Some researchers have investigated the possible links between SBS and stress. Their results, though not clear-cut, lead to think that SBS may well be responsible for the stress rather than the reverse.(83)

Psychological factors may play a role by increasing the stress of people and thus making them more susceptible to environmental factors.(84) In a multifactorial analysis, it was shown that in addition to the building factor, other factors like sex, job and psychosocial factors are associated with the prevalence of mucosal irritation and general symptoms.(85)

# CHAPTER 3

## 3. TEST FACILITY

Source control and an adequate supply of outdoor air are the two strategies used to achieve good indoor air quality. However, the more outdoor air that is supplied, the more energy is needed to heat/cool that outdoor air. Significant energy savings can be achieved if we were to supply the required outdoor air only when the need arose. This would ensure enough outdoor air to keep the indoor air quality acceptable, without over-ventilating This is accomplished through the use of demand-controlled ventilating (DCV) systems For this project, it was necessary to simultaneously compare two identical floors of an office building, so that thermal loads would be equivalent In a previous study, it was shown that all of the parameters tested (indoor air quality, thermal comfort, occupant perception, and energy demand) were equivalent on both floors.(3,30)

The building used for the study was given to us following an agreement between the Institut de recherche en santé et en sécurité du travail (IRSST) and the Société immobilière du Québec (SIQ). It was chosen primarily for the fact that each floor is serviced by its own independent, yet identical, ventilation system. Furthermore, the occupation density of the building was highly variable when compared to typical Montreal office buildings.

The 11 storey office building is situated in a sub-urban area of downtown Montreal. Because of confidentiality, the exact building location cannot be revealed. It is surrounded by a busy autoroute parallel to the St. Lawrence River and a steel and tire deposit area (on the south side), by a heavily travelled bridge and parking lot (on the east side), and by a parking lot (on the north side). The building is unattached to any other building.

The climate surrounding the testing site is dominated by weather conditions characteristic of the eastern part of Canada. The monthly temperatures for the year of testing are shown in Table 3.1. These were collected in the direct vicinity of the test building.

Table 3.1 Monthly exterior temperatures (°C)*

| MONTH | MAXIMUM | MINIMUM | MEAN |
|---|---|---|---|
| May 1990 | 28,9 | 2,3 | 16,1 |
| June 1990 | 29,5 | 8,4 | 19,1 |
| July 1990 | 31,0 | 12,6 | 21,9 |
| August 1990 | 29,4 | 3,0 | 17,3 |
| September 1990 | 25,2 | 2,6 | 11,1 |
| October 1990 | 19,5 | -11,2 | 3,0 |
| November 1990 | 17,8 | -16,2 | -2,3 |
| December 1990 | 6,5 | -30,8 | -10,2 |
| January 1991 | 11,4 | -32,2 | -9,7 |
| February 1991 | 11,7 | -23,3 | -5,4 |
| March 1991 | 18,1 | -10,6 | 2,5 |
| April 1991 | 30,7 | 0,0 | 11,2 |

* All detailed, raw data can be found at the IRSST through Ms. Nicole Goyer

## 3.1 Building Layout and Envelope Properties

Because the building had been built right after the Energy Crisis of the early 1970's, its envelope is considered to be tight. No building plans existed of the exterior walls.

Figures 3.1 and 3.2 show the 8th and 9th floor plans, respectively.

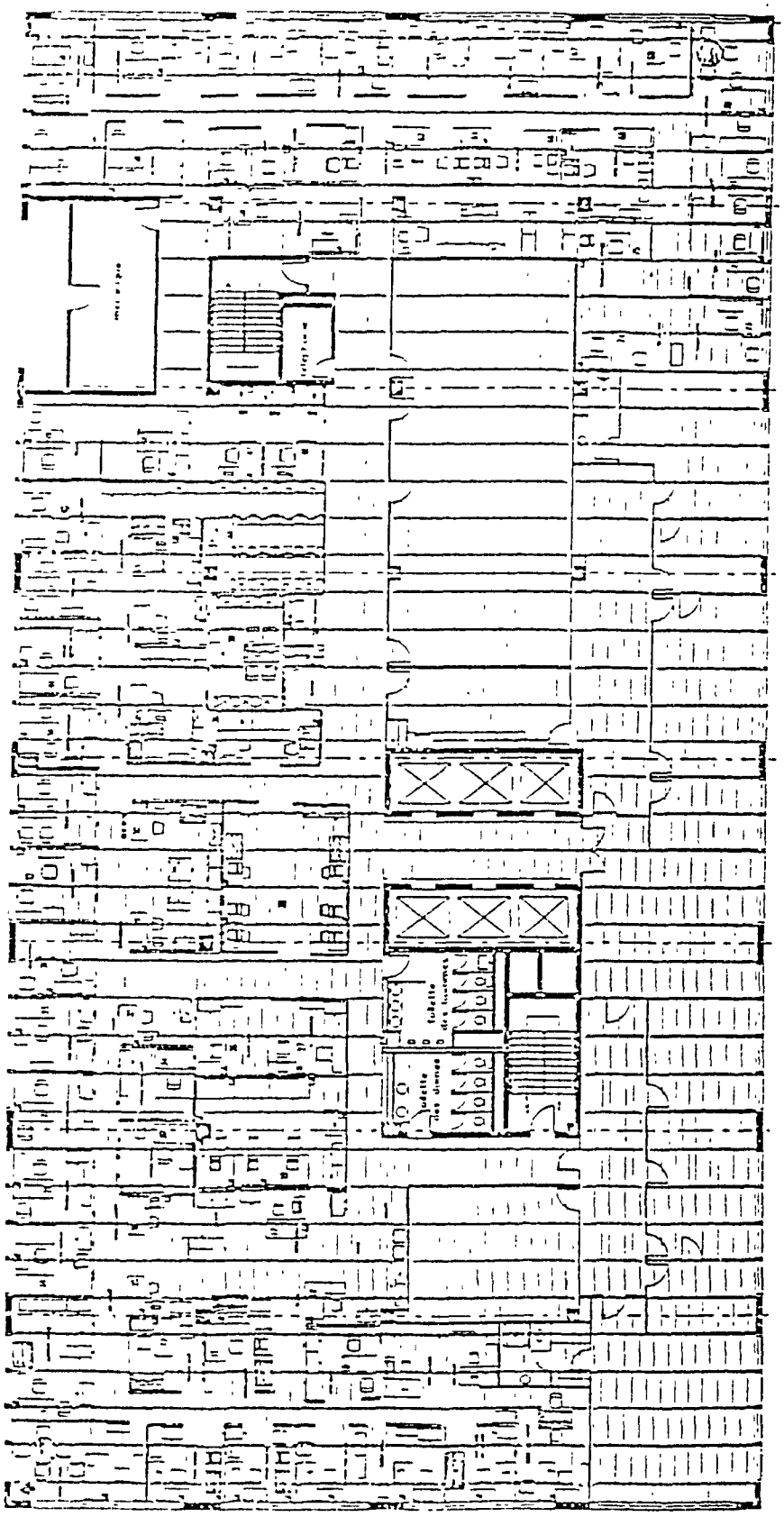



Figure 3.1 Building floor plan, 8th floor

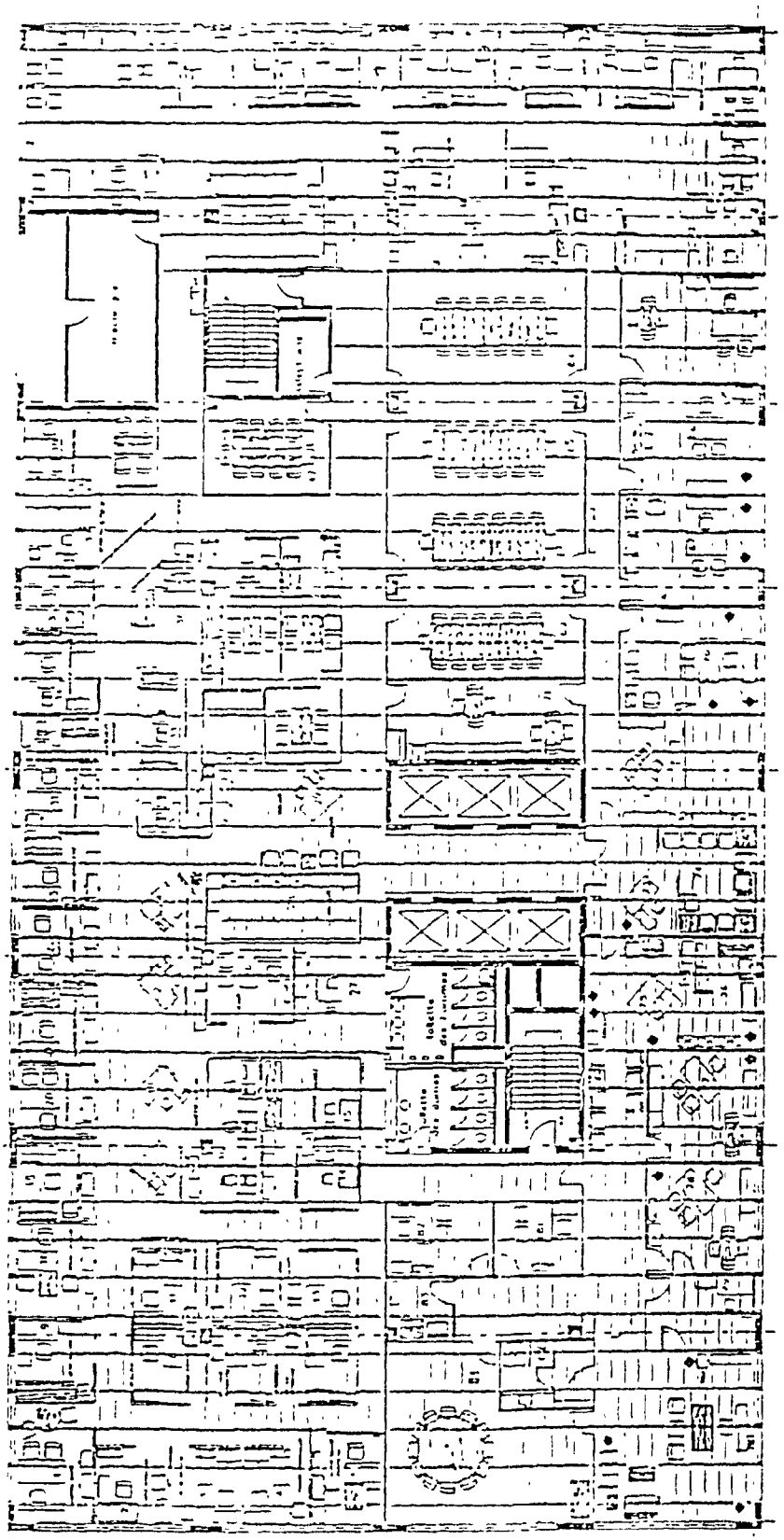


Figure 3.2 Building floor plan, 9th floor

The building contained a total of twelve stories; eleven floors and a basement. The $11^{th}$ floor is the cafeteria, and the basement contains a parking area, a delivery station for mail and merchandise, and a maintenance equipment storage room.

The building, constructed during 1973-1974, consists of 11 stories with an average 1800 $m^2$ each and a ceiling height of 3 meters. The building was almost totally renovated during the years 1988 and 1989. The renovations were on a large scale; both the air distribution systems and the total interior were gutted out and replaced. The building construction is of masonry with 90% exterior glass. The windows consist of two large glass panes, and are equipped with horizontal blinds. Figure 3.3 shows a photo of the building exterior.

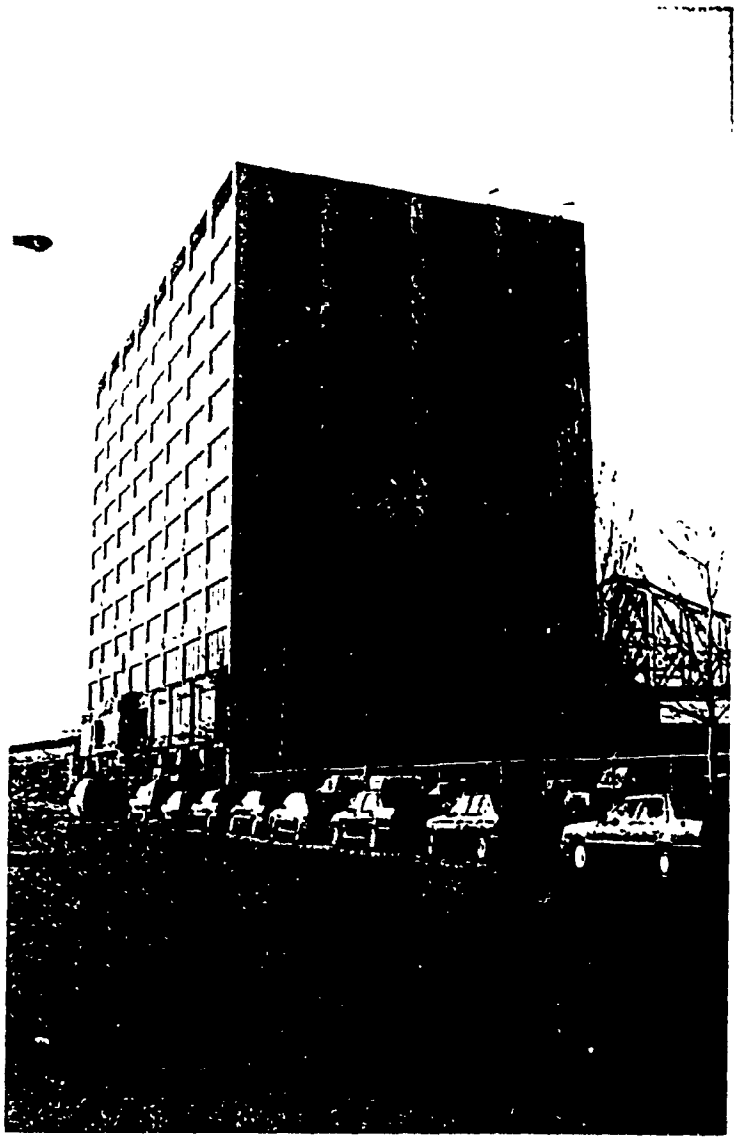


Figure 3.3 Photo of building exterior

All floors are covered with grey, synthetic carpeting, which is vacuum-cleaned nightly, during weekdays, i.e. Monday to Friday. The carpet brand name was

undisclosed to us, even after enquiries were directed to the building owner. The walls are painted with an oil-based paint of icy colours (peach, mint, grey). The suspended ceiling is made of semi-hard yellow foam acoustic tiles of a white colour. Again, the brand name was undisclosed to us.

The lighting is supplied by fluorescent lights located in the suspended ceiling. These are turned on automatically at about 7:00 in the morning. They are later turned off automatically at 11:00 P.M..

As for aggravating objects in the working zones, that is equipment which produces noise, pollutants, or heat, being a newly-automated office area, the only equipment producing any noise is the matrix dot printers. There only exists one photocopier per floor, and the ozone emitted from it was not detectable with our instrumentation.

The only cleansers used by the building maintenance personnel are ordinary, commercial cleaning products. They vacuum the floors, collect the garbage, occasionally dust the desk-tops, and disinfect the washrooms nightly.

The two floors chosen for the study are the 8$^{th}$ and 9$^{th}$, and from hereafter, they will be the only floors discussed. The criterion for their choice was to have two floors identical in occupation density, working hours, ventilation distribution, and

workspace layout. The floors are divided into 60 to 80 open-area offices with 1,2 to 1,8 meter high partitions (no spacing off the floor), 14 closed offices, and 4 conference rooms, one lounge room, two public and two private washrooms, and 6 elevators (3 of which descend to the basement). The study considered only the open-area offices (from hereon, this area will be called the working zones in question), since the other offices are separated from the open-area as to ventilation distribution, by doors which are perpetually left closed, and by a dividing wall which also separates the suspended ceiling.

Each floor is occupied by approximately 100 white collar workers, but since the building is open to the public, the number of people varies. The occupation density is approximately 6 people/100 $m^2$.

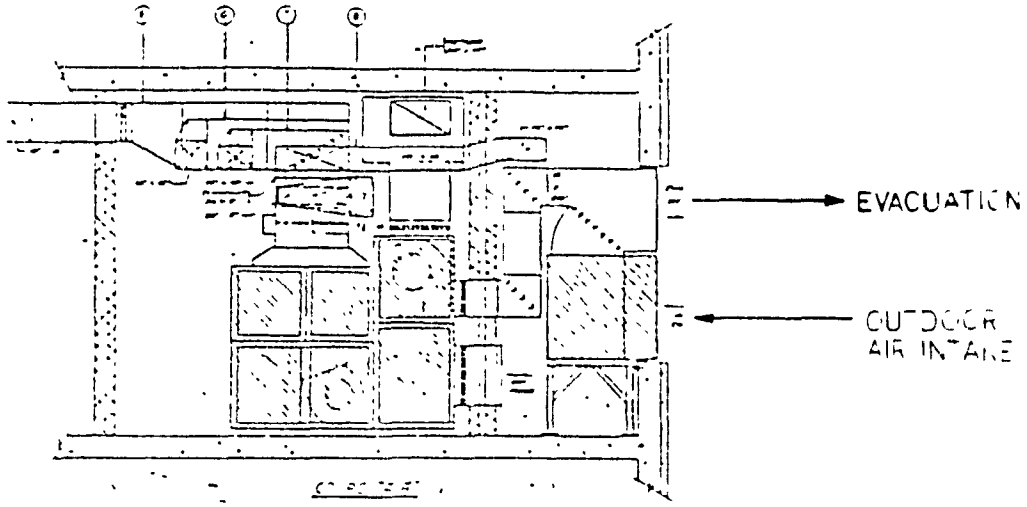
## 3.2 Heating, Ventilating, and Air-Conditioning Systems

Each floor has one mechanical room consisting of two identical air handling systems (AHU-A and AHU-B). Figures 3.4 and 3.5 show the air distribution systems. A third, smaller system ventilates only the conference rooms and closed offices. Each floor is heated and cooled with electric energy Heating required to offset building skin heat loss as well as infiltration and ventilation heating loads is provided by straight electric heating elements Each floor is cooled by two

direct expansion evaporators and condensing units, one for each air handling system.

The Heating, Ventilation, and Air-Conditioning System (HVAC) consists of a double duct constant air volume system (CV) with the fresh air intake and exhaust on each floor, on the wall facing west. Each floor's units are located directly above (or below) the other. As originally installed, each air handling system used outdoor air for economy cooling when the outdoor air temperature was between 13 and 18°C.

Both systems take outdoor air from individual outdoor air intake louvres. The outside air is mixed with return air in proportion to the temperature of the outdoor air, then filtered with mineral wool filters, humidified by steam humidifiers (from October 1$^{rst}$ to April 1$^{rst}$), and heated/cooled if necessary. According to the building operation personnel, the filters are changed every 2 months during the winter season, and every 1,5 months during the summer (by visual inspection). Heating/cooling is provided by adjusting the thermostats placed throughout the working zones. The supply temperature is maintained at 13 and 50°C during the summer and winter, respectively. According to the building operation personnel, it is not unusual that the compressors cool during the winter months of January and February due to overheating in the supply duct. Figure 3.4 shows the air handling units of one floor; two side views are shown.



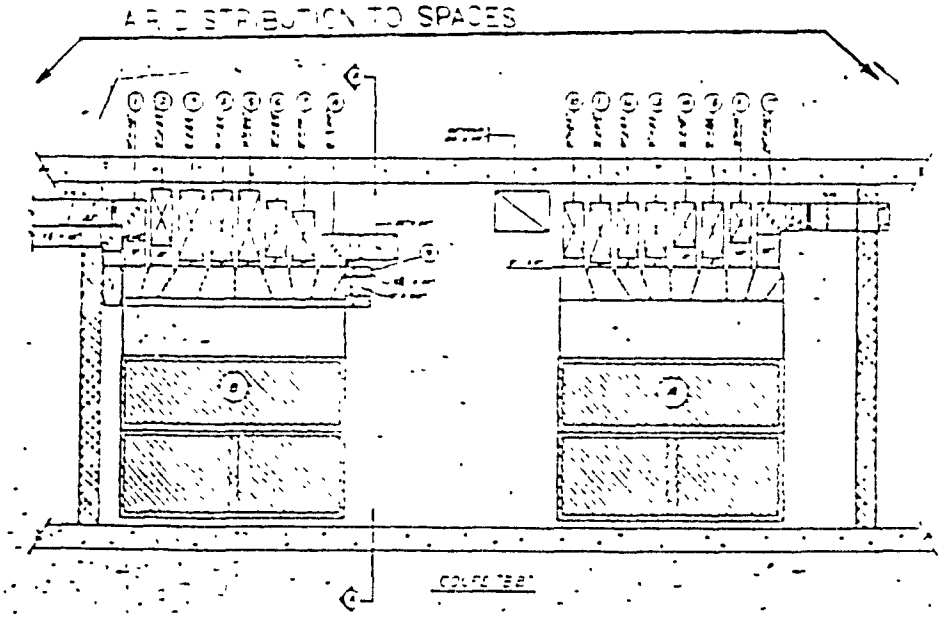




Figure 3.4 Air handling units of one floor (two side views)

The conventional system functions as follows: once the mixing temperature rises or descends to a temperature other than the ideal, the outdoor air dampers modulate. In the summer, if the supply temperature is too high, the outdoor air dampers begin to close; if the supply temperature is too low, the outdoor air dampers begin to open. The opposite is true for the winter season: if the supply is too high, the dampers open; if the supply is too low, the dampers close.

The air is supplied to the floor through ducts which branch off throughout the floor and lead to square conic, four-way diffusers in the ceiling in the interior work zones and to linear slot diffusers in the ceiling along the periphery. One hundred diffusers are located throughout each floor to supply the air flow to the various zones. The average air volume supplied per floor is 9000 l/s (corresponding to approximately 90 l/s/person of total air). The layout is shown on Figure 3.5.

Exhaust grilles are located throughout the ceiling in the interior work zones. The return air is collected from the plenum, and is then drawn into the mechanical room by parallel exhaust fans. Consequently, it can either be exhausted or mixed with outdoor air to be supplied to the floor. Restroom exhaust is provided by separate fans and exhaust ducts leading to the roof of the building.

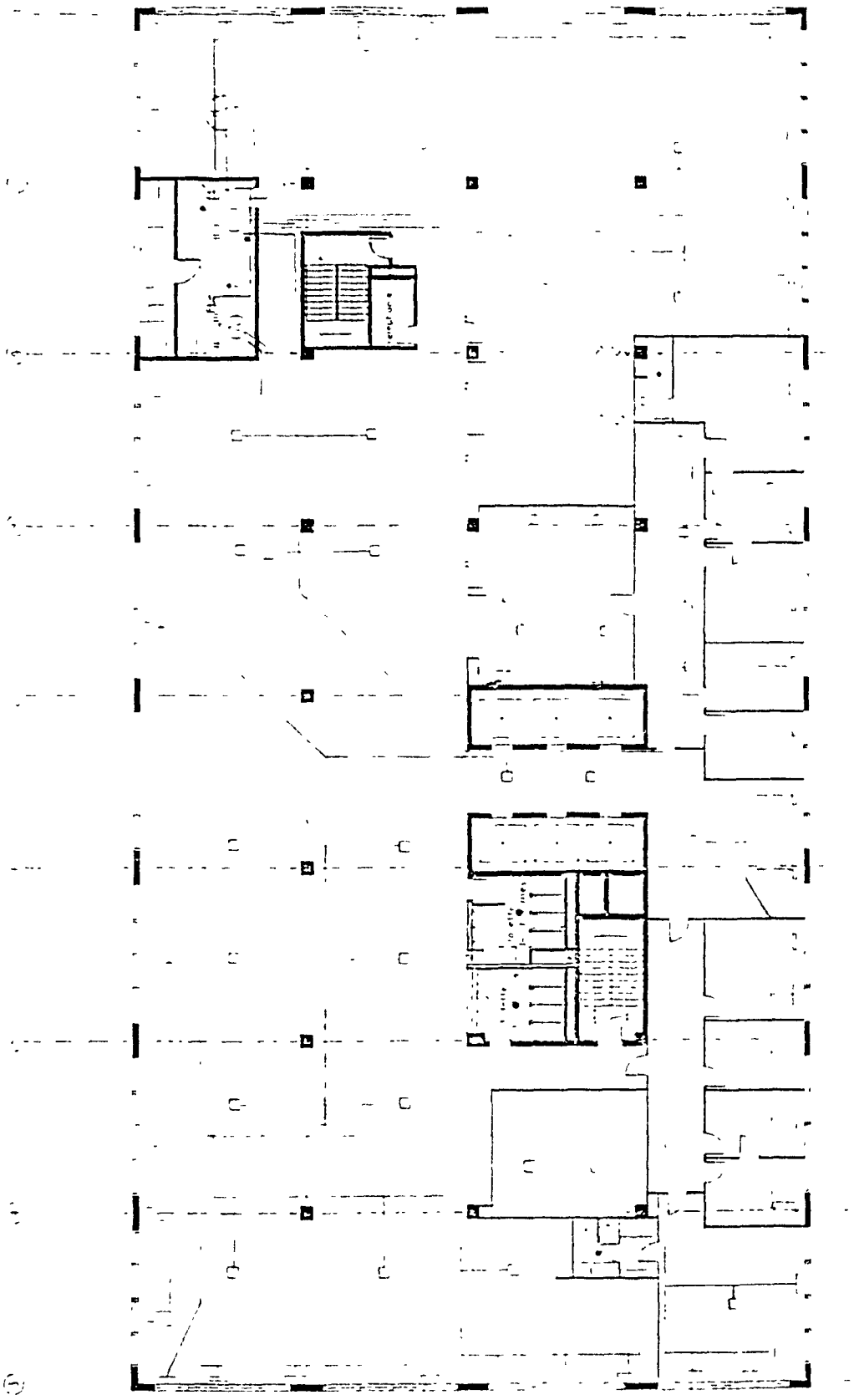


Figure 3.5 Air distribution system (one floor)

## 3.3 Ventilation Control System

The two air handling systems used electric temperature controls throughout. The $CO_2$-based ventilation capability was added to both air handling systems of one floor (the 8$^{th}$ floor) by utilizing a $CO_2$-based ventilation controller (model ref. no. 8225) manufactured and marketed by ACME Engineering in Montreal.

The $CO_2$-based ventilation controller employs a compact, highly sensitive infrared emission-type gas analyzer. The unit is designed for wall mounting in the mechanical room, with remote sensors in the occupied spaces. Room air is pumped from the occupied spaces via the plastic tubing, through the gas analyzer at about 2 l/min, for a pre-set time per sensor.

Figure 3.6 shows a photo of the $CO_2$ control unit. The typical application of the device is to provide added ventilation to the space on a modulating basis. The $CO_2$-based ventilation controller is self-calibrated at the end of each sampling cycle with soda lime (equivalent to a zero-gas). The sensor detects exclusively $CO_2$.

Figure 3.6 Photo of $CO_2$-control monitor

The $CO_2$-based ventilation controller was functionally integrated into the control system as shown in Figure 3.7. The $CO_2$-based ventilation controller provided outdoor ventilation air to the space when the average space $CO_2$ concentration exceeded the control set point. When the set point was exceeded, the outside air damper was opened to the minimum position. As the $CO_2$ increased, so did the opening of the dampers, up to a maximum opening when the $CO_2$ reached the upper limit set-point.

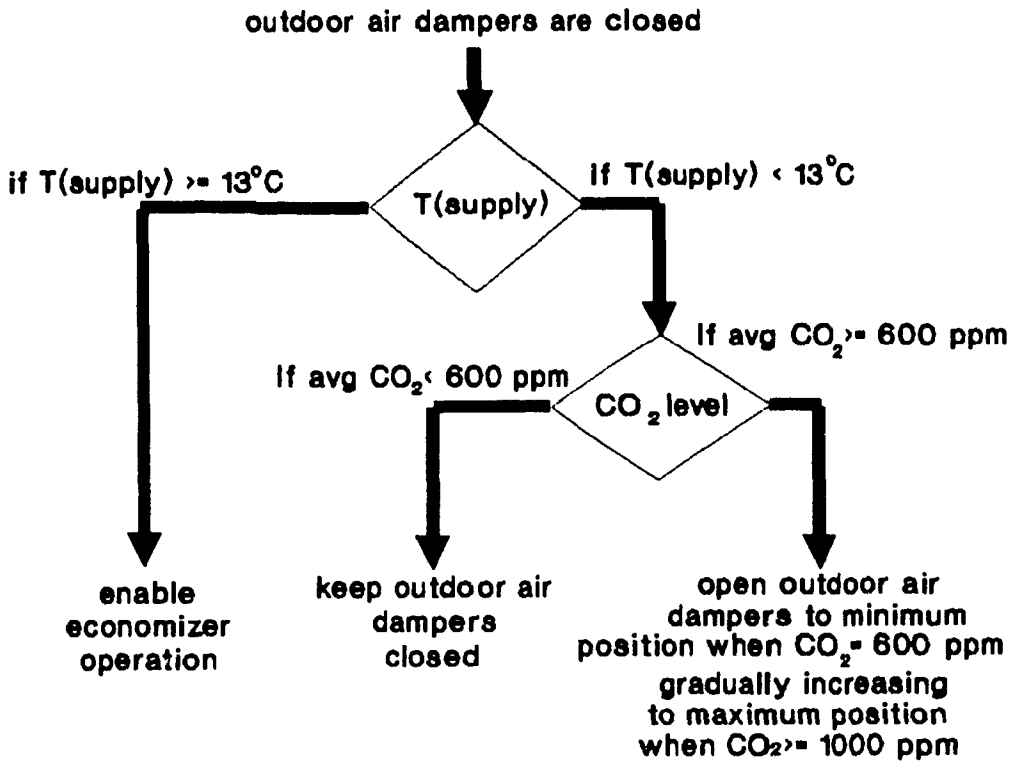



Figure 3.7 $CO_2$-based ventilation damper control strategy

The $CO_2$-based ventilation controller is designed for wall mounting near the AHU, with remote sensors mounted at representative locations in the occupied space. As shown in Figure 3.8, these locations were near representative work-stations. The typical installation is shown in Figure 3.9.

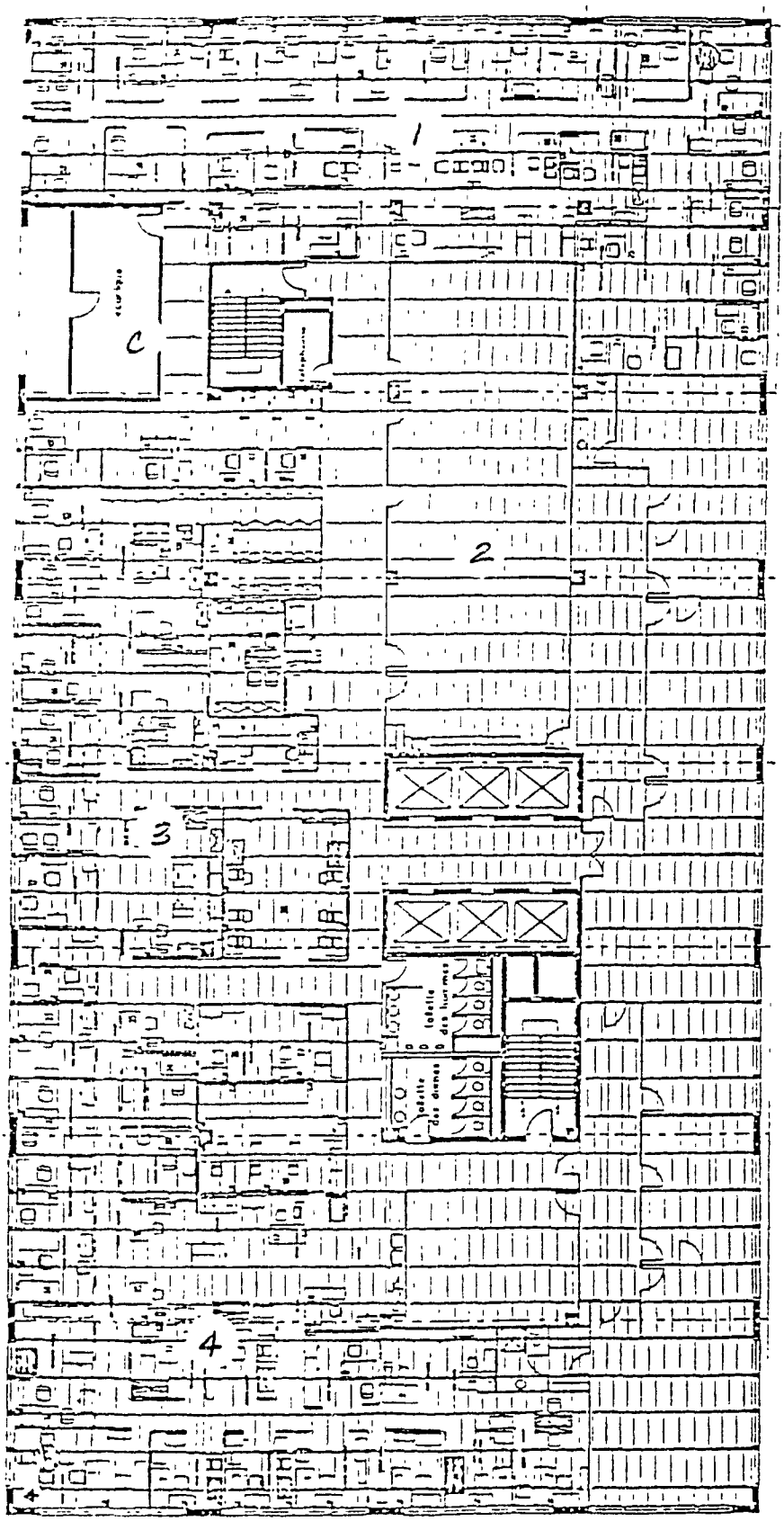



Figure 3.8 8th floor plan with $CO_2$-control sensors

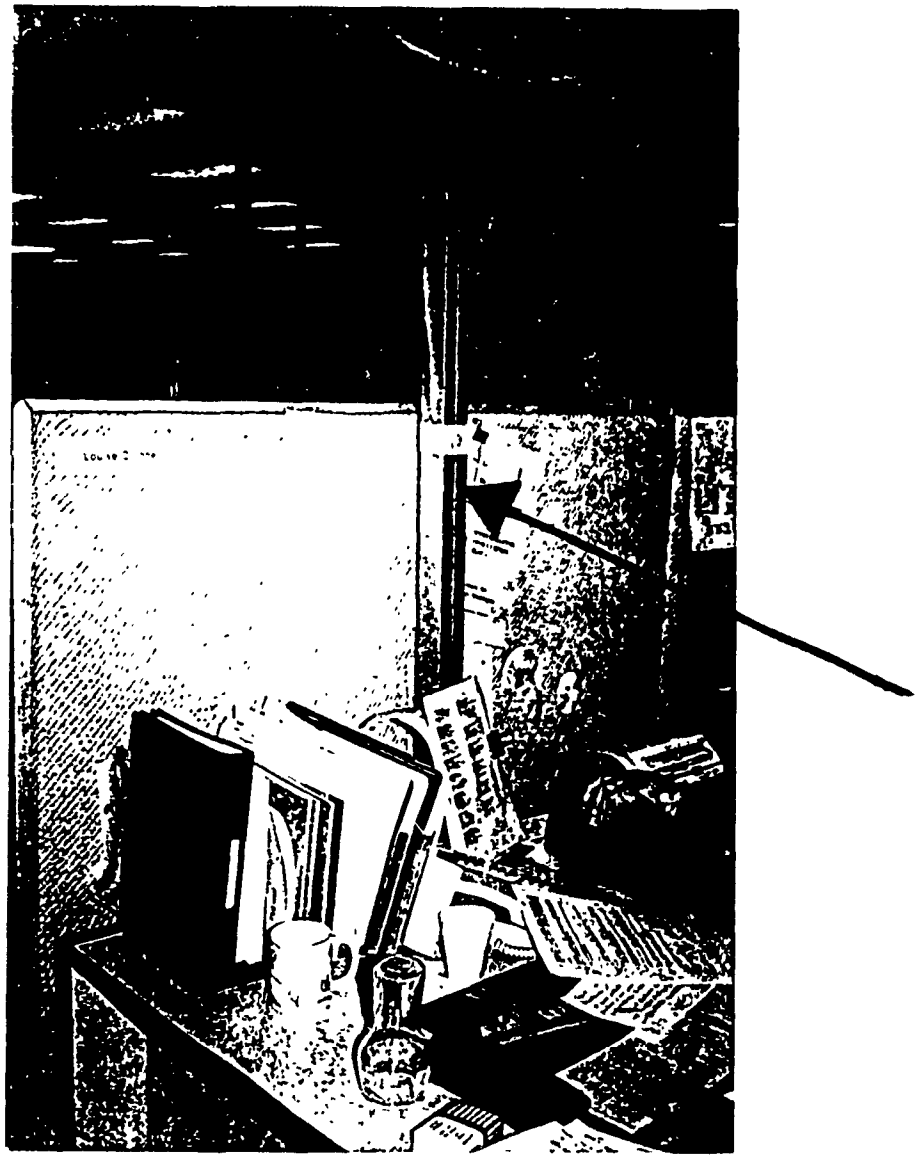


Figure 3.9 Typical $CO_2$-sensor installation

Both the $CO_2$-control system on the 8$^{th}$ floor and the conventional system on the 9$^{th}$ floor are in operation 24 hours a day, 7 days a week. If necessary, the floors

are flushed with outdoor air at 11:00 P.M., nightly, to reduce the heating load.

The ventilation systems (including only the units in the mechanical rooms, and not the supply ducts or diffusers and grilles) are cleaned with AJAX and water once a year, before the cooling periods. At this point, the mechanical rooms are also painted with oil-based paints. The diffusers are cleaned with an AJAX and water solution whenever the maintenance personnel has the time (equivalent to once a year).

# CHAPTER 4

## 4. INDOOR AIR QUALITY ANALYSIS

Considerable research has gone into DCV systems over the past 10 years. Up until 1983, most papers on DCV systems stressed energy savings and pay-back times, but it is indoor air quality that is being emphasized in more recent works.(1) The carbon dioxide control system is designed to limit the carbon dioxide level produced by the occupants in a space. The $CO_2$ level is also used as a surrogate for other contaminants produced by people or their activities. If the use of outdoor air is to be restricted with the provision that the $CO_2$ level be held below a certain limit, there must be assurance that other contaminants are also controlled at concentrations below accepted limits. The following chapter will show that the indoor air quality will not deteriorate with the use of a $CO_2$-control system (both floors had identical air quality levels before).(30)

The indoor air quality parameters studied are carbon dioxide, formaldehyde, volatile organic compounds, particles, and ventilation. These were measured for three consecutive working days, from 7:00 A.M. to 7:00 P.M., every third week of every month. The $8^{th}$ floor ($CO_2$-controlled) and the $9^{th}$ floor were monitored simultaneously.

## 4.1 Carbon Dioxide

Ten $CO_2$ sampling stations were chosen as per Figure 1.1 (stations 1 to 10). A direct reading instrument (ADC, range 0 - 5000 ppm, infrared gas analyzer) was used to measure $CO_2$ hourly. The IRSST method #34-A was followed.(86)

Since $CO_2$ levels vary throughout the day (with a minimum in the morning, a maximum in the afternoon, and a return to the minimum in the evening), only the maximum daily values will be discussed. This maximum value is the maximum of the average of all ten sampling stations for that hour. The reference level was taken outside before 7:00 A.M..

The results obtained are given in Table 4.1 and in Figure 4.1.

Table 4.1 Maximum daily $CO_2$ levels (in ppm)

| DAY 1 | | | DAY 2 | | | DAY 3 | | |
|---|---|---|---|---|---|---|---|---|
| $8^{th}CO_2$ | $9^{th}$ | ref | $8^{th}CO_2$ | $9^{th}$ | ref | $8^{th}CO_2$ | $9^{th}$ | ref |
| May 1990 | | | | | | | | |
| 564 | 849 | 380 | 482 | 662 | 390 | 780 | 822 | 410 |
| June 1990 | | | | | | | | |
| 646 | 703 | 360 | 723 | 722 | 370 | 783 | 797 | 380 |
| July 1990 | | | | | | | | |
| 579 | 537 | 390 | 558 | 585 | 410 | 526 | 516 | 370 |
| August 1990 | | | | | | | | |
| 629 | 699 | 410 | 698 | 784 | 410 | 695 | 644 | 470 |
| September 1990 | | | | | | | | |
| 600 | 542 | 370 | 788 | 674 | 440 | 574 | 635 | 370 |
| October 1990 | | | | | | | | |
| 531 | 512 | 410 | 538 | 484 | 380 | 635 | 618 | 400 |
| November 1990 | | | | | | | | |
| 502 | 472 | 390 | 484 | 489 | 390 | 508 | 518 | 390 |
| December 1990 | | | | | | | | |
| 519 | 513 | 420 | 543 | 510 | 430 | 517 | 515 | 410 |
| January 1991 | | | | | | | | |
| 549 | 509 | 400 | 486 | 457 | 370 | 453 | 465 | 360 |
| February 1991 | | | | | | | | |
| 448 | 468 | 360 | 470 | 445 | 370 | 465 | 464 | 440 |
| March 1991 | | | | | | | | |
| 471 | 481 | 380 | 488 | 653 | 390 | 460 | 409 | 370 |
| April 1991 | | | | | | | | |
| 450 | 454 | 370 | 736 | 871 | 400 | 782 | 720 | 370 |
| Standards | | | | | | | | |
| RRQWE (42) | | less than 5000 | | | | | | |
| ASHRAE (29) | | less than 1000 | | | | | | |

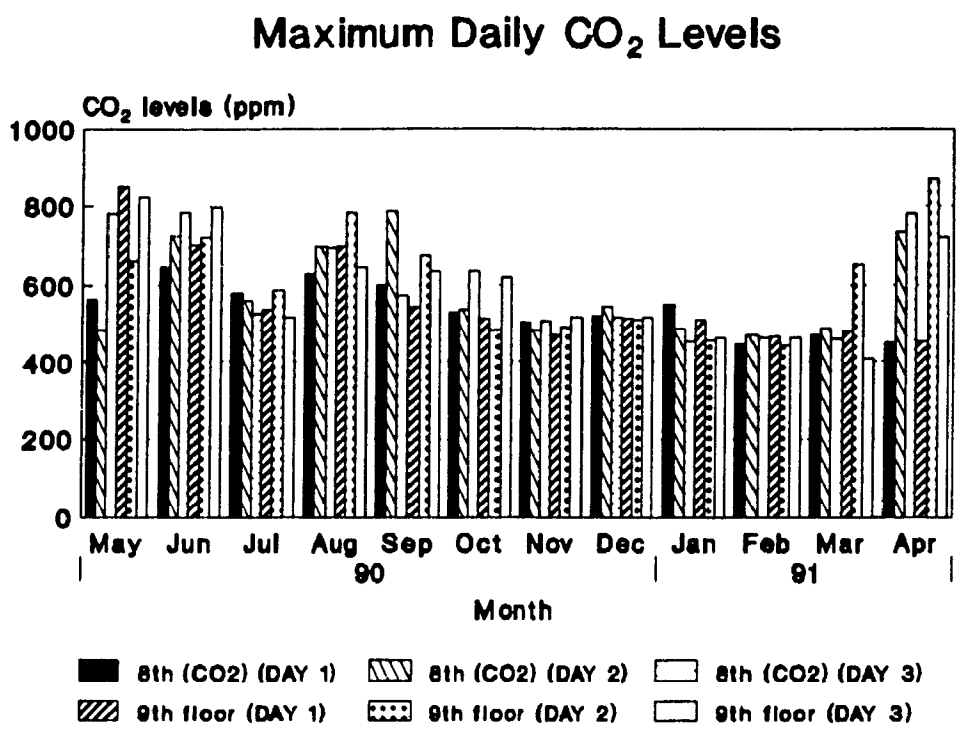



Figure 4.1 Monthly carbon dioxide results

Comparing the results to the recommended values, one can see that the carbon dioxide level during the course of the study remained well below the limits (maximum level less than 900 ppm).

All of the results which were above 600 ppm were due to the fact that the outdoor air dampers were closed and/or many visitors were present.

When comparing the maximum levels from both floors, one cannot say that one floor experienced higher levels than the other. The differences between the two floors range from 1 to 285 ppm, with an average of 51 ppm. The big differences between the two floors occurred when only one floor received a large amount of visitors.

Therefore, although the $CO_2$-run floor does not seem to keep the $CO_2$ levels much lower than on the normally-run floor, one can say that the $CO_2$-control system does not worsen the indoor air quality.

## 4.2 Formaldehyde

Three formaldehyde sampling stations were chosen as per Figure 1.1 (stations 1, 5, and 7). A sampling station was also set up outside the building for the last month. The IRSST method #216-1 was followed.(86) The formaldehyde was collected on orbo adsorbent tubes, impregnated with N-benzylethanolamine These were attached to personal air pumps sampling at a frequency of 0,5 l/min The tubes were then analyzed by gas chromatography

The results obtained are given in Table 4.2 and in Figure 4.2. The concentrations shown represent the whole sampling period of three days.

Table 4.2 Results of formaldehyde sampling (in $\mu g/m^3$)

| work station from Figure 1.1 | | | | | | | |
|---|---|---|---|---|---|---|---|
| 8th floor ($CO_2$) | | | | 9th floor | | | |
| 1 | 5 | 7 | avg | 1 | 5 | 7 | avg |
| May 1990 | | | | | | | |
| 9 | 8 | 6 | 8 | 11 | 11 | 10 | 11 |
| June 1990 | | | | | | | |
| 23 | 30 | 32 | 28 | 34 | 35 | 36 | 35 |
| July 1990 | | | | | | | |
| 30 | 28 | 29 | 29 | 27 | 36 | 26 | 30 |
| August 1990 | | | | | | | |
| 35 | 25 | 33 | 31 | 35 | 38 | 28 | 34 |
| September 1990 | | | | | | | |
| 19 | 17 | 22 | 19 | 16 | 13 | 12 | 14 |
| October 1990 | | | | | | | |
| 11 | 7 | 3 | 7 | 15 | 8 | 10 | 11 |
| November 1990 | | | | | | | |
| 17 | 17 | 14 | 16 | 14 | 14 | 13 | 14 |
| December 1990 | | | | | | | |
| 11 | 9 | 9 | 10 | 10 | 9 | 5 | 8 |
| January 1991 | | | | | | | |
| 12 | 12 | 13 | 12 | 10 | 10 | 11 | 10 |
| February 1991 | | | | | | | |
| 11 | 6 | 6 | 8 | 6 | 6 | 7 | 6 |
| March 1991 | | | | | | | |
| 14 | 17 | 16 | 16 | 17 | 11 | 15 | 14 |
| April 1991 | | | | | | | |
| 10 | 12 | 12 | 11 | 9 | 11 | 13 | 11 |
| 1 meter from building exterior 11 | | | | | | | |

| Standards | |
|---|---|
| RRQWE (42) | less than 3000 |
| ASHRAE (29) | less than 60 |

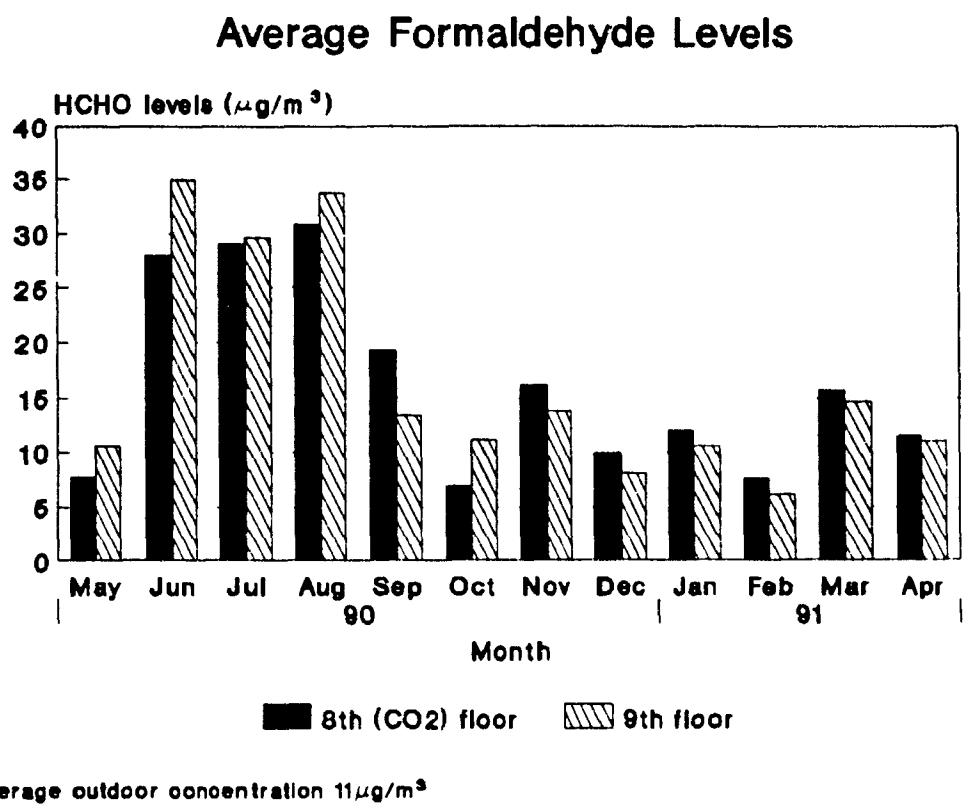



Figure 4.2 Monthly formaldehyde results

Comparing the results to the recommended values, one can see that the formaldehyde level during the course of the study remained well below the limits (maximum level approximately < 2% of the provincial regulation and < 63% of the ASHRAE recommendation).

The results found during the summer months seem to be higher than those found throughout the remainder of the year. This is most probably due to the fact that

the outdoor air dampers were closed during these warm months.

When comparing the average concentrations from both floors, one cannot say that one floor experienced higher levels than the other. The differences between the two floors range from 0 to 7 $\mu g/m^3$, with an average of 3 $\mu g/m^3$.

Therefore, although the $CO_2$-control does not result in lower formaldehyde levels, one can say that the $CO_2$-control system does not worsen the indoor air quality.

## 4.3 Volatile Organic Compounds

Three VOC sampling stations were chosen as per Figure 1.1 (stations 1, 5, and 7). The IRSST method #80-1 was used.(86) The VOCs were collected on activated charcoal tubes attached to personal air pumps sampling at a frequency of 0,2 l/min. These were then analyzed by gas chromatography.

The results obtained are given in Table 4.3 and in Figure 4.3. The concentrations shown represent the whole sampling period of three days. The concentrations represent the total hydrocarbons found (using stoddard solvent as the indicator).

Table 4.3 Results of VOC sampling (in mg/m$^3$)

| work station from Figure 1.1 | | | | | | | |
|---|---|---|---|---|---|---|---|
| 8th floor ($CO_2$) | | | | 9th floor | | | |
| 1 | 5 | 7 | avg | 1 | 5 | 7 | avg |
| May 1990 | | | | | | | |
| t d * | 1,7 | 1,9 | 1,8 | 14,3 | 9,7 | 5,0 | 9,7 |
| June 1990 | | | | | | | |
| 8,4 | 8,3 | 6,1 | 7,6 | 22,5 | 19,5 | 9,9 | 17,3 |
| July 1990 | | | | | | | |
| 5,5 | 3,0 | 2,1 | 3,5 | 4,3 | 5,0 | 5,1 | 4,8 |
| August 1990 | | | | | | | |
| 8,2 | 8,2 | 3,1 | 6,5 | 9,3 | 11,3 | 7,5 | 9,3 |
| September 1990 | | | | | | | |
| 11,9 | 2,9 | 4,9 | 6 6 | 5,2 | 8,1 | 5,0 | 6,1 |
| October 1990 | | | | | | | |
| 2,9 | 2 3 | 0,0 | 1,7 | 4,0 | 6,2 | 3,0 | 4,4 |
| November 1990 | | | | | | | |
| 1,7 | 1 5 | 0 3 | 1 1 | 2,1 | 3,6 | 1,3 | 2 3 |
| December 1990 | | | | | | | |
| 2,5 | 1,6 | 0,5 | 1,5 | 2,0 | 3,0 | 0,8 | 1,9 |
| January 1991 | | | | | | | |
| 3,4 | 2 3 | 0,7 | 2,1 | t d | 5,9 | 4,8 | 5,4 |
| February 1991 | | | | | | | |
| 1,3 | 1,7 | 0,3 | 1 1 | 1,6 | 5,7 | 2 1 | 3,1 |
| March 1991 | | | | | | | |
| 2,2 | 1,4 | 0,5 | 1,4 | 0,7 | 5,1 | 2,0 | 2,6 |
| April 1991 | | | | | | | |
| 6,5 | 3,6 | 4,0 | 4,7 | 4,8 | 8,0 | 6,5 | 6,4 |
| Standards | | | | | | | |
| RRQWE (42) | | | less than 575 of stoddard solvent for total hydrocarbons | | | | |
| ASHRAE (29) | | | less than 52,5 of stoddard solvent for total hydrocarbons | | | | |

* technical difficulty

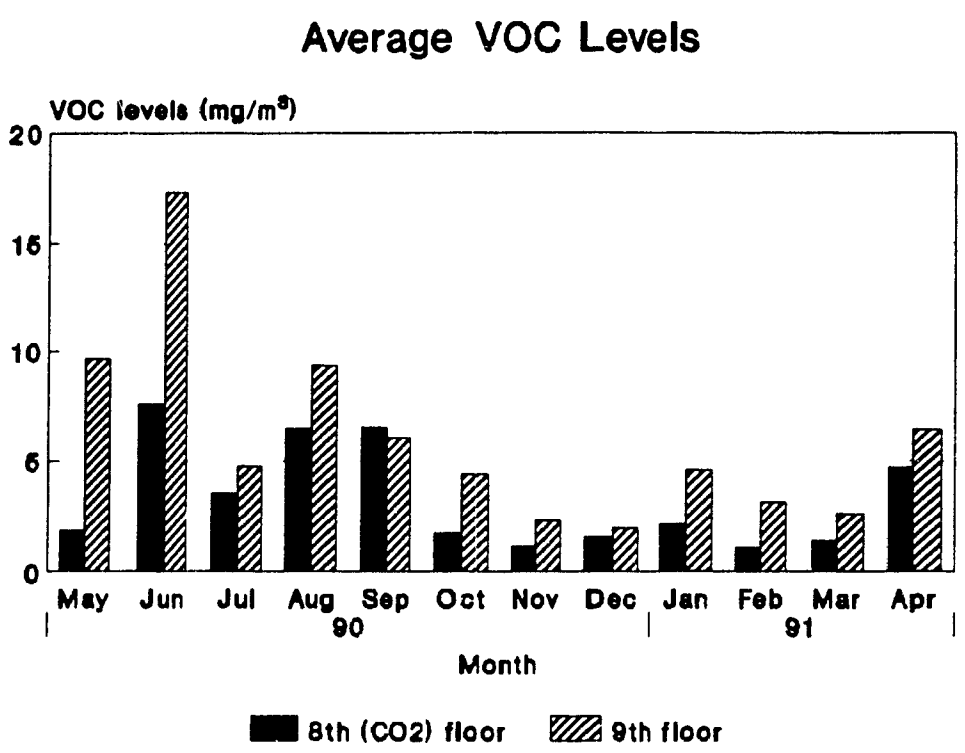



Figure 4.3 Monthly VOC results

Comparing the results to the recommended values, one can see that the VOC levels during the course of the study remained well below the limits (maximum stoddard solvent levels approximately < 3% of the provincial regulation, and < 43% of the ASHRAE recommendation).

The results found during the summer months seem to be higher than those found throughout the remainder of the year. This is most probably due to the fact that

the outdoor air dampers were closed during these warm months, as has been seen in previous work.(59) Indoor air VOC concentrations tend to increase very quickly as ventilation decreases below a rate within the range of 0,6 to 1,2 ach.(60) This can be validated by comparing the VOC results found above, and the air change rates in Table 4.5. The highest VOC concentrations were found when the air change rates were below 0,9 ach Furthermore, these data correspond to the highest relative humidity readings (see Table 5.1). This would suggest that VOC concentration is proportional to the relative humidity, unlike what has been found in previous works (56) They suggested that the concentration of some VOC's was inversely proportional to the relative humidity The correlation was attributed to the effect of air humidity on the emission from materials. This does not seem to be the case in this research work

When comparing the average concentrations from both floors, one can see that the 9$^{th}$ floor consistently experienced slightly higher levels than the 8$^{th}$ ($CO_2$) floor The differences between the two floors range from 0,4 to 9,7 mg/m$^3$, with an average of 2,9 mg/m$^3$.

Since the $CO_2$-control does result in slightly lower VOC levels, one can say that the $CO_2$-control system does not worsen the indoor air quality

## 4.4 Particles

Three dust sampling stations were chosen as per Figure 1.1 (stations 1, 5, and 7). Two sampling stations were also set up outside the building for the last month. The IRSST method #48-1 was followed.(86) Personal air pumps at about 1,5 l/min air flow rates with pre-weighed filters were used to collect total dust. The filters were then weighed in a laboratory.

The results obtained are given in Table 4.4 and in Figure 4.4. The concentrations shown represent the whole sampling period of three days.

Table 4.4 Results of total dust sampling (in $\mu g/m^3$)

| work station from Figure 1.1 | | | | | | | |
|---|---|---|---|---|---|---|---|
| 8th floor ($CO_2$) | | | | 9th floor | | | |
| 1 | 2 | 3 | avg | 1 | 2 | 3 | avg |
| May 1990 | | | | | | | |
| 25 | 34 | 12 | 24 | 19 | 31 | 32 | 27 |
| June 1990 | | | | | | | |
| 32 | 43 | t d * | 25 | t d | 26 | 40 | 22 |
| July 1990 | | | | | | | |
| 14 | 0** | 0 | 5 | 0 | 0 | 13 | 4 |
| August 1990 | | | | | | | |
| 7 | 16 | 17 | 13 | 12 | 23 | 3 | 13 |
| September 1990 | | | | | | | |
| 13 | 19 | 0 | 11 | 6 | 16 | 9 | 10 |
| October 1990 | | | | | | | |
| 7 | 21 | 18 | 15 | 8 | t d | 24 | 22 |
| November 1990 | | | | | | | |
| 5 | 45 | 18 | 23 | 18 | 29 | 16 | 21 |
| December 1990 | | | | | | | |
| 22 | 16 | 30 | 23 | 20 | 12 | 11 | 14 |
| January 1991 | | | | | | | |
| 17 | 25 | 30 | 24 | 16 | 38 | 15 | 23 |
| February 1991 | | | | | | | |
| 32 | 18 | 33 | 28 | 0 | 25 | 25 | 17 |
| March 1991 | | | | | | | |
| 73 | 45 | 101 | 73 | 0 | 28 | 35 | 21 |
| April 1991 | | | | | | | |
| 14 | 22 | 13 | 16 | 6 | 17 | 9 | 11 |
| 0,3 meters before outdoor air dampers = 74 | | | | 1 meter from building exterior = 36 | | | |

| Standards | |
|---|---|
| RRQWE (42) | less than 10 000 |
| ASHRAE (29) | less than 40 |

* technical difficulty

** 0 denotes not detected

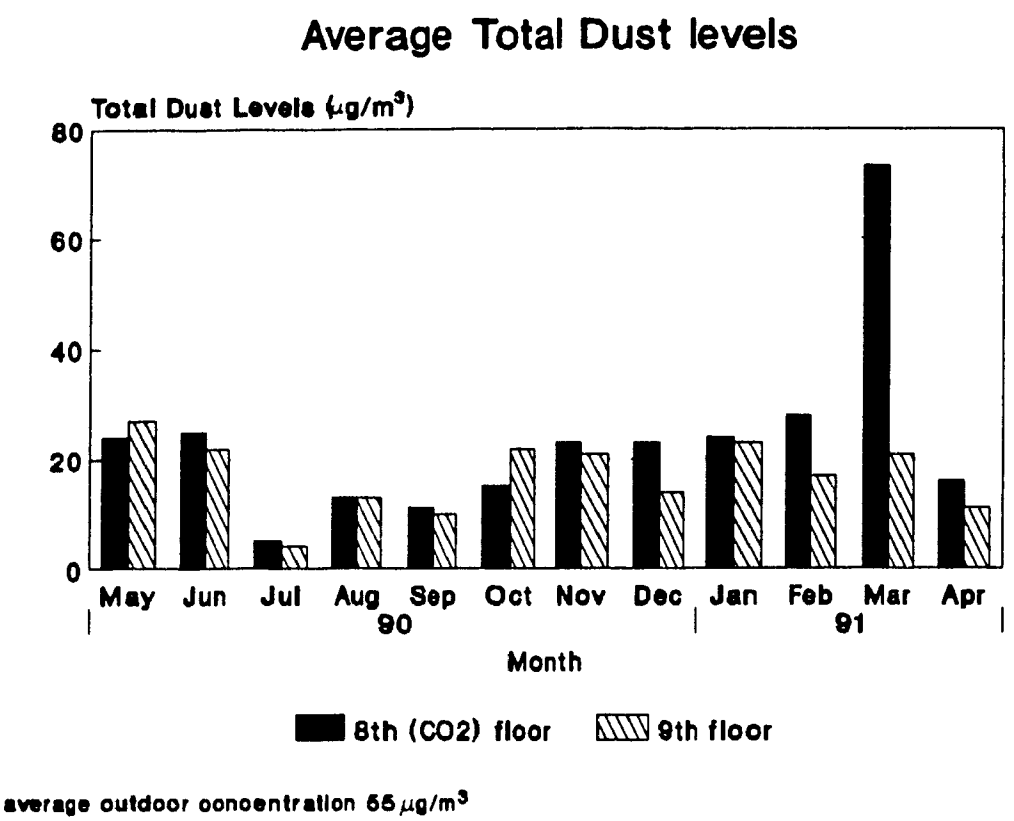



Figure 4.4 Monthly dust results

Comparing the results to the recommended values, one can see that the total dust level during the course of the study remained well below the provincial regulation (maximum level approximately < 4%). However, the ASHRAE recommendation was surpassed on six out of 72 occasions, with the maximum level being approximately 2 times the limit.

The two sampling stations that were set up outside (for the last month) showed relatively elevated dust levels; indicating that the dust is originally in the outdoor air, and depends mainly on the filters in the HVAC system to be removed. The high values in the work zones could be a result of an inefficient filtration system. The concentration of particles in the indoor air tends to increase as more outdoor air is used.(25) However, this correlation cannot be extrapolated from the above data. There does not seem to be any variation in the results throughout the year (except for an inexplicable high value during the month of March 1991), even though there was a large variation in the amount of outdoor air being supplied (as seen in Table 4.5).

The City of Montreal's environmental department was contacted to acquire information on exterior contaminant levels. For the dust concentration in outdoor air, at their closest sampling station to this building, an average level of 56 $\mu g/m^3$ was found in 1989.(87) The data for later dates unfortunately is not yet available. However, comparing this value with the data, one can see that it is relatively equivalent to what was sampled during the month of April, outdoors.

When comparing the average concentrations from both floors, one can see that the 8$^{th}$ ($CO_2$-control) floor consistently experienced slightly higher levels than the 9$^{th}$ floor. The differences between the two floors range from 0 to 52 $\mu g/m^3$, with an average of 8 $\mu g/m^3$.

Therefore, the $CO_2$-control does result in slightly higher total dust levels. However, this may attributed to an inefficient filtration system.

## 4.5 Ventilation

The tracer gas decay technique was used to measure air change rates during our monthly testing periods. The 9th floor was tested on the first of three days, while the 8th was tested on the third; to avoid any interzonal problems. Approximately four litres of sulphur-hexafluoride ($SF_6$) were injected at the outdoor air dampers of the floor under study. A mixing period of about 30 minutes was allotted. Air samples were then taken at 5 locations throughout the floor (stations 1, 3, 5, 7, and 9, from Figure 1.1), in 9 continuous sequences, so as to average a time period of about 8 minutes between sequences (a total of about 80 minutes of sampling). These air samples were then sent to a laboratory for the $SF_6$ concentration.

This method of calculating the rate of indoor-outdoor air exchange does not differentiate between the mechanisms of exchange (mechanical or infiltration) but includes both.

The results of the tracer gas decay method are given in Table 4.5 and in Figure 4.5. The air changes shown represent the average of the air changes found throughout the five sampling stations. These air change rates are applicable to the total three-day sampling periods since it was noted that the outdoor air dampers remained almost always fixed throughout the three testing days.

Table 4.5 Average air change rates per hour

| month | $8^{th}$ $(CO_2)$ | $9^{th}$ floor |
|---|---|---|
| May 1990 | 1,7 | 1,7 |
| June 1990 | 0,7 | 0,4 |
| July 1990 | 0,6 | 0,4 |
| August 1990 | 0,7 | 0,4 |
| September 1990 | 0,8 | 3,1 |
| October 1990 | 0,9 | 3,0 |
| November 1990 | 2,6 | 2,5 |
| December 1990 | 2,8 | 2,3 |
| January 1991 | 2,3 | 2,2 |
| February 1991 | 2,8 | 2,4 |
| March 1991 | 3,0 | 2,6 |
| April 1991 | 0,8 | 3,0 |
| AVERAGE OF YEAR | 1,6 | 2,0 |

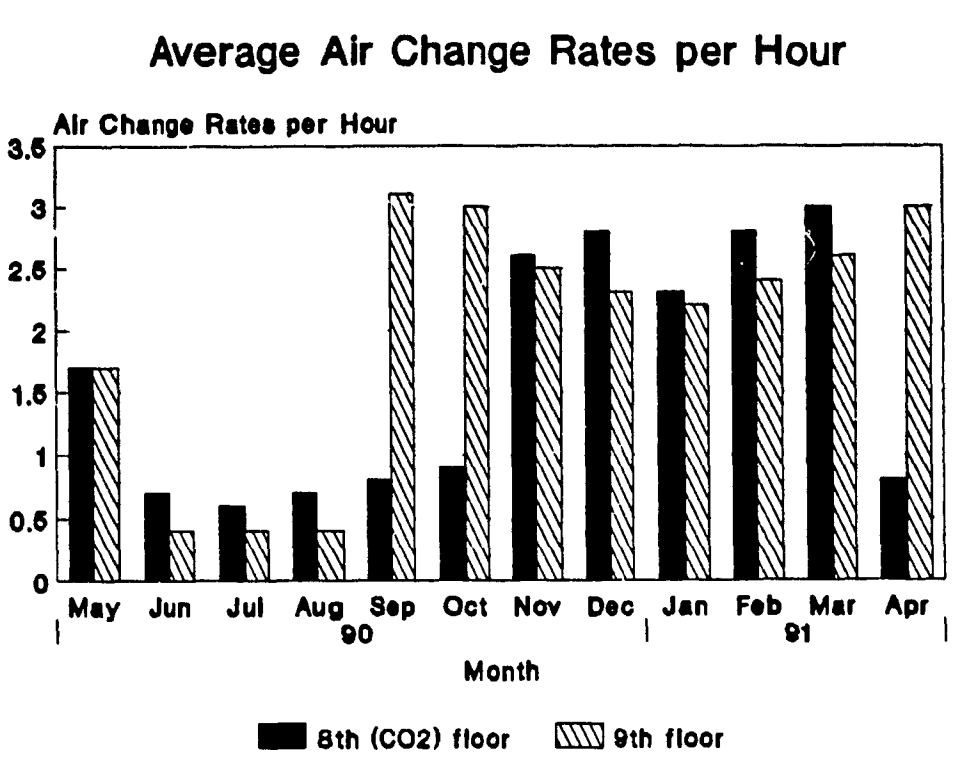



Figure 4.5 Monthly air change rates

To arrive at the actual outdoor air flow rates being supplied, one would multiply the air change rate by the volume being supplied, with the proper time and volume conversions. For example, for an air change rate of 1,7 ach, the flow rate would be $(1,7\ h^{-1})(5400\ m^3)(1000\ l/m^3)/(3600\ s/h) = 2550\ l/s$. Because the building is open to the public, it is not possible to arrive at the actual rate per person. However, if one were to assume that there are approximately 100 people per floor, one would arrive at 26 l/s/person. To satisfy the standards, the RRQWE limit

of 2,4 l/s/person, at 100 people, would ask for a minimum air change rate of 0,16 ach; the ASHRAE limit of 10 l/s/person would have a value of 0,67 ach. Both space requirements are satisfied, with 100 people/1800 $m^2$ (maximum 126 people per 1800 $m^2$ for ASHRAE; and maximum 180 people per 1800 $m^2$ for RRQWE).

From the results, one can see that there is sufficient amount of outdoor air most of the time, except for the summer months (with respect to ASHRAE). The RRQWE limit was always satisfied. However, it must be noted that this is assuming 100 people are present per floor. During the summer, at least 2/3 of the workers are on vacation, so the low air change rates would still satisfy ASHRAE since there are less people to supply air to.

The air change rates found during the summer months are much lower than those found throughout the remainder of the year. This is due to the fact that the outdoor air dampers were closed during these warm months. The $CO_2$ levels were low on the 8$^{th}$ floor, and the 9$^{th}$ floor dampers closed to keep the cooling demand low. The 8$^{th}$ ($CO_2$-controlled) floor dampers also remained closed during the spring and fall seasons, whereas the 9$^{th}$ floor dampers opened to allow for free-cooling. During the fall, the $CO_2$ levels surpassed the control set-point on certain occasions, however the temperature control system (installed by the building owner) overrode the $CO_2$ control. Both floors had opened dampers during the winter-time due to excessive heat gains in the occupied spaces.

When comparing the average air change rates from both floors, one can see that the 8th ($CO_2$) floor consistently experienced slightly higher levels than the 9th floor (excluding the months of September, October, and April). The differences between the two floors range from 0 to 2,3 ach, with an average of 0,7 ach. The reason for this is most probably due to a higher leakage rate through the dampers of the 8th ($CO_2$) floor.(30)

However, the larger air change rates on the 9th floor during the months of September, October, and April compensate for the rest of the year. The 8th ($CO_2$) floor still yields a lower annual average air exchange rate than the 9th floor; proving that the $CO_2$-control system does eliminate excessive ventilation.

## 4.6 System Performance

The following table shows a summary of the $CO_2$-control system performance.

Table 4.6 $CO_2$-control system performance

| MONTH | $CO_2$-control readings | ACTION |
|---|---|---|
| May 1990 | all below 600 ppm | no action |
| June 1990 | all below 600 ppm | no action |
| July 1990 | all below 600 ppm | no action |
| August 1990 | all below 600 ppm | no action |
| September 1990 | all below 600 ppm<br>except:<br>-maximum average of 620 ppm for a maximum time of 20 minutes | no action |
| October 1990 | all below 600 ppm<br>except:<br>-maximum average of 630 ppm for a maximum time of 50 minutes | no action |
| November 1990 | all below 600 ppm<br>except:<br>-maximum average of 635 ppm for a maximum time of one hour | no action |
| December 1990 | all below 600 ppm | no action |
| January 1991 | all below 600 ppm | no action |
| February 1991 | all below 600 ppm | no action |
| March 1991 | all below 600 ppm | no action |
| April 1991 | all below 600 ppm<br>except:<br>-maximum average of 640 ppm for a maximum time of 50 minutes | no action<br>except:<br>-dampers opened for a maximum time of 40 minutes due solely to the control system when the sensors read from 600 to 640 ppm |

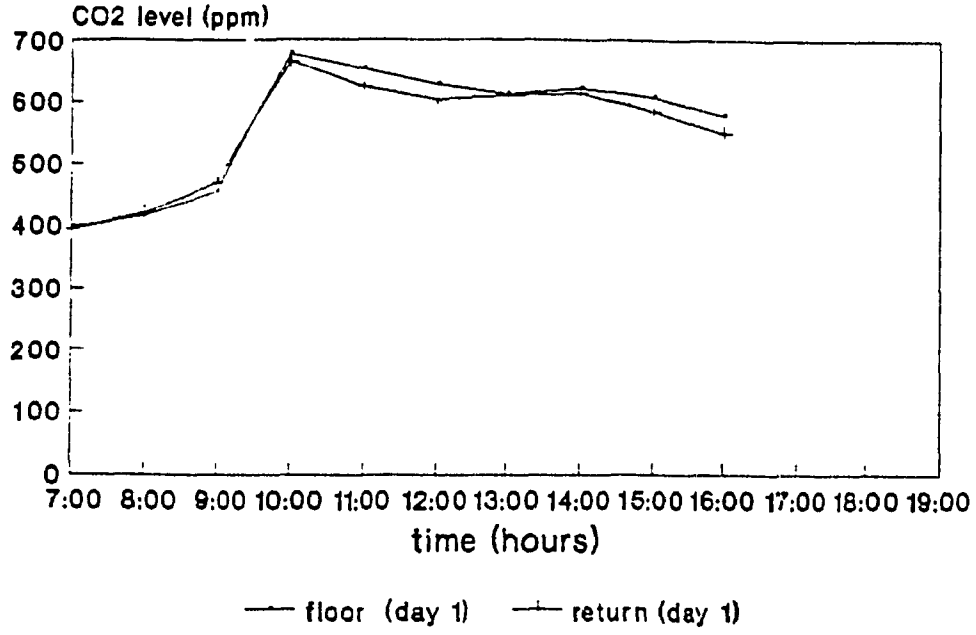
As can be seen from the above summary, the $CO_2$ monitor almost never gave the signal for the dampers to open. This was mainly due to the low $CO_2$ concentrations in the space; as seen in Table 4.1.

During the months of May, June, and August, the levels found in Table 4.1 (as read by a direct reading instrument during our monthly visits) were higher than those detected by the $CO_2$-control monitor. This could be due to the functioning of the monitor itself; although levels at the work-stations were above 600 ppm some of the time, the level was not maintained long enough for the control monitor to detect it and to react to it. A greater response would have been generated with a greater occupation density.

During the months of September, October, and November, the $CO_2$-control monitor did detect higher $CO_2$ levels, however, no action signal was sent to the outdoor air dampers. On these particular occasions, the temperature control system (installed by the building owner) overrode the $CO_2$ control. According to the temperature sensor in the supply duct, the interior temperature was not satisfactory. Even though the $CO_2$-control monitor did not control the dampers as was expected or wished, during this time, the system was still able to keep the $CO_2$ levels below the ASHRAE recommended limit of 1000 ppm; as seen in Table 4.1.

## 4.7 Optimum Sensor Location

Following, in Figure 4.6, are some representative plots of carbon dioxide levels measured in the main return/exhaust duct, and in the work zones (average of ten stations).



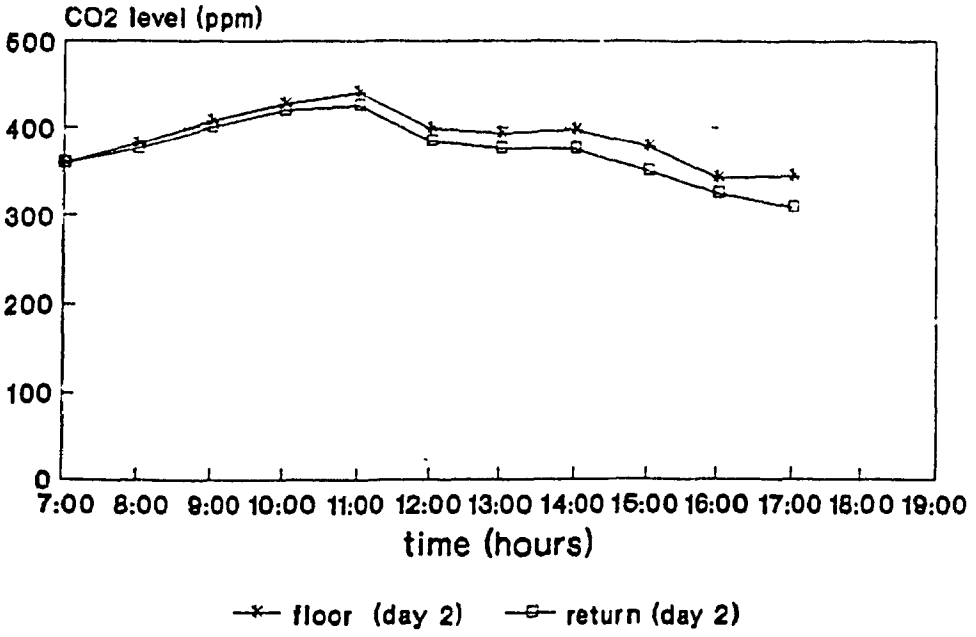
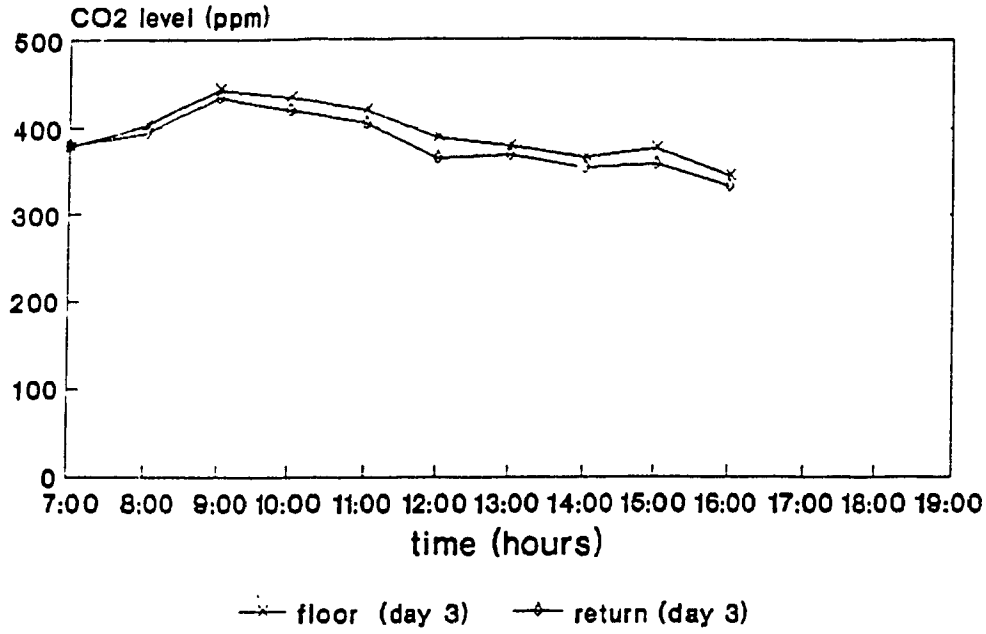




Figure 4.6 Typical carbon dioxide levels



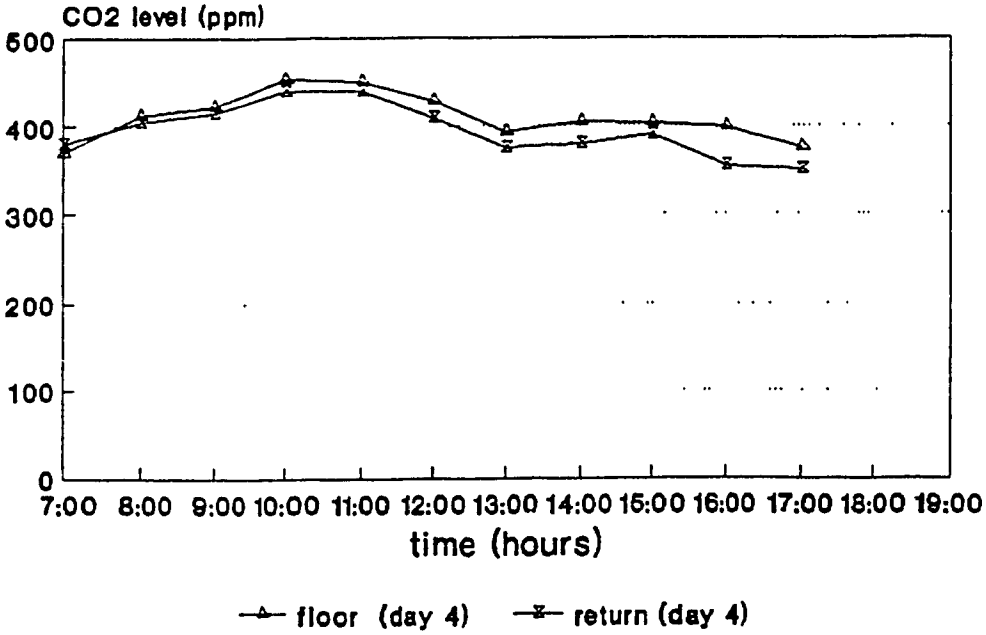




Figure 4.6 (cont'd)

One can see that the $CO_2$ measured in the work zones is somewhat greater than the $CO_2$ in the main return duct. The optimum sensor location for the $CO_2$-control system would be in the critical work zones, at breathing level, where one would detect the higher $CO_2$ level. The return duct eventually contains only a diluted average of what is found at the work-stations. However, as is the case in this building, placing the sensors in the return duct would probably have given adequate responses. Care must be taken to ensure that the sensor would still be able to function under such high velocities; so the control sensor, if placed in the return duct, should be placed away from the return fan (to avoid high velocities and turbulence).

A reason why the return duct levels were similar to those in the work zones is probably the fact of the low occupant density. It could also be due to the fact that there is adequate movement of air in the space; resulting in a good mixture of old and new air.(30) However, if this were not the case, and the air was not adequately mixed throughout the zone, one might experience very high $CO_2$ levels at the work station, compared to a low $CO_2$ level in the return duct.

The location of the sensor must be chosen with care. It must be located away from excessive air draughts; the monitor would not be able to detect the correct $CO_2$ level since the air would not remain around the sensor long enough.

On the other hand, the sensor should not be located in areas where there is no air movement, for example, where the air is stagnant, and is not adequately evacuated from the space. In this type of location, the $CO_2$ monitor would continuously detect elevated levels of $CO_2$, resulting in continuous signals to open the dampers, resulting in over-ventilation and excessive energy consumption. No matter how much fresh air is being supplied, none of it will reach this stagnant area, so the $CO_2$ level being detected would never change. In this case, this particular stagnant area would have to be treated separately.

If it is assumed that there is a good mixture of air in the work zone, the sensors should be placed in typical work-stations.

## 4.8 Conclusions

The indoor air quality parameters studied are carbon dioxide, formaldehyde, volatile organic compounds, particles, and ventilation. These were measured for three working days, every third week of every month. The 8$^{th}$ floor ($CO_2$-controlled) and the 9$^{th}$ floor were monitored simultaneously. The system performance was also discussed, as was the optimum sensor location.

All of the contaminant concentrations satisfied the applicable standards and regulations:

1) the maximum $CO_2$ level was less than 85% of the ASHRAE recommendation of 1000 ppm;

2) the maximum formaldehyde concentration was less than 63% of the ASHRAE recommendation of 60 $\mu g/m^3$;

3) the maximum VOC concentration was less than 43% of the ASHRAE recommendation of 52,5 $mg/m^3$; and

4) the average total dust concentration was less than the ASHRAE recommendation, however the individual sampling stations surpassed it six times out of 72 (maximum level being about twice as high as the limit of 40 $\mu g/m^3$). However, the maximum level was less than 4% of the provincial regulation.

Since most of the results are within the ASHRAE recommended limits, it is not necessary to produce detailed statistical analysis of the differences between the two floors. It is not the difference that is important in this work, but the fact that the ASHRAE limits are respected.

The $CO_2$-control system does not worsen the quality of the air. From previous work, it was found that both floors experienced equivalent levels of the various contaminants.(30) After implementation of the control system, the 8$^{th}$ ($CO_2$) floor did not experience worst conditions than the 9$^{th}$ floor:

1) when comparing the maximum $CO_2$ levels and the average formaldehyde concentrations from both floors, no floor experienced higher levels;

2) when comparing the average VOC concentrations from both floors, the 9$^{th}$ floor consistently experienced slightly higher levels than the 8$^{th}$ ($CO_2$) floor;

3) when comparing the average total dust concentrations from both floors, the 8$^{th}$ ($CO_2$) floor consistently experienced slightly higher levels than the 9$^{th}$ floor; and

4) when comparing the average air change rates from both floors, the 8$^{th}$ ($CO_2$) floor consistently experienced slightly higher levels than the 9$^{th}$ floor, due to a higher leakage rate through the dampers of the 8$^{th}$ ($CO_2$) floor.(30) However, the 8$^{th}$ ($CO_2$) floor still yields a lower annual air exchange rate than the 9$^{th}$ floor; proving that the $CO_2$-control system does eliminate excessive ventilation.

Therefore, the indoor air quality does not seem to worsen with the $CO_2$-controlled system as compared to the outdoor temperature-controlled system.

This control system can be used in the office environment, as long as the occupation density is great enough to generate a response from the control monitor. The $CO_2$-control set-points must be low enough so that they satisfy the present air quality standards and comfort recommendations.

Some papers dealt with $CO_2$ versus temperature control, with the temperature control being dominant.(13) It was shown that the temperature control was dominant when the outdoor temperature was above 10°C. When the temperature dropped, the $CO_2$ sensor called for more air first. This was not the case for this project, where the controlling sensors were not parallel, but in sequence (the supply air temperature being dominant). In this work, the temperature sensor overrode the $CO_2$-control during the months of September, October, and November, indicating that this particular building had more severe thermal needs than large occupant-generated $CO_2$ levels during this period.

The optimum sensor location would be at the critical work-station, however, placement in the return duct would also produce adequate results in this particular case due to the good air movement in the work zone (effective replacement of old air with new air was indicated by the uniformity of the $CO_2$

levels throughout the work zone).(30)

Since this study was done by comparing two floors simultaneously (and not sequentially), the results shown reflect the true differences between two outdoor air control systems ($CO_2$ versus exterior temperature). Previous work has only been able to study the differences sequentially.(1)

# CHAPTER 5

## 5. THERMAL COMFORT ANALYSIS

Ventilation of indoor spaces with outdoor air is one of the main means one has of controlling contaminant levels in the indoor air. It has been shown in the previous chapter that a $CO_2$-controlled system does not deteriorate the indoor air quality of the work zone. However, there must also be assurance that the thermal comfort does not worsen. The following chapter will show that the thermal comfort will not deteriorate with the use of a $CO_2$-control system (both floors had identical thermal comfort levels before).(30)

The thermal comfort parameters studied are dry-bulb and operative temperatures, relative humidity, air diffusion performance index, vertical temperature gradients, air velocities, and global thermal comfort indices. These were measured for three working days, every third week of every month. The $8^{th}$ floor ($CO_2$-controlled) and the $9^{th}$ floor were monitored simultaneously.

## 5.1 Temperature and Relative Humidity

Nine temperature and relative humidity stations were chosen as per Figure 1.1 (stations 1 to 6, and 8 to 10). A direct reading instrument (Bruël & Kjaer Thermal Comfort Meter Type 1212) was used to measure operative temperature, for 20 minutes per station. These were coupled with relative humidity and dry bulb temperature readings taken with an Air-Probe YA-100-Hygromer by Rotronic Instrument Corp.. This direct reading instrument includes a temperature sensor (RTD Pt-100 Ohm, range: -30 to +70°C) and a relative humidity sensor (Rotronic Hygromer C-80, range: 0 to 100% Rh). The 8th and 9th floor readings were taken sequentially. Due to the unavailability of several of these instruments, and lack of technical help, it was not possible to take readings continuously. However, it was found in previous works, that these parameters were uniform throughout the working zone, and that hourly variations were minimal.(30) So, the stations were monitored sequentially, throughout the three working days each month. The readings were taken in the following order:

| day | time | station |
|---|---|---|
| 1 | 2:30 PM | 8 |
| | 3:10 PM | 7 |
| 2 | 10:00 AM | 4 |
| | 10:40 AM | 3 |
| | 2:00 PM | 9 |
| | 2:40 PM | 6 |
| 3 | 1:30 PM | 1 |
| | 2:10 PM | 2 |
| | 2:50 PM | 5 |

Therefore, the results shown in Table 5.1 are the instantaneous values. These are assumed to be representative of the whole floor, for the whole testing period.(30) Furthermore, it was assumed that the occupants were clothed in typical seasonal clothing, and that their work was mainly sedentary, to be able to compare the results with the existing standards.

Table 5.1 Operative temperature, dry-bulb temperature, and relative humidity readings (°C/°C/%)

| | work station from Figure 1.1 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 8 | 9 | 10 |
| May 1990 | | | | | | | | | |
| | | | | | $8^{th}$ ($CO_2$) floor | | | | |
| $T_o$ | 22,7 | 24,5 | 24,3 | 22,5 | 24,9 | 23,5 | 23,9 | 24,3 | 23,9 |
| $T_{db}$ | 22,3 | 23,2 | 23,1 | 21,8 | 23,6 | 22,9 | 25,6 | 24,0 | 23,1 |
| rH | 30,5 | 30,1 | 27,4 | 29,1 | 29,8 | 26,5 | 23,8 | 27,0 | 27,6 |
| | | | | | $9^{th}$ floor | | | | |
| $T_o$ | 23,5 | 24,5 | 24,5 | 23,1 | 24,9 | 23,0 | 22,4 | 23,5 | 24,0 |
| $T_{db}$ | 22,8 | 23,5 | 22,9 | 22,5 | 23,8 | 22,2 | 21,8 | 22,7 | 23,2 |
| rH | 30,8 | 31,1 | 27,8 | 29,6 | 31,2 | 30,3 | 30,7 | 29,4 | 28,0 |
| June 1990 | | | | | | | | | |
| | | | | | $8^{th}$ ($CO_2$) floor | | | | |
| $T_o$ | 24,0 | 24,2 | 25,3 | 23,6 | 24,0 | 27,8 | 23,1 | 26,5 | 25,7 |
| $T_{db}$ | 22,5 | 22,9 | 23,7 | 23,9 | 23,1 | 24,2 | 23,3 | 22,1 | 23,1 |
| rH | 46,4 | 45,6 | 39,6 | 38,5 | 44,3 | 44,8 | 42,3 | 43,5 | 44,0 |
| | | | | | $9^{th}$ floor | | | | |
| $T_o$ | 25,5 | 24,4 | 25,7 | 24,8 | 26,8 | 26,1 | 26,5 | 26,6 | 24,2 |
| $T_{db}$ | 23,1 | 23,2 | 23,7 | 23,3 | 23,4 | 24,1 | 24,0 | 23,0 | 23,3 |
| rH | 41,3 | 41,3 | 39,4 | 40,2 | 40,4 | 42,5 | 42,6 | 41,0 | 42,3 |
| July 1990 | | | | | | | | | |
| | | | | | $8^{th}$ ($CO_2$) floor | | | | |
| $T_o$ | 26,5 | 25,6 | 25,0 | 24,8 | 24,0 | 24,1 | 24,3 | 24,4 | OR* |
| $T_{db}$ | 24,2 | 23,8 | 24,1 | 24,3 | 23,4 | 22,5 | 23,8 | 22,5 | 22,1 |
| rH | 39,1 | 40,0 | 42,3 | 40,1 | 35,6 | 42,6 | 39,0 | 43,3 | 45,1 |
| | | | | | $9^{th}$ floor | | | | |
| $T_o$ | 25,6 | 24,9 | 25,3 | 25,0 | 25,3 | 25,2 | 25,1 | 24,7 | 25,0 |
| $T_{db}$ | 24,0 | 24,0 | 24,2 | 23,6 | 24,6 | 24,2 | 23,7 | 23,0 | 23,7 |
| rH | 39,2 | 38,6 | 41,1 | 42,5 | 37,2 | 41,3 | 41,8 | 43,9 | 43,3 |

| | work station from Figure 1.1 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 8 | 9 | 10 |
| August 1990 | | | | | | | | | |
| $8^{th}$ ($CO_2$) floor | | | | | | | | | |
| $T_o$ | 24,5 | 25,4 | 24,8 | 23,6 | 26,6 | 26,8 | 25,2 | 26,3 | 26,4 |
| $T_{db}$ | 24,2 | 24,2 | 23,3 | 23,3 | 26,1 | 25,5 | 24,2 | 25,6 | 25,2 |
| rH | 40,2 | 40,6 | 31,9 | 39,5 | 37,1 | 33,3 | 39,3 | 37,6 | 38,3 |
| $9^{th}$ floor | | | | | | | | | |
| $T_o$ | 25,7 | 25,7 | 25,3 | 24,1 | 25,9 | 26,7 | 25,7 | 25,7 | 25,6 |
| $T_{db}$ | 24,0 | 23,7 | 23,6 | 22,8 | 24,8 | 24,6 | 24,4 | 24,5 | 24,2 |
| rH | 40,6 | 41,8 | 33,1 | 37,2 | 40,0 | 37,4 | 37,5 | 40,9 | 41,1 |
| September 1990 | | | | | | | | | |
| $8^{th}$ ($CO_2$) floor | | | | | | | | | |
| $T_o$ | 23,6 | 24,5 | 23,8 | 23,5 | 24,4 | 23,9 | 23,1 | 22,4 | 23,8 |
| $T_{db}$ | 23,1 | 22,6 | 21,8 | 23,3 | 22,8 | 23,0 | 23,0 | 21,3 | 22,3 |
| rH | 35,9 | 33,3 | 30,4 | 30,3 | 30,2 | 26,8 | 29,6 | 31,8 | 28,0 |
| $9^{th}$ floor | | | | | | | | | |
| $T_o$ | 24,7 | 25,6 | 24,2 | 23,8 | 24,2 | 24,7 | 23,8 | 24,4 | 25,0 |
| $T_{db}$ | 22,8 | 23,4 | 22,6 | 22,4 | 22,8 | 23,5 | 23,6 | 23,0 | 22,9 |
| rH | 34,9 | 33,8 | 28,9 | 30,0 | 41,1 | 23,5 | 24,4 | 29,8 | 28,0 |
| October 1990 | | | | | | | | | |
| $8^{th}$ ($CO_2$) floor | | | | | | | | | |
| $T_o$ | 22,3 | 24,4 | 24,6 | 23,4 | 24,1 | 25,0 | 22,2 | 22,6 | 24,2 |
| $T_{db}$ | 21,5 | 23,1 | 23,6 | 23,1 | 22,8 | 24,2 | 22,1 | 21,7 | 23,0 |
| rH | 32,5 | 30,8 | 28,9 | 29,3 | 30,5 | 26,3 | 28,2 | 31,7 | 30,1 |
| $9^{th}$ floor | | | | | | | | | |
| $T_o$ | 23,4 | 24,4 | 24,5 | 23,2 | 24,1 | 25,4 | 25,2 | 25,0 | 25,0 |
| $T_{db}$ | 21,9 | 22,9 | 23,5 | 21,0 | 23,2 | 23,4 | 25,2 | 24,1 | 23,1 |
| rH | 31,1 | 29,9 | 29,1 | 32,7 | 28,0 | 26,4 | 24,1 | 28,4 | 30,3 |

| | work station from Figure 1.1 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 8 | 9 | 10 |
| November 1990 | | | | | | | | | |
| $8^{th}$ ($CO_2$) floor | | | | | | | | | |
| $T_o$ | 23,7 | 25,1 | 25,3 | 23,8 | 24,9 | 24,6 | 24,3 | 23,3 | 24,0 |
| $T_{db}$ | 23,1 | 23,7 | 23,6 | 23,6 | 23,3 | 23,6 | 23,5 | 22,4 | 22,7 |
| rH | 29,0 | 29,9 | 28,9 | 25,2 | 28,6 | 26,7 | 26,7 | 29,4 | 26,6 |
| $9^{th}$ floor | | | | | | | | | |
| $T_o$ | 24,2 | 24,5 | 25,1 | 23,2 | 24,5 | 23,9 | 23,2 | 24,3 | 24,2 |
| $T_{db}$ | 23,2 | 22,8 | 23,0 | 21,8 | 23,6 | 22,3 | 22,0 | 23,0 | 22,9 |
| rH | 25,8 | 26,6 | 28,2 | 28,6 | 27,4 | 30,7 | 30,1 | 28,6 | 25,9 |
| December 1990 | | | | | | | | | |
| $8^{th}$ ($CO_2$) floor | | | | | | | | | |
| $T_o$ | 24,0 | 24,7 | 25,0 | 23,4 | 25,2 | 24,8 | 22,4 | 21,9 | 24,4 |
| $T_{db}$ | 23,9 | 23,2 | 23,7 | 23,1 | 23,7 | 24,1 | 22,5 | 21,3 | 22,8 |
| rH | 18,2 | 17,9 | 26,8 | 28,5 | 12,9 | 19,7 | 20,5 | 31,4 | 26,6 |
| $9^{th}$ floor | | | | | | | | | |
| $T_o$ | 25,0 | 26,0 | 24,7 | 24,4 | 25,0 | 25,1 | 23,9 | 22,8 | 24,2 |
| $T_{db}$ | 23,3 | 23,9 | 22,8 | 22,5 | 23,5 | 24,4 | 23,0 | 21,2 | 23,5 |
| rH | 20,5 | 20,2 | 31,2 | 32,5 | 22,4 | 21,1 | 21,7 | 30,7 | 27,2 |
| January 1991 | | | | | | | | | |
| $8^{th}$ ($CO_2$) floor | | | | | | | | | |
| $T_o$ | 23,8 | 24,8 | 24,4 | 23,4 | 24,6 | 24,9 | 22,3 | 22,4 | 23,7 |
| $T_{db}$ | 23,2 | 23,5 | 23,8 | 22,8 | 23,9 | 23,8 | 22,1 | 22,1 | 22,2 |
| rH | 21,1 | 19,2 | 14,6 | 18,9 | 18,1 | 16,6 | 18,2 | 22,3 | 19,7 |
| $9^{th}$ floor | | | | | | | | | |
| $T_o$ | 25,3 | 26,3 | 24,2 | 23,0 | 24,2 | 24,0 | 22,2 | 22,8 | 24,4 |
| $T_{db}$ | 24,5 | 24,5 | 23,0 | 22,5 | 23,1 | 22,8 | 20,6 | 22,2 | 23,7 |
| rH | 18,7 | 19,0 | 19,9 | 17,6 | 18,4 | 15,0 | 16,8 | 16,1 | 15,4 |

| | work station from Figure 1.1 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 8 | 9 | 10 |
| February 1991 | | | | | | | | | |
| $8^{th}$ ($CO_2$) floor | | | | | | | | | |
| $T_o$ | 22,9 | 24,9 | 24,5 | 23,2 | 24,7 | 24,8 | 22,8 | 23,0 | 24,1 |
| $T_{db}$ | 22,3 | 23,6 | 23,6 | 23,2 | 23,4 | 23,9 | 22,2 | 22,2 | 22,8 |
| rH | 30,2 | 28,0 | 29,9 | 28,4 | 26,3 | 28,2 | 29,7 | 31,3 | 25,4 |
| $9^{th}$ floor | | | | | | | | | |
| $T_o$ | 23,6 | 24,5 | 24,0 | 23,4 | 24,3 | 24,4 | 23,6 | 23,0 | 23,6 |
| $T_{db}$ | 22,4 | 22,9 | 22,2 | 22,4 | 23,7 | 23,1 | 22,4 | 21,9 | 23,0 |
| rH | 24,8 | 24,3 | 25,3 | 28,6 | 23,7 | 30,0 | 30,7 | 26,2 | 24,4 |
| March 1991 | | | | | | | | | |
| $8^{th}$ ($CO_2$) floor | | | | | | | | | |
| $T_o$ | 23,1 | 25,3 | 24,8 | 22,9 | 26,5 | 23,2 | 21,5 | 25,0 | 24,2 |
| $T_{db}$ | 22,5 | 23,4 | 23,5 | 22,7 | 25,4 | 22,2 | 20,9 | 22,8 | 22,7 |
| rH | 14,2 | 12,1 | 21,9 | 28,3 | 7,7 | 28,5 | 32,5 | 27,5 | 22,1 |
| $9^{th}$ floor | | | | | | | | | |
| $T_o$ | 24,8 | 25,5 | 23,9 | 23,0 | 25,7 | 22,8 | 22,4 | 24,7 | 24,7 |
| $T_{db}$ | 23,5 | 24,0 | 23,0 | 21,5 | 23,9 | 22,0 | 21,1 | 22,7 | 23,0 |
| rH | 13,6 | 12,8 | 21,6 | 29,6 | 9,2 | 31,1 | 32,1 | 33,1 | 28,6 |
| April 1991 | | | | | | | | | |
| $8^{th}$ ($CO_2$) floor | | | | | | | | | |
| $T_o$ | 22,0 | 24,3 | 24,8 | 23,3 | 25,3 | 24,9 | 23,9 | 24,2 | 24,1 |
| $T_{db}$ | 21,2 | 22,6 | 24,2 | 23,0 | 24,3 | 24,0 | 23,7 | 23,8 | 22,7 |
| rH | 29,6 | 27,7 | 23,9 | 23,8 | 25,2 | 24,3 | 24,6 | 26,6 | 28,1 |
| $9^{th}$ floor | | | | | | | | | |
| $T_o$ | 23,5 | 23,0 | 25,5 | 24,5 | 24,4 | 24,7 | 24,1 | 25,3 | 25,5 |
| $T_{db}$ | 22,2 | 22,3 | 24,6 | 23,3 | 23,5 | 23,4 | 23,1 | 24,5 | 24,1 |
| rH | 26,5 | 26,8 | 25,3 | 26,5 | 26,3 | 25,4 | 25,7 | 27,7 | 28,1 |

* beyond instrument measuring range

To compare the results to the recommended limits, the data is plotted on the ASHRAE comfort chart, from Figures 5.1 to 5.12; each figure representing a particular month.

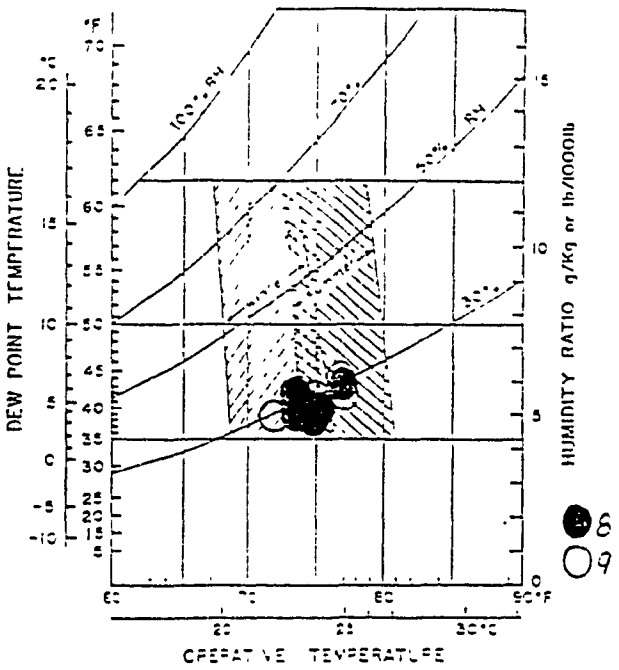



Figure 5.1 Comparison with ASHRAE thermal comfort chart (May 1990)

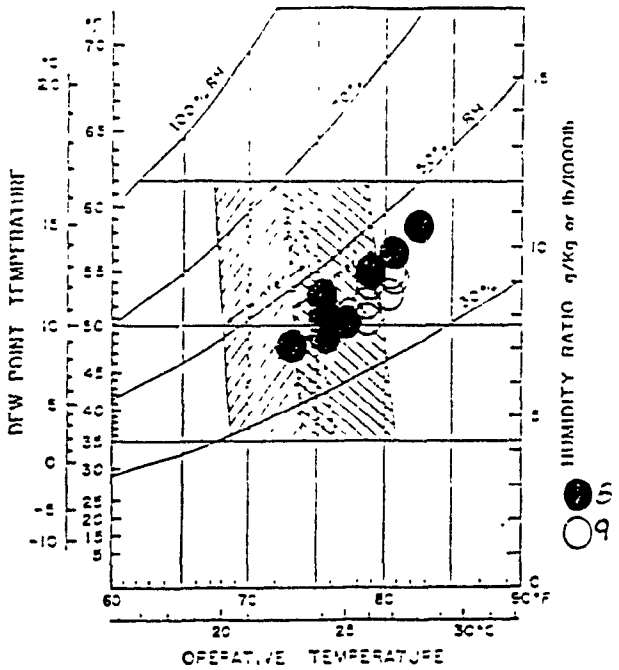



Figure 5.2 Comparison with ASHRAE thermal comfort chart (June 1990)

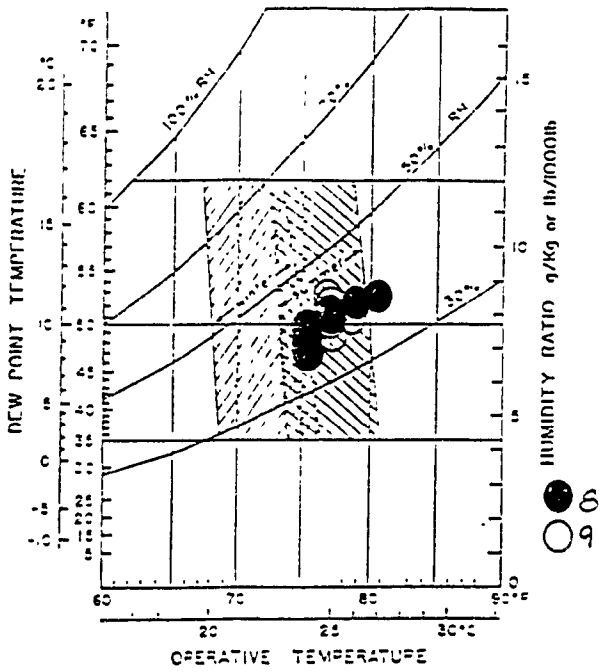



Figure 5.3 Comparison with ASHRAE thermal comfort chart (July 1990)

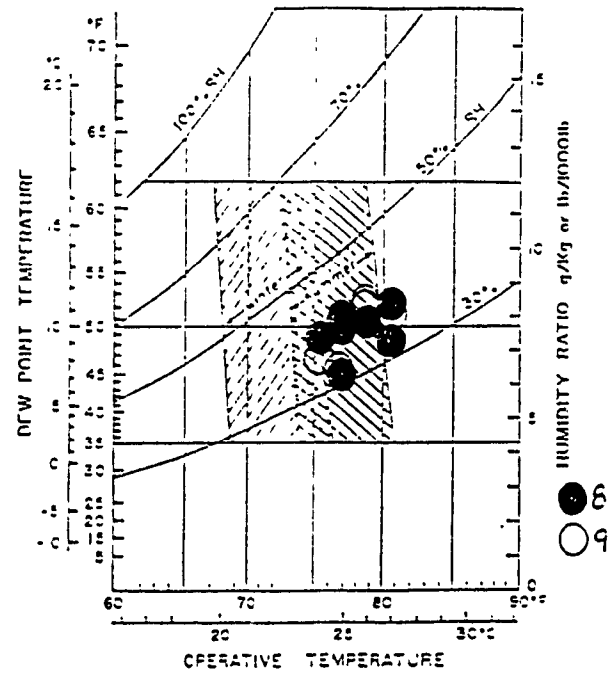



Figure 5.4 Comparison with ASHRAE thermal comfort chart (August 1990)

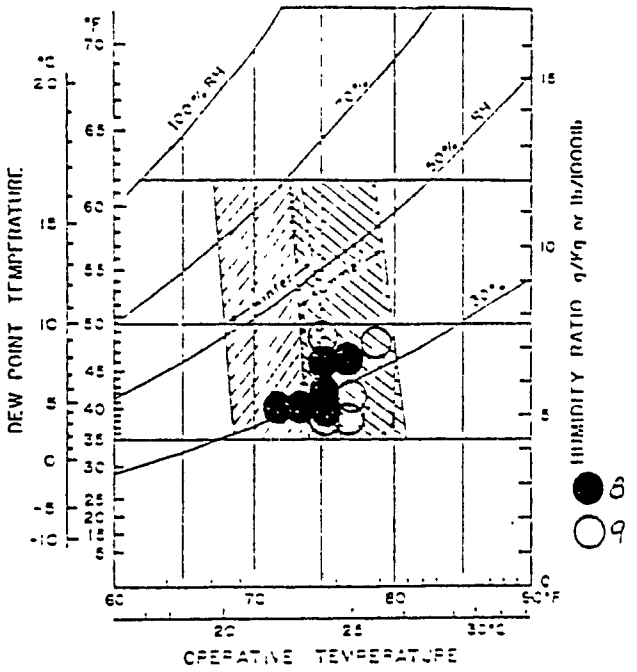



Figure 5.5 Comparison with ASHRAE thermal comfort chart (September 1990)

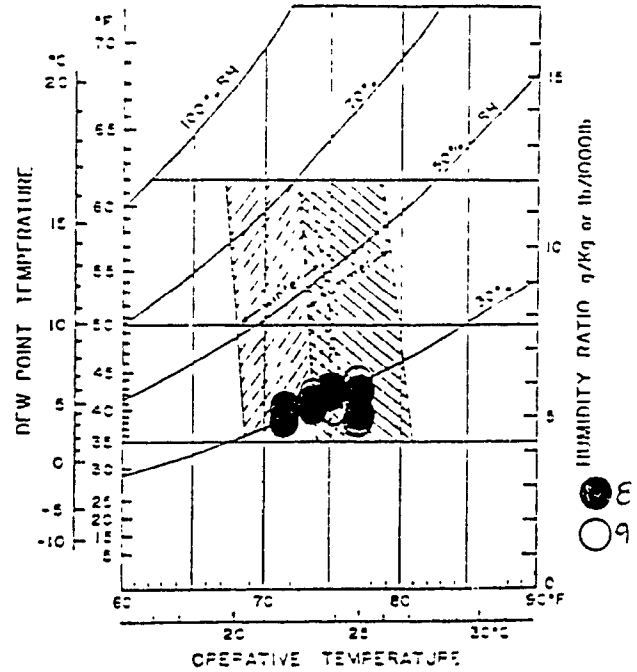



Figure 5.6 Comparison with ASHRAE thermal comfort chart (October 1990)

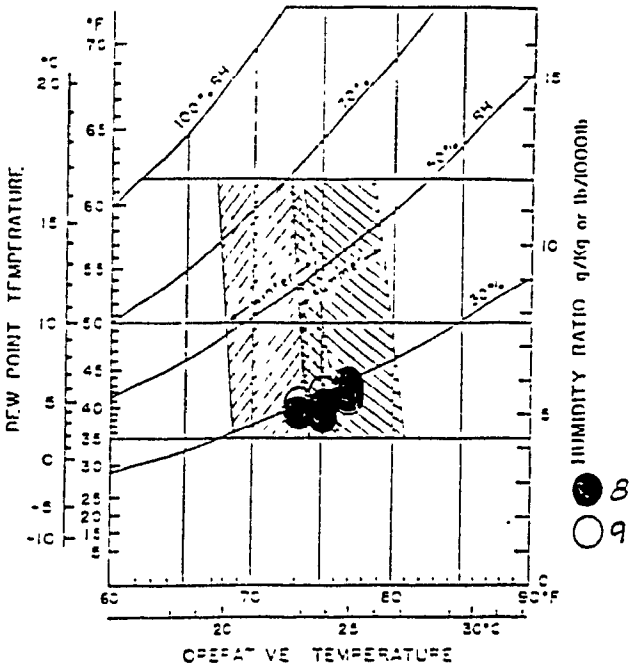



Figure 5.7 Comparison with ASHRAE thermal comfort chart (November 1990)

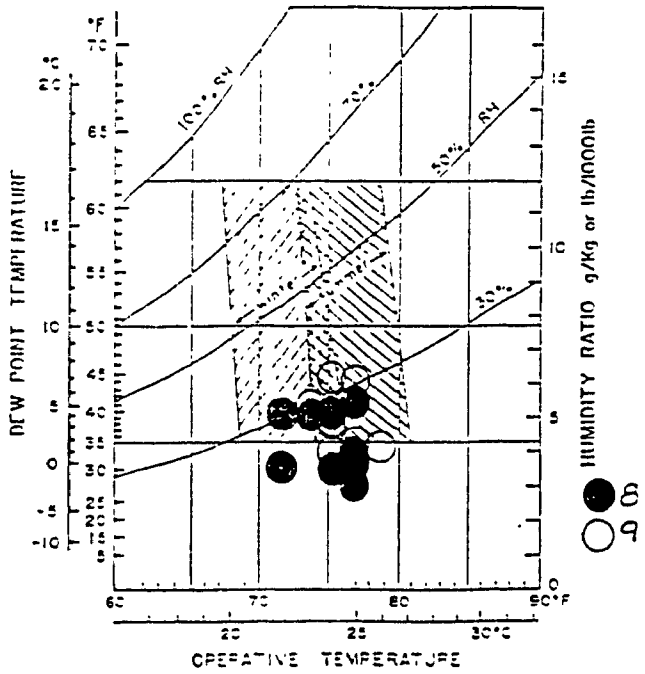



Figure 5.8 Comparison with ASHRAE thermal comfort chart (December 1990)

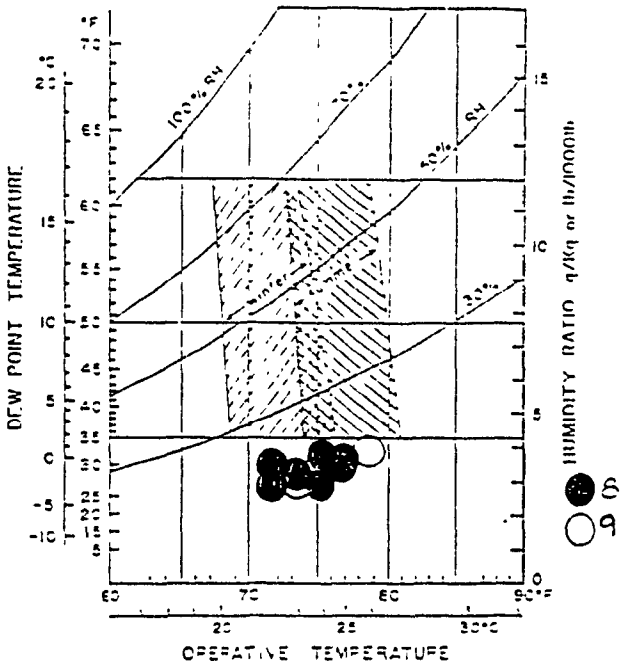



Figure 5.9 Comparison with ASHRAE thermal comfort chart (January 1991)

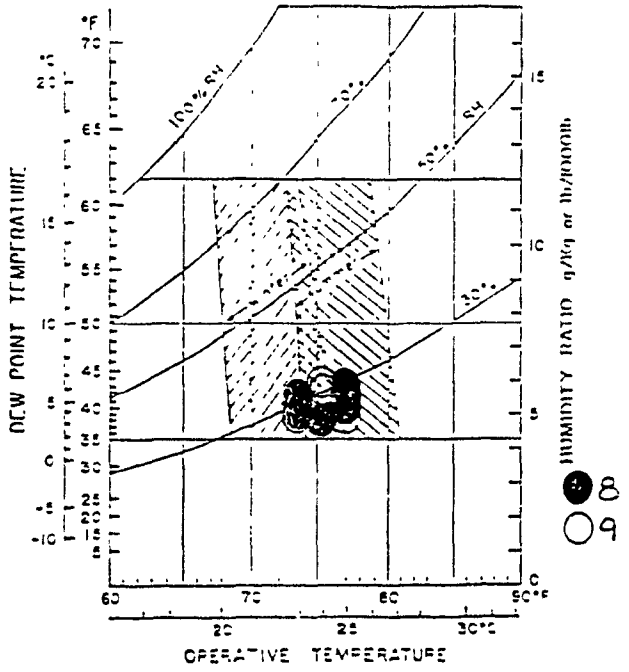



Figure 5.10 Comparison with ASHRAE thermal comfort chart (February 1991)

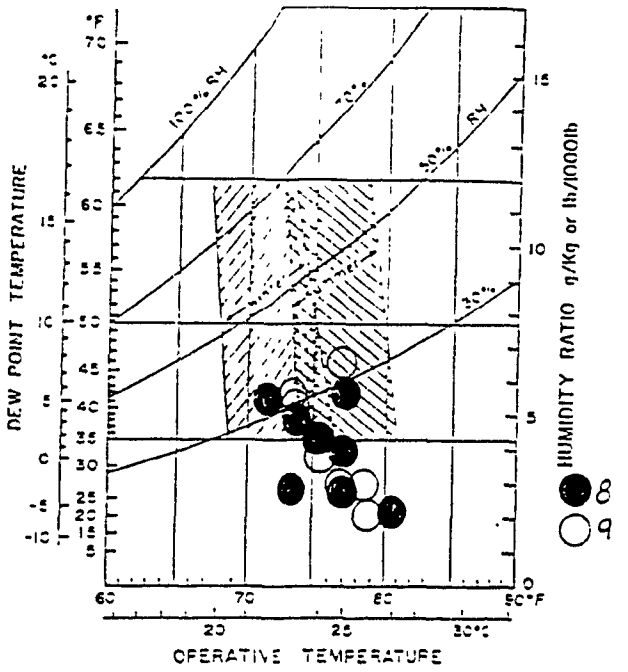



Figure 5.11 Comparison with ASHRAE thermal comfort chart (March 1991)

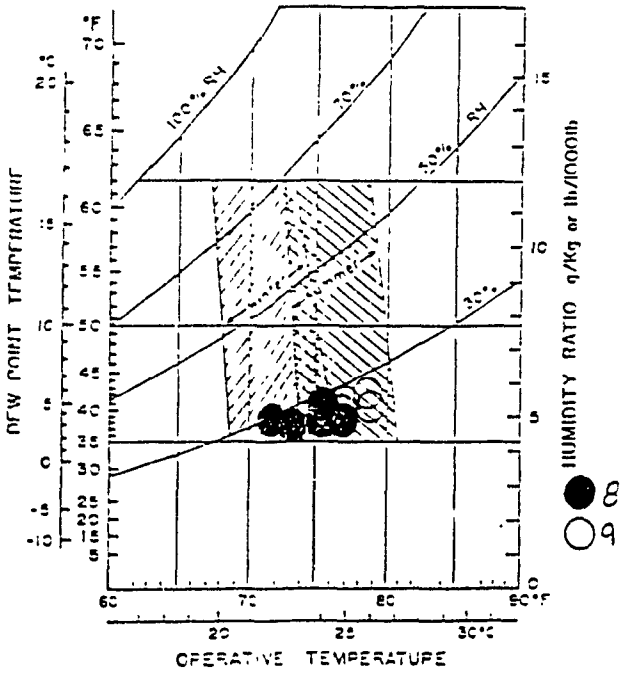



Figure 5.12 Comparison with ASHRAE thermal comfort chart (April 1991)

The above data shows that the ASHRAE standard and the provincial regulations are satisfied for most of the year. Table 5.2 shows the exceptions.

Table 5.2 Months showing non-compliance with standards

| MONTH | FLOOR | NON-COMPLIANCE | RESPECTIVE STANDARD |
|---|---|---|---|
| June 1990[1] | 8 ($CO_2$) | operative temperatures too high | ASHRAE |
| | 9 | operative temperatures too high | ASHRAE |
| July 1990[1] | 8 ($CO_2$) | operative temperatures too high | ASHRAE |
| August 1990[1] | 8 ($CO_2$) | operative temperatures too high | ASHRAE |
| | 9 | operative temperatures too high | ASHRAE |
| December 1990[2] | 8 ($CO_2$) | very low relative humidities | ASHRAE and RRQWE |
| January 1991[2] | 8 ($CO_2$) | very low relative humidities | ASHRAE and RRQWE |
| | 9 | very low relative humidities | ASHRAE and RRQWE |
| March 1991[2] | 8 ($CO_2$) | very low relative humidities[3] | ASHRAE and RRQWE |
| | 9 | very low relative humidities[3] | ASHRAE and RRQWE |

[1] under-designed compressors
[2] under-designed humidifiers
[3] humidifiers under repair

Both floors seem to have reacted similarly, with respect to the standards, except for the months of July and December. In July, one reading of operative temperature on the 8$^{th}$ ($CO_2$) floor was above the ASHRAE comfort limit. For this testing period, the 8$^{th}$ ($CO_2$) floor experienced slightly higher air change rates, which could have resulted in a higher indoor temperature, considering the warm weather conditions. In December, 50 % of the data from the 8$^{th}$ ($CO_2$) floor fell

below the ASHRAE comfort limit. For this testing period, higher air change rates were also experienced on this floor, however, this does not explain the low relative humidities.

Therefore, although the $CO_2$-run floor does not result in more comfortable conditions, one cannot say that the $CO_2$-control system worsens the thermal comfort. Previous work has shown that a $CO_2$-control system used alone can cause thermal discomfort, especially during the summer months.(24) This is not the case in this project, since the only two differences found occured during the months of July (for only one reading out of ten) and December.

## 5.2 Air Diffusion Performance Index (ADPI)

The ANSI/ASHRAE 113P "Method of testing for room air diffusion" was used to measure ADPI.(77) The data acquisition system used is the "ANNIE-II" by TSI Incorporated, coupled with a portable IBM-PC compatible computer, 5 TSI Model 1621 temperature transducers (range: 0 to 100°C), and 4 TSI Model 1620 air velocity transducers (range: 0 to 3 m/s, omni-directional).

Approximately 30 test points were selected in the horizontal direction for each test zone. The area facing west (see Figure 1.1; zone includes stations 5, 6, and 7) was chosen for the afternoon testing period since the thermal load was the greatest at that time due to the sunshine. Consequently, the area facing east (see Figure 1.1; zone includes stations 1 and 2) was tested in the morning. Therefore, each data shown below in Table 5.3 and Figure 5.13 represents a testing period of about two hours.

Table 5.3 Results of ADPI testing (%)

| month | work zone | | | |
|---|---|---|---|---|
| | 8th floor ($CO_2$) | | 9th floor | |
| | east | west | east | west |
| May 1990 | 90,8 | 97,0 | 91,4 | 97,4 |
| June 1990 | 92,6 | 98,5 | 88,5 | 96,6 |
| July 1990 | 85,5 | 97,0 | 95,4 | 90,5 |
| August 1990 | 92,5 | 77,4[a] | 91,7 | 88,5 |
| September 1990 | 94,2 | 97,0 | 87,5 | 97,9 |
| October 1990 | 84,2 | 97,0 | 91,9 | 89,6 |
| November 1990 | 80,2 | 96,9 | 83,8 | 88,6 |
| December 1990 | 73,3[b] | 96,1 | 79,7[c] | 88,6 |
| January 1991 | 67,5[b] | 90,0 | 87,9 | 88,2 |
| February 1991 | 79,3[b] | 90,2 | 94,6 | 93,6 |
| March 1991 | 72,8[b] | 79,6[b] | 75,0[b] | 84,0 |
| April 1991 | 100,0 | 90,2 | 95,6 | 90,5 |
| Standard | | | | |
| ASHRAE (77) | | greater than 80 | | |

[a] The temperature measured at 1,7 m above the floor was too warm for such low velocities

[b] The temperature measured at all levels was too warm for such low velocities (due to broken compressor)

[c] The temperature measured at 0,6, 1,1, and 1,7 m above the floor was too warm for such low velocities. The temperature measured at 0,1 m above the floor was too cold for such high velocities. The velocity measured at 0,1 m above the floor was too high for such low temperatures.

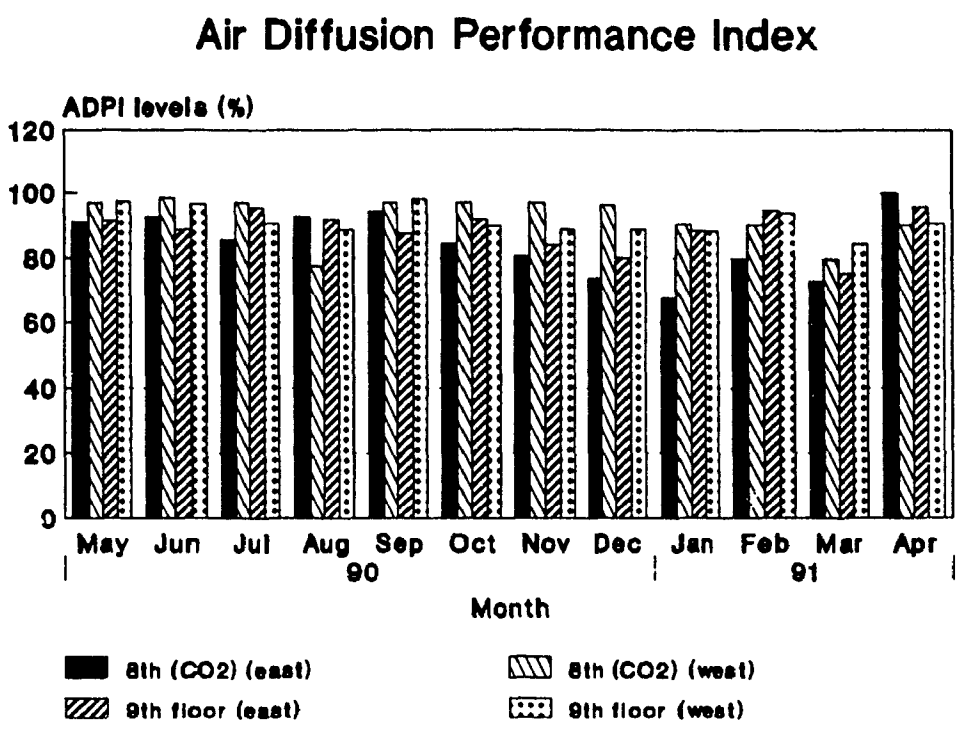



Figure 5.13 Monthly ADPI results

Comparing our results to the recommended level, we can see that almost all of the testing was above the comfort limit; only eight incidents (out of 48) were below 80%; the reasons why are stated above.

It had been noted on several occasions that the building operation personnel would diminish the volumetric air flows in certain diffusers due to very adamant complaints from the occupants. This would cause a thorough off-balancing of the

distribution system, causing the other diffusers to accept even larger volumetric flows. This is another factor that affected the ADPI results; as seen during the month of March, especially, when a noticeable decrease in ADPI was seen throughout all zones.

When comparing the levels from both floors, the 9$^{th}$ floor seems to experience higher ADPI values (especially for the east zone). The differences between the two floors range from 0,4 to 20,4%, with an average of 5,7%. The big differences between the two floors occurred when only one floor had malfunctions (or repairs) in the ventilation system.

Therefore, although the $CO_2$-run floor does not produce higher ADPI values; the decreases resulted from intentional changes in distribution flows, and not as a result of the $CO_2$-control system.

## 5.3 Vertical Temperature Gradients

The vertical temperature gradients used correspond to the measured values found during the ADPI testing, using two of the five temperature transducers. These were placed at 0,1 and 1,7 m from the floor. The results in Table 5.4 and

Figure 5.14 show the maximum vertical temperature gradients for that test zone and period.

Table 5.4 Maximum vertical temperature gradients (°C)

| month | work zone | | | |
|---|---|---|---|---|
| | 8th floor ($CO_2$) | | 9th floor | |
| | east | west | east | west |
| May 1990 | 0,7 | 1,1 | 1,1 | 1,0 |
| June 1990 | 1,1 | 1,8 | 1,3 | 1,1 |
| July 1990 | 1,3 | 1,2 | 0,6 | 1,2 |
| August 1990 | 0,8 | 3,2[1] | 0,8 | 1,5 |
| September 1990 | 0,7 | 1,3 | 3,0 | 1,1 |
| October 1990 | 0,9 | 0,5 | 1,8 | 1,1 |
| November 1990 | 0,6 | 0,6 | 2,6 | 0,9 |
| December 1990 | 1,4 | 0,5 | 3,2[1] | 1,9 |
| January 1991 | 1,8 | 1,4 | 3,0[1] | 2,5 |
| February 1991 | 1,2 | 1,1 | 1,7 | 1,0 |
| March 1991 | 0,9 | 1,1 | 3,6[1] | 0,8 |
| April 1991 | 0,9 | 1,2 | 1,2 | 1,2 |
| Standard | | | | |
| ASHRAE (74) | | less than 3 | | |

[1] air temperatures much higher than floor temperatures (due to broken compressor)

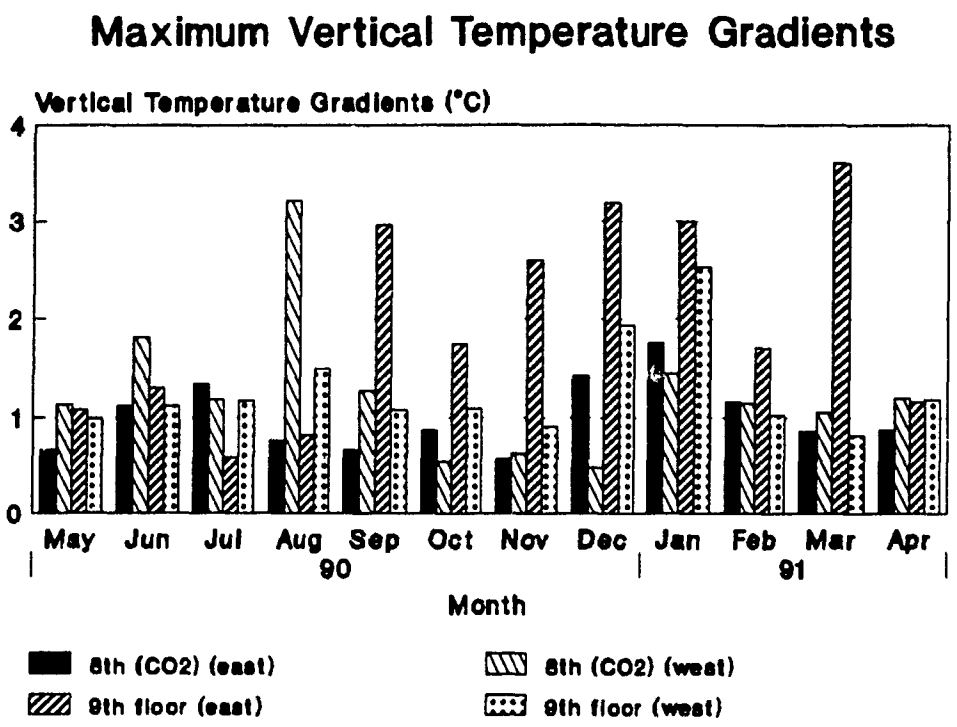



Figure 5.14 Monthly vertical temperature gradients

Comparing our results to the recommended level, we can see that almost all of the testing was above the comfort limit; only four incidents (out of 48) had vertical temperature differences above 3°C, and that was due to a broken compressor.

When comparing the levels from both floors, the 8$^{th}$ ($CO_2$) floor seems to experience higher vertical temperature gradients for the area facing west. The 9$^{th}$ floor experienced larger vertical temperature gradients for the area facing east.

The differences between the two floors range from 0,0 to 2,8°C, with an average of 0,8°C.

Therefore, although the $CO_2$-run floor does not produce lower vertical temperature gradients, one cannot say that the $CO_2$-control system worsens the gradient levels.

## 5.4 Air Velocity

The air velocities used correspond to the measured values found during the ADPI testing, using only the four air velocity transducers. These were placed at 0,1 m, 0,6 m, 1,1 m, and 1,7 m above the floor. The results in Table 5.5 and Figure 5.15 show the average air velocities for that test zone and period.

Table 5.5 Average air velocities (m/s)

| month | work zone | | | |
|---|---|---|---|---|
| | 8th floor ($CO_2$) | | 9th floor | |
| | east | west | east | west |
| May 1990 | 0,13 | 0,11 | 0,13 | 0,12 |
| June 1990 | 0,12 | 0,12 | 0,13 | 0,11 |
| July 1990 | 0,13 | 0,13 | 0,14 | 0,12 |
| August 1990 | 0,13 | 0,10 | 0,15 | 0,12 |
| September 1990 | 0,13 | 0,13 | 0,10 | 0,14 |
| October 1990 | 0,13 | 0,12 | 0,13 | 0,13 |
| November 1990 | 0,11 | 0,12 | 0,11 | 0,11 |
| December 1990 | 0,11 | 0,13 | 0,11 | 0,11 |
| January 1991 | 0,08 | 0,11 | 0,09 | 0,12 |
| February 1991 | 0,11 | 0,09 | 0,13 | 0,11 |
| March 1991 | 0,09 | 0,09 | 0,08 | 0,10 |
| April 1991 | 0,12 | 0,08 | 0,08 | 0,09 |

| Standards | |
|---|---|
| PWC (79) | from 0,09 to 0,25 |
| ASHRAE (74) | - less than 0,15 (winter)<br>- less than 0,25 (summer) with allowable increase of 0,275 m/s/°C from 26°C to 28°C |

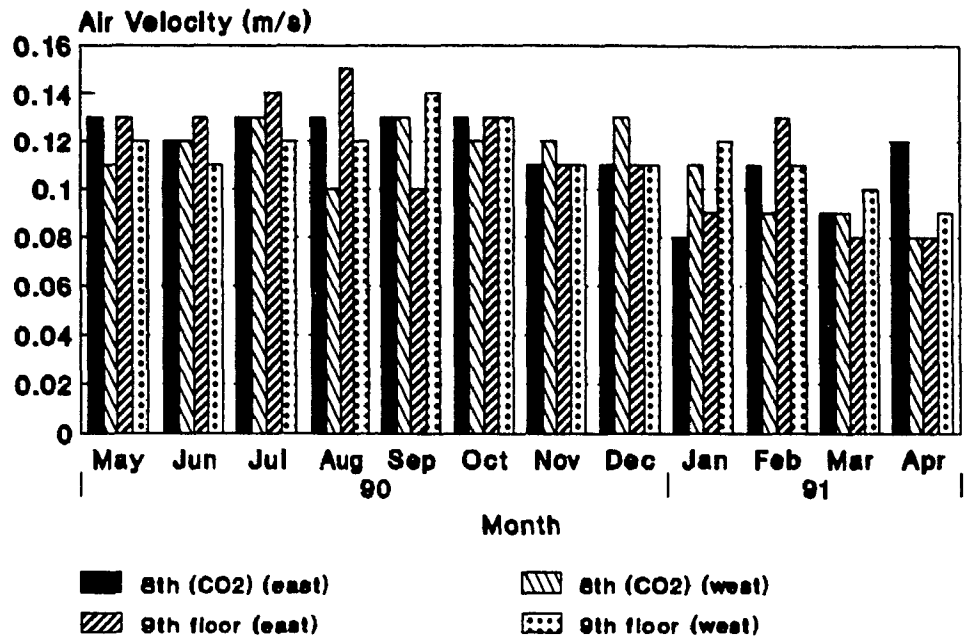



Figure 5.15 Monthly air velocities

Comparing our results to the recommended level, we can see that the highest average velocity found was 0,15 m/s; which is within the ASHRAE limits. However, there are 4 incidents (out of 48) which have air velocities below the PWC recommendation on both floors, which might cause sensations of stagnant air.

The velocities do not seem to differ with time, which is to be expected from a constant volume distribution system. However, a certain decrease was noticed in the year 1991, due to the fact that the building operating personnel changed the volumetric flow in certain zones.

When comparing the levels from both floors, the 9$^{th}$ floor seems to experience higher air velocities for the area facing west. The differences between the two floors range from 0 to 0,04 m/s, with an average of 0,01 m/s.

Therefore, although the $CO_2$-run floor does not produce more comfortable air velocities, one cannot say that the $CO_2$-control system worsens the air movement.

## 5.5 Global Thermal Comfort (PMV and PPD)

Global thermal comfort levels were taken using the Bruël & Kjaer Thermal Comfort Meter Type 1212. These were taken at 9 locations per floor (see stations 1 to 6, and 8 to 10, in Figure 1.1), for 20 minutes per station, over a period of 3 working days, once a month. A second direct reading instrument was used to measure dry-bulb temperature and relative humidity. These two readings were used to find the water vapour pressure in the air. The actual clothing and activity

levels of the workers were used. Due to the unavailability of several of these instruments, and lack of technical help, it was not possible to take readings continuously. However, it was found in previous works that these parameters were uniform throughout the working zone, and that hourly variations were minimal.(30) So, the stations were monitored sequentially, as discussed in section 5.1.

Following, in Table 5.6 are the instantaneous results of the Predicted Percentage Dissatisfied (PPD) and the respective Predicted Mean Vote (PMV). These are shown graphically in Figures 5.16 to 5.27.

Table 5.6 PPD (%) and PMV (-2 to +2) responses

| | work station from Figure 1.1 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 8 | 9 | 10 |
| May 1990 | | | | | | | | | |
| $8^{th}$ ($CO_2$) floor | | | | | | | | | |
| PPD | 22 | 23 | 41 | 6 | 16 | 7 | 20 | 7 | 15 |
| PMV | -0,9 | -0,9 | -1,2 | -0,2 | -0,7 | -0,3 | -0,8 | -0,2 | -0,7 |
| $9^{th}$ floor | | | | | | | | | |
| PPD | 8 | 23 | 32 | 7 | 14 | 17 | 71 | 19 | 15 |
| PMV | -0,4 | -0,9 | -1,0 | -0,2 | -0,7 | -0,7 | -1,8 | -0,8 | -0,7 |
| June 1990 | | | | | | | | | |
| $8^{th}$ ($CO_2$) floor | | | | | | | | | |
| PPD | 46 | 47 | 12 | 68 | 32 | 51 | OR# | 78 | 7 |
| PMV | -1,4 | -1,5 | -0,6 | -1,7 | -1,1 | -1,3 | OR | -1,9 | -0,4 |
| $9^{th}$ floor | | | | | | | | | |
| PPD | 74 | 56 | 78 | OR | 64 | 44 | 69 | 55 | 22 |
| PMV | -2,0 | -1,5 | -1,9 | OR | -1,6 | -1,3 | -1,8 | -1,6 | -1,1 |
| July 1990 | | | | | | | | | |
| $8^{th}$ ($CO_2$) floor | | | | | | | | | |
| PPD | 66 | 69 | 21 | 76 | 35 | 62 | 33 | 63 | OR |
| PMV | -1,7 | -1,8 | -0,9 | -1,9 | -1,6 | -1,8 | -1,1 | -1,7 | OR |
| $9^{th}$ floor | | | | | | | | | |
| PPD | 36 | 76 | 14 | 65 | 28 | 70 | 71 | 63 | 45 |
| PMV | -1,3 | -1,9 | -0,8 | -1,7 | -1,5 | -1,8 | -1,8 | -1,7 | -1,3 |

| | work station from Figure 1.1 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 8 | 9 | 10 |
| August 1990 | | | | | | | | | |
| $8^{th}$ ($CO_2$) floor | | | | | | | | | |
| PPD | 7 | 32 | 9 | 6 | 7 | 17 | 14 | 12 | 13 |
| PMV | 0,2 | -1,0 | -0,4 | 0,1 | -0,3 | -0,7 | 0,6 | 0,6 | 0,6 |
| $9^{th}$ floor | | | | | | | | | |
| PPD | 6 | 52 | 20 | 25 | 9 | 13 | 8 | 16 | 10 |
| PMV | 0,2 | -1,5 | -0,9 | -1,0 | 0,4 | 0,6 | 0,3 | -0,7 | -0,5 |
| September 1990 | | | | | | | | | |
| $8^{th}$ ($CO_2$) floor | | | | | | | | | |
| PPD | 7 | 11 | 43 | 9 | 9 | 10 | 39 | 56 | 5 |
| PMV | -0,3 | 0,5 | -1,2 | 0,4 | -0,4 | 0,5 | -1,2 | -1,5 | 0,0 |
| $9^{th}$ floor | | | | | | | | | |
| PPD | 19 | 6 | 13 | 67 | 13 | 36 | 10 | 51 | 11 |
| PMV | 0,8 | 0,1 | -0,6 | -1,7 | 0,6 | -1,1 | -0,5 | -1,4 | -0,5 |
| October 1990 | | | | | | | | | |
| $8^{th}$ ($CO_2$) floor | | | | | | | | | |
| PPD | 52 | 38 | 27 | 11 | 5 | 14 | 37 | 43 | 10 |
| PMV | -1,4 | -1,2 | -1,0 | 0,5 | -0,1 | -0,6 | -1,1 | -1,3 | 0,5 |
| $9^{th}$ floor | | | | | | | | | |
| PPD | 16 | 11 | 8 | 9 | 18 | 5 | 5 | 21 | 13 |
| PMV | 0,7 | -0,5 | 0,4 | 0,4 | -0,7 | 0,0 | 0,0 | 0,8 | -0,6 |

| | work station from Figure 1.1 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 8 | 9 | 10 |
| November 1990 | | | | | | | | | |
| $8^{th}$ ($CO_2$) floor | | | | | | | | | |
| PPD | 27 | 6 | 14 | 10 | 6 | 8 | 5 | 10 | 38 |
| PMV | -1,0 | -0,2 | 0,6 | 0,5 | 0,1 | -0,3 | 0,1 | -0,5 | -1,2 |
| $9^{th}$ floor | | | | | | | | | |
| PPD | 30 | 5 | 14 | 10 | 8 | 12 | 5 | 6 | 6 |
| PMV | -1,0 | 0,0 | 0,6 | -0,5 | -0,3 | -0,6 | 0,1 | -0,2 | -0,1 |
| December 1990 | | | | | | | | | |
| $8^{th}$ ($CO_2$) floor | | | | | | | | | |
| PPD | 15 | 8 | 13 | 5 | 6 | 6 | 10 | 71 | 10 |
| PMV | 0,7 | -0,4 | 0,6 | 0,1 | -0,2 | 0,1 | 0,5 | -1,8 | 0,5 |
| $9^{th}$ floor | | | | | | | | | |
| PPD | 14 | 8 | 13 | 10 | 7 | 9 | OR | 21 | 19 |
| PMV | -0,7 | -0,3 | 0,6 | -0,5 | -0,2 | -0,4 | OR | -0,9 | -0,8 |
| January 1991 | | | | | | | | | |
| $8^{th}$ ($CO_2$) floor | | | | | | | | | |
| PPD | 24 | 9 | 19 | 13 | 7 | 17 | 6 | 10 | 22 |
| PMV | -0,9 | -0,4 | -0,8 | -0,6 | -0,3 | 0,7 | -0,2 | -0,5 | -0,9 |
| $9^{th}$ floor | | | | | | | | | |
| PPD | 8 | 7 | 15 | 29 | 12 | 11 | 13 | 13 | 11 |
| PMV | -0,3 | -0,2 | 0,7 | -1,0 | -0,6 | 0,5 | -0,6 | 0,6 | -0,5 |

| | work station from Figure 1.1 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 8 | 9 | 10 |
| February 1991 | | | | | | | | | |
| $8^{th}$ ($CO_2$) floor | | | | | | | | | |
| PPD | 10 | 7 | 26 | 32 | 11 | 6 | 11 | 17 | 20 |
| PMV | 0,5 | -0,3 | -1,0 | 1,0 | 0,5 | -0,1 | 0,5 | -0,7 | 0,8 |
| $9^{th}$ floor | | | | | | | | | |
| PPD | 9 | 13 | 19 | 46 | 8 | 9 | 13 | 12 | 7 |
| PMV | 0,4 | -0,6 | 0,8 | -1,4 | -0,3 | -0,4 | 0,6 | -0,6 | -0,3 |
| March 1991 | | | | | | | | | |
| $8^{th}$ ($CO_2$) floor | | | | | | | | | |
| PPD | 13 | 8 | 12 | 36 | 7 | 38 | 6 | 11 | 10 |
| PMV | 0,6 | -0,3 | 0,5 | -1,1 | 0,3 | -1,2 | 0,1 | -0,5 | 0,4 |
| $9^{th}$ floor | | | | | | | | | |
| PPD | 21 | 13 | 11 | 9 | 23 | 18 | 35 | 9 | 32 |
| PMV | 0,8 | -0,6 | 0,5 | -0,4 | 0,9 | -0,8 | -1,1 | -0,4 | -1,0 |
| April 1991 | | | | | | | | | |
| $8^{th}$ ($CO_2$) floor | | | | | | | | | |
| PPD | 6 | 10 | 12 | 28 | 5 | 15 | 17 | 7 | 13 |
| PMV | 0,2 | 0,4 | -0,6 | -1,0 | 0,0 | 0,6 | 0,7 | -0,3 | 0,6 |
| $9^{th}$ floor | | | | | | | | | |
| PPD | 9 | 13 | 10 | 5 | 8 | 11 | 36 | 26 | 6 |
| PMV | 0,4 | -0,6 | 0,5 | -0,1 | -0,4 | -0,5 | -1,1 | 1,0 | 0,2 |
| Standard | | | | | | | | | |
| ASHRAE (74) | | | | less than 20 PPD | | | | | |

* beyond instrument detection range

To compare the results to the recommended limit, the data is plotted on the PMV vs PPD chart, from Figures 5.16 to 5.27; each figure representing a particular month.

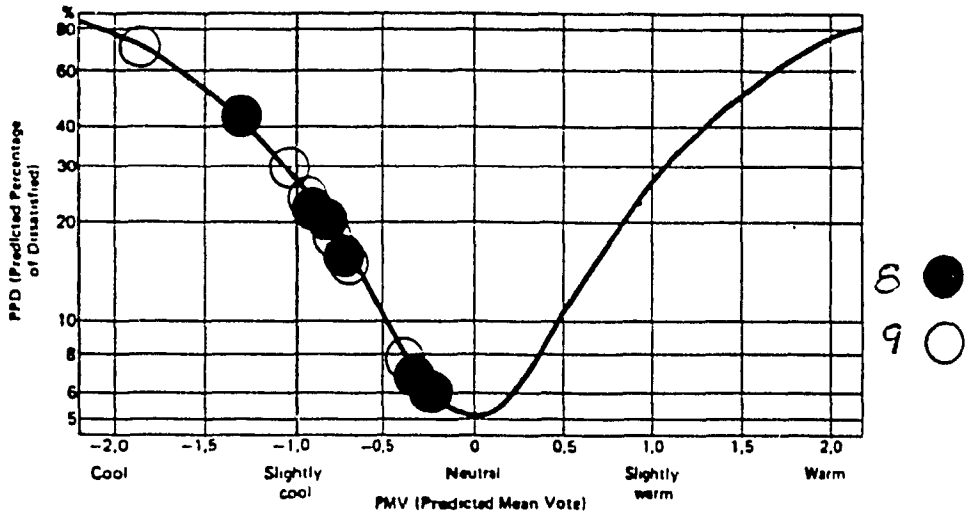



Figure 5.16 Comparison with PPD and PMV chart (May 1990)

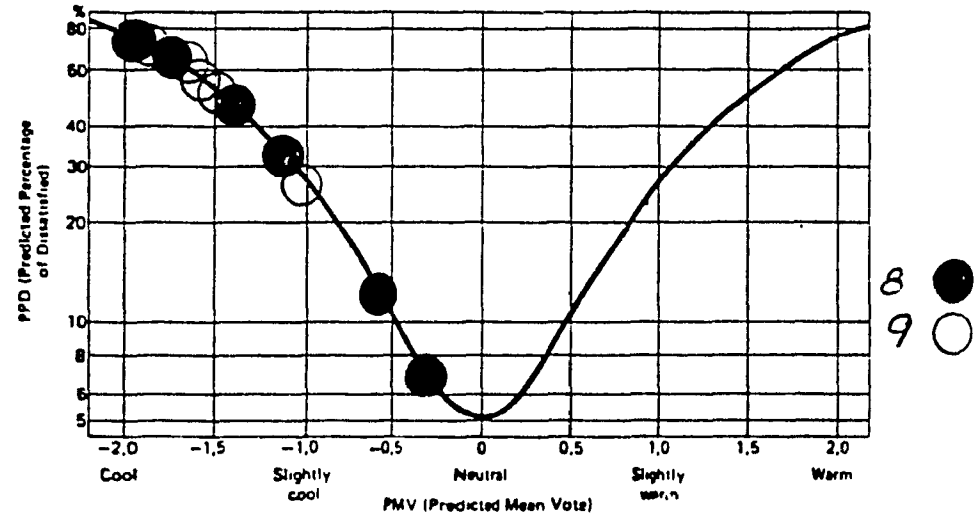



Figure 5.17 Comparison with PPD and PMV chart (June 1990)

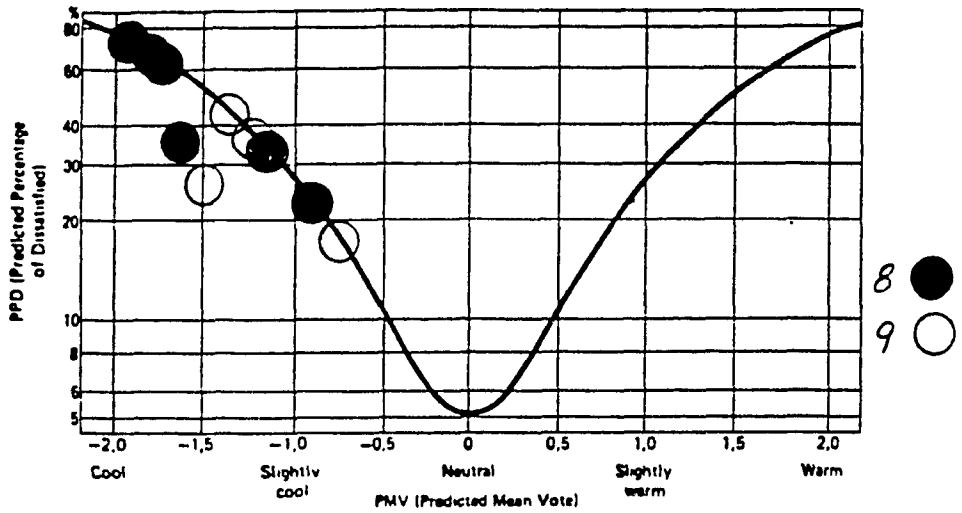



Figure 5.18 Comparison with PPD and PMV chart (July 1990)

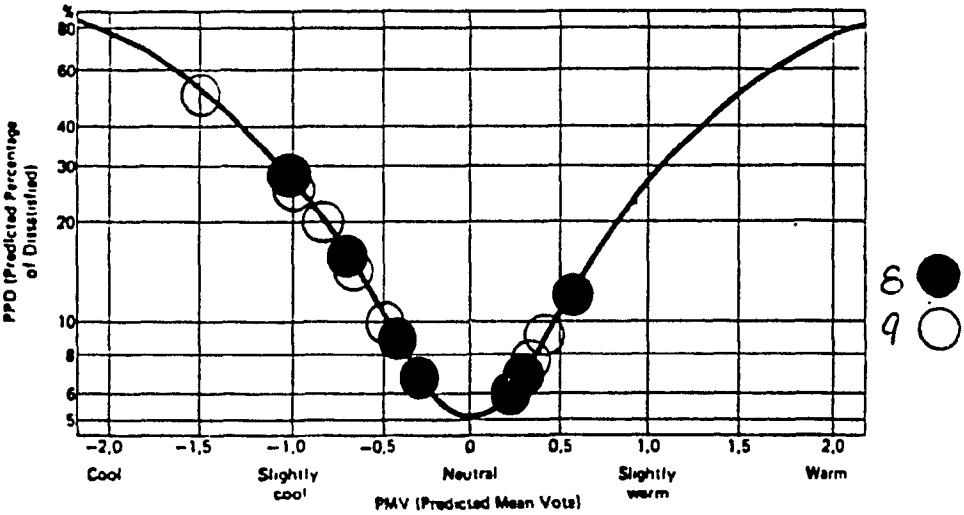



Figure 5.19 Comparison with PPD and PMV chart (August 1990)

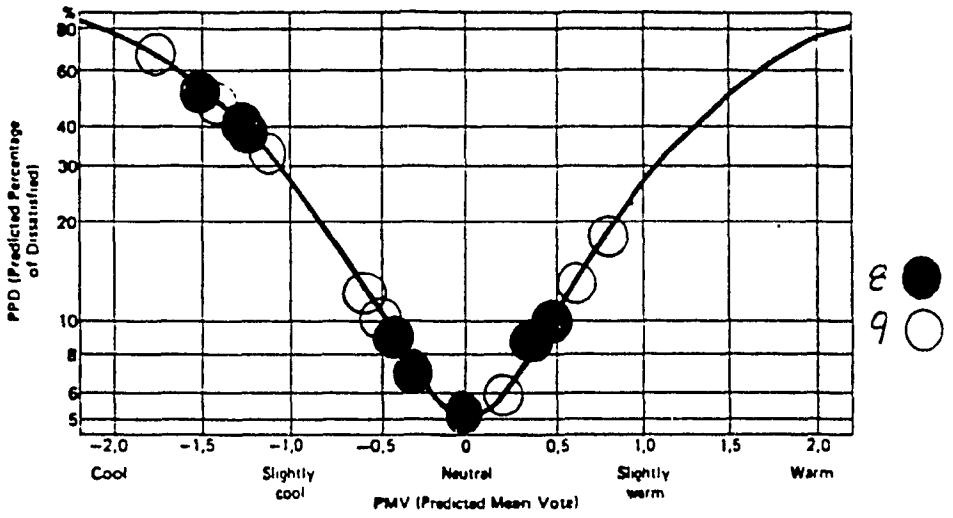



Figure 5.20 Comparison with PPD and PMV chart (September 1990)

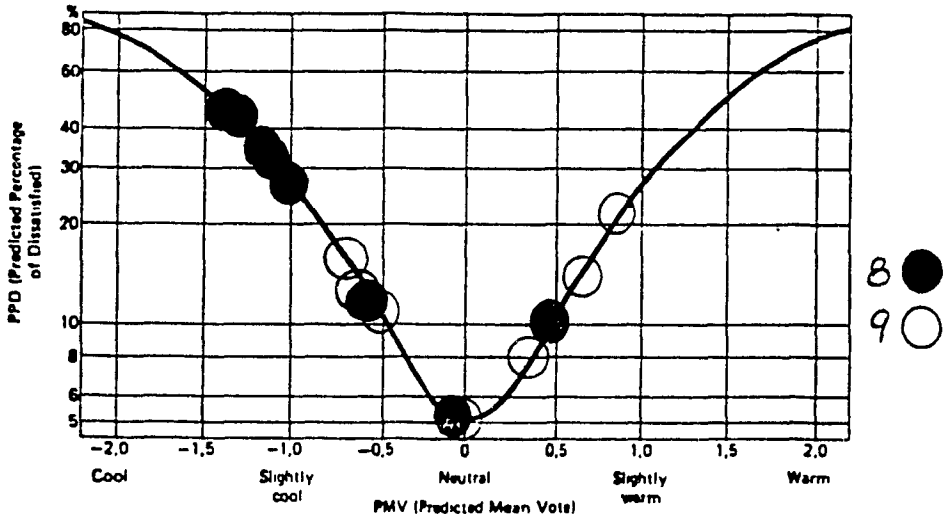



Figure 5.21 Comparison with PPD and PMV chart (October 1990)

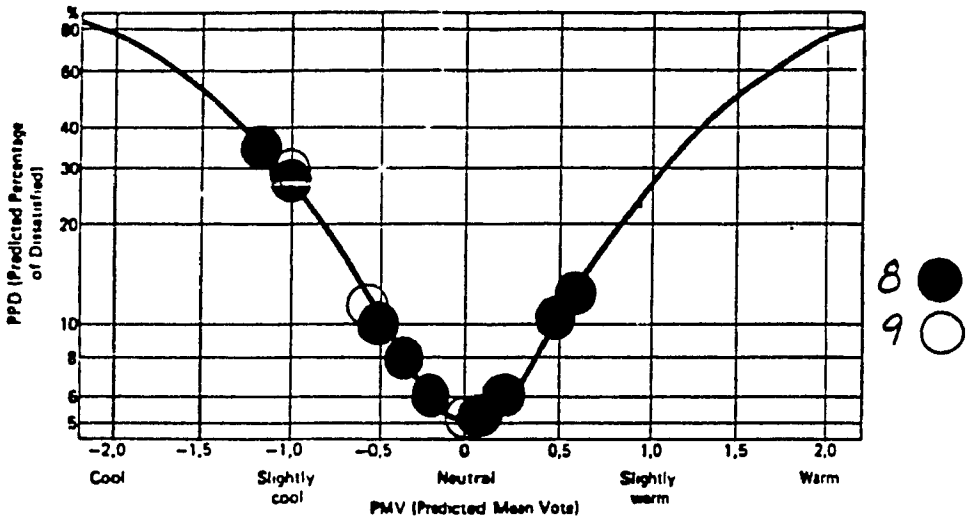



Figure 5.22 Comparison with PPD and PMV chart (November 1990)

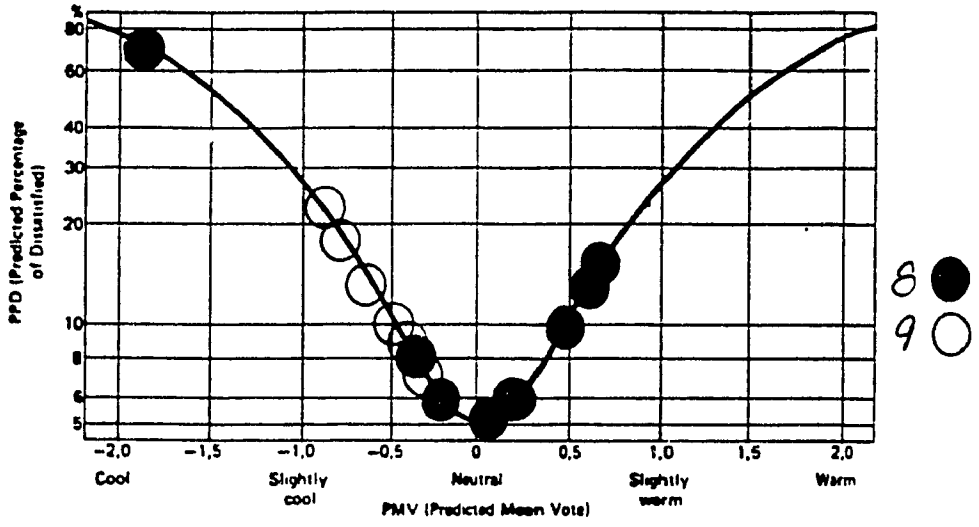



Figure 5.23 Comparison with PPD and PMV chart (December 1990)

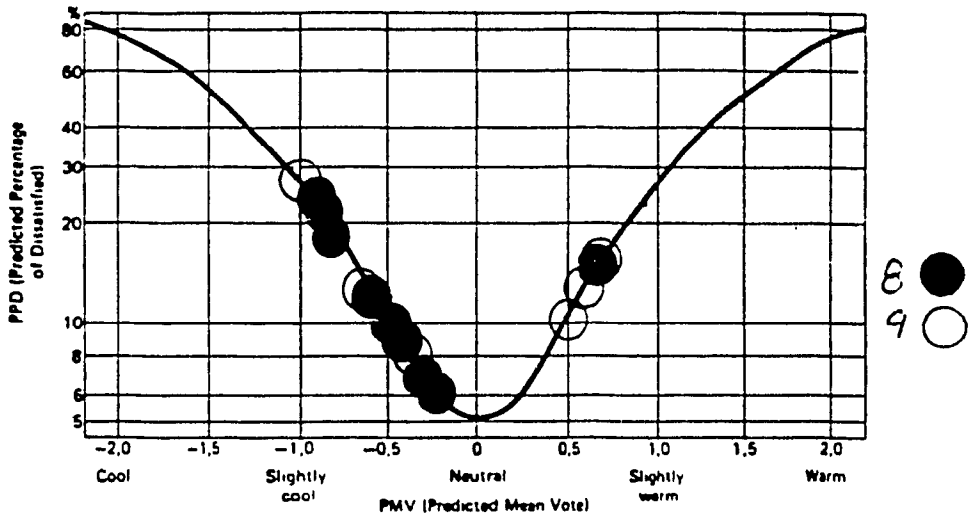



Figure 5.24 Comparison with PPD and PMV chart (January 1991)

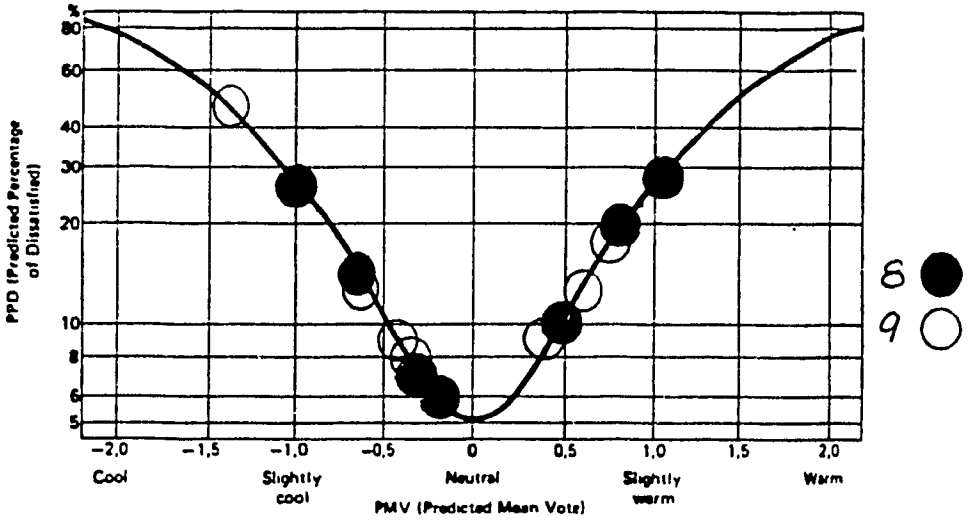



Figure 5.25 Comparison with PPD and PMV chart (February 1991)

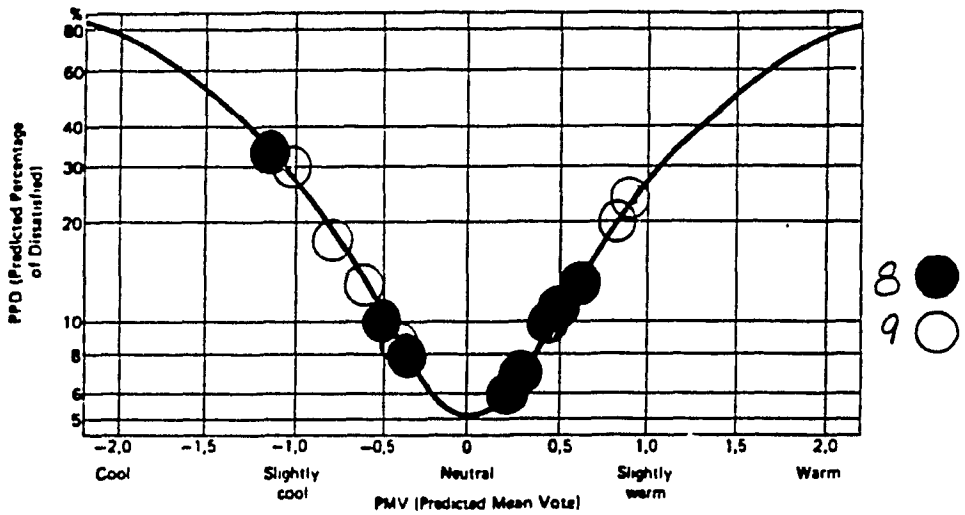



Figure 5.26 Comparison with PPD and PMV chart (March 1991)

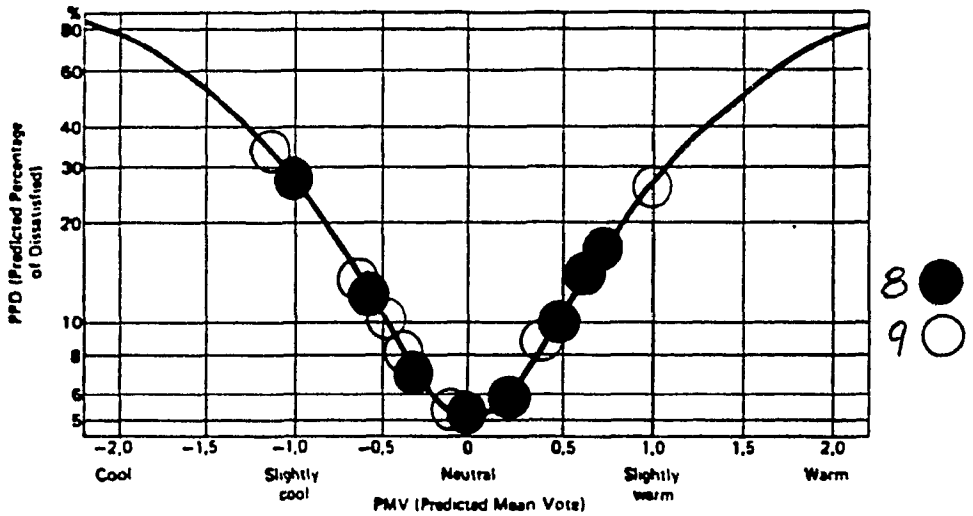



Figure 5.27 Comparison with PPD and PMV chart (April 1991)

As seen in the above figures, the data consistently falls within the range of 5 to 78 % dissatisfied, with a predicted mean vote ranging from slightly warm to cool. Table 5.7 shows a summary of the analysis, including the number of work stations which do not satisfy the ASHRAE maximum limit of 20 % dissatisfaction.

Table 5.7 Analysis of PPD and PMV responses

| MONTH | FLOOR | PPD (%) range | PMV (warm to cool) range | NUMBER OF STATIONS (out of 9) NON-COMPLYING WITH ASHRAE |
|---|---|---|---|---|
| May 1990 | $8^{th}$ ($CO_2$) | 6 to 41 | neutral to slightly cool | 4 |
| | $9^{th}$ | 7 to 71 | neutral to cool | 3 |
| June 1990 | $8^{th}$ ($CO_2$) | 7 to 78 | neutral to cool | 7 |
| | $9^{th}$ | 22 to 78 | slightly cool to cool | 8 |
| July 1990 | $8^{th}$ ($CO_2$) | 21 to 76 | slightly cool to cool | 9 |
| | $9^{th}$ | 14 to 76 | slightly cool to cool | 8 |
| August 1990 | $8^{th}$ ($CO_2$) | 6 to 32 | slightly warm to slightly cool | 1 |
| | $9^{th}$ | 6 to 52 | slightly warm to cool | 2 |
| September 1990 | $8^{th}$ ($CO_2$) | 5 to 56 | slightly warm to cool | 3 |
| | $9^{th}$ | 6 to 67 | slightly warm to cool | 3 |
| October 1990 | $8^{th}$ ($CO_2$) | 5 to 52 | slightly warm to slightly cool | 5 |
| | $9^{th}$ | 5 to 21 | slightly warm to slightly cool | 1 |

| MONTH | FLOOR | PPD (%) range | PMV (warm to cool) range | NUMBER OF STATIONS (out of 9) NON-COMPLYING WITH ASHRAE |
|---|---|---|---|---|
| November 1990 | 8th ($CO_2$) | 5 to 38 | slightly warm to slightly cool | 2 |
| | 9th | 5 to 30 | slightly warm to slightly cool | 1 |
| December 1990 | 8th ($CO_2$) | 5 to 71 | slightly warm to cool | 1 |
| | 9th | 7 to 21 | slightly warm to slightly cool | 2 |
| January 1991 | 8th ($CO_2$) | 6 to 24 | slightly warm to slightly cool | 2 |
| | 9th | 7 to 29 | slightly warm to slightly cool | 2 |
| February 1991 | 8th ($CO_2$) | 6 to 32 | slightly warm to slightly cool | 2 |
| | 9th | 7 to 46 | slightly warm to slightly cool | 1 |
| March 1991 | 8th ($CO_2$) | 6 to 38 | slightly warm to slightly cool | 2 |
| | 9th | 9 to 35 | slightly warm to slightly cool | 4 |
| April 1991 | 8th ($CO_2$) | 5 to 28 | slightly warm to slightly cool | 1 |
| | 9th | 5 to 36 | slightly warm to slightly cool | 2 |

The range of the predicted mean vote seems to be similar on both floors, except for the months of May, June, and August, when the 9th floor seemed cooler than the 8th ($CO_2$) floor. The reverse was true during the month of December. The

number of stations not respecting the ASHRAE maximum of 20 % dissatisfaction varies from 1 to 9 (out of 9) on each floor. The two months having the greatest number of non-complying stations are June and July (range of 7 to 9 stations). Both floors had similar numbers of unsatisfactory stations throughout the year.

By grouping the seasons and floors together, the following patterns emerge:

-during the spring months, the mean vote ranged from slightly warm to slightly cool;

-during the summer months, the mean vote ranged from slightly warm to cool;

-during the fall months, the mean vote ranged from slightly warm to cool; and

-during the winter months, the mean vote ranged from slightly warm to slightly cool.

There sometimes seems to be a contradiction between the readings of the global comfort (indicating mostly cooler environments) and the operative and dry-bulb temperatures from Table 5.1 (indicating mostly warmer environments). This may put into evidence the need to re-evaluate the responses from the comfort indices with respect to our Canadian climate. However, that is not within the scope of this work.

Since the $CO_2$-run floor does not result in lower dissatisfaction levels, one can say that the $CO_2$-control system does not worsen the thermal comfort as perceived by the instrument.

## 5.6 Conclusions

The thermal comfort parameters studied are temperature (operative and dry-bulb), relative humidity, air diffusion performance index, vertical temperature gradients, air velocities, and global thermal comfort indices. These were measured for three working days, every third week of every month. The 8$^{th}$ floor ($CO_2$-controlled) and the 9$^{th}$ floor were monitored simultaneously, when possible.

Most of the parameters satisfied the applicable standards and regulations:

1) the operative temperature was within the ASHRAE comfort limits except for the months of June, July, and August, when it was too high (due to under-designed compressors, as declared by the building maintenance personnel);

2) the dry-bulb temperature was always above the minimum of 20°C required by the RRQWE;

3) the relative humidity was always within the ASHRAE comfort limits, and above the minimum of 20% required by the RRQWE except for the months of December, January, and March (due to under-designed humidifiers, as declared by the building maintenance personnel);

4) the ADPI was always above 80% as recommended, except for 8 times out of 48 (probably due to volumetric flow rate changes done by the building maintenance personnel);

5) the vertical temperature gradients were always below the maximum of 3°C as recommended by ASHRAE, except for 4 occasions out of 48 (due to broken compressors);

6) the air velocities were within the ASHRAE maximum limits for comfort, however 4 incidents out of 48 seemed to have too low velocities, inducing sensations of stagnant air (as recommended by PWC); and

7) the global thermal comfort indices seemed to indicate dissatisfaction levels ranging from 5 to 78% (from slightly warm to cool sensations), surpassing

the maximum of 20% dissatisfaction as recommended by ASHRAE 33% of the time, divided more or less evenly throughout the whole year.

The $CO_2$-control system does not worsen the thermal comfort. Most of the discomfort sited above was due to other components of the ventilation system. From previous work, it was found that both floors experienced equivalent levels of the various parameters.(30) It is not necessary to produce detailed statistical analysis of the differences between the two floors. The objective of this work was to show that the two floors would respect the ASHRAE standards. After implementation of the control system, the 8$^{th}$ floor ($CO_2$) did not experience worst conditions than the 9$^{th}$ floor:

1) when comparing the instantaneous results of operative and dry-bulb temperatures, maximum vertical temperature gradients, and relative humidities from both floors, no floor consistently experienced higher levels;

2) when comparing the zonal ADPI levels from both floors, the 9$^{th}$ floor seems to experience higher levels than the 8$^{th}$ ($CO_2$) floor;

3) when comparing the average air velocities from both floors, the 9$^{th}$ floor seems to experience higher levels; and

4) when comparing the global thermal comfort indices, no floor consistently experienced higher levels of dissatisfaction over the other.

Therefore, the thermal comfort does not worsen with the implementation of a $CO_2$-controlled system as compared to the outdoor temperature-controlled system. As was seen in the previous chapter, the supply air temperature sensor overrode the $CO_2$-control during the months of September, October, and November. However, no marked difference was found between these three months and the rest of the year, with respect to the thermal comfort parameters.

The results do not indicate that $CO_2$ is either a good or bad indicator for thermal comfort, except that the installation of a $CO_2$-control monitor does not compromise the thermal environment.

Some work has shown that $CO_2$ control alone can cause thermal comfort problems, especially during the summer months.(24) The only discomfort which was felt was due to other components in the ventilation system, and not the supply temperature and $CO_2$ controls.

# CHAPTER 6

## 6. OCCUPANT PERCEPTION ANALYSIS

As mentioned previously, ASHRAE defines acceptable indoor air quality as being

> "air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction."(29)

An acceptable thermal environment is further defined as follows: "an environment which at least 80% of the occupants would find thermally acceptable."(74)

If the use of outdoor air is to be restricted with the provision that the $CO_2$ level be held below a certain limit, there must be assurance that occupant acceptance does not diminish. Saving energy at the expense of occupant acceptance would be an unattractive compromise. The following chapter will show that the occupants do not perceive a deterioration in their working environment with the $CO_2$-controlled system as compared to the outdoor temperature-controlled system (both floors had identical responses before).(3)

The subjective response of the occupants to the environment was measured with a questionnaire, as shown in the Appendix. The questionnaire was distributed throughout the two floors, to all occupants in the open-area offices, every 3$^{rd}$

Wednesday morning of every month. These were then collected that same afternoon.

## 6.1 Response Rate

Table 6.1 and Figure 6.1 show the response rate for the distributed questionnaires.

Table 6.1 Monthly response rate (in percentage)

| month | response rate | |
|---|---|---|
| | $8^{th}$ ($CO_2$) | $9^{th}$ |
| May 1990 | 44 | 44 |
| June 1990 | 55 | 46 |
| July 1990 | 57 | 83 |
| August 1990 | 73 | 63 |
| September 1990 | 63 | 42 |
| October 1990 | 58 | 50 |
| November 1990 | 62 | 50 |
| December 1990 | 51 | 44 |
| January 1991 | 67 | 45 |
| February 1991 | 62 | 59 |
| March 1991 | 64 | 42 |
| April 1991 | 44 | 50 |
| Average | 58 | 52 |

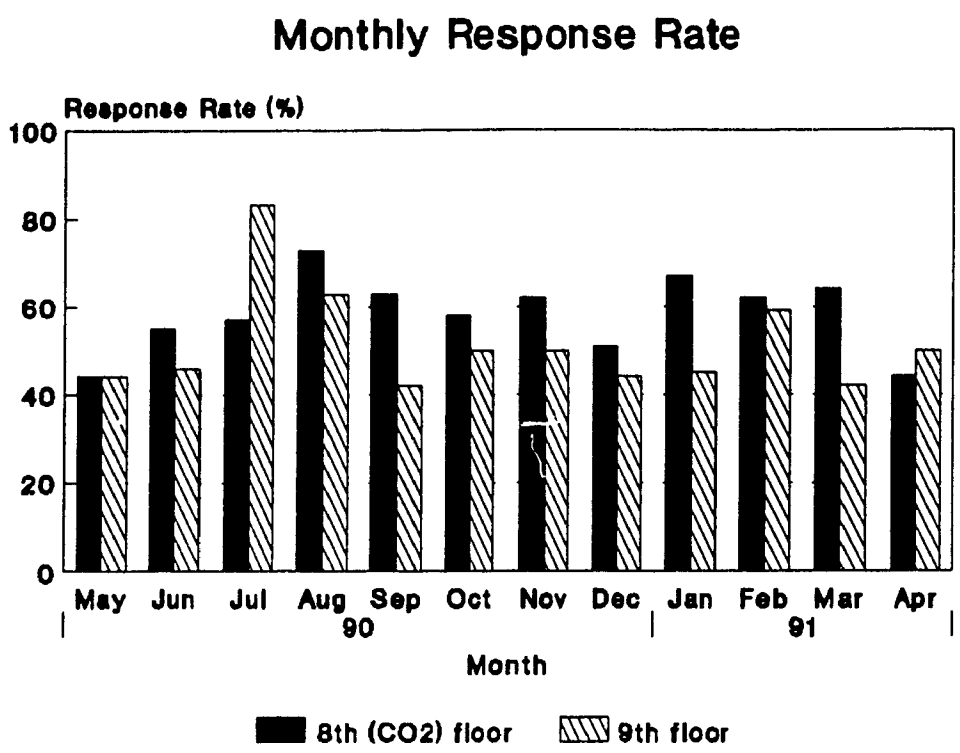



Figure 6.1 Monthly response rate

The average response rates for the 8th and 9th floors are 58% and 52%, respectively. There seems to be a higher monthly response rate from the 8th ($CO_2$) floor.

## 6.2 Detailed Results

The results obtained are given beginning with Table 6.2. Since ASHRAE prescribes the use of a "majority (80% or more) of the people exposed" as its criteria for satisfaction, only the answer chosen by the majority is relevant.(29,74) So to simplify the presentation of the results, only the answer chosen by the majority is shown. In other words, for each question, only the response which yielded the highest score is presented. The score is represented as a percentage of the total which answered that question. When no majority was evident (i.e., when two or more responses were chosen by an equivalent number of people), "no majority" is indicated next to the response in the following tables. The detailed responses can be found in the Appendix.

Table 6.2 Monthly majority response of question #3 (corresponding percentage)

| month | question and response | |
|---|---|---|
| | 8th ($CO_2$) | 9th |
| | #3. The temperature is cold, cool, comfortable, warm, hot | |
| May 1990 | comfortable 50% | cool 36% |
| June 1990 | cold 48% | comfortable 39% |
| July 1990 | no majority | cool 43% |
| August 1990 | comfortable 47% | comfortable 50% |
| September 1990 | comfortable 36% | cool 44% |
| October 1990 | comfortable 36% | comfortable 37% |
| November 1990 | comfortable 29% | comfortable 39% |
| December 1990 | comfortable 40% | comfortable 31% |
| January 1991 | cool 32% | comfortable 33% |
| February 1991 | comfortable 35% | cool 33% |
| March 1991 | comfortable 33% | comfortable 50% |
| April 1991 | cool 32% | comfortable 50% |

From the results obtained, we can see that for eight months of the year, the occupants felt that the temperature was comfortable (except for the months of June, January, and April which seemed cool on the 8th ($CO_2$) floor; and the months of May, July, September, and February which also seemed cool on the 9th floor). The two floors felt "comfortable" and "cool" for the same number of months; so one cannot say that one floor was more uncomfortable than the other.

Table 6.3 Monthly majority response of question #4 (corresponding percentage)

| month | question and response | |
|---|---|---|
| | 8th ($CO_2$) | 9th |
| | #4. Does the temperature vary during the day? no, a little, adequately, a lot, excessively<br>If yes, at what time?<br>Increases or decreases? | |
| May 1990 | no 36% | a lot 60%<br>AM 50%<br>no majority |
| June 1990 | no 36% | no majority |
| July 1990 | no 50% | a lot 60%<br>no majority |
| August 1990 | a lot 47%<br>PM 100%<br>increases 100% | no majority |
| September 1990 | a lot 37%<br>PM 67%<br>decreases 57% | a little 39%<br>PM 50%<br>increases 60% |
| October 1990 | adequately 36%<br>PM 75%<br>no majority | a lot 35%<br>PM 100%<br>increases 83% |
| November 1990 | no 30% | no majority |
| December 1990 | adequately 39%<br>PM 75%<br>no majority | a lot 36%<br>PM 75%<br>decreases 50% |
| January 1991 | no majority | no 37% |
| February 1991 | adequately 32%<br>PM 75%<br>increases 57% | no majority |
| March 1991 | adequately 31%<br>PM 58%<br>increases 60% | a little 38%<br>PM 80%<br>increases 60% |
| April 1991 | adequately 43%<br>PM 86%<br>increases 57% | adequately 47%<br>PM 75%<br>no majority |

The hourly variation in temperature seemed to be adequate, as felt by the occupants on the 8th ($CO_2$) floor; except for the month of August, where an uncomfortable increase in temperature was noted in the afternoon, and for the month of September, where an uncomfortable decrease in temperature was noted in the afternoon. For the 9th floor; only one third of the year had adequate hourly temperature variations. The months of May and July were uncomfortable due to changes in temperature; but no consensus was determined as to when and how. The month of October was uncomfortable due to an increase in temperature in the afternoon, and the month of December, was uncomfortable due to a decrease in temperature noted in the afternoon.

The 9th floor occupants expressed uncomfortable conditions more often than the 8th ($CO_2$) floor.

Table 6.4 Monthly majority response of question #5 (corresponding percentage)

| month | question and response | | | |
|---|---|---|---|---|
| | 8th ($CO_2$) | | 9th | |
| | #5. The air is dry, slightly dry, satisfactory, slightly humid, humid | | | |
| May 1990 | dry | 54% | dry | 63% |
| June 1990 | dry | 52% | dry | 44% |
| July 1990 | dry | 46% | dry | 44% |
| August 1990 | slightly dry | 46% | slightly dry | 40% |
| September 1990 | dry | 52% | dry | 53% |
| October 1990 | dry | 60% | dry | 60% |
| November 1990 | dry | 43% | dry | 65% |
| December 1990 | dry | 63% | dry | 56% |
| January 1991 | dry | 50% | dry | 50% |
| February 1991 | dry | 62% | dry | 55% |
| March 1991 | dry | 44% | dry | 47% |
| April 1991 | dry | 52% | dry | 39% |

The air was considered to be slightly dry to dry all of the time, by the majority of the occupants. Both floors responded identically throughout the year.

Table 6.5 Monthly majority response of question #6 (corresponding percentage)

| month | question and response | |
|---|---|---|
| | 8th ($CO_2$) | 9th |
| | #6. The ventilation is drafty, slightly drafty, adequate, slightly stuffy, stuffy | |
| May 1990 | adequate 44% | stuffy 31% |
| June 1990 | no majority | slightly stuffy 27% |
| July 1990 | adequate 39% | slightly drafty 40% |
| August 1990 | adequate 50% | slightly drafty 33% |
| September 1990 | slightly drafty 31% | slightly drafty 28% |
| October 1990 | slightly drafty 37% | slightly stuffy 39% |
| November 1990 | adequate 57% | stuffy 35% |
| December 1990 | adequate 37% | stuffy 38% |
| January 1991 | adequate 37% | no majority |
| February 1991 | adequate 35% | no majority |
| March 1991 | adequate 41% | adequate 33% |
| April 1991 | adequate 44% | adequate 41% |

The ventilation was considered to be adequate for the 8th ($CO_2$) floor at all times, except for the months of September and October, when it was slightly drafty. The ventilation was never considered to be adequate by the majority of the occupants on the 9th floor, except for the months of March and April. It was slightly drafty for the months of July, August, and September; slightly stuffy for the months of June and October; and stuffy for the months of May, November, and December. It is evident that the 9th floor occupants felt more uncomfortable than the 8th ($CO_2$) floor.

Table 6.6 Monthly majority response of question #7 (corresponding percentage)

| month | question and response | | | |
|---|---|---|---|---|
| | 8th ($CO_2$) | | 9th | |
| | #7. Do you feel a draft on the back of your neck? no, rarely, sometimes, often, regularly | | | |
| May 1990 | no | 65% | no | 50% |
| June 1990 | no | 57% | no | 56% |
| July 1990 | no | 54% | often | 40% |
| August 1990 | no | 76% | no | 53% |
| September 1990 | no | 55% | no | 61% |
| October 1990 | no | 64% | no | 75% |
| November 1990 | no | 84% | no | 75% |
| December 1990 | no | 56% | no | 67% |
| January 1991 | no | 66% | no | 65% |
| February 1991 | no | 66% | no | 75% |
| March 1991 | no | 59% | no | 71% |
| April 1991 | no | 70% | no | 61% |

As seen in the above results, the occupants never felt a draft on the back of their necks (except for the month of July, on the 9th floor, when it was felt often). However, it was noted that the occupants placed make-shift dampers atop of the ceiling diffusers so that the air would not fall directly onto them. The air flows seemed to be uncomfortably high along the periphery, and uncomfortably low in the centre of the floor. Comparing the answers from both floors, one can say that the responses are almost identical.

Table 6.7 Monthly majority response of question #8 (corresponding percentage)

| month | question and response | | | |
|---|---|---|---|---|
| | 8th ($CO_2$) | | 9th | |
| | #8. Are your feet cold? no, rarely, sometimes, often, regularly | | | |
| May 1990 | no | 46% | no majority | |
| June 1990 | no | 47% | no | 38% |
| July 1990 | sometimes | 46% | no majority | |
| August 1990 | no | 46% | no | 60% |
| September 1990 | no | 38% | no | 61% |
| October 1990 | no | 48% | no | 70% |
| November 1990 | no | 58% | no | 70% |
| December 1990 | no | 59% | no | 56% |
| January 1991 | no | 65% | no | 65% |
| February 1991 | no | 55% | no | 55% |
| March 1991 | no | 46% | no | 53% |
| April 1991 | no | 55% | no | 67% |

The occupants never felt cold at the feet level (except for the month of July, on the 8th ($CO_2$) floor, and then again, only sometimes). The responses are practically identical on both floors.

Table 6.8 Monthly majority response of question #9 (corresponding percentage)

| month | question and response | |
|---|---|---|
| | 8th ($CO_2$) | 9th |
| | #9. If you are seated next to a window, does the window affect your thermal comfort? no, a little, adequately, a lot, excessively | |
| May 1990 | no majority | a lot 75% |
| June 1990 | adequately 30% | adequately 57% |
| July 1990 | a little 33% | no majority |
| August 1990 | a lot 36% | adequately 50% |
| September 1990 | a lot 50% | a little 44% |
| October 1990 | a lot 35% | no 57% |
| November 1990 | no majority | no majority |
| December 1990 | no 33% | no majority |
| January 1991 | a little 31% | a lot 30% |
| February 1991 | no majority | no 36% |
| March 1991 | a lot 35% | no majority |
| April 1991 | no majority | no majority |

For the occupants seated along the periphery, the majority said they did not perceive any uncomfortable changes in temperature (except for the months of August, September, October, and March on the 8th ($CO_2$) floor, and for the months of May and January on the 9th floor). Comparing the results from both floors, it seems that the 8th ($CO_2$) floor occupants seated next to a window were more uncomfortable than those on the 9th floor, since they complained twice as often.

Table 6.9 Monthly majority response of question #10 (corresponding percentage)

| month | question and response | |
|---|---|---|
| | 8th ($CO_2$) | 9th |
| | #10. In your opinion, the quality of the air is: very good, good, satisfactory, unsatisfactory, bad | |
| May 1990 | bad 39% | unsatisfactory 57% |
| June 1990 | satisfactory 36% | satisfactory 31% |
| July 1990 | bad 39% | unsatisfactory 44% |
| August 1990 | no majority | no majority |
| September 1990 | no majority | bad 38% |
| October 1990 | no majority | unsatisfactory 33% |
| November 1990 | unsatisfactory 48% | satisfactory 47% |
| December 1990 | no majority | unsatisfactory 38% |
| January 1991 | unsatisfactory 44% | satisfactory 35% |
| February 1991 | unsatisfactory 48% | unsatisfactory 33% |
| March 1991 | unsatisfactory 61% | no majority |
| April 1991 | unsatisfactory 56% | satisfactory 65% |

The majority of the occupants found the quality of the air satisfactory less than one third of the time (8th floor: bad for the months of May and July, and unsatisfactory for the months of November, January, February, March, and April; 9th floor: bad for the month of September, and unsatisfactory for the months of May, July, October, December, and February). However, it was noted occasionally that some people did not answer the question on indoor air quality. Instead, they stated they did not know enough to judge. There seems to be dissatisfaction felt more often on the 8th ($CO_2$) floor than on the 9th, since the $CO_2$-

controlled floor found the quality of the air satisfactory only once throughout the whole year.

Table 6.10 Monthly majority response of question #11 (corresponding percentage)

| month | question and response | |
|---|---|---|
| | 8th ($CO_2$) | 9th |
| | #11. Does the quality of the air change during the day? no, a little, adequately, a lot, excessively | |
| May 1990 | no 39% | a lot 20% |
| June 1990 | no 33% | a lot 50% |
| July 1990 | no 54% | a lot 44% |
| August 1990 | a lot 44% | a lot 42% |
| September 1990 | adequately 32% | a little 38% |
| October 1990 | adequately 60% | a lot 32% |
| November 1990 | no 32% | a little 32% |
| December 1990 | a little 31% | no majority |
| January 1991 | a little 36% | no 44% |
| February 1991 | no 33% | no 42% |
| March 1991 | adequately 40% | no majority |
| April 1991 | adequately 44% | a little 47% |

The occupants on the 8th ($CO_2$) floor found there were "no" to "adequate" variations in the quality of the air throughout the day; it was always bad or unsatisfactory. During the month of August, however, they voted a large change in air quality; but there was no consensus as to the quality of the air, to begin with.

The occupants from the 9th floor voted for "no" to "little" variations half of the year, and a lot of variation in air quality the other half of the year. When they perceived stable conditions, the quality was either satisfactory or bad. When unstable conditions were felt, the quality also ranged from satisfactory to unsatisfactory.

Table 6.11 Monthly majority response of question #12 (corresponding percentage)

| month | question and response | | | |
|---|---|---|---|---|
| | 8th ($CO_2$) | | 9th | |
| | #12. In general, the thermal environment is: very comfortable, comfortable, adequate, slightly unacceptable, unacceptable | | | |
| May 1990 | slightly unacceptable | 38% | unacceptable | 67% |
| June 1990 | no majority | | no majority | |
| July 1990 | unacceptable | 46% | slightly unacceptable | 63% |
| August 1990 | no majority | | adequate | 47% |
| September 1990 | slightly unacceptable | 38% | adequate | 33% |
| October 1990 | slightly unacceptable | 39% | slightly unacceptable | 35% |
| November 1990 | slightly unacceptable | 43% | adequate | 40% |
| December 1990 | adequate | 42% | adequate | 56% |
| January 1991 | slightly unacceptable | 41% | adequate | 40% |
| February 1991 | slightly unacceptable | 35% | adequate | 53% |
| March 1991 | slightly unacceptable | 36% | no majority | |
| April 1991 | slightly unacceptable | 35% | adequate | 41% |

The majority of the occupants on the 8th ($CO_2$) floor found the thermal environment adequate for the month of December, only. It was slightly unacceptable to unacceptable for the rest of the year. Contrarily, the 9th floor occupants found the thermal environment adequate for more than half of the year. It was unacceptable for the months of May, July and October. However, it is difficult to generalize on the thermal comfort responses, since people sitting next to each other responded with opposite comments.

Comparing the responses from each floor, it is evident that the occupants on the 8th ($CO_2$) floor are much less satisfied with their thermal environment than those on the 9th floor.

Table 6.12 Monthly majority response of question #13 (corresponding percentage)

| month | question and response | | | |
|---|---|---|---|---|
| | 8th ($CO_2$) | | 9th | |
| | #13. Do you perceive odours regularly? no, less than once a day, once a day, more than once a day, regularly<br>If yes, what odours? | | | |
| May 1990 | no | 50% | no majority | |
| June 1990 | no | 52% | no | 47% |
| July 1990 | no | 50% | no | 40% |
| August 1990 | no | 55% | no | 47% |
| September 1990 | no | 58% | no | 59% |
| October 1990 | no | 64% | no | 58% |
| November 1990 | no | 52% | no | 61% |
| December 1990 | no | 40% | no | 60% |
| January 1991 | no | 50% | no | 53% |
| February 1991 | regularly<br>food, solvent, and cigarettes | 35%<br>25% | no | 61% |
| March 1991 | no | 43% | no | 41% |
| April 1991 | no | 65% | no | 71% |

The majority of the occupants from both floors do not perceive odours regularly, however, the main odours that are perceived are cigarette smoke, food, and solvent. One occupant said the solvent smell, one day in February, was so strong that she became ill and had to leave the building. However, we were not able to detect strong concentrations with our testing, and we were not aware of any

renovations or solvent generation coming from elsewhere in the building, or outside.

Table 6.13 Monthly majority response of question #14 (corresponding percentage)

| month | question and response | |
|---|---|---|
| | 8th ($CO_2$) | 9th |
| | #14. Please note how you think the physical environment (air quality, thermal comfort, ventilation) affects your productivity: 40% or more increase, 30% increase, 20% increase, 10% increase, no effect, 10% decrease, 20% decrease, 30% decrease, 40% decrease | |
| May 1990 | not asked | not asked |
| June 1990 | not asked | not asked |
| July 1990 | not asked | not asked |
| August 1990 | not asked | not asked |
| September 1990 | not asked | not asked |
| October 1990 | not asked | not asked |
| November 1990 | not asked | not asked |
| December 1990 | -10 38% | no majority |
| January 1991 | -10 41% | no majority |
| February 1991 | -20 32% | -20 22% |
| March 1991 | -20 41% | -10 47% |
| April 1991 | -20 46% | no majority |

Finally, the majority of the occupants found that their physical environment had little effect on their productivity (10% decrease for the months of December and January, and 20% decrease for the months of February, March and April on the 8$^{th}$ ($CO_2$) floor; 10% decrease for the month of March and 20% decrease for the month of February on the 9$^{th}$ floor). Some occupants stated that their decrease in productivity in the afternoon was directly related to the overheating of the ambient temperature and the bad air quality in the afternoon. It seems that the perceived change in productivity decreases more on the 8$^{th}$ floor than on the 9$^{th}$ floor. Some occupants have actually stated that the "global environment" at their homes gives them higher productivity rates. One occupant stated that it is the comfort that should matter, and not the quality of the air. Openable windows was a suggestion given to us by more than one occupant, as a solution to "the problem".

The occupants on the 8$^{th}$ ($CO_2$) floor seem to be more dissatisfied with their working environment than the occupants on the 9$^{th}$ floor (with respect to indoor air quality, thermal comfort, and discomfort from a window). However, the 9$^{th}$ floor occupants complained more about the hourly temperature variations and the air velocities (adequacy of ventilation).

## 6.3 Comparison with ASHRAE

To compare our results with the ASHRAE standards, we would add all of the respondents which answered "satisfactory", "good", and "very good" air quality; and "adequate", "comfortable", and "very comfortable" thermal environment. These totals are shown in Tables 6.14 and 6.15, and in Figure 6.2 below.

Table 6.14 Detailed totals of responses for indoor air quality (%)

| floor | question and answer | | | | | | |
|---|---|---|---|---|---|---|---|
| | #10. In your opinion, the quality of the air is | | | | | | |
| | very good | good | satisfactory | sub-total good | unsatisfactory | bad | sub-total bad |
| May 1990 | | | | | | | |
| 8 | 0 | 5 | 30 | 35 | 26 | 39 | 65 |
| 9 | 0 | 7 | 0 | 7 | 57 | 36 | 93 |
| June 1990 | | | | | | | |
| 8 | 0 | 6 | 36 | 42 | 29 | 29 | 58 |
| 9 | 0 | 19 | 31 | 50 | 25 | 25 | 50 |
| July 1990 | | | | | | | |
| 8 | 0 | 23 | 31 | 54 | 7 | 39 | 46 |
| 9 | 0 | 0 | 33 | 33 | 44 | 23 | 67 |
| August 1990 | | | | | | | |
| 8 | 0 | 0 | 26 | 26 | 37 | 37 | 74 |
| 9 | 7 | 8 | 31 | 46 | 23 | 31 | 54 |

| floor | question and answer | | | | | | |
|---|---|---|---|---|---|---|---|
| | *10. In your opinion, the quality of the air is | | | | | | |
| | very good | good | satisfactory | sub-total good | unsatisfactory | bad | sub-total bad |
| September 1990 | | | | | | | |
| 8 | 0 | 0 | 41 | 41 | 41 | 18 | 59 |
| 9 | 5 | 19 | 25 | 49 | 13 | 38 | 51 |
| October 1990 | | | | | | | |
| 8 | 3 | 4 | 38 | 45 | 38 | 17 | 55 |
| 9 | 0 | 11 | 28 | 39 | 33 | 28 | 61 |
| November 1990 | | | | | | | |
| 8 | 4 | 7 | 31 | 42 | 48 | 10 | 58 |
| 9 | 0 | 6 | 47 | 53 | 26 | 21 | 47 |
| December 1990 | | | | | | | |
| 8 | 0 | 4 | 40 | 44 | 40 | 16 | 56 |
| 9 | 0 | 31 | 19 | 50 | 38 | 12 | 50 |
| January 1991 | | | | | | | |
| 8 | 2 | 12 | 21 | 35 | 44 | 21 | 65 |
| 9 | 0 | 18 | 35 | 53 | 29 | 18 | 47 |
| February 1991 | | | | | | | |
| 8 | 4 | 0 | 22 | 26 | 48 | 26 | 74 |
| 9 | 0 | 28 | 28 | 56 | 33 | 11 | 44 |
| March 1991 | | | | | | | |
| 8 | 3 | 3 | 26 | 32 | 61 | 7 | 68 |
| 9 | 0 | 12 | 35 | 47 | 35 | 18 | 53 |
| April 1991 | | | | | | | |
| 8 | 11 | 5 | 17 | 33 | 56 | 11 | 67 |
| 9 | 0 | 12 | 65 | 77 | 18 | 5 | 23 |

Less than 80% express satisfaction with the indoor air quality, and this, at all times throughout the testing year. Therefore, according to the ASHRAE standard, this environment is not perceived as acceptable, with respect to the quality of the indoor air. It is evident, by comparing the results from both floors, that the 8th ($CO_2$) floor occupants were less satisfied than the 9th floor.

Table 6.15 Detailed totals of responses for thermal comfort (%)

| floor | question and answer | | | | | | |
|---|---|---|---|---|---|---|---|
| | *12. In general, the thermal environment is | | | | | | |
| | very comfortable | comfortable | adequate | sub-total good | slightly unac-ceptable | unac-ceptable | sub-total bad |
| May 1990 | | | | | | | |
| 8 | 0 | 4 | 25 | 29 | 38 | 33 | 71 |
| 9 | 0 | 0 | 20 | 20 | 13 | 67 | 80 |
| June 1990 | | | | | | | |
| 8 | 0 | 3 | 25 | 28 | 36 | 36 | 72 |
| 9 | 0 | 19 | 31 | 50 | 19 | 31 | 50 |
| July 1990 | | | | | | | |
| 8 | 7 | 8 | 31 | 46 | 8 | 46 | 54 |
| 9 | 0 | 0 | 25 | 25 | 63 | 12 | 75 |
| August 1990 | | | | | | | |
| 8 | 4 | 5 | 27 | 36 | 32 | 32 | 64 |
| 9 | 0 | 0 | 47 | 47 | 33 | 20 | 53 |
| September 1990 | | | | | | | |
| 8 | 0 | 6 | 35 | 41 | 38 | 21 | 59 |
| 9 | 0 | 17 | 33 | 50 | 28 | 22 | 50 |

| floor | question and answer | | | | | | |
|---|---|---|---|---|---|---|---|
| | *12. In general, the thermal environment is | | | | | | |
| | very comfortable | comfortable | adequate | sub-total good | slightly unac-ceptable | unac-ceptable | sub-total bad |
| October 1990 | | | | | | | |
| 8 | 0 | 7 | 36 | 43 | 39 | 18 | 57 |
| 9 | 0 | 15 | 25 | 40 | 35 | 25 | 60 |
| November 1990 | | | | | | | |
| 8 | 0 | 0 | 40 | 40 | 43 | 17 | 60 |
| 9 | 5 | 5 | 40 | 50 | 25 | 25 | 50 |
| December 1990 | | | | | | | |
| 8 | 3 | 4 | 42 | 49 | 39 | 12 | 51 |
| 9 | 0 | 13 | 56 | 69 | 6 | 25 | 31 |
| January 1991 | | | | | | | |
| 8 | 3 | 12 | 29 | 44 | 41 | 15 | 56 |
| 9 | 5 | 15 | 40 | 60 | 15 | 25 | 40 |
| February 1991 | | | | | | | |
| 8 | 0 | 3 | 31 | 34 | 35 | 31 | 66 |
| 9 | 0 | 15 | 53 | 68 | 0 | 32 | 32 |
| March 1991 | | | | | | | |
| 8 | 3 | 4 | 33 | 40 | 36 | 24 | 60 |
| 9 | 0 | 12 | 35 | 47 | 35 | 18 | 53 |
| April 1991 | | | | | | | |
| 8 | 10 | 15 | 30 | 55 | 35 | 10 | 45 |
| 9 | 0 | 24 | 41 | 65 | 29 | 6 | 35 |

Less than 80% find the environment thermally acceptable, and this, at all times throughout the testing year. Therefore, according to the ASHRAE standard, this environment is not perceived as acceptable, with respect to the thermal comfort. As was found before, the 8$^{th}$ ($CO_2$) floor occupants are consistently more unsatisfied than the 9$^{th}$ floor occupants.

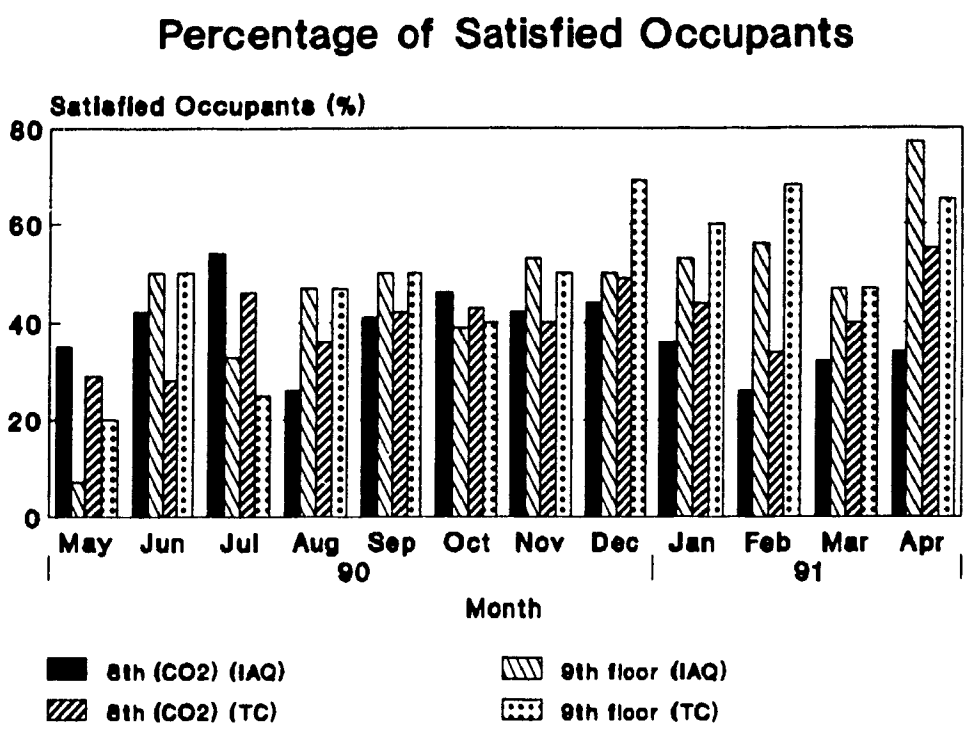



Figure 6.2 Monthly satisfied occupants

The 8$^{th}$ ($CO_2$) floor complained more about the quality of the air and the thermal environment. This corresponds with the larger decrease in productivity perceived by the 8$^{th}$ floor occupants as compared to that by the 9$^{th}$ floor. Similarly to what was found in previous work, the level of discomfort seems greater during the summer months (looking at the trend of thermal comfort satisfaction).(24)

## 6.4 Productivity

The perceived effect of the working environment on the occupants' productivity was compared to their perception of the indoor air quality and the thermal environment (see Figures 6.3 and 6.4).

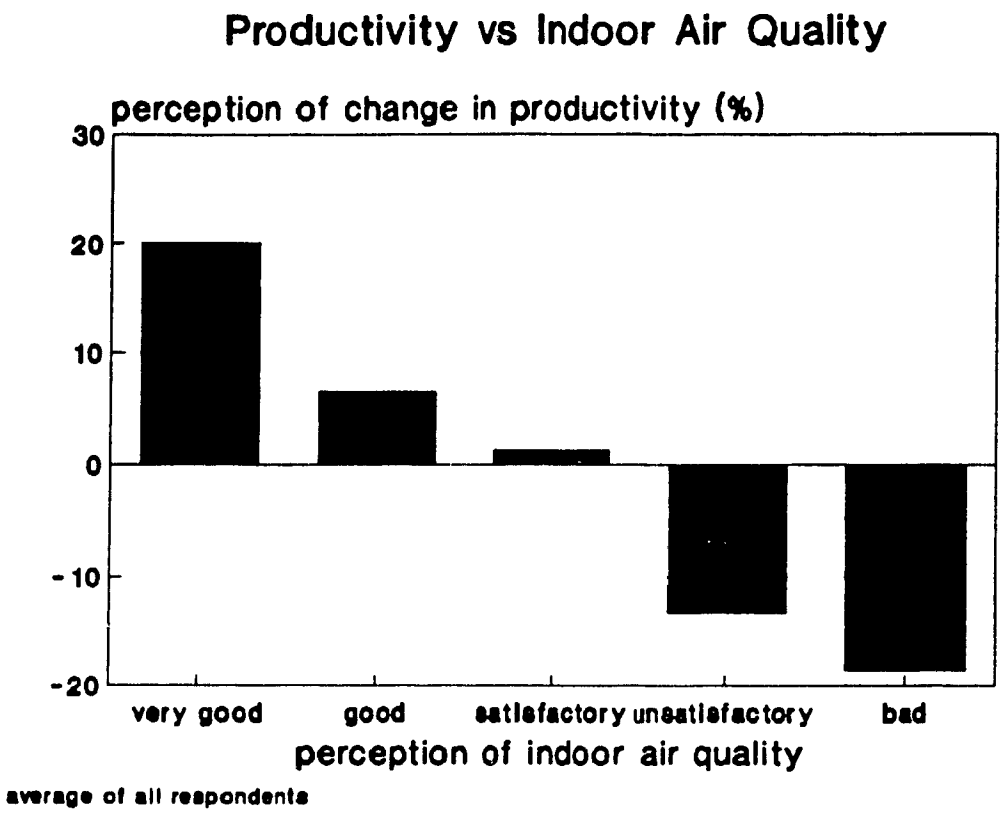



Figure 6.3 Perceived productivity vs perceived indoor air quality

It is obvious that the occupants' perceived change in productivity is proportional to the change in the working environment, be it indoor air quality or thermal comfort. Similar responses were found in a previous work, where almost 20% of the employees were convinced that an unacceptable indoor environment reduces their working efficiency.(32)

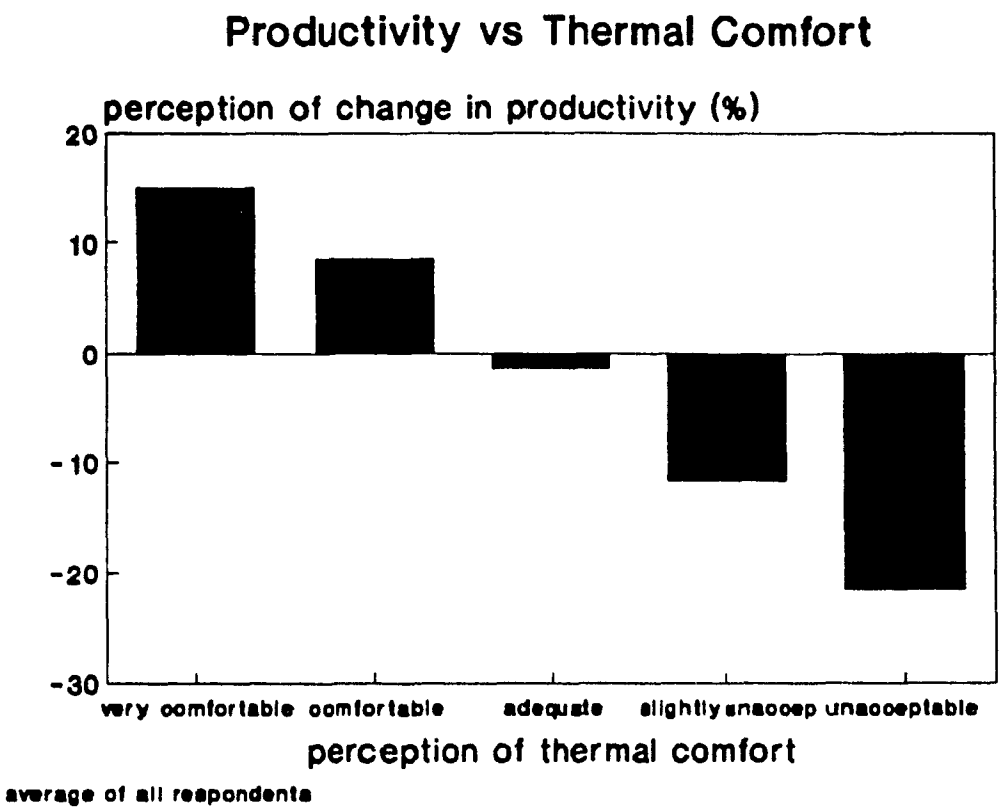



Figure 6.4 Perceived productivity vs perceived thermal comfort

As was seen before, the majority of the occupants were unsatisfied with both parameters, therefore indicating a 12 to a 22% decrease in productivity. If one were to convert this amount into dollars, one would find that much would be lost due to an unsatisfactory environment; showing the importance of keeping the quality of the air and the thermal environment within satisfactory limits (81) Other factors such as lighting, acoustics, privacy, salaries, etc., all have an effect on one's productivity; but were not within the scope of this work. It was assumed that the contribution of these factors was similar on both floors.(3)

## 6.5 Perceived vs Measured

The following will compare the various parameters as perceived by the occupants and as measured objectively.

### Temperature

Half of the time (13 out of 24), the occupants responded that the temperature was comfortable when indeed both the operative and dry-bulb temperatures were within the comfort limits During the months of June, August, January, and April, the majority of the occupants on the 8$^{th}$ ($CO_2$) floor felt cooler than the measured and recorded temperatures. Similarly, the 9$^{th}$ floor occupants felt cooler than the actual comfort conditions recorded during the months of May, June, July, August, September, and February. Occupants in a previous study also reported feeling more comfortable and generally cooler in the warm season than in the cold season regardless of the ventilation conditions.(25) This puts into evidence the question of validity of the existing comfort standards.

Humidity

Only 5 out of 24 times did the occupants respond that the air was dry when indeed the relative humidities were below the comfort limits. At least 39% and not more than 65% of the occupants always complained the air was dry. However, except for the months of December, January, and March, the relative humidity was always within the comfort limits.

Air Velocity

Half of the time, the occupants responded that the ventilation was adequate when indeed the air velocities were within comfortable limits. At least 28% of the occupants perceived greater air movements than measured for the months of July ($9^{th}$), August ($9^{th}$), September (both floors), and October ($8^{th}$). Also, at least 25% of the occupants perceived lesser air movements than measured for the months of May, June, October, November, and December, and this only for the $9^{th}$ floor occupants.

Vertical Temperature Gradients

Although the vertical difference was occasionally more than the maximum recommended, the occupants did not complain of local discomfort. Following is a list of the discrepancies:

-during the month of July, 46% of the occupants on the 8$^{th}$ ($CO_2$) floor sometimes felt coldness at their feet; while the measured vertical temperature gradients were within the comfort limits; and

-during the months of August (8$^{th}$), September (9$^{th}$), December (9$^{th}$), January (9$^{th}$), and March (9$^{th}$), at least 46% of the occupants never felt coldness at their feet; while the measured vertical temperature gradients were outside the comfort limits.

Air Quality

All of the parameters tested indicated a satisfactory air quality with respect to the standards, except for the months of June, November, and March, where the dust levels were too high on the 8$^{th}$ ($CO_2$) floor. However, the occupants' responses do not correspond to the measured data. The occupants complained even when there were no contaminants present at uncomfortable levels. A comparison

between the outdoor air change rates and the degree of satisfaction of the occupants does not produce any clear conclusion. The level of satisfaction does not seem to be in any way related to the amount of outdoor air being supplied. It is interesting to note that the 8$^{th}$ ($CO_2$) floor occupants did complain more than those on the 9$^{th}$ floor. This puts into question that maybe the occupants were hyper-sensitive with respect to the dust levels, and equated this to the general indoor air quality. Otherwise, this could be due to factors other than those measured. The 9$^{th}$ floor occupants are classified as "professionals" who spend their working week commuting between Quebec City and Montreal. The 8$^{th}$ ($CO_2$) floor occupants are classified as "clerks" who spend all of their working week at their desk. Although "job satisfaction" was not asked on the questionnaire (due to opposition from personnel management) it has been noted that the occupants of the 9$^{th}$ floor seem more content with their work position. The questionnaire responses could reflect such satisfaction (or lack of it)

A small increase in dissatisfaction was noted throughout the year for the 8$^{th}$ ($CO_2$) floor, with respect to indoor air quality. This could have been due to the increased irritation of the occupants with respect to having to answer yet another questionnaire. Another probable reason is the freeze which was implemented on their salaries, at about midway throughout our study. Psychological factors may play a role by increasing the stress of people and thus making them more susceptible to environmental factors.(84) In a multifactorial analysis, it was shown

that in addition to the building factor, other factors like sex, job and psychosocial factors are associated with the prevalence of mucosal irritation and general symptoms.(85)

Thermal Comfort

Comparing the thermal comfort readings to the questionnaire results, we find that the complaints do not correspond to the measured levels of global thermal comfort, except for the months of June (both floors), July (both floors), September ($9^{th}$), December ($8^{th}$), February ($9^{th}$), and April ($9^{th}$), when the measured levels of predicted percentage of dissatisfied were similar to the number of occupants which indicated dissatisfaction on their questionnaires. For the remainder of the year, the PPD values were much lower than the number of dissatisfied occupants.

Finally, it seems that the $9^{th}$ floor occupants' responses were dissimilar to the measured values more often than the $8^{th}$ ($CO_2$) floor. This puts into question the validity of their responses, indicating that maybe the $8^{th}$ ($CO_2$) floor's dissatisfaction is not really that much greater than the $9^{th}$ floor's.

## 6.6 Conclusions

The subjective response of the occupants to their working environment was measured with a questionnaire. The questionnaire was distributed throughout the two floors to all occupants in the open-area offices, every third Wednesday of every month.

The average response rates of 58 and 52%, for the 8$^{th}$ ($CO_2$) and 9$^{th}$ floors, respectively, were deemed acceptable as being representative of the total population.

When the questionnaires were analyzed, and the majority responses highlighted, the following summary prevailed for most of the year:

-the temperature was comfortable and somewhat stable throughout the day;

-the air was dry;

-the ventilation was deemed adequate only on the 8$^{th}$ ($CO_2$) floor; no consistent response was given to qualify the ventilation on the 9$^{th}$ floor;

-most did not feel drafts on the back of their necks;

-most did not experience coldness at their feet;

-most felt the window affected their thermal comfort to a minimal degree;

-the quality of the air was unsatisfactory;

-the thermal environment was deemed unacceptable on the 8$^{th}$ ($CO_2$) floor, and perceived adequate on the 9$^{th}$ floor;

-no odours were perceived regularly, however the odours that did prevail were cigarettes, solvent, and food; and

-the productivity was perceived as decreasing up to 20% due to the interior environment.

More than 20% were unsatisfied with the indoor air quality, and more than 30% were unsatisfied with the thermal environment, at all times. Therefore, according to the ASHRAE standards, this environment is not perceived as acceptable.

The productivity was found to be directly proportional to the perception of the quality of the indoor environment.

The occupants of the 8$^{th}$ ($CO_2$) floor seem to be more dissatisfied with their working environment (with respect to indoor air quality and thermal comfort) than the occupants of the 9$^{th}$ floor, indicating the effect of other psychological or "global environmental" factors.

However, the occupants' responses do not generally correspond with the actual, measured data, especially on the 9$^{th}$ floor. This questions the validity of those responses, indicating that perhaps the 8$^{th}$ ($CO_2$) floor's dissatisfaction is not that much greater than the 9$^{th}$ floor's. The satisfaction of both floors was found to be equivalent before implementation of the control system.(3)

Therefore, although the occupants were unaware of any changes in their HVAC systems, the demand controlled ventilation floor perceived more dissatisfaction than the normally-run floor; however, this difference cannot be validated with the measured values. So, one cannot say that implementation of a DCV system improves or decreases the satisfaction of the occupants.

# CHAPTER 7

## 7. ENERGY DEMAND ANALYSIS

A potential source of energy conservation exists within the commercial sector in business establishments that have a transient occupancy rate, yet operate ventilation systems at code-specified maximum occupancy levels, or as a function of exterior temperature. This leads to excessive use of outdoor air and wasted energy since the buildings operate most of the time with considerably less than the designed occupant load. This project was undertaken to show that a carbon-dioxide sensor that measures the occupant-generated carbon dioxide could be used to control the use of outdoor air in a more efficient manner. A ventilating system under the control of a carbon dioxide sensor could provide outdoor air when needed but restrict its use when it is not needed. The following chapter will show that the use of a $CO_2$-control system will definitely lessen energy consumption (both floors had identical energy demand patterns before).(30)

Separate electric power meters were installed in all four ventilation systems (two per floor); to measure all power used for heating and cooling throughout the full year (365 days, 24 hours per day). Four XT-103 Electrical Current Stick-On Loggers from ACR Systems Inc. were used. Each one has a range of 0 to

250 Amps (AC). The two loggers for each floor were added so as to arrive at a total energy consumption for each floor. Both floors were monitored simultaneously.

## 7.1 Monthly Energy Consumption

The energy demands for each floor were originally equivalent. The consumption after the installation of the $CO_2$-control system are shown in Table 7.1 and in Figure 7.1.

Table 7.1 Energy consumption per floor (kWh)

| month | floor | | |
|---|---|---|---|
| | $8^{th}$ ($CO_2$) | $9^{th}$ | $8^{th}$-$9^{th}$ |
| May 1990 | 163 027 | 152 834 | 10 193 |
| June 1990* | 37 294 | 38 183 | -899 |
| July 1990 | 145 745 | 147 978 | -2 233 |
| August 1990 | 161 742 | 196 723 | -34 981 |
| September 1990 | 287 503 | 363 572 | -76 069 |
| October 1990 | 486 044 | 665 287 | -179 243 |
| November 1990 | 683 127 | 746 384 | -63 257 |
| December 1990 | 899 715 | 888 417 | 11 298 |
| January 1991 | 775 723 | 843 118 | -67 395 |
| February 1991 | 664 445 | 790 041 | -125 596 |
| March 1991 | 494 986 | 559 631 | -64 645 |
| April 1991 | 221 211 | 294 377 | -73 166 |
| Total | 5,021E6 | 5,687E6 | -6,660E5 |

*incomplete due to technical error

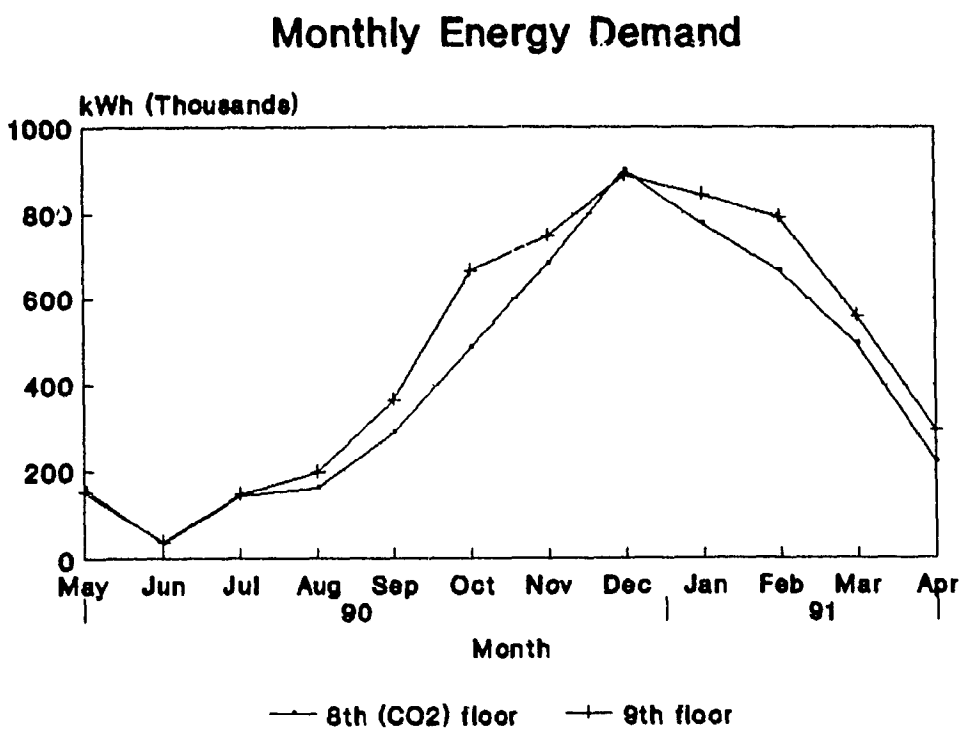



Figure 7 1 Monthly difference in energy consumption

From the above graph, one can see that the $CO_2$-controlled HVAC system ($8^{th}$ floor) consumed much less energy.

The greatest energy saving occurred during the month of October, when little outdoor air was supplied on the $CO_2$-controlled floor, indicating that the supply air temperature and the $CO_2$ levels were adequate. The $9^{th}$ floor admitted almost always 100% outdoor air.

During the winter months of November, December, January, February, and March, both floors had large amounts of outdoor air being supplied to them. However, the $CO_2$-controlled floor definitely consumed much less energy than the 9$^{th}$ floor. Similar phenomena occurred on both floors:

-because the controlling thermostats are located in the corner offices, these are the ones which demand the most heating. This in turn increases the hot deck temperature.

-for the 8$^{th}$ ($CO_2$) floor, the controlling temperature sensor is placed in the supply duct. Since the supply duct keeps getting hotter, the outdoor air dampers open to try to cool the supply duct temperature to the ideal level. When this ideal level is reached, the outdoor air dampers close. They remain closed until the supply duct becomes hot, again, due to the occupant demand for heat. The cycle continues, resulting in an intermittent demand for more heat.

-for the 9$^{th}$ floor, the controlling temperature sensor is placed outside, close to the exhaust and outdoor air ducts. Since it is sensing a warmer temperature than the real one, the outdoor air dampers open to admit this warmer air. However, the air being admitted is actually colder than what the sensor is reading. So, the hot deck increases

the heat being supplied to the mixing duct, resulting in a continuous demand for more heat.

Therefore, since the heating demand is intermittent on the 8th ($CO_2$) floor, but continuous on the 9th floor, the latter consumes more energy. The only exception occurs during the month of December, when the 9th floor consumed less energy than the 8th ($CO_2$) floor. However, the difference is small compared to the rest of the winter season. The only probable explanation would be that the corner offices on the 9th floor were unoccupied for most of this month, resulting in lower heating demands.

During the summer months of May, June, July, and August, both floors had minimal to some amounts of outdoor air being supplied to them. However, the $CO_2$-controlled floor definitely consumed much less energy than the 9th floor. Similar phenomena occurred on both floors:

-for the 8th ($CO_2$) floor, the controlling temperature sensor is placed in the supply duct. Since the supply duct would get too hot by admitting hot outdoor air, the outdoor air dampers close. If needed to further lower the cooling demand, the compressors automatically start to cool the supply duct temperature to the ideal level. When this ideal

level is reached, the compressors stop. This results in an intermittent demand for more cooling.

-for the 9th floor, the controlling temperature sensor is placed outside, close to the exhaust and outdoor air ducts, and the compressor motors. Since it is sensing an even hotter temperature than the real one, the outdoor air dampers remain closed. If needed to further lower the cooling demand, the compressors automatically start to cool the supply air. This results in a continuous demand for cooling, since the outdoor temperature being sensed is always higher than ideal.

Therefore, since the cooling demand is intermittent on the 8th ($CO_2$) floor, but continuous on the 9th floor, the latter consumes more energy. The only exception occurred during the month of May, when the 9th floor consumed less energy than the 8th ($CO_2$) floor. However, the difference seems small compared to the rest of the summer season. The only probable explanation would be that at some point in time, the outdoor temperature fell drastically, allowing the 9th floor to be cooled by the outdoor air, without the compressors. Whilst on the 8th ($CO_2$) floor, the dampers would remain closed since both the supply temperature and the $CO_2$ levels were adequate, but the compressors would still be operating.

Hence, the implementation of the $CO_2$ control (and supply temperature sensor) resulted in a lower energy consumption.

## 7.2 Annual Savings and Payback Period

The estimated savings obtained from using such a control system can be calculated as follows:

| | | |
|---|---|---|
| -normal control (kWh) | : | 5,687E6 |
| -$CO_2$-control (kWh) | : | 5,021E6 |
| -energy savings (kWh) | : | 5,687E6 - 5,021E6 = 6,660E5 |
| -percent savings | : | (6,660E5/5,687E6)*100 = 12% |

Table 7.2, below, shows the estimated costs per month, using an assumed Hydro schedule of:

0,0404 $/kWh for the first 120 kWh,

0,0410 $/kWh for the next 78 000 kWh, and

0,0256 $/kWh for the balance.(88)

Table 7.2 Estimated energy costs (Canadian dollars)

| MONTH | 8th ($CO_2$) | 9th floor |
|---|---|---|
| May 1990 | 5 376,47 | 5 115,53 |
| June 1990 | 1 528,98 | 1 565,43 |
| July 1990 | 4 934,05 | 4 991,21 |
| August 1990 | 5 343,57 | 6 239,08 |
| September 1990 | 8 563,05 | 10 510,42 |
| October 1990 | 13 645,70 | 18 234,32 |
| November 1990 | 18 691,03 | 20 310,41 |
| December 1990 | 24 235,68 | 23 946,45 |
| January 1991 | 21 061,48 | 22 786,80 |
| February 1991 | 18 212,77 | 21 428,03 |
| March 1991 | 13 874,62 | 15 529,53 |
| April 1991 | 6 865,98 | 8 739,03 |
| TOTAL | 142 333,38 | 159 396,24 |

Therefore, the payback period can be estimated as follows:

-initial cost and installation : 7 000,00 $

-savings ($9^{th}$ - $8^{th}$) : 17 062,86 $

-payback period : (7 000,00/17 062,86)

: 0,4 years.

In previous studies, when actual measurements were taken, saving in energy consumption reported ranged from 8 to 40%.(7,11,21,25) Pay-back periods have been reported to range from 1 to 6 years.(4,10,20,21,25,27) However, the comparative studies were done by alternating the controls, allowing for great errors with respect to dynamic exterior conditions. No one did a simultaneous comparison between two identical systems. The results from the present work correspond well with previous studies.

Figure 7.2, below, shows the monthly energy consumption plotted against that month's average temperature. This figure can be used to estimate the consumption and savings for future years.

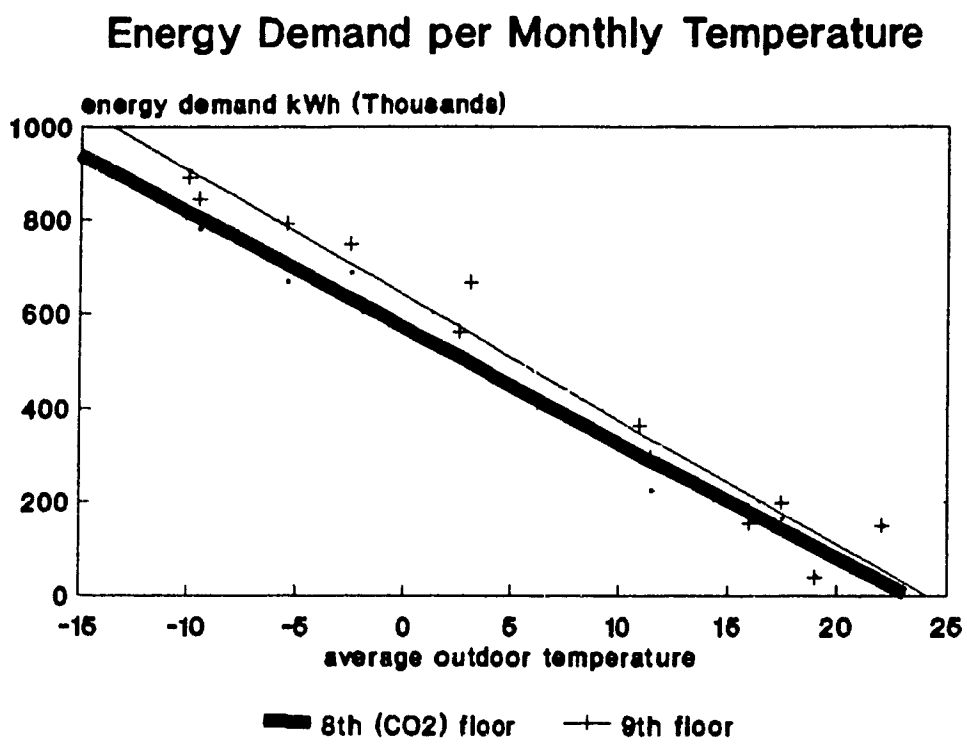



Figure 7.2 Energy consumption for average monthly temperature

As can be seen, the greatest energy savings can be obtained during the winter months, when the temperature is less than 0°C.

## 7.3 Conclusions

Separate electric power meters were installed in all four ventilation systems (two per floor); to measure all power used for heating and cooling throughout the full year (365 days, 24 hours per day). Both floors were monitored simultaneously.

A large difference in energy consumption was found between the normal and $CO_2$-controlled ventilation systems. An energy saving of 12% was calculated by using the $CO_2$-control system (and supply temperature sensor). The payback period was estimated at being 0,4 years. These results compare well with previous studies.

Since this study was done by comparing two floors simultaneously (and not sequentially), the results shown reflect the true differences between two outdoor air control systems. Previous work has only been able to study the differences sequentially.(1)

# CHAPTER 8

## 8. SUMMARY AND RECOMMENDATIONS

The primary goals of demand-controlled ventilation systems are to guarantee an equivalent or better indoor air quality and thermal comfort, and to save energy. This project was undertaken to show that a carbon dioxide sensor that measures the occupant generated carbon dioxide could be used to control the use of outdoor air in a more efficient manner. This study was designed to measure indoor air contaminant levels, thermal comfort levels, subjective occupant response, and energy consumption for heating and cooling.

From the review of the literature, it can be seen that experimental work on demand-controlled ventilation has concentrated only on the energy savings and pay-back times. The $CO_2$-control system was mainly used in public rooms. The lower limit set-point for pneumatic controls was 850 ppm and higher; which already is known to be an uncomfortable level for occupants.(28) The upper limit set-point was 1200 ppm and higher; which does not even ensure that the ASHRAE standard is satisfied.(29) The control sensors were placed in the return or exhaust ducts; the optimum placement was never questioned. The control system was compared to the normal mode of operation, but only sequentially, and not simultaneously.

## 8.1 The Purpose and Methodology of the Present Study

Such a study was unprecedented due to its length and magnitude. No other work has monitored all of the parameters included in this report for as long as one calendar year; verifying the effect of the changing seasons. Furthermore, the energy consumption was actually logged and the savings were calculated, and not estimated as had been done in the past. No other project has been able to compare its control system with an identical normal system simultaneously. The optimum sensor location was validated.

The methodology was experimental. Actual test data was collected over four seasons. Each scheduled test period consisted of one week per month, for 12 consecutive months. The testing was performed simultaneously on two floors of an office building--one floor operating under the normal mode, and the other floor operating under the ambient $CO_2$ control mode. Along with the $CO_2$ control, a supply temperature sensor was installed by the building owner to ensure adequate thermal conditions.

The following parameters were measured for one week per month, for 12 consecutive months: indoor air quality parameters (carbon dioxide, formaldehyde, volatile organic compounds, particles, ventilation, and system performance); thermal comfort parameters (dry-bulb and operative temperature,

relative humidity, air diffusion performance index, vertical temperature gradients, air velocity, and thermal comfort PMV and PPD); and occupant perception. The energy demand was monitored continuously throughout the 12 months, i.e. 365 days.

This study verified

-that the indoor air quality did not worsen;

-that the thermal comfort did not worsen;

-that the occupants did not perceive a deterioration in their working environment; and

-that the energy consumption lessened with the $CO_2$-controlled system as compared to the outdoor temperature-controlled system.

## 8.2 The General Results of the Present Study

The system generally performed as expected. Under the $CO_2$ control mode, the $CO_2$ setpoints were 600 to 1000 ppm of $CO_2$. The system was normally operated with the outdoor air dampers opened in cold weather because of the overheating inside (due to the poorly designed HVAC system location). Furthermore, there were never enough people at one time or for long enough to raise the $CO_2$ level to the control point. Consequently, operation of the overriding temperature

control kept the building well ventilated (thermally). Finally, it was clear that the normal mode of control produced excess ventilation.

Use of the $CO_2$ control system permitted the ventilating system to be safely operated with the outdoor air dampers closed. Leakage through the dampers provided sufficient outdoor air for the number of people normally in the zone. The $CO_2$ control system would provide additional outdoor air whenever the occupancy load required it. The additional temperature control assured that the zone temperatures were within pre-determined comfort limits.

The ASHRAE ventilation standard offers two methods for controlling indoor air quality.(29) The first is to prescribe various amounts of outdoor air per person for different settings. The second allows the building operation personnel to reduce the outdoor air intake as long as there are no known contaminants at harmful concentrations. This project indeed showed that a $CO_2$ and supply temperature control was able to limit the amount of outdoor air and still keep all of the contaminants below the recommended maximum limits.

This control system had no real effect on indoor air quality and thermal comfort (similar levels were found on both floors), but it had a great effect on energy consumption.

This DCV system provides a good compromise between energy conservation and indoor air quality.

## INDOOR AIR QUALITY

The air quality, as expected, was generally good. No significant contaminant concentrations were found. Carbon dioxide, formaldehyde, and VOC levels were all well below the recommended limits. Total dust levels exceeded the ASHRAE recommended maximum for three months of the year, on the $CO_2$-controlled floor.

The $CO_2$-control system adequately kept the indoor $CO_2$ levels below 1000 ppm, with the optimum sensor location being at the work-station.

## THERMAL COMFORT

The thermal comfort was generally adequate on both floors.

Discomfort would be felt during the winter months when very low relative humidities were recorded, due to under-designed humidifiers. Very warm operative temperatures were also recorded during the summer months, due to

under-designed compressors. The Air Diffusion Performance Index was low due to warm temperatures coupled with low air velocities, and due to volumetric flow rate changes done by the building operation personnel. Vertical temperature gradients exceeded the recommended level due to very warm air temperatures at neck level (also resulting from under-designed compressors). A small percentage of air velocities recorded fell below the minimum comfort recommendation, also due to the volumetric flow rate changes. The Predicted Percentage of Dissatisfied was above the recommended maximum more than one third of the time due to a slightly cool to cool environment.

Therefore, the thermal comfort does not worsen with the implementation of a $CO_2$-controlled system as compared to the outdoor temperature-controlled system.

## OCCUPANT PERCEPTION

The occupants' responses did not correspond to the measurements taken objectively. This may put in evidence the inadequacy of the "state-of-the-art" measuring equipment to read much lower levels.

The occupants perceived that their productivity is proportional to their perception of the indoor environment; indicating that higher productivity rates can be

achieved by better controlling the working environment above satisfactory levels.

Finally, more than 20% of the occupants were unsatisfied of their working environment (indoor air quality and thermal comfort) all of the time. The 8$^{th}$ floor occupants complained much more of both indoor air quality and thermal comfort, however, their complaints could not be validated with the measured data, indicating that other "global" factors may be influencing their environmental satisfaction.

## ENERGY CONSUMPTION

A difference in energy consumption was found between both floors. An energy savings of 12% was found by using the $CO_2$-control system (and supply air temperature sensor). The payback period was calculated using a pre-determined cost schedule, and was found to be 0,4 years.

## 8.3 The Contributions and Recommendations of this Research

The main contributions of this thesis are as follows:

1) it has been shown that demand-controlled ventilation using indoor $CO_2$ as an indicator does not worsen indoor air quality and thermal comfort;

2) it has been shown that demand-controlled ventilation can be used in the office environment;

3) it has been shown that the $CO_2$-control set-points must be low enough so that they satisfy the present air quality standards and comfort recommendations;

4) it has been shown that the optimum sensor location would be at the critical work-station, however, placement in the return duct would also produce adequate results depending on the contaminant removal efficiency;

5) this project was unprecedented by the fact that the comparative testing was done simultaneously, and not sequentially; and

6) it has been shown that occupants' complaints do not necessarily reflect the measured results.

Building owners might blindly add such a control system to any building, without validating its use. A control system based on measuring the $CO_2$ concentration is most valuable in buildings where the occupants are the main cause of pollutants. When planning such a system, it is advantageous if the building is divided into zones with equal occupant densities. Rooms used at limited times should be treated as separate control zones. If such a division is possible, it is desirable that the analyzer equipment has a control unit for all the zones. There could be a problem when the occupant density is low, and other contaminant sources are present. Another sensor capable of monitoring volatile organic hydrocarbons or some other family of common contaminants may be needed, along with periodic testing of other parameters. Otherwise, this control system would definitely be an energy conservation tool.

## 8.4 Future Research Needs

From this work, it is obvious that much more can be done to improve our standard design methods for ventilation systems. This project has shown that without compromising the indoor air quality and thermal comfort, one can still

obtain energy savings through the use of a carbon dioxide control system. By controlling even more parameters, one may be able to also improve indoor air quality and thermal comfort. For example, one may couple the carbon dioxide sensors with other irritating contaminant sensors or with temperature sensors. These sensors would definitely need to be able to detect the contaminants at much lower levels than the present "state-of-the-art" equipment available. A revision of the comfort limits for all parameters would need to take place to verify the sensitivity of occupants being submitted to more than one contaminant at a time. The resulting pleasant working environment would definitely compensate for the initial cost of such an implementation. There is a definite need for "intelligent" design strategies in the commercial building sector.(89)

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# APPENDIX A. QUESTIONNAIRE

## Questionnaire sur la qualité de l'air

IRSST
Institut de recherche en santé et en sécurité du travail du Québec

**Veuillez répondre à ce questionnaire en considérant uniquement votre poste de travail, et en vous référant à la dernière semaine.**

1 Où est situé votre poste de travail ?

étage
- ❑ au centre de l'édifice
- ❑ à la périphérie

2. Si vous travaillez en périphérie, indiquez le nom des rues

_____

_____

_____

3 La température est
- ❑ fraîche
- ❑ légèrement fraîche
- ❑ convenable
- ❑ légèrement chaude
- ❑ chaude

4 La température a-t-elle changé durant la journée?
- ❑ non
- ❑ un peu
- ❑ moyennement
- ❑ beaucoup
- ❑ excessivement

Si oui, vers quelle heure? _____

Est-ce qu'elle augmente ou diminue? _____

5 L'air est
- ❑ sec
- ❑ légèrement sec
- ❑ satisfaisant
- ❑ légèrement humide
- ❑ humide

6. La ventilation est
- ❑ excessive
- ❑ légèrement excessive
- ❑ adéquate
- ❑ légèrement insuffisante
- ❑ insuffisante

7 Recevez-vous de l'air directement sur la nuque?
- ❑ non
- ❑ rarement
- ❑ parfois
- ❑ souvent
- ❑ régulièrement

8 Avez-vous froid aux pieds?
- ❑ non
- ❑ rarement
- ❑ parfois
- ❑ souvent
- ❑ régulièrement

9 Si votre poste de travail est près d'une fenêtre, ressentez-vous le froid? chaud (été)
- ❑ non
- ❑ un peu (chaud/froid)
- ❑ moyennement
- ❑ beaucoup
- ❑ excessivement
- ❑ ne s'applique pas

10 La qualité de l'air que vous respirez est
- ❑ très bonne
- ❑ bonne
- ❑ satisfaisante
- ❑ insatisfaisante
- ❑ mauvaise

11 La qualité de l'air change-t-elle durant la journée?
- ❑ non
- ❑ un peu
- ❑ moyennement
- ❑ beaucoup
- ❑ excessivement

12. En général l'environnement thermique (le confort résultant de la température de l'air ambiant, de l'humidité et de la circulation d'air) est
- ❑ très confortable
- ❑ confortable
- ❑ convenable
- ❑ légèrement inacceptable
- ❑ inacceptable

13 Percevez-vous régulièrement des odeurs?
- ❑ non
- ❑ moins d'une fois par jour
- ❑ une fois par jour
- ❑ plus d'une fois par jour
- ❑ régulièrement

Si oui, de quelles odeurs s'agit-il?
D'où proviennent-elles?

_____

_____

14. S.V.P. notez comment vous pensez que l'environnement physique (la qualité de l'air, le confort thermique, la ventilation) au travail influence votre productivité:

- ____40 % ou plus d'augmentation de productivité
- ____30 % d'augmentation
- ____20 % d'augmentation
- ____10 % d'augmentation
- ____pas d'effet
- ____10 % de baisse
- ____20 % de baisse
- ____30 % de baisse
- ____40 % de baisse de productivité

# APPENDIX B. MONTHLY RESPONSES TO QUESTIONNAIRE

ANSWERS TO QUESTIONNAIRE MONTH MAY 1990 FLOOR 8

NUMBER OF DISTRIBUTED QUESTIONNAIRES 55

NUMBER OF ANSWERED QUESTIONNAIRES 24

RESPONSE RATE 43.6%

1. OU EST SITUE VOTRE POSTE DE TRAVAIL?

| CENTRE | PERIPHERIE |
|---|---|
| 8.3% | 91.7% |

2 INDIQUEZ LE NOM DES RUES

| FULLUM | F/S | STE-CATHERINE | S/P | PARTHENAIS |
|---|---|---|---|---|
| 8.3% | 12.5% | 8.3% | 0.0% | 12.5% |

| P/N | NOTRE-DAME | CENTRE |
|---|---|---|
| 8.3% | 12.5% | 37.5% |

3 LA TEMPERATURE EST

| FRAICHE | LEG FRAICHE | CONVENABLE | LEG CHAUDE | CHAUDE |
|---|---|---|---|---|
| 35.0% | 5.0% | 50.0% | 5.0% | 5.0% |

4 LA TEMPERATURE A-T-ELLE CHANGE DURANT LA JOURNEE?

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 36.4% | 22.7% | 18.2% | 9.1% | 13.6% |

5 L'AIR EST:

| SEC | LEG SEC | SATISFAISANT | LEG HUMIDE | HUMIDE |
|---|---|---|---|---|
| 54.2% | 8.3% | 33.3% | 4.2% | 0.0% |

6 LA VENTILATION EST

| EXCESSIVE | LEG EXCESSIVE | | ADEQUATE | LEG INSUFFISANTE | INSUFFISANTE |
|---|---|---|---|---|---|
| 30 4% | 4 3% | | 43 5% | 0.0% | 21.7% |

7 L'AIR DIRECTEMENT SUR LA NUQUE

| :'ON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 65 2% | 13 0% | 13 0% | 4 3% | 4 3% |

8 FRAICHEUR AU PIEDS

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 45 8% | 8 3% | 25 0% | 20 8% | 0 0% |

9 FENETRE, FROID/CHAUD

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT | NE S'APPLIQUE PAS |
|---|---|---|---|---|---|
| 9.1% | 13 6% | 13 6% | 9 1% | 4 5% | 50 0% |

10 QUALITE DE L'AIR

| TRES BONNE | BONNE | SATISFAISANTE | INSATISFAISANTE | MAUVAISE |
|---|---|---|---|---|
| 0 0% | 4 3% | 30 4% | 26 1% | 39 1% |

11 QUALITE DE L'AIR CHANGE-T-ELLE

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 39 1% | 17 4% | 8 7% | 17 4% | 17 4% |

12 L'ENVIRONNEMENT THERMIQUE EST

| TRES CONFORTABLE | CONFORT | CONVENABLE | LEG INACC | INACCEPTABLE |
|---|---|---|---|---|
| 0 0% | 4 2% | 25 0% | 37 5% | 33 3% |

13 PERCEVEZ-VOUS REGULIEREMENT DES ODEURS

| NON | <1FOIS/JOUR | 1FOIS/JOUR | +1FOIS/JOUR | REGULIEREMENT |
|---|---|---|---|---|
| 50 0% | 18 2% | 9.1% | 0 0% | 22 7% |

ANSWERS TO QUESTIONNAIRE | MONTH. MAY 1990 | FLOOR 9

| | |
|---|---|
| NUMBER OF DISTRIBUTED QUESTIONNAIRES | 36 |
| NUMBER OF ANSWERED QUESTIONNAIRES | 16 |
| RESPONSE RATE | 44 4% |

1. OU EST SITUE VOTRE POSTE DE TRAVAIL?

| CENTRE | PERIPHERIE |
|---|---|
| 26 7% | 73 3% |

2 INDIQUEZ LE NOM DES RUES

| FULLUM | F/S | STE-CATHERINE | S/P | PARTHENAIS |
|---|---|---|---|---|
| 0 0% | 0 0% | 6 3% | 0 0% | 18 8% |

| P/N | NOTRE-DAME | CENTRE |
|---|---|---|
| 0 0% | 6 3% | 68 8% |

3 LA TEMPERATURE EST

| FRAICHE | LEG FRAICHE | CONVENABLE | LEG CHAUDE | CHAUDE |
|---|---|---|---|---|
| 27.3% | 36 4% | 18 2% | 18 2% | 0 0% |

4 LA TEMPERATURE A-T-ELLE CHANGE DURANT LA JOURNEE?

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 20 0% | 6 7% | 13 3% | 60 0% | 0 0% |

5 L'AIR EST

| SEC | LEG SEC | SATISPAISANT | LEG HUMIDE | HUMIDE |
|---|---|---|---|---|
| 62.5% | 25 0% | 0 0% | 12 5% | 0 0% |

6 LA VENTILATION EST

| EXCESSIVE | LEG EXCESSIVE | ADEQUATE | LEG INSUFFISANTE | INSUFFISANTE |
|---|---|---|---|---|
| 18 8% | 18 8% | 12 5% | 18.8% | 31 3% |

7. L'AIR DIRECTEMENT SUR LA NUQUE

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 50.0% | 0 0% | 25 0% | 6.3% | 18 8% |

8 FRAICHEUR AU PIEDS

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 37 5% | 12 5% | 37.5% | 6.3% | 6 3% |

9 FENETRE. FROID/CHAUD

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT | NE S'APPLIQUE PAS |
|---|---|---|---|---|---|
| 0 0% | 0 0% | 6 7% | 20 0% | 0.0% | 73.3% |

10 QUALITE DE L'AIR

| TRES BONNE | BONNE | SATISFAISANTE | INSATISFAISANTE | MAUVAISE |
|---|---|---|---|---|
| 0 0% | 7.1% | 0 0% | 57 1% | 35 7% |

11 QUALITE DE L'AIR CHANGE-T-ELLE

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 20.0% | 6 7% | 20.0% | 33 3% | 20.0% |

12 L'ENVIRONNEMENT THERMIQUE EST

| TRES CONFORTABLE | CONFORT | CONVENABLE | LEG INACC | INACCEPTABLE |
|---|---|---|---|---|
| 0 0% | 0 0% | 20 0% | 13.3% | 66.7% |

13 PERCEVEZ-VOUS REGULIEREMENT DES ODEURS·

| NON | <1FOIS/JOUR | 1FOIS/JOUR | +1FOIS/JOUR | REGULIEREMENT |
|---|---|---|---|---|
| 35 7% | 14 3% | 7.1% | 7.1% | 35.7% |

ANSWERS TO QUESTIONNAIRE MONTH JUNE 1990 FLOOR 8

| | |
|---|---|
| NUMBER OF DISTRIBUTED QUESTIONNAIRES | 55 |
| NUMBER OF ANSWERED QUESTIONNAIRES | 30 |
| RESPONSE RATE | 54 5% |

1 OU EST SITUE VOTRE POSTE DE TRAVAIL?

| CENTRE | PERIPHERIE |
|---|---|
| 21 4% | 78 6% |

2 INDIQUEZ LE NOM DES RUES

| FULLUM | F/S | STE-CATHERINE | S/P | PARTHENAIS |
|---|---|---|---|---|
| 3 3% | 3 3% | 23 3% | 3 3% | 16 7% |

| P/N | NOTRE-DAME | CENTRE |
|---|---|---|
| 3 3% | 3 3% | 43 3% |

3 LA TEMPERATURE EST

| FRAICHE | LEG FRAICHE | CONVENABLE | LEG CHAUDE | CHAUDE |
|---|---|---|---|---|
| 48 1% | 29 6% | 14 8% | 7 4% | 0 0% |

4 LA TEMPERATURE A-T-ELLE CHANGE DURANT LA JOURNEE?

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 35 7% | 21 4% | 28 6% | 10 7% | 3 6% |

5 L'AIR EST

| SEC | LEG SEC | SATISFAISANT | LEG HUMIDE | HUMIDE |
|---|---|---|---|---|
| 51 7% | 31 0% | 13 8% | 3 4% | 0 0% |

6 LA VENTILATION EST

| EXCESSIVE | LEG EXCESSIVE | ADEQUATE | LEG INSUFFISANTE | INSUFFISANTE |
|---|---|---|---|---|
| 24.1% | 27.6% | 27.6% | 13 8% | 6.9% |

7 L'AIR DIRECTEMENT SUR LA NUQUE

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 56 7% | 6 7% | 20 0% | 6 7% | 10 0% |

8 FRAICHEUR AU PIEDS

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 46 7% | 6 7% | 36 7% | 10 0% | 0.0% |

9 FENETRE, FROID/CHAUD

| NON | UN PEU | MOYENNEMENT | BEAUCOUP |
|---|---|---|---|
| 13 3% | 13 3% | 16 7% | 13 3% |

| EXCESSIVEMENT | NE S'APPLIQUE PAS |
|---|---|
| 0 0% | 43 3% |

10. QUALITE DE L'AIR

| TRES BONNE | BONNE | SATISFAISANTE | INSATISFAISANTE | MAUVAISE |
|---|---|---|---|---|
| 0 0% | 7.1% | 35.7% | 28 6% | 28.6% |

11 QUALITE DE L'AIR CHANGE-T-ELLE

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 33 3% | 22.2% | 11.1% | 29 6% | 3 7% |

12 L'ENVIRONNEMENT THERMIQUE EST

| TRES CONFORTABLE | CONFORT | CONVENABLE | LEG INACC | INACCEPTABLE |
|---|---|---|---|---|
| 0 0% | 3 6% | 25 0% | 35 7% | 35 7% |

13 PERCEVEZ-VOUS REGULIEREMENT DES ODEURS

| NON | <1FOIS/JOUR | 1FOIS/JOUR | +1FOIS/JOUR | REGULIEREMENT |
|---|---|---|---|---|
| 51 7% | 24 1% | 13 8% | 3 4% | 6 9% |

ANSWERS TO QUESTIONNAIRE | MONTH JUNE 1990 | FLOOR 9

NUMBER OF DISTRIBUTED QUESTIONNAIRES 35

NUMBER OF ANSWERED QUESTIONNAIRES 16

RESPONSE RATE 45 7%

1 OU EST SITUE VOTRE POSTE DE TRAVAIL?

| CENTRE | PERIPHERIE |
|---|---|
| 40 0% | 60 0% |

2 INDIQUEZ LE NOM DES RUES

| FULLUM | F/S | STE-CATHERINE | S/P | PARTHENAIS |
|---|---|---|---|---|
| 0 0% | 6 3% | 18 8% | 0 0% | 18 8% |

| P/N | NOTRE-DAME | CENTRE |
|---|---|---|
| 0 0% | 6 3% | 50 0% |

3 LA TEMPERATURE EST

| FRAICHE | LEG FRAICHE | CONVENABLE | LEG CHAUDE | CHAUDE |
|---|---|---|---|---|
| 23 1% | 23.1% | 38 5% | 15 4% | 0.0% |

4 LA TEMPERATURE A-T-ELLE CHANGE DURANT LA JOURNEE?

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 21 4% | 14 3% | 28 6% | 28.6% | 7.1% |

5. L'AIR EST

| SEC | LEG SEC | SATISFAISANT | LEG HUMIDE | HUMIDE |
|---|---|---|---|---|
| 43 8% | 31 3% | 25 0% | 0.0% | 0.0% |

6 LA VENTILATION EST

| EXCESSIVE | LEG EXCESSIVE | ADEQUATE | LEG INSUFFISANTE | INSUFFISANTE |
|---|---|---|---|---|
| 20 0% | 20 0% | 20 0% | 26 7% | 13 3% |

7. L'AIR DIRECTEMENT SUR LA NUQUE

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 56 3% | 12 5% | 18 8% | 12 5% | 0 0% |

8 FRAICHEUR AU PIEDS

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 37 5% | 18 8% | 25 0% | 12 5% | 6 3% |

9 FENETRE, FROID/CHAUD

| NON | UN PEU | MOYENNEMENT | BEAUCOUP |
|---|---|---|---|
| 0 0% | 13 3% | 26 7% | 6 7% |

| EXCESSIVEMENT | NE S'APPLIQUE PAS |
|---|---|
| 0 0% | 53 3% |

10 QUALITE DE L'AIR

| TRES BONNE | BONNE | SATISFAISANTE | INSATISFAISANTE | MAUVAISE |
|---|---|---|---|---|
| 0 0% | 18 7% | 31 3% | 25 0% | 25 0% |

11 QUALITE DE L'AIR CHANGE-T-ELLE

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 6.3% | 18 8% | 25 0% | 50 0% | 0 0% |

12 L'ENVIRONNEMENT THERMIQUE EST

| TRES CONFORTABLE | CONFORT | CONVENABLE | LEG INACC | INACCEPTABLE |
|---|---|---|---|---|
| 0 0% | 18 8% | 31 3% | 18 8% | 31 3% |

13 PERCEVEZ-VOUS REGULIEREMENT DES ODEURS

| NON | <1FOIS/JOUR | 1FOIS/JOUR | +1FOIS/JOUR | REGULIEREMENT |
|---|---|---|---|---|
| 46 7% | 20 0% | 6.7% | 6 7% | 20 0% |

ANSWERS TO QUESTIONNAIRE MONTH JULY 1990 FLOOR 8

NUMBER OF DISTRIBUTED QUESTIONNAIRES 23

NUMBER OF ANSWERED QUESTIONNAIRES 13

RESPONSE RATE 56 5%

1 OU EST SITUE VOTRE POSTE DE TRAVAIL?

| CENTRE | PERIPHERIE |
|---|---|
| 0 0% | 100 0% |

2 INDIQUEZ LE NOM DES RUES

| FULLUM | F/S | STE-CATHERINE | S/P | PARTHENAIS |
|---|---|---|---|---|
| 7.7% | 7 7% | 46 2% | 0 0% | 7 7% |

| P/N | NOTRE-DAME | CENTRE |
|---|---|---|
| 0 0% | 7 7% | 23 1% |

3 LA TEMPERATURE EST

| FRAICHE | LEG FRAICHE | CONVENABLE | LEG CHAUDE | CHAUDE |
|---|---|---|---|---|
| 33 3% | 33 3% | 25 0% | 8 3% | 0 0% |

4 LA TEMPERATURE A-T-ELLE CHANGE DURANT LA JOURNEE?

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 50 0% | 8.3% | 16 7% | 25 0% | 0 0% |

5 L'AIR EST

| SEC | LEG SEC | SATISFAISANT | LEG HUMIDE | HUMIDE |
|---|---|---|---|---|
| 46 2% | 23 1% | 30 8% | 0 0% | 0 0% |

6 LA VENTILATION EST

| EXCESSIVE | LEG EXCESSIVE | ADEQUATE | LEG INSUFFISANTE | INSUFFISANTE |
|---|---|---|---|---|
| 15 4% | 30 8% | 38 5% | 7.7% | 7.7% |

7 L'AIR DIRECTEMENT SUR LA NUQUE

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 53 8% | 0 0% | 15 4% | 23 1% | 7 7% |

8 FRAICHEUR AU PIEDS

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 38 5% | 0 0% | 46 2% | 7 7% | 7 7% |

9 FENETRE, FROID/CHAUD

| NON | UN PEU | MOYENNEMENT | BEAUCOUP |
|---|---|---|---|
| 15 4% | 23 1% | 0 0% | 15 4% |

| EXCESSIVEMENT | NE S'APPLIQUE PAS |
|---|---|
| 15 4% | 30 8% |

10 QUALITE DE L'AIR

| TRES BONNE | BONNE | SATISFAISANTE | INSATISFAISANTE | MAUVAISE |
|---|---|---|---|---|
| 0 0% | 23 1% | 30 8% | 7.7% | 38 5% |

11 QUALITE DE L'AIR CHANGE-T-ELLE

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 53 8% | 23 1% | 7 7% | 15 4% | 0 0% |

12. L'ENVIRONNEMENT THERMIQUE EST

| TRES CONFORTABLE | CONFORT | CONVENABLE | LEG INACC | INACCEPTABLE |
|---|---|---|---|---|
| 7 7% | 7 7% | 30 8% | 7 7% | 46 2% |

13. PERCEVEZ-VOUS REGULIEREMENT DES ODEURS

| NON | <1FOIS/JOUR | 1FOIS/JOUR | +1FOIS/JOUR | REGULIEREMENT |
|---|---|---|---|---|
| 50 0% | 25 0% | 8 3% | 8 3% | 8 3% |

ANSWERS TO QUESTIONNAIRE | MONTH JULY 1990 | FLOOR: 9

| | |
|---|---|
| NUMBER OF DISTRIBUTED QUESTIONNAIRES | 12 |
| NUMBER OF ANSWERED QUESTIONNAIRES | 10 |
| RESPONSE RATE | 83.3% |

1 OU EST SITUE VOTRE POSTE DE TRAVAIL?

| CENTRE | PERIPHERIE |
|---|---|
| 33 3% | 66 7% |

2 INDIQUEZ LE NOM DES RUES

| FULLUM | F/S | STE-CATHERINE | S/P | PARTHENAIS |
|---|---|---|---|---|
| 0 0% | 10.0% | 20 0% | 0 0% | 10 0% |

| P/N | NOTRE-DAME | CENTRE |
|---|---|---|
| 0 0% | 0 0% | 0.0% |

3 LA TEMPERATURE EST

| FRAICHE | LEG FRAICHE | CONVENABLE | LEG CHAUDE | CHAUDE |
|---|---|---|---|---|
| 14 3% | 42 9% | 28 6% | 14 3% | 0.0% |

4 LA TEMPERATURE A-T-ELLE CHANGE DURANT LA JOURNEE?

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 0 0% | 20 0% | 20 0% | 60 0% | 0.0% |

5 L'AIR EST

| SEC | LEG SEC | SATISFAISANT | LEG HUMIDE | HUMIDE |
|---|---|---|---|---|
| 44 4% | 33 3% | 11 1% | 0 0% | 11.1% |

6 LA VENTILATION EST.

| EXCESSIVE | LEG EXCESSIVE | ADEQUATE | LEG INSUFFISANTE | INSUFFISANTE |
|---|---|---|---|---|
| 20 0% | 40 0% | 10 0% | 10 0% | 20 0% |

7 L'AIR DIRECTEMENT SUR LA NUQUE

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 10 0% | 10 0% | 20 0% | 40 0% | 20 0% |

8 FRAICHEUR AU PIEDS

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 33 3% | 22 2% | 33 3% | 11 1% | 0 0% |

9 FENETRE, FROID/CHAUD

| NON | UN PEU | MOYENNEMENT | BEAUCOUP |
|---|---|---|---|
| 10 0% | 0 0% | 20 0% | 20 0% |

| EXCESSIVEMENT | NE S'APPLIQUE PAS |
|---|---|
| 0 0% | 50 0% |

10 QUALITE DE L'AIR

| TRES BONNE | BONNE | SATISFAISANTE | INSATISFAISANTE | MAUVAISE |
|---|---|---|---|---|
| 0.0% | 0 0% | 33 3% | 44 4% | 22 2% |

11 QUALITE DE L'AIR CHANGE-T-ELLE

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 11 1% | 22 2% | 22 2% | 44 4% | 0 0% |

12 L'ENVIRONNEMENT THERMIQUE EST

| TRES CONFORTABLE | CONFORT | CONVENABLE | LEG INACC | INACCEPTABLE |
|---|---|---|---|---|
| 0 0% | 0 0% | 25 0% | 62.5% | 12 5% |

13 PERCEVEZ-VOUS REGULIEREMENT DES ODEURS

| NON | <1FOIS/JOUR | 1FOIS/JOUR | +1FOIS/JOUR | REGULIEREMENT |
|---|---|---|---|---|
| 40 0% | 20 0% | 10 0% | 20 0% | 10.0% |

ANSWERS TO QUESTIONNAIRE MONTH AUGUST 1990 ETAGE 8

NUMBER OF DISTRIBUTED QUESTIONNAIRES 30

NUMBER OF ANSWERED QUESTIONNAIRES 22

RESPONSE RATE 73 3%

1 OU EST SITUE VOTRE POSTE DE TRAVAIL?

| CENTRE | PERIPHERIE |
|---|---|
| 9 5% | 90 5% |

2 INDIQUEZ LE NOM DES RUES

| FULLUM | F/S | STE-CATHERINE | S/P | PARTHENAIS |
|---|---|---|---|---|
| 9 1% | 0 0% | 9 1% | 4 5% | 27 3% |

| P/N | NOTRE-DAME | CENTRE |
|---|---|---|
| 4 5% | 4 5% | 40 9% |

3 LA TEMPERATURE EST

| FRAICHE | LEG FRAICHE | CONVENABLE | LEG CHAUDE | CHAUDE |
|---|---|---|---|---|
| 29 4% | 0 0% | 47 1% | 5 9% | 17 6% |

4. LA TEMPERATURE A-T-ELLE CHANGE DURANT LA JOURNEE?

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 0 0% | 10 5% | 21 1% | 47 4% | 21 1% |

5 L'AIR EST.

| SEC | LEG SEC | SATISPAISANT | LEG HUMIDE | HUMIDE |
|---|---|---|---|---|
| 40 9% | 45 5% | 4 5% | 9 1% | 0 0% |

6 LA VENTILATION EST

| EXCESSIVE | LEG EXCESSIVE | ADEQUATE | LEG INSUFFISANTE | INSUFFISANTE |
|---|---|---|---|---|
| 10 0% | 5 0% | 50 0% | 5 0% | 30.0% |

7 L'AIR DIRECTEMENT SUR LA NUQUE

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 76 2% | 0 0% | 14 3% | 4 8% | 4 8% |

8 FRAICHEUR AU PIEDS

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 45 5% | 9 1% | 18 2% | 27.3% | 0 0% |

9 PENETRE, FROID/CHAUD

| NON | UN PEU | MOYENNEMENT | BEAUCOUP |
|---|---|---|---|
| 4 5% | 13 6% | 9 1% | 22 7% |

| EXCESSIVEMENT | NE S'APPLIQUE PAS |
|---|---|
| 13 6% | 36 4% |

10 QUALITE DE L'AIR

| TRES BONNE | BONNE | SATISFAISANTE | INSATISFAISANTE | MAUVAISE |
|---|---|---|---|---|
| 0 0% | 0 0% | 26.3% | 36 8% | 36 8% |

11 QUALITE DE L'AIR CHANGE-T-ELLE

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 12 5% | 6 3% | 25.0% | 43 8% | 12.5% |

12. L'ENVIRONNEMENT THERMIQUE EST

| TRES CONFORTABLE | CONFORT | CONVENABLE | LEG INACC | INACCEPTABLE |
|---|---|---|---|---|
| 4 5% | 4 5% | 27 3% | 31.8% | 31 8% |

13 PERCEVEZ-VOUS REGULIEREMENT DES ODEURS

| NON | <1FOIS/JOUR | 1FOIS/JOUR | +1FOIS/JOUR | REGULIEREMENT |
|---|---|---|---|---|
| 55 0% | 10 0% | 15 0% | 0 0% | 20 0% |

ANSWERS TO QUESTIONNAIRE MONTH AUGUST 1990 FLOOR: 9

| | |
|---|---|
| NUMBER OF DISTRIBUTED QUESTIONNAIRES | 24 |
| NUMBER OF ANSWERED QUESTIONNAIRES | 15 |
| RESPONSE RATE· | 62.5% |

1 OU EST SITUE VOTRE POSTE DE TRAVAIL?

| CENTRE | PERIPHERIE |
|---|---|
| 26 7% | 73 3% |

2 INDIQUEZ LE NOM DES RUES

| FULLUM | F/S | STE-CATHERINE | S/P | PARTHENAIS |
|---|---|---|---|---|
| 0 0% | 6 7% | 20 0% | 0.0% | 13.3% |

| P/N | NOTRE-DAME | CENTRE |
|---|---|---|
| 6 7% | 20 0% | 33 3% |

3 LA TEMPERATURE EST

| FRAICHE | LEG FRAICHE | CONVENABLE | LEG CHAUDE | CHAUDE |
|---|---|---|---|---|
| 25.0% | 0 0% | 50.0% | 25 0% | 0 0% |

4 LA TEMPERATURE A-T-ELLE CHANGE DURANT LA JOURNEE?

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 15 4% | 23 1% | 23 1% | 15 4% | 23.1% |

5 L'AIR EST

| SEC | LEG SEC | SATISFAISANT | LEG HUMIDE | HUMIDE |
|---|---|---|---|---|
| 33 3% | 40 0% | 20 0% | 6.7% | 0.0% |

6. LA VENTILATION EST

| EXCESSIVE | LEG EXCESSIVE | ADEQUATE | LEG INSUFFISANTE | INSUFFISANTE |
|---|---|---|---|---|
| 6 7% | 33 3% | 26 7% | 13 3% | 20 0% |

7 L'AIR DIRECTEMENT SUR LA NUQUE

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 53 3% | 13 3% | 6 7% | 13 3% | 13 3% |

8. FRAICHEUR AU PIEDS

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 60 0% | 20 0% | 6 7% | 6 7% | 6 7% |

9 FENETRE, FROID/CHAUD

| NON | UN PEU | MOYENNEMENT | BEAUCOUP |
|---|---|---|---|
| 6 7% | 13 3% | 33 3% | 6 7% |

| EXCESSIVEMENT | NE S'APPLIQUE PAS |
|---|---|
| 6 7% | 33 3% |

10 QUALITE DE L'AIR

| TRES BONNE | BONNE | SATISFAISANTE | INSATISFAISANTE | MAUVAISE |
|---|---|---|---|---|
| 7.7% | 7 7% | 30 8% | 23 1% | 30 8% |

11. QUALITE DE L'AIR CHANGE-T-ELLE

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 33 3% | 25 0% | 0 0% | 41 7% | 0 0% |

12 L'ENVIRONNEMENT THERMIQUE EST

| TRES CONFORTABLE | CONFORT | CONVENABLE | LEG INACC | INACCEPTABLE |
|---|---|---|---|---|
| 0 0% | 0 0% | 46 7% | 33 3% | 20.0% |

13 PERCEVEZ-VOUS REGULIEREMENT DES ODEURS·

| NON | <1FOIS/JOUR | 1FOIS/JOUR | +1FOIS/JOUR | REGULIEREMENT |
|---|---|---|---|---|
| 46 7% | 26 7% | 0.0% | 6 7% | 20.0% |

ANSWERS TO QUESTIONNAIRE | MONTH SEPTEMBER 1990 | FLOOR 8

NUMBER OF DISTRIBUTED QUESTIONNAIRES 48

NUMBER OF ANSWERED QUESTIONNAIRES 30

RESPONSE RATE 62 5%

1. OU EST SITUE VOTRE POSTE DE TRAVAIL?

| CENTRE | PERIPHERIE |
|---|---|
| 24 1% | 75 9% |

2 INDIQUEZ LE NOM DES RUES

| FULLUM | F/S | STE-CATHERINE | S/P | PARTHENAIS |
|---|---|---|---|---|
| 3 3% | 0 0% | 13 3% | 3 3% | 20 0% |

| P/N | NOTRE-DAME | CENTRE |
|---|---|---|
| 0 0% | 10 0% | 50 0% |

3. LA TEMPERATURE EST

| FRAICHE | LEG FRAICHE | CONVENABLE | LEG CHAUDE | CHAUDE |
|---|---|---|---|---|
| 25 0% | 32 1% | 35 7% | 7 1% | 0 0% |

4 LA TEMPERATURE A-T-ELLE CHANGE DURANT LA JOURNEE?

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 22 2% | 18 5% | 18 5% | 37 0% | 3 7% |

5 L'AIR EST

| SEC | LEG SEC | SATISFAISANT | LEG HUMIDE | HUMIDE |
|---|---|---|---|---|
| 51 9% | 40.7% | 3 7% | 3 7% | 0 0% |

6 LA VENTILATION EST

| EXCESSIVE | LEG EXCESSIVE | ADEQUATE | LEG INSUFFISANTE | INSUFFISANTE |
|---|---|---|---|---|
| 19 2% | 30 8% | 23 1% | 7 7% | 19.2% |

7 L'AIR DIRECTEMENT SUR LA NUQUE

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 55 2% | 3 4% | 17 2% | 17.2% | 6 9% |

8 FRAICHEUR AU PIEDS

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 37 9% | 10 3% | 20 7% | 31 0% | 0 0% |

9 FENETRE, FROID/CHAUD

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | |
|---|---|---|---|---|
| 3.3% | 6 7% | 6 7% | 23 3% | |
| | | EXCESSIVEMENT | | NE S'APPLIQUE PAS |
| | | 6.7% | | 53.3% |

10 QUALITE DE L'AIR

| TRES BONNE | BONNE | SATISFAISANTE | INSATISFAISANTE | MAUVAISE |
|---|---|---|---|---|
| 0 0% | 0 0% | 41 4% | 41 4% | 17.2% |

11 QUALITE DE L'AIR CHANGE-T-ELLE

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 24 0% | 16 0% | 32.0% | 28.0% | 0 0% |

12 L'ENVIRONNEMENT THERMIQUE EST

| TRES CONFORTABLE | CONFORT | CONVENABLE | LEG INACC | INACCEPTABLE |
|---|---|---|---|---|
| 0 0% | 6 9% | 34 5% | 37 9% | 20 7% |

13. PERCEVEZ-VOUS REGULIEREMENT DES ODEURS

| NON | <1FOIS/JOUR | 1FOIS/JOUR | +1FOIS/JOUR | REGULIEREMENT |
|---|---|---|---|---|
| 57 7% | 15 4% | 7 7% | 7 7% | 11 5% |

ANSWERS TO QUESTIONNAIRE MONTH SEPTEMBER 1990 FLOOR: 9

NUMBER OF DISTRIBUTED QUESTIONNAIRES 41

NUMBER OF ANSWERED QUESTIONNAIRES 17

RESPONSE RATE 41.5%

1 OU EST SITUE VOTRE POSTE DE TRAVAIL?

| CENTRE | PERIPHERIE |
|---|---|
| 33 3% | 66 7% |

2 INDIQUEZ LE NOM DES RUES

| PULLUM | F/S | STE-CATHERINE | S/P | PARTHENAIS |
|---|---|---|---|---|
| 11 1% | 5 6% | 16 7% | 0 0% | 16 7% |

| P/N | NOTRE-DAME | CENTRE |
|---|---|---|
| 0 0% | 0 0% | 50 0% |

3 LA TEMPERATURE EST

| FRAICHE | LEG FRAICHE | CONVENABLE | LEG CHAUDE | CHAUDE |
|---|---|---|---|---|
| 12 5% | 43 8% | 18 8% | 12 5% | 12 5% |

4 LA TEMPERATURE A-T-ELLE CHANGE DURANT LA JOURNEE?

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 11 1% | 38 9% | 22 2% | 22 2% | 5 6% |

5 L'AIR EST

| SEC | LEG SEC | SATISFAISANT | LEG HUMIDE | HUMIDE |
|---|---|---|---|---|
| 52 9% | 17 6% | 29 4% | 0.0% | 0 0% |

6. LA VENTILATION EST

| EXCESSIVE | LEG EXCESSIVE | ADEQUATE | LEG INSUFFISANTE | INSUFFISANTE |
|---|---|---|---|---|
| 11.1% | 27 8% | 22 2% | 16 7% | 22 2% |

7 L'AIR DIRECTEMENT SUR LA NUQUE

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 61 1% | 0 0% | 11 1% | 11 1% | 16 7% |

8 FRAICHEUR AU PIEDS

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 61 1% | 11 1% | 16 7% | 5 6% | 5 6% |

9 FENETRE. FROID/CHAUD

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | |
|---|---|---|---|---|
| 11 1% | 22 2% | 5 6% | 11 1% | |
| | | EXCESSIVEMENT | | NE S APPLIQUE PAS |
| | | 0 0% | | 50 0% |

10 QUALITE DE L'AIR

| TRES BONNE | BONNE | SATISFAISANTE | INSATISFAISANTE | MAUVAISE |
|---|---|---|---|---|
| 6 3% | 18 8% | 25 0% | 12 5% | 37 5% |

11 QUALITE DE L'AIR CHANGE-T-ELLE

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 12 5% | 37 % | 18 8% | 25 0% | 6 3% |

12 L'ENVIRONNEMENT THERMIQUE EST

| TRES CONFORTABLE | CONFORT | CONVENABLE | LEG INACC | INACCEPTABLE |
|---|---|---|---|---|
| 0 0% | 16 7% | 33 3% | 27 8% | 22.2% |

13 PERCEVEZ-VOUS REGULIEREMENT DES ODEURS

| NON | <1FOIS/JOUR | 1FOIS/JOUR | +1FOIS/JOUR | REGULIEREMENT |
|---|---|---|---|---|
| 58 8% | 11 8% | 0 0% | 11 8% | 17.6% |

ANSWERS TO QUESTIONNAIRE MONTH OCTOBER 1990 FLOOR 8

NUMBER OF DISTRIBUTED QUESTIONNAIRES 48

NUMBER OF ANSWERED QUESTIONNAIRES 28

RESPONSE RATE 58 3%

1 OU EST SITUE VOTRE POSTE DE TRAVAIL?

| CENTRE | PERIPHERIE |
|---|---|
| 14 3% | 85 7% |

2 INDIQUEZ LE NOM DES RUES

| FULLUM | F/S | STE-CATHERINE | S/P | PARTHENAIS |
|---|---|---|---|---|
| 3 6% | 0 0% | 17 9% | 7 1% | 28 6% |

| P/N | NOTRE-DAME | CENTRE |
|---|---|---|
| 3 6% | 7 1% | 32 1% |

3 LA TEMPERATURE EST

| FRAICHE | LEG FRAICHE | CONVENABLE | LEG CHAUDE | CHAUDE |
|---|---|---|---|---|
| 20 0% | 20 0% | 36 0% | 20 0% | 4 0% |

4 LA TEMPERATURE A-T-ELLE CHANGE DURANT LA JOURNEE?

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 9 5% | 20 0% | 36 0% | 20 0% | 28 6% |

5 L'AIR EST

| SEC | LEG SEC | SATISFAISANT | LEG HUMIDE | HUMIDE |
|---|---|---|---|---|
| 60 0% | 24 0% | 12 0% | 4 0% | 0 0% |

6 LA VENTILATION EST

| EXCESSIVE | LEG EXCESSIVE | ADEQUATE | LEG INSUFFISANTE | INSUFFISANTE |
|---|---|---|---|---|
| 14 8% | 37 0% | 25 9% | 11 1% | 11 1% |

7 L'AIR DIRECTEMENT SUR LA NUQUE

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 64 3% | 10 7% | 14 3% | 10 7% | 0 0% |

8 FRAICHEUR AU PIEDS

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 48 0% | 8 0% | 32 0% | 8 0% | 4 0% |

9 FENETRE, FROID/CHAUD

| NON | UN PEU | MOYENNEMENT | BEAUCOUP |
|---|---|---|---|
| 11 5% | 19 2% | 7 7% | 23 1% |

| EXCESSIVEMENT | NE S'APPLIQUE PAS |
|---|---|
| 3 8% | 34 6% |

10 QUALITE DE L'AIR

| TRES BONNE | BONNE | SATISFAISANTE | INSATISFAISANTE | MAUVAISE |
|---|---|---|---|---|
| 4 2% | 4 2% | 37 5% | 37 5% | 16 7% |

11 QUALITE DE L'AIR CHANGE-T-ELLE

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 16 0% | 12 0% | 60 0% | 8 0% | 4 0% |

12 L'ENVIRONNEMENT THERMIQUE EST

| TRES CONFORTABLE | CONFORT | CONVENABLE | LEG INACC | INACCEPTABLE |
|---|---|---|---|---|
| 0 0% | 7 1% | 35 7% | 39 3% | 17 9% |

13 PERCEVEZ-VOUS REGULIEREMENT DES ODEURS

| NON | <1FOIS/JOUR | 1FOIS/JOUR | +1FOIS/JOUR | REGULIEREMENT |
|---|---|---|---|---|
| 64 0% | 12 0% | 4 0% | 8 0% | 12 0% |

ANSWERS TO QUESTIONNAIRE MONTH OCTOBER 1990 FLOOR 9

| | |
|---|---|
| NUMBER OF DISTRIBUTED QUESTIONNAIRES | 40 |
| NUMBER OF ANSWERED QUESTIONNAIRES | 20 |
| RESPONSE RATE | 50 0% |

1 OU EST SITUE VOTRE POSTE DE TRAVAIL?

| CENTRE | PERIPHERIE |
|---|---|
| 40 0% | 60 0% |

2 INDIQUEZ LE NOM DES RUES

| FULLUM | F/S | STE-CATHERINE | S/P | PARTHENAIS |
|---|---|---|---|---|
| 0 0% | 0 0% | 5 0% | 0 0% | 25.0% |

| P/N | NOTRE-DAME | CENTRE |
|---|---|---|
| 0 0% | 5 0% | 65 0% |

3 LA TEMPERATURE EST

| FRAICHE | LEG FRAICHE | CONVENABLE | LEG CHAUDE | CHAUDE |
|---|---|---|---|---|
| 0 0% | 15 8% | 36 8% | 15 8% | 31 6% |

4 LA TEMPERATURE A-T-ELLE CHANGE DURANT LA JOURNEE?

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 15 0% | 30 0% | 5 0% | 35 0% | 15 0% |

5 L'AIR EST

| SEC | LEG SEC | SATISFAISANT | LEG HUMIDE | HUMIDE |
|---|---|---|---|---|
| 60 0% | 20 0% | 15 0% | 5.0% | 0 0% |

6 LA VENTILATION EST

| EXCESSIVE | LEG EXCESSIVE | ADEQUATE | LEG INSUFFISANTE | INSUFFISANTE |
|---|---|---|---|---|
| 5 6% | 5 6% | 22 2% | 38 9% | 27 8% |

7 L'AIR DIRECTEMENT SUR LA NUQUE

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 75 0% | 10 0% | 10 0% | 5 0% | 0 0% |

8 FRAICHEUR AU PIEDS

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 70 0% | 5 0% | 20 0% | 5 0% | 0 0% |

9 FENETRE, FROID/CHAUD

| NON | UN PEU | MOYENNEMENT | BEAUCOUP |
|---|---|---|---|
| 20 0% | 5 0% | 5 0% | 5 0% |

| EXCESSIVEMENT | NE S APPLIQUE PAS |
|---|---|
| 0 0% | 65 0% |

10 QUALITE DE L'AIR

| TRES BONNE | BONNE | SATISFAISANTE | INSATISFAISANTE | MAUVAISE |
|---|---|---|---|---|
| 0 0% | 11 1% | 27 8% | 33 3% | 27 8% |

11 QUALITE DE L'AIR CHANGE-T-ELLE

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 21 1% | 26 3% | 10 5% | 31 6% | 10 5% |

12 L'ENVIRONNEMENT THERMIQUE EST

| TRES CONFORTABLE | CONFORT | CONVENABLE | LEG INACC | INACCEPTABLE |
|---|---|---|---|---|
| 0 0% | 15 0% | 25 0% | 35 0% | 25 0% |

13 PERCEVEZ-VOUS REGULIEREMENT DES ODEURS

| NON | <1FOIS/JOUR | 1FOIS/JOUR | +1FOIS/JOUR | REGULIEREMENT |
|---|---|---|---|---|
| 57 9% | 15 8% | 10 5% | 0 0% | 15 8% |

ANSWERS TO QUESTIONNAIRE MONTH NOVEMBER 1990 FLOOR 8

| | |
|---|---|
| NUMBER OF DISTRIBUTED QUESTIONNAIRES | 50 |
| NUMBER OF ANSWERED QUESTIONNAIRES | 31 |
| RESPONSE RATE | 62 0% |

1 OU EST SITUE VOTRE POSTE DE TRAVAIL?

| CENTRE | PERIPHERIE |
|---|---|
| 16 1% | 83 9% |

2 INDIQUEZ LE NOM DES RUES

| FULLUM | F/S | STE-CATHERINE | S/P | PARTHENAIS |
|---|---|---|---|---|
| 6 5% | 0 0% | 19 4% | 3 2% | 25 8% |

| P/N | NOTRE-DAME | CENTRE |
|---|---|---|
| 0 0% | 6 5% | 38 7% |

3 LA TEMPERATURE EST

| FRAICHE | LEG FRAICHE | CONVENABLE | LEG CHAUDE | CHAUDE |
|---|---|---|---|---|
| 25 0% | 14 3% | 28 6% | 21 4% | 10 7% |

4 LA TEMPERATURE A-T-ELLE CHANGE DURANT LA JOURNEE?

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 29 6% | 22 2% | 18 5% | 25 9% | 3 7% |

5 L'AIR EST

| SEC | LEG SEC | SATISFAISANT | LEG HUMIDE | HUMIDE |
|---|---|---|---|---|
| 43 3% | 30 0% | 23 3% | 0 0% | 3 3% |

6 LA VENTILATION EST

| EXCESSIVE | LEG EXCESSIVE | ADEQUATE | LEG INSUFFISANTE | INSUFFISANTE |
|---|---|---|---|---|
| 3 3% | 13 3% | 56 7% | 10 0% | 16 7% |

7 L'AIR DIRECTEMENT SUR LA NUQUE

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 83 9% | 3 2% | 3 2% | 3 2% | 6 5% |

8 FRAICHEUR AU PIEDS

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 58 1% | 9 7% | 16 1% | 16 1% | 0 0% |

9 FENETRE, FROID/CHAUD

| NON | UN PEU | MOYENNEMENT | BEAUCOUP |
|---|---|---|---|
| 20 0% | 6 7% | 10 0% | 20 0% |

| EXCESSIVEMENT | NE S'APPLIQUE PAS |
|---|---|
| 3 3% | 40 0% |

10 QUALITE DE L AIR

| TRES BONNE | BONNE | SATISFAISANTE | INSATISFAISANTE | MAUVAISE |
|---|---|---|---|---|
| 3 4% | 6 9% | 31 0% | 48 3% | 10 3% |

11 QUALITE DE L'AIR CHANGE-T-ELLE

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 32 1% | 25 0% | 25 0% | 14 3% | 3 6% |

12 L'ENVIRONNEMENT THERMIQUE EST

| TRES CONFORTABLE | CONFORT | CONVENABLE | LEG INACC | INACCEPTABLE |
|---|---|---|---|---|
| 0.0% | 0.0% | 40.0% | 43.3% | 16.7% |

13 PERCEVEZ-VOUS REGULIEREMENT DES ODEURS

| NON | <1FOIS/JOUR | 1FOIS JOUR | +1FOIS JOUR | REGULIEREMENT |
|---|---|---|---|---|
| 51.7% | 20.7% | 10.3% | 0.0% | 17.2% |

ANSWERS TO QUESTIONNAIRE | MONTH: NOVEMBER 1990 | FLOOR: 9

NUMBER OF DISTRIBUTED QUESTIONNAIRES 40

NUMBER OF ANSWERED QUESTIONNAIRES 20

RESPONSE RATE 50.0%

1 OU EST SITUE VOTRE POSTE DE TRAVAIL?:

| CENTRE | PERIPHERIE |
|---|---|
| 27.8% | 72.2% |

2 INDIQUEZ LE NOM DES RUES

| FULLUM | F/S | STE-CATHERINE | S/P | PARTHENAIS |
|---|---|---|---|---|
| 5.0% | 0.0% | 15.0% | 0.0% | 25.0% |

| P/N | NOTRE-DAME | CENTRE |
|---|---|---|
| 0.0% | 0.0% | 55.0% |

3 LA TEMPERATURE EST

| FRAICHE | LEG FRAICHE | CONVENABLE | LEG CHAUDE | CHAUDE |
|---|---|---|---|---|
| 16.7% | 22.2% | 38.9% | 5.6% | 16.7% |

4 LA TEMPERATURE A-T-ELLE CHANGE DURANT LA JOURNEE?:

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 27.8% | 22.2% | 16.7% | 27.8% | 5.6% |

5 L'AIR EST

| SEC | LEG SEC | SATISFAISANT | LEG HUMIDE | HUMIDE |
|---|---|---|---|---|
| 65.0% | 25.0% | 10.0% | 0.0% | 0.0% |

6 LA VENTILATION EST

| EXCESSIVE | LEG EXCESSIVE | ADEQUATE | LEG INSUFFISANTE | INSUFFISANTE |
|---|---|---|---|---|
| 5 0% | 5 0% | 25 0% | 30 0% | 35 0% |

7. L'AIR DIRECTEMENT SUR LA NUQUE

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 75 0% | 5 0% | 15 0% | 0 0% | 5 0% |

8 FRAICHEUR AU PIEDS

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 70 0% | 5 0% | 15 0% | 5 0% | 5 0% |

9 FENETRE FROID/CHAUD

| NON | UN PEU | MOYENNEMENT | BEAUCOUP |
|---|---|---|---|
| 15 0% | 15 0% | 0 0% | 10 0% |

| EXCESSIVEMENT | NE S'APPLIQUE PAS |
|---|---|
| 0 0% | 60 0% |

10 QUALITE DE L AIR

| TRES BONNE | BONNE | SATISFAISANTE | INSATISFAISANTE | MAUVAISE |
|---|---|---|---|---|
| 0 0% | 5 3% | 47 4% | 26 3% | 21 1% |

11 QUALITE DE L'AIR CHANGE-T-ELLE

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 21 1% | 31 6% | 5 3% | 26 3% | 15 8% |

12 L'ENVIRONNEMENT THERMIQUE EST

| TRES CONFORTABLE | CONFORT | CONVENABLE | LEG INACC | INACCEPTABLE |
|---|---|---|---|---|
| 5 0% | 5 0% | 40 0% | 25 0% | 25.0% |

13 PERCEVEZ-VOUS REGULIEREMENT DES ODEURS

| NON | <1FOIS/JOUR | 1FOIS/JOUR | +1FOIS/JOUR | REGULIEREMENT |
|---|---|---|---|---|
| 61 1% | 16 7% | 0 0% | 16 7% | 5 6% |

ANSWERS TO QUESTIONNAIRE MONTH DECEMBER 1990 FLOOR 8

| | |
|---|---|
| NUMBER OF DISTRIBUTED QUESTIONNAIRES | 53 |
| NUMBER OF ANSWERED QUESTIONNAIRES | 27 |
| RESPONSE RATE | 50.9% |

1 OU EST SITUE VOTRE POSTE DE TRAVAIL?

| CENTRE | PERIPHERIE |
|---|---|
| 16.0% | 84.0% |

2 INDIQUEZ LE NOM DES RUES

| FULLUM | F'S STE-CATHERINE | | S/P | PARTHENAIS |
|---|---|---|---|---|
| 3.7% | 3.7% | 22.2% | 3.7% | 18.5% |
| P/N | NOTRE-DAME | CENTRE | | |
| 3.7% | 7.4% | 37.0% | | |

3 LA TEMPERATURE EST

| FRAICHE | LEG FRAICHE | CONVENABLE | LEG CHAUDE | CHAUDE |
|---|---|---|---|---|
| 12.0% | 16.0% | 40.0% | 32.0% | 0.0% |

4 LA TEMPERATURE A-T-ELLE CHANGE DURANT LA JOURNEE?

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 17.4% | 26.1% | 39.1% | 13.0% | 4.3% |

5 L'AIR EST

| SEC | LEG SEC | SATISFAISANT | LEG HUMIDE | HUMIDE |
|---|---|---|---|---|
| 63.0% | 22.2% | 14.8% | 0.0% | 0.0% |

6 LA VENTILATION EST

| EXCESSIVE | LEG EXCESSIVE | ADEQUATE | LEG INSUFFISANTE | INSUFFISANTE |
|---|---|---|---|---|
| 11 1% | 29 6% | 37 0% | 18 5% | 3 7% |

7 L AIR DIRECTEMENT SUR LA NUQUE

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 55 6% | 11 1% | 18 5% | 7 4% | 7 4% |

8 FRAICHEUR AU PIEDS

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 59 3% | 7 4% | 29 6% | 3 7% | 0 0% |

9 FENETRE FROID CHAUD

| NON | UN PEU | MOYENNEMENT | BEAUCOUP |
|---|---|---|---|
| 20 0% | 16 0% | 12 0% | 8 0% |

| EXCESSIVEMENT | NE S APPLIQUE PAS |
|---|---|
| 4 0% | 40 0% |

10 QUALITE DE L AIR

| TRES BONNE | BONNE | SATISFAISANTE | INSATISFAISANTE | MAUVAISE |
|---|---|---|---|---|
| 0 0% | 4 0% | 40 0% | 40 0% | 16 0% |

11 QUALITE DE L AIR CHANGE-T-ELLE

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 26.9% | 30.8% | 23.1% | 15.4% | 3.8% |

12 L ENVIRONNEMENT THERMIQUE EST

| TRES CONFORTABLE | CONFORT | CONVENABLE | LEG INACC | INACCEPTABLE |
|---|---|---|---|---|
| 3.8% | 3.8% | 42.3% | 38.5% | 11.5% |

13 PERCEVEZ-VOUS REGULIEREMENT DES ODEURS

| NON | <1FOIS JOUR | 1FOIS JOUR | +1FOIS JOUR | REGULIEREMENT |
|---|---|---|---|---|
| 40.0% | 20.0% | 24.0% | 0.0% | 16.0% |

14 L INFLUENCE SUR PRODUCTIVITE

| | |
|---|---|
| +40% | 8.3% |
| +30% | 0.0% |
| +20% | 0.0% |
| +10% | 4.2% |
| PAS D EFFET | 8.3% |
| -10% | 37.5% |
| -20% | 29.2% |
| -30% | 12.5% |
| -40% | 0.0% |

ANSWERS TO QUESTIONNAIRE MONTH DECEMBER 1990 FLOOR 9

NUMBER OF DISTRIBUTED QUESTIONNAIRES 36

NUMBER OF ANSWERED QUESTIONNAIRES 16

RESPONSE RATE 44 4%

1 OU EST SITUE VOTRE POSTE DE TRAVAIL?

| CENTRE | PERIPHERIE |
|---|---|
| 20 0% | 80 0% |

2 INDIQUEZ LE NOM DES RUES

| FULLUM | F/S | STE-CATHERINE | S'P | PARTHENAIS |
|---|---|---|---|---|
| 12 5% | 0 0% | 6 3% | 0 0% | 12 5% |

| P/N | NOTRE-DAME | CENTRE |
|---|---|---|
| 0 0% | 6 3% | 62 5% |

3 LA TEMPERATURE EST

| FRAICHE | LEG FRAICHE | CONVENABLE | LEG CHAUDE | CHAUDE |
|---|---|---|---|---|
| 18 8% | 18 8% | 31 3% | 18 8% | 12 5% |

4 LA TEMPERATURE A-T-ELLE CHANGE DURANT LA JOURNEE?

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 7 1% | 28 6% | 21 4% | 35 7% | 7 1% |

5 L'AIR EST

| SEC | LEG SEC | SATISFAISANT | LEG HUMIDE | HUMIDE |
|---|---|---|---|---|
| 56 3% | 12 5% | 31 3% | 0 0% | 0 0% |

6 LA VENTILATION EST

| EXCESSIVE | LEG EXCESSIVE | ADEQUATE | LEG INSUFFISANTE | INSUFFISANTE |
|---|---|---|---|---|
| 6 3% | 12 5% | 31 3% | 12 5% | 37 5% |

7 L AIR DIRECTEMENT SUR LA NUQUE

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 66 7% | 6 7% | 20 0% | 6 7% | 0 0% |

8 FRAICHEUR AU PIEDS

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 56 3% | 18 8% | 25 0% | 0 0% | 0 0% |

9 FENETRE FROID CHAUD

| NON | UN PEU | MOYENNEMENT | BEAUCOUP |
|---|---|---|---|
| 6 3% | 12 5% | 12 5% | 0 0% |

| EXCESSIVEMENT | NE S APPLIQUE PAS |
|---|---|
| 0 0% | 68 8% |

10 QUALITE DE L AIR

| TRES BONNE | BONNE | SATISFAISANTE | INSATISFAISANTE | MAUVAISE |
|---|---|---|---|---|
| 0 0% | 31 3% | 18 8% | 37 5% | 12 5% |

11 QUALITE DE L AIR CHANGE-T-ELLE

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 31 3% | 25 0% | 12 5% | 31 3% | 0 0% |

12 L ENVIRONNEMENT THERMIQUE EST

| TRES CONFORTABLE | CONFORT | CONVENABLE | LEG INACC | INACCEPTABLE |
|---|---|---|---|---|
| 0 0% | 12 5% | 56 3% | 6 3% | 25 0% |

13 PERCEVEZ-VOUS REGULIEREMENT DES ODEURS

| NON | <1FOIS/JOUR | 1FOIS/JOUR | +1FOIS JOUR | REGULIEREMENT |
|---|---|---|---|---|
| 60 0% | 33 3% | 0 0% | 6 7% | 0 0% |

14 L INFLUENCE SUR PRODUCTIVITE

| | |
|---|---|
| +40% | 8 3% |
| +30% | 8 3% |
| +20% | 0 0% |
| +10% | 8 3% |
| PAS D'EFFET | 16 7% |
| -10% | 25 0% |
| -20% | 8 3% |
| -30% | 25 0% |
| -40% | 0 0% |

ANSWERS TO QUESTIONNAIRE MONTH JANUARY 1991 FLOOR 8

NUMBER OF DISTRIBUTED QUESTIONNAIRES 52

NUMBER OF ANSWERED QUESTIONNAIRES 35

RESPONSE RATE 67 3%

1 OU EST SITUE VOTRE POSTE DE TRAVAIL?

| CENTRE | PERIPHERIE |
|---|---|
| 20 0% | 80 0% |

2 INDIQUEZ LE NOM DES RUES

| FULLUM | F/S | STE-CATHERINE | S/P | PARTHENAIS |
|---|---|---|---|---|
| 5 7% | 2 9% | 20 0% | 2 9% | 22 9% |

| P/N | NOTRE-DAME | CENTRE |
|---|---|---|
| 0 0% | 2 9% | 42 9% |

3 LA TEMPERATURE EST

| FRAICHE | LEG FRAICHE | CONVENABLE | LEG CHAUDE | CHAUDE |
|---|---|---|---|---|
| 16 1% | 32 3% | 29 0% | 9 7% | 12 9% |

4 LA TEMPERATURE A-T-ELLE CHANGE DURANT LA JOURNEE?

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 18 2% | 27 3% | 24 2% | 27 3% | 3 0% |

5 L'AIR EST

| SEC | LEG SEC | SATISFAISANT | LEG HUMIDE | HUMIDE |
|---|---|---|---|---|
| 50 0% | 26 5% | 20 6% | 2 9% | 0 0% |

6 LA VENTILATION EST

| EXCESSIVE | LEG EXCESSIVE | ADEQUATE | LEG INSUFFISANTE | INSUFFISANTE |
|---|---|---|---|---|
| 14 3% | 20 0% | 37 1% | 8 6% | 20 0% |

7 L'AIR DIRECTEMENT SUR LA NUQUE

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 65 7% | 11 4% | 11 4% | 8 6% | 2 9% |

8 FRAICHEUR AU PIEDS

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 64 7% | 2 9% | 17 6% | 11 8% | 2 9% |

9 FENETRE FROID CHAUD

| NON | UN PEU | MOYENNEMENT | BEAUCOUP |
|---|---|---|---|
| 11 8% | 17 6% | 11 8% | 8 8% |

| EXCESSIVEMENT | NE S APPLIQUE PAS |
|---|---|
| 5 9% | 44 1% |

10 QUALITE DE L AIR

| TRES BONNE | BONNE | SATISFAISANTE | INSATISFAISANTE | MAUVAISE |
|---|---|---|---|---|
| 2 9% | 11 8% | 20 6% | 44 1% | 20 6% |

11 QUALITE DE L'AIR CHANGE-T-ELLE

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 21 2% | 36 4% | 18 2% | 21 2% | 3 0% |

12 L'ENVIRONNEMENT THERMIQUE EST

| TRES CONFORTABLE | CONFORT | CONVENABLE | LEG INACC | INACCEPTABLE |
|---|---|---|---|---|
| 2.9% | 11.8% | 29.4% | 41.2% | 14.7% |

13 PERCEVEZ-VOUS REGULIEREMENT DES ODEURS

| NON | <1FOIS JOUR | 1FOIS JOUR | +1FOIS JOUR | REGULIEREMENT |
|---|---|---|---|---|
| 50.0% | 20.6% | 14.7% | 0.0% | 14.7% |

14 L INFLUENCE SUR PRODUCTIVITE

| | |
|---|---|
| +40% | 0.0% |
| +30% | 0.0% |
| +20% | 7.4% |
| +10% | 3.7% |
| PAS D EFFET | 11.1% |
| -10% | 40.7% |
| -20% | 22.2% |
| -30% | 11.1% |
| -40% | 3.7% |

ANSWERS TO QUESTIONNAIRE | MONTH JANUARY 1991 | FLOOR 9

NUMBER OF DISTRIBUTED QUESTIONNAIRES 42

NUMBER OF ANSWERED QUESTIONNAIRES 19

RESPONSE RATE 45 2%

1 OU EST SITUE VOTRE POSTE DE TRAVAIL?

| CENTRE | PERIPHERIE |
|---|---|
| 29 4% | 70 6% |

2 INDIQUEZ LE NOM DES RUES

| PULLUM | F/S | STE-CATHERINE | S/P | PARTHENAIS |
|---|---|---|---|---|
| 0 0% | 0 0% | 25 0% | 0 0% | 20 0% |

| P/N | NOTRE-DAME | CENTRE |
|---|---|---|
| 0 0% | 10 0% | 45 0% |

3 LA TEMPERATURE EST

| FRAICHE | LEG FRAICHE | CONVENABLE | LEG CHAUDE | CHAUDE |
|---|---|---|---|---|
| 16 7% | 22 2% | 33 3% | 22 2% | 5 6% |

4 LA TEMPERATURE A-T-ELLE CHANGE DURANT LA JOURNEE?

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 36 8% | 22 2% | 33 3% | 22 2% | 5.6% |

5 L'AIR EST

| SEC | LEG SEC | SATISFAISANT | LEG HUMIDE | HUMIDE |
|---|---|---|---|---|
| 50 0% | 35 0% | 15 0% | 0 0% | 0 0% |

6 LA VENTILATION EST

| EXCESSIVE | LEG EXCESSIVE | ADEQUATE | LEG INSUFFISANTE | INSUFFISANTE |
|---|---|---|---|---|
| 15 8% | 21 1% | 15 8% | 0 0% | 21 1% |

7 L'AIR DIRECTEMENT SUR LA NUQUE

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 65 0% | 10 0% | 15 0% | 5 0% | 5 0% |

8 FRAICHEUR AU PIEDS

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 65 0% | 10 0% | 15 0% | 10 0% | 0 0% |

9 FENETRE FROID'CHAUD

| NON | UN PEU | MOYENNEMENT | BEAUCOUP |
|---|---|---|---|
| 10 0% | 10 0% | 10 0% | 15 0% |

| EXCESSIVEMENT | NE S APPLIQUE PAS |
|---|---|
| 5 0% | 50 0% |

10 QUALITE DE L AIR

| TRES BONNE | BONNE | SATISFAISANTE | INSATISFAISANTE | MAUVAISE |
|---|---|---|---|---|
| 0 0% | 17 6% | 35 3% | 29 4% | 17 6% |

11 QUALITE DE L'AIR CHANGE-T-ELLE

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 44 4% | 16 7% | 11 1% | 27 8% | 0 0% |

12 L'ENVIRONNEMENT THERMIQUE EST

| TRES CONFORTABLE | CONFORT | CONVENABLE | LEG INACC | INACCEPTABLE |
|---|---|---|---|---|
| 5 0% | 15 0% | 40 0% | 15 0% | 25 0% |

13 PERCEVEZ-VOUS REGULIEREMENT DES ODEURS

| NON | <1FOIS/JOUR | 1FOIS/JOUR | +1FOIS/JOUR | REGULIEREMENT |
|---|---|---|---|---|
| 52 9% | 23 5% | 17 6% | 5 9% | 0 0% |

14 L INFLUENCE SUR PRODUCTIVITE

| | |
|---|---|
| +40% | 0 0% |
| +30% | 5 6% |
| +20% | 11 1% |
| +10% | 5 6% |
| PAS D'EFFET | 22 2% |
| -10% | 5 6% |
| -20% | 22 2% |
| -30% | 16 7% |
| -40% | 11 1% |

ANSWERS TO QUESTIONNAIRE MONTH. FEBRUARY 1991 FLOOR 8

| | |
|---|---|
| NUMBER OF DISTRIBUTED QUESTIONNAIRES | 47 |
| NUMBER OF ANSWERED QUESTIONNAIRES | 29 |
| RESPONSE RATE | 61 7% |

1 OU EST SITUE VOTRE POSTE DE TRAVAIL?

| CENTRE | PERIPHERIE |
|---|---|
| 10 7% | 89 3% |

2 INDIQUEZ LE NOM DES RUES

| FULLUM | F/S STE-CATHERINE | | S/P | PARTHENAIS |
|---|---|---|---|---|
| 7 1% | 3 6% | 14 3% | 3 6% | 21 4% |
| P/N | NOTRE-DAME | CENTRE | | |
| 0 0% | 3 6% | 46 4% | | |

3 LA TEMPERATURE EST

| FRAICHE | LEG FRAICHE | CONVENABLE | LEG CHAUDE | CHAUDE |
|---|---|---|---|---|
| 13 0% | 26 1% | 34 8% | 17 4% | 8 7% |

4 LA TEMPERATURE A-T-ELLE CHANGE DURANT LA JOURNEE?

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 16 0% | 24 0% | 32 0% | 16 0% | 12 0% |

5 L'AIR EST

| SEC | LEG SEC | SATISFAISANT | LEG HUMIDE | HUMIDE |
|---|---|---|---|---|
| 61 5% | 38 5% | 0 0% | 0 0% | 0 0% |

6 LA VENTILATION EST

| EXCESSIVE | LEG EXCESSIVE | ADEQUATE | LEG INSUFFISANTE | INSUFFISANTE |
|---|---|---|---|---|
| 10 3% | 17 2% | 34 5% | 20 7% | 17 2% |

7 L'AIR DIRECTEMENT SUR LA NUQUE

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 65 5% | 10 3% | 10 3% | 6 9% | 6 9% |

8 FRAICHEUR AU PIEDS

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 55 2% | 10 3% | 17 2% | 17 2% | 0 0% |

9 FENETRE, FROID/CHAUD

| NON | UN PEU | MOYENNEMENT | BEAUCOUP |
|---|---|---|---|
| 14 3% | 17 9% | 3 6% | 10 7% |

| EXCESSIVEMENT | NE S'APPLIQUE PAS |
|---|---|
| 17 9% | 35 7% |

10 QUALITE DE L'AIR

| TRES BONNE | BONNE | SATISFAISANTE | INSATISFAISANTE | MAUVAISE |
|---|---|---|---|---|
| 3 7% | 0 0% | 22 2% | 48 1% | 25 9% |

11 QUALITE DE L'AIR CHANGE-T-ELLE

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 33 3% | 18 5% | 25 9% | 14 8% | 7 4% |

12. L'ENVIRONNEMENT THERMIQUE EST

| TRES CONFORTABLE | CONFORT | CONVENABLE | LEG INACC | INACCEPTABLE |
|---|---|---|---|---|
| 0.0% | 3.8% | 30.8% | 34.6% | 30.8% |

13 PERCEVEZ-VOUS REGULIEREMENT DES ODEURS

| NON | <1FOIS/JOUR | 1FOIS JOUR | +1FOIS/JOUR | REGULIEREMENT |
|---|---|---|---|---|
| 17.4% | 30.4% | 17.4% | 0.0% | 34.8% |

14 L'INFLUENCE SUR PRODUCTIVITE

| | |
|---|---|
| +40% | 10.5% |
| +30% | 5.3% |
| +20% | 0.0% |
| +10% | 5.3% |
| PAS D'EFFET | 10.5% |
| -10% | 26.3% |
| -20% | 31.6% |
| -30% | 10.5% |
| -40% | 0.0% |

ANSWERS TO QUESTIONNAIRE | MONTH FEBRUARY 1991 | FLOOR 9

NUMBER OF DISTRIBUTED QUESTIONNAIRES 34

NUMBER OF ANSWERED QUESTIONNAIRES 20

RESPONSE RATE 58 8%

1 OU EST SITUE VOTRE POSTE DE TRAVAIL?

| CENTRE | PERIPHERIE |
|---|---|
| 47 4% | 52 6% |

2 INDIQUEZ LE NOM DES RUES

| FULLUM | F/S | STE-CATHERINE | S/P | PARTHENAIS |
|---|---|---|---|---|
| 0 0% | 0 0% | 20 0% | 0 0% | 15 0% |

| P/N | NOTRE-DAME | CENTRE |
|---|---|---|
| 0 0% | 15 0% | 50 0% |

3 LA TEMPERATURE EST

| FRAICHE | LEG FRAICHE | CONVENABLE | LEG CHAUDE | CHAUDE |
|---|---|---|---|---|
| 11 1% | 33 3% | 27 8% | 16 7% | 11 1% |

4 LA TEMPERATURE A-T-ELLE CHANGE DURANT LA JOURNEE?

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 31 6% | 10 5% | 31 6% | 21 1% | 5 3% |

5 L'AIR EST

| SEC | LEG SEC | SATISFAISANT | LEG HUMIDE | HUMIDE |
|---|---|---|---|---|
| 55 0% | 25 0% | 20 0% | 0 0% | 0 0% |

6 LA VENTILATION EST

| EXCESSIVE | LEG EXCESSIVE | ADEQUATE | LEG INSUFFISANTE | INSUFFISANTE |
|---|---|---|---|---|
| 25 0% | 20 0% | 25 0% | 15 0% | 15 0% |

7 L'AIR DIRECTEMENT SUR LA NUQUE

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 75 0% | 0 0% | 15 0% | 10 0% | 0 0% |

8 FRAICHEUR AU PIEDS

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 55 0% | 5 0% | 25 0% | 15 0% | 0 0% |

9 FENETRE, FROID/CHAUD

| NON | UN PEU | MOYENNEMENT | BEAUCOUP |
|---|---|---|---|
| 20 0% | 10 0% | 10 0% | 10 0% |

| EXCESSIVEMENT | NE S APPLIQUE PAS |
|---|---|
| 5 0% | 45 0% |

10 QUALITE DE L AIR

| TRES BONNE | BONNE | SATISFAISANTE | INSATISFAISANTE | MAUVAISE |
|---|---|---|---|---|
| 0 0% | 27 8% | 27 8% | 33 3% | 11 1% |

11 QUALITE DE L'AIR CHANGE-T-ELLE

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 42 1% | 15 8% | 10 5% | 26 3% | 5 3% |

12 L'ENVIRONNEMENT THERMIQUE EST

| TRES CONFORTABLE | CONFORT | CONVENABLE | LEG INACC | INACCEPTABLE |
|---|---|---|---|---|
| 0 0% | 15 8% | 52 6% | 0 0% | 31 6% |

13 PERCEVEZ-VOUS REGULIEREMENT DES ODEURS

| NON | <1FOIS/JOUR | 1FOIS/JOUR | +1FOIS/JOUR | REGULIEREMENT |
|---|---|---|---|---|
| 61 1% | 11 1% | 5 6% | 5 6% | 16 7% |

14 L'INFLUENCE SUR PRODUCTIVITE

| | |
|---|---|
| +40% | 11 1% |
| +30% | 11 1% |
| +20% | 0 0% |
| +10% | 5 6% |
| PAS D'EFFET | 16 7% |
| -10% | 11 1% |
| -20% | 22 2% |
| -30% | 11 1% |
| -40% | 11 1% |

ANSWERS TO QUESTIONNAIRE MONTH MARCH 1991 FLOOR 8

NUMBER OF DISTRIBUTED QUESTIONNAIRES 53

NUMBER OF ANSWERED QUESTIONNAIRES 34

RESPONSE RATE 64.2%

1 OU EST SITUE VOTRE POSTE DE TRAVAIL?

| CENTRE | PERIPHERIE |
|---|---|
| 24.2% | 75.8% |

2 INDIQUEZ LE NOM DES RUES

| FULLUM | F.S. STE-CATHERINE | | S.P. | PARTHENAIS |
|---|---|---|---|---|
| 5.9% | 0.0% | 17.6% | 2.9% | 23.5% |

| P/N | NOTRE-DAME | CENTRE |
|---|---|---|
| 2.9% | 8.8% | 38.2% |

3 LA TEMPERATURE EST

| FRAICHE | LEG FRAICHE | CONVENABLE | LEG CHAUDE | CHAUDE |
|---|---|---|---|---|
| 30.0% | 23.3% | 33.3% | 10.0% | 3.3% |

4 LA TEMPERATURE A-T-ELLE CHANGE DURANT LA JOURNEE?

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 25.0% | 12.5% | 31.3% | 21.9% | 9.4% |

5 L'AIR EST

| SEC | LEG SEC | SATISFAISANT | LEG HUMIDE | HUMIDE |
|---|---|---|---|---|
| 44.1% | 23.5% | 26.5% | 5.9% | 0.0% |

6 LA VENTILATION EST

| EXCESSIVE | LEG EXCESSIVE | ADEQUATE | LEG INSUFFISANTE | INSUFFISANTE |
|---|---|---|---|---|
| 15 6% | 25 0% | 40 6% | 6 3% | 12 5% |

7 L AIR DIRECTEMENT SUR LA NUQUE

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 58 8% | 2 9% | 23 5% | 5 9% | 8 8% |

8 FRAICHEUR AU PIEDS

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 45 5% | 18 2% | 27 3% | 6 1% | 3 0% |

9 FENETRE FROID/CHAUD

| NON | UN PEU | MOYENNEMENT | BEAUCOUP |
|---|---|---|---|
| 12 1% | 12 1% | 15 2% | 21 2% |

| EXCESSIVEMENT | NE S APPLIQUE PAS |
|---|---|
| 0 0% | 39 4% |

10 QUALITE DE L AIR

| TRES BONNE | BONNE | SATISFAISANTE | INSATISFAISANTE | MAUVAISE |
|---|---|---|---|---|
| 3 2% | 3 2% | 25 8% | 61 3% | 6 5% |

11 QUALITE DE L AIR CHANGE-T-ELLE

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 16 7% | 26 7% | 40 0% | 13 3% | 3 3% |

12. L'ENVIRONNEMENT THERMIQUE EST

| TRES CONFORTABLE | CONFORT | CONVENABLE | LEG INACC | INACCEPTABLE |
|---|---|---|---|---|
| 3 0% | 3 0% | 33 3% | 36 4% | 24 2% |

13 PERCEVEZ-VOUS REGULIEREMENT DES ODEURS

| NON | <1FOIS/JOUR | 1FOIS JOUR | +1FOIS/JOUR | REGULIEREMENT |
|---|---|---|---|---|
| 43 3% | 16 7% | 13 3% | 3 3% | 23 3% |

14 L'INFLUENCE SUR PRODUCTIVITE

| | |
|---|---|
| +40% | 9 1% |
| +30% | 4 5% |
| +20% | 4 5% |
| +10% | 4 5% |
| PAS D EFFET | 13 6% |
| -10% | 18 2% |
| -20% | 40 9% |
| -30% | 4 5% |
| -40% | 0 0% |

ANSWERS TO QUESTIONNAIRE MONTH MARCH 1991 FLOOR 9

| | |
|---|---|
| NUMBER OF DISTRIBUTED QUESTIONNAIRES | 41 |
| NUMBER OF ANSWERED QUESTIONNAIRES | 17 |
| RESPONSE RATE | 41 5% |

1 OU EST SITUE VOTRE POSTE DE TRAVAIL?

| CENTRE | PERIPHERIE |
|---|---|
| 35 7% | 64 3% |

2 INDIQUEZ LE NOM DES RUES

| FULLUM | F/S STE-CATHERINE | | S/P | PARTHENAIS |
|---|---|---|---|---|
| 0 0% | 0 0% | 11 8% | 0 0% | 35 3% |
| P/N | NOTRE-DAME | CENTRE | | |
| 0 0% | 11 8% | 41 2% | | |

3 LA TEMPERATURE EST

| FRAICHE | LEG FRAICHE | CONVENABLE | LEG CHAUDE | CHAUDE |
|---|---|---|---|---|
| 16 7% | 16 7% | 50 0% | 16 7% | 0 0% |

4 LA TEMPERATURE A-T-ELLE CHANGE DURANT LA JOURNEE?

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 12 5% | 37 5% | 25 0% | 18 8% | 6 3% |

5 L AIR EST

| SEC | LEG SEC | SATISFAISANT | LEG HUMIDE | HUMIDE |
|---|---|---|---|---|
| 46 7% | 33 3% | 20 0% | 0 0% | 0 0% |

6 LA VENTILATION EST

| EXCESSIVE | LEG EXCESSIVE | ADEQUATE | LEG INSUFFISANTE | INSUFFISANTE |
|---|---|---|---|---|
| 13 3% | 26 7% | 33 3% | 6 7% | 20 0% |

7 L'AIR DIRECTEMENT SUR LA NUQUE

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 70 6% | 0 0% | 17 6% | 11 8% | 0 0% |

8 FRAICHEUR AU PIEDS

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 52 9% | 5 9% | 29 4% | 11 8% | 0 0% |

9 FENETRE FROID/CHAUD

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | |
|---|---|---|---|---|
| 17 6% | 5 9% | 11 8% | 17 6% | |
| | EXCESSIVEMENT | NE S APPLIQUE PAS | | |
| | 5 9% | 41 2% | | |

10 QUALITE DE L AIR

| TRES BONNE | BONNE | SATISFAISANTE | INSATISFAISANTE | MAUVAISE |
|---|---|---|---|---|
| 0 0% | 11 8% | 35 3% | 35 3% | 17 6% |

11 QUALITE DE L'AIR CHANGE-T-ELLE

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 25 0% | 25 0% | 18 8% | 18 8% | 12 5% |

12 L'ENVIRONNEMENT THERMIQUE EST

| TRES CONFORTABLE | CONFORT | CONVENABLE | LEG INACC | INACCEPTABLE |
|---|---|---|---|---|
| 0 0% | 11 8% | 35 3% | 35.3% | 17.6% |

13 PERCEVEZ-VOUS REGULIEREMENT DES ODEURS

| NON | <1FOIS/JOUR | 1FOIS/JOUR | +1FOIS/JOUR | REGULIEREMENT |
|---|---|---|---|---|
| 41 2% | 23 5% | 0 0% | 0 0% | 35 3% |

14 L'INFLUENCE SUR PRODUCTIVITE

| | |
|---|---|
| +40% | 0 0% |
| +30% | 0 0% |
| +20% | 6 7% |
| +10% | 6 7% |
| PAS D EFFET | 13 3% |
| -10% | 46 7% |
| -20% | 20 0% |
| -30% | 6 7% |
| -40% | 0 0% |

ANSWERS TO QUESTIONNAIRE MONTH APRIL 1991 FLOOR 8

| | |
|---|---|
| NUMBER OF DISTRIBUTED QUESTIONNAIRES | 48 |
| NUMBER OF ANSWERED QUESTIONNAIRES | 21 |
| RESPONSE RATE | 43 8% |

1 OU EST SITUE VOTRE POSTE DE TRAVAIL?

| CENTRE | PERIPHERIE |
|---|---|
| 21 1% | 78 9% |

2 INDIQUEZ LE NOM DES RUES

| FULLUM | F/S | STE-CATHERINE | S/P | PARTHENAIS |
|---|---|---|---|---|
| 4 8% | 0 0% | 19 0% | 4 8% | 23 8% |

| P/N | NOTRE-DAME | CENTRE |
|---|---|---|
| 0 0% | 0 0% | 47 6% |

3 LA TEMPERATURE EST

| FRAICHE | LEG FRAICHE | CONVENABLE | LEG CHAUDE | CHAUDE |
|---|---|---|---|---|
| 15 8% | 31 6% | 26 3% | 15 8% | 10 5% |

4 LA TEMPERATURE A-T-ELLE CHANGE DURANT LA JOURNEE?

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 9 5% | 28 6% | 42 9% | 19 0% | 0 0% |

5 L'AIR EST

| SEC | LEG SEC | SATISFAISANT | LEG HUMIDE | HUMIDE |
|---|---|---|---|---|
| 52 4% | 28 6% | 14 3% | 4 8% | 0 0% |

6 LA VENTILATION EST

| EXCESSIVE | LEG EXCESSIVE | ADEQUATE | LEG INSUFFISANTE | INSUFFISANTE |
|---|---|---|---|---|
| 0 0% | 22 2% | 44 4% | 5 6% | 27 8% |

7 L AIR DIRECTEMENT SUR LA NUQUE

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 70 0% | 10 0% | 15 0% | 5 0% | 0 0% |

8 FRAICHEUR AU PIEDS

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 55 0% | 25 0% | 15 0% | 5 0% | 0 0% |

9 FENETRE FROID CHAUD

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT | NE S APPLIQUE PAS |
|---|---|---|---|---|---|
| 14 3% | 14 3% | 9 5% | 14 3% | 0 0% | 47 6% |

10 QUALITE DE L'AIR

| TRES BONNE | BONNE | SATISFAISANTE | INSATISFAISANTE | MAUVAISE |
|---|---|---|---|---|
| 11 1% | 5 6% | 16 7% | 55 6% | 11 1% |

11 QUALITE DE L'AIR CHANGE-T-ELLE

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 16 7% | 11 1% | 44 4% | 27 8% | 0 0% |

12 L'ENVIRONNEMENT THERMIQUE EST

| TRES CONFORTABLE | CONFORT | CONVENABLE | LEG INACC | INACCEPTABLE |
|---|---|---|---|---|
| 10 0% | 15 0% | 30 0% | 35 0% | 10 0% |

13 PERCEVEZ-VOUS REGULIEREMENT DES ODEURS

| NON | <1FOIS/JOUR | 1FOIS/JOUR | +1FOIS JOUR | REGULIEREMENT |
|---|---|---|---|---|
| 65 0% | 10 0% | 15 0% | 5 0% | 5 0% |

14 L INFLUENCE SUR PRODUCTIVITE

| | |
|---|---|
| +40% | 7 7% |
| +30% | 0 0% |
| +20% | 7 7% |
| +10% | 7 7% |
| PAS D EFFET | 7 7% |
| -10% | 15 4% |
| -20% | 46 2% |
| -30% | 0 0% |
| -40% | 7 7% |

ANSWERS TO QUESTIONNAIRE MONTH APRIL 1991 FLOOR 9

| | |
|---|---|
| NUMBER OF DISTRIBUTED QUESTIONNAIRES | 34 |
| NUMBER OF ANSWERED QUESTIONNAIRES | 17 |
| RESPONSE RATE: | 50 0% |

1. OU EST SITUE VOTRE POSTE DE TRAVAIL?

| CENTRE | PERIPHERIE |
|---|---|
| 47 1% | 52 9% |

2 INDIQUEZ LE NOM DES RUES

| FULLUM | P/S | STE-CATHERINE | S/P | PARTHENAIS |
|---|---|---|---|---|
| 0 0% | 5 6% | 11 1% | 0 0% | 22 2% |

| P/N | NOTRE-DAME | CENTRE |
|---|---|---|
| 0 0% | 11 1% | 50 0% |

3 LA TEMPERATURE EST

| FRAICHE | LEG FRAICHE | CONVENABLE | LEG CHAUDE | CHAUDE |
|---|---|---|---|---|
| 0 0% | 18 8% | 50 0% | 18 8% | 12 5% |

4. LA TEMPERATURE A-T-ELLE CHANGE DURANT LA JOURNEE?

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 13 3% | 20 0% | 46 7% | 20 0% | 0 0% |

5. L'AIR EST:

| SEC | LEG SEC | SATISFAISANT | LEG HUMIDE | HUMIDE |
|---|---|---|---|---|
| 38.9% | 27 8% | 16 7% | 5 6% | 11 1% |

6 LA VENTILATION EST

| EXCESSIVE | LEG EXCESSIVE | ADEQUATE | LEG INSUFFISANTE | INSUFFISANTE |
|---|---|---|---|---|
| 5 9% | 23.5% | 41 2% | 11 8% | 17 6% |

7 L'AIR DIRECTEMENT SUR LA NUQUE

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 61 1% | 5 6% | 33 3% | 0 0% | 0 0% |

8 FRAICHEUR AU PIEDS

| NON | RAREMENT | PARFOIS | SOUVENT | REGULIEREMENT |
|---|---|---|---|---|
| 66 7% | 5 6% | 22 2% | 5 6% | 0.0% |

9 FENETRE. FROID/CHAUD

| NON | UN PEU | MOYENNEMENT | BEAUCOUP |
|---|---|---|---|
| 16 7% | 16 7% | 5 6% | 5 6% |

| EXCESSIVEMENT | NE S'APPLIQUE PAS |
|---|---|
| 5 6% | 50 0% |

10 QUALITE DE L'AIR

| TRES BONNE | BONNE | SATISFAISANTE | INSATISFAISANTE | MAUVAISE |
|---|---|---|---|---|
| 0 0% | 11 8% | 64 7% | 17 6% | 5.9% |

1. ÉLITE DE L'AIR CHANGE-T-ELLE

| NON | UN PEU | MOYENNEMENT | BEAUCOUP | EXCESSIVEMENT |
|---|---|---|---|---|
| 17 6% | 47 1% | 17 6% | 11 8% | 5 9% |

12 L'ENVIRONNEMENT THERMIQUE EST

| TRES CONFORTABLE | CONFORT | CONVENABLE | LEG INACC | INACCEPTABLE |
|---|---|---|---|---|
| 0 0% | 23 5% | 41 2% | 29 4% | 5 9% |

13 PERCEVEZ-VOUS REGULIEREMENT DES ODEURS

| NON | <1FOIS/JOUR | 1FOIS/JOUR | +1FOIS/JOUR | REGULIEREMENT |
|---|---|---|---|---|
| 70 6% | 11 8% | 0 0% | 0 0% | 17 6% |

14 L'INFLUENCE SUR PRODUCTIVITE

| | |
|---|---|
| +40% | 11 8% |
| +30% | 5 9% |
| +20% | 17 6% |
| +10% | 11 8% |
| PAS D'EFFET | 17 6% |
| -10% | 17 6% |
| -20% | 11 8% |
| -30% | 5 9% |
| -40% | 0 0% |