

RESEARCH REPORT



Influence of an Electronic Air Cleaner on Indoor Ozone



CMHC—HOME TO CANADIANS

Canada Mortgage and Housing Corporation (CMHC) has been Canada's national housing agency for more than 60 years.

Together with other housing stakeholders, we help ensure that Canada maintains one of the best housing systems in the world. We are committed to helping Canadians access a wide choice of quality, affordable homes, while making vibrant, healthy communities and cities a reality across the country.

For more information, visit our website at **www.cmhc.ca**

You can also reach us by phone at 1-800-668-2642
or by fax at 1-800-245-9274.

Outside Canada call 613-748-2003 or fax to 613-748-2016.

Canada Mortgage and Housing Corporation supports the Government of Canada policy on access to information for people with disabilities. If you wish to obtain this publication in alternative formats, call 1-800-668-2642.

Influence of an Electronic Air Cleaner on Indoor Ozone

Prepared for:

Research Division
Canada Mortgage and Housing Corporation
700 Montreal Road
Ottawa, Ontario
K1A 0P7

CMHC Project Manager: Don Fugler

Prepared By:

Bowser Technical Inc
222 Memorial Drive
Brantford, Ontario
N3R 5T1

Principal Investigator: Dara Bowser

March 2003

This study was conducted for Canada Mortgage and Housing Corporation (CMHC) under Part IX of the National Housing Act. The analysis, interpretations and recommendations are those of the Consultant and do not necessarily reflect the views of CMHC.

Acknowledgments

The authors would like to thank the following individuals and organizations who contributed to the quality of this project:

Lisa Wardell Consumer Product Safety Bureau, Health Canada
Ottawa

Bud Offermann PE CIH, Indoor Environmental Engineering
San Francisco

Thomas J. Phillips California Air Resources Board
Sacramento

Charmaine Roye Homeowner

The Project Team Dara Bowser
Sandra Vos
Will Kwan

EXECUTIVE SUMMARY

Plate and wire type Electronic Air Cleaners (EAC) are frequently found in the central forced air systems of Canadian houses. They are often sold on the basis of their potential to relieve the symptoms of those who suffer from allergy-related and respiratory conditions.

It is known that these devices produce ozone during operation, and ozone is a known respiratory irritant. Recent findings lead to the possibility that EAC devices may contribute to raising indoor ozone to levels which could have a negative health impact.

Experiments were carried out to determine the degree to which ozone levels are influenced in a home due to the operation of an EAC and whether or not the ozone levels are affected by changes in house ventilation rate and changes in airflow through the device.

All of the experiments are based on one air-handler and EAC arrangement in one home in Brantford Ontario, Canada during November and December 2000. A total of 185 hours of data were obtained under varying conditions of house ventilation, EAC airflow and EAC operation. The air-handling system was operated continuously and all of the windows were kept closed.

Samples were obtained using a real-time data acquisition system using a UV Photometric ozone monitor sampling from outside, upstream of the EAC, office area (basement), downstream of EAC, bedroom (upstairs). Continuous weather data was used to predict air-exchange rates.

Data was analyzed using a model which accounted for air-change, internal removal, source strength and filtration of incoming air. Using house characteristic and source-strength values obtained from the experiments, inside ozone levels were predicted for a variety of air-change rates and outdoor ozone levels.

It was concluded that the continuous operation of an EAC could result in a rise of inside ozone concentration by 7 to 10 ppb higher than that which would normally be expected without EAC operation, or with intermittent EAC operation. Ozone concentration increase can be expected to be higher than this for smaller homes and homes with more smooth surfaces (e.g. smooth floors in place of carpeted). Conversely, the increase will be lower for larger homes with less smooth surfaces.

Changes in airflow through the EAC had a minor effect on ozone levels. Reducing the airflow by 50% resulted in an increase of ozone production and interior levels of less than 10%.

No conclusions were able to be reached concerning the effect of ventilation and filtration by the building envelope due to the lack of difference between indoor and outdoor ozone levels experienced during the experimental period.

As a consequence of these findings, winter-time Indoor/Outdoor ratios used for predictive population studies may require revision upwards from current estimates for houses equipped with continuously operating EAC's. Summer-time I/O ratios for air-conditioned houses may also require revision if the house also contains an EAC.

In homes equipped with an EAC and a continuously operating air-handling system, it is possible that the indoor air will exceed the 1 hour health-based Reference Level values for outdoor air proposed by the Canadian Federal-Provincial Working Group on Air Quality Objectives and Guidelines, (Ref 11).

EAC devices appear to be capable of elevating the ozone level inside a home to levels which are continuously at or above 10 ppb. Current knowledge does not allow us to state that the health of susceptible individuals will not be affected.

RÉSUMÉ

INFLUENCE D'UN PURIFICATEUR D'AIR ÉLECTRONIQUE SUR LA PRODUCTION D'OZONE À L'INTÉRIEUR

Au Canada, l'installation centrale à air pulsé de l'habitation est bien souvent pourvue d'un purificateur d'air électronique à plaques et fils. Les purificateurs se vendent souvent sur la foi de leur capacité à soulager les symptômes des personnes souffrant d'allergies ou de troubles respiratoires.

Il passe pour avéré que le fonctionnement de ces dispositifs produit de l'ozone, irritant respiratoire connu. Des recherches récentes indiquent que ces dispositifs peuvent contribuer à hausser le niveau intérieur d'ozone, ce qui risque de porter préjudice à la santé des occupants.

Des expériences visaient à déterminer à quel point le niveau d'ozone dans une maison est influencé par le fonctionnement d'un purificateur d'air électronique et si la variation du taux de ventilation dans la maison ou les changements de mouvement d'air traversant le dispositif exercent des répercussions sur la quantité d'ozone.

Toutes les expériences ont été fondées sur un système de circulation d'air et un purificateur d'air électronique installés dans une maison de Brantford, en Ontario, en novembre et décembre 2000. En tout, 185 heures de données ont été obtenues dans différentes conditions de ventilation, de mouvement d'air et de fonctionnement du purificateur d'air. Le système de circulation d'air a fonctionné continuellement et toutes les fenêtres ont été tenues fermées.

Des échantillons ont été obtenus à l'aide d'un système d'acquisition de données en temps réel faisant appel à un appareil de mesure de l'ozone avec détecteur photométrique UV prélevant les échantillons depuis l'extérieur, en amont du purificateur d'air, de l'aire de bureau (sous-sol), en aval du purificateur d'air, dans une chambre (en haut). Des données météorologiques continues ont servi à prédire les taux de renouvellement d'air.

Les données ont été analysées au moyen d'un modèle tenant compte du renouvellement d'air, de l'enlèvement interne, de l'intensité de la source et de la filtration de l'air admis. Exploitant les caractéristiques de la maison et les valeurs d'intensité de la source obtenues des expériences, les niveaux d'ozone intérieurs ont été prédits pour différents taux de renouvellement d'air et niveaux d'ozone extérieurs.

On a conclu que le fonctionnement continu d'un purificateur d'air électronique pouvait entraîner une augmentation de la concentration d'ozone intérieure de 7 à 10 ppb plus élevée que ce à quoi on s'attendrait sans un purificateur d'air électronique ou en le faisant fonctionner par intermittence. On peut s'attendre à ce que l'augmentation de la concentration d'ozone soit plus élevée dans des petites maisons et dans celles qui présentent davantage de surfaces lisses (sols lisses au lieu de tapis ou moquette). Par contre, l'augmentation serait moindre dans les grandes maisons présentant moins de surfaces lisses.

Les changements de mouvement d'air traversant le purificateur d'air électronique ont exercé peu d'effet sur les niveaux d'ozone. Réduire le mouvement d'air de moitié a donné lieu à une augmentation de la production d'ozone et à des niveaux intérieurs de moins de 10 %.

Aucune conclusion n'a pu être tirée quant à l'effet de la ventilation et de la filtration par l'enveloppe du bâtiment en raison du manque d'écart entre les niveaux d'ozone intérieurs et extérieurs subis au cours de la période d'expérience.

Par suite de ces résultats, les ratios intérieurs-externes en hiver pourraient devoir être revus à la hausse à partir des estimations courantes touchant les maisons équipées d'un purificateur d'air électronique fonctionnant en permanence. De même, les ratios intérieurs-externes en été pour les maisons climatisées pourraient également devoir être revus si la maison était aussi équipée d'un purificateur d'air électronique.

Dans les maisons équipées d'un purificateur d'air électronique et d'un système de traitement d'air fonctionnant continuellement, il se peut que l'air intérieur dépasse les valeurs du niveau de référence de 1 heure en air extérieur que propose le groupe de travail fédéral-provincial sur les objectifs et les lignes directrices de la qualité de l'air. Les purificateurs d'air électroniques semblent être capables de hausser le niveau d'ozone à l'intérieur d'une maison à des niveaux égalant ou dépassant toujours 10 ppb.



National Office

Bureau national

700 Montreal Road
Ottawa ON K1A 0P7
Telephone: (613) 748-2000

700 chemin de Montréal
Ottawa ON K1A 0P7
Téléphone : (613) 748-2000

Puisqu'on prévoit une demande restreinte pour ce document de recherche, seul le résumé a été traduit.

La SCHL fera traduire le document si la demande le justifie.

Pour nous aider à déterminer si la demande justifie que ce rapport soit traduit en français, veuillez remplir la partie ci-dessous et la retourner à l'adresse suivante :

Centre canadien de documentation sur l'habitation
Société canadienne d'hypothèques et de logement
700, chemin Montréal, bureau CI-200
Ottawa (Ontario)
K1A 0P7

Titre du rapport: _____

Je préférerais que ce rapport soit disponible en français.

NOM _____

ADRESSE _____

rue

App.

ville

province

Code postal

No de téléphone () _____

CONTENTS

1	OVERVIEW, DISCUSSION OF OBJECTIVES	-1-
1.1	<u>Introduction</u>	-1-
1.2	<u>Objectives</u>	-1-
1.3	<u>Limitations</u>	-2-
1.4	<u>Ozone</u>	-2-
1.5	<u>Electronic Air Cleaners and Ozone</u>	-3-
1.6	<u>Personal Exposure</u>	-4-
1.7	<u>Air Exchange, Surface Removal, and Indoor Outdoor Ozone Ratio</u>	-5-
2	DISCUSSION OF METHODS	-6-
2.1	<u>Description of Experiment</u>	-6-
2.2	<u>Sampling</u>	-7-
2.3	<u>Data Organization</u>	-7-
3	DISCUSSION/RESULTS	-9-
3.1	<u>EAC On vs EAC Off</u>	-9-
3.3	<u>Low Flow vs High Flow</u>	-11-
3.4	<u>Low Ventilation vs High Ventilation</u>	-12-
3.5	<u>Contribution of EAC to Indoor Ozone</u>	-12-
4	CONCLUSIONS	-16-
4.1	<u>Contribution of the EAC to Indoor Ozone levels</u>	-16-
4.2	<u>Airflow Through the EAC</u>	-16-
4.3	<u>Ventilation</u>	-16-
4.4	<u>Exposure</u>	-16-
4.5	<u>Health Effects</u>	-16-
5	RECOMMENDATIONS	-17-
	REFERENCES	-18-

1 OVERVIEW, DISCUSSION OF OBJECTIVES

1.1 Introduction

Plate and wire type Electronic Air Cleaners (EAC) are frequently found in the central forced air systems of Canadian Houses. They are usually marketed as devices intended to improve the well-being of the home occupants by reducing exposure to airborne particles and relieving the symptoms of those who suffer from allergy-related and respiratory conditions.

It is known that these devices produce ozone during operation, and ozone is known to be a respiratory irritant. Until recently, it has been the position of the building and residential indoor-air quality community that these devices did not significantly decrease air quality due to their relatively small ozone production rates. Furthermore, it is held that the primary source of indoor ozone is from infiltration of outdoor air, and that the small amounts of ozone generated by the EAC would not contribute to any significant rise in indoor ozone.

Recent studies have found:

- 1) There is statistically significant rise in wintertime indoor ozone levels in Canadian (Toronto area) homes which are equipped with EAC's. (Ref 19) See also Appendix E.3.
- 2) Production of ozone from EAC's does not appear to be related to maintenance, cleanliness or condition, rather it appears to be relatively constant, provided that the device is functioning. (Ref 3). See also appendix E.6
- 3) The Lowest Observable Adverse Effect Levels (LOAEL) have been estimated to be 20 ppb and 25 ppb for non-accidental mortality and respiratory hospital admissions, respectively. (Ref 4) These levels are significantly lower than previously accepted, and are within the range of ozone levels recorded inside homes which were equipped with EAC devices. (Ref 3).
- 4) The products of indoor chemical reaction of ozone with VOC's, alkenes, aldehydes and aromatics, can be more toxic, irritating, odourous, and/or damaging to materials than their precursors. (Ref 26)(Ref 28)
- 5) Ozone exposure has both a priming effect on allergen-induced responses as well as an intrinsic inflammatory action in the nasal airways of house dust-mite sensitive asthmatics. (Ref 22)

The combination of these recent findings lead to the possibility that EAC devices may contribute to raising indoor ozone to levels which could have a negative health impact.

The contribution of an EAC device may also contribute to distortion of studies which examine the exposure of personal exposure to ground-level (outdoor) ozone. Given that typical activity patterns lead to 80% of personal time being spent indoors, even a small change in the indoor level would have a significant effect on personal time-weighted exposure to ozone.

1.2 Objectives

- 1.2.1 To determine the degree to which ozone levels may be influenced in a home due to the operation of an EAC.

- 1.2.2 To determine whether or not the ozone levels induced by an EAC are affected by:
- a) Changes in house ventilation rate.
 - b) Changes in airflow through the EAC.

1.3 Limitations

All of the experiments are based on one air-handler and EAC arrangement in one home in Brantford Ontario Canada. The arrangement simulated the typical Canadian installation arrangement for these devices. From a regional outdoor air pollution perspective, the location is considered to be in the "Great Lakes Basin" area.

The test conditions replicate typical southern Ontario Canadian winter conditions and home operation.

This study applies only to EAC's mounted in central air handling systems which are operated continuously. Continuous operation of the air-handling system is usually a discretionary decision of the house occupant. Continuous operation is a worst-case scenario as the EAC does not produce ozone when the air handling system is not operating.

Some EAC's are available as portable "in-room" devices, an arrangement which is not addressed in this study.

In the context of Canadian housing stock, the range of air-change rates (0.43 Ach to 0.654) does not represent homes which have very low winter-time air-change rates (less than 0.3 ACH) nor very high winter-time air change rates. (Larger than 1.0 ACH).

The air-exchange flows in the house were such that all of the incoming airflow occurred via infiltration through the structure and fabric of the building. This is representative of houses without mechanical ventilation, or houses with "exhaust only" ventilation. It may not be representative of homes with mechanical outside air intakes, such as would be present for outdoor air ducts connected to forced air system, or for central heat recovery ventilation systems.

1.4 Ozone

Outdoor ozone (also called ground-level or tropospheric ozone) is produced in the presence of sunlight when oxides of nitrogen (NO_x) volatile organic compounds (VOCs) and oxygen interact.

There are significant differences in ozone levels during the day and night and during the winter and summer. Dense urban areas with high insolation and higher temperatures will experience higher levels of ozone. Locations downwind from these cities may experience higher night-time levels of ozone as a result of the transportation time of the smog moving into their area. Northern hemisphere locations will also experience greater increases in summer levels when compared to winter levels (Ref 11).

Ground level ozone is one of the primary outdoor air pollution components in Southern Ontario. Levels of outdoor ozone in the Great Lake Basin Area of Southern Ontario (Windsor to Quebec corridor) are often higher than the current Canadian National Ambient Air Quality Objective of 82 ppb and have been for many years (Ref 9). This is due in part to the transportation of ground level ozone from the Ohio Valley.

Environment Canada currently issues smog warnings when the level of ozone is expected to exceed 80 ppb. (Ref 11.) Individuals who have sensitive respiratory tracts (suffering from asthma or other respiratory condition) are advised to stay indoors where ozone levels are expected to be lower.

The current Health Canada Exposure Guidelines for Residential Indoor Air Quality (Ref 12) for Ozone is 120 ppb for 1 hour exposure. Other standards set substantially lower limits, for example, the US Food and Drug Administration (1974) standard is 50 ppb maximum, not to be exceeded at any time.

Numerous research papers have identified respiratory symptoms beginning at ozone levels of 80 ppb. Decrements in lung function in healthy children have been suggested for concentrations as low as 60 ppb (Ref 24)

Analysis of data from 13 Canadian cities resulted in the conclusion that the risk associated with hospitalization for respiratory diseases is 1.04%¹ per 10 ppb increase in the daily one hour maximum ozone, beginning at 25ppb. The same research concluded that the risk for non-accidental mortality is 0.79%² per 10 ppb increase in daily one-hour maximum outdoor ozone level. The LOAEL with statistical significance for non-accidental mortality is 20 ppb. (Ref 11, Appendix E.8)

Some negative effects of ozone are:

- lung inflammation,
- airway hyper-activity,
- decreased lung volumes,
- respiratory symptoms,
- reduced exercise capacity,
- increased hospital admissions for respiratory diseases
- possible increase in mortality rates
- exacerbation of allergic symptoms

1.5 Electronic Air Cleaners and Ozone

Plate & wire Electronic Air Cleaners (also called electrostatic precipitator) are a popular type of forced air system air cleaner and have been installed in Canadian homes for at least 20 years. The Canadian National Energy Use Database (Ref 21) reports that 23.9% of new homes built in Canada in 1994 were equipped with these devices. The number of these devices installed as retrofit to existing homes is not available, however they are known to be a popular option for homeowners who upgrade or improve their central forced air HVAC systems. EAC devices are sold on the basis that they will benefit the health of those persons who suffer from allergy-related or respiratory problems. (Ref 14)

It is known that these units produce ozone during operation. The manufacturer of the EAC unit tested states that an EAC can be expected to add 5 ppb to the steady state indoor level of ozone in a house. (Ref 13) In more detailed statements which specifically address the ozone issue, the manufacturer states that the typical range of indoor ozone in homes and offices equipped with EAC's is 0 to 10 ppb and that in test chambers and houses, the maximum levels created ranged between 5 and 20 ppb. (Ref 15)

Laboratory test of EAC devices found that 42 mg/hr could be emitted by such a device in operation. (Ref 8)

In-situ tests of EAC's under a wide range of operating and maintenance conditions found ozone production rates averaging 37 mg/hr. (Ref 3)

¹ 95% Confidence level: 0.78-1.30%

² 95% Confidence level: 0.59-0.99%

EAC devices installed as a part of central heating and air conditioning systems usually only operate when the air handling system is circulating air. As such, their operation may not be continuous if the central air handler does not operate continuously. If the air handling system only operates on a demand for heating for example, the operating fraction may be as small as 20% during a normal winter. Newer two-stage heating systems can be expected to have operation fractions of more than 20% but these systems do not yet have significant market penetration. On the other hand, continuous operation of the air handling system is becoming a popular option and some new ventilation designs depend upon the continuous operation of the air handling system in order to distribute ventilation air throughout the house. Usually, the continuous operation flowrate is lower than the heating or air conditioning flowrate.

1.6 Personal Exposure

For ozone the primary determinants of personal exposure are concentration, duration, pattern of exposure and the inhalation rate of the individual during exposure. (Ref 11).

A field study of ozone exposure in Toronto was conducted in 1992 as part of the Canadian Regional Assessment Modeling (CREAM) study (Reference 19). The study used passive ozone samplers which were located inside and outside of 50 homes and worn by 123 study participants.

The following results were obtaining from the personal exposure monitors.

Home indoor winter 1.6 ppb ³	7 day average
Home indoor, summer, daytime, 7.1 ppb ⁴	12 hr average
Home indoor, summer, nighttime, 6.2 ⁵ ppb	12 hr average

From activity records of the study participants, the following activity patterns were established:

Wintertime;	79% of time (+/- 13%) indoors (at home fraction not given)
Summertime,	45% of time (+/-32%)at home indoors

Based on the samplers located inside and outside homes this study also found

Indoor/Outdoor ozone ratios of:

0.07+/-0.10	Wintertime (weekly)
0.40+/-0.29	Summertime (weekly)

Based on this and data from similar studies, predictive estimates of personal exposure can be made based on data from regional ambient monitoring locations. One such predictive model is the Probabilistic National (Ambient Air Quality Standard) Exposure Model (pNEM). As applied in Reference 11, this method was used to predict personal exposure to ozone. Assumptions of micro-environments included indoor and outdoor locations and the relative degree of exposure for each were combined along with other data to predict personal exposure to ozone. The indoor micro-environments included houses with and without air conditioning, and assumed that there was no indoor source of ozone.

³ N=114, +/-4.1 ppb

⁴ N = 199, +/-12.6 ppb

⁵ N = 160, +/-9.5 ppb

1.7 Air Exchange, Surface Removal, and Indoor Outdoor Ozone Ratio

Many researchers (Ref 9,19,26) have related the rate of air exchange to the Indoor/Outdoor ratio (I/O Ratio) and the rate at which Ozone decays by interacting with surfaces inside the building. Most models used for residential ozone do not consider that inside sources of ozone are significant, and that there is no filtering effect on air which comes into the building from the outside. Some researchers have described models which also include terms for inside sources and the filtration effect of the building envelope or intake air filters. (Ref 7).

Without an indoor source, prediction models will show that as the air exchange rate increases, the proportion of indoor ozone to outdoor ozone rises. In homes, with an indoor source of ozone, however, the effect of air exchange on the indoor ozone level depends on the strength of indoor source(s) compared to the outside ozone level. If the indoor source strength were high enough, and the outdoor level low enough, increases in air exchange may result in reduction of the indoor zone levels relative to outside.

Many models include a term meant to describe the rate at which ozone is being removed from the house by interaction with the internal surfaces in the homes. In the model used for this study and in references 26, 19, and 7, the term which describes indoor decay is:

$$K_T = V_d(A/V)$$

Where:

K_T = Decay rate Air Changes per Hour
 V_d = Deposition velocity
 A = Surface area available for deposition⁶.
 V = Volume of the space

The surface area-to-volume ratio (A/V) can vary depending on the size of the room, furnishings and types of surface covers present. Ozone removal rates are expected to be higher in smaller rooms than larger rooms due to the higher surface to volume ratios of the smaller rooms. Smooth surfaces have less surface area than fleecy areas, and therefore the removal rate of ozone is expected to be lower for smooth surfaces than for fleecy surfaces.

Many of the Indoor/Outdoor Ozone models (Ref 19,26,9) do not consider whether or not the path of entry would affect the quantity of ozone in the incoming air. Where a penetration factor was included, it was usually assumed to be unity, that is to say there is not filtration effect on incoming air. An assumption of unity for penetration factor of ozone carried into a home from outside may be assumed to be correct for large openings such as windows or intentional ventilation intake ducts, but may not be correct when the outdoor air enters through small openings, cracks and through the fabric of the building (insulation cavities, etc). Entry through the fabric of the building may reduce the amount of ozone in the incoming air stream due to the large surface areas presenting to the incoming air stream.

⁶ In this case, the surface area available for deposition is taken as the total of all interior wall, ceiling and floor surfaces, not including furniture

2 DISCUSSION OF METHODS

2.1 Description of Experiment

An Electronic Plate & Wire type Air cleaner (EAC) was mounted in the Bowser Technical Inc filter test facility (see appendix B.1). No special preparation of the air cleaner was made except that the joints between the air cleaner and the ductwork of the test facility were sealed. The access door and power supply assembly were not modified and it is probable that there was some air-leakage from the laboratory room into the airstream via these paths.

The laboratory and instrument room was located in the furnace/utility/laundry/mechanical room of a 2-level (basement and upper floor) home located in Branford, Ontario, Canada. The upper floor of the house contains the normal sleeping, living and food preparation rooms and the lower level contains the furnace/utility/laundry/mechanical room and a home office. The home was normally occupied by one person during the day and 2 persons during the evening and overnight. The home does not contain any significant quantity of exposed pine wood nor were cleaning products with pine or citrus scents used. Additional details concerning the home are given in appendix A.

The air cleaner pre-filter and collection elements were cleaned prior to test, but were not cleaned between test cycles. Over the testing period, there were no indications such as increased resistance to airflow or declining collection efficiency that would indicate that cleaning was required or that the performance of the air cleaner was changing. The period over which the test were conducted (14 days) is significantly less than the recommended service intervals for this EAC (3 to 6 months).

A total of 185 hours of data were obtained consisting of 14 separate experimental arrangements. The experiments ranging in duration from 3 hours to 21 hours with the average experimental period being 13 hours. Sampling occurred at all times of the day and night, and where possible, an effort was made to obtain both daytime and night-time data for each particular experiment.

Variables of the experiments were as follows:

- EAC on vs EAC off
- Air Handler High (340 L/s) [720 cfm] vs Air Handler Low (166 L/s), [352 cfm]
- Ventilation Low (Natural only) vs Ventilation High (Added Exhaust 47 L/s)

At least one experiment was conducted for each of the possible combinations of variable conditions.

With respect to airflow through the EAC, the size of EAC used for these experiments is recommended for applications with flow rates between 235 and 660 L/s. The low speed operation of the air handling system in these experiments is below the manufacturer's suggested minimum airflow. At the same time, the installation is representative of typical Canadian configurations and the "low flow" switch on the EAC did not prevent it's operation. A smaller EAC unit is available with a more appropriate airflow range, however the smaller unit is not typically installed, even if the system capacity is small⁷.

⁷ Local heating wholesale supplier does not stock smaller unit and sales staff cannot remember ever having sold one.

With respect to the ventilation rates, for the low ventilation condition, the weather variables were measured continuously during the experimental period and a natural infiltration value was predicted using the AIM2 model (see appendix D.2). During periods of high ventilation, the natural ventilation was calculated as described previously and the combined effect of natural and exhaust ventilation was predicted using the Keil-Wilson [Ref 27] relationship.

All experiments occurred between November 19th and December 3rd, 2000. During the conduct of experiments, all of the windows were kept closed, corresponding to typical Canadian "Shoulder-Season" (late fall) home operation.

The operation of the air handling system was not expected to affect the air change rate for the home as substantially all of the ductwork is located within the building envelope.

2.2 Sampling

Samples were obtained using the Bowser Technical Inc real-time air sampling rig (see appendix C.1) arranged so that samples were obtained from the following stations:

- 1) Outside
- 2) Air Intake to EAC
- 3) Office Area (Basement)
- 4) Air discharge from EAC
- 5) Bedroom (Upstairs)

The outside sampling point was located under an over-hanging roof area (covered patio) approximately 2.5 metres from the house and 1 metre from the roof edge. Height above grade was 3 metres.

The office sampling point was located in a "Home Office" area in the basement of the house. There is one computer, a laser printer and a computer monitor in continuous operation within 1.5 metre radius of the pick-up location. The height above floor level is 1.6 metres. Occupancy of the office area was extremely variable during the testing periods.

The bedroom sampling point is located at 2 metres above the floor, and approximately 4 metres from the supply air inlet to the room and 1.5 metres from a supply air inlet located in an adjacent bathroom. There is no return air inlet in the room. The bedroom was normally occupied by two persons from midnight until 7:00 a.m. and not during the daytime hours.

Equipment located in the home which could be sources of ozone include computers, computer monitors, a laser-printer, solenoid valves, and data acquisition equipment. The effect of these sources on the results is discussed in section 3.1.

Sampling interval was 1.5 minutes with a 0.25 minute hold period between samples so that the time for a each complete set of 5 samples was 8.75 minutes.

2.3 Data Organization

Where a "House average" value is used, it has been calculated using the average of the office and bedroom values.

Interior ozone levels are reported as absolute values as well as offsets above or below the outside level, or as ratios of indoor vs outdoor level. An indoor/outdoor ratio of 0.5 would indicate for example, that the inside measurements were 50% of the outdoor levels. A ratio of 1.5 would indicate that indoor levels were 150% of outdoors.

3 DISCUSSION/RESULTS

3.1 EAC On vs EAC Off

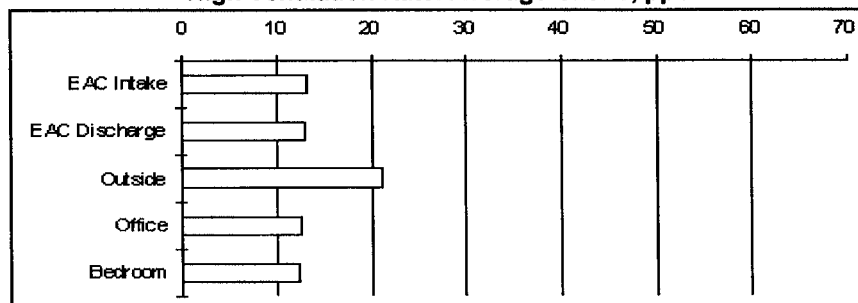
Table 1			
Ozone	EAC OFF N = 7	EAC ON N = 7	CHANGE
Outside	21 ppb (+/- 4.0)	22 ppb (+/-4.3)	+1.2 ppb
Bedroom	12 ppb (+/-0.1)	21 ppb (+/-1.9)	+8.8 ppb
House Average	12.5 ppb (+/-0.1)	18.5 ppb (+/-1.0)	+6.0 ppb
Bedroom/Outdoor ratio	0.6 (+/-0.2)	1.0 (+/-0.28)	+0.4

With the EAC off, the inside O₃ levels were uniform and there was little or no variability between experiments. The lack of variability within and between data sets indicates that interior sources of O₃ other than the EAC, such as the computers, solenoid valves and data acquisition equipment resulted in the house having a "baseline" level of about 13 ppb irrespective of other factors.

With the EAC in operation, the bedroom levels were found to be slightly higher than the office location. It is surmised that the bedroom sample point recorded higher values because:

- 1) the sample intake was more directly exposed to airstreams exiting from supply registers and/or;
- 2) infiltrating air was more abundant in the basement (office) area during the type of weather which was predominant during the testing periods, and/or,
- 3) the office area is physically smaller than the bedroom, and the lower ozone levels may be due to the higher surface to volume ratio, resulting in higher surface deposition rates and/or,
- 4) the office area has substantial amounts of exposed surfaces which are known to be highly reactive with ozone and have high deposition rates per unit surface area such as office paper⁸

Figure 1
Experiment #8, EAC Off, Low Air Handler Airflow,
High Ventilation Rate. Average Ozone, ppb



With the EAC off, there was no measurable difference between the ozone levels in the airstream entering the EAC (upstream) and the airstream leaving the EAC

⁸ Reference 18 found that new office paper had the highest deposition velocity of all of the materials tested.

(downstream). The inside O_3 level was consistently lower than outside⁹. The Bedroom/Outdoor ratio averaged 0.6 (Table 1). Absolute interior levels of ozone were between 12 and 13 ppb under most conditions. A typical data set for this condition is shown in Figure 1.

With the EAC on, there was a significant increase in ozone levels in the airstream leaving the EAC (EAC discharge) when compared to the ozone levels of the airstream entering the EAC (EAC intake). The Bedroom/Outdoor ratio increased to 1.0. Absolute levels rose to 21 ppb for the bedroom and 19 ppb for the house average. A typical data set is shown in Figures 2 and 3 below. During this particular experiment, absolute bedroom levels rose to as high as 30 ppb and the experiment was discontinued when the house occupant, who is asthmatic began to experience airway restriction to the extent that medication was required¹⁰.

Figure 3
Experiment #7b, EAC On, Low Air Handler Airflow,
Low Ventilation Rate. Average Ozone, ppb

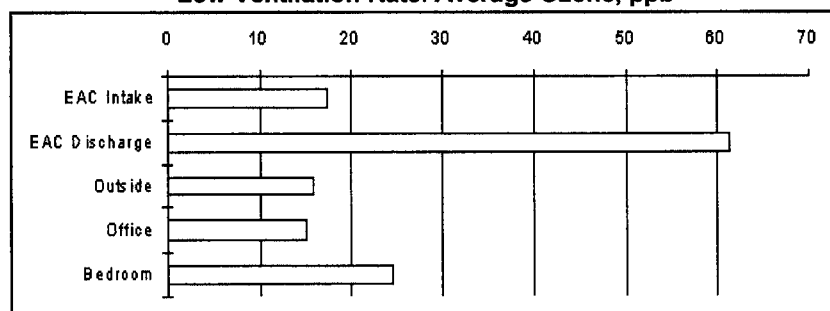
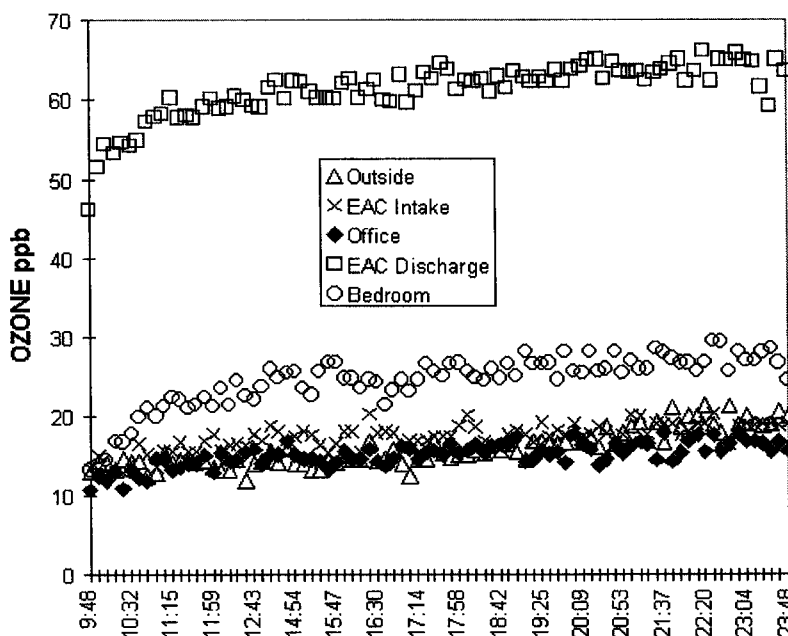


Figure 2
Experiment #7b, EAC On, Airflow Low, Ventilation Low



⁹ Except for one data period during which the outdoor ozone level was particularly low (13 ppb vs 21 ppb average of the entire data set).

¹⁰ The asthmatic house occupant is allergic to House Dust Mite (HDM) allergen. Reference 22 has shown a relationship between ozone and increased late-phase allergic symptoms of HDM-allergic asthmatics.

3.2 Source Strength

There was no measurable O₃ originating from the EAC when it was off.

The change in intake vs discharge O₃ concentration was used in conjunction with the measured airflow through the EAC and expressed as a source strength in mg/hr. (See appendix D.3) The source strengths measured for this EAC agree well with the source strengths measured in 1997 (Ref 3). In that study, the mean source strength was 37 (+/- 20) mg/hr for both dirty and clean EAC's. The measured source strength also agree well with laboratory measurements of EAC operation carried out by Hanley et al. (Ref 8).

3.3 Low Flow vs High Flow

When the EAC was off, a small but significant (t-test, p<0.05) drop in the Total and EAC Source Strengths was measured for the high flow condition when compared to the low flow condition. It is possible that this apparent drop in source strength is due to increased deposition velocity caused by higher air velocity in the ductwork and in the living spaces which occurs due to the increased air handling system airflow. (Table 2)

TABLE 2			
EAC OFF	LOW FLOW (166 L/s) N = 4	HIGH FLOW (340 L/s) N = 3	CHANGE
Total Source Strength^(A)	57 mg/hr (+/- 2.7)	55 mg/hr (+/-1.0)	-2.1 ppb
EAC Source Strength^(B)	-0.4 mg/hr (+/- 0.4)	-1.4 mg/hr (+/- 0.6)	-1.0 ppb
Bedroom	12 ppb (+/- 0.2)	12 ppb (+/- 0.1)	-1.7 ppb
Outdoor	18 ppb (+/- 3.3)	24 ppb (+/- 0.8)	+5.9 ppb
Bedroom/Outdoor Ratio	0.7 (+/- 0.2)	0.5 (+/- 0.0)	-0.2
(A) Total Source Strength is the source-strength from all internal sources calculated using equation 1 (Section 3.5) assuming f=0, no removal of ozone from incoming ventilation air.			
(B) EAC Source Strength is calculated from the measured EAC intake and discharge concentrations and the mass flow rate of air through the EAC. See appendix section D.3.			

When the EAC is operating, there is a small, but statistically significant difference (t-test, p <0.05) decrease in the Total and EAC source strength. Both source values and the bedroom concentration increase by less than 10% when the airflow is reduced by approximately 50%. The apparently larger change in Total source strength when compared to EAC source strength may be due to an increase in O₃ deposition velocity caused by increased duct and room air velocities resulting from higher air handler airflows. (Table 3).

TABLE 3			
EAC ON	LOW FLOW (166 L/s) N = 2	HIGH FLOW (340 L/s) N = 5	CHANGE
Total Source Strength^(A)	109 mg/hr (+/- 15.9)	100 mg/hr (+/-8.7)	-9.3 ppb
EAC Source Strength^(B)	48 mg/hr (+/- 5.4)	44 mg/hr (+/- 3.1)	-4.2 ppb
Bedroom	23 ppb (+/- 2.8)	21 ppb (+/- 1.5)	-1.7 ppb
Outdoor	19.5 ppb (+/- 5.0)	22.5 ppb (+/- 4.3)	+3.0 ppb
Bedroom/Outdoor Ratio	1.2 (+/- 0.5)	1.0 (+/- 0.2)	-0.25
(A) Total Source Strength is the source-strength from all internal sources calculated using equation 1 (Section 3.5) assuming f=0, no removal of ozone from incoming ventilation air.			
(B) EAC Source Strength is calculated from the measured EAC intake and discharge concentrations and the mass flow rate of air through the EAC. See appendix section D.3.			

3.4 Low Ventilation vs High Ventilation

When the EAC is off, the data essentially no change in internal ozone parameters. (Table 4). The change in Bedroom/Outdoor ratio occurs due to change in the outdoor ozone levels between the two test conditions and not because of a change in internal conditions.

TABLE 4		
EAC OFF	LOW VENT N = 3	HIGH VENT N = 4
Total Source Strength^(A)	56 mg/hr (+/- 1.0)	57 mg/hr (+/- 3.1)
EAC Source Strength^(B)	-1 mg/hr (+/- 0.5)	0 mg/hr (+/- 0.3)
Bedroom	12 ppb (+/- 0.1)	12 ppb (+/- 0.2)
Outdoor	22 ppb (+/- 3.1)	19 ppb (+/- 4.2)
Bedroom/Outdoor Ratio	0.6 (+/- 0.1)	0.7 (+/- 0.2)
Ventilation Air Changes per Hour	0.43 (+/- 0.03)	0.65 (+/- 0.01)
(A) Total Source Strength is the source-strength from all internal sources calculated using equation 1 (Section 3.5) assuming $f=0$, no removal of ozone from incoming ventilation air.		
(B) EAC Source Strength is calculated from the measured EAC intake and discharge concentrations and the mass flow rate of air through the EAC. See appendix section D.3.		

With the EAC operating, a small but statistically significant (t-test, $P<0.05$) difference in the Total Source Strength and a corresponding drop in the bedroom absolute ozone level was noted. The larger change in the Bedroom/Outdoor ratio is attributable to the change in outdoor ozone levels. (Table 5)

TABLE 5			
EAC ON	LOW VENT N = 4	HIGH VENT N = 3	CHANGE
Total Source Strength^(A)	104 mg/hr (+/- 14.8)	101 mg/hr (+/- 2.8)	-2.4 ppb
EAC Source Strength^(B)	45 mg/hr (+/- 5.5)	45 mg/hr (+/- 0.8)	0 ppb
Bedroom	22 ppb (+/- 2.6)	21 ppb (+/- 0.2)	-0.8 ppb
Outdoor	23 ppb (+/- 5.0)	20 ppb (+/- 6.8)	-3.4 ppb
Bedroom/Outdoor Ratio	1.0 (+/- 0.4)	1.1 (+/- 0.2)	+0.08
Ventilation Air Changes per Hour	0.40 (+/- 0.07)	0.68 (+/- 0.03)	+0.28
(A) Total Source Strength here is the source-strength from all internal sources calculated using equation 1 (Section 3.5) assuming $f=0$, no removal of ozone from incoming ventilation air.			
(B) EAC Source Strength is calculated from the measured EAC intake and discharge concentrations and the mass flow rate of air through the EAC. See appendix section D.3.			

3.5 Contribution of EAC to Indoor Ozone

When the following mass-balance model was applied as if conditions are at a steady-state (Eq 3 from reference 7) and assuming that the incoming filtration factor $f = 0$, a background source of 57 mg/hr (+/-2.3)¹¹ O₃ due to equipment operating in the home was apparent. Ordinarily, it would be assumed that residential indoor sources of O₃ are very small or non-existent (Ref 26).

¹¹ Based on a K_T value of 5.623 ACH, and a V_D value of 0.083 cm/s which gave the best fit to measured experimental values. The values are higher than obtained by other researchers, for example, Lee et al (Ref 19) obtained an average K_T value of 2.80 and a V_D value of 0.049 for 123 California homes, however they may reflect the lower deposition velocity resulting from the intermittent operation of the central air-handling system, or a qualitative difference in the nature of the surfaces in the home (e.g. less carpeted surfaces etc).

$$C_i = \{K_v(1-f)C_o + S/V\}/(K_v + K_T) \quad \text{equation 1}$$

Where:

- C_i = Concentration, indoors
- K_v = Air Exchange, Air Changes per Hour
- C_o = Concentration, outdoors
- S = Source Strength, indoors
- V = Volume of house/space
- f = Filtration factor, 0 = no filtration of incoming air, 1 = 100% filtration.
- K_T = Decay rate, Air changes per hour, as follows:

$$K_T = V_d(A/V) \quad \text{equation 2}$$

Where:

- V_d = Deposition velocity¹²
- A = Surface area available for deposition. In this case, taken as the total of all interior wall, ceiling and floor surfaces, not including furniture.

This model was used to predict the levels of ozone which would be experienced in this house. The assumptions used for this model are as follows:

- 1) No internal sources of O_3 except EAC
- 2) Air change rates of 0.2, 0.7 and 1.0. This approximates the winter (0.69 ACH) and summer (1.04 ACH) air exchange rates reported for Toronto area houses in Reference 19. The 0.2 ACH value represents a newer, more air-tight home with minimal ventilation.
- 3) Outdoor range of 0 to 100 ppb ozone based on normal range of winter and summer ozone in the Great Lakes Basin 2Area..
- 4) Ozone production rate of the EAC set at 46 mg/hr continuously, based on the experimental data from this study.

Predicted indoor concentrations of ozone are shown for each of the three air-change cases in Figure 4.

Table 6 shows that the expected rise of O_3 concentration due to EAC operation ranges from 9.2 to 8.1 ppb for high through low air exchange cases respectively. In a home equipped with a continuously operating EAC, the concentration of ozone might be substantially increased over the mean values of 1.6 ppb (winter), 7.1 ppb (summer, day) and 6.2 ppb (summer, night) reported in Reference 19.

Concerning the LOAEL levels of 20 and 25 ppb proposed in Reference 11, an addition of 9 ppb during the winter would result in the 20 ppb threshold being achieved in 5% of the homes studied in Reference 19¹³. An addition of 9 ppb during the summer would result in the 20 ppb threshold being exceeded in 25% of the homes studied.. The 25 ppb threshold would be exceeded in slightly less than 10%¹⁴ of these homes.

¹² There is no separate term for chemical reaction losses therefore this term includes those losses.

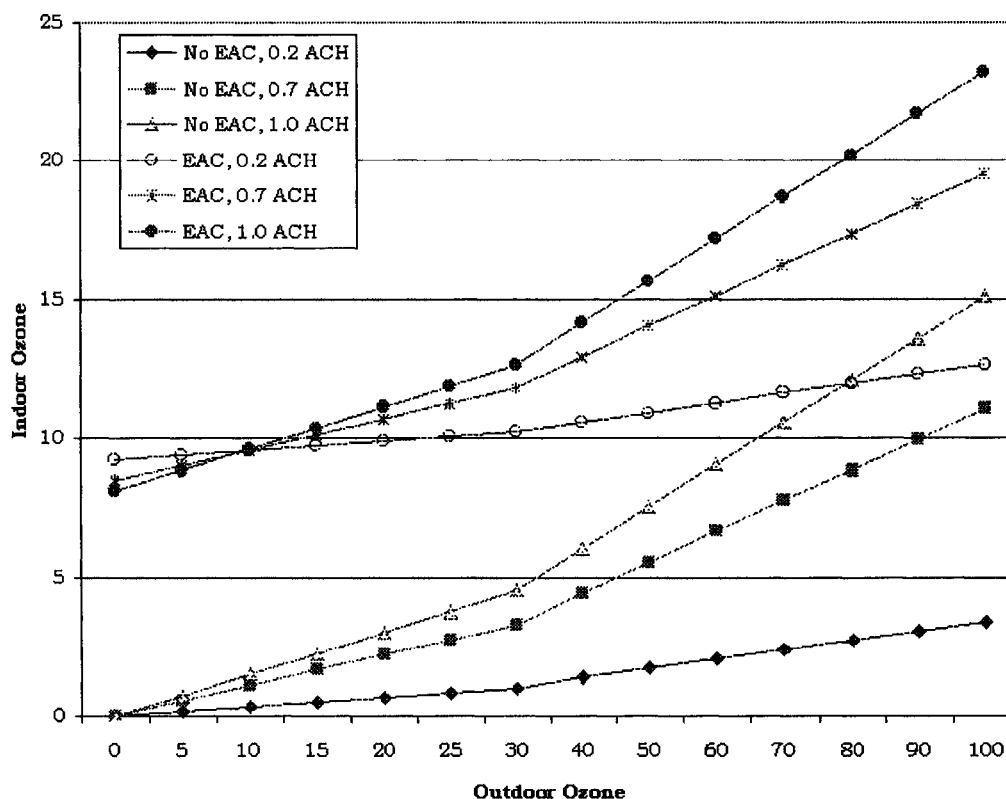
¹³ The 95 percentile weekly average winter indoor ozone level is 4.0 ppb (max 29.4 ppb) (Ref 19). The LOAEL levels are 1-hour maximums.

¹⁴ The 90 percentile 12-hour daytime average summer indoor ozone level is 15.7 ppb (max 149 ppb) (Ref 19). The LOAEL levels are 1-hour maximums.

Indoor/Outdoor ratios are also substantially affected. The change in I/O ratio at outdoor ozone levels of 15 and 20 ppb are also listed in Table 6.

Table 6 Predicted Changes Due to Operation of EAC					
ACH.	Rise in indoor O ₃ ppb	I/O ratio 15 ppb outside		I/O ratio 20 ppb outside	
		EAC off	EAC on	EAC off	EAC on
0.2	9.2	0.03	0.65	0.03	0.49
0.7	8.5	0.11	0.68	0.11	0.53
1	8.1	0.15	0.69	0.15	0.56

Figure 4
Predicted Indoor Ozone Levels



Reference 19 found that the I/O ratio for homes without EAC during the winter was 0.05. In the summer, the I/O ratio for homes without EAC was 0.45. The same study found the mean wintertime outdoor level of ozone to be 15.4 +/- 6.0 ppb and the mean, outdoor daytime summer ozone level to be 19.1 +/- 10.0 ppb. Using the predicted changes in I/O ratio in table 7 it can be seen that it is possible that the I/O ratio for a home with closed windows and a continuously operating EAC could experience substantially different I/O ratios, particularly in the winter.

Indoor ozone levels may be higher than predicted here if the home was smaller and was equipped with less reactive surfaces (e.g. smooth floors in place of carpet). Using the previous model and assuming lower deposition velocity of $V_d = 0.049^{15}$, the inside ozone level might rise to 30 ppb or higher (Outdoor = 80 ppb, ACH = 0.7).

¹⁵ Reference 19 identified a mean V_d of 0.049 cm/s in a study of 123 California Homes

At the same time, interior ozone levels may be lower than predicted if the home was larger, if it was equipped with more reactive surfaces (carpet in place of smooth floors etc), if the air handling system was operated discontinuously or if a smaller EAC was used.

Reference 19 found that a sub-group of houses with EAC's experienced higher I/O ratios (0.13 ± 0.12) than those without (0.05 ± 0.05) during the winter. This change is not as great as predicted from the data in Table 6, however it is likely that not all of the houses in reference 19 had air-handling systems which operated continuously. Intermittent operation of the air-handling system would tend to reduce the discharge of ozone from the EAC, by a factor of up to 80%.

For summer operation, the predictive model used here does not appear to be valid for the results recorded in Reference 19, probably due to the opening of windows during the summer.

4 CONCLUSIONS

4.1 Contribution of the EAC to Indoor Ozone levels

The continuous operation of this Electronic Air Cleaner resulted in a rise of average interior ozone concentration by 8 to 10 ppb higher than that which would normally be expected without the operation of the EAC. The 8 to 10 ppb is in addition to the ozone produced by other internal sources and infiltration of outdoor air. With rising air change rates and higher outdoor ozone levels, the increase caused by the EAC is less pronounced.

4.2 Airflow Through the EAC

Ozone production by the EAC increased slightly with lowered airflow. In addition, there appeared to be a lowering in the deposition rate of ozone within the house which may be attributable to lower air velocities over duct and house-interior surface. Although this appeared to affect overall ozone contribution by less than 10%, the tendency of modern air-handling systems to be operated continuously at lower airflow will tend to exacerbate the accumulation of ozone in the interior environment.

4.3 Ventilation

For the Canadian home tested, when operated in winter mode (i.e. all the windows and doors are shut), for the range of exterior ozone levels measured during this study, and for the type of ventilation arrangement, no conclusion could be reached as the effect on indoor levels. A conclusion could be reached if testing were undertaken during a time period when outdoor levels are substantially higher than indoor levels.

4.4 Exposure

EAC operation may have a significant effect on personal exposure models. Indoor absolute ozone levels may be substantially higher inside a home equipped with an EAC, than one without, particularly if the home is small, has large areas of "smooth/hard" surfaces such as smooth rather than carpeted floors and the air handling system is operated continuously.

Winter and summer-time Indoor/Outdoor ratios typically used for predictive population studies may need to be decreased for houses equipped with continuously operating EAC's.

4.5 Health Effects

EAC devices are sold on the basis of their potential to improve the health of a person with respiratory challenges. Such a person currently receives advice for public agencies to remain indoors on days with high outdoor ozone. In homes equipped with an EAC and a continuously operating air-handling system, it is possible that the indoor air will exceed the 1 hour Reference Level values for outdoor air proposed by the WGAQOG, (Ref 11). In these situations, a susceptible individual would not necessarily have a sanctuary from the effects of ozone.

EAC devices are promoted by their manufacturers as having beneficial health effects for persons with respiratory conditions such as HDM allergic asthma. Ozone is known to worsen the symptoms of this population¹⁶ and persons with these types of allergies are often advised to convert carpeted floors to smooth finishes. It is possible that the combination of ozone creation by an EAC and the reduction of reactive surfaces will result in ozone levels which exacerbate the symptoms of an allergic asthmatic person,

¹⁶ Reference 22 concluded for asthmatics allergic to House Dust Mite Allergen (HDM), exposure to ozone exacerbates airway responsiveness.

reducing or obviating any putative benefit¹⁷ that the EAC may have by way of reduction of HDM allergen in the home.

It is possible, but not proven, that adverse health effects exist for ozone exposure to levels as low as 10 ppb¹⁸. EAC devices appear to be capable of elevating the ozone level inside a home to levels which are continuously at or above 10 ppb. Current knowledge does not allow us to state that the health of susceptible individuals will not be affected.

5 RECOMMENDATIONS

- 5.1 More study of residential indoor sources of ozone such as EAC's is required. The findings of this single example need to be verified as being true for more than just a single house. Study parameters should be expanded to investigate:
- 1) the effect of house volume, types of surfaces, and
 - 2) the filtration of incoming ozone by the envelope of the building,
 - 3) the effect of other appliances which may contribute ozone
- 5.2 More study of health effects is indicated, particularly for susceptible individuals such as those with HDM allergic asthma.

¹⁷ Reference 17 concludes that removal of HDM from a household environment by a centrally mounted filter or EAC is not likely to be successful due to the high settling rate of HDM particles.

¹⁸ The Reference Level value for non-accidental morbidity (20 ppb) proposed by the WGAQOG does not represent a threshold value, as regression analysis of the data upon which the value is based shows a trend continuing to levels as low as 10 ppb. The value of 20 ppb was chosen because insufficient data was available below 20 ppb to confirm the analysis (See Appendix E.8)

REFERENCES

1. **Avol EL; Navidi WC; Colome SD; MODELING OZONE LEVELS IN AND AROUND SOUTHERN CALIFORNIA HOMES**, Environmental Science & Technology, Vol 32:4, pp463-468, 1998
2. **Boeniger MF; USE OF OZONE GENERATING DEVICES TO IMPROVE INDOOR AIR QUALITY**, Am Ind Hyg Assoc J, 1995; 56(6), pp590-598
3. **Bowser DB, Fugler D, Kwan W, EVALUATION OF RESIDENTIAL FURNACE FILTERS**, Canada Mortgage and Housing, 1999, Cat. No. NH15-318/1999E, ISBN 0-660-17813-3
4. **Burnett RT, ESTIMATING A "NATIONAL REFERENCE LEVEL" FOR OZONE IN CANADA**, Special analysis for WGAQOG (Ref 11) Appendix A, 1998
5. **Burnett RT, Dales RE, Raizenne ME, Krewski D, Summers PW, Roberts GR, Raad-Young M, Dann T. & Brook J., EFFECT OF LOW AMBIENT LEVELS OF OZONE AND SULFATES ON THE FREQUENCY OF RESPIRATORY ADMISSIONS TO ONTARIO HOSPITALS**, Environmental Research, 65, 172-194 (1994).
6. **CAN/CGSB-149.10-M86; DETERMINATION OF THE AIRTIGHTNESS OF BUILDING ENVELOPES BY THE FAN DEPRESSURIZATION METHOD**; Canadian General Standards Board; December 1986
7. **Freijer JJ, Bloemen HJ. Th, MODELING RELATIONSHIPS BETWEEN INDOOR AND OUTDOOR AIR QUALITY**, J. Air & Waste Management Association, vol 50: pp292-300, 2000
8. **Hanley JT; Smith DD; TESTING CRITERIA FOR ELECTRONIC AIR CLEANERS**; Canadian Electrical Assn. CEA 906 U 708 PH. II, 1993
9. **Hayes SR; USE OF AN INDOOR AIR QUALITY MODEL (IAQM) TO ESTIMATE INDOOR OZONE LEVELS**; J. Air & Waste Management Association, vol 41: pp161-170, 1991
10. **Health Canada, GREAT LAKES HEALTH EFFECTS PROGRAM - GLHEP. OUTDOOR AIR AND YOUR HEALTH: A SUMMARY OF RESEARCH RELATED TO THE HEALTH EFFECTS OF OUTDOOR AIR POLLUTION IN THE GREAT LAKES BASIN**; Air Quality Health Effects Research Station, Environmental Health Directorate, Health Canada.
11. **Health Canada, NATIONAL AMBIENT AIR QUALITY OBJECTIVES FOR GROUND LEVEL OZONE, SCIENCE ASSESSMENT DOCUMENT**, Report by Federal Provincial Working Group on Air Quality Objectives and Guidelines, July 1999, ISBN 0-662-64394-1, Catalogue No; En42-17/7-2-1999
12. **Health Canada. 1989 revised; EXPOSURE GUIDELINES FOR RESIDENTIAL INDOOR AIR QUALITY**; Health Canada, Ottawa, Ontario. Cat no. H49-58/1990E, ISBN 0-622-17882-3
13. **Honeywell, DOES THE HONEYWELL ELECTRONIC AIR CLEANER PRODUCE OZONE?**, Honeywell Inc Web Document, www.honeywell.ca/perfect-climate, February 10, 1997
14. **Honeywell, COMFORTABLE LIVING AT IT'S BEST**, Honeywell Inc sales literature, A1492, 10/96

15. **Honeywell**; OZONE; Honeywell Air Quality Report, Honeywell Inc, undated
16. **HRAI-SkillTech**; RESIDENTIAL AIR SYSTEM DESIGN STUDENT REFERENCE GUIDE; Heating Refrigerating and Air Conditioning Institute of Canada; 1998 Edition; August 1998
17. **Institute of Medicine (U.S.)**, Committee on the Assessment of Asthma and Indoor Air, CLEARING THE AIR: ASTHMA AND INDOOR EXPOSURES, 2000, pp 383-385, ISBN 0-309-06496-1
18. **Kleno JG**, Clausen PA, Weschler CJ, Wolkoff F, DETERMINATION OF OZONE REMOVAL RATES BY SELECTED BUILDING PRODUCTS USING THE FLEC EMISSION CELL, Environmental Science Technol., 2001, 35, pp 2548-2553
19. **Lee K.**, Vallarino J; Dumyahn, T. Ozkaynak, H; & Spengler J; OZONE DECAY RATES IN RESIDENCES, Journal of Air & Waste Management Assoc. 49, pp 1238-1244, 1999
Liu LJ; Koutrakis P; Leech J; Broder I; ASSESSMENT OF OZONE EXPOSURES IN THE GREATER METROPOLITAN TORONTO AREA; J Air Waste Manage Assoc, 45(4), pp23-34, 1995
20. **Liu LJ**; Koutrakis P; Suh HH; Mulik JD; Burton RM; USE OF PERSONAL MEASUREMENTS FOR OZONE EXPOSURE ASSESSMENT: A PILOT STUDY, Environ Health Perspect, 101(4), pp 318-324, 1993
21. **National Energy Use Database**. 1997. TRENDS IN ENERGY CHARACTERISTICS IN CANADA; Natural Resources Canada, Ottawa, Ontario. April 1997, Cat no. M92-136/1994, ISBN 0-622-62970-1
22. **Peden DB**, Woodrow R, Setzer JR, Devlin RB, OZONE EXPOSURE HAS BOTH A PRIMING EFFECT ON ALLERGEN-INDUCED RESPONSES AND AN INTRINSIC INFLAMMATORY ACTION IN THE NASAL AIRWAYS OF PERENNIALY ALLERGIC ASTHMATICS, Am J Respir Crit Care Med 1995; 151, pp 1336-1345
23. **Reiss, R**; Ryan PB; Tibbetts SJ; Koutrakis P; MEASUREMENT OF ORGANIC ACIDS, ALDEHYDES & KETONES IN RESIDENTIAL ENVIRONMENTS & THEIR RELATION TO OZONE; J. Air & Waste Management Association, vol 45: pp811-822, Oct 1995
24. **Spector DM**; Lippman, M; Liou, PJ; Thurston, GD; et al; EFFECTS OF AMBIENT OZONE ON RESPIRATORY FUNCTION IN ACTIVE, NORMAL CHILDREN; American Review of Respiratory Disease, # 137, pp 313-320, 1988
25. **Walker IS**; Wilson DJ; THE ALBERTA AIR INFILTRATION MODEL; University of Alberta Dept of Mechanical Engineering Technical report # 71, January 1990
26. **Weschler C.**, OZONE IN INDOOR ENVIRONMENTS: CONCENTRATION AND CHEMISTRY, Indoor Air; 2000: 10 pp 269-288
27. **Wilson DJ**; Walker IS; COMBINING AIR INFILTRATION AND EXHAUST VENTILATION; Preceding of INDOOR AIR '90, Toronto 1990, pp 467-472
28. **Wolkoff P**, Calusen PA, Wilkins CK, Nielsen GD, FORMATION OF STRONG AIRWAY IRRITANTS IN TERPENE/OZONE MIXTURES, Indoor Air 2000; 10, pp 82-91