INDOOR AIR QUALITY AND VENTILATION RATES IN R-2000 HOUSES

Final Report

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EXECUTIVE SUMMARY

Industry experience suggests that reducing the standard for ventilation rates would allow R-2000 energy targets to be met more cost effectively. Reduced ventilation rates would lower ventilation heat losses, which in turn would allow the use of lower-cost heat recovery ventilators (HRVs). Many R-2000 houses are operated at ventilation rates well below the standard; thus, lowering the requirements would simply be acknowledging what many R-2000 occupants are doing anyway. However, decreasing ventilation rates will affect indoor air quality (IAQ).

The current standard for ventilation, CSA F326 Residential Mechanical Ventilation Systems, requires a certain number of litres per second of fresh air for each type of room in a house. In R-2000 houses, this air is brought through an HRV, so the HRV installed each house must have the capacity to meet that flow rate when run at its high speed. It is not proposed that the capacity of HRVs be reduced, but that R-2000 houses could be certified if they pass their energy consumption targets with seventy-five percent the F326 standard flow rate, i.e., with the HRV set to a lower speed. This report examines the IAQ implications of reducing the "R-2000 design ventilation rates" to seventy-five percent of the F326 standard. Specifically, it asks whether such reductions would affect the requirement that R-2000 houses have better IAQ than the average Canadian house.

The investigation begins by examining several recent studies on IAQ in Canadian houses, and producing distributions of the source strengths of substances which affect IAQ. The substances investigated are total volatile organic compounds (TVOCs), formaldehyde (HCHO), carbon dioxide (CO_2), and water vapour (RH). The fiftieth and ninetieth percentile source strengths are then used to predict IAQ in forty-seven new R-2000 houses at various ventilation rates. The fiftieth percentile, or median, is used to predict IAQ in average houses, while the ninetieth percentile indicates the potential for health and comfort problems in the one-in-ten worst houses.

IAQ predictions are based on total ventilation rates which include both mechanical and natural ventilation. The HOT2000 program is used to predict total ventilation based on the measured airtightness of each house, and four mechanical ventilation rates. The mechanical rates include the F326 capacity, the actual rate for each house, a rate reduced by the average actual-to-standard ratio, and the new proposed rate. Actual (measured) mechanical ventilation rates in the forty-seven R-2000 houses range from 25% to 128% of the F326 capacity. Regional averages vary from 59% in Ontario to 80% in Atlantic Canada. The average for all forty-seven R-2000 houses is 70% of the F326 capacity, which is very close to the proposed rate.

For each IAQ substance, the two source strengths are combined with the four total ventilation rates to produce eight potential concentrations for each of the forty-seven R-2000 houses. These concentrations are compared with the averages from this study, and with existing guidelines. In the case of formaldehyde (HCHO), the Health Canada "Target Level" is 0.05 ppm which is almost identical to the average level, and the "Action Level" is 0.10 ppm. The data indicate that reducing ventilation rates from F326 to the proposed rate would increase the percentage of houses exceeding the target (average) level for formaldehyde from 1.7% to 4.7%. None would exceed the action level at either ventilation rate. Thus, the conclusion is that reduced ventilation rates will result in a small increase in formaldehyde pollution, but if reduced ventilation is combined with reduced sources of HCHO, then actual HCHO concentrations should decrease.

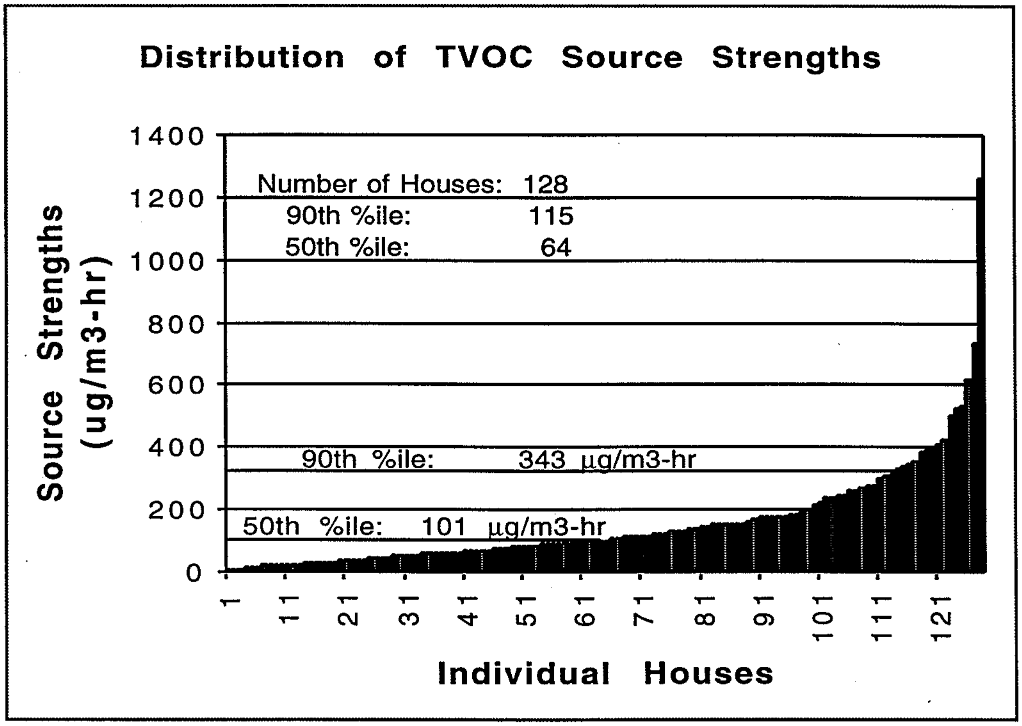

Figure S-1. Distribution of TVOCs Source Strengths with 90th and 50th Percentiles.

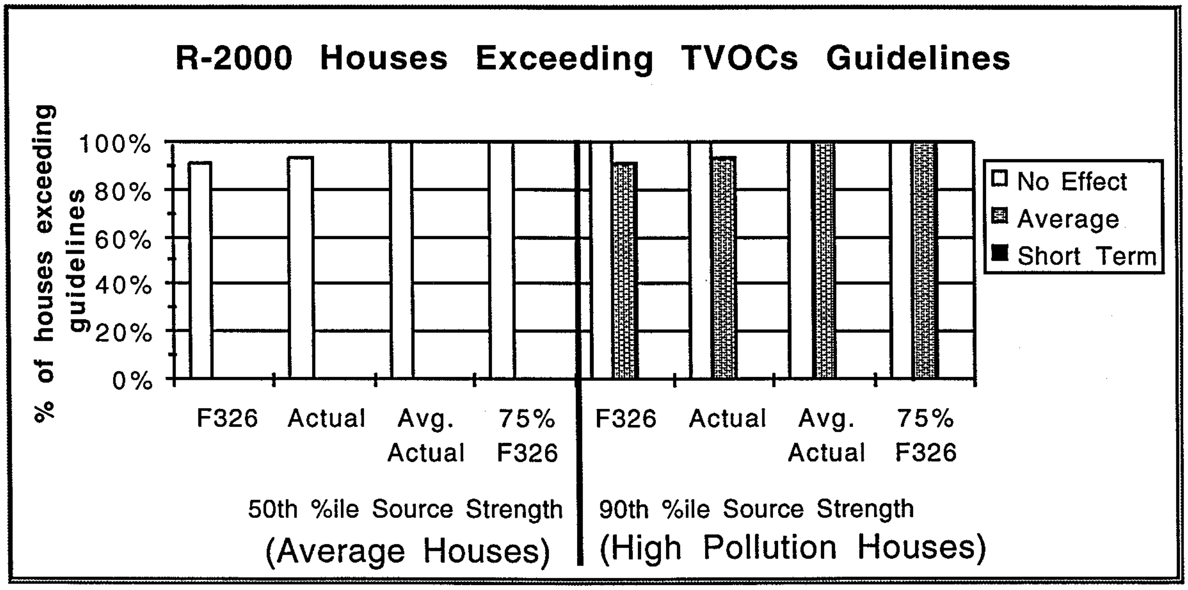

Figure S-2. Houses which exceed the Guidelines for TVOCs by Source Strengths and Total Ventilation Rates.

TVOCs are the IAQ factor most likely to cause problems if ventilation rates are reduced. The "No Effect" level for TVOCs is 200 micrograms per cubic meter ($\mu g/m^3$), the average is 585 $\mu g/m^3$, and the "Short Term" level is 3000 $\mu g/m^3$. Figure S-1 shows the distribution of TVOCs source strengths, and Figure S-2 displays the results of combining the fiftieth and ninetieth percentile source strengths with the four ventilation rates for each of the forty-seven R-2000 houses. Ninety-one percent of the houses exceed the no-effect guideline even when the average source strength is combined with the highest ventilation rate. As ventilation rates are decreased, the number of houses exceeding the no-effect guideline rises to 100%.

At the higher source strength, all of the houses exceed the no-effect guideline with all ventilation rates, and 91% exceed the level of the average house with the F326 ventilation rates. (This indicates that around 9% of all R-2000 houses would have more TVOCs than the average house). As ventilation rates are lowered, all ninetieth percentile houses exceed both the no-effect guideline and average house level. Thus, the number of houses exceeding the guidelines increases significantly as the ventilation rates are decreased. With the ninetieth percentile and 75% of the F326 capacity, 32% of the houses have concentrations of over 1000 $\mu g/m^3$, and one has over 1600 $\mu g/m^3$. In no case is the short-term guideline exceeded, but these levels of TVOCs could be high enough to cause additional occupant irritation and discomfort, and possible health effects. For this reason, we strongly recommend that decreases in the R-2000 design rate for mechanical ventilation be coupled with the elimination of materials with high VOC emissions.

For carbon dioxide (CO_2) the average indoor level is 748 ppm. The "Discomfort Level" is 1000 ppm, and the "Long-Term Limit" is 3500 ppm. The results of combining source strengths and ventilation rates indicate that CO_2 is not likely to be a serious problem in R-2000 houses, even with reduced ventilation rates. However, the source strengths are based on average CO_2 concentrations during a week of monitoring. CO_2 generation varies greatly, depending on the number of people in a given area of the house and their activity level. Simple models of bedrooms with both direct-ducted and recirculating fresh air supplies indicate that the Discomfort Level would be exceeded at the proposed R-2000 design ventilation rate. Thus, we recommend that reduced ventilation rates be combined with more careful balancing so that flows to bedrooms are maintained at the current F326 levels. This is more critical for direct-ducted houses, but should also be done in those with recirculating supplies.

Health Canada recommends that relative humidity (RH) be kept between 30% and 55% during the heating season. The results indicate that reducing the R-2000 design ventilation rate will not have a significant effect on RH levels in R-2000 houses. The percentage of houses in which either RH limit would be affected by ventilation rates is very small. More importantly, occupants would still have the capacity and control to deal with damp or dry conditions in their homes. Thus, the question of whether to reduce the R-2000 design ventilation rate should be decided on the basis of the other IAQ factors.

Based on the above results, our recommendation is to accept the proposed reduction in ventilation rates as part of an optional package. This would allow R-2000 houses to be built either to current standards, or to the new standards which would include *all* of the following:

1. The capacity of the mechanical ventilation systems in R-2000 houses shall be maintained at the current F326 standard.

2. The mechanical ventilation rate at which R-2000 houses can be certified to meet their energy targets may be reduced to seventy-five percent (75%) of the current F326 standard, but no lower.

3. Additional restrictions shall be placed on the construction materials allowed within the air, or air/vapour, barrier of the houses. These restrictions shall include all (rather than two) of the options in the current "environmental pick list", and the following additions to that list:

   (i) Carpeting (except as noted) shall be labelled under the Carpet and Rug Institute's program.

   (vii) Homogeneous vinyl flooring shall not be used. Linoleum or composite type vinyl tiles can be used.

   (viii) Particle board flooring underlayment shall not be used unless all exposed surfaces are sealed with an Environmental Choice water based sealer or another low toxicity sealer.

4. Air flows to bedrooms shall be more carefully balanced, and maintained at the current F326 levels.

5. An extensive monitoring program is to be undertaken to determine the IAQ of a number of houses built in accordance with the reduced ventilation package. This program would include tests of IAQ and air change rates, and emissions tests of various materials used in the houses, at construction, occupancy and six months after occupancy.

High indoor air quality is an essential part of the R-2000 program. We believe that the proposed package would maintain or improve IAQ in R-2000 houses while allowing them to meet their energy targets more cost-effectively. The monitoring program would provide information which would allow further improvements in future standards.

QAI ET TAUX DE RENOUVELLEMENT DE L'AIR DES MAISONS R-2000

RÉSUMÉ

L'expérience acquise dans l'industrie tend à démontrer qu'avec la réduction de la norme sur les taux de renouvellement de l'air il serait possible d'atteindre les objectifs énergétiques du Programme de la maison R-2000 avec un meilleur rapport coût-efficacité. Une telle réduction diminuerait les pertes thermiques dues à la ventilation, ce qui rendrait possible l'utilisation de ventilateurs-récupérateurs de chaleur moins coûteux. Dans beaucoup de Maisons R-2000, les taux de renouvellement d'air sont bien au-dessous de la norme; l'abaissement des exigences ne ferait donc que coïncider avec ce que font de nombreux occupants des Maisons R-2000 de toute façon. La réduction des taux de renouvellement d'air aurait cependant des effets sur la qualité de l'air à l'intérieur des habitations (QAI).

La norme de renouvellement de l'air actuellement en vigueur, soit la CSA F326, Ventilation mécanique des habitations, exige un certain nombre de litres d'air frais par seconde pour chaque genre de pièce de maison. Dans les Maisons R-2000, cet air est amené au moyen d'un ventilateur-récupérateur de chaleur; dans chacune des maisons, cet appareil doit donc avoir la capacité d'assurer ce débit lorsqu'il tourne à grande vitesse. On ne propose pas de réduire la puissance des ventilateurs-récupérateurs, mais plutôt d'homologuer les Maisons R-2000 qui atteignent leurs objectifs de consommation d'énergie avec un débit équivalent à soixante-quinze pour cent de la norme F326, c'est-à-dire avec un ventilateur-récupérateur réglé à une vitesse inférieure. Le présent rapport présente l'analyse des effets sur la QAI de la réduction des taux de renouvellement de l'air des habitations de modèle R-2000 à soixante-quinze pour cent de la norme F326. De façon plus précise, il traite des effets possibles de telles réductions au regard de l'exigence selon laquelle une Maison R-2000 doit avoir une meilleure QAI que la maison canadienne moyenne.

La recherche débute par une analyse de plusieurs études récentes sur la QAI dans les maisons canadiennes et par la production de tableaux de distribution des concentrations-sources des substances qui ont des effets sur la QAI. Les substances sur lesquelles a porté la recherche sont les composés organiques volatils totaux (COVT), le formaldéhyde (HCHO), le dioxyde de carbone (CO_2) et la vapeur d'eau (HR). Nous nous servons alors des concentrations-sources des 50^e et 90^e percentiles pour faire des prévisions sur la QAI dans quarante-sept maisons R-2000 neuves, à divers taux de renouvellement d'air. Le 50^e percentile, qui est aussi la médiane, sert à prédire la QAI dans les maisons moyennes, tandis que le 90^e percentile sert à indiquer les problèmes éventuels de santé et d'inconfort dans l'une des dix pires maisons.

Les prévisions concernant la QAI sont fondées sur les taux globaux de ventilation comprenant la ventilation mécanique et la ventilation naturelle. Nous nous servons du programme Hot-2000 pour prédire la ventilation totale en nous fondant sur l'étanchéité mesurée de chaque maison et sur quatre taux de ventilation mécanique. Ces derniers taux comprennent la capacité définie dans la norme F326, le taux réel de chacune des maisons, un taux réduit calculé à partir du rapport moyen taux réel-norme, et le nouveau taux proposé. Les taux réels (mesurés) de ventilation mécanique dans les quarante-sept Maisons R-2000 varient de 25 à 128 % de la capacité définie dans la norme F326. Les moyennes régionales varient de 59 % en Ontario à 80 % dans les provinces de l'Atlantique. Pour l'ensemble des quarante-sept Maisons R-2000, la moyenne est de 70 % de la capacité établie dans la norme F326, ce qui est très près du taux proposé.

Pour chacune des substances déterminant la QAI, les concentrations-sources des deux percentiles sont combinées aux quatre taux globaux de renouvellement de l'air de façon à obtenir huit concentrations possibles pour chacune des quarante-sept Maisons R-2000. Ces concentrations sont ensuite comparées aux moyennes obtenues dans cette étude et avec les lignes directrices en vigueur. Dans le cas du formaldéhyde (HCHO), le niveau visé par Santé Canada est de 0,05 mg/l, ce qui est presque identique au niveau moyen, et le niveau d'intervention est de 0,10 mg/l. Les données indiquent qu'une diminution des taux de renouvellement de l'air définis dans la norme F326 pour les

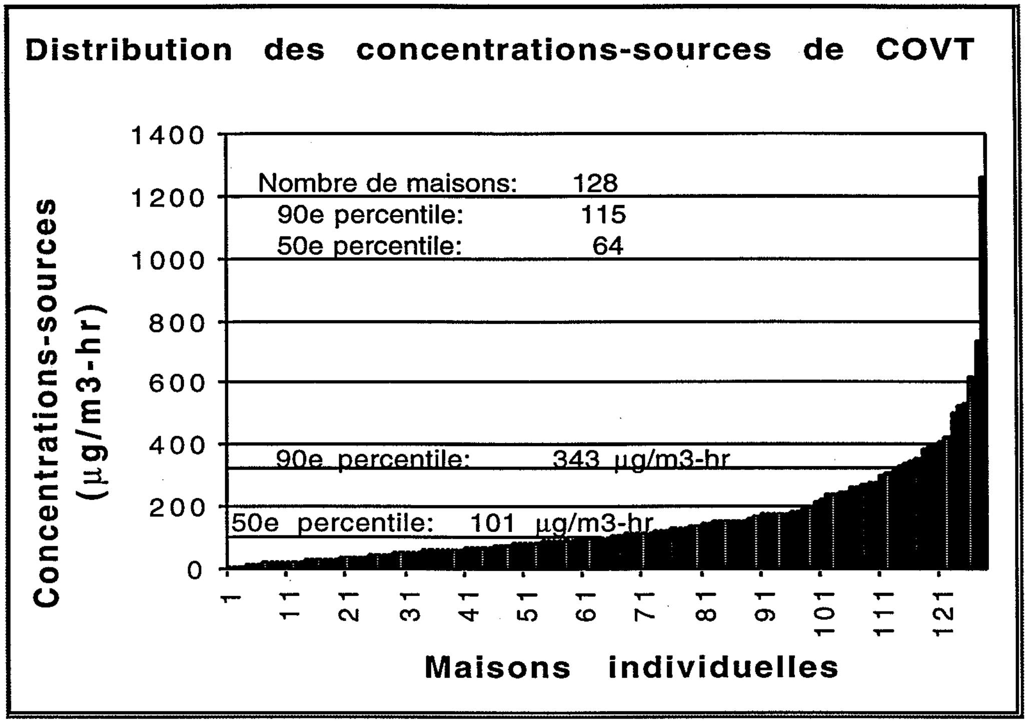

Figure S-1. Distribution des concentrations-sources de COVT avec les 90e et 50e percentiles.

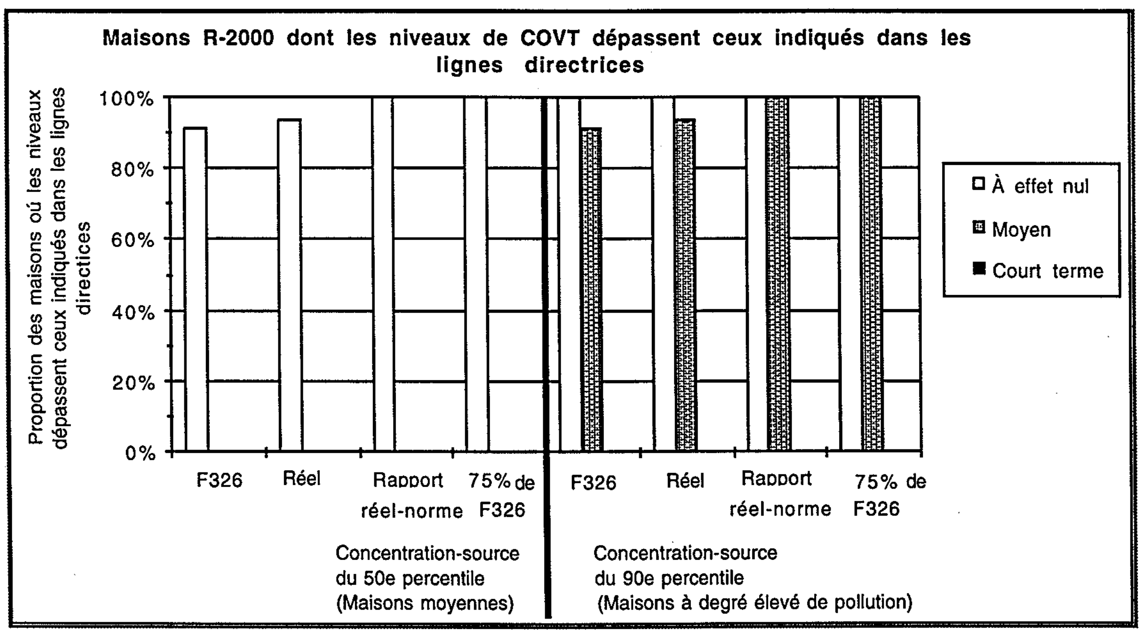

Figure S-2. Maisons dont les niveaux de COVT dépassent ceux indiqués dans les lignes directrices, par concentrations-sources et taux globaux de renouvellement de l'air.

ramener aux niveaux proposés augmenterait de 1,7 à 4,7 % la proportion des maisons où le niveau visé (moyen) pour le formaldéhyde serait dépassé. Aucune ne dépasserait le niveau d'intervention, quel que soit le taux de renouvellement de l'air. Nous en concluons donc qu'une réduction des taux de renouvellement de l'air produirait une légère augmentation de la pollution par le formaldéhyde, mais, si elle est combinée à une réduction des sources de HCHO, les concentrations réelles de HCHO devraient alors diminuer.

Ce sont les COVT qui sont les plus susceptibles de causer des problèmes de QAI avec une réduction des taux de renouvellement de l'air. Le niveau à «effet nul» pour les COVT est de 200 microgrammes par mètre cube ($\mu g/m^3$), la moyenne se situant à 585 $\mu g/m^3$, le niveau «court terme» étant de 3 000 $\mu g/m^3$. La figure S-1 donne la distribution des concentrations-sources des COVT, tandis que la figure S-2 montre les résultats de la mise en rapport des concentrations-sources des 50e et 90e percentiles avec les quatre taux de renouvellement de l'air pour l'ensemble des quarante-sept Maisons R-2000. Quatre-vingt-onze pour cent des maisons dépassent le niveau à effet nul défini dans les lignes directrices, même dans les cas où la concentration-source moyenne est combinée au taux de renouvellement de l'air le plus élevé. Lorsque l'on diminue le taux de renouvellement de l'air, la proportion des maisons où le niveau à effet nul défini dans les lignes directrices est dépassé atteint 100 %.

À la plus forte concentration-source, le niveau à effet nul est dépassé dans toutes les maisons et ce, pour tous les taux de renouvellement de l'air, tandis que le niveau de la maison moyenne est dépassé dans 91 % des cas avec les taux de renouvellement de l'air de la norme F326. (Ceci montre qu'environ 9 % de l'ensemble des Maisons R-2000 auraient plus de COVT que la maison moyenne). Lorsque l'on abaisse le taux de renouvellement de l'air, toutes les maisons du 90e percentile dépassent à la fois le niveau à effet nul des lignes directrices et le niveau de la maison moyenne. Ainsi, le nombre de maisons où les COVT dépassent les niveaux définis dans les lignes directrices augmente de manière significative avec la réduction des taux de renouvellement de l'air. Avec le 90e percentile et 75 % de la capacité définie dans la norme F326, 32 % des maisons montrent des concentrations de plus de 1 000 $\mu g/m^3$, l'une atteignant plus de 1 600 $\mu g/m^3$. Les lignes directrices pour le court terme ne sont jamais dépassées, mais ces niveaux de COVT pourraient être suffisamment élevés pour entraîner une irritation et un inconfort accrus chez les occupants, et éventuellement avoir des effets sur leur santé. Pour cette raison, nous recommandons fortement que la réduction des taux de ventilation mécanique prévus pour le modèle R-2000 soit accompagnée d'une élimination des matières produisant des rejets élevés de COV.

Pour le dioxyde de carbone (CO_2), le niveau moyen à l'intérieur est de 748 mg/l. Le «niveau d'inconfort» est de 1 000 mg/l, et la «limite à long terme» est de 3 500 mg/l. Les résultats obtenus en combinant les concentrations-sources et les taux de renouvellement de l'air montrent que le CO_2 n'est pas susceptible de causer un problème grave dans les Maisons R-2000, même avec des taux de renouvellement de l'air réduits. Toutefois, les concentrations-sources de CO_2 sont fondées sur les concentrations moyennes mesurées pendant une semaine d'observation. La production de CO_2 varie considérablement en fonction du nombre de personnes dans une section donnée de la maison et de leur niveau d'activité. Des modèles simples de chambre à coucher avec canalisation directe et d'autres dotées d'installations de remise en circulation d'air frais montrent que le niveau d'inconfort serait dépassé au taux de renouvellement de l'air proposé pour le modèle R-2000. Nous recommandons donc que la réduction des taux de renouvellement de l'air s'accompagne d'un équilibrage plus minutieux de façon à ce que le débit vers les chambres à coucher soit maintenu au niveau prévu actuellement dans la norme F326. Il s'agit là d'une mesure essentielle dans les maisons munies d'une canalisation directe, mais le tout devrait également se faire dans les maisons disposant d'installations de remise en circulation d'air.

Santé Canada recommande que l'humidité relative (HR) soit maintenue entre 30 et 55 % pendant la période de chauffage des habitations. Les résultats indiquent qu'une réduction du taux de renouvellement de l'air dans le modèle R-2000 n'aura pas d'effet significatif sur les niveaux d'humidité relative dans les Maisons R-2000. La proportion des maisons dans lesquelles une limite ou l'autre du niveau de HR serait touchée par les taux de renouvellement de l'air est très faible. Plus important encore, les occupants auraient toujours la possibilité de conserver un contrôle sur le degré d'humidité et de sécheresse dans leur maison. La décision de réduire ou non les taux de renouvellement de l'air du modèle R-2000 devrait donc être prise en fonction des autres facteurs influant sur la QAI.

À partir des résultats analysés précédemment, nous recommandons d'accepter la réduction proposée des taux de renouvellement d'air, mais comme partie d'un ensemble facultatif. Ceci rendrait possible la construction de Maisons R-2000 selon les normes actuellement en vigueur ou selon de nouvelles normes qui comprendraient *tous* les éléments suivants :

1. La puissance des systèmes de ventilation mécanique des Maisons R-2000 doit être maintenue au niveau actuel établi dans la norme F326.

2. Le taux de ventilation mécanique auquel il peut être certifié qu'une maison R-2000 atteint ses objectifs de consommation d'énergie peut être réduit à soixante-quinze pour cent (75 %) du taux établi dans la norme F326, mais il ne doit pas être inférieur.

3. Il faut imposer des restrictions supplémentaires sur les matériaux de construction autorisés dans les pare-vent ou les pare-air/pare-vapeur des maisons. Ces restrictions doivent inclure toutes les options (plutôt que deux seulement) de la «liste environnementale à utiliser» actuelle, ainsi que les ajouts suivants à cette liste :

   i) Les tapis posés (sauf pour ce qui est indiqué) doivent porter le label du programme du *Carpet and Rug Institute*.

   vii) On ne doit pas mettre un revêtement de sol de vinyle homogène. On peut utiliser du linoléum ou des carreaux de vinyle de type composite.

   viii) On ne doit pas se servir de sous-couches de revêtement de sol en panneaux de particules, à moins que toutes les surfaces exposées soient enduites d'un apprêt à l'eau mentionné dans le Choix environnemental ou d'un autre apprêt de faible toxicité.

4. Les débits d'air vers les chambres à coucher doivent être équilibrés plus minutieusement et maintenus aux niveaux en vigueur dans la norme F326.

5. Il faut mettre en marche un vaste programme d'observation visant à établir la QAI d'un certain nombre de maisons construites selon des normes réduites de renouvellement d'air. Ce programme comprendrait des mesures de la QAI et des taux de renouvellement de l'air, ainsi que des mesures des rejets des divers matériaux utilisés dans les maisons lors de la construction, au moment de l'entrée dans la maison et six mois après le début de l'occupation.

La qualité élevée de l'air à l'intérieur des habitations est un élément essentiel du Programme de la maison R-2000. Nous croyons que l'ensemble proposé de mesures permettrait de maintenir à son niveau actuel ou d'améliorer la QAI dans les Maisons R-2000, tout en assurant l'atteinte des objectifs énergétiques avec un meilleur rapport coût-efficacité. Le programme d'observation fournirait les informations nécessaires à d'autres améliorations des normes dans l'avenir.

INTRODUCTION

R-2000 building industry experience suggests that energy targets could be met more cost effectively if the standard for ventilation rates were reduced. Reduced ventilation rates would lower ventilation heat losses, which in turn would allow the use of lower-cost heat recovery ventilators (HRVs). Many R-2000 houses are operated at ventilation rates well below the standard; thus, lowering the requirements would simply be acknowledging what many R-2000 occupants are doing anyway. However, decreasing ventilation rates will affect indoor air quality (IAQ).

The current standard for ventilation, CSA F326 Residential Mechanical Ventilation Systems, requires a certain number of litres per second of fresh air for each type of room in a house. In R-2000 houses, this air is brought through an HRV, so the HRV installed each house must have the capacity to meet that flow rate when run at its high speed. It is not proposed that the capacity of HRVs be reduced, but that R-2000 houses could be certified if they pass their energy consumption targets with seventy-five percent the F326 standard flow rate, i.e., with the HRV set to a lower speed. This report examines the IAQ implications of reducing the "R-2000 design ventilation rates", or "R-2000 design rates," to seventy-five percent of the F326 standard. Specifically, it asks whether such reductions would affect the requirement that R-2000 houses have better IAQ than the average Canadian house.

The investigation begins by examining several recent studies on IAQ in Canadian houses, and producing distributions of the source strengths of substances which affect IAQ. The substances investigated are total volatile organic compounds (TVOCs), formaldehyde (HCHO), carbon dioxide (CO_2), and water vapour (RH). Selected source strength percentiles are then used to predict IAQ in forty-seven new R-2000 houses at various ventilation rates. The fiftieth percentile is used to predict IAQ in average houses, while the ninetieth percentile indicates the potential for health and comfort problems in higher pollution houses. The ventilation rates include the F326 capacity, the actual rate for each house, a rate reduced by the average actual-to-standard ratio, and the proposed new rate. The resulting substance concentrations are compared with the averages from this study, and with existing guidelines.

The results indicate that ventilation rates can be reduced while maintaining better IAQ in R-2000 houses than in average Canadian houses, subject to the following conditions: The reduced R-2000 design rates should be combined with lower emission materials in R-2000 houses, and with better balancing of flows to bedrooms. This combination would significantly reduce the number of "problem" houses at the high end of the indoor pollution range which would otherwise be increased by reduced ventilation rates. The combination of reduced ventilation with stricter material standards and balanced air flows would be an optional package for R-2000 builders; R-2000 houses could also continue to be built with the current standards for materials and ventilation.

SOURCES OF DATA

In order to be used for this analysis, studies of IAQ in Canadian single family (detached) housing had to meet the following criteria:

1. Include indoor concentrations of at least one of the following substances: Total Volatile Organic Compounds (TVOCs - actually a "family" of substances), Formaldehyde (HCHO), Carbon Dioxide (CO_2), and Water Vapour (Relative Humidity or RH).

2. Include an actual air change, or ventilation, rate for the house during the time (usually a week) when the concentrations were measured. This allows the concentration (e.g. $\mu g/m^3$) to be converted to a source strength (e.g., $\mu g/m^3$-hr) which can then be used to predict concentrations in other houses with given air change rates.

3. In the case of HCHO, each house must have been less than two years old at the time of the study. This is because approximately one-half of HCHO in new houses is generally believed to be emitted by building materials whose emissions become insignificant after about two years.

4. In the case of RH, there must be enough data to determine average indoor and outdoor mixing ratios W (kg water / kg air). For example, temperature and RH must be recorded both indoors and outdoors. This is because outdoor water vapour contributes a significant and variable proportion to indoor RH. Outdoor CO_2 is also significant, but was taken as a constant 348 ppm. Outdoor concentrations of TVOCs and HCHO are assumed to be zero.

Data was taken from the following sources:

1. A study by the Saskatchewan Research Council (SRC) reported in a spreadsheet, and in a CMHC report.[1] This study included data on TVOCs in forty-four houses.

2. Two reports for Natural Resources Canada (NRCan) by Howell-Mayhew Engineering on houses in Alberta.[2,3] These reports included data on HCHO; the first in fifteen older conventional houses, and the second in twenty houses, including ten R-2000s.

3. A survey of houses in Nova Scotia for NRCan by Healthy Homes Consulting (unpublished) which included data on HCHO and CO_2 in ten conventional and ten R-2000 houses.

4. The 1989 NRCan/CMHC/NRC study[4] which included HCHO data on forty-seven new conventional houses.

5. Data from a spreadsheet produced by Unies Ltd. as part of a study[5] which included data on TVOCs in thirty-nine houses in Winnipeg and Edmonton.

6. The CMHC report *Ventilation and Air Quality Testing in Electrically Heated Housing*,[6] which included data on HCHO, TVOCs, and CO_2 in thirty conventional houses, and RH in seven of them.

7. A report for NRCan by Sheltair Scientific Ltd.[7], which included data on CO_2 in sixteen houses, including eight R-2000s, in the Vancouver area.

8. Recent monitoring of conventional and R-2000 houses in Ontario and New Brunswick for NRCan done by Buchan, Lawton, Parent Ltd., Enermodal Engineering Ltd, Scanada Consultants, and R. Clarke Designs (unpublished).

9. A report on moisture source strengths which the authors did for CMHC.[8]

All of the data was combined in a single spreadsheet which included the conversion of the data from concentrations and air change rates to source strengths. Data on age of houses at the time of testing, and occupancy was also included. The single spreadsheet was then split up into separate spreadsheets for each substance which were then sorted by source strengths to obtain their distributions. HCHO was also graphed by age of house before eliminating houses less than two years old, and CO_2 was correlated with occupancy rates. Data on required and actual ventilation rates in newer R-2000 houses was drawn from sources 2, 3, 7 and 8, above.

VENTILATION RATES

According to the *R-2000 Design Approval Procedures and Guidelines*,[9] "The Ventilation Systems in R-2000 homes must be designed and installed according to CAN/CSA-F326-M91, Residential Mechanical Ventilation Systems" (p. 31). This standard, which is usually referred to as F326, is a minimum requirement for mechanical ventilation capacity, based on the number of rooms in the house. It requires 5 L/s for each habitable room in the house, except for master bedrooms and basements which require 10 L/s.[10] The total mechanical ventilation requirement for the house can be expressed either as a flow (L/s), or as an air change rate ACH (air changes per hour). Flow is converted into ACH by multiplying by 3.6 to convert to m^3/hr, and then dividing by the house volume. In R-2000 houses, the mechanical ventilation is almost always supplied by a Heat Recovery Ventilator (HRV) with balanced flows, so that both the exhaust and fresh air flows are equal to the F326 requirement when the HRV is operated at its high flow setting.

In addition to the mechanical ventilation, each house will also have natural ventilation, i.e., air flow through cracks in and around walls, windows, doors, etc. The rate of natural ventilation depends on the airtightness of the house, and conditions such as indoor-outdoor temperature difference and wind speed. In all R-2000 houses, airtightness is measured by a fan-door test. The combination of the mechanical and natural ventilation is the total ventilation rate. Total ventilation can be estimated from mechanical ventilation, airtightness and average conditions by models such as AIM-2. In this study, total ventilation is estimated by the AIM-2 model which is part of HOT2000 and AUDIT2000. This method takes into account mechanical ventilation, measured airtightness, and average monthly weather conditions for the location of each house.* It is used to estimate the following total ventilation rates:

1. One based on the F326 standard for each house,

---

* An alternative to the AIM-2 model would be the total ventilation rates as measured by perfluorocarbon tracer gas (PFT) tests. PFT is probably more accurate than AIM-2, but only for conditions during the week in which the test was conducted, while AIM-2 estimates seasonal conditions.

2. One based on the measured mechanical ventilation rate for each house, which is often less than the F326 standard because homeowners choose to operate their HRVs at low fan settings,

3. Rate 1) for each house multiplied by the average ratio of rate 2) to rate 1) for all of the forty-seven houses in the study. This is called the average actual and is equal to 76% of rate 1) for each house, and

4. One based on the proposed R-2000 design rates, which are 75% of the F326 capacity.

The ventilation rates for each house (ACH) are shown in the tables in Appendix II. The first two columns show the mechanical ventilation rates required by the F326 standard and as measured. The next three columns show the total ventilation rates estimated to occur when the mechanical rate is set to F326, actual, and 75% of F326, i.e., rates 1), 2) and 4) above. Table 1 shows how the mechanical and total ventilation rates compare with the F326 standard, by regions and for all forty-seven houses in this study. The data indicate that the average actual mechanical ventilation rate is very close to the proposed R-2000 design ventilation rate. It should be noted that actual ventilation rates are not exact since we do not have sufficient information on the amount of time during which HRVs run at high speed due to dehumidistat settings or occupant intervention. Also, the actual average is affected by a small number of houses which are run at less than fifty percent of the F326 level.

Region	Average Ratios of Actual to F326 Ventilation Rates	
	Mechanical	Total
British Columbia	60%	71%
Alberta	77%	83%
Ontario	59%	64%
Atlantic Canada	80%	85%
ALL	70%	76%
Minimum, All	25%	45%
Maximum, All	128%	117%

Table 1: Average Ratios of Actual/F326 Ventilation Rates.

FORMALDEHYDE (HCHO)

According to Health Canada,[11] formaldehyde is a colourless gas with a pungent odour. The major health effect of formaldehyde in air is irritation of the eyes, nose and throat. Animal and laboratory studies have shown that formaldehyde is carcinogenic, genotoxic and mutagenic. "Although the epidemiological studies conducted to date provide little convincing evidence that formaldehyde is carcinogenic in human populations, the possibility cannot be excluded owing to limitations of the available data" (ref 11, p. 12). The exposure guidelines for formaldehyde in

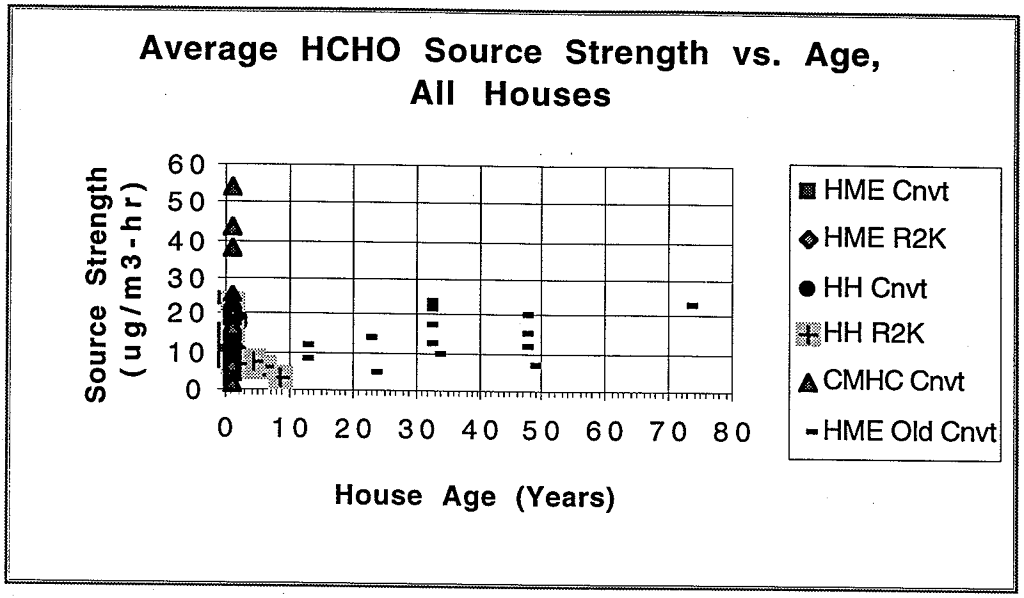

Figure 1. Relationship between HCHO Source Strengths and Age of House during data collection.

	Houses		
	All	Conventional	R-2000
Number	97	73	24
Average	0.050	0.053	0.039
Standard Deviation	0.028	0.028	0.027
Minimum	0.008	0.008	0.012
Maximum	0.141	0.141	0.140

Table 2. Statistics on Concentrations of HCHO in Conventional & R-2000 Houses.
All values are parts per million (ppm), except numbers.

residential indoor air are an "Action Level" of 120 μg/m³ (0.10 ppm), and a "Target Level" of 60 μg/m³ (0.05 ppm) (ibid, p. 11). The Target Level is almost identical to the average concentration from houses in this study, 59.8 μg/m³, so 60 μg/m³ is used as both the Target and Average level.

Figure 1 shows the relationship between HCHO source strengths and the ages of houses at the time of data collection. It shows that the highest source strengths occur in houses which are one or two years old. All houses which are more than two years old are excluded from this study because we are concerned with the IAQ problems which will be most sever during the first year or two of occupancy. The average HCHO concentration in all houses less than two years old is 59.8 µg/m³ (0.05 ppm). Table 2 compares statistics for formaldehyde concentrations for all of these houses, and for the conventional and R-2000 houses among them. The average concentration in R-2000s is twenty-six percent less than the average in conventional house, but the averages are within half a standard deviation of each other. Thus, the formaldehyde levels in R-2000 houses appear to be slightly less than in conventional houses, but the difference may not be significant.

Figure 2 shows the distribution of HCHO source strengths for all houses which were less than two years old when data on HCHO concentrations was collected in them. The number of these houses is ninety-seven, so the fiftieth percentile source strength occurs in the forty-ninth house, and is 11.4 µg/m³-hr. The ninetieth percentile occurs in the eighty-seventh house and is 22.8 µg/m³-hr. Figure I-1 in Appendix I is a graph comparing the binned HCHO source strengths with normal and log-normal distributions. Like the distributions of the other IAQ substances in this report, HCHO seems to have a distribution which is closer to log-normal than to normal; its distribution peaks significantly before the mean, and there are more high values than in a normal distribution. Of the ninety-seven houses in the source strength distribution, twenty-four are R-2000 houses. Eleven of the R-2000 houses are above the fiftieth percentile, and two are above the ninetieth percentile. This indicates that the distribution of HCHO source strengths does not differ significantly between R-2000 and conventional houses.

Figure 3 displays the results of combining the fiftieth and ninetieth percentile source strengths with the four total ventilation rates for each of the forty-seven R-2000 houses in this study. (Figure 3 is a summary of Table II-1 in Appendix II.) Each of the two source strengths is multiplied by each of the four ventilation rates to give eight concentrations, or exposure levels, for each house. The exposure levels are compared with the Health Canada target and action guidelines in each house, and the number of houses with levels which exceed the guidelines is shown in the graph. At the fiftieth percentile source strength, three of the forty-seven houses (6%) exceed the target guideline (and average concentration) with their actual ventilation rates, while none of them exceed either of the guidelines at either the present of proposed standard rates. This indicates that average R-2000 houses would not have significant levels of HCHO pollution even at reduced ventilation rates.

Combining the ninetieth percentile source strength with actual ventilation rates, twenty-nine of the houses exceed the target guidelines, and three exceed the much more significant action guideline. All three of these houses have mechanical ventilation rates of less than half the F326 standard, and one is at forty percent of F326. When their ventilation rates meet the F326 standard, then eight of them exceed the target guideline, and the number would increases to twenty-two if the standard were reduced to 75%. This indicates that, at actual rates, around six percent (29/47 x 10%) of R-2000 houses may have significant levels of HCHO, and 0.6 % may have serious levels. Reducing the R-2000 design rate would probably not have any practical effect since most houses are being operated near the reduced rate in any case. Comparing the current and proposed standards indicates that the percentage of houses exceeding the target (average) level for formaldehyde would rise from 1.7% to 4.7%, while none would exceed the action level. Thus, the conclusion is that reduced ventilation rates will result in a small increase in formaldehyde pollution, but if reduced ventilation is combined with reduced sources of HCHO, then actual HCHO concentrations should decrease.

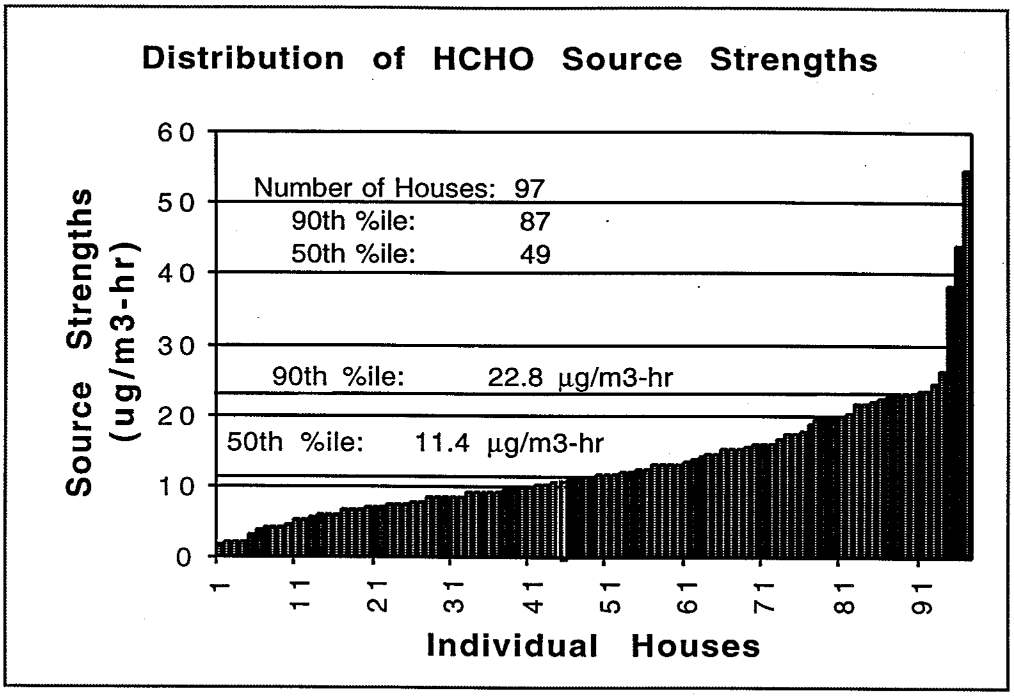

Figure 2. Distributions of HCHO Source Strengths with 90th and 50th Percentiles.

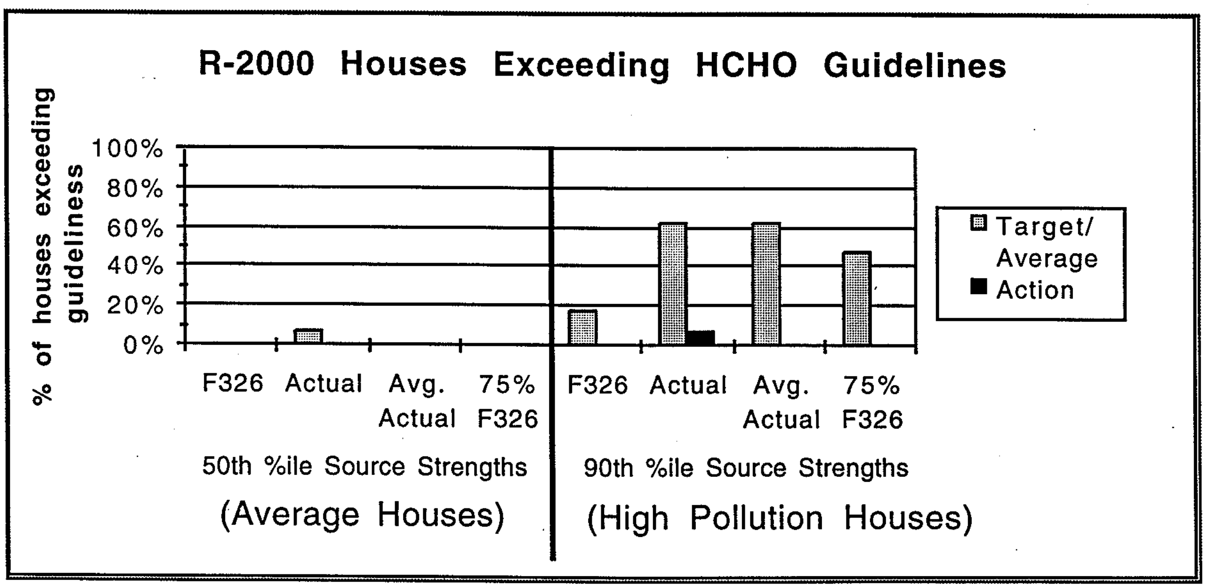

Figure 3. Houses which exceed the Health Canada Guidelines for HCHO by Source Strength and Total Ventilation Rates.

TOTAL VOLATILE ORGANIC COMPOUNDS (TVOCs)

Volatile organic compounds (VOCs) are chemicals containing carbon which vaporize at temperatures between 50 and 260 °C. Between fifty and three-hundred individual VOCs are normally found in air samples from non-industrial environments. They are emitted by building and furniture materials, cleaning compounds, glues, spray cans, copy machines, human metabolism and smoking. Eighty-two percent of common VOCs are known or suspected mucous membrane or eye irritants, and twenty-five percent of them are known or suspected human carcinogens. Measuring all relevant individual VOCs is expensive and time consuming, so a single test of total volatile organic compounds (TVOCs) is often used as an indicator.[12,13]

According to Lars Molhave[12], the TVOCs level below which no effects can be detected is 200 µg/m³, while above 3,000 µg/m³ most people will experience discomfort. These concentrations will be referred to as the "No Effect" and "Short Term" levels, respectively. The forty-four houses studied by the Saskatchewan Research Council[14] had an average concentration of 555 µg/m³, and the average for this study, which includes the SRC's houses and 84 additional ones, is 586 µg/m³. Thus, we take 585 µg/m³ as the average level for Canadian houses. Table 3 compares statistics on the concentrations of TVOCs in all houses, conventional, and R-2000 houses. The average concentration in R-2000 houses is thirty-two percent less than in conventional houses, but the low number of R-2000s and the high standard deviations probably make this difference statistically insignificant. Howell-Mayhew Engineering[3] made individual measurements of twenty-two common VOCs in ten conventional, and ten R-2000, houses in Alberta. Their average of combined VOC measurements are: conventional houses: 437 µg/m³ and R-2000 houses: 311 µg/m³. This contrasts with the SRC average of 248 µg/m³ in conventional houses. Again, these results do not show a clear difference between VOC concentrations in conventional and R-2000 houses.

	Houses		
	All	Conventional	R-2000
Number	128	119	9
Average	558	571	388
Standard Deviation	482	494	227
Minimum	40	40	80
Maximum	2806	2806	730

Table 3. Statistics on Concentrations of TVOCs in Conventional & R-2000 Houses.
All values are micrograms per cubic meter (µg/m³), except numbers.

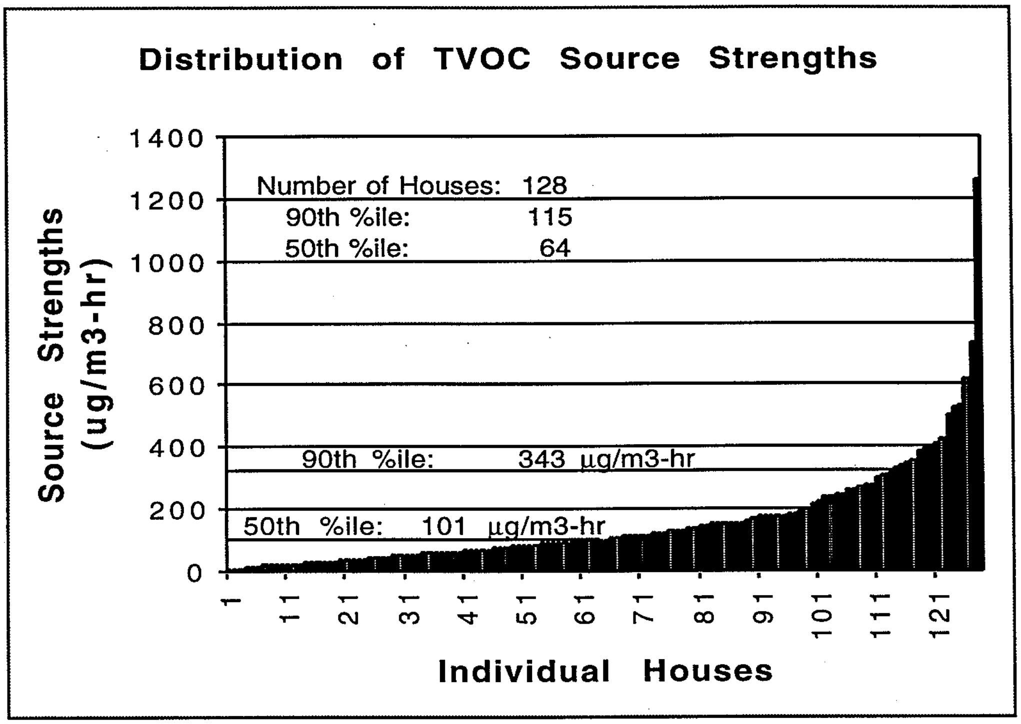

Figure 4. Distribution of TVOCs Source Strengths with 90th and 50th Percentiles.

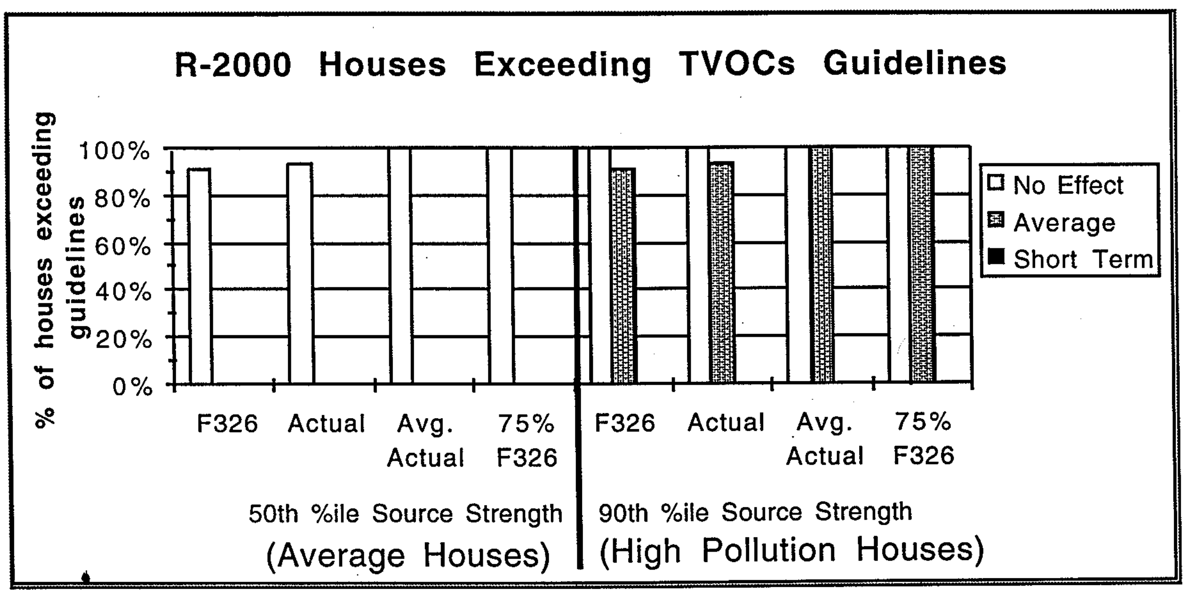

Figure 5. Houses which exceed the Guidelines for TVOCs by Source Strengths and Total Ventilation Rates.

Figure 4 shows the distribution of TVOCs source strengths for all houses for which data on TVOCs were available. The number of these houses is 128, so the fiftieth percentile occurs in the sixty-fourth house, and is 101 μg/m³-hr. The ninetieth percentile occurs in the 115th house, and is 343 μg/m³-hr. Figure I-2 in Appendix I compares the binned TVOCs source strengths with normal and log-normal distributions. The distribution appears to be closer to log-normal than to normal. Of the 128 houses in the source strength distribution, nine are R-2000. Two of the R-2000 houses are above the fiftieth percentile, and none are above the ninetieth percentile. This indicates that source strengths in R-2000 houses may be weaker than in conventional houses, but the small number of R-2000 houses does not give much significance to this conclusion.

Figure 5 displays the results of combining the fiftieth and ninetieth percentile source strengths with the four ventilation rates for each of the forty-seven R-2000 houses. Ninety-one percent of the houses exceed the no-effect guideline even when the lower source strength is combined with the highest ventilation rate. As ventilation rates are decreased, the number of houses exceeding the no-effect guideline rises to 100%. At the higher source strength, all of the houses exceed the no-effect guideline with all ventilation rates, and 91% exceed the level of the average house with the F326 ventilation rates. (This indicates that around 9% of all R-2000 houses would have more TVOCs than the average house). As ventilation rates are lowered, all ninetieth percentile houses exceed both the no-effect guideline and average house level. Thus, the number of houses exceeding the guidelines increases significantly as the ventilation rates are decreased. As can be seen in Table II-2, with the ninetieth percentile and 75% of the F326 standard, fifteen of the houses have concentrations of over 1,000 μg/m³, and one has over 1600 μg/m³. In no case is the short-term guideline exceeded, but this does not mean that significant health effects will not occur.

TVOCs are the IAQ factor most likely to cause problems. There is no indication that the short term guidelines would ever be exceeded, and the additional number of cases exceeding the level of the average house would be around one or two percent. However, the resulting levels of TVOCs could be high enough to cause additional occupant irritation and discomfort. For this reason, we strongly recommend that decreases in the R-2000 design rate for mechanical ventilation be coupled with the elimination of materials with high VOC emissions.

CARBON DIOXIDE (CO_2)

According to Health Canada, [11] "Carbon dioxide is a colourless, odourless and non-flammable gas, which is produced by metabolic processes and by the combustion of fossil fuels. The average concentration of carbon dioxide in the atmosphere is about 620 mg/m³ (≈340 ppm), but levels vary widely with time and location" (p. 8).

> In several studies, comfort factors have been correlated with carbon dioxide concentrations. Collectively, these studies suggest that carbon dioxide concentrations above 1800 mg/m³ (1000 ppm) are indicative that there is an inadequate supply of fresh air, although complaints have been documented at concentrations as low as 1100 mg/m³ (600 ppm). However, from a review of the direct physiological effects of exposure to carbon dioxide, as opposed to subjective symptoms, a higher maximum exposure concentration is recommended... (p. 4).

An increase in the ambient level of carbon dioxide brings about a rise in the acidity of

> the blood and an increase in the rate and depth of breathing. Over prolonged periods, of the order of days, regulation of blood carbon dioxide levels occurs by kidney action and the metabolism of bone calcium. The latter process leads to some demineralization of the bone. (p. 8).
>
> The lowest concentration at which adverse health effects have been observed in humans is 12 600 mg/m^3 (7000 ppm) . . . A maximum exposure level of 6300 mg/m^3 (3500 ppm) should provide a sufficient margin . . . (p. 9)

Based on the above, this study uses 1000 ppm as a discomfort limit, and 3500 ppm as the long-term limit. The average concentration for the sixty-five houses with CO_2 data in this study is 748 ppm.

Concentrations of CO_2 are generally recorded in ppm or parts per million by volume. Concentrations in ppm can be converted to mg/m^3 as follows: One ppm of CO_2 is equal to 1.0 x 10^{-6} kilomole of CO_2 per kilomole of air ($kmol_{CO2}/kmol_a$). Thus, the mass of one ppm of CO_2 in one kmol of air is:

$$m_{CO2} = \frac{n_{CO2}\,R^*}{R_{CO2}} = \frac{1.0 \times 10^{-6}\ kmol_{CO2} \times 8.3143 \times 10^{3}\ J\ K^{-1}\ kmol^{-1}}{188.92\ J\ K^{-1}\ kg^{-1}}$$

$$= 4.4010 \times 10^{-5}\ kg.$$

The volume of 1 kmol of air at standard temperature and pressure is:

$$V = \frac{n\,R^*\,T}{P} = \frac{1\ kmol \times 8.4143 \times 10^{-3}\ J\ K^{-1}\ kmol^{-1} \times 293.15\ K}{101325\ Pa}$$

$$= 24.054\ m^3.$$

Thus, the mass of one ppm of CO_2 in one m^3 of air is:

$$\frac{4.4010 \times 10^{-5}\ kg_{CO2}}{24.054\ m^3} = 1.8296 \times 10^{-6}\ kg/m^3$$

$$= 1.8296\ mg/m^3.$$

In order to convert indoor concentrations of CO_2 to source strengths, it is also necessary to subtract the average outdoor concentration. According to measurements made at the same time that indoor concentrations were measured this spring outdoor concentration is 348 ppm. Thus, indoor concentrations in ppm are converted to source strength S (mg/m^3-hr) as follows:

$$S\ (mg/m^3\text{-}hr) = (C_{in}\ (ppm) - 348\ ppm) \times 1.8296\ mg/m^3\text{-}ppm \times ACH\ (/hr).$$

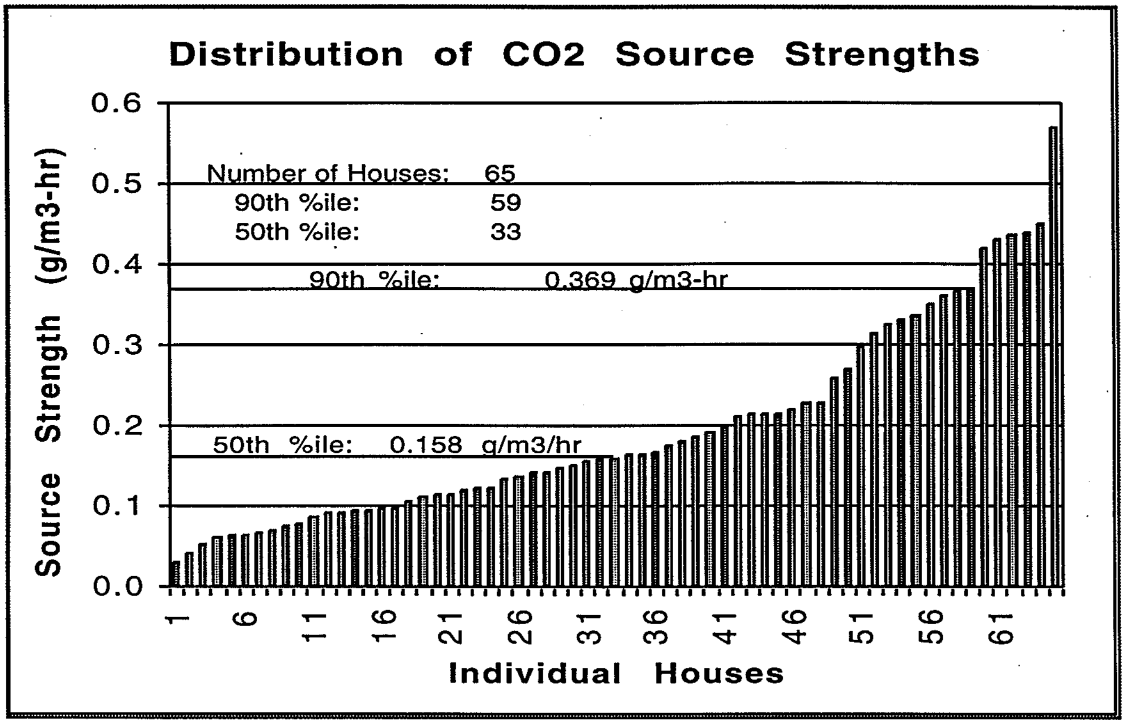

Figure 6. Distribution of CO_2 Source Strengths with 90th and 50th Percentiles.

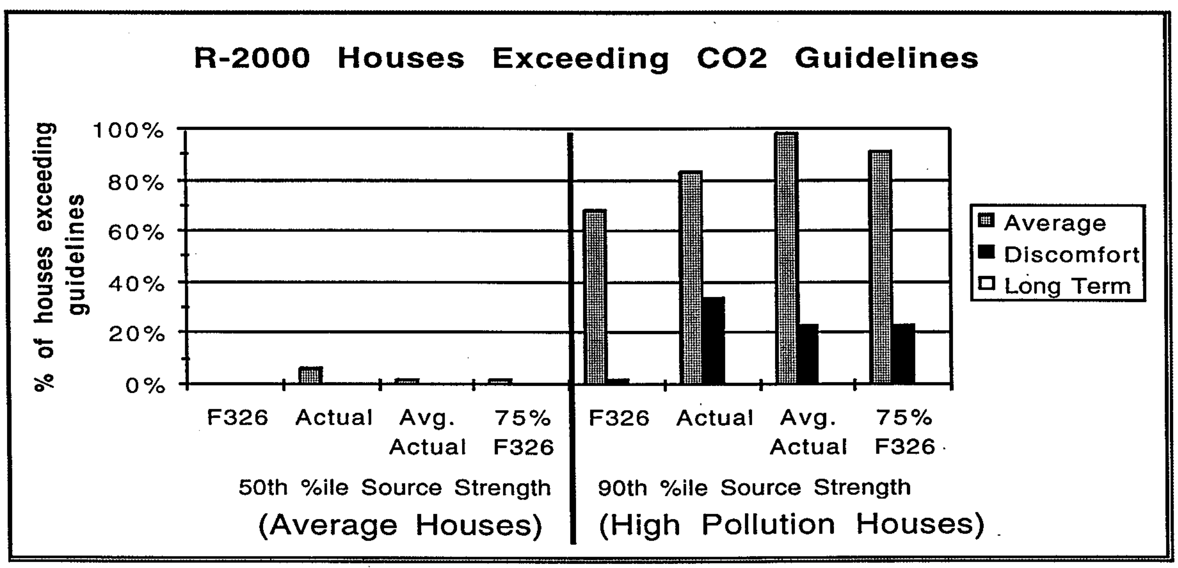

Figure 7. Houses which exceed the Guidelines for CO_2, by Source Strengths and Total Ventilation Rates.

Similarly, to convert a source strength and a ventilation rate into an indoor concentration, it is necessary to add the outdoor concentration:

$$C_{in}\ (\text{ppm}) = \frac{S\ (\text{mg/m}^3\text{-hr})}{1.8296\ \text{mg/m}^3\text{-ppm x ACH (/hr)}} + 348\ \text{ppm.}$$

Figure 6 shows the distribution of CO_2 source strengths for the 65 houses with CO_2 data. The ninetieth percentile is house 59 with a source strength of 0.369 g/m^3-hr, and the fiftieth percentile occurs in house 33 and is 0.158 g/m^3-hr. These correspond to average occupancies of 6.9 and 2.9 people, given the average volume of 613 m^3 for these houses, and a CO_2 generation rate of 0.3 L/min-per (see below). Figure I-3 in Appendix I compares the binned distribution of CO_2 source strengths with normal and log-normal distributions; the distribution appears to be closer to log-normal than to normal, and may have more than one mode. Figure 7 combines the fiftieth and ninetieth percentile source strengths with the four total ventilation rates for the R-2000 houses, to show how many would exceed the guidelines. At the fiftieth percentile source strength, less than seven percent of the houses are above the average of 748 ppm, and neither of the guidelines are exceeded, at any of the ventilation rates. This indicates that most R-2000 houses would not have CO_2 problems, even with reduced ventilation. Combining the ninetieth percentile source strength with the F326 standard ventilation results in sixty-eight percent of these houses (seven percent of all houses) with above average CO_2 levels, and two percent (0.2% of all) above the discomfort level. When ventilation rates are reduced, then more houses exceed the average and discomfort levels, but none come close to exceeding the long-term guideline. These results indicate that CO_2 is not likely to be a serious problem in R-2000 houses, even with reduced ventilation rates. However, these source strengths are based on average CO_2 concentrations during a week of monitoring. CO_2 generation varies greatly, depending on the number of people in a given area of the house and their activity level, so many houses will probably have high levels of CO_2 for short periods.

To investigate the issue of high concentrations in specific times and places, we consider a master bedroom occupied by two people with the door closed. If the house has a direct-ducted, rather than recirculating, air supply, then according to the F326 standard, the master bedroom should be supplied with ten litres per second of fresh air which is 36.0 m^3/hr. Two people at low levels of activity will each generate around 0.17 L/sec of CO_2,[15] which is 37.3 g/hr for both of them. Thus, the concentration in the bedroom would be

$$\begin{aligned} C &= \frac{37{,}300\ \text{mg/hr}}{1.8296\ \text{mg/m}^3\text{-ppm x } 36.0\ \text{m}^3\text{/hr}} + 348\ \text{ppm} \\ &= 566\ \text{ppm} + 348\ \text{ppm} \\ &= 914\ \text{ppm} \end{aligned}$$

which is below the discomfort level of 1000 ppm. However, if the ventilation were reduced to 75% of the F326 level, or 27.0 m^3/hr, then the resulting concentration would be 1,100 ppm which is ten percent above the discomfort level. For this reason, we recommend that decreases in the R-2000 design ventilation rate be combined with more careful balancing of the supplies to individual rooms which would maintain ventilation in bedrooms at the current level.

IAQ-R2000 Master Bedroom Recirculation CO2 Model								
Number of occupants:		2						
CO2 gen/occupant:		0.17	L/min =	18.66	g/hr			
Total CO2 generation:				37.32	g/hr			
CO2 in indoor (recirc) air:								
	F326:	629	ppm					
	75% of F326:	723	ppm					
CO2 in fresh air:		348	ppm					
F326 Requirement					75% of F326 Requirement			
Outdoor air	Ventilation	CO2 Content of			Outdoor air	Ventilation	CO2 Content of	
in supply	required in	air supply	bedrm air		in supply	required in	air supply	bedrm air
air, %	MBedrm, L/s	(ppm)	(ppm)		air, %	MBedrm, L/s	(ppm)	(ppm)
0	20	629	910		0.00	20	723	1010
5	19	615	910		3.75	19	709	1010
10	18	601	920		7.50	18	695	1010
15	17	587	920		11.25	17	681	1010
20	17	573	910		15.00	17	667	1000
25	16	559	910		18.75	16	653	1010
30	15	545	920		22.50	15	639	1020
35	15	531	910		26.25	15	625	1000
40	14	517	920		30.00	14	611	1020
45	14	503	910		33.75	14	596	1000
50	13	489	920		37.50	13	582	1020
55	13	474	910		41.25	13	568	1000
60	13	460	900		45.00	13	554	990
65	12	446	920		48.75	12	540	1010
70	12	432	900		52.50	12	526	1000
75	11	418	930		56.25	11	512	1030
80	11	404	920		60.00	11	498	1010
85	11	390	910		63.75	11	484	1000
90	11	376	890		67.50	11	470	980
95	10	362	930		71.25	10	456	1020
100	10	348	910		75.00	10	442	1010
	Bedroom CO2 concentrations rounded to 10 ppm.							

Table 4. Calculation of CO_2 Concentrations in a Master Bedroom with Recirculating Air Supply, with F326 and 75% of F326 Ventilation Rates.

If the house ducting is recirculating, then the situation is more complex. In order to estimate the CO_2 concentration in the bedroom, it is first necessary to estimate the CO_2 content of the air in the rest of the house, since this is the recirculating air. Then the concentration of the air entering the bedroom depends on its ratio of fresh to recirculating air. We take a typical house of 641 m^3 with an F326 ventilation rate of 0.3 ACH or 192 m^3/hr. With an occupancy of three people, the

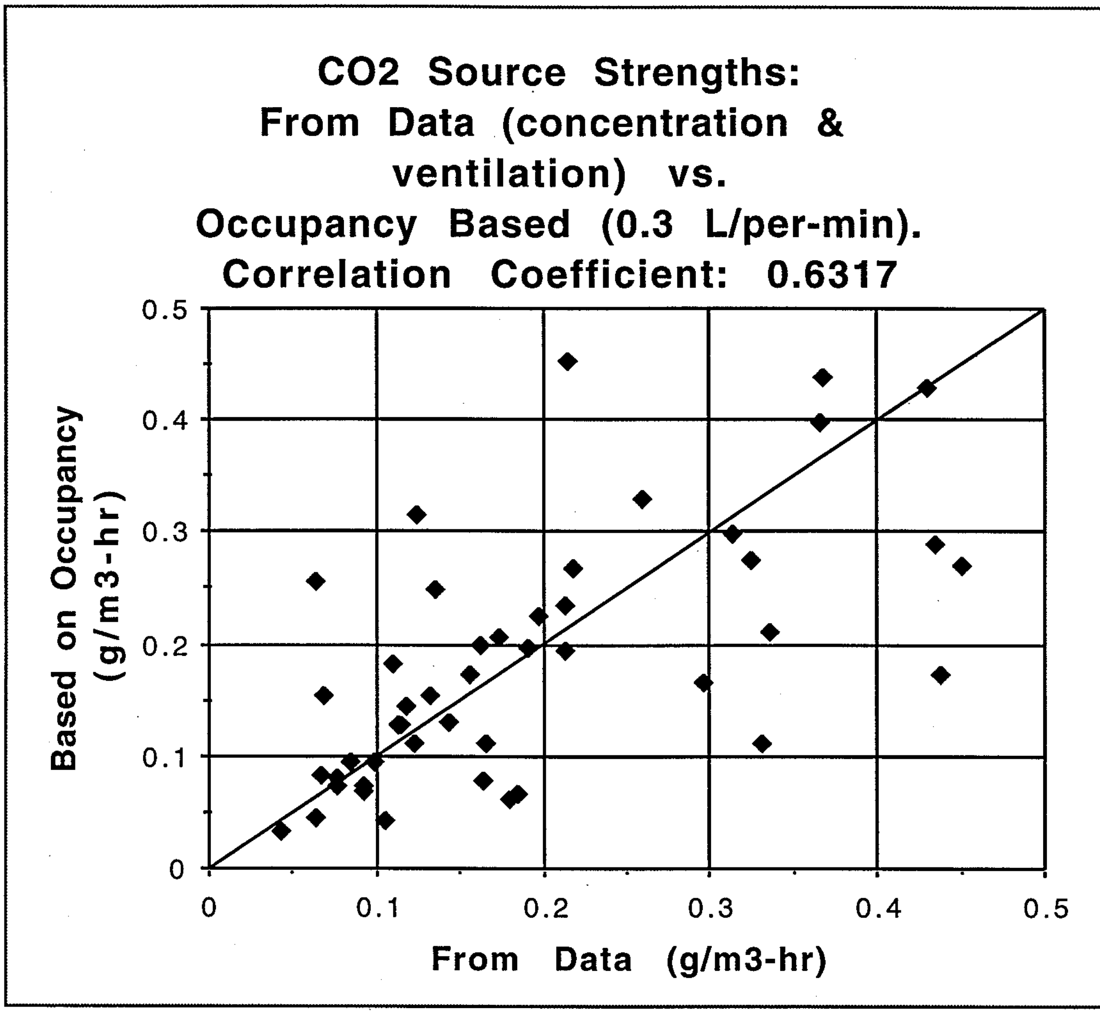

Figure 8. Correlation of CO_2 Source Strengths from Data and Occupancy Rates.

ventilation rate is 17.8 L/s per person which corresponds closely to the basis of the F326 standard. If each person's average CO_2 generation rate throughout the day is 0.3 L/min (see Ref. 15, and below), then the total generation is 98.8 g/hr, and the CO_2 content of the house air is 629 ppm. (Concentrations might be higher in the early stages of the night, and lower later on.) The F326 standard specifies a range of recirculating supply rates with a percentage of fresh air for each rate. These are shown in the first two columns of Table 4. The third column shows the CO_2 concentration of the air entering the bedroom, and the fourth column shows the resulting concentration of CO_2 in the bedroom. All values are below the discomfort level.

If the fresh air supply for the house were reduced to 75% of the F326 standard, then the CO_2 concentration in the house would rise to 723 ppm (close to the average of 748 ppm for houses in this report). If the percentage of fresh air in the bedroom's supply also drops to 75% of F326, then the results are shown in the last four columns of Table 4. Most are just over the discomfort level, but none exceed it by more than three percent. Thus, if ventilation rates are reduced to 75% of the F326 standard, extra care should be taken to ensure that bedrooms receive at least their share of the total ventilation in houses with recirculating air supplies.

Occupancy data were available for 46 of these houses. (Occupancy includes the number of people living in the house, and the average amount of time they spend at home.) Each person can be assumed to generate approximately 0.30 litres of CO_2 per minute,[15] which is 32.9 g/hr. (0.17 L/min was taken as low activity rate for the bedroom calculations, and 0.3 L/min as an average rate for all at-home activities.) Figure 8 shows the relationship between CO_2 source strengths calculated from concentrations and air change rates, and those based on occupancy. The correlation coefficient (r^2) is 0.6317 which seems reasonable considering the variables involved: Occupancy rates are estimates and will vary from day to day, other CO_2 sources such as pets, baking and wine and beer making are not accounted for, and neither are sinks such as house plants, or curing concrete. The 0.3 L/min-per which produces this correlation corresponds to "office work" (Ref. 15, p. 22).

RELATIVE HUMIDITY (RH)

Of the four IAQ factors in this report, relative humidity is the most difficult to evaluate for two reasons. First, it is difficult to obtain data on moisture source strengths. This requires monitoring of temperature and humidity both indoors and outdoors for a period of a week or more. If there are significant changes in outdoor humidity levels just before or during the monitoring period, the absorption or release of moisture by the house and its furnishing can affect the apparent source strength. Second, even given good data on source strengths, it is difficult to predict indoor RH levels because they are strongly affected by outdoor humidity levels which vary greatly during the heating season. Health Canada[9] recommends that RH be kept between 30% and 55% during the heating season. Long exposures to low RH may cause dryness of the skin and mucous membranes. High RH may cause increased sweating and loss of electrolytes, promote growth of moulds, fungi and mites which may cause allergies. High RH can also cause condensation on windows.

Data on source strengths were taken from two articles. The first was an earlier report by the authors[6] which was based on three sources of data: 1) the AQ200 data set, a *Survey of New Merchant Built Canadian Detached Houses* used to establish a baseline for comparison with R-2000 houses, 2) a report called the microbiological study which included older houses, and 3) hourly data on four R-2000 houses. The second study was excluded from this report because many of these older houses had exposed earth in their basements; this provides a source of moisture which is not found in R-2000 houses. This left a total of thirty houses. The second article[6] was a recent study of housing in Québec which included source strengths for seven houses. Figure 9 shows the distribution of source strengths for all thirty-seven houses. Since both low and high RH can affect IAQ, we have used the tenth and ninetieth percentile source strengths, rather than the fiftieth and ninetieth as with the other substances. The tenth percentile occurs in the fourth house, and is 0.19 g/m^3-hr. The ninetieth percentile occurs in the thirty-third house and is 0.86 g/m^3-hr. Figure I-4 in Appendix I compares the binned distribution of moisture source strengths with normal and log-normal distributions.

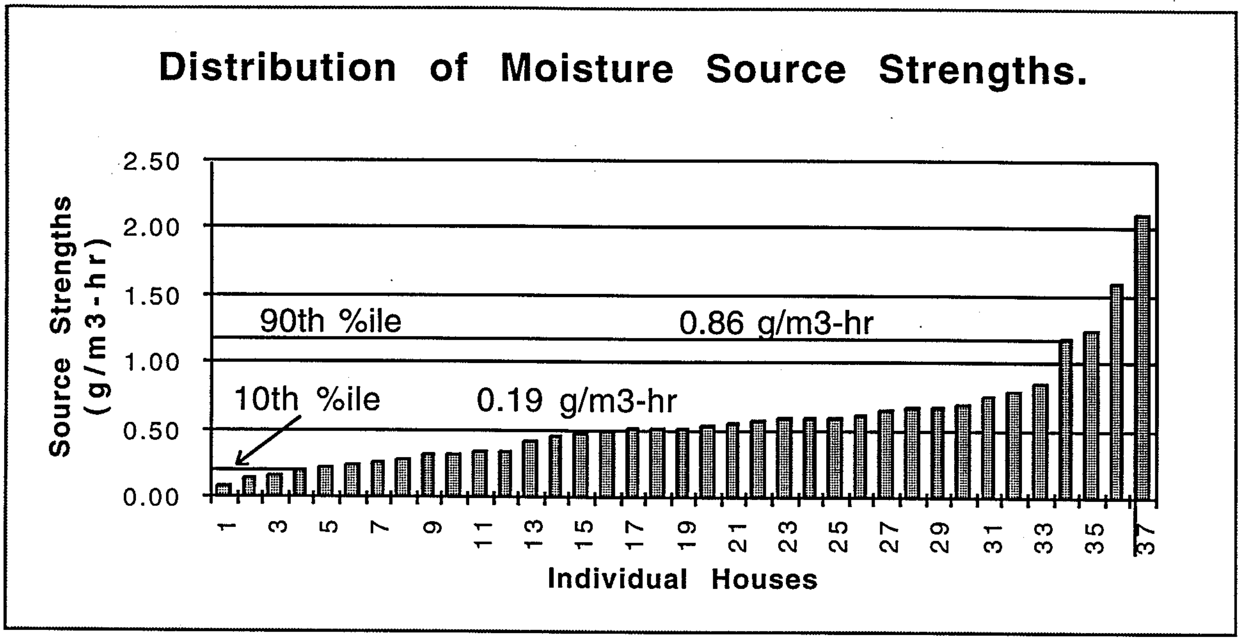

Figure 9: Distribution of Moisture Source Strengths with 90th and 50th Percentiles.

Conditions	T_d (°C)	T_w (°C)	RH (%)	W (kg_w/kg_a)	Source Strength %ile	% of houses outside Low Limit	% of houses outside High Limit	Range of RH (%)
Dry, Edmonton, Jan.	-16.1	-16.7	68	0.00062	10	100	0	6 - 12
					90	94 - 100	0	12 - 40
Medium Dry, Montreal, Jan.	-10.0	-10.6	81	0.00130	10	100	0	11 - 17
					90	85 - 100	0	11 - 45
Medium Moist, Montreal, Mar.	-2.4	-3.8	76	0.00230	10	100	0	18 - 24
					90	43 - 85	0	24 - 52
Moist, Vancouver, May	12.2	9.6	73	0.00630	10	0	0	46 - 52
					90	0	40 - 92	51 - 80

Table 5. Outdoor Conditions and Summary of resulting Indoor RH.

In order to investigate the results of these source strengths on indoor RH, it is necessary to select outdoor conditions. We chose four monthly average conditions of dry bulb temperature T_d and wet bulb temperature T_w from the HOT2000 weather files. These represent a range from very dry to very moist conditions, and are shown in Table 5. Indoor RH also depends on indoor T which is assumed to be 20 °C. Given outdoor mixing ratio W_e, ventilation rate ACH, and source strength S, one can calculate the indoor mixing ratio W_i as follows:

$$W_i = \frac{S}{ACH \times \rho \times 1000\ g_w/kg_w} + W_e$$

$$= \frac{S}{ACH * 1200} + W_e$$

where ρ is the density of air, 1.20 kg/m3.

RH can then be calculated as the vapour pressure of the indoor air e_i divided by its saturation vapour pressure e_s, while e_i is a function of W_i and air pressure P:

$$RH = e_i/e_s$$

and

$$e_i = \frac{P}{\varepsilon/W_i - 1}$$

where ε is the ratio of the molecular weights of water to air, 0.62198.

Thus,

$$RH = \frac{P}{\varepsilon\, e_s/W_i - 1}$$

$$\approx \frac{(P/\varepsilon)\, W_i}{e_s}$$

$$= W_i \times 162907 / e_s.$$

Substituting the above equation for W_i:

$$RH = \{W_e + (S / 1200)\}\ (162907 / e_s)$$

where W_e is given by the outdoor conditions, and e_s by the indoor T.

The results of combining outdoor conditions, percentile source strengths and ventilation rates in the forty-seven R-2000 houses are shown in Tables II-4 through II-7 (Appendix II), and summarized in Table 5. Under dry conditions, all combinations of source strengths and ventilation rates result in indoor RHs below the low limit of 30%, except for three cases; these three combine very low actual ventilation rates with the ninetieth percentile source strengths. With the low source strength, indoor RH varies from six to twelve percent. If the source strength were zero, then RH would be four percent in all cases. With the high source strength, RH varies from twelve to forty percent. At both the F326 ventilation rates and at the proposed reduced rates, all houses are below the low limit. This indicates that reducing ventilation rates will not solve problems of dryness under dry conditions.

Combining medium-dry conditions with the lower source strength results in RHs between eleven and seventeen percent, i.e., in all houses being below the low limit. With the higher source strength and F326 ventilation rates, all houses are still below the lower limit (RHs from sixteen to twenty-five percent). At the proposed ventilation rate, ninety-six percent of the houses are still below the lower limit. Thus, under medium dry conditions, reduced ventilation rates could relieve dry conditions, but only in around half a percent of all houses. When medium-moist conditions are combined with the low source strength, all houses are still below the low limit at all ventilation rates (RHs from eighteen to twenty-two percent). With the high source strengths, the percentage of houses below the low limit varies from twenty to forty (RHs from twenty-four to fifty-two percent). At the F326 ventilation rate, forty percent of the R-2000 houses are below the low limit, while at the proposed reduced rate, twenty-nine percent are below the limit. Thus, under medium-moist conditions, reduced ventilation rates might relieve dryness in around one percent of R-2000 houses. Results for these conditions are shown in Figure 10.

Under moist conditions and with the low source strength, all forty-seven of the R-2000 houses are within the limits of relative humidity (RHs between forty-six and fifty-two percent). At the higher source strength, between nineteen and forty-three percent of the houses are above the high limit. Their RHs vary between fifty-one and eighty percent, but excluding a few houses with very low actual ventilation rates, the highest RH is sixty-eight percent. As shown in Figure 11, the F326 rate results in nineteen percent of the R-2000 houses being above the upper limit, while the reduced rate increase this number to thirty-eight percent. This indicates that under moist conditions reducing the ventilation rate could cause increased moisture problems, but only in around two percent of all R-2000 houses.

Our conclusion is that reducing the R-2000 design ventilation rate will not have a significant effect on RH levels in R-2000 houses. The percentage of houses in which either RH limit would be affected by ventilation rates is very small. More importantly, occupants would still have the capacity and control to deal with damp or dry conditions in their homes. People can sense dry conditions directly by resulting dry skin, noses and throats, and can increase humidification or decrease ventilation accordingly. Similarly, damp conditions result in musty smells and condensation on windows, and people can respond with less humidification or more ventilation. In fact, this is often done automatically, since most HRVs are controlled by dehumidistats which switch to high ventilation rates when RH exceeds the occupant-selected set point. The high ventilation rate will still be at least the F326 standard, since it is not proposed that capacity be reduced. Thus, the question of whether to reduce the R-2000 design ventilation rate should be decided on the basis of the other IAQ factors.

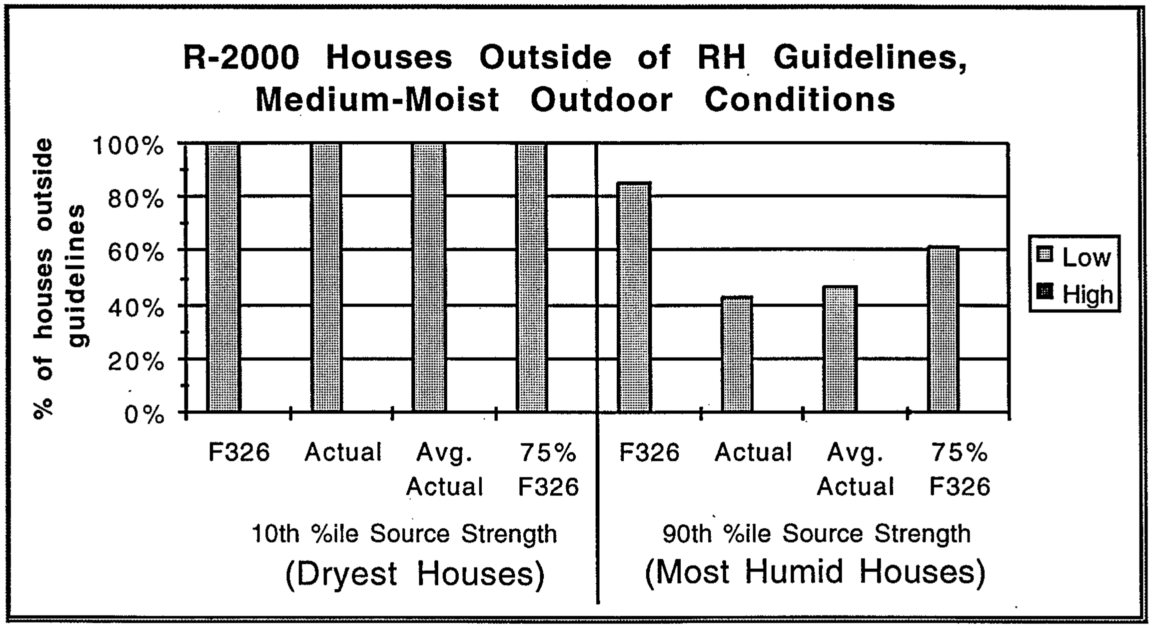

Figure 10. Houses which are outside the Low and High Limits for RH under Medium-Moist Conditions, by Source Strength and Total Ventilation Rates.

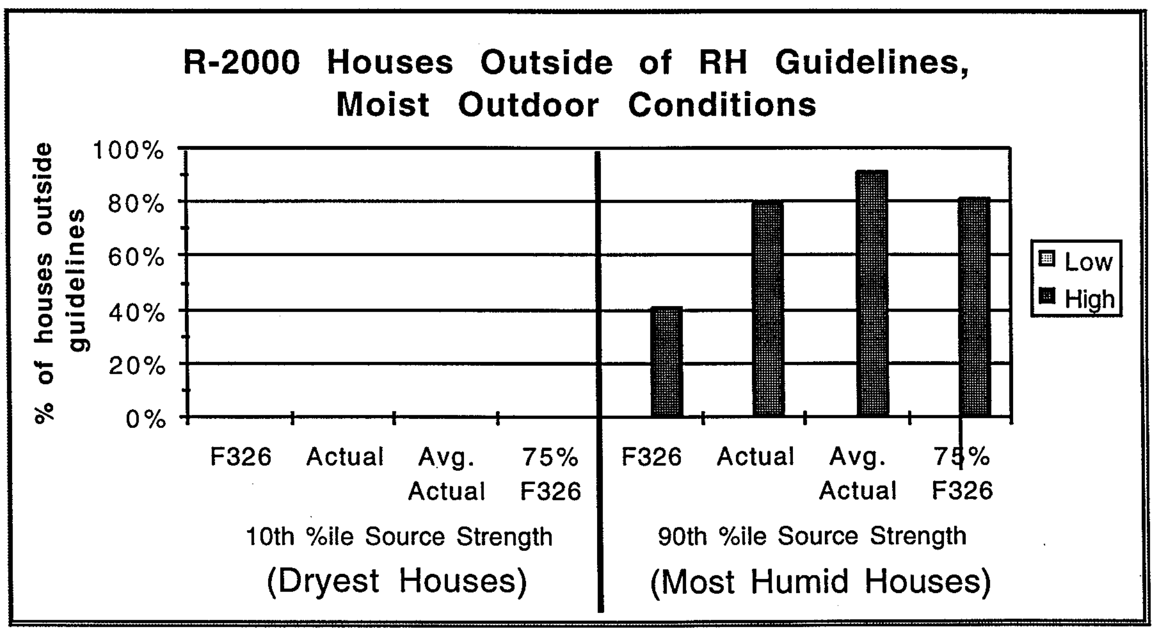

Figure 11. Houses which are outside the Low and High Limits for RH under Moist Conditions, by Source Strength and Total Ventilation Rates.

CONCLUSIONS & RECOMMENDATIONS

People in the R-2000 industry have proposed that the mechanical ventilation rates at which R-2000 houses can be certified should be reduced to 75% of the current F326 standard. Our data indicate that the proposed rate is very close to the actual average rate at which occupants run their HRVs. Thus, compared with the current situation, the proposed changes would have little effect on indoor air quality. In some cases, the proposed standard would appear to be an improvement over the actual practice, but this is due to a small number of houses which are operated at well below the proposed rates. In comparing the actual and proposed standards, our results indicate the following effects for the four IAQ substances investigated:

1. Formaldehyde (HCHO). The proposed standard would increase the number of R-2000 houses exceeding the Target guideline (which is also the average level) by around three percent. There is no indication that any R-2000 houses would exceed the Action guideline. Thus, the resulting increase in formaldehyde pollution would be small, and should be easy to prevent by stricter standards on formaldehyde emitting materials.

2. Total Volatile Organic Compounds (TVOCs). TVOCs appear to be the limiting factor. Even at the F326 standard, most R-2000 houses would exceed the No Effect level, and around nine percent would exceed the level of the average house. Reduced ventilation rates would increase these numbers by a few percent, probably leading to more "problem houses." Thus, decreased ventilation rates should definitely be accompanied by decreases in VOC emitting materials.

3. Carbon Dioxide (CO_2). The average levels of CO_2 in R-2000 houses would not be significantly affected by the proposed reductions in ventilation. However, levels in closed bedrooms could go above the Discomfort level. For this reason, reductions should be accompanied by better balancing of flows which maintain current standards of flows to bedrooms. This is most critical in houses in which fresh air is direct-ducted, but should also be done in those with recirculating supplies.

4. Relative Humidity (RH). Relative humidity is not relevant to the question of reduced ventilation rates. Reduced rates would relieve dryness in a small number of cases, but they would also worsen dampness in a similar number. Occupants can sense dry or damp conditions and take appropriate actions.

Our recommendation is to accept the proposed reduction in ventilation rates as part of an optional package. This would allow R-2000 houses to be built either to current standards, or to the new standards which would include *all* of the following:

1. The capacity of the mechanical ventilation systems in R-2000 houses shall be maintained at the current F326 standard.

2. The mechanical ventilation rate at which R-2000 houses can be certified to meet their energy targets may be reduced to seventy-five percent (75%) of the current F326 standard, but no lower.

3. Additional restrictions shall be placed on the construction materials allowed within the air, or air/vapour, barrier of the houses. These restrictions shall include all (rather than two) of the options in the current "environmental pick list", and the following additions to that list:

    (i) Carpeting (except as noted) shall be labelled under the Carpet and Rug Institute's program.

    (vii) Homogeneous vinyl flooring shall not be used. Linoleum or composite type vinyl tiles can be used.

    (viii) Particle board flooring underlayment shall not be used unless all exposed surfaces are sealed with an Environmental Choice water based sealer or another low toxicity sealer.

4. Air flows to bedrooms shall be more carefully balanced, and maintained at the current F326 levels.

5. An extensive monitoring program be undertaken to determine the IAQ of a number of houses built in accordance with the reduced ventilation package. This program would include tests of IAQ and air change rates, and emissions tests of various materials used in the houses, at construction, occupancy and six months after occupancy.

High indoor air quality is an essential part of the R-2000 program. We believe that the proposed package would maintain or improve IAQ in R-2000 houses while allowing them to meet their energy targets more cost-effectively. The monitoring program would provide information which would allow further improvements in future standards.

APPENDIX I

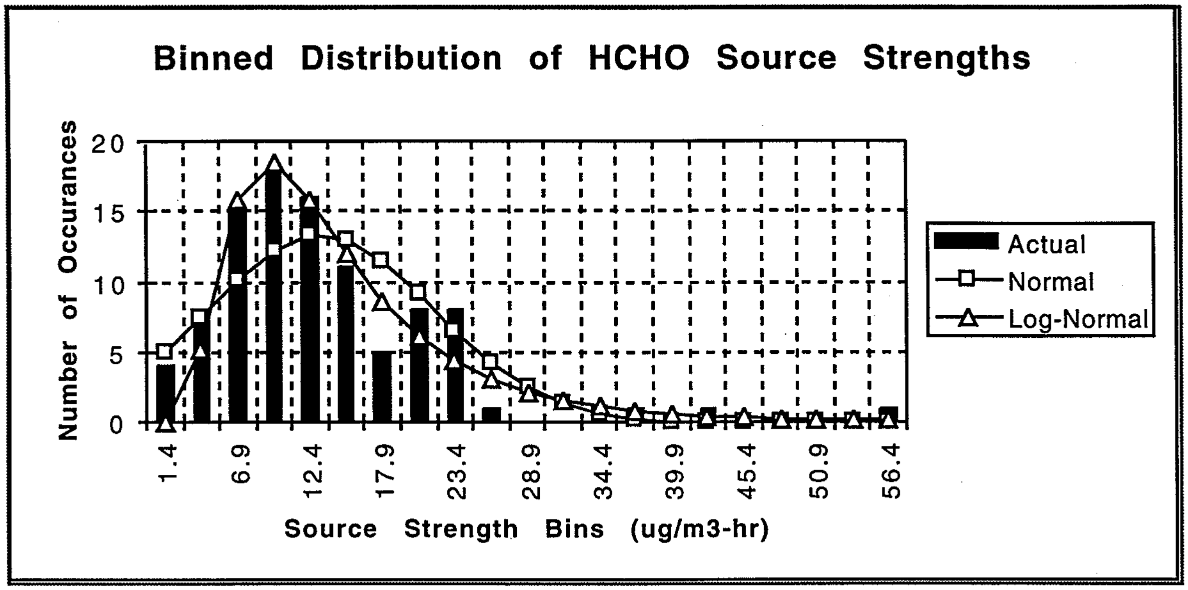

Figure I-1. Binned Distribution of HCHO Source Strengths with Normal & Log-Normal Distributions.

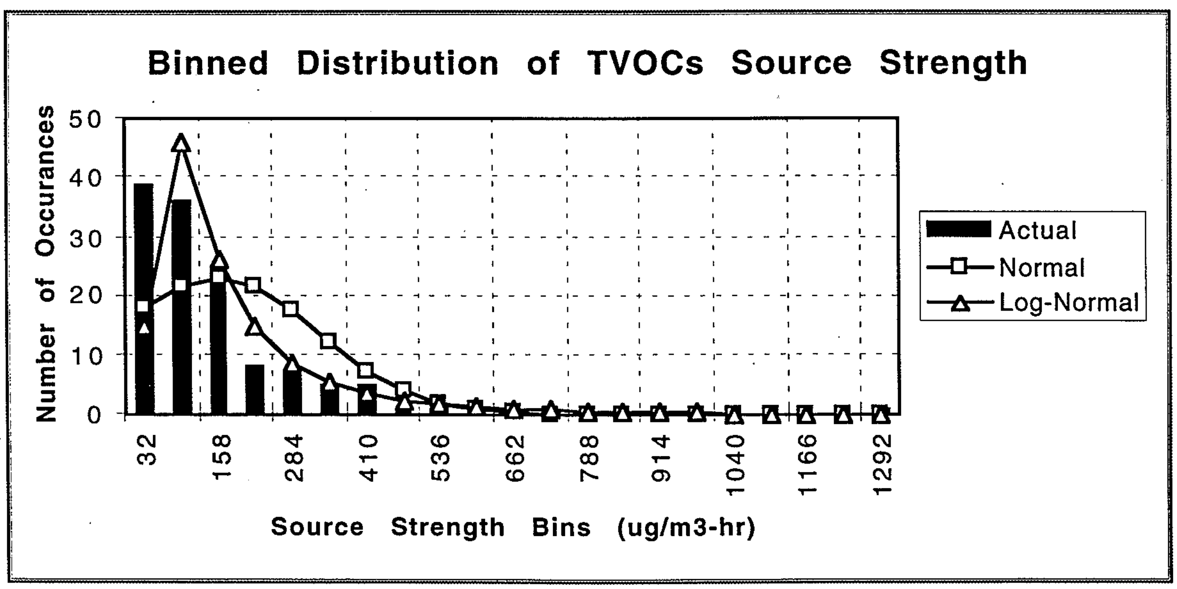

Figure I-2. Binned Distribution of TVOCs Source Strengths with Normal & Log-Normal Distributions.

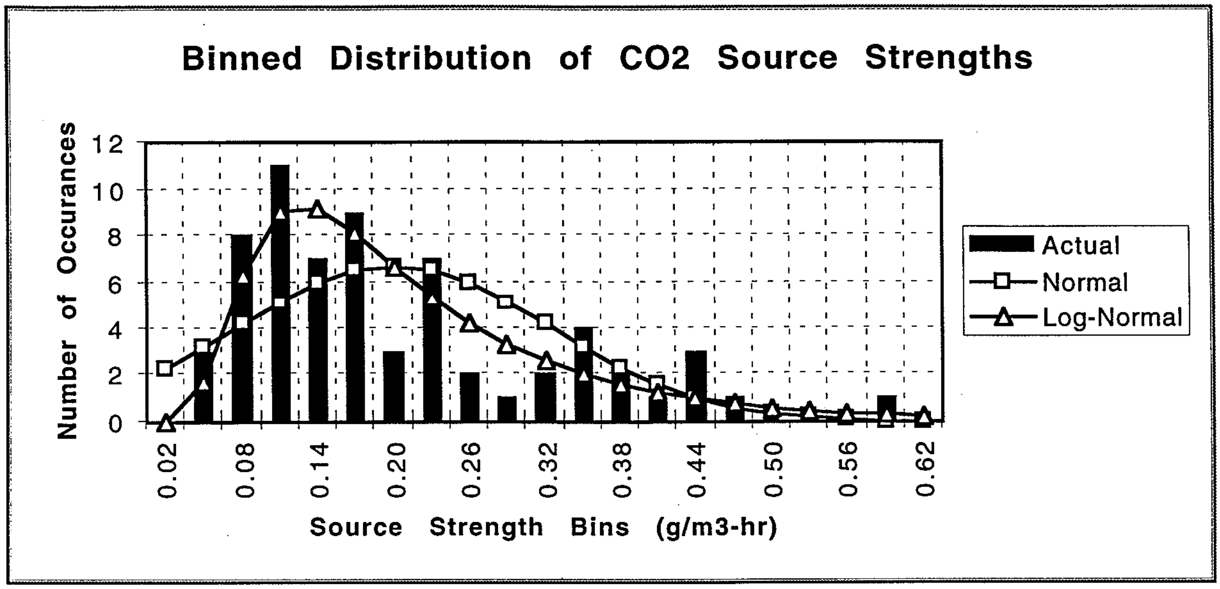

Figure I-3. Binned Distribution of CO_2 Source Strengths with Normal & Log-Normal Distributions.

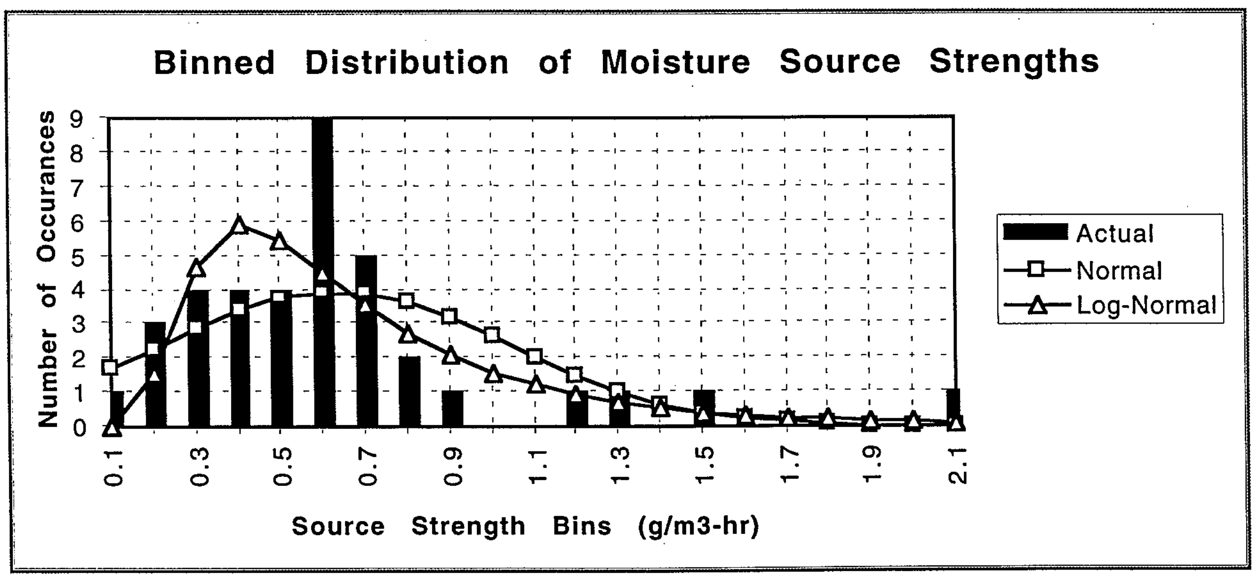

Figure I-4. Binned Distribution of Moisture Source Strengths with Normal & Log-Normal Distributions.

APPENDIX II

IAQ-R2000-Exposures

Calculations of exposure levels to formaldehyde (HCHO) based on percentile source strengths from the spreadsheet IAQ-R2000-HCHO.
- John Gusdorf, NRCan, 13 July, 1995

These results based on total ventilation, i.e., mechanical plus natural ventilation as calulated by AUDIT2OOO.

Source Strengths ($\mu g/m^3$-hr)		Short-Term Exposure Limits ($\mu g/m^3$)	
50th %ile:	11.4	Target:	60
90th %ile:	22.8	Action:	120

VENTILATION RATES & RESULTING EXPOSURES IN R-2000 HOUSES:

	Ventilation Rates (ACH)					HCHO Exposure Levels ($\mu g/m^3$) with Total Ventilation							
	Mechanical		Total (AUDIT2000)			50th %ile Source Strength				90th %ile Source Strength			
HOUSE	F-326	Actual	F-326	Actual	75% of F-326	F-326	Actual	Avg of Act/F326	75% of F-326	F-326	Actual	Avg of Act/F326	75% of F-326
AB-R1	0.30	0.23	0.49	0.43	0.42	23	27	30	27	46	53	60 t	54
AB-R2	0.36	0.36	0.47	0.47	0.38	24	24	32	30	49	49	64 t	60
AB-R3	0.37	0.26	0.44	0.33	0.35	26	35	34	33	51	69 t	67 t	65 t
AB-R4	0.30	0.16	0.43	0.30	0.36	26	38	35	32	53	77 t	69 t	64 t
AB-R5	0.30	0.26	0.38	0.34	0.31	30	33	39	37	60	66 t	78 t	74 t
AB-R6	0.32	0.26	0.44	0.39	0.36	26	30	34	32	51	59	67 t	63 t
AB-R7	0.30	0.26	0.42	0.37	0.34	27	31	36	33	55	61 t	72 t	67 t
AB-R8	0.30	0.17	0.44	0.31	0.36	26	37	34	32	52	73 t	69 t	63 t
AB-R9	0.34	0.28	0.46	0.40	0.37	25	29	33	31	50	57	66 t	61 t
AB-R10	0.41	0.28	0.54	0.42	0.44	21	28	28	26	42	55	55	52
ON-ER1	0.34	0.36	0.55	0.39	0.47	21	29	27	25	41	59	54	49
ON-ER2	0.38	0.16	0.46	0.24	0.37	25	47	32	31	49	94 t	64 t	62 t
ON-ER3	0.30	0.08	0.47	0.24	0.39	24	47	32	29	49	93 t	64 t	58
ON-ER4	0.42	0.28	0.50	0.35	0.39	23	32	30	29	46	64 t	60 t	58
ON-SR1	0.30	0.13	0.31	0.14	0.24	37	82 t	48	48	73 t	163 A	96 t	96 t
ON-SR2	0.32	0.21	0.39	0.28	0.31	29	40	38	37	58	81 t	77 t	74 t
ON-SR3	0.33	0.13	0.53	0.33	0.45	22	35	28	26	43	69 t	57	51
ON-SR4	0.30	0.12	0.34	0.16	0.27	33	70 t	44	43	66 t	140 A	87 t	85 t
ON-BR1	0.32	0.23	0.37	0.27	0.29	31	42	41	40	62 t	84 t	82 t	80 t
ON-BR2	0.36	0.17	0.46	0.27	0.37	25	42	32	31	49	84 t	64 t	61 t
ON-BR3	0.32	0.15	0.35	0.18	0.27	32	63 t	42	42	64 t	126 A	84 t	83 t
ON-BR4	0.24	0.22	0.33	0.31	0.27	35	37	46	43	69 t	74 t	91 t	85 t
ON-BR5	0.23	0.18	0.27	0.22	0.21	43	52	56	55	85 t	103 t	111 t	109 t
NS101	0.30	0.19	0.50	0.39	0.43	23	29	30	27	45	58	59	53
NS102	0.50	0.5	0.65	0.65	0.53	17	17	23	22	35	35	46	43
NS103	0.36	0.12	0.51	0.28	0.42	22	41	29	27	44	82 t	58	54
NS104	0.44	0.31	0.50	0.38	0.40	23	30	30	29	45	61 t	59	58
NS105	0.39	0.36	0.54	0.51	0.45	21	22	28	26	42	45	55	51
NS106	0.30	0.28	0.41	0.39	0.34	28	29	37	34	55	59	73 t	68 t
NS115	0.30	0.38	0.50	0.58	0.42	23	20	30	27	46	39	60	54
NS117	0.32	0.20	0.58	0.47	0.50	20	24	26	23	39	49	51	45
NS118	0.51	0.51	0.68	0.68	0.55	17	17	22	21	33	33	44	41
NS122	0.50	0.51	0.64	0.65	0.52	18	18	23	22	36	35	47	44
NB-R1	0.42	0.27	0.50	0.35	0.40	23	33	30	29	46	65 t	60	58
NB-R2	0.35	0.20	0.38	0.23	0.30	30	50	39	39	59	100 t	78 t	77 t
NB-R3	0.37	0.34	0.56	0.53	0.46	21	22	27	25	41	43	54	49
NB-R4	0.37	0.28	0.55	0.45	0.45	21	25	27	25	42	51	55	50
NB-R5	0.51	0.42	0.60	0.51	0.48	19	22	25	24	38	44	49	48
NB-R6	0.39	0.25	0.48	0.34	0.38	24	34	31	30	47	67 t	62 t	60
NRC51	0.30	0.16	0.36	0.22	0.28	32	52	42	40	63 t	103 t	83 t	80 t
NRC52	0.30	0.15	0.49	0.33	0.41	23	34	31	28	47	69 t	61 t	55
NRC53	0.30	0.24	0.58	0.52	0.51	20	22	26	23	39	44	51	45
NRC54	0.36	0.24	0.47	0.35	0.38	25	33	32	30	49	66 t	64 t	61 t
NRC57	0.39	0.20	0.54	0.34	0.44	21	34	28	26	42	67 t	56	52
NRC60	0.34	0.25	0.40	0.31	0.31	29	37	38	37	58	74 t	76 t	74 t
NRC61	0.30	0.17	0.36	0.24	0.29	32	48	42	39	64 t	96 t	84 t	78 t
NRC62	0.30	0.15	0.43	0.28	0.39	26	41	35	29	53	82 t	69 t	58

Ratios of Total Ventilation Rates:	
Average of Actual/F326:	76%
Minimum of Actual/F326:	45%

t means exceeds the target level.
A means exceeds the action level.

Table II-1: Spreadsheet to calculate HCHO concentrations.

IAQ-R2000-Exposures
Calculations of exposure levels to TVOCs based on percentile source strengths from the spreadsheet IAQ-R2000-TVOC.
- John Gusdorf, NRCan, 13 July, 1995

These results based on total ventilation, i.e., mechanical plus natural ventilation as calulated by AUDIT2OOO.

Source Strengths (µg/m³-hr)		Exposure Limits (µg/m³)	
50th %ile:	118	No effect:	200
90th %ile:	352	Average House:	585
		Short-term:	3000

VENTILATION RATES & RESULTING EXPOSURES IN R-2000 HOUSES:

HOUSE	Ventilation Rates (ACH) Mechanical F-326	Mechanical Actual	Total (AUDIT2000) F-326	Total Actual	Total 75% of F-326	TVOC Exposure Levels (µg/m³) with Total Ventilation: 50th %ile Source Strength F-326		Actual		Avg of Act/F326		75% of F-326		90th %ile Source Strength F-326		Actual		Avg of Act/F326		75% of F-326	
AB-R1	0.30	0.23	0.49	0.43	0.42	239	n	277	n	315	n	282	n	714	A	826	A	939	A	842	A
AB-R2	0.36	0.36	0.47	0.47	0.38	252	n	252	n	332	n	309	n	752	A	752	A	990	A	921	A
AB-R3	0.37	0.26	0.44	0.33	0.35	267	n	358	n	351	n	337	n	796	A	1067	A	1048	A	1006	A
AB-R4	0.30	0.16	0.43	0.30	0.36	273	n	397	n	359	n	330	n	813	A	1185	A	1070	A	983	A
AB-R5	0.30	0.26	0.38	0.34	0.31	309	n	343	n	406	n	384	n	921	A	1023	A	1212	A	1147	A
AB-R6	0.32	0.26	0.44	0.39	0.36	266	n	306	n	350	n	326	n	795	A	912	A	1046	A	972	A
AB-R7	0.30	0.26	0.42	0.37	0.34	284	n	317	n	373	n	346	n	846	A	946	A	1113	A	1032	A
AB-R8	0.30	0.17	0.44	0.31	0.36	271	n	381	n	357	n	328	n	809	A	1135	A	1065	A	978	A
AB-R9	0.34	0.28	0.46	0.40	0.37	259	n	297	n	341	n	319	n	774	A	887	A	1018	A	951	A
AB-R10	0.41	0.28	0.54	0.42	0.44	218	n	284	n	287	n	269	n	651	A	848	A	856	A	802	A
ON-ER1	0.34	0.36	0.55	0.39	0.47	215	n	304	n	282	n	253	n	640	A	907	A	842	A	755	A
ON-ER2	0.38	0.16	0.46	0.24	0.37	254	n	490	n	335	n	320	n	759	A	1461	A	998	A	954	A
ON-ER3	0.30	0.08	0.47	0.24	0.39	252	n	484	n	332	n	300	n	752	A	1443	A	990	A	896	A
ON-ER4	0.42	0.28	0.50	0.35	0.39	237	n	333	n	312	n	302	n	708	A	994	A	932	A	900	A
ON-SR1	0.30	0.13	0.31	0.14	0.24	379	n	843	A	499	n	500	n	1132	A	2514	A	1489	A	1492	A
ON-SR2	0.32	0.21	0.39	0.28	0.31	303	n	418	n	399	n	382	n	905	A	1248	A	1191	A	1139	A
ON-SR3	0.33	0.13	0.53	0.33	0.45	224	n	359	n	295	n	265	n	668	A	1070	A	879	A	791	A
ON-SR4	0.30	0.12	0.34	0.16	0.27	343	n	728	A	451	n	440	n	1023	A	2173	A	1346	A	1313	A
ON-BR1	0.32	0.23	0.37	0.27	0.29	323	n	434	n	425	n	413	n	964	A	1294	A	1269	A	1231	A
ON-BR2	0.36	0.17	0.46	0.27	0.37	254	n	437	n	335	n	316	n	759	A	1304	A	998	A	941	A
ON-BR3	0.32	0.15	0.35	0.18	0.27	333	n	656	A	439	n	431	n	994	A	1956	A	1308	A	1285	A
ON-BR4	0.24	0.22	0.33	0.31	0.27	360	n	382	n	473	n	440	n	1073	A	1139	A	1412	A	1313	A
ON-BR5	0.23	0.18	0.27	0.22	0.21	440	n	534	n	579	n	565	n	1313	A	1593	A	1728	A	1684	A
NS101	0.30	0.19	0.50	0.39	0.43	235	n	303	n	309	n	277	n	701	A	905	A	923	A	826	A
NS102	0.50	0.50	0.65	0.65	0.53	181		181		238	n	223	n	539	n	539	n	709	A	667	A
NS103	0.36	0.12	0.51	0.28	0.42	230	n	426	n	302	n	278	n	685	A	1271	A	901	A	830	A
NS104	0.44	0.31	0.50	0.38	0.40	234	n	314	n	308	n	299	n	698	A	936	A	919	A	891	A
NS105	0.39	0.36	0.54	0.51	0.45	217	n	231	n	285	n	264	n	647	A	689	A	851	A	787	A
NS106	0.30	0.28	0.41	0.39	0.34	288	n	304	n	379	n	352	n	859	A	907	A	1130	A	1051	A
NS115	0.30	0.38	0.50	0.58	0.42	236	n	203	n	311	n	278	n	705	A	605	A	928	A	830	A
NS117	0.32	0.20	0.58	0.47	0.50	202	n	253	n	266	n	235	n	603	A	754	A	793	A	700	A
NS118	0.51	0.51	0.68	0.68	0.55	173		173		227	n	213	n	515	n	515	n	678	A	635	A
NS122	0.50	0.51	0.64	0.65	0.52	184		182		243	n	229	n	550	n	543	n	724	A	682	A
NB-R1	0.42	0.27	0.50	0.35	0.40	236	n	336	n	311	n	299	n	704	A	1003	A	926	A	891	A
NB-R2	0.35	0.20	0.38	0.23	0.30	308	n	520	n	405	n	400	n	919	A	1551	A	1209	A	1193	A
NB-R3	0.37	0.34	0.56	0.53	0.46	212	n	223	n	279	n	254	n	632	A	665	A	832	A	759	A
NB-R4	0.37	0.28	0.55	0.45	0.45	216	n	262	n	284	n	261	n	645	A	782	A	848	A	779	A
NB-R5	0.51	0.42	0.60	0.51	0.48	195		230	n	257	n	248	n	583	n	685	A	767	A	739	A
NB-R6	0.39	0.25	0.48	0.34	0.38	246	n	349	n	324	n	310	n	735	A	1041	A	967	A	924	A
NRC51	0.30	0.16	0.36	0.22	0.28	328	n	536	n	431	n	415	n	978	A	1600	A	1287	A	1239	A
NRC52	0.30	0.15	0.49	0.33	0.41	242	n	355	n	318	n	286	n	721	A	1060	A	949	A	852	A
NRC53	0.30	0.24	0.58	0.52	0.51	203	n	226	n	267	n	233	n	606	A	676	A	797	A	696	A
NRC54	0.36	0.24	0.47	0.35	0.38	254	n	341	n	334	n	315	n	757	A	1017	A	996	A	939	A
NRC57	0.39	0.20	0.54	0.34	0.44	220	n	347	n	290	n	269	n	657	A	1035	A	864	A	804	A
NRC60	0.34	0.25	0.40	0.31	0.31	299	n	384	n	393	n	382	n	891	A	1147	A	1173	A	1139	A
NRC61	0.30	0.17	0.36	0.24	0.29	331	n	498	n	436	n	407	n	989	A	1485	A	1301	A	1214	A
NRC62	0.30	0.15	0.43	0.28	0.39	274	n	424	n	360	n	303	n	817	A	1266	A	1075	A	905	A

Ratios of Total Ventilation Rates:	
Average of Actual/F326:	76%
Minimum of Actual/F326:	45%

n means exceeds the No-Effect Level.
A means exceeds the level of the average house.
X means exceeds the short-term exposure limits.

Table II-2: Spreadsheet to calculate TVOCs concentrations.

IAQ-R2000-Exposures

Calculations of exposure levels to CO_2 based on percentile source strengths from the spreadsheet IAQ-R2000-C02.
- John Gusdorf, NRCan, 14 July, 1995

These results based on total ventilation, i.e., mechanical plus natural ventilation as calulated by AUDIT2OOO.

Source Strengths (g/m^3-hr)		Short-Term Exposure Limits (ppm)	
50th %ile:	0.158	Study Average:	748
90th %ile:	0.369	Discomfort:	1000
		Long-term:	3500

VENTILATION RATES & RESULTING EXPOSURES IN R-2000 HOUSES:

	Ventilation Rates (ACH)					CO_2 Exposure Levels (ppm) with Total Ventilation							
	Mechanical		Total (AUDIT2000)			50th %ile Source Strength				90th %ile Source Strength			
HOUSE	F-326	Actual	F-326	Actual	75% of F-326	F-326	Actual	Avg of Act/F326	75% of F-326	F-326	Actual	Avg of Act/F326	75% of F-326
AB-R1	0.30	0.23	0.49	0.43	0.42	523	551	578	555	757 a	821 a	886 a	830 a
AB-R2	0.36	0.36	0.47	0.47	0.38	532	532	591	574	779 a	779 a	915 a	876 a
AB-R3	0.37	0.26	0.44	0.33	0.35	543	610	605	595	804 a	959 a	948 a	924 a
AB-R4	0.30	0.16	0.43	0.30	0.36	547	639	610	589	814 a	1027 d	961 a	911 a
AB-R5	0.30	0.26	0.38	0.34	0.31	574	599	645	629	876 a	934 a	1043 d	1005 d
AB-R6	0.32	0.26	0.44	0.39	0.36	543	572	604	587	803 a	870 a	947 a	905 a
AB-R7	0.30	0.26	0.42	0.37	0.34	556	580	621	601	833 a	890 a	986 a	939 a
AB-R8	0.30	0.17	0.44	0.31	0.36	546	627	609	588	812 a	998 a	958 a	908 a
AB-R9	0.34	0.28	0.46	0.40	0.37	538	565	598	581	791 a	856 a	931 a	893 a
AB-R10	0.41	0.28	0.54	0.42	0.44	508	556	558	545	721	834 a	838 a	807 a
AB-R10	0.41	0.28	0.54	0.42	0.44	508	556	558	545	721	834 a	838 a	807 a
ON-ER1	0.34	0.36	0.55	0.39	0.47	505	571	555	533	715	868 a	830 a	781 a
ON-ER2	0.38	0.16	0.46	0.24	0.37	534	706	593	582	783 a	1185 d	920 a	894 a
ON-ER3	0.30	0.08	0.47	0.24	0.39	532	702	591	568	779 a	1174 d	915 a	861 a
ON-ER4	0.42	0.28	0.50	0.35	0.39	522	592	577	569	754 a	918 a	882 a	864 a
ON-SR1	0.30	0.13	0.31	0.14	0.24	626	965 a	713	714	996 a	1788 d	1201 d	1202 d
ON-SR2	0.32	0.21	0.39	0.28	0.31	570	654	640	627	866 a	1063 d	1030 d	1001 d
ON-SR3	0.33	0.13	0.53	0.33	0.45	512	610	564	542	731	961 a	851 a	801 a
ON-SR4	0.30	0.12	0.34	0.16	0.27	599	881 a	678	670	934 a	1593 d	1119 d	1100 d
ON-BR1	0.32	0.23	0.37	0.27	0.29	585	665	659	650	900 a	1089 d	1075 d	1053 d
ON-BR2	0.36	0.17	0.46	0.27	0.37	534	668	593	579	783 a	1095 d	920 a	887 a
ON-BR3	0.32	0.15	0.35	0.18	0.27	592	828 a	669	663	918 a	1468 d	1097 d	1084 d
ON-BR4	0.24	0.22	0.33	0.31	0.27	611	627	694	670	963 a	1001 d	1157 d	1100 d
ON-BR5	0.23	0.18	0.27	0.22	0.21	670	739	772 a	761 a	1100 d	1260 d	1338 d	1313 d
NS101	0.30	0.19	0.50	0.39	0.43	520	570	574	551	750 a	866 a	877 a	821 a
NS102	0.50	0.5	0.65	0.65	0.53	480	480	522	512	657	657	754 a	730
NS103	0.36	0.12	0.51	0.28	0.42	516	660	569	552	740	1076 d	864 a	824 a
NS104	0.44	0.31	0.50	0.38	0.40	519	578	573	567	748 a	884 a	874 a	858 a
NS105	0.39	0.36	0.54	0.51	0.45	507	517	557	541	719	743	836 a	799 a
NS106	0.30	0.28	0.41	0.39	0.34	559	571	625	606	840 a	868 a	995 a	950 a
NS115	0.30	0.38	0.50	0.58	0.42	521	496	576	552	752 a	694	880 a	824 a
NS117	0.32	0.20	0.58	0.47	0.50	496	533	543	520	693	780 a	802 a	749 a
NS118	0.51	0.51	0.68	0.68	0.55	474	474	514	504	643	643	736	712
NS122	0.50	0.51	0.64	0.65	0.52	483	481	526	515	663	659	763 a	739
NB-R1	0.42	0.27	0.50	0.35	0.40	521	594	575	567	751 a	922 a	879 a	858 a
NB-R2	0.35	0.20	0.38	0.23	0.30	573	728	645	641	874 a	1236 d	1041 d	1032 d
NB-R3	0.37	0.34	0.56	0.53	0.46	503	511	552	534	710	729	824 a	783 a
NB-R4	0.37	0.28	0.55	0.45	0.45	506	540	556	539	717	796 a	834 a	794 a
NB-R5	0.51	0.42	0.60	0.51	0.48	491	516	536	529	682	740	787 a	772 a
NB-R6	0.39	0.25	0.48	0.34	0.38	528	603	585	575	769 a	945 a	902 a	877 a
NRC52	0.30	0.15	0.49	0.33	0.41	525	608	581	557	761 a	955 a	892 a	836 a
NRC53	0.30	0.24	0.58	0.52	0.51	497	514	544	519	695	735	805 a	746
NRC54	0.36	0.24	0.47	0.35	0.38	534	598	592	578	782 a	931 a	919 a	886 a
NRC57	0.39	0.20	0.54	0.34	0.44	509	602	560	545	724	941 a	843 a	808 a
NRC60	0.34	0.25	0.40	0.31	0.31	567	629	636	627	858 a	1005 d	1020 d	1001 d
NRC61	0.30	0.17	0.36	0.24	0.29	591	712	667	646	914 a	1199 d	1093 d	1043 d
NRC62	0.30	0.15	0.43	0.28	0.39	548	659	612	570	816 a	1073 d	964 a	866 a

Ratios of Total Ventilation Rates:	
Average of Actual/F326:	76%
Minimum of Actual/F326:	45%

a means exceeds the level of the average house.
d means exceeds the discomfort level.
L means exceeds the long-term level.

Table II-3. Spreadsheet to calculate CO_2 concentrations.

IAQ-R2000-Exposures to RH
Calculations of "exposure levels" to Relative Humidity (ø) based on percentile source strengths from the spreadsheet IAQ-R2000-RH.
- John Gusdorf, NRCan, 18 July, 1995

These results based on total ventilation, i.e., mechanical plus natural ventilation as calulated by AUDIT2000.

Source Strengths (g/m^3-hr)		Relative Humidity Limits:	
10th %ile:	0.190	Low:	30%
90th %ile:	0.860	High:	55%

Conditions: Dry, Edmonton, January.

	T (C)	ø (%)	e_s (Pa)	W (kg/kg)
Outdoor:	-16.1	68%	149	.0006
Indoor:	20.0	-	2339	-

VENTILATION RATES & RESULTING EXPOSURES IN R-2000 HOUSES:

HOUSE	Ventilation Rates (ACH): Mechanical F-326	Mechanical Actual	Total (AUDIT2000) F-326	Total Actual	Total 75% of F-326	RH 10th %ile Source Strength: F-326	10th Actual	10th Avg of Act/F326	10th 75% of F-326	RH 90th %ile Source Strength: F-326	90th Actual	90th Avg of Act/F326	90th 75% of F-326
AB-R1	0.30	0.23	0.49	0.43	0.42	7% L	7% L	7% L	7% L	14% L	16% L	18% L	16% L
AB-R2	0.36	0.36	0.47	0.47	0.38	7% L	7% L	7% L	7% L	15% L	15% L	18% L	17% L
AB-R3	0.37	0.26	0.44	0.33	0.35	7% L	8% L	8% L	7% L	16% L	19% L	19% L	19% L
AB-R4	0.30	0.16	0.43	0.30	0.36	7% L	8% L	8% L	7% L	16% L	21% L	20% L	18% L
AB-R5	0.30	0.26	0.38	0.34	0.31	7% L	8% L	8% L	8% L	17% L	19% L	22% L	21% L
AB-R6	0.32	0.26	0.44	0.39	0.36	7% L	7% L	8% L	7% L	16% L	17% L	19% L	18% L
AB-R7	0.30	0.26	0.42	0.37	0.34	7% L	7% L	8% L	8% L	16% L	18% L	20% L	19% L
AB-R8	0.30	0.17	0.44	0.31	0.36	7% L	8% L	8% L	7% L	16% L	20% L	19% L	18% L
AB-R9	0.34	0.28	0.46	0.40	0.37	7% L	7% L	8% L	7% L	15% L	17% L	19% L	18% L
AB-R10	0.41	0.28	0.54	0.42	0.44	6% L	7% L	7% L	7% L	14% L	16% L	16% L	16% L
ON-ER1	0.34	0.36	0.55	0.39	0.47	6% L	7% L	7% L	7% L	13% L	17% L	16% L	15% L
ON-ER2	0.38	0.16	0.46	0.24	0.37	7% L	9% L	7% L	7% L	15% L	25% L	18% L	18% L
ON-ER3	0.30	0.08	0.47	0.24	0.39	7% L	9% L	7% L	7% L	15% L	25% L	18% L	17% L
ON-ER4	0.42	0.28	0.50	0.35	0.39	7% L	7% L	7% L	7% L	14% L	18% L	18% L	17% L
ON-SR1	0.30	0.13	0.31	0.14	0.24	8% L	12% L	9% L	9% L	20% L	40%	25% L	25% L
ON-SR2	0.32	0.21	0.39	0.28	0.31	7% L	8% L	8% L	8% L	17% L	22% L	21% L	20% L
ON-SR3	0.33	0.13	0.53	0.33	0.45	6% L	8% L	7% L	7% L	14% L	20% L	17% L	16% L
ON-SR4	0.30	0.12	0.34	0.16	0.27	8% L	11% L	9% L	8% L	19% L	35%	23% L	23% L
ON-BR1	0.32	0.23	0.37	0.27	0.29	7% L	8% L	8% L	8% L	18% L	23% L	22% L	22% L
ON-BR2	0.36	0.17	0.46	0.27	0.37	7% L	8% L	7% L	7% L	15% L	23% L	18% L	18% L
ON-BR3	0.32	0.15	0.35	0.18	0.27	7% L	10% L	8% L	8% L	18% L	32%	23% L	23% L
ON-BR4	0.24	0.22	0.33	0.31	0.27	8% L	8% L	9% L	8% L	20% L	20% L	24% L	23% L
ON-BR5	0.23	0.18	0.27	0.22	0.21	8% L	9% L	10% L	10% L	23% L	27% L	29% L	28% L
NS101	0.30	0.19	0.50	0.39	0.43	7% L	7% L	7% L	7% L	14% L	17% L	17% L	16% L
NS102	0.50	0.5	0.65	0.65	0.53	6% L	6% L	7% L	6% L	12% L	12% L	14% L	14% L
NS103	0.36	0.12	0.51	0.28	0.42	6% L	8% L	7% L	7% L	14% L	22% L	17% L	16% L
NS104	0.44	0.31	0.50	0.38	0.40	7% L	7% L	7% L	7% L	14% L	18% L	17% L	17% L
NS105	0.39	0.36	0.54	0.51	0.45	6% L	6% L	7% L	7% L	14% L	14% L	16% L	16% L
NS106	0.30	0.28	0.41	0.39	0.34	7% L	7% L	8% L	8% L	17% L	17% L	20% L	19% L
NS115	0.30	0.38	0.50	0.58	0.42	7% L	6% L	7% L	7% L	14% L	13% L	18% L	16% L
NS117	0.32	0.20	0.58	0.47	0.50	6% L	7% L	7% L	7% L	13% L	15% L	16% L	14% L
NS118	0.51	0.51	0.68	0.68	0.55	6% L	6% L	6% L	6% L	12% L	12% L	14% L	13% L
NS122	0.50	0.51	0.64	0.65	0.52	6% L	6% L	7% L	6% L	12% L	12% L	15% L	14% L
NB-R1	0.42	0.27	0.50	0.35	0.40	7% L	7% L	7% L	7% L	14% L	19% L	17% L	17% L
NB-R2	0.35	0.20	0.38	0.23	0.30	7% L	9% L	8% L	8% L	17% L	26% L	21% L	21% L
NB-R3	0.37	0.34	0.56	0.53	0.46	6% L	6% L	7% L	7% L	13% L	14% L	16% L	15% L
NB-R4	0.37	0.28	0.55	0.45	0.45	6% L	7% L	7% L	7% L	13% L	15% L	16% L	15% L
NB-R5	0.51	0.42	0.60	0.51	0.48	6% L	6% L	7% L	7% L	13% L	14% L	15% L	15% L
NB-R6	0.39	0.25	0.48	0.34	0.38	7% L	8% L	7% L	7% L	15% L	19% L	18% L	17% L
NRC51	0.30	0.16	0.36	0.22	0.28	7% L	9% L	8% L	8% L	18% L	27% L	23% L	22% L
NRC52	0.30	0.15	0.49	0.33	0.41	7% L	8% L	7% L	7% L	15% L	19% L	18% L	16% L
NRC53	0.30	0.24	0.58	0.52	0.51	6% L	6% L	7% L	7% L	13% L	14% L	16% L	14% L
NRC54	0.36	0.24	0.47	0.35	0.38	7% L	8% L	7% L	7% L	15% L	19% L	18% L	18% L
NRC57	0.39	0.20	0.54	0.34	0.44	6% L	8% L	7% L	7% L	14% L	19% L	17% L	16% L
NRC60	0.34	0.25	0.40	0.31	0.31	7% L	8% L	8% L	8% L	17% L	21% L	21% L	20% L
NRC61	0.30	0.17	0.36	0.24	0.29	7% L	9% L	8% L	8% L	18% L	25% L	23% L	22% L
NRC62	0.30	0.15	0.43	0.28	0.39	7% L	8% L	8% L	7% L	16% L	22% L	20% L	17% L

Ratios of Total Ventilation Rates:
Average of Actual/F326: 76%
Minimum of Actual/F326: 45%

L means less than the low limit for RH.
S means greater than the high limit for RH.

Table I-4: Spreadsheet to calculate RH levels, Dry Conditions.

IAQ-R2000-Exposures to RH

Calculations of "exposure levels" to Relative Humidity (ø) based on percentile source strengths from the spreadsheet IAQ-R2000-RH.

- John Gusdorf, NRCan, 18 July, 1995

These results based on total ventilation, i.e., mechanical plus natural ventilation as calulated by AUDIT2OOO.

	Source Strengths (g/m^3-hr)		Relative Humidity Limits:
10th %ile:	0.190	Low:	30%
90th %ile:	0.860	High:	55%

Conditions: Medium-Dry, Montreal, January.

	T (C)	ø (%)	e_s (Pa)	W (kg/kg)
Outdoor:	-10.0	81%	260	.0013
Indoor:	20.0	-	2339	-

VENTILATION RATES & RESULTING EXPOSURES IN R-2000 HOUSES:

HOUSE	Ventilation Rates (ACH) Mechanical F-326	Mechanical Actual	Total (AUDIT2000) F-326	Total Actual	Total 75% of F-326	RH 10th %ile F-326		RH 10th %ile Actual		RH 10th %ile Avg of Act/F326		RH 10th %ile 75% of F-326		RH 90th %ile F-326		RH 90th %ile Actual		RH 90th %ile Avg of Act/F326		RH 90th %ile 75% of F-326	
AB-R1	0.30	0.23	0.49	0.43	0.42	11%	L	12%	L	12%	L	12%	L	19%	L	21%	L	22%	L	21%	L
AB-R2	0.36	0.36	0.47	0.47	0.38	11%	L	11%	L	12%	L	12%	L	20%	L	20%	L	23%	L	22%	L
AB-R3	0.37	0.26	0.44	0.33	0.35	11%	L	12%	L	12%	L	12%	L	20%	L	24%	L	24%	L	23%	L
AB-R4	0.30	0.16	0.43	0.30	0.36	12%	L	13%	L	12%	L	12%	L	21%	L	26%	L	24%	L	23%	L
AB-R5	0.30	0.26	0.38	0.34	0.31	12%	L	12%	L	13%	L	13%	L	22%	L	24%	L	26%	L	25%	L
AB-R6	0.32	0.26	0.44	0.39	0.36	11%	L	12%	L	12%	L	12%	L	20%	L	22%	L	24%	L	23%	L
AB-R7	0.30	0.26	0.42	0.37	0.34	12%	L	12%	L	12%	L	12%	L	21%	L	22%	L	25%	L	24%	L
AB-R8	0.30	0.17	0.44	0.31	0.36	12%	L	13%	L	12%	L	12%	L	20%	L	25%	L	24%	L	23%	L
AB-R9	0.34	0.28	0.46	0.40	0.37	11%	L	12%	L	12%	L	12%	L	20%	L	22%	L	23%	L	22%	L
AB-R10	0.41	0.28	0.54	0.42	0.44	11%	L	12%	L	12%	L	11%	L	18%	L	21%	L	21%	L	20%	L
ON-ER1	0.34	0.36	0.55	0.39	0.47	11%	L	12%	L	12%	L	11%	L	18%	L	22%	L	21%	L	20%	L
ON-ER2	0.38	0.16	0.46	0.24	0.37	11%	L	14%	L	12%	L	12%	L	20%	L	30%	L	23%	L	23%	L
ON-ER3	0.30	0.08	0.47	0.24	0.39	11%	L	14%	L	12%	L	12%	L	20%	L	29%	L	23%	L	22%	L
ON-ER4	0.42	0.28	0.50	0.35	0.39	11%	L	12%	L	12%	L	12%	L	19%	L	23%	L	22%	L	22%	L
ON-SR1	0.30	0.13	0.31	0.14	0.24	13%	L	17%	L	14%	L	14%	L	25%	L	45%		30%		30%	
ON-SR2	0.32	0.21	0.39	0.28	0.31	12%	L	13%	L	13%	L	13%	L	22%	L	27%	L	26%	L	25%	L
ON-SR3	0.33	0.13	0.53	0.33	0.45	11%	L	12%	L	12%	L	11%	L	18%	L	24%	L	21%	L	20%	L
ON-SR4	0.30	0.12	0.34	0.16	0.27	12%	L	16%	L	13%	L	13%	L	24%	L	40%		28%	L	28%	L
ON-BR1	0.32	0.23	0.37	0.27	0.29	12%	L	13%	L	13%	L	13%	L	23%	L	27%	L	27%	L	26%	L
ON-BR2	0.36	0.17	0.46	0.27	0.37	11%	L	13%	L	12%	L	12%	L	20%	L	27%	L	23%	L	22%	L
ON-BR3	0.32	0.15	0.35	0.18	0.27	12%	L	15%	L	13%	L	13%	L	23%	L	37%		28%	L	27%	L
ON-BR4	0.24	0.22	0.33	0.31	0.27	12%	L	13%	L	13%	L	13%	L	24%	L	25%	L	29%	L	28%	L
ON-BR5	0.23	0.18	0.27	0.22	0.21	13%	L	14%	L	14%	L	14%	L	28%	L	32%		34%		33%	
NS101	0.30	0.19	0.50	0.39	0.43	11%	L	12%	L	12%	L	12%	L	19%	L	22%	L	22%	L	21%	L
NS102	0.50	0.5	0.65	0.65	0.53	11%	L	11%	L	11%	L	11%	L	17%	L	17%	L	19%	L	18%	L
NS103	0.36	0.12	0.51	0.28	0.42	11%	L	13%	L	12%	L	12%	L	19%	L	27%	L	22%	L	21%	L
NS104	0.44	0.31	0.50	0.38	0.40	11%	L	12%	L	12%	L	12%	L	19%	L	22%	L	22%	L	22%	L
NS105	0.39	0.36	0.54	0.51	0.45	11%	L	11%	L	12%	L	11%	L	18%	L	19%	L	21%	L	20%	L
NS106	0.30	0.28	0.41	0.39	0.34	12%	L	12%	L	13%	L	12%	L	21%	L	22%	L	25%	L	24%	L
NS115	0.30	0.38	0.50	0.58	0.42	11%	L	11%	L	12%	L	12%	L	19%	L	18%	L	22%	L	21%	L
NS117	0.32	0.20	0.58	0.47	0.50	11%	L	11%	L	11%	L	11%	L	18%	L	20%	L	20%	L	19%	L
NS118	0.51	0.51	0.68	0.68	0.55	11%	L	11%	L	11%	L	11%	L	16%	L	16%	L	19%	L	18%	L
NS122	0.50	0.51	0.64	0.65	0.52	11%	L	11%	L	11%	L	11%	L	17%	L	17%	L	19%	L	19%	L
NB-R1	0.42	0.27	0.50	0.35	0.40	11%	L	12%	L	12%	L	12%	L	19%	L	23%	L	22%	L	22%	L
NB-R2	0.35	0.20	0.38	0.23	0.30	12%	L	14%	L	13%	L	13%	L	22%	L	31%		26%	L	26%	L
NB-R3	0.37	0.34	0.56	0.53	0.46	11%	L	11%	L	12%	L	11%	L	18%	L	18%	L	21%	L	20%	L
NB-R4	0.37	0.28	0.55	0.45	0.45	11%	L	11%	L	12%	L	11%	L	18%	L	20%	L	21%	L	20%	L
NB-R5	0.51	0.42	0.60	0.51	0.48	11%	L	11%	L	11%	L	11%	L	17%	L	19%	L	20%	L	19%	L
NB-R6	0.39	0.25	0.48	0.34	0.38	11%	L	12%	L	12%	L	12%	L	19%	L	24%	L	23%	L	22%	L
NRC51	0.30	0.16	0.36	0.22	0.28	12%	L	14%	L	13%	L	13%	L	23%	L	32%		27%	L	27%	L
NRC52	0.30	0.15	0.49	0.33	0.41	11%	L	12%	L	12%	L	12%	L	19%	L	24%	L	22%	L	21%	L
NRC53	0.30	0.24	0.58	0.52	0.51	11%	L	11%	L	11%	L	11%	L	18%	L	19%	L	20%	L	19%	L
NRC54	0.36	0.24	0.47	0.35	0.38	11%	L	12%	L	12%	L	12%	L	20%	L	23%	L	23%	L	22%	L
NRC57	0.39	0.20	0.54	0.34	0.44	11%	L	12%	L	12%	L	12%	L	18%	L	24%	L	21%	L	20%	L
NRC60	0.34	0.25	0.40	0.31	0.31	12%	L	13%	L	13%	L	13%	L	22%	L	25%	L	26%	L	25%	L
NRC61	0.30	0.17	0.36	0.24	0.29	12%	L	14%	L	13%	L	13%	L	23%	L	30%		27%	L	26%	L
NRC62	0.30	0.15	0.43	0.28	0.39	12%	L	13%	L	12%	L	12%	L	21%	L	27%	L	24%	L	22%	L

Ratios of Total Ventilation Rates:

Average of Actual/F326:	76%
Minimum of Actual/F326:	45%

L means less than the low limit for RH.

S means greater than the high limit for RH.

Table I-5: Spreadsheet to calculate RH levels, Medium-Dry Conditions.

IAQ-R2000-Exposures to RH

Calculations of "exposure levels" to Relative Humidity (ø) based on percentile source strengths from the spreadsheet IAQ-R2000-RH.
- John Gusdorf, NRCan, 18 July, 1995

These results based on total ventilation, i.e., mechanical plus natural ventilation as calulated by AUDIT2OOO.

Source Strengths (g/m^3-hr)		Relative Humidity Limits:	
10th %ile:	0.190	Low:	30%
90th %ile:	0.860	High:	55%

Conditions: Medium-Moist, Montreal, March.

	T (C)	ø (%)	e_s (Pa)	W (kg/kg)
Outdoor:	-2.4	76%	501	.0023
Indoor:	20.0	-	2339	-

VENTILATION RATES & RESULTING EXPOSURES IN R-2000 HOUSES:

HOUSE	Ventilation Rates (ACH): Mechanical F-326	Mechanical Actual	Total (AUDIT2000) F-326	Total Actual	Total 75% of F-326	RH, 10th %ile Source Strength: F-326		Actual		Avg of Act/F326		75% of F-326		RH, 90th %ile Source Strength: F-326		Actual		Avg of Act/F326		75% of F-326	
AB-R1	0.30	0.23	0.49	0.43	0.42	18%	L	19%	L	19%	L	19%	L	26%	L	28%	L	30%	L	28%	L
AB-R2	0.36	0.36	0.47	0.47	0.38	19%	L	19%	L	19%	L	19%	L	27%	L	27%	L	30%		29%	L
AB-R3	0.37	0.26	0.44	0.33	0.35	19%	L	20%	L	19%	L	19%	L	28%	L	31%		31%		30%	
AB-R4	0.30	0.16	0.43	0.30	0.36	19%	L	20%	L	20%	L	19%	L	28%	L	33%		31%		30%	
AB-R5	0.30	0.26	0.38	0.34	0.31	19%	L	19%	L	20%	L	20%	L	29%	L	31%		33%		32%	
AB-R6	0.32	0.26	0.44	0.39	0.36	19%	L	19%	L	19%	L	19%	L	27%	L	29%	L	31%		30%	
AB-R7	0.30	0.26	0.42	0.37	0.34	19%	L	19%	L	20%	L	19%	L	28%	L	30%	L	32%		31%	
AB-R8	0.30	0.17	0.44	0.31	0.36	19%	L	20%	L	20%	L	19%	L	28%	L	32%		31%		30%	
AB-R9	0.34	0.28	0.46	0.40	0.37	19%	L	19%	L	19%	L	19%	L	27%	L	29%	L	31%		30%	L
AB-R10	0.41	0.28	0.54	0.42	0.44	18%	L	19%	L	19%	L	19%	L	25%	L	28%	L	28%	L	28%	L
ON-ER1	0.34	0.36	0.55	0.39	0.47	18%	L	19%	L	19%	L	19%	L	25%	L	29%	L	28%	L	27%	L
ON-ER2	0.38	0.16	0.46	0.24	0.37	19%	L	21%	L	19%	L	19%	L	27%	L	37%		30%		30%	L
ON-ER3	0.30	0.08	0.47	0.24	0.39	19%	L	21%	L	19%	L	19%	L	27%	L	37%		30%		29%	L
ON-ER4	0.42	0.28	0.50	0.35	0.39	18%	L	19%	L	19%	L	19%	L	26%	L	30%		29%	L	29%	L
ON-SR1	0.30	0.13	0.31	0.14	0.24	20%	L	24%	L	21%	L	21%	L	32%		52%		37%		37%	
ON-SR2	0.32	0.21	0.39	0.28	0.31	19%	L	20%	L	20%	L	20%	L	29%	L	34%		33%		32%	
ON-SR3	0.33	0.13	0.53	0.33	0.45	18%	L	20%	L	19%	L	19%	L	26%	L	31%		29%	L	27%	L
ON-SR4	0.30	0.12	0.34	0.16	0.27	19%	L	23%	L	20%	L	20%	L	31%		47%		35%		35%	
ON-BR1	0.32	0.23	0.37	0.27	0.29	19%	L	20%	L	20%	L	20%	L	30%	L	35%		34%		34%	
ON-BR2	0.36	0.17	0.46	0.27	0.37	19%	L	20%	L	19%	L	19%	L	27%	L	35%		30%		30%	L
ON-BR3	0.32	0.15	0.35	0.18	0.27	19%	L	22%	L	20%	L	20%	L	30%		44%		35%		34%	
ON-BR4	0.24	0.22	0.33	0.31	0.27	20%	L	20%	L	21%	L	20%	L	31%		32%		36%		35%	
ON-BR5	0.23	0.18	0.27	0.22	0.21	20%	L	21%	L	22%	L	21%	L	35%		39%		41%		40%	
NS101	0.30	0.19	0.50	0.39	0.43	18%	L	19%	L	19%	L	19%	L	26%	L	29%	L	29%	L	28%	L
NS102	0.50	0.5	0.65	0.65	0.53	18%	L	18%	L	18%	L	18%	L	24%	L	24%	L	26%	L	26%	L
NS103	0.36	0.12	0.51	0.28	0.42	18%	L	20%	L	19%	L	19%	L	26%	L	34%		29%	L	28%	L
NS104	0.44	0.31	0.50	0.38	0.40	18%	L	19%	L	19%	L	19%	L	26%	L	29%	L	29%	L	29%	L
NS105	0.39	0.36	0.54	0.51	0.45	18%	L	18%	L	19%	L	19%	L	25%	L	26%	L	28%	L	27%	L
NS106	0.30	0.28	0.41	0.39	0.34	19%	L	19%	L	20%	L	20%	L	28%	L	29%	L	32%		31%	
NS115	0.30	0.38	0.50	0.58	0.42	18%	L	18%	L	19%	L	19%	L	26%	L	25%	L	29%	L	28%	L
NS117	0.32	0.20	0.58	0.47	0.50	18%	L	19%	L	19%	L	18%	L	25%	L	27%	L	27%	L	26%	L
NS118	0.51	0.51	0.68	0.68	0.55	18%	L	18%	L	18%	L	18%	L	24%	L	24%	L	26%	L	25%	L
NS122	0.50	0.51	0.64	0.65	0.52	18%	L	18%	L	18%	L	18%	L	24%	L	24%	L	26%	L	26%	L
NB-R1	0.42	0.27	0.50	0.35	0.40	18%	L	19%	L	19%	L	19%	L	26%	L	30%		29%	L	29%	L
NB-R2	0.35	0.20	0.38	0.23	0.30	19%	L	21%	L	20%	L	20%	L	29%	L	38%		33%		33%	
NB-R3	0.37	0.34	0.56	0.53	0.46	18%	L	18%	L	19%	L	19%	L	25%	L	26%	L	28%	L	27%	L
NB-R4	0.37	0.28	0.55	0.45	0.45	18%	L	19%	L	19%	L	19%	L	25%	L	27%	L	28%	L	27%	L
NB-R5	0.51	0.42	0.60	0.51	0.48	18%	L	18%	L	19%	L	19%	L	24%	L	26%	L	27%	L	27%	L
NB-R6	0.39	0.25	0.48	0.34	0.38	19%	L	19%	L	19%	L	19%	L	27%	L	31%		30%	L	29%	L
NRC51	0.30	0.16	0.36	0.22	0.28	19%	L	21%	L	20%	L	20%	L	30%		39%		34%		34%	
NRC52	0.30	0.15	0.49	0.33	0.41	18%	L	20%	L	19%	L	19%	L	26%	L	31%		30%	L	28%	L
NRC53	0.30	0.24	0.58	0.52	0.51	18%	L	18%	L	19%	L	18%	L	25%	L	26%	L	28%	L	26%	L
NRC54	0.36	0.24	0.47	0.35	0.38	19%	L	19%	L	19%	L	19%	L	27%	L	31%		30%		30%	L
NRC57	0.39	0.20	0.54	0.34	0.44	18%	L	19%	L	19%	L	19%	L	26%	L	31%		28%	L	28%	L
NRC60	0.34	0.25	0.40	0.31	0.31	19%	L	20%	L	20%	L	20%	L	29%	L	32%		33%		32%	
NRC61	0.30	0.17	0.36	0.24	0.29	19%	L	21%	L	20%	L	20%	L	30%		37%		35%		33%	
NRC62	0.30	0.15	0.43	0.28	0.39	19%	L	20%	L	20%	L	19%	L	28%	L	34%		31%		29%	L

Ratios of Total Ventilation Rates:	
Average of Actual/F326:	76%
Minimum of Actual/F326:	45%

L means less than the low limit for RH.
S means greater than the high limit for RH.

Table I-6: Spreadsheet to calculate RH levels, Medium-Moist Conditions.

IAQ-R2000-Exposures to RH

Calculations of "exposure levels" to Relative Humidity (ø) based on percentile source strengths from the spreadsheet IAQ-R2000-RH.

- John Gusdorf, NRCan, 18 July, 1995

These results based on total ventilation, i.e., mechanical plus natural ventilation as calulated by AUDIT2OOO.

Source Strengths (g/m^3-hr)		Relative Humidity Limits:		Conditions: Moist, Vancouver, May.	T (C)	ø (%)	e_s (Pa)	W (kg/kg)
10th %ile:	0.190	Low:	30%	Outdoor:	12.2	73%	1421	.0063
90th %ile:	0.860	High:	55%	Indoor:	20.0	-	2339	-

VENTILATION RATES & RESULTING EXPOSURES IN R-2000 HOUSES:

	Ventilation Rates (ACH)					Relative Humidity Levels with Total Ventilation											
HOUSE	Mechanical		Total (AUDIT2000)			10th %ile Source Strength				90th %ile Source Strength							
	F-326	Actual	F-326	Actual	75% of F-326	F-326	Actual	Avg of Act/F326	75% of F-326	F-326		Actual		Avg of Act/F326		75% of F-326	
AB-R1	0.30	0.23	0.49	0.43	0.42	46%	47%	47%	47%	54%		56%	H	57%	H	56%	H
AB-R2	0.36	0.36	0.47	0.47	0.38	46%	46%	47%	47%	55%		55%		58%	H	57%	H
AB-R3	0.37	0.26	0.44	0.33	0.35	46%	47%	47%	47%	55%	H	59%	H	59%	H	58%	H
AB-R4	0.30	0.16	0.43	0.30	0.36	46%	48%	47%	47%	55%	H	61%	H	59%	H	58%	H
AB-R5	0.30	0.26	0.38	0.34	0.31	47%	47%	48%	48%	57%	H	58%	H	61%	H	60%	H
AB-R6	0.32	0.26	0.44	0.39	0.36	46%	47%	47%	47%	55%	H	57%	H	59%	H	58%	H
AB-R7	0.30	0.26	0.42	0.37	0.34	47%	47%	47%	47%	56%	H	57%	H	60%	H	59%	H
AB-R8	0.30	0.17	0.44	0.31	0.36	46%	47%	47%	47%	55%	H	60%	H	59%	H	58%	H
AB-R9	0.34	0.28	0.46	0.40	0.37	46%	47%	47%	47%	55%		57%	H	58%	H	57%	H
AB-R10	0.41	0.28	0.54	0.42	0.44	46%	47%	47%	46%	53%		56%	H	56%	H	55%	H
ON-ER1	0.34	0.36	0.55	0.39	0.47	46%	47%	47%	46%	53%		57%	H	56%	H	55%	
ON-ER2	0.38	0.16	0.46	0.24	0.37	46%	49%	47%	47%	55%		65%	H	58%	H	57%	H
ON-ER3	0.30	0.08	0.47	0.24	0.39	46%	48%	47%	47%	55%		64%	H	58%	H	57%	H
ON-ER4	0.42	0.28	0.50	0.35	0.39	46%	47%	47%	47%	54%		58%	H	57%	H	57%	H
ON-SR1	0.30	0.13	0.31	0.14	0.24	47%	52%	49%	49%	60%	H	80%	H	65%	H	65%	H
ON-SR2	0.32	0.21	0.39	0.28	0.31	47%	48%	48%	47%	57%	H	62%	H	61%	H	60%	H
ON-SR3	0.33	0.13	0.53	0.33	0.45	46%	47%	47%	46%	53%		59%	H	56%	H	55%	H
ON-SR4	0.30	0.12	0.34	0.16	0.27	47%	51%	48%	48%	58%	H	75%	H	63%	H	63%	H
ON-BR1	0.32	0.23	0.37	0.27	0.29	47%	48%	48%	48%	58%	H	62%	H	62%	H	61%	H
ON-BR2	0.36	0.17	0.46	0.27	0.37	46%	48%	47%	47%	55%		62%	H	58%	H	57%	H
ON-BR3	0.32	0.15	0.35	0.18	0.27	47%	50%	48%	48%	58%	H	72%	H	62%	H	62%	H
ON-BR4	0.24	0.22	0.33	0.31	0.27	47%	47%	48%	48%	59%	H	60%	H	64%	H	63%	H
ON-BR5	0.23	0.18	0.27	0.22	0.21	48%	49%	49%	49%	63%	H	67%	H	68%	H	68%	H
NS101	0.30	0.19	0.50	0.39	0.43	46%	47%	47%	47%	54%		57%	H	57%	H	56%	H
NS102	0.50	0.5	0.65	0.65	0.53	46%	46%	46%	46%	52%		52%		54%		53%	
NS103	0.36	0.12	0.51	0.28	0.42	46%	48%	47%	47%	54%		62%	H	57%	H	56%	H
NS104	0.44	0.31	0.50	0.38	0.40	46%	47%	47%	47%	54%		57%	H	57%	H	57%	H
NS105	0.39	0.36	0.54	0.51	0.45	46%	46%	47%	46%	53%		54%		56%	H	55%	H
NS106	0.30	0.28	0.41	0.39	0.34	47%	47%	47%	47%	56%	H	57%	H	60%	H	59%	H
NS115	0.30	0.38	0.50	0.58	0.42	46%	46%	47%	47%	54%		53%		57%	H	56%	H
NS117	0.32	0.20	0.58	0.47	0.50	46%	46%	46%	46%	52%		55%		55%	H	54%	
NS118	0.51	0.51	0.68	0.68	0.55	46%	46%	46%	46%	51%		51%		54%		53%	
NS122	0.50	0.51	0.64	0.65	0.52	46%	46%	46%	46%	52%		52%		54%		54%	
NB-R1	0.42	0.27	0.50	0.35	0.40	46%	47%	47%	47%	54%		58%	H	57%	H	57%	H
NB-R2	0.35	0.20	0.38	0.23	0.30	47%	49%	48%	48%	57%	H	66%	H	61%	H	61%	H
NB-R3	0.37	0.34	0.56	0.53	0.46	46%	46%	47%	46%	53%		53%		56%	H	55%	
NB-R4	0.37	0.28	0.55	0.45	0.45	46%	46%	47%	46%	53%		55%	H	56%	H	55%	
NB-R5	0.51	0.42	0.60	0.51	0.48	46%	46%	46%	46%	52%		54%		55%		54%	
NB-R6	0.39	0.25	0.48	0.34	0.38	46%	47%	47%	47%	54%		59%	H	58%	H	57%	H
NRC51	0.30	0.16	0.36	0.22	0.28	47%	49%	48%	48%	58%	H	67%	H	62%	H	62%	H
NRC52	0.30	0.15	0.49	0.33	0.41	46%	47%	47%	47%	54%		59%	H	57%	H	56%	H
NRC53	0.30	0.24	0.58	0.52	0.51	46%	46%	46%	46%	53%		54%		55%	H	54%	
NRC54	0.36	0.24	0.47	0.35	0.38	46%	47%	47%	47%	55%		58%	H	58%	H	57%	H
NRC57	0.39	0.20	0.54	0.34	0.44	46%	47%	47%	46%	53%		59%	H	56%	H	55%	H
NRC60	0.34	0.25	0.40	0.31	0.31	47%	48%	48%	47%	57%	H	60%	H	61%	H	60%	H
NRC61	0.30	0.17	0.36	0.24	0.29	47%	49%	48%	48%	58%	H	65%	H	62%	H	61%	H
NRC62	0.30	0.15	0.43	0.28	0.39	46%	48%	47%	47%	56%	H	62%	H	59%	H	57%	H

Ratios of Total Ventilation Rates:	
Average of Actual/F326:	76%
Minimum of Actual/F326:	45%

L means less than the low limit for RH.

S means greater than the high limit for RH.

Table I-7. Spreadsheet to calculate RH levels, Moist Conditions.

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