Air Exfiltration and Moisture Accumulation in Residential Wall Cavities

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ABSTRACT

Exfiltration of indoor air from buildings during the heating season is known to be the main reason for moisture accumulation within wall cavities. A two-dimensional computer model is used to numerically analyze the effect of exfiltration of indoor air on residential wall cavities exposed to Canadian and Finnish weather conditions at various locations. Irrespective of the airflow rate chosen for the analysis, it is shown that at most of the locations an appreciable amount of moisture accumulates within the cavity during the heating season. However, at most locations during the drying period, the cavity dries out, though some part of the cavity may take a longer time to achieve this. At locations such as Winnipeg (Canada), with very cold winter conditions, certain parts of the wall assembly may remain wet for a good part of the year. If the cold season is long, as at Resolute Bay (Canada), the drying period is not enough to dry the cavity, and the effect of exfiltration becomes a cumulative one. The general conclusion is that the levels of moisture content and temperature of indoor and outdoor air govern the hygrothermal behavior of the cavities, while the rate of exfiltration is immaterial.

INTRODUCTION

Long-term performance of buildings is governed by their response to the heat, air, and moisture transport processes that are the consequences of ever-changing outdoor conditions. In countries with a cold climate, these transport processes often result in moisture deposition within wall cavities. One major source for moisture that leads to such deposition is the indoor air; for human comfort, it is desirable to maintain a certain level of humidity in the indoor environment. Moisture from the indoor environment is transported into the wall cavity through two mechanisms, vapor diffusion and exfiltration. In countries such as Canada and Finland, it is a code requirement to install a vapor retarder at the warm surface of the wall assembly. Such an installation will effectively retard moisture transport through the mechanism of diffusion, but this does not prevent the other mechanism of moisture transport, which in most buildings is the dominating one (Latta 1976).

The work described in this paper was initiated in response to a Canadian Standards Association standard on residential mechanical ventilation systems, viz., CAN/CSA-F326-M91. One of the specifications in the standard reads as follows: "The pressure increase in the dwelling unit relative to the outside does not exceed the lesser of 10 Pa or the value to which any installed vented combustion appliance has been certified by an accredited agency or specified by the manufacturer."

Such a specification resulted in the following questions:

- What is the effect of "overpressurization" on the moisture performance of the building envelope?
- Is the upper limit of 10 Pa (0.04 in.of water) an acceptable number at all Canadian locations?

These questions are difficult to answer through experimental observations. So it was decided to simulate the performance of a current timber-frame wall, exposed to Canadian weather conditions at selected locations, through computer model calculations (numerical analyses). For the purpose of comparison, simulations were also done using selected Finnish weather conditions. This paper reports the results from a series of such calculations.

THE RESIDENTIAL WALL ASSEMBLY

The residential wall assembly selected for the numerical analysis is shown schematically in Figure 1. It is a 150-mm-wide timber-frame cavity wall filled with glass fiber insulation. The interior finish is 12-mm-thick gypsum board with a type I vapor retarder and the exterior sheathing is 11-mm-thick wood chipboard. The wall is 2 m high.

THE AIM OF THE ANALYSIS

The objective of the work described in this paper was to investigate numerically the effect of air exfiltration on the hygrothermal behavior of residential wall assemblies exposed to Canadian and Finnish weather conditions for one year. Earlier investigations (Kumaran 1992) have shown that the worst-case scenario of exfiltration is when the air enters the cavity at the top of the wall assembly and leaves at the bottom, as shown in Figure 2. Hence this path of

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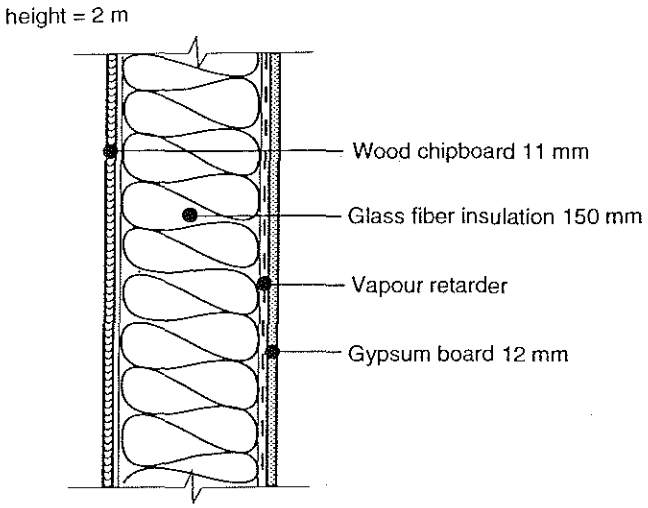


Figure 1 *Simulated wall structure for nonuniform air-flow.*

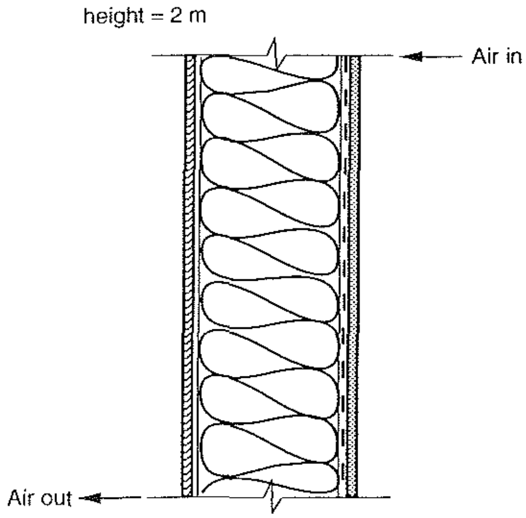


Figure 2 *The worst-case scenario of exfiltration through the selected wall assembly.*

exfiltration was selected for the simulation. The exfiltration was assumed to be the result of an overpressure of 10 Pa (0.04 in.of water) in the building. A field investigation (Shaw 1987) showed that in a typical Canadian residential building, this will correspond to an exfiltration rate of 0.98 $L/(m^2 \cdot s)$.

BOUNDARY CONDITIONS, MATERIAL PROPERTIES, AND INITIAL VALUES

The gypsum board with the vapor retarder is specified as an interior vapor resistance. This restricts the vapor diffusion to the limit allowed by the vapor permeances of gypsum board and the vapor retarder. The "specific air permeability" of the insulation in the horizontal direction is 2.5×10^{-9} m^2 and in the vertical direction, 5.0×10^{-9} m^2. The thermal conductivity and water vapor permeability of the insulation are functions of temperature. The thermal conductivity of dry chipboard is treated as a constant, 0.13 W/(m.K) (0.9014 Btu·in./(hr·ft^2·°F)), while the water vapor permeability is a function of moisture content and temperature. The dry densities of the insulation and chipboard are 20 and 700 kg/m^3, respectively.

The outside air temperature and relative humidity varied according to the weather data from selected locations. For this study, solar radiation to and longwave radiation from the outer surface of the wall were omitted. The simulations for a one-year exposure were done using weather data from nine Canadian and three Finnish locations, listed in Table 1. From October 1 to May 1, the indoor air is maintained at 21°C and 30% RH. For the rest of the year, the indoor temperature and relative humidity are the same as the outside temperature and relative humidity.

The initial moisture content of the glass fiber and chipboard were calculated from sorption curves and corresponded to 30% RH. The simulations were started July 3, which corresponded approximately to the middle of the drying period. At this starting point, the equilibrium moisture content corresponded relatively well to the chosen initial conditions. This made it possible to analyze the yearly moisture accumulation from just one year's simulation. (Alternatively, one could start from January 1, but this being at the middle of the heating season, the assumed initial moisture content is unrealistic and simulations will have to be done for two successive years.)

TABLE 1
Location and Minimum and Maximum Temperatures of the Weather Patterns Used in the Simulations (during the Heating Season, the Indoor Conditions are 21°C and 30% RH and the Exfiltration Rate is 0.98 $L/(m^2 \cdot s)$

Location	Northern Lattitude	Temperature (°C)	
		Minimum	Maximum
Canada			
Edmonton	53°32'	-32	+32
Fredericton	45°92'	-31	+37
Montreal	45°47'	-30.5	+32
Ottawa	45°45'	-30	+30.5
Resolute Bay	74°72'	-41.5	+16
Toronto	43°80'	-22.5	+32
Vancouver	49°25'	-12.5	+27
Windsor	42°27'	-19	+35
Winnipeg	49°90'	-39	+33
Finland			
Helsinki	60°10'	-30	+28.5
Jyväskylä	62°15'	-35	+27
Sodakylä	67°20'	-40	+26

In an attempt to identify permissible levels of indoor humidity, simulations were also carried out by varying the values from 30% RH. Also, the effect of airflow rates on hygrothermal behavior was numerically analyzed. The case shown in Figure 2 generates nonuniform airflow within the cavity and, in particular, at the interface of the insulation and the exterior sheathing. For comparison, simulations were done by uniformly distributing the flow field over the surface of the structure and the results compared with the flow pattern give by the case in Figure 2. The boundary conditions used in these calculations are summarized in Table 2. All these additional simulations are referred to as sensitivity analysis in this paper.

SIMULATION MODEL

The computer program used for the calculations is described in Ojanen et al. (1989). The program uses a finite-difference technique to solve the transient heat, air, and moisture transfers in two-dimensional multilayer building structures. Heat is transferred by conduction and convection and moisture by diffusion and convection; however, the water vapor permeability to define diffusion is derived from total moisture diffusivity (Kohonen 1984) and sorption isotherm for the full range of moisture content. The material properties that are needed in the simulations are dry density, thermal conductivity, heat capacity, air permeability, vapor permeability, and sorption isotherm. Material properties are functions of temperature and moisture content. The effect of phase transitions on heat transport is accounted for. Weather data files are used to create hourly changing boundary conditions.

RESULTS AND DISCUSSION

Simulations were done for a 52-week period starting from July 3. In the finite-difference formulation of the wall cavity, the airflow rate of 0.98 $L/(m^2{\cdot}s)$ was expressed as 1.96 $L/(s{\cdot}m)$; this means that the wall section in Figure 1 is 1 m deep and the crack is arbitrarily chosen to be 2 cm wide, and, depending upon the finite-diffrence matrix used, this width can be altered to appropriately define the airflow rate of 0.98 $L/(m^2{\cdot}s)$. The analysis generated hourly values for pressure, temperature, water vapor pressure, and airflow velocity fields, as well as net moisture flow into or out of the structure caused by exfiltration, the moisture content distributions in the material layers, and the total moisture content of the structure. The air flowing into the structure has a partial vapor pressure of 745 Pa (2.98 in. of water) during the heating period. If the temperature in the structure approaches, say, 0°C , water vapor condensation is facilitated. Moisture is also accumulated in material layers due to their sorption properties. The results from the simulation are discussed below under three sections: hygrothermal behavior, thermal behavior, and sensitivity analysis.

TABLE 2
Boundary Conditions Used in the Sensitivity Analysis

Location	Airflow Rate $L/(m^2{\cdot}s)$	Indoor RH %
Sodankylä	0.98	30
	0.50	30
	0.25	30
	0.10	30
	0.98	25
	0.98	20
	0.98 (uniformly distributed)	30
Vancouver	0.98 (uniformly distributed)	30

Hygrothermal Behavior

The net convective moisture flux into the structure depends on the vapor pressure of the indoor air, which flows into the structure, and that of the outflowing air:

$$g_{net} = q_{m,a} \left[\{ p_v M_v /(p_a M_a) \}_{in} - \{ p_v M_v /(p_a M_a) \}_{s,out} \right] , \tag{1}$$

where

g_{net} = net convective moisture flux, $kg/(s.m^2)$;
$q_{m,a}$ = air mass flow rate through the structure, $kg/(s.m^2)$;
M = molar mass;
in = inside air;
s,out = air flowing out of the structure;
a = air;
v = vapor.

In calculations, the approximation

$$g_{net} = q_{Vin} \left[\{ p_v M_v /(RT) \}_{in} - \{ p_v M_v /(RT) \}_{s,out} \right], \tag{2}$$

where

q_{Vin} is the airflow rate from inside air into the structure ($m^3/(s{\cdot}m^2)$), was used when solving for the net moisture flow. Positive values for g_{net} mean that moisture is accumulating in the structure, and negative values mean that air convection is drying out the structure.

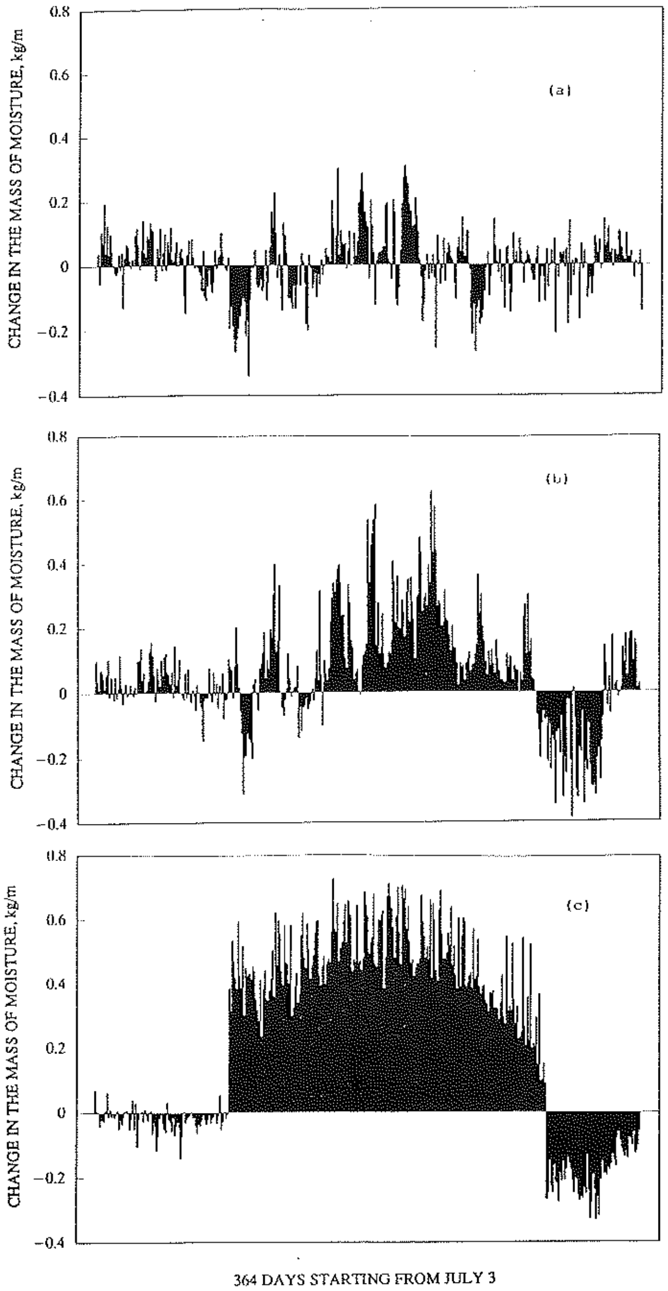


Figure 3 *The calculated daily change of total mass of moisture in the analyzed structure due to air exfiltration in (a) Vancouver, (b) Helsinki, and (c) Resolute Bay climatic conditions.*

Figure 3 shows the calculated daily net mass of moisture (g_{net} × 24 h × 2.0 m) that flows into or out of the structure in Vancouver and Resolute Bay in Canada and Helsinki, Finland, during one year. The weather in Vancouver is mild, and it gave the lowest moisture accumulation in the structure. When exposed to the weather conditions of a very cold region, Resolute Bay, the hourly mass of moisture accumulation was positive for most of the year. In Helsinki weather, an appreciable amount of moisture accumulated during wintertime.

The calculated monthly net and cumulative mass of moisture accumulation in Vancouver, Helsinki, and Resolute Bay are presented in an alternative format in Figure 4. When the last cumulative moisture value (in June) exceeds 0 kg/m, air exfiltration has caused yearly net moisture accumulation in the structure during the calculation period. Figure 4 shows that in Resolute Bay the exfiltartion considered here causes large amount of moisture to condense in the structure, which does not get time to dry out. The situation is the same in Helsinki, but the cumulative effect is much smaller than in Resolute Bay.

In the simulations, the drying of the structure through the wood chipboard by diffusion was also taken into account, and all the moisture was absorbed by the materials according to their sorption properties. Moisture was found to accumulate mostly near the interface of chipboard and thermal insulation. Vertical moisture content distributions of the chipboard and the outer part of the glass fiber layer are presented in two-week intervals throughout the year in Figure 5 for Vancouver, in Figure 6 for Helsinki, in Figure 7 for Winnipeg, and in Figure 8 for Resolute Bay weather conditions. The moisture content values of the chipboard represent the horizontal average values of the 11-mm-thick chipboard at each height. For glass fiber, the moisture contents are those of the outer node of the material layer, which in the finite-difference representation was also 11 mm thick.

At every location selected, moisture accumulated in the material layers during the heating period. According to the calculations, a good part of the moisture was accumulated at the upper part of the structure, close to the interface of the insulation and the sheathing, where the warm and humid airflow met the cold outer layers. Only in the mild climate in Vancouver did the maximum moisture content of the chipboard remain at a relatively low level, under 0.2 kg/kg. In Helsinki, the maximum value was about 0.5 kg/kg, and in Winnipeg and Resolute Bay, the total saturation value, 1.0 kg/kg (corresponding to about 700 kg/m^3 with this material), was nearly reached. As stated in the previous paragraph, in Resolute Bay yearly moisture accumulation in the structure was clearly indicated, i.e., the moisture content at the end of the simulation period had siginificantly increased from the initial values. The exact position of the moisture in real structures may differ from the calculated because the freezing of water and the water flow at the interface of the material layers could not be simulated. Even then the calculated total moisture balance of the structure is a reliable figure that can be compared between the different cases analyzed.

Figure 9 shows the total mass of moisture per surface area of structure (kg/m^2) as a function of time for all locations. (The dimension 1 kg/m^2 corresponds to a 1-mm-thick water layer per total structural thickness). When the maximum total mass of moisture was used as a criterion, the climate conditions analyzed could be sorted according to the increasing risks in hygrothermal behavior during

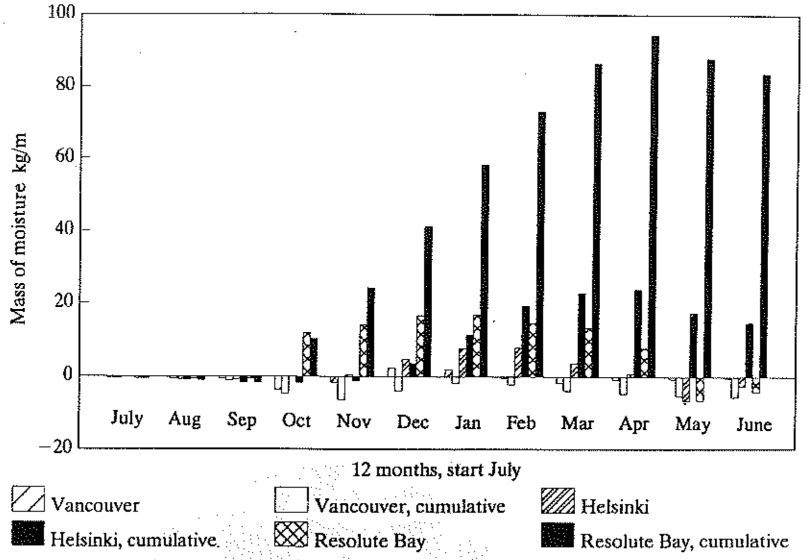


Figure 4 *Calculated monthly and cumulative changes of total mass of moisture in the analyzed structure due to air exfiltration in Vancouver, Helsinki, and Resolute Bay climatic conditions.*

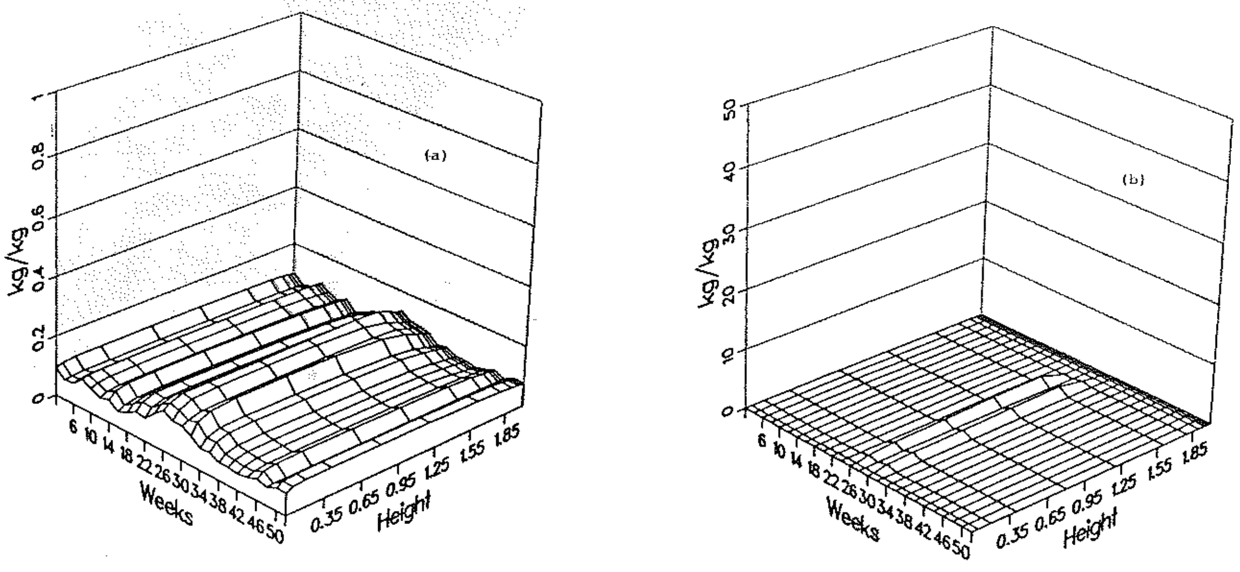


Figure 5 *Vertical moisture content distribution of (a) the chipboard and (b) the outer 11 mm of the glass fiber insulation at two-week intervals in Vancouver climatic conditions.*

exfiltration from less to more severe, as listed in Table 3. The maximum moisture values are compared to the yearly mean temperature, vapor pressure, and saturation vapor pressure values in Table 3.

The locations chosen for this investigation, based on the simulation results, can be grouped into three: mild, medium, and cold. In mild climates (Vancouver and Windsor), the moisture accumulation is relatively small during the winter. In very cold climates (Resolute Bay, Sodankylä, Winnipeg), the possibility for yearly moisture accumulation exists. At the remaining locations that belong to the medium climate group, the moisture accumulation can be high during the heating season, but the structures should be able to dry out during summertime.

The maximum amount of moisture is , as an approximation, inversely proportional to the yearly mean outdoor temperature. The only exception in the Canadian climate was between Vancouver and Windsor. In Windsor higher maximum moisture accumulation with higher outdoor mean temperature is shown. This can be attributed to the longer and colder winter period at Windsor than at Vancouver.

Also, the Finnish climate has shorter winters and summers than the Canadian climate but with approximately the same mean outdoor temperatures. For example, during

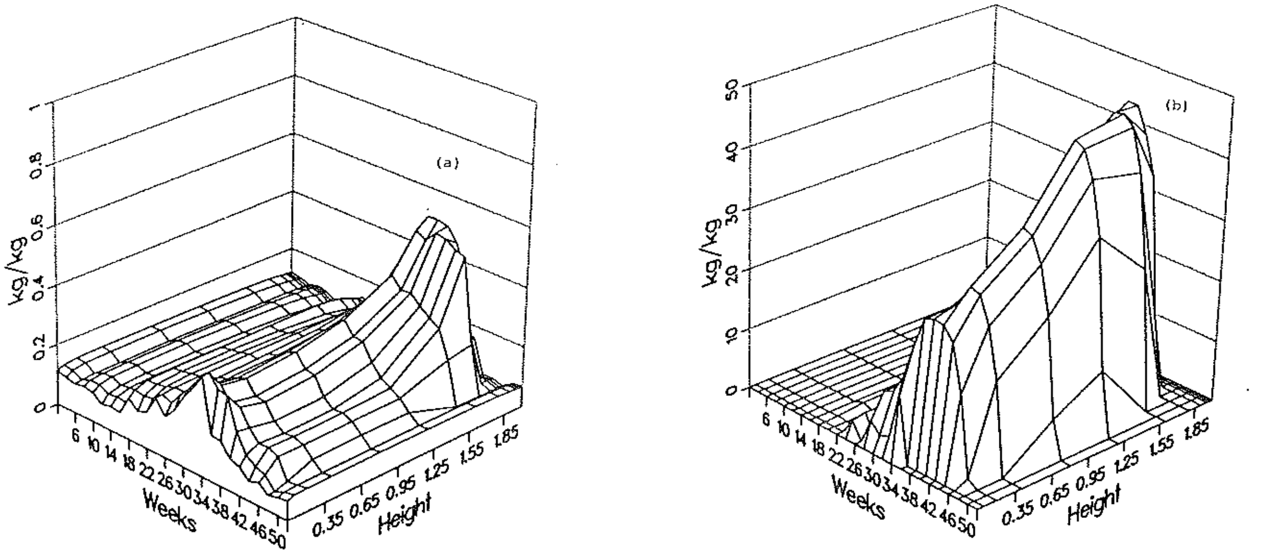


Figure 6 *Vertical moisture content distribution of (a) the chipboard and (b) the outer 11 mm of the glass fiber insulation at two-week intervals in Helsinki climatic conditions.*

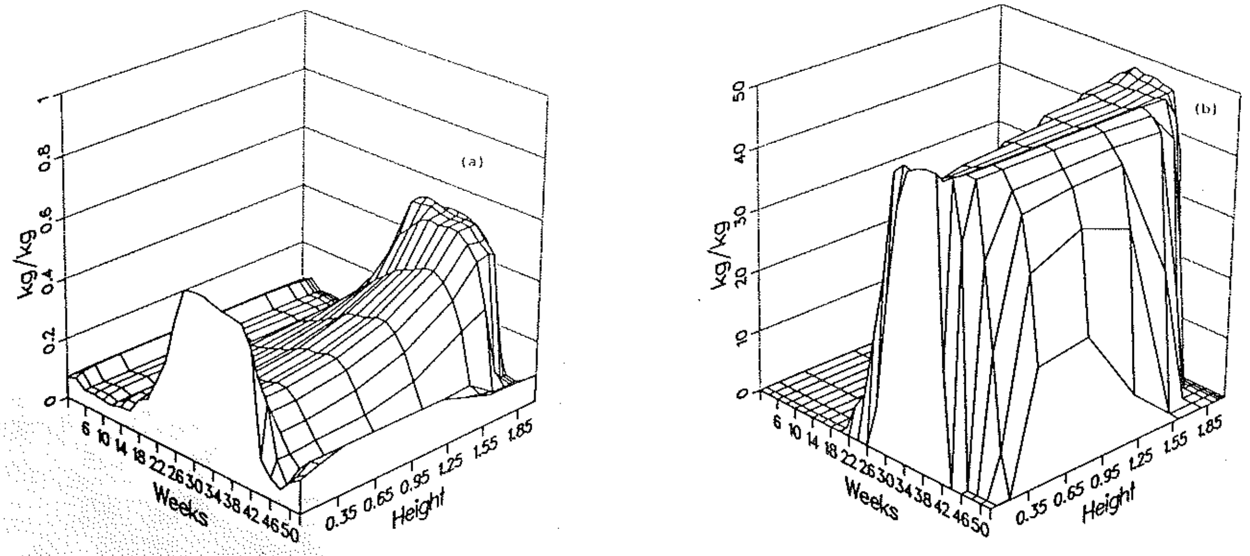


Figure 7 *Vertical moisture content distribution of (a) the chipboard and (b) the outer 11 mm of the glass fiber insulation at two-week intervals in Winnipeg climatic conditions.*

wintertime in Ottawa, there are longer cold periods than at Helsinki. Therefore, the calculated moisture accumulation in Helsinki during the heating season was found to be smaller than that in Ottawa.

Figure 10 shows the daily mean outdoor air temperature variation at the three locations: Vancouver, Helsinki, and Resolute Bay. A correlation could be seen between the outside air temperature, the length of the cold season, and the accumulation of moisture in the structure.

Thermal Behavior

During the heating season, exfiltrating air warms up the structure, and temperatures around the main airflow route are usually higher than that in a nonconvective case (uniformly distributed airflow). Therefore, in a case with nonuniform air exfiltration, the temperature of the outflowing air is significantly higher than that of the outside surface of the structure during the heating season. Table 4

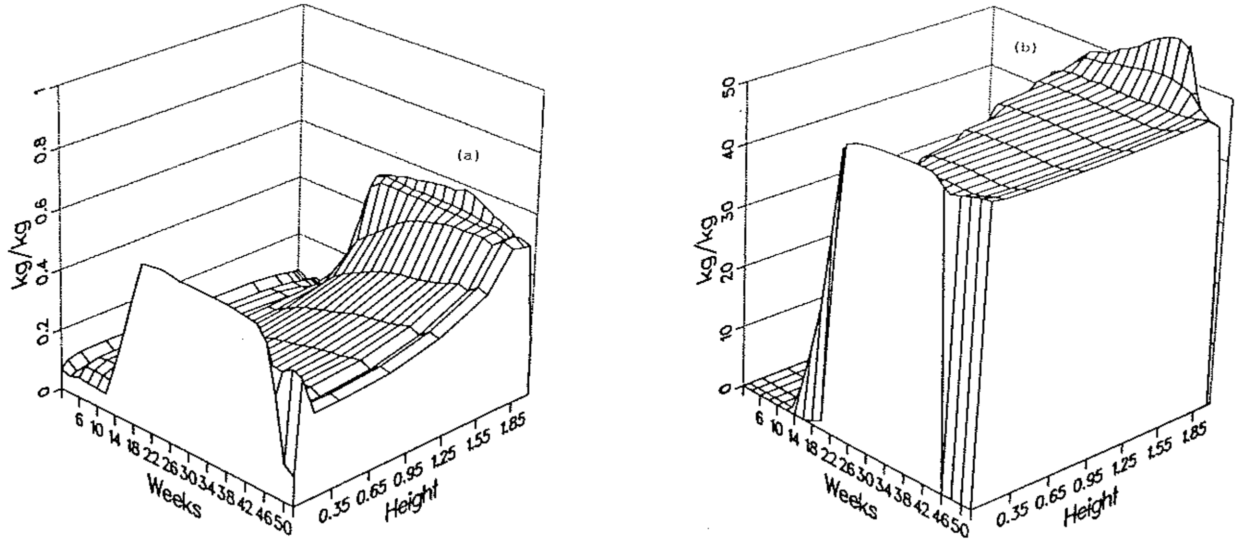
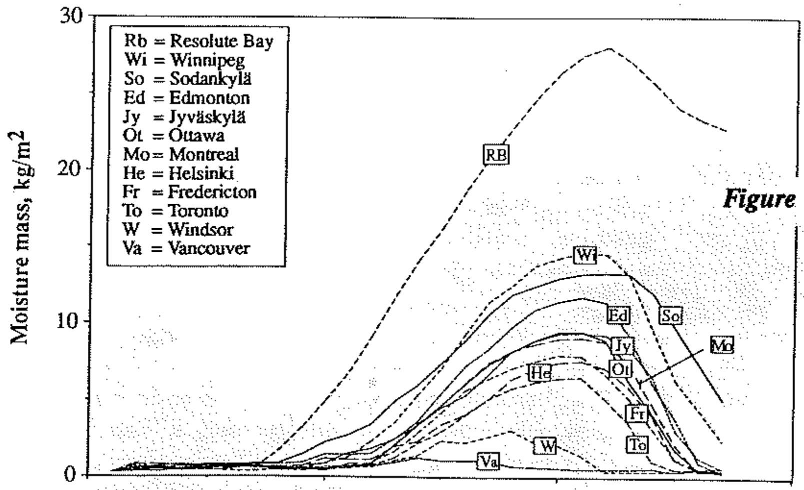


Figure 8 *Vertical moisture content distribution of (a) the chipboard and (b) the outer 11 mm of the glass fiber insulation at two-week intervals in Resolute Bay climatic conditions.*



One year, two week intervals, start July 3

Figure 9 *Calculated total mass of moisture per surface area of structure (kg/m^2) as a function of time for all the analyzed locations.*

TABLE 3

The Locations Used in the Simulation Arranged in the Order of Increasing Risk of Moisture Accumulation According to the Simulation Results. For Comparison, the Yearly Mean Values for Outdoor Temperature T, Water Vapor Pressure p_v, and Saturation Vapor Pressure $p_{v,sat}$ Are Also Listed.

Location	Maximum Mass of Moisture kg/m^2	Outdoor Climate (Yearly mean)		
		T(°C)	P_v(Pa)	$P_{v,sat}$(Pa)
Vancouver	1.0	9.13	960.4	1257.1
Windsor	3.0	9.77	996.2	1489.4
Toronto	6.5	6.90	877.0	1252.2
Helsinki	7.6	4.31	755.7	1005.0
Fredericton	8.0	5.88	813.1	1218.7
Montreal	9.1	5.73	831.0	1236.2
Jyväskylä	9.4	2.79	706.9	935.4
Ottawa	9.5	5.71	828.2	1241.6
Edmonton	11.8	1.77	600.1	956.5
Sodankylä	13.3	-0.80	565.7	770.7
Winnipeg	14.6	1.62	699.1	1052.7
Resolute Bay	28.1	-16.54	219.7	270.3

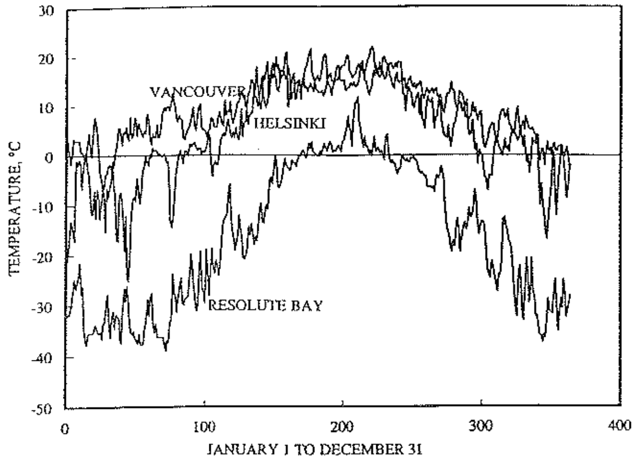


Figure 10 *Daily mean outdoor air temperature variation at Vancouver, Helsinki, and Resolute Bay during one year.*

shows the temperatures of the out-flowing air and chipboard with different airflow rates and also with a uniformly distributed airflow when the outside air was at -9.5 °C. The results are chosen from the calculations using real weather data of Sodankylä, Finland, in late February, and so they do not present a stationary case.

For example, with outside temperature at -9.5°C and with an airflow rate of 1.96 L/s·m, which is called the reference case hereafter, the minimum and maximum temperatures of the inner surface of the chipboard were −7.5°C and +0.2°C, respectively, the maximum being at the upper part of the structure. The temperature of the out-flowing air was +5.9°C. In this case, condensation conditions existed inside the structure (Sodankylä weather data, February). Almost the whole interface of the glass fiber and chipboard was at 100% RH, but the calculated vapor pressure of the air flowing out through the crack was only about 500 Pa (2 in. of water), 54% RH. The out-flowing air was not saturated because of the nonuniform airflow through the structure, which caused the higher temperaure.

With airflow rate at 1.00 L/(s·m), the outflowing air temperature was +0.3°C with a saturation vapor pressure about 625 Pa (2.5 in. of water), which is lower than that of the incoming airflow at 745 Pa (2.98 in. of water), but the calculated vapor pressure of the out flowing air was only about 405 Pa (1.62 in. of water), 65% RH. Water vapor pressure of the outflowing air depends not only on the temperature but also on the airflow rate and flow pattern through the structure and the moisture conditions of the material layers. When the exfiltrating airflow rate is decreased, the temperature of the outflowing air also decreases. This means that with smaller airflow rates, the accumulation of moisture starts with higher outside air temperatures than in the reference case. Therefore, the amount of moisture accumulation in a structure due to air exfiltration will not show a linear correlation to the airflow rate with nonuniform airflows.

TABLE 4

Calculated Temperature of Air Flowing Out of the Structure ($T_{s,out}$) and the Minimum (min) and Maximum (max) Values for the Temperature (T_{cb}) of the Inner Surface of the Chipboard; the Outdoor Temperature at That Stage Was −9.5°C

Airflow Rate L/(m²·s)	Temperature (°C)		
	$T_{s,out}$	$T_{cb,min}$	$T_{cb,max}$
0.98	+5.9	-7.5	+0.2
0.50	+0.3	-8.0	-2.5
0.25	-3.7	-8.5	-4.1
0.10	-6.5	-8.7	-5.2
0.98 (uniformly distributed)	-8.6	-7.3	-7.3

With uniformly distributed air exfiltration, the out-flowing air temperature was as low as -8.6°C (Table 4), which is relatively close to the outside air temperature. In this case, the drying effect of the outflowing air, in terms of the saturation vapor pressure, is much lower than in the reference case. Uniformly distributed airflow will probably cause moisture accumulation to start at higher outdoor temperatures than in a nonuniform case.

Sensitivity Analysis

The weather pattern of Sodankylä was selected for the sensitivity analysis. In the reference case, with 1.96 L/(s·m) airflow rate in the beginning of July, about 45% of the maximum moisture content reached during a one-year simulation was retained by the structure. This result, as well as the local moisture content values during the heating seasons, indicate severe problems with the hygrothermal behavior of the structure at this location.

The exfiltrating airflow rate and the relative humidity of the inside air were changed according to Table 2. The calculation results are presented using the mass of moisture per surface area of structure as a function of time, corresponding to the results shown in Figure 9; Figure 11 shows the results for different airflow rates, Figure 12 the comparison between uniformly distributed and nonuniform airflow routes, and Figure 13 those for different inside air relative humidities.

When the airflow rate (Figure 11) was decreased from the reference value, the drying of the structure becomes slower. After a one-year simulation, the total mass of moisture in the structure with 1.00 L/(s·m) airflow rate was higher than that in the reference case. With airflow rate at 0.20 L/(s.m), the yearly maximum and the end value for the mass of moisture per structural area were about 4.1 kg/m^2 and 1.8 kg/m^2, respectively. These correspond to about 30% of those with almost ten times higher airflow rate in the Sodankylä climate.

Figure 11 results show that correlation between the air exfiltration flow rate and moisture accumulation is not linear. It is difficult to determine a limit value for a safe air exfiltration flow rate in a cold climate because the risk of

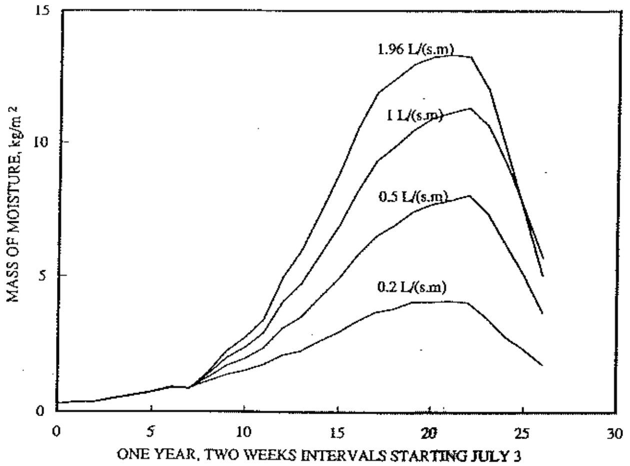


Figure 11 *The effect of exfiltration airflow rates on the total moisture absorption in the structure in climatic conditions of Sodankylä, Finland.*

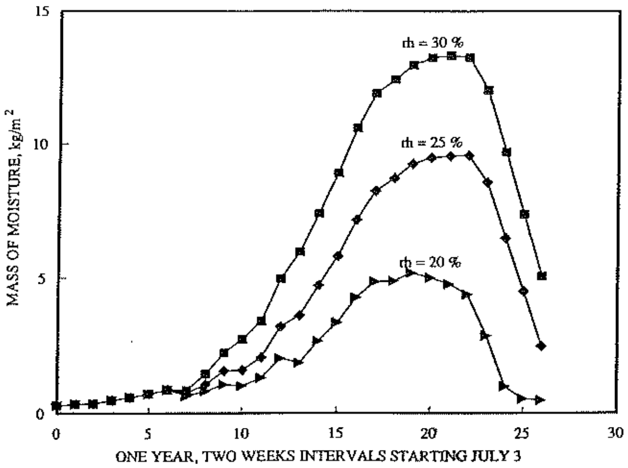


Figure 12 *Comparison of moisture accumulation between uniformly distributed and nonuniform exfiltration airflow.*

moisture accumulation is indicated also with a very low airflow rate. In very cold climates, any kind of air exfiltration will result in moisture accumulation at some location on the interface of the insulation and the sheathing considered here. If that moisture remains at that location for some period during the heating season, the temperature field within the cavity may favor chemical or biological processes that degrade the performance of the component in the wall assembly.

If the airflow rate of 1.96 L/(s·m) is uniformly distributed (Figure 12) over the surface area of the structure, moisture accumulation starts earlier than in the case with the reference airflow route. This is due to the low temperature and higher vapor pressure value of the air flowing out of the structure (Table 4). However, the uniformly distributed moisture dries out faster than the more locally accumulated situation from the reference case. The maximum value of total moisture mass in the cold climate was about 4% smaller than in the reference case with nonuniform airflow and in the mild Vancouver climate, about 45% higher, albeit still relatively small. In mild climates, the uniformly distributed air exfiltration may cause higher maximum values of moisture in structures than with the reference-type flow pattern.

According to the total accumulated mass of moisture in the structure, the differences in the hygrothermal behavior of the structure between uniformly distributed air exfiltration and the reference case are small. However, a nonuniform air exfiltration will cause much higher local moisture content values when compared with the uniform airflow. Therefore a nonuniform airflow may result in deteriorated hygrothermal behavior of the structure.

The effect of inside air relative humidity on moisture accumulation (Figure 13) was significantly stronger than that of the airflow rate. In the reference case, the partial vapor pressure of the inside air was already relatively low, 745 Pa (2.98 in. of water). When this was decreased to 500 Pa (2 in. of water), about 20% RH, the yearly cumulative effect could be avoided, but the maximum mass of moisture per structural area was still about 5 kg/m^2. On the other hand, high inside air vapor pressure values will also increase the risks of moisture accumulation in milder climatic conditions.

CONCLUDING REMARKS

The numerically analyzed cases of air exfiltration presented here show the risks of moisture accumulation in residential wall cavities and the effects of airflow rate, airflow route, inside air vapor pressure, and climatic conditions on the extent of moisture accumulation. Exact criteria and acceptable limit values for the variables of air

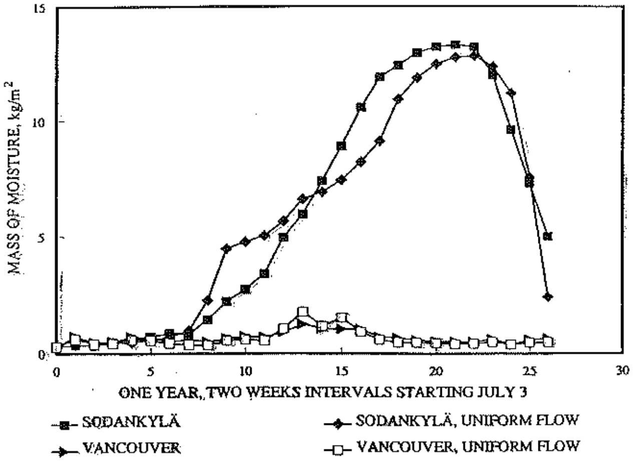


Figure 13 *The effect of inside air relative humidity (T_{in} = +21°C) on the moisture accumulation in the structure in climatic conditions of Sodankylä, Finland, with exfiltration airflow rate 1.96 L/(m^2·s).*

exfiltration cannot be given by simulation results only because the moisture distribution in real cases with three-dimensional heat, air, and moisture transfer differs from the numerical, two-dimensional approximation.

Moisture accumulation during air exfiltration depends on the vapor pressure of the air flowing into and out of the structure. Inside air relative humidity and temperature set the level for the convective moisture flow into the structure. When the outdoor temperature is low, say, under 0°C, the air flowing out of the structure has relatively low saturation vapor pressure. Depending on the indoor air vapor pressure, air exfiltration can bring more moisture into the structure than it can take out. Thus the main factors causing moisture accumulation during air exfiltration are the indoor and outdoor climatic conditions, especially vapor pressure and temperature. If the weather pattern has several months of cold, there may even be yearly moisture accumulation in the structure with typical indoor air vapor pressure values.

Though the amount of moisture accumulated depends on the airflow rate, from the practical point of view this is not the real issue. If the indoor and outdoor climatic conditions allow moisture accumulation, any small exfiltration airflow rates may produce high local moisture content values in material layers.

With uniformly distributed air exfiltration, moisture accumulation starts earlier in the weather cycle, but it will also dry out the structure faster than in the case of a nonuniform airflow. A nonuniform airflow may cause higher local moisture accumulation and, therefore, also more risks for the hygrothermal behavior of the structure than a uniform airflow.

According to the results from the present numerical analysis, a 10 Pa (0.04 in. of water) overpressure inside a building may cause harmful moisture accumulation within the wall and subsequent degraded hygrothermal behavior of the structure in most Canadian and Finnish locations. Though simulations show that, except in Resolute Bay, the cavity on the whole dries out in the warmer part of the annual cycle, at places such as Winnipeg severe cold weather results in the deposition moisture at certain preferred locations. These locations may remain wet for a considerable part of the year, and the long-term hygrothermal behavior of these locations may significantly differ from that of the rest of the wall assembly. Depending on the material behavior, geographic location (outdoor conditions), and indoor vapor pressure of the building, overpressurization may have to be avoided to ensure the long-term performance of the structure.

The work described in this paper is the result of a preliminary investigation. If one has to develop design guidelines, many calculations similar to those in the sensitivity analyses should be carried out. Furthermore, detailed information on the biological, physical, and chemical behavior of building materials, induced by moisture and temperature, should be available to assess the long-term performance of building components.

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