INVESTIGATION OF THE PERFORMANCE OF GYPSUM SHEATHING

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SUMMARY

The computer program EMPTIED was used to assess the moisture performance of representative brick veneer and exterior insulation finish system (EIFS) walls under the climate conditions for fifteen locations in Canada. The indoor conditions were assumed to be those expected in a one-bedroom apartment occupied by two persons which was ventilated with outdoor air at a constant rate of 0.3 air changes per hour.

The results obtained suggest that if insulation is installed in the stud space of either of these wall types, the temperature of the gypsum sheathing is likely to fall below the indoor dewpoint temperature in all locations unless an excessive thickness of exterior insulation is applied. If the stud space is left uninsulated, however, only modest thicknesses of exterior insulation should be able to maintain the sheathing temperature above the room dewpoint temperature. For walls with insulation in the stud space and 25 mm and 50 mm of exterior insulation, the limiting leakage areas that would restrict the moisture content of the gypsum sheathing to below that conducive to mold and mildew growth, and to that for saturation and possible structural deterioration, were determined for each city.

An experimental study in which gypsum sheathing was exposed to condensation conditions under a temperature gradient helped to establish the limiting moisture content conditions for these assessments but raised questions regarding the conventional assumption that condensation will occur on all surfaces which fall below the dewpoint temperature of the air in contact with them. When considered with the analyses and measurements of the some other researchers, the observations made suggest that condensation will form on non-absorptive surfaces that are below the dewpoint temperature but may not occur on absorptive materials until they reach a moisture content in equilibrium with 100% relative humidity. These observations further suggest a number of possibilities for the protection of gypsum sheathing from condensation and for the development of improved building envelope design details.

INVESTIGATION OF THE PERFORMANCE OF GYPSUM SHEATHING

EXECUTIVE SUMMARY

Gypsum sheathing used in brick veneer and exterior insulation finish system (EIFS) walls in high-rise residential buildings has exhibited mold and mildew growth and in some cases has become saturated with water when additional insulation has been installed in the space between the supporting metal studs. These conditions are usually attributed to the lowering of the sheathing temperature below the dewpoint of the indoor air and the resultant migration and condensation of moisture due to vapour diffusion and air exfiltration. Several approaches can be suggested that could avoid or alleviate these problems.

Condensation could be avoided if the sheathing is maintained at a temperature above the dewpoint temperature of the room air at all times. If the stud space is left uninsulated, modest amounts of insulation applied outside of the sheathing may be sufficient, but if insulation is applied between the studs, outside insulation thicknesses could become prohibitive.

Mold and mildew could possibly be avoided if the moisture content of the sheathing did not reach a level that allows development and growth of such microorganisms. In the case of wood and wood products this level is usually assumed to be the fibre saturation point, corresponding to the moisture content reached with continued exposure to air at 100% relative humidity.

Similarly, if the amount of moisture accumulating on the sheathing could be kept below that required for complete saturation, structural deterioration of the sheathing could presumably be prevented.

Protection of the gypsum sheathing from the effects of moisture condensing on its inner face offers another approach. Covering the inner face of the gypsum with a layer of Tyvek or similar vapour permeable but watershedding material would be one method, allowing water vapour to pass through but preventing condensed moisture from being absorbed at the surface of the sheathing. A more radical departure from traditional practice would involve using polyethylene film over the sheathing surface to prevent both vapour diffusion and water absorption into the sheathing. In both cases provision would have to be made to remove any condensed moisture to outside by drainage or other means.

In order to establish the appropriate limiting moisture content values and to observe the wetting characteristics of protected and unprotected gypsum sheathing under condensing conditions, an experimental study was undertaken during the late winter and early spring in Calgary. The lack of sustained cold weather conditions prevented any long term study of condensation conditions, but the measurements and observations made provided sufficient data to undertake an analysis of the suggested approaches using the EMPTIED computer progam for fifteen locations in Canada.

The indoor conditions used for the analyses were based on the monthly average outdoor conditions for each city assuming a ventilation rate of 0.3 air changes per hour for a one bedroom apartment of 70 square metres occupied by two persons whose activities generated 0.375 kilograms of moisture per hour. The indoor air temperature was assumed to be constant at 23° C throughout the year.

Based on these indoor conditions and utilizing the "bin" weather data for the particular location, the EMPTIED program was used to estimate the thickness of exterior insulation required to keep the sheathing surface above the room dewpoint temperature, presumably avoiding condensation, when the stud space was insulated or uninsulated. The limiting leakage areas required to keep the moisture content of the gypsum sheathing below the levels for mold and mildew development and below saturation were also calculated for walls with stud space insulation having 25mm and 50mm of exterior insulation applied. These data are presented in tabular format for each of the two wall types, brick veneer and EIFS.

During the experimental study, the published work of investigators in the USA on the analysis of moisture in walls relating to the NIST computer program MOIST was provided by CMHC. The USA experimental work confirmed the limiting moisture content values obtained for gypsum sheathing and the analytical approach taken by the USA investigators offered a basis for explaining some other observations obtained in the Calgary experiments.

In all of the studies in Calgary, no visible condensation was observed on the unprotected gypsum sheathing even when it was exposed to condensation conditions on the warm side. Furthemore, it exhibited no measurable increase in moisture content until a less permeable material was applied against its outer, colder surface. Under these latter circumstances, the gypsum board increased in moisture content, but only to a value representing that at equilibrium with 100% relative humidity. This may not have been a limiting value but weather conditions did not permit longer term testing. When Tyvek or polyethylene was used to protect the inner face of the sheathing, condensation on their surfaces was observed.

The observations with respect to unprotected gypsum sheathing are consistent with conventional diffusion theory, in that gypsum sheathing exhibits a water vapour permeance about equal to that of still air or mineral fibre insulation and the vapour pressure at its surface remains below the saturation vapour pressure at that location. On this basis, continuity of vapour flow is maintained and no condensation point is reached on or within the gypsum. When a less permeable material is located on the cold side of the sheathing, the vapour pressure at the interface may rise above the saturation vapour pressure and condensation could occur. The same reasoning could explain why condensation was observed on the polyethylene protected gypsum, but not why condensation occured on a highly permeable material such as Tyvek.

A logical answer is inherent in the USA investigators analytical approach. They do not assume that condensation occurs on any surface when it falls below the dewpoint temperature. If the material is non-absorptive such as Tyvek or polyethylene, condensation will occur. If the material is absorptive, it will first tend to increase in moisture content to come to equilibrium with air at 100% relative humidity. The absorbed moisture will migrate into the material and it will continue to increase in moisture content, until it reaches a level on its cold side that is in equilibrium with the conditions on that face. If the cold side face is exposed to an air space or in contact with equally permeable material, it may not be at 100% rh and diffusion may continue to a colder condensing surface. However, if the cold side face is covered with a less permeable material, conditions are likely to reach 100% relative humidity at the outer surface and the moisture content will increase further. If the vapour pressure levels are such that continuity of flow cannot be maintained, free moisture may begin to accumulate at the interface and the gypsum may eventually become saturated.

This analysis also serves to explain some observations in practice. Where saturation of gypsum sheathing has occured in brick veneer walls, sheathing paper has usually been involved. In EIFS walls the gypsum sheathing is covered with expanded polystyrene (EPS) insulation. In both cases a material of lower permeance has been applied to the exterior face and a moisture build-up would seem possible. This situation is inherent in EIFS walls but the elimination of sheathing paper in brick veneer construction might lead to fewer problems. The use of high permeance materials such as Tyvek as sheathing paper might satisfy diffusion theory but its non-absorptive characteristics might induce condensation. It could be suggested that the same phenomona may be factors in the mold and mildew occurrences experienced on interior gypsum board finishes.

Some further studies would seem to be necessary to investigate the effects of these features on moisture accumulation under steady state conditions as well as during exposure to natural weather. The steady state experiments could be carried out to assess the effects of longer term exposure and of maintaining more severe, below freezing conditions. The exposure tests under natural climate would be best for assessing the performance of full scale panels and particularly those involving inner face protection of the gypsum sheathing and drainage from the lower track of steel stud assemblies. It is planned to submit proposals for these additional studies for consideration by the CMHC External Grants Program.

INVESTIGATION OF THE PERFORMANCE OF GYPSUM SHEATHING

INTRODUCTION

Gypsum sheathing used in brick veneer and EIFS walls in high-rise residential buildings has exhibited mold and mildew growth and in some cases has become saturated with water when additional insulation has been installed in the space between the supporting metal studs. These conditions are usually attributed to the lowering of the sheathing temperature below the dewpoint of the indoor air and the resultant migration and condensation of moisture due to vapour diffusion and air exfiltration. Several approaches can be suggested that could avoid or alleviate these problems.

Condensation could be avoided if the sheathing is maintained at a temperature above the dewpoint temperature of the room air at all times. If the stud space is left uninsulated, modest amounts of insulation applied outside of the sheathing may be sufficient, but if insulation is applied between the studs, outside insulation thicknesses could become prohibitive.

Mold and mildew could possibly be avoided if the moisture content of the sheathing did not reach a level that allowed development and growth of such microorganisms. In the case of wood and wood products this level is usually assumed to be the fibre saturation point, corresponding to the moisture content reached with continued exposure to air at 100% relative humidity.

Similarly, if the amount of moisture accumulating on the sheathing could be kept below that required for complete saturation, structural deterioration of the sheathing could presumably be prevented.

The idea of protecting the gypsum sheathing from the effects of moisture condensing on its inner face offers other possilities.

Covering the inner face of the gypsum with a layer of Tyvek or similar vapour permeable but watershedding material would be one method, allowing water vapour to pass through but preventing condensed moisture from being absorbed at the surface of the sheathing. This would be in keeping with traditional concepts of condensation control, that of avoiding vapour barriers toward the exterior.

A departure from traditional practice would involve using polyethylene film over the sheathing surface to prevent both vapour diffusion and water absorption into the sheathing. In both cases provision would have to be made to remove any condensed moisture to outside through drainage or other means.

In order to establish the appropriate limiting moisture content values and to observe the wetting characteristics of protected and unprotected gypsum sheathing under condensing conditions, an experimental study was undertaken during the late winter and early spring in Calgary. The lack of sustained cold weather conditions prevented any long term study of condensation conditions, but the measurements and observations made, provided sufficient data to undertake an analysis of the suggested approaches using the EMPTIED computer progam for fifteen locations in Canada.

EXPERIMENTAL STUDIES

The basic test panel consisted of an 18 mm thick exterior plywood panel 200 mm wide and 2000 mm high with 18 mm x 50 mm furring strips around its perimeter and vertical centre line to create two separate, 400 mm wide simulated stud spaces. The panel was installed in an exterior door opening so that the simulated stud spaces were open to the building interior.

Two 400 mm x 2000 mm samples of gypsum wallboard were installed side-by-side to cover the interior face of this panel. The inside faces of both samples were initially left unprotected. An open-faced test chamber equipped with electric heaters and a recirculating humidifier was positioned against the samples to hold them in place and to maintain warm side conditions approaching 100% relative humidity.

The weather conditions initially experienced resulted in air temperatures of 5° to 7° C on the exterior side, (stud spaces) of the gypsum board samples with air temperatures of 10° to 15° C on the interior side. No evidence of condensation on the interior faces was observed during the first week and periodic weighing of the samples showed no measurable change. The test was therefore discontinued and the test chamber withdrawn.

In preparation for the next opportunity for cold weather conditions, one 400 mm wide gypsum board sample was covered with 6 mil polyethylene and the other left unprotected. In addition, a 25 mm thick layer of fibrous insulation (washable air filter media) was installed over the inside face of both samples. It was reasoned that this would lower the temperature at the sample faces well below the dewpoint temperature maintained in the test chamber. After a week long period with air temperatures of 0° to 5° C on the exterior face of the samples and test chamber conditions of 10° to 15° C approaching 100% relative humidity, water droplets were observed on the polyethylene over the lower portion of the protected sample, but no evidence of surface condensation was noted on the unprotected gypsum board. Neither gypsum board sample exhibited any measurable gain in weight. When the test chamber was pulled back and the samples freed for weighing, water droplets were observed over the inner face of the exterior plywood cladding in the stud space covered by the unprotected gypsum board, but the inner face of the plywood in the stud space covered by the poly-protected gypsum board was dry.

From a consideration of the information supplied by Jacques Rousseau regarding the NBS program MOIST, it seemed possible that highly permeable and absorptive materials such as gypsum board might not exhibit surface condensation until they became completely saturated, or unless the surface was well below freezing. It was also felt that a different situation might occur when the gypsum board was applied to a less permeable substrate such as the EPS insulation in EIF wall designs or if sheathing paper was installed as in brick veneer construction.

In order to investigate this aspect, an exterior acrylic gloss paint was applied to the outside face of the two gypsum board samples and they were re-installed in the test arrangement. For expediency, and anticipating the lack of suitably cold weather, the 6 mil polyethylene was replaced with a sheet of Tyvek and a final test was undertaken over several days when temperature conditions were similar to those experienced previously. Droplets of moisture were noticed on the surface of the Tyvek over the lower portion of the panel and the lower surface of the unprotected panel felt, and seemed to appear damp. Weighing of the samples indicated a gain of about 2% for the Tyvek protected sample and 3% for the unprotected sample. No noticeable condensation was apparent on the interior surface of the exterior plywood cladding in either stud space.

It became apparent during the week of April 12 that no suitably cold weather was likely to be experienced in Calgary this spring, and the test chamber study was discontinued.

ANALYSIS OF RESULTS

The conventional approach toward predicting condensation from air exfiltration assumes that condensation will occur on a surface that is below the dewpoint temperature of the indoor air. It is also assumes that if the estimated dewpoint temperature is located within an air space or within a very permeable material such as fibrous insulation, the condensing plane will be located at the next coldest surface. This is most likely to be the case for non-absorptive surfaces but absorptive surfaces may be a different matter.

The approach taken by Burch and Thomas (1) recognizes that absorptive materials will first take up water vapour from the air in accordance with the relative humidity to which they are exposed, reaching some limiting value at 100% relative humidity. In the case of wood based materials this is the so-called 'fibre saturation point.' For gypsum board it has been determined that the equilibrium moisture content at 100% rh is from 2.5% to 3% moisture content by weight (2). Equilibrium moisture contents for other sheathing materials have also been measured (2), as have their water vapour permeabilities under different mean relative humidities (3).

Two notable observations from these studies are :

- the very large increase in permeance exhibited by some materials at high relative humidities and,
- confirmation of the very high permeance of gypsum board - equivalent to that of the air films in the test arrangement.

Similar observations of the effect of relative humidity on permeance were made by researchers at NRC and Pennsylvania State College in the 1960's and the effect has always been recognized in discussing the different values obtained from the standard dry-cup and wet-cup test methods (4, 5).

The observations made in the current study suggest that gypsum board subjected to a temperature gradient may not exhibit condensation or a significant increase in moisture content even if it is at a temperature below the dewpoint temperature of the air at its warmer face. It can be suggested that this is a parallel situation to that of highly permeable fibrous insulation mentioned previously, where condensation will occur on the next coldest plane and any adsorbed moisture will migrate, by diffusion, to the colder, condensing surface.

In the first test undertaken, unprotected gypsum board separated two closed air spaces at different temperatures. The warm face was exposed to warmer, near saturated air in the humidified chamber with the cold side facing a colder, painted plywood surface across an air space. The warm side of the gypsum board was exposed to air at 100% relative humidity while the cold side was exposed to air at a relative humidity less than 100%, the outer air space dewpoint temperature being related to that of the colder inner face of the exterior plywood. Thus, moisture absorbed on the warm side of the gypsum board would tend to migrate by diffusion through the gypsum and be absorbed, or condense on the inner face of the exterior plywood. The gypsum should not be expected to reach a moisture content as high as that in equilibrium with 100% relative humidity.

In the second test, the warm side face of one sample was covered with 6 mil polyethylene and a one inch thick layer of permeable insulation was applied over both specimens. It would be expected that the inner surface of both samples would be at a temperature well below the dewpoint temperature of the air in the humidified chamber and moisture droplets on the polyethylene showed this to be the case. The absence of visible condensation on the unprotected gypsum board and lack of any gain in weight can be attributed to the drying effect of exposure to the cold condensing surface of the exterior plywood.

In the the third test, the exterior surface of both samples had been painted with an exterior gloss acrylic paint and the polyethylene film was replaced by a layer of Tyvek. Droplets of moisture were observed on the surface of the Tyvek and wetness was noted on the unprotected panel. Weighing of the panels indicated a similar increase in moisture content of from 2% to 3%. The paint film applied to the outer face of the gypsum board presumably inhibited drying to the exterior plywood and may have provided a non-absorptive surface for condensation. It could be that the vapour resistance of the paint film maintained conditions at 100% rh within the gypsum board or that condensation occured and even higher moisture contents might have been reached if the test had been continued for a longer period. The build-up of moisture in the gypsum board seems logical, but why was condensation observed on the very permeable Tyvek?

Although permeable to water vapour, Tyvek is not absorptive to liquid water and under condensation conditions water droplets could be formed. With absorptive surfaces, water vapour concentrations approaching 100% relative humidity first result in absorption and liquid water will not appear until the surface, or the material, reaches a point of saturation such as the "fibre saturation point" for wood based materials.

Burch and Thomas (1) refer to this as "maximum sorption", the point where liquid water begins to appear in the pore structure. When all pore structures are filled with liquid water the condition is referred to as "saturation". The values quoted for conifer softwoods such as are used in construction are 27% of the dry mass for "maximum sorption", and 230% for saturation. It is commonly accepted that for wood and wood based products, maximum sorption is the maximum amount of moisture that can be taken on without degredation (1, 2). Apparently the IEA have issued guidelines recommending lower values (3).

Richards et al. (3) have determined the sorption isotherms for a number of building materials including gypsum board, for which they found the "maximum sorption" to be around 2.5 to 3.5%. Richards (7) determined moisture contents at saturation of 175% for sugar pine, 100%

for particle board, 130% for plywood and 100% for gypsum board. This value for gypsum board is the same as that obtained by immersing gypsum board in water in a manner similar to the method commonly used in practice to determine the water absorption characteristics of bricks (8).

WALL PERFORMANCE EVALUATION

Some specifics of the original criteria for evaluation of walls incorporating gypsum sheathing were modified in view of the above analysis.

- the outer surface of the gypsum sheathing, representing the sheathing paper or inner face of foamed polystyrene insulation was chosen as the condensing plane, rather than the inner face of the gypsum board
- a permeance of 333 $ng/m^2 \times s \times Pa$ (resistance = 0.003 $m^2 \times s \times Pa/ng$) was assumed for the sheathing paper and foamed polystyrene insulation
- to be consistent with other investigators, a "maximum sorption" value of 3% was used in place of a measured saturation moisture content of the paper facing to indicate the potential onset of mildew and mold formation (the limiting moisture content for deterioration of gypsum board remained at 100%)
- all walls were considered to have a 6 mil polyethylene vapour barrier installed beneath the interior finish with a permeance of 3.4 $ng/m^2 \times s \times Pa$ (resistance = 0.294 $m^2 \times s \times Pa/ng$)

Two basic wall constructions, steel studs with brick veneer and steel studs with exterior insulation finish (EIFS) were assessed using the computer program EMPTIED using the "bin" weather data for fifteen cities across Canada.

The first analysis determined the thickness of exterior insulation (on the exterior face of the gypsum sheathing) that was required to maintain the temperature of the inner face of the sheathing above the dewpoint temperature of the indoor air. The second series determined the air tightness required to limit the maximum moisture content of the gypsum sheathing to 3%. The third series determined the air tightness required to limit the moisture content of the gypsum sheathing to 100%. The limiting air tightness was expressed as a leakage opening area in square centimetres per square metre (cm^2/m^2), one square metre being approximately the area of one stud space.

ESTIMATING INDOOR CONDITIONS

The indoor humidity conditions have a significant influence on the moisture performance of exterior envelope, particularly when air exfiltration occurs. It is reasonable to expect that indoor air temperatures will remain nearly constant at about 23° C but the humidity of the indoor air will be determined by the balance between moisture generated indoors by the occupants activities and the moisture lost through ventilation with outdoor air. The rates of moisture generation in residential occupancies is determined primarily by the number of occupants and estimates can be made on this basis. The moisture content of the ventilating air will, however, be determined by the climatic conditions of a particular area, as will the rate of moisture removal for a specific ventilation rate.

Current requirements for residential ventilation appear to be considering a value of 0.3 air changes per hour. Assuming a one bedroom suite occupied by two persons would have a volume of about 70 x 2.5 = 175 m^3, the rate of ventilation for 0.3 ach would be 52.5 m^3/h or 62.5 kg/h. With a rate of moisture generation of 0.375 kg/h, the increase in moisture content of the air would be 0.375/62.5 = 0.006 kg moisture/kg dry air.

Based on this value and the monthly outdoor conditions for each location, the average monthly indoor relative humidities for an air temperature of 23° C were calculated for each city and these values are listed in Table 1. They essentially represent maximum conditions for summer and minimum conditions for winter. Windows will likely be opened more in summer and the increased ventilation rate will lower indoor relative humidities. In winter, intentional humidification may be employed to raise indoor humidities, particularly in colder regions.

For purposes of this study the values shown are suggested as representative of the conditions likely to exist in similar occupancies in each locale, with no occupant operational involvement.

BRICK VENEER WALLS

The thermal and moisture properties of the basic brick veneer wall input to the EMPTIED program are as listed below.

	LAYER THICKNESS	THERMAL RESISTANCE	VAPOUR RESISTANCE
INSIDE SURFACE	10.00	0.12000	0.00000
GYPSUM BOARD	12.50	0.08000	0.00033
VAPOUR BARRIER	0.15	0.00000	0.29400
INSULATION	90.00	2.00000	0.00036
GYPSUM SHEATHING	12.50	0.08000	0.00033
INSULATION	25.00	0.62500	0.00300
AIR SPACE	25.00	0.17000	0.00015
BRICK	100.00	0.08000	0.02200
OUTSIDE SURFACE	10.00	0.04000	0.00000

The results of the analyses undertaken are shown in Table 2. The thicknesses of exterior insulation required to maintain the interior face of the gypsum board above the dewpoint temperature of the indoor air with no insulation in the stud space are listed in the first column. The thicknesses required for each locale with insulation installed in the stud space are listed in the second column.

It will be noted that when no insulation is installed in the stud space, 25 mm of exterior insulation is sufficient to avoid condensation in all locations except for Winnipeg, where 38 mm is required. When the stud space is insulated, at least 100 mm of exterior insulation is indicated.

The third and fourth columns list the maximum leakage opening areas (cm^2/m^2) that will allow the moisture content of the gypsum sheathing to reach a value of 3%, when conditions for mold or mildew might be expected to be maintained. Both columns represent walls with insulation installed in the stud space (walls with an uninsulated stud space were not considered since only one city, Winnipeg, was likely to be a candidate).

The third column relates to walls with 25 mm of exterior insulation while the fourth column represents walls where 50 mm of exterior insulation is installed.

The fifth and sixth columns list the maximum leakage opening areas (cm^2 / m^2) that will allow the calculated moisture content of the gypsum sheathing to reach 100%, when the gypsum would be saturated. Again, both columns apply to a wall with insulation installed in the stud space, the fifth column relating to 25 mm of external insulation with the sixth column listing values for 50 mm of external insulation.

EIFS WALLS

The thermal and moisture properties of the basic EIFS wall input to the EMPTIED program are as listed below.

	LAYER THICKNESS	THERMAL RESISTANCE	VAPOUR RESISTANCE
INSIDE SURFACE	10.00	0.12000	0.00000
GYPSUM BOARD	12.50	0.08000	0.00033
POLYETHYLENE	0.15	0.00000	0.29400
INSULATION	90.00	2.00000	0.00036
GYPSUM SHEATHING	12.50	0.08000	0.00033
EPS INSULATION	25.00	0.62500	0.00300
STUCCO	10.00	0.02000	0.00212
OUTSIDE SURFACE	10.00	0.03000	0.00000

The results of the analyses undertaken are shown in Table 3. The thicknesses of exterior insulation required to maintain the interior face of the gypsum board above the dewpoint temperature of the indoor air with no insulation in the stud space are listed in the first column. The thicknesses required for each locale with insulation installed in the stud space are listed in the second column.

It will be noted that when no insulation is installed in the stud space, 25 mm of exterior insulation is sufficient to avoid condensation in all locations except for Quebec City, wher 38 mm is required. When the stud space is insulated, at least 100 mm of exterior insulation is required, except for Vancouver.

The third and fourth columns list the maximum leakage opening areas (cm^2/m^2) that will allow the moisture content of the gypsum sheathing to reach a value of 3%, when conditions for mold or mildew might be expected to be maintained. Both columns represent walls with insulation installed in the stud space (walls with an uninsulated stud space were not considered since only one city, Quebec, was likely to be involved). The third column relates to walls with 25 mm of exterior insulation while the fourth column represents walls where 50 mm of exterior insulation is installed.

The fifth and sixth columns list the maximum leakage opening areas (cm^2 / m^2) that will allow the calculated moisture content of the gypsum sheathing to reach 100%, when the gypsum would be saturated. Again, both columns apply to a wall with insulation installed in the stud space, the fifth column relating to 25 mm of external insulation with the sixth column listing values for 50 mm of external insulation.

WALLS WITH PROTECTED GYPSUM SHEATHING

It would seem reasonable to assume that a layer of polyethylene over the inside face of gypsum sheathing would prevent any increase in moisture content of the sheathing due to water vapour from indoors, and the limited experimental study demonstrated this. It might be suggested that a layer of Tyvek could limit the moisture content attained by the gypsum board to that resulting from exposure to 100% relative humidity on the warm side. The experimental study was not of sufficient duration to establish this, but if the Tyvek was able to prevent liquid water from contacting the absorbent surface of the gypsum board its moisture content could conceivably be limited to 3% with this approach.

In consideration of these possibilities, the amount of moisture that could accumulate on a protective polyethylene layer could be estimated from the results for the situations of columns three and four, and for both the polyethylene and Tyvek protective layers for the situations of columns five and six. The gypsum board would be assumed to remain dry under the polyethylene and reach a maximum of 3% under the Tyvek. The moisture accumulation would represent the potential amount of moisture to be drained from the lower track in each case.

CONCLUSIONS AND RECOMMENDATIONS

The computer program EMPTIED has been used to assess the moisture performance of representative brick veneer and EIFS walls for fifteen locations in Canada. The results suggest that if insulation is installed in the stud space of either of these wall types, the temperature of the gypsum sheathing is likely to fall below the indoor dewpoint temperature in all locations unless an excessive thickness of exterior insulation is applied. If the stud space is left uninsulated, only modest thicknesses of exterior insulation should be able to maintain the sheathing temperature above the room dewpoint temperature.

For walls with insulation in the stud space, the limiting leakage areas to avoid; 1) moisture contents conducive to mold and mildew growth and, 2) saturation of the gypsum sheathing, were calculated for each of the locations. These values were based on the estimated indoor conditions for a specific occupancy based on a continuous ventilation rate of 0.3 air changes per hour and the published monthly average outdoor conditions for the city involved.

The experimental observations provided some support for the moisture absorption criteria used in the calculations but raised questions regarding the conventional assumption that condensation will occur on all surfaces which fall below the dewpoint temperature of the air in contact with them. When considered with the analyses and measurements of the some other researchers, the observations made suggest that the processes leading to moisture build-up on components that fall below the predicted dewpoint temperature might be as follows:

- if an absorptive surface falls below the dewpoint temperature it tends to absorb water vapour until it comes to a moisture content in equilibrium with air at 100% relative humidity
- the absorbed moisture migrates by diffusion or by other means into the material and the material increases in moisture content
- if the outer surface is exposed to an equally permeable or more permeable component, the moisture will continue to diffuse outward, presumably toward a surface at which a lower vapour pressure is maintained. In this case, the material may never reach the "maximum sorption" or "fibre saturation" value
- if evaporation from the outer surface is inhibited by a less permeable material, the moisture content of the material will tend to increase, eventually reaching or exceeding the "maximum sorption" or "fibre saturation" value
- when the material reaches the "maximum sorption" value, condensation as liquid water could be initiated at the surface and might lead to a further increase in the moisture content of the material up to the "saturation" value
- when the condensing surface is below freezing it may be that condensation will occur as frost even on absorbent surfaces but will be absorbed and migrate as liquid water when conditions rise above 0^{o} C

The implication of these processes in regard to current wall constructions utilizing gypsum sheathing need to be considered.

In situations where the exterior surface of gypsum sheathing is left exposed to the air space behind brick veneer or precast concrete, or where highly permeable fibrous insulation board is applied without adhesives, the gypsum board may not reach serious moisture levels from air leakage or vapour diffusion from the indoors.

In most EIFS and brick veneer walls, however, a less permeable material covers the exterior face of the gypsum sheathing; in EIFS walls it is the adhesive and foamed polystyrene insulation, in brick veneer it is usually asphalt saturated sheathing paper or 15# roofing felt.

The permeance of 25 mm thick EPS bead board is between 116 - 336 ng/m^2 x s x Pa, about one tenth of that for gypsum board (2860 ng/m^2 x s x Pa). Other EIFS walls utilizing mechanically fastened, rigid mineral fibre insulation instead of foamed polystyrene might exhibit a permeance of 2450 ng/m^2 x s x Pa, equivalent to that of gypsum board.

Asphalt saturated sheathing paper as used in brick veneer construction can exhibit a permeance of from 190 to 1160 ng/m^2 x s x Pa, and 15# roofing felt can exhibit a permeance of from 57 to 320 ng/m^2 x s x Pa, values that are generally lower than that of gypsum board.

With these less permeable materials applied to its outer surface, the inner surface of the gypsum will begin to absorb vapour from the air as the relative humidity increases and the moisture content will increase until the gypsum board reaches the maximum sorption value. If the inner surface is below the dewpoint temperature under these conditions, condensation as liquid water may occur, increasing the moisture content further until saturation is reached.

It might be concluded from this analysis that walls with sheathing paper or with less permeable exterior insulation are more likely to experience moisture accumulation in the gypsum sheathing than walls where the sheathing paper is omitted or where more permeable exterior insulation is employed.

As was observed, and consistent with the foregoing analysis, covering the inner face of gypsum sheathing with polyethylene will prevent condensed moisture being absorbed by the gypsum sheathing. If the exterior surface is exposed to an air space or to permeable insulation, the exterior surface of the sheathing will tend to come to equilibrium with the lower vapour pressures in the exterior colder regions of the wall and hence to relative humidities of less than 100%.

If a vapour permeable but non-absorptive material such as Tyvek is applied over the inner surface, it will likely protect the inner face of the sheathing from liquid water but the relative humidity at the inner face of the sheathing will be close to 100% and the gypsum board will tend to reach a moisture content approaching maximum absorption (2.5 to 3%). The relative humidity at the outer face of the sheathing will be determined by the permeance of the adjacent materials; lower with permeable materials and higher with less permeable materials.

In both of these cases provision must be made for drainage of the condensed liquid to outside, otherwise the moisture accumulated in the space will continue to maintain conditions at 100% relative humidity and little drying will be achieved even when warmer temperatures prevail.

With brick veneer-steel stud construction the creation or provision of drain holes in the lower track would allow such drainage to take place onto the required flashing above the ledger angle, and through weep holes to outside. With field-constructed EIFS walls, suitable flashing could be provided under the lower track and carried through an open horizontal joint to the exterior. The drainage openings could be designed into the metal framing of factory-prefabricated EIFS panels and similar flashing arrangements carried out at the horizontal joints.

If no such drainage arrangements are made and moisture is allowed to accumulate in the lower track, premature failure of the sheathing and metal framing could be expected. On the other hand, provision of adequate drainage openings and inner surface protection of gypsum sheathing could result in the successful moisture performance of wall systems where some air leakage openings or vapour barrier imperfections occur.

It should also be recognized that in both systems, the outer flange of the steel stud to which the sheathing is attached is also a non-absorbent surface and similarly prone to condensation of moisture on its surface. It may thus act as a locale for condensation of vapour that might otherwise diffuse through the gypsum sheathing, which if not drained away, may serve to maintain high moisture conditions within the stud space.

The metal studding is also a locale for air circulation across the insulated stud space. The metal studs consist of open-sided channels with the edges of the "legs" of the vertical members bent inward to provide added stiffness. When batt insulation is inserted into the open side of the stud, vertical, vee-shaped channels tend to be created in the insulation and these will permit air circulation across the insulation (9). If an opening through the interior finish exists at this location, room air may be drawn into the stud space and circulate around the insulation to contact the sheathing and exterior leg of the stud.

Further experimental studies on the performance of gypsum sheathing under condensation conditions would be necessary to validate the moisture absorption processes outlined or to confirm the suggested design approaches. The processes would best be investigated under controlled conditions in order that sufficient time could be allowed for moisture pick up and temperatures below freezing could be maintained. Based on the outcome of such studies, laboratory and field investigation of full scale panels with different design features could be undertaken.

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TABLE 1

ESTIMATED INDOOR HUMIDITIES IN OCCUPIED APARTMENTS

	VIC	VAN	EDM	CAL	REG	WIN	THU	TOR	OTT	MON	QUE	FRE	CHA	HAL	STJ
JANUARY	47	45	30	31	29	28	29	35	32	32	31	33	35	39	38
FEBRUARY	49	48	32	33	30	29	30	35	33	33	31	33	34	38	37
MARCH	48	49	35	35	34	33	34	39	37	37	35	37	38	40	39
APRIL	52	52	41	39	41	42	40	46	45	44	41	43	43	46	42
MAY	57	59	48	46	50	50	49	57	57	57	52	53	52	54	48
JUNE	63	67	59	55	62	66	62	72	73	74	68	67	66	66	58
JULY	68	73	68	62	70	77	73	80	82	84	77	78	79	78	71
AUGUST	69	74	67	61	65	77	72	81	80	82	74	77	79	80	72
SEPTEMBER	66	69	54	50	53	59	60	70	69	69	63	65	67	73	63
OCTOBER	59	60	43	41	43	47	48	56	54	54	50	52	55	59	53
NOVEMBER	52	58	36	35	35	37	39	47	44	44	41	44	47	52	48
DECEMBER	50	54	32	32	31	31	32	38	35	35	33	36	38	42	41

TABLE 2

STEEL STUD BRICK VENEER WALLS

	NO CONDENSATION STUD SPACE INSULATION		MOISTURE CONTENT 3% EXTERIOR INSULATION		MOISTURE CONTENT 100% EXTERIOR INSULATION	
	NO	YES	25mm	50mm	25mm	50mm
	EXTERIOR INSULATION REQ'D		LIMITING LEAKAGE AREA		LIMITING LEAKAGE AREA	
VICTORIA	0 mm	125 mm	0.05	1.5	1.80	47
VANCOUVER	13 mm	125 mm	0.04	0.5	1.60	13
EDMONTON	25 mm	200 mm	0.03	0.21	1.0	6.7
CALGARY	25 mm	200 mm	0.04	0.23	1.25	7.5
REGINA	25 mm	200 mm	0.03	0.12	1.0	4.0
WINNIPEG	38 mm	225 mm	0.03	0.13	1.0	4.5
THUNDER BAY	25 mm	200 mm	0.03	0.13	1.0	4.5
TORONTO	25 mm	150 mm	0.05	1.10	1.8	35.0
OTTAWA	13 mm	150 mm	0.03	0.13	1.0	4.3
MONTREAL	13 mm	150 mm	0.043	1.2	1.5	35.0
QUEBEC CITY	13 mm	150 mm	0.023	0.10	0.85	3.25
FREDERICTON	13 mm	150 mm	0.025	0.11	0.95	3.8
CHARLOTTETOWN	13 mm	125 mm	0.023	0.11	0.86	3.8
HALIFAX	13 mm	125 mm	0.022	0.09	0.86	3.1
ST. JOHN'S	13 mm	100 mm	0.02	0.13	0.82	4.0

TABLE 3

STEEL STUD EIFS WALLS

	NO CONDENSATION STUD SPACE INSULATION NO	NO CONDENSATION STUD SPACE INSULATION YES	MOISTURE CONTENT 3% EXTERIOR INSULATION 25mm	MOISTURE CONTENT 3% EXTERIOR INSULATION 50mm	MOISTURE CONTENT 100% EXTERIOR INSULATION 25mm	MOISTURE CONTENT 100% EXTERIOR INSULATION 50mm
	EXTERIOR INSULATION REQ'D		LIMITING LEAKAGE AREA		LIMITING LEAKAGE AREA	
VICTORIA	13mm	100mm	0.03	0.30	1.20	10.0
VANCOUVER	13mm	75mm	0.03	0.14	1.10	4.5
EDMONTON	25mm	175mm	0.02	0.07	0.75	2.5
CALGARY	25mm	163mm	0.03	0.12	0.90	4.2
REGINA	25mm	175mm	0.03	0.07	0.77	2.5
WINNIPEG	25mm	200mm	0.02	0.07	0.77	2.5
THUNDER BAY	25mm	200mm	0.02	0.05	0.64	1.7
TORONTO	75mm	200mm	0.04	0.90	1.25	17.5
OTTAWA	25mm	175mm	0.02	0.08	0.84	2.8
MONTREAL	25mm	175mm	0.03	0.20	1.05	6.8
QUEBEC CITY	38mm	125mm	0.018	0.06	0.68	2.0
FREDERICTON	25mm	125mm	0.02	0.07	0.78	2.4
CHARLOTTETOWN	25mm	125mm	0.02	0.05	0.67	1.87
HALIFAX	0mm	113mm	0.016	0.06	0.66	1.7
ST. JOHN'S	13mm	113mm	0.015	0.05	0.62	1.72