# A PROCEDURE FOR ESTIMATING THE MOISTURE PERFORMANCE OF BUILDING ENVELOPES

Louis Reginato[1] and Gustav Handegord[2]


## ABSTRACT

E.M.P.T.Y., a computer program for estimating Envelope Moisture Performance Through the Year, is described. It is based on the calculated, steady state thermal conditions resulting from the anticipated, incremental changes in the indoor to outdoor temperature difference for a given locality. Monthly "bin" data, primarily intended for energy analysis, are utilized to calculate the thermal conditions within a particular envelope, and the amount of condensation expected is determined on the basis of the psychrometric processes involved. The arrangement and moisture storage capacity of the materials in the assembly, and the temperature conditions to which they are exposed, are proposed as a basis for evaluating the potential for moisture problems to develop.

Application of the program in determining limiting values for air leakage criteria, in establishing design principles, and as a basis for materials selection and development are discussed, with consideration given toward simplification of the procedure and to the incorporation of vapour diffusion as a contributing mechanism.


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## INTRODUCTION

The computer program E.M.P.T.Y., Envelope Moisture Performance Through the Year, was developed as part of a project undertaken by TROW Consulting Engineers for Canada Mortgage and Housing Corporation (CMHC). The overall objective of the project was to develop a set of criteria for the air leakage characteristics required of exterior envelopes of buildings to avoid problems from concealed condensation. E.M.P.T.Y was developed as a means to predict the amount of condensation likely to accumulate in an exterior envelope as a result of air leakage due to stack effect during a representative year.

The program calculates the rate of accumulation and rate of removal of moisture resulting from air exfiltration based on the temperature gradient through the envelope, the dewpoint temperature of the indoor and outdoor air, and the rate of air flow through the envelope. The approach taken considers the psychrometric processes and principles involved and their application in predicting the rates of moisture accumulation during an annual cycle [1]. Consideration is given to the effects of drainage and of moisture storage within the building products and materials currently used in the exterior envelopes of low- and high-rise residential buildings.

## THE ANALYTICAL MODEL

The physical model on which the program is based is illustrated in Figure 1.

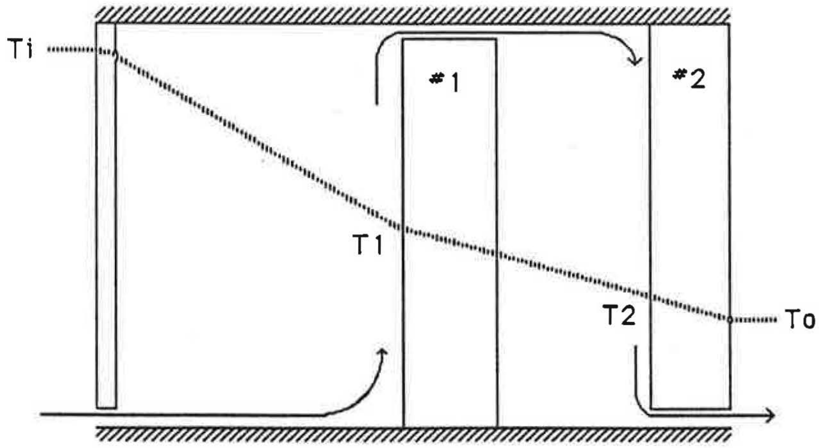


**FIGURE 1**

The following assumptions were made in the development of the program:

1. The model assumes multi-layer construction consisting of spaces that are closed at their perimeter but interconnected, in series, by small openings of equal cross-sectional area extending through the intervening materials. The intervening materials and lateral boundaries themselves are assumed to be impermeable to the flow of air.
2. Steady state conditions are achieved after an incremental change in boundary conditions.
3. Components are either saturated with water or at a moisture content in equilibrium with the relative humidity of the air at the particular location.
4. Condensation occurs on all solid surfaces that are below the dewpoint temperature of the air at that particular location. Evaporation occurs on all solid surfaces that are above the dewpoint temperature at that particular location.
5. Air leakage through the envelope has no influence on the thermal conditions within the envelope.
6. There is continuity of air flow through the model.
7. The rate if air flow varies with the pressure difference to the power $n = 0.7$.

## ENGINEERING AND COMPUTATIONAL PROCEDURE

The following general procedure is used by the program in the determination of moisture conditions within the envelope.

1. Selection is made by the user from a list of exterior wall constructions typical of low- and high-rise residential construction.
2. The outdoor temperature at which Plane 1, (typically the inner face of a non-porous sheathing), reaches a temperature equal to the indoor dewpoint temperature is determined from the thermal characteristics of the envelope, the indoor dry bulb temperature and the indoor dewpoint temperature. This temperature is referred to as OUTEMP. This establishes the outdoor temperature below which condensation will begin to occur at Plane 1. At this point the moisture content of the interior air, $W_{in}$, is also calculated.
3. Three general conditions are then evaluated.
   (a) The outdoor temperature is above the indoor temperature. - This establishes the condition where stack effect is reversed and outdoor air infiltrates.
   (b) The outdoor temperature is below OUTEMP. - In this case air is exfiltrating.
   (c) The outdoor temperature is above OUTEMP but is below the indoor temperature. - In this case air is exfiltrating.
4. Outdoor Dry bulb temperatures taken from the ASHRAE program BINREAD [2], as organized in "bins" for each month are then assessed in light of the aforementioned three categories. "Bin "data is organized in such a way that each month is broken down into the total number of hours that temperatures within a given two degree temperature spread occurs. The total hours are further broken down into six, four hour "bins".

   The lower value for all two degree temperature spreads in the month are fitted into one of the above categories and the resulting moisture conditions within the envelope are evaluated. For each outdoor temperature the pressure differential due to stack pressure is determined and the resultant air flow and mass flow are calculated. As well, the temperatures of Plane 1 and Plane 2 corresponding to the particular outdoor temperature, and the saturation moisture contents in kilograms of moisture per kilogram of dry air associated with the temperatures of Planes 1 and 2, ($W_1$ and $W_2$), are calculated. In each category the resultant condensation or evaporation is multiplied by the total number of hours that the temperatures within the given two degree spread occurred.

) Outdoor Temperature Above Indoor Temperature - Infiltration

If the outdoor dry bulb temperature falls within this category then air is infiltrating. Under most conditions the outdoor air will be humidified if any moisture is present at Plane 2. The amount of moisture evaporated from Plane 2, per kg of air flow,will be equal to the difference between the outdoor air moisture content ($W_o$) and the moisture content of saturated air associated with the temperature at Plane 2 ($W_2$). The air at Plane 2 is assumed to be at 100% rh and at a dry bulb temperature equal to the dewpoint temperature. The air then leaves Plane 2 saturated at a temperature equal to the air temperature existing at Plane 2. Since the temperature gradient is decreasing towards the inside, condensation (dehumidification) will then occur at Plane 1. The amount of condensation per kg of air flow, will thus be equal to the difference between the moisture content of the approaching air ($W_2$) and the moisture content of saturated air corresponding to the temperature at Plane 1 ($W_1$).

It is also possible that condensation may occur at Plane 2 if the outdoor air is extremely humid ($W_o > W_2$). In this case the air is dehumidified. The amount of moisture removed per kg of air flow would be equal to the difference in moisture content of the incoming air ($W_o$) and the moisture content corresponding to saturated air at the Plane 2 temperature ($W_2$). Condensation will then occur at Plane 1, as described above.

If Plane 2 is dry (no moisture in the material) and $W_o$ is less that $W_2$ then the incoming air is cooled to the temperature of Plane 2 but no condensation takes place. Condensation or evaporation will then occur at Plane 1 depending on the respective moisture contents $W_2$ and $W_1$.

i) Outdoor Temperature is below OUTEMP - Exfiltration

In this case the temperature decreases towards the outdoors and therefore both planes will experience condensation. Exfiltrating air will first encounter Plane 1 which will be at a temperature below the indoor dewpoint. The air is cooled and dehumidified and will leave Plane 1 saturated (100% rh) with a dewpoint temperature equal to the Plane 1 temperature. The amount of moisture condensed, per kg of air flow, will be equal to ($W_{in}$-$W_1$). The leaving air will then encounter Plane 2 whose temperature will be below the Plane 1 dewpoint temperature. The amount of condensation per kg of air flow will be equal to ($W_1$-$W_2$.) Air leaves this point saturated at the Plane 2 temperature and mixes with the outdoor air.

(iii) Outdoor Temperature Between Indoor Temperature and OUTEMP - Exfiltration

In this category air is exfiltrating and a condition for evaporation of moisture from Plane 1 and Plane 2 is possible if outdoor temperatures result in temperatures at Plane 1 or Plane 2, that are above the their respective controlling dewpoints.

If Plane 1 is wet then exfiltrating air will be cooled and humidified. The amount of evaporation, per kg of air flow, will be equal to $W_1$-$W_{in}$ The air will leave Plane 1 saturated (100% rh) with a dewpoint temperature equal to the Plane 1 temperature. Condensation and consequent dehumidification will then occur at Plane 2 since the temperature decreases towards the outdoors and the approaching air is saturated at the Plane 1 temperature. The amount of condensation, per kg of air flow, will be equal to $W_2$-$W_1$.

If Plane 1 is dry, then the exfiltrating air will be cooled to the Plane 1 temperature. Condensation or evaporation may toccur at Plane 2 depending on the moisture contents $W_1$ and $W_2$. Evaporation will occur at Plane 2 when the exterior temperature rises above the temperature which results in a Plane 2 temperature above the dewpoint temperature established at Plane 1.

(iv) Summation of the Data

The results of each month are then summed. The amounts of condensation and evaporation at each plane are summed separately according to the category and particular circumstance in which the condensation or evaporation occurred. This allows for manipulation of the data later in the program where some condensation and evaporation components are considered only if special circumstances exist, e.g. Plane 1 or Plane 2 is dry. As well, the effects of the condensation and evaporation component are dependent upon the previous month's results.

5. The results of the bin data analysis are compiled on a monthly basis. Condensation and evaporation components are summed separately with consideration given to the moisture contents of Plane 1 and Plane 2 of the present and previous month. If condensation exceeds evaporation then the accumulation is considered to be absorbed by the material used. If the absorbed amount exceeds a predetermined maximum absorption for that particular material, then the difference between the material's absorption capacity and the amount to be absorbed is assumed to drain from the material.

   If evaporation exceeds condensation and the material is wet, then the net amount is subtracted from the absorbed moisture.

ı. A printout of the results, specifying the condensation, evaporation, drainage and absorption of moisture in kg per square meter of envelope area, is then presented for Plane 1 and Plane 2.

## ERALL PROGRAM FRAMEWORK

The overall program framework of E.M.P.T.Y. consists of two programs written BASIC, combined and then compiled using the TURBOBASIC utility. The first gram constitutes the analysis of the "bin data" in terms of condensation and evaporation in the building envelope. The second, entitled BINREAD, is an ASHRAE program provides "bin data" for five Canadian cities, Vancouver, Edmonton, Winnipeg, onto and Montreal. BINREAD has been modified and incorporated into E.M.P.T.Y. se programs are supported by data files that contain meteorological information for the ve cities. The program flowchart is presented in Figure 2.

## STEM REQUIREMENTS

In order to run E.M.P.T.Y. the following equipment is required.

1. IBM or compatible MS-DOS microcomputer with a minimum of 128k memory,
2. At least one 320 or 360K 5 1/4" floppy disk drive,
3. A monitor, either monochrome or colour,
4. PC or MS-DOS 3.0 or higher,
5. Compatible dot-matrix printer.

## M.P.T.Y. SOURCE CODE

The source code for E.M.P.T.Y. and BINREAD is written in BASIC. The code is ed in ASCII format and may be accessed with a number of editors. Turbo BASIC was d to write the program.

Any user familiar with BASIC will find modification of the program relatively aightforward. A program listing has been provided to more easily facilitate any difications. Although the program will operate without compiling, it is recommended it it be compiled. E.M.P.T.Y. was compiled using the Turbo BASIC compiler. wever, any compatible compiler may be used.

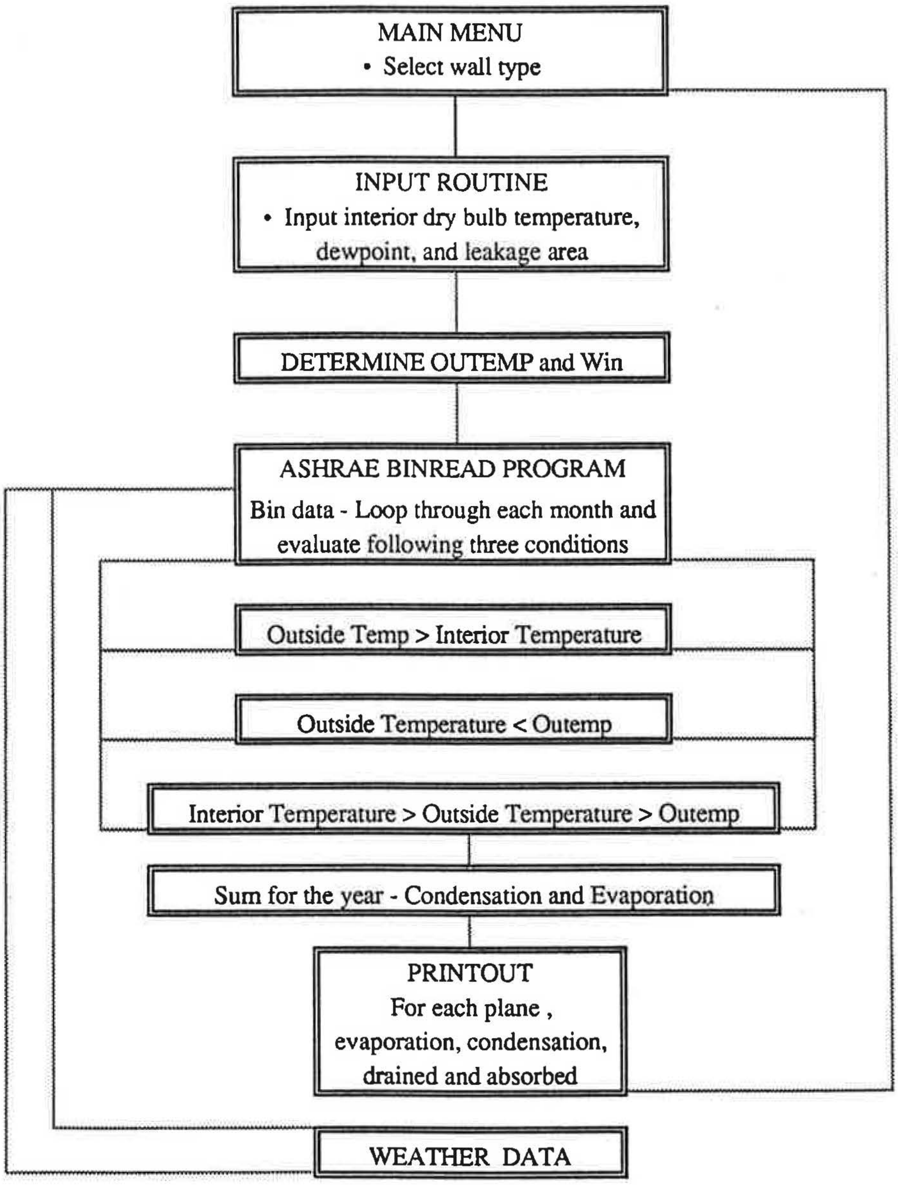


**FIGURE 2**
**PROGRAM FLOWCHART**

## LICATION OF THE PROGRAM

The program was used to determine the rate of air leakage that would result in the ure content of materials within a particular envelope just reaching the level at which oration would begin to occur, a level established through a series of questionnaires to iel of experts. Four representative wall constructions were chosen and calculations rtaken for the five climate regions available on the ASHRAE diskettes. The results are narized in Table 1 with the materials that reached a critical moisture content in each underlined.

It is interesting to note that the limiting leakage area will tend be greater if the ure storage capacity of the materials involved are increased, such as by increasing thickness. If drainage from the condensing planes is provided, as assumed in the am, the use of a non-absorbent material, or the application of a non-absorbent surface absorbent material, should eliminate any problems due to condensation on that plane. ent "rules" regarding the location of vapour barriers may be violated, however.

**TABLE 1**

LIMITING LEAKAGE OPENING AREAS

$(\text{centimetre})^2 / (\text{metre})^2$ per storey

| WALL 1 | WALL 2 | WALL 3 | WALL 4 |
|---|---|---|---|
| /psum Board | Gypsum Board | Gypsum Board | Gypsum Board |
| Insulation | Insulation | Insulation | Insulation |
| Waferboard | Gypsum Sheath | Glass Fiber | Polystyrene |
| Hardboard | Brick | Hardboard | Hardboard |
| **MONTREAL** | | | |
| 0.42 | 0.97 | 0.11 | 0.11 |
| **TORONTO** | | | |
| 0.44 | 1.0 | 0.12 | 0.12 |
| **WINNIPEG** | | | |
| 0.29 | 0.66 | 0.09 | 0.09 |
| **EDMONTON** | | | |
| 0.34 | 0.77 | 0.10 | 0.10 |
| **VANCOUVER** | | | |
| 0.57 | 1.4 | 0.12 | 0.12 |

Comparison of Walls 3 and 4 suggests that both constructions have the same effect on the moisture content of absorbent siding. The current program only considers air leakage, however, and with vapour diffusion included, the result should be quite different. Incorporation of vapour diffusion as a parallel mechanism in the program is to be undertaken, based on the same psychrometric principles. This should also enable the program to be used to evaluate the moisture performance of walls in hot as well as cold climates.

The results given by the program for these and other constructions are to be compared with those obtained from a simpler, graphical technique based on Reference [1], using only monthly average temperatures for the particular locality. Consideration is also being given to augmenting the program to employ limiting criteria based on the length of time that wet materials are exposed to temperatures at which deterioration could take place.

## ACKNOWLEDGEMENTS

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## REFERENCES

[1] Handegord, G. O. "Prediction of the Moisture Performance of Walls," ASHRAE Transactions, Volume 91, Part 2, 1985.

[2] Bin and Degree-hour Weather Data for Simplified Energy Calculations, Disk 1 - Canada and Northwestern U.S. / Zones 1 &2. ASHRAE, Atlanta, 1985.