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National Institute of Standards and Technology

NIST Special Publication 853

MOIST

A PC Program for Predicting Heat and Moisture Transfer in Building Envelopes

Release 2.0

Douglas M. Burch and William C. Thomas

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- Computer Services[2]
- Computer Systems and Communications[2]
- Information Systems

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[1]At Boulder, CO 80303.
[2]Some elements at Boulder, CO 80303.

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CONTENTS

DISCLAIMER AND CONDITIONS

The authors have made a concerted effort to find and remove errors in the coding of program MOIST. However, we make no guarantee that the program is free from errors or that the results produced with it will be free of errors. We assume no responsibility or liability for the accuracy of the program or for the results which may come from its use.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) has consented to permit NIST to use their WYEC hourly weather data for six U.S. cities with MOIST. These weather data will permit you to learn how to use the program and perform a limited amount of analysis. You may obtain WYEC hourly weather data for forty other U.S. cities and five Canadian cities from ASHRAE located at 1791 Tullie Circle, NE, Atlanta, GA 30329-2305.

MOIST was compiled in Microsoft FORTRAN (Release 5.0).

Some copies of this publication are being disseminated without the diskette containing the program software. For more information or to request the diskette, contact the Heat Transfer Group, NIST, Building 226, Room B320, Gaithersburg, MD 20899, telephone 301-975-5648.

SYSTEM REQUIREMENTS

Your computer needs to be equipped with the following hardware: a 286, 386, or 486 processor; 512 kilobytes of memory or more; a math co-processor; and a hard drive with at least 2 megabytes and preferably 5 megabytes available for program and data storage. The monitor must have either EGA or VGA graphics capability. The operating system must be MS-DOS 3.1 or higher.

PREFACE

The authors would like to thank the National Institute of Standards and Technology and the Department of Energy (through the Oak Ridge National Laboratory) for funding the development of MOIST. In addition, the authors would like to thank ASHRAE for agreeing to permit us to release WYEC hourly weather data for six U.S. cities.

WARNING

For demonstration purposes, the program is loaded with values for two parameters (convergence criteria and maximum iteration) which make the program run faster. When you run a problem for analysis, it is essential that you use appropriate values for these parameters (see Chapter 8 - Achieving Convergence for Mathematical Solution).

Chapter 1. Introduction

Brief Description of MOIST

MOIST is a user-friendly, personal computer program that predicts the one-dimensional transfer of heat and moisture. With MOIST, you will be able to easily define a wall, cathedral ceiling, or low-slope roof construction. You will subsequently be able to investigate the effect of various parameters on the moisture accumulation within layers of construction. For example, you will be able to conduct computer runs for different U.S. and Canadian cities, thereby investigating the effect of climate on moisture accumulation. You will be able to determine if a vapor retarder is needed, and if needed, where it should be placed relative to the other materials. MOIST allows the user to vary easily the building materials and their relative placement and predicts the resulting moisture accumulation within each as a function of time for the selected climate. MOIST permits the evaluation of the effect of the water-vapor resistance offered by paint layers, wallpaper, and vapor retarders. Finally, MOIST can be used to produce moisture control guidelines.

The algorithms in the program can predict moisture transfer for the diffusion regime through the capillary flow regime. The program has a provision to account for convective moisture transfer by including embedded cavities which may be coupled to indoor or outdoor air. The program generates a plot on the computer screen of the average moisture content of the construction layers versus time as the program executes. The program generates output files which may be imported into plotting programs for preparing reports.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) has consented to permit NIST to release their Weather Year for Energy Calculations (WYEC) weather data for the following six U.S. cities: a cold climate (Madison, WI), intermediate winter climates (Boston, MA and Washington, DC), a mild winter climate (Atlanta, GA), a Pacific northwest climate (Portland, OR), and a hot and humid climate (Lake Charles, LA). These weather data will permit you to learn how to use the program and perform a limited amount of analysis. You may obtain WYEC hourly weather data for 40 other U.S. cities and five Canadian cities from ASHRAE located at 1791 Tullie Circle, NE, Atlanta, GA 30329-2305.

Information on the theory and validation of MOIST is given in Appendix A.

Limitations of MOIST

One of the most significant limitations of MOIST is that the model is one dimensional. This means that it does not include the effect of framing members and the two and three dimensional effects associated with infiltration. However, the authors believe that the model is and the third layer (plywood) is displayed in green (upper curve). In the sample problem, we treated the glass-fiber insulation as a non-storage layer (i.e., a layer with negligible moisture storage). For this reason, the moisture content of the glass-fiber insulation (layer 2) is not shown.

In the graph on the computer screen, the vertical axis displays the relative moisture content of the construction layers. The term "relative moisture content" is defined as the moisture content of the material divided by moisture content of the material at maximum sorption[1]. The dashed horizontal line in the center of the graph depicts a relative moisture content of 1. This is the critical moisture content above which liquid water appears in the pore structure of the material. Relative time is displayed on the horizontal axis. A relative time of 0 corresponds to the start of a simulation and a value of 1 corresponds to the end of the simulation.

At this point, you may want to take a brief break and allow the computer simulation to finish executing. Some benchmark times for MOIST to complete this sample problem are given in the following table.

---

[1]Maximum sorption is the moisture content of a material in equilibrium with air saturated with water vapor.

CPU	Speed, Mhz	Time, min
286	6	154
386	16	26
486	66	2.25

(You can interrupt execution by either a <ctrl-break> command or rebooting. When the <ctrl-break> is entered, the DOS prompt will eventually appear and you then need to issue <MODE CO80> to reset the screen to text mode.)

After Program MOIST completes the simulation, it displays a "☺" icon at the lower-right corner of the computer screen. You may return to MAIN MENU by pressing the Enter key. To exit the program, select 7 from the MAIN MENU by:

Enter: 7

Press: <Enter>.

Explanation of Files in Directory MOIST

After exiting Program MOIST, your computer screen should display C:\MOIST. You may examine the files in Directory MOIST by:

Enter: DIR

Press: <Enter>.

The following listing of files should appear on your computer screen. An explanation of each file is given below.

```
Volume in drive C is C DRIVE
Volume Serial Number is 3A38-11EF
Directory of C:\MOIST

.            <DIR>      07-23-93   5:01p
..           <DIR>      07-23-93   5:01p
MOIST    EXE     387978 06-16-93   4:38p
PDATA    DAT       4708 07-23-93   4:20p
DEFSET   DAT        293 07-23-93   4:21p
CONST    DAT        233 07-23-93   4:21p
PEROD    DAT         62 06-22-93   4:18p
OUT      DAT        112 07-23-93   4:22p
WYBOSMA          718320 11-17-92   1:52p
WYWASDC          718320 11-17-92   2:19p
WYPOROR          718320 11-17-92  11:30a
WYMADWI          718320 11-17-92   1:39p
WYATLGA          718320 11-17-92   9:48a
WYLKCLA          718320 11-17-92  10:19a
CHECK    DAT       4691 07-27-93   1:23p
RUN1     OUT      33050 07-27-93   1:23p
RUN1     MC        1144 07-27-93   1:23p
       17 file(s)    4742191 bytes
                     8366080 bytes free
```

<u>MOIST.EXE</u>: This is Program MOIST.

<u>PDATA.DAT</u>: This file contains the property data for the materials.

<u>DEFSET.DAT</u>: This file contains the input parameters.

<u>CONST.DAT</u>: This file contains the construction parameters.

PEROD.DAT: This file contains the analysis intervals.

OUT.DAT: This file contains the selection of output and plot files which will be generated during the execution of MOIST.

WYBOSMA: This file contains weather data for Boston, MA.

WYWASDC: This file contains weather data for Washington, DC.

WYPOROR: This file contains weather data for Portland, OR.

WYMADWI: This file contains weather data for Madison, WI.

WYATLGA: This file contains weather data for Atlanta, GA.

WYLKCLA: This file contains weather data for Lake Charles, LA.

CHECK.DAT: This file contains diagnostic parameters used by the authors to debug the program.

The remaining files are output files for the sample problem which you just ran on your computer.

RUN1.OUT: This file contains data that summarizes the property data, input parameters, and construction parameters for your simulation. It also contains the unprocessed simulation results. We recommend that you print out this file to document your computer run.

RUN1.MC: This file contains the average moisture content of the layers of the construction displayed in column format F10.2[2]. Program MOIST sends a set of values to this file at the print interval specified in ANALYSIS INTERVALS.

If you installed only one weather data file, then the other weather files will not appear in Directory MOIST.

[2]A column format of F10.2 indicates that the column width is 10, and the numerical values are displayed with two digits given to the right of the decimal point.

Chapter 3. Getting Hard Copy Documentation for a Computer Run

If you would like a hard copy documenting your computer run, you may send RUN1.OUT to a printer attached to your computer. You may accomplish this from Directory MOIST by:

Enter: PRINT RUN1.OUT

Press: <Enter>.

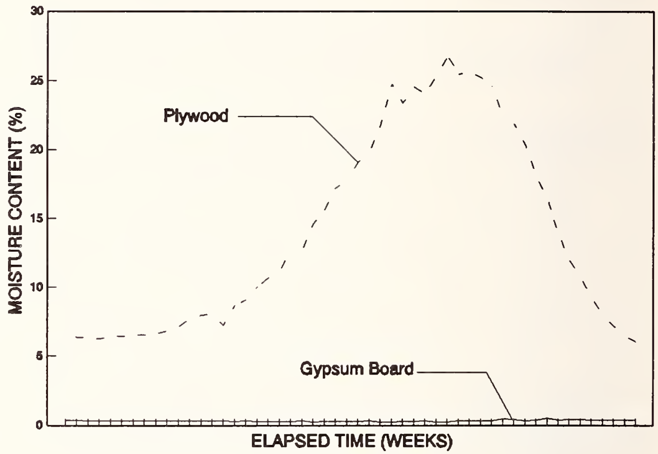
Several pages of this file are given in Appendix B. File RUN1.OUT is very long. Therefore, you may want to modify the output file options (see Chapter 5) and print only the abbreviated hard copy documentation and omit unprocessed output results.

Chapter 4. Getting a Plot for a Report

If you would like a "hard copy" of a plot for a report, then you can import one of the plotting output files (e.g., RUN1.MC) to a commercially available spread-sheet program with plotting capability (e.g., LOTUS 123[3]).

Let's examine how you would obtain a report plot for the moisture content of the construction layers for the sample problem. The data are contained in file RUN1.MC and are printed out in Appendix C. The first and second columns are the weekly moisture contents (expressed in percent) for the gypsum board and plywood siding, respectively. The rows correspond to sequential sets of weekly values. Each of the moisture contents is averaged over the thickness of the layer. You can import file RUN1.MC into a spread-sheet program with plotting capability and obtain the following line plot in just a few minutes.

[3]Reference here to Lotus 123 is only for illustration purposes and does not constitute an endorsement of this program by the Government.



Note: Each division on the horizontal axis corresponds to 1 week.

and the third layer (plywood) is displayed in green (upper curve). In the sample problem, we treated the glass-fiber insulation as a non-storage layer (i.e., a layer with negligible moisture storage). For this reason, the moisture content of the glass-fiber insulation (layer 2) is not shown.

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---

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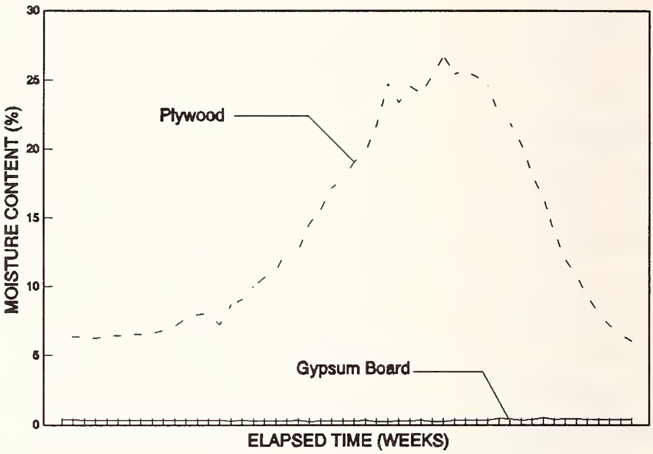


Note: Each division on the horizontal axis corresponds to 1 week.

Chapter 5. Modifying the Input Data for a Computer Run

In this chapter, we show you how to modify the property data for a material, the input parameters, the building construction, the analysis intervals, and the output files for a computer run. We use the sample problem as an example.

Modifying Property Data

Go to the MAIN MENU in MOIST and select PROPERTY DATA by:

Enter: 1

Press: <Enter>.

The resulting screen display is given below. The four options discussed below are permitted.

```
MAKE APPROPRIATE SELECTION

    1  CREATE A NEW PROPERTY DATA FILE
    2  EDIT AN EXISTING PROPERTY DATA FILE
    3  ADD A NEW MATERIAL
    4  RETURN TO MAIN MENU

ENTER SELECTION (1-4)
```

If you select option 1, you will be prompted to enter all the properties for each of the materials. This option is used by the authors of the program to generate the property data file (PDATA.DAT). You generally will not use this option. If you inadvertently enter this option, then you may exit the program by performing a "warm" boot (i.e., press the keys <Ctrl>, <Alt>, <Del> simultaneously). Specifying zero materials after the prompt: HOW MANY MATERIALS DO YOU WANT TO ENTER? will cause all data in the property data file to be deleted.

The selection of option 2 allows you to change one of the properties for a particular material. This option is discussed in the section below.

The selection of option 3 permits you to add a new material to the catalog of property data. If you select this option, then you will be prompted to enter appropriate property data for the new material.

Selection of option 4 causes the computer to return to the MAIN MENU of Program MOIST.

To modify one of the property data for a material, select option 2 for PROPERTY DATA by:

Enter: 2

Press: <Enter>.

Your computer screen now displays the following listing of materials. Let's modify item 4 (exterior grade plywood). This is accomplished by:

```
WHICH MATERIAL TO YOU WANT TO EDIT?

 1  GYPSUM BOARD                  2  SUGAR PINE
 3  FIBER BOARD SHEATHING         4  EXTERIOR GRADE PLYWOOD
 5  ORIENTED STRAND BOARD         6  MICROFINE PARTICLE BOARD
 7  WAFER BOARD SIDING            8  STURDY BRACE BOARD
 9  CELLULOSE INSULATION         10  FOAM CORE SHEATHING
11  GLASS FIBER INSULATION       12  KRAFT PAPER
13  ROOFING SHINGLES             14  PERMEABLE BOARD
15  BRICK                        16  CONCRETE BLOCK
17  GLASS FIBER BOARD            18  CONCRETE
19  BUILT-UP ROOFING             20  GRAVEL
21  6-MIL POLYETHYLENE           22  BUILDING PAPER
23  EXTRUDED POLYSTYRENE         24  EXPANDED POLYSTYRENE
25  CEMENT PARGE COAT            26  STUCCO FINISH
27  ALUMINUM SIDING              28  AIR BARRIER

ENTER MATERIAL NUMBER (ENTER 0 TO QUIT)
```

Enter: 4

Press: <Enter>.

The table of coefficients given below is now displayed on your computer screen.

```
EXTERIOR GRADE PLYWOOD
 SORPTION COEFFICIENTS
 1  A1..........................   .3441E+00
 2  A2..........................   .6177E+01
 3  A3..........................   .8283E+00
 CAPILLARY COEFFICIENTS
 4  LIQUID PERMEABILITY..........   .2787E-19
 5  DRY POROSITY.................   .6360E+00
 HEAT TRANSFER PROPERTIES
 6  DRY DENSITY..................   .5094E+03
 7  SPECIFIC HEAT................   .1214E+04
 8  DRY THERMAL CONDUCTIVITY.....   .1154E+00
 PERMEABILITY PROPERTIES
 9  1ST FIT COEFFICIENT..........  -.2666E+02
10  2ND FIT COEFFICIENT..........  -.6368E+01
11  3RD FIT COEFFICIENT..........   .8889E+01

 ENTER NUMBER OF PROPERTY (ENTER 0 TO QUIT)
```

The coefficients are:

<u>Items 1, 2, and 3</u>. These are the moisture storage coefficients for the material. They are the coefficients for the relation between moisture content (γ) and relative humidity (ϕ), or

$$\gamma = \frac{A1 \cdot \phi}{(1 + A2 \cdot \phi)(1 - A3 \cdot \phi)} \tag{1}$$

In the above equation, both γ and ϕ are expressed as a fraction. This equation is called the sorption isotherm function. Many of the moisture storage coefficients provided to you in the PROPDAT.DAT file are based on NIST measurements by R.F. Richards, D.M. Burch, and W.C. Thomas (1992)[4].

<u>Item 4</u>. This is the liquid permeability of the saturated porous media expressed in m^2 (ft^2).

<u>Item 5</u>. This is dry porosity (e_d) of the porous media defined as the ratio of the pore volume to total volume. It may be expressed in terms of dry density (ρ_d) and density of the solid material (ρ_s) that comprises the porous media, or:

$$e_d = 1 - \frac{\rho_d}{\rho_s} \tag{2}$$

[4]References are cited at the end of the text.

Item 6. This the dry density (ρ_d) of the material expressed in kg/m^3 (lb/ft^3).

Item 7. This is the dry specific heat of the material expressed in J/kg·°C (Btu/lb·°F).

Item 8. This is the thermal conductivity of the material expressed in W/m·°C (Btu/h·ft·°F).

Items 9, 10, and 11. These are the water vapor permeability coefficients. They are the coefficients for the empirical permeability equation expressed as a function of relative humidity (ϕ), or:

$$\mu = \exp(a1 + a2 \cdot \phi + a3 \cdot \phi^2) \tag{3}$$

In the above equation, permeability is expressed in kg/s·m·Pa (grains/h·ft·inHg), and relative humidity (ϕ) is expressed as a fraction. Many of the water-vapor permeability coefficients provided on the PROPDAT.DAT file are based on NIST measurements by D.M. Burch, W.C. Thomas, and A.H. Fanney (1992).

Now let's change the thermal conductivity of the plywood to 0.12 W/m·°C. This is accomplished by selecting Item 8 or:

Enter: 8

Press: <Enter>.

When you see the message on the screen prompting you to enter the new value:

Enter: 0.12

Press: <Enter>.

The computer screen now displays the revised table of coefficients. Check to make sure you entered the correct value. At this point, you may either revise another value or select 0 to exit this sheet of the program. Let's select 0. You should next see the options for PROPERTY DATA. By selecting 4, the computer program returns to MAIN MENU.

Modifying Input Parameters

From MAIN MENU, let's select INPUT PARAMETERS by:

Enter: 2

Press: <Enter>.

Your computer screen should now display the options for the INPUT PARAMETERS.

```
MAKE APPROPRIATE SELECTION

    1 CREATE A NEW INPUT PARAMETER FILE
    2 REVISE EXISTING INPUT PARAMETER FILE
    3 RETURN TO MAIN MENU

ENTER SELECTION (1-3)
```

Select 2 to revise the existing Input Parameter File. Your computer screen should now display the following input parameters.

```
 1  TYPE SOLUTION? (ISOTHERMAL=1 NONISOTHERMAL=2)        2
 2  CONVECTION COEF AT INSIDE SURFACE                    3.600
 3  CONVECTION COEF AT OUTSIDE SURFACE                  12.400
 4  CONVERGENCE CRITERIA FOR MOISTURE SOLUTION         .1000E-02
 5  MAXIMUM ITERATIONS IN MOISTURE LOOP                 20
 6  SOLAR ABSORPTANCE OF EXTERIOR SURFACE                .700
 7  SURFACE TILT (DEGREES)                              90.
 8  SURFACE AZIMUTH (DEGREES)                            0.
 9  INDOOR TEMPERATURE                                  21.000
10  INDOOR RELATIVE HUMIDITY, PERCENT                   35.000
11  BOUNDARY FILE TYPE (WYEC=1, SPECIAL=2)               1
12  BOUNDARY FILE NAME                                  WYMADWI
13  INSIDE SURF PAINT PERMEANCE                          575.000
14  OUTSIDE SURF PAINT PERMEANCE                          115.000

ENTER ITEM NUMBER (ENTER 0 TO QUIT)
```

The input parameters are explained below:

Item 1. This is the type of solution. For type=1, an isothermal solution is obtained (i.e., the temperature of the layers are set equal to the initial temperatures of the layers and held constant thereafter). For type=2, the temperatures of the layers are calculated at each time step of the analysis.

Items 2 and 3. These are the convection coefficients at the inside and outside surfaces of the construction, respectively, expressed in W/m^2·°C (Btu/h·ft^2·°F). They do not include the radiation heat transfer coefficient. We suggest that you obtain appropriate coefficients for your particular application from the ASHRAE 1993 Handbook of Fundamentals. However, the simulation results will often not be significantly affected by the particular coefficients that you use.

Item 4. This is the convergence criteria (ϵ) for the moisture solution. When the condition given below is satisfied at all locations within the building construction, then the iterative calculation proceeds to the next time step.

$$\left| \frac{\gamma_{new} - \gamma_{prev}}{\gamma_{prev}} \right| < \epsilon \tag{4}$$

where γ_{new} is the newly calculated moisture content and γ_{prev} is the previously calculated moisture content. In the sample problem, a value of 0.1×10^{-2} is used to make the problem run faster for demonstration purposes. When you run a problem for analysis, we recommend you use a value of 0.1×10^{-3} when liquid water is not present and 0.1×10^{-6} when model MOIST determines that liquid water is present in the pore structure. Smaller ϵ values require more computer time. The selection of an appropriate value for this parameter to achieve convergence is discussed later.

Item 5. This is the maximum number of iterations that the program will attempt to satisfy the convergence criteria given in eq (4). In the sample problem a value of 20 is used to make the problem run faster for demonstration purposes. When you run a problem for analysis, we recommend a value of 50 when program MOIST determines that liquid water is not present and a value of 500 when liquid water is present. The selection of an appropriate value for this parameter to achieve convergence is discussed later.

Item 6. This is the solar absorptance of the exterior surface. The sample problem uses a solar absorptance of 0.7. We recommend a value of 0.3 for light-colored surfaces, 0.6 for medium-colored surfaces, and 0.8 for dark-colored surfaces.

Item 7. This is the surface tilt expressed in angular degrees. Select 90° for vertical surfaces and 0° for horizontal surfaces.

Item 8. This is the surface azimuth expressed in angular degrees. A north azimuth is 0°.

Item 9. This is the indoor dry-bulb temperature expressed in °C (°F).

Item 10. This is the indoor relative humidity expressed as a percent.

Item 11. This is the boundary file type. For Type=1, the program expects the WYEC weather data. For

Type=2, the program expects special weather data with indoor temperature, indoor relative humidity, outdoor temperature, and outdoor relative humidity presented in a column format of 4F12.4. This option permits you to enter your own weather data files from laboratory or field experiments.

Item 12. This is the file name for the weather data to be analyzed. For example, if you want MOIST to use Madison, WI weather data, then Item 12 must be WYMADWI. It is imperative that you use the exact ASHRAE file name, so that the program can identify the longitude, latitude, and time zone for the location. For MOIST to run successfully, you must install the specified weather data file in Directory MOIST (see Chapter 2).

Items 13 and 14. These are the permeances of the inside and outside surfaces coverings, respectively, expressed in $ng/s{\cdot}m^2{\cdot}Pa$ ($perm_{IP}$)[5].

Now let's change the indoor relative humidity to 50%. This is accomplished by selecting Item 10 by:

Enter: 10

Press: <Enter>.

When you see the message on the screen prompting you to enter the new value:

---

[5] 1 $perm_{IP}$ = 1 $grain/(h{\cdot}ft^2{\cdot}inHg)$

Enter: 50

Press: <Enter>.

It is imperative to enter a realistic indoor relative humidity value (i.e., $0 < rh < 100$). A relative humidity outside this range will produce invalid results. The computer screen displays the revised table of input parameters. Check to make sure you entered the correct value, as no check on the validity of the value is provided by MOIST.

At this point, you may either revise another input parameter or select 0 to exit this sheet of the program. Select 0 and exit. You should next see the options for INPUT PARAMETERS. By selecting 3, the computer program returns to MAIN MENU.

Modifying Building Construction

From MAIN MENU, let's select BUILDING CONSTRUCTION by:

Enter: 3

Press: <Enter>.

The resulting screen display follows. The three options discussed below are permitted.

```
MAKE APPROPRIATE SELECTION

    1 CREATE A NEW BUILDING CONSTRUCTION FILE
    2 REVISE EXISTING BUILDING CONSTRUCTION FILE
    3 RETURN TO MAIN MENU

ENTER SELECTION (1-3)
```

If you select option 1, you will be prompted to enter all the data for a new building construction file. The procedure for carrying this out is given in Chapter 7.

The selection of option 2 permits you to alter one of the parameters for the existing building construction file. The procedure for carrying this out is given below.

The selection of option 3 causes the program to return to the MAIN MENU of Program MOIST.

In this section, we show you how to modify an existing building construction. To carry this out, select option 2. The computer screen now displays the following parameters for the building construction.

```
  1  GYPSUM BOARD                2  SUGAR PINE
  3  FIBER BOARD SHEATHING       4  EXTERIOR GRADE PLYWOOD
  5  ORIENTED STRAND BOARD       6  MICROFINE PARTICLE BOARD
  7  WAFER BOARD SIDING          8  STURDY BRACE BOARD
  9  CELLULOSE INSULATION       10  FOAM CORE SHEATHING
 11  GLASS FIBER INSULATION     12  KRAFT PAPER
 13  ROOFING SHINGLES           14  PERMEABLE BOARD
 15  BRICK                      16  CONCRETE BLOCK
 17  GLASS FIBER BOARD          18  CONCRETE
 19  BUILT-UP ROOFING           20  GRAVEL
 21  6-MIL POLYETHYLENE         22  BUILDING PAPER
 23  EXTRUDED POLYSTYRENE       24  EXPANDED POLYSTYRENE
 25  CEMENT PARGE COAT          26  STUCCO FINISH
 27  ALUMINUM SIDING            28  AIR BARRIER


LAY  DES    L      T      MC    NX    R     M      VEI    VEO   SIDE
1     1   1.300  21.0    .5     2
2                                    1.9 1900.0   .000   .000    0
3     4   1.300  21.0   7.0     2

 ENTER WHICH LAYER DO YOU WANT TO CHANGE (0 TO QUIT)
```

A list of building storage materials and corresponding identification numbers is given at the top. A table summarizing the parameters for the construction layers is given below this list. Each row corresponds to a particular layer of the construction. If the layer is a storage layer (i.e., it stores both heat and moisture), then the parameters for the layer are given in subsequent columns at the left side of the table. These are:

description (DES)[6],

thickness (L) expressed in cm (in),

[6]The column headings are for the Building Construction Table displayed on your computer screen.

initial temperature (T) expressed in °C (°F),

initial moisture content (MC) expressed as a percent, and

number of finite-difference nodes in the layer (NX)

On the other hand, if the layer is a non-storage layer (e.g., air space, glass-fiber insulation, or vapor retarder), the parameters are:

thermal resistance (R) expressed in $m^2 \cdot °C/W$ ($h \cdot ft^2 \cdot °F/Btu$),

permeance (M) expressed in $ng/s \cdot m^2 \cdot Pa$ ($perm_{IP}$)

air exfiltration flux at the inside surface (VEI) expressed in m^3/h per m^2 (ft^3/h per ft^2),

air infiltration flux at the outside surface (VEO) expressed in m^3/h per m^2 (ft^3/h per ft^2), and

convective layer "node" location (SIDE)

are given in consecutive columns at the right side of the table. The inclusion of convective fluxes in computer simulations is discussed later in Chapter 6.

Let's include a vapor retarder in the sample problem. This may be accomplished by changing the permeance of the non-storage layer (LAY=2) from M = 1900 ng/s·m^2·Pa (33.1 perm$_{IP}$) to M = 57.5 ng/s·m^2·Pa (1.0 perm$_{IP}$). You can select layer 2 by:

Enter: 2

Press: <Enter>.

Your computer screen now displays the following.

```
SELECT PARAMETER

1   R
2   M
3  VEI
4  VEO
5  SIDE

ENTER ITEM NUMBER
```

Enter 2 to modify the permeance (M). The program next prompts you to enter the new value. Enter 57.5 ng/s·m^2·Pa (1.0 perm$_{IP}$). The computer screen displays the revised wall construction. Check that you entered the correct value.

At this point, you may either revise another wall construction parameter or select 0 to exit this sheet of the program. Let's select 0 and exit. You should next see the options for WALL CONSTRUCTIONS. By selecting 3, the computer program returns you to the MAIN MENU for Program MOIST.

Modifying Analysis Intervals

From MAIN MENU, let's select ANALYSIS INTERVALS by:

Enter: 4

Press: <Enter>.

The program now displays options for ANALYSIS INTERVALS (see below).

```
MAKE APPROPRIATE SELECTION

  1 CREATE A NEW ANALYSIS INTERVAL FILE
  2 REVISE EXISTING ANALYSIS INTERVAL FILE
  3 RETURN TO MAIN MENU

ENTER SELECTION (1-3)
```

As in the previous example, you may select option 1 to create a new analysis interval file, select option 2 to revise an existing analysis interval file, or select option 3 to return to the MAIN MENU of Program MOIST.

Select revise existing analysis interval file by:

Enter: 2

Press: <Enter>.

The program now displays the parameters for ANALYSIS INTERVALS for the sample problem (see below). These parameters are:

```
COMPUTER ANALYSIS
  1  FIRST DAY  . . . . . . . . . . 182
  2  LAST DAY . . . . . . . . . . . 546
  PRINTING AND PLOTTING
  3  FIRST DAY  . . . . . . . . . . 182
  4  LAST DAY . . . . . . . . . . . 546
  5  INTERVAL (HOURS) . . . . . . . 168

  ENTER ITEM NUMBER (ENTER 0 TO QUIT)
```

Items 1 and 2. These are pointers that instruct MOIST to carry out an analysis starting with the first Julian[7] calendar day and ending with the last Julian day for the period of analysis. Program MOIST is set up to execute the number of consecutive calendar years specified by the user. The first day of the first year is designated 1. The last day of the first year is designated 365. The first day of the second year is designated 366, etc.

Items 3 and 4. These are pointers that instruct MOIST to send print and plot data to the output files starting with the first Julian day and ending with the last Julian day. These pointers may be different from those for the computer analysis. This makes it possible to include a pre-conditioning period in the computer analysis when print and plot data are not sent to output files. Here, the term "pre-conditioning" denotes a period of time, placed in front of the period of analysis, which serves to initialize the simulation results so that they are

[7]In the Julian calendar, the days of the year are numbered and referred to consecutively. For example, Julian day 45 refers to February 14.

independent of assumed initial moisture content and temperature.

Item 5. This is how often print and plot data are sent to output files. If Item 5 is 168, print and plot data are sent to the output file every 168 hours (or once a week) of simulation time.

The Julian days at the end of the months covering a 2-year period are given in the following table. This table will assist you in choosing appropriate values for the Julian day pointers.

Let's add a 6-month pre-conditioning period to the computer analysis. This will cause the 1-year simulation results sent to the print and plot output files to be less dependent on the selection of the initial temperature (T) and moisture content (MC) of the layers in BUILDING CONSTRUCTION. You can accomplish this by selecting Item 1 by:

Enter: 1

Press: <Enter>.

Month	Year	Julian Day[8]
January	1	31
February	1	59
March	1	90
April	1	120
May	1	151
June	1	181
July	1	212
August	1	243
September	1	273
October	1	304
November	1	334
December	1	365

[8]at end of month.

Month	Year	Julian Day[8]
January	2	396
February	2	424
March	2	455
April	2	485
May	2	516
June	2	546
July	2	577
August	2	608
September	2	638
October	2	669
November	2	699
December	2	730

[8]at end of month

When the program prompts you for a new value, enter 1 instead of 182. This causes the program to start the analysis 182 days sooner, thereby pre-conditioning the previous 1-year results with 182 days.

From the ANALYSIS INTERVAL screen, enter 0 to quit. This will take you back to a menu options screen where you will enter 3 to return to the MAIN MENU of Program MOIST.

Modifying Output Files

From MAIN MENU, select OUTPUT FILES by:

Enter: 5

Press: <Enter>.

The program now displays options for OUTPUT FILES. As in the previous example, you may select option 1 to create a new list of output files, select option 2 to revise an existing list of output files, or select option 3 to return to MAIN MENU. Let's select revise existing list of output files by entering 2.

The computer screen now displays a menu of files that you can select for output and plotting (see below). Program MOIST sends a set of certain parameters to selected files at the print interval specified in ANALYSIS INTERVALS. If a "Y" appears to the right of an item, then a file for this item will be generated by the program. On the other hand, an "N" indicates that no file for this item will be generated by the program. The file options are:

```
1 BOUNDARY CONDITIONS . . . . . . . . . . . . . .   N
2 AVERAGE MOISTURE CONTENT OF LAYERS . . . . . .   Y
3 SURFACE MOISTURE CONTENT OF LAYERS . . . . . .   N
4 SURFACE RELATIVE HUMIDITY OF LAYERS  . . . . .   N
5 WEEKLY AVG SURFACE RELATIVE HUMIDITY OF LAYERS   N
6 ABBREVIATED HARDCOPY DOCUMENTATION . . . . . .   N
7 FULL HARDCOPY DOCUMENTATION  . . . . . . . . .   Y
8 TIME AVG SURFACE HEAT FLUXES . . . . . . . . .   N
9 SURFACE MOISTURE FLUXES  . . . . . . . . . . .   N

 ENTER ITEM NUMBER (ENTER 0 TO QUIT)
```

<u>1 BOUNDARY CONDITIONS</u>. This item causes a file to be generated that contains the boundary conditions (indoor temperature and water-vapor pressure and outdoor dry-bulb temperature, water-vapor pressure, sol-air temperature, and dew-point temperature) displayed in a column format of F10.4. All quantities are time-averaged between the print intervals. Temperatures are expressed in °C for SI units and °F for English units. Vapor pressures are expressed in Pa for SI units and in Hg for English units. File name is run-name plus extension "BND" (e.g., RUN1.BND).

<u>2 AVERAGE MOISTURE CONTENT OF LAYERS</u>. This item causes a file to be generated that contains the spatial-average moisture content of the layers of the construction to be displayed in a column format of F7.2. Moisture content is expressed as a percent. File name is run-name plus extension "MC" (e.g., RUN1.MC).

<u>3 SURFACE MOISTURE CONTENT OF LAYERS</u>. This item causes a file to be generated that contains the moisture content at the inside surface, interfaces between layers, and outside surface displayed in column format F7.2. Moisture content is expressed as a percent. File name is run-name plus extension "SMC" (e.g., RUN1.SMC).

<u>4 SURFACE RELATIVE HUMIDITY OF LAYERS</u>. This item causes a file to be generated that contains the instantaneous relative humidity at the inside surface, interfaces between layers, and outside surface displayed in column format F7.2. Relative humidity is expressed

as a percent. File name is run-name plus extension "SRH" (e.g., RUN1.SRH).

5 WEEKLY AVG SURFACE RELATIVE HUMIDITY OF LAYERS. This item causes a file to be generated that contains the time-average relative humidity at the inside surface, interface between layers, and outside surface displayed in a column format of F7.2. The relative humidity is time-averaged between the print intervals. Relative humidity is expressed as a percent. File name is the run-name plus extension "ARH" (e.g., RUN1.ARH).

6 ABBREVIATED HARD COPY DOCUMENTATION. This item causes a file to be generated that contains PROPERTY DATA, INPUT PARAMETERS, WALL CONSTRUCTION, ANALYSIS INTERVALS, and OUTPUT FILES. The unprocessed output results for the computer simulation will not appear at the end of the file. File name is run-name plus extension "OUT" (e.g., RUN1.OUT).

7 FULL HARDCOPY DOCUMENTATION. This item causes a file to be generated that is the same as Item 6, except the unprocessed output results for the computer simulation will appear at the end of the file. Full hard copy documentation for the sample problem is given in Appendix B. File name is run-name plus extension "OUT" (e.g., RUN1.OUT).

8 TIME AVG SURFACE HEAT FLUXES. This item causes a file to be generated that contains the time-averaged heat fluxes at the inside and outside surfaces of the construction displayed in a column format of F7.4. The fluxes are time-averaged between the print intervals. The units are W/m^2 for SI units and $Btu/h{\cdot}ft^2$ for English units. File name is run-name plus extension "AQ" (e.g., RUN1.AQ).

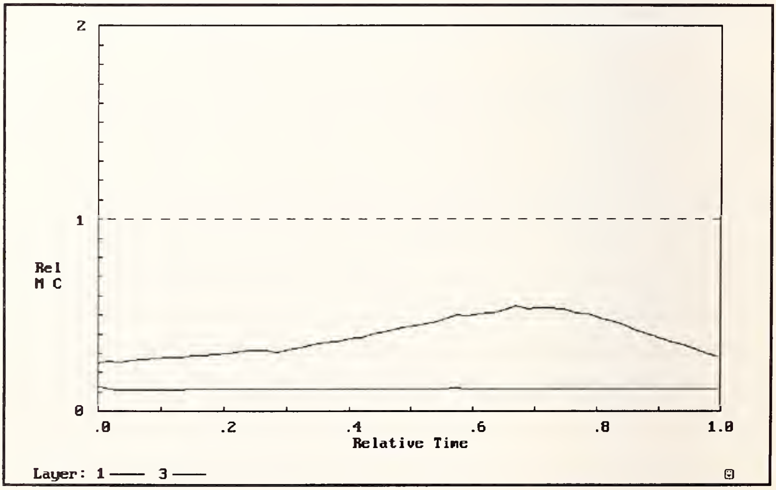
9 SURFACE MOISTURE FLUXES. This item causes a file to be generated that contains the instantaneous moisture fluxes at the inside and outside surfaces of the construction displayed in a column format of E15.6. The "E" indicates that the results are displayed in engineering (or scientific) format (e.g., 1.3 E-3 or 1.3×10^{-3}). The units are $ng/s{\cdot}m^2$ for SI units and $grains/h{\cdot}ft^2$ for English units. File name is run-name plus extension "MF" (e.g., RUN1.MF).

To change the selection status of a file for printing and plotting, enter the item number after the prompt ENTER ITEM NUMBER (ENTER 0 TO QUIT). Then, at the prompt ENTER REVISION (Y OR N) enter a "Y" if you want this file generated or a "N" if you do not want this file generated. After each selection, the program will redisplay the OUTPUT FILE MENU. Continue in this fashion until you are ready to quit this menu, then type "0" to return to the MAIN MENU of Program MOIST.

Running the Revised Sample Problem

You may now run the revised sample problem by selecting 6 from the MAIN MENU. You should name your revised sample problem RUN2, so that new output files will be generated by the program. If you name the revised sample problem RUN1, then the output files generated by the program will write over the existing RUN1 output files. The revised sample problem takes somewhat longer to run because of the addition of a pre-conditioning period to the problem.

After running the revised sample problem, the computer screen will display the following graph. The moisture content of the plywood is considerably lower due to the presence of the vapor retarder in the construction.

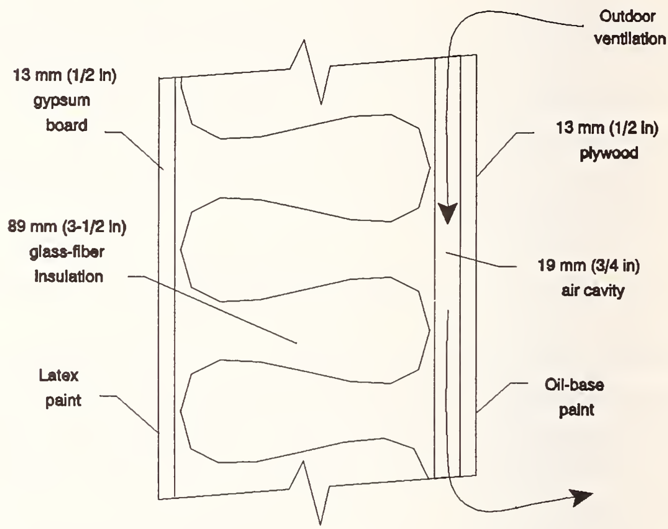


Chapter 6. Including Convection in a Problem

The program has a provision for including a convective "node" at either the inside surface (I) or outside surface (O) of an adjacent layer. This convection node may be coupled to either the indoor or outdoor air. The procedure for including a convective node is explained by way of an example.

Consider the following wall construction. This wall has a 19 mm (3/4 in) thick air cavity between the wall insulation and the plywood siding. Let's assume that this cavity is ventilated continuously with outdoor air at a rate of 6 air changes per hour (ACH). This air change rate may be multiplied by the volume of a 1 m^2 (ft^2) section of air cavity to give 0.114 m^3/h per m^2 (0.375 ft^3/h per ft^2). Generally, the node location [SIDE = I (inside) or O (outside)] should be the bounding surface of the cavity where the highest moisture concentration is expected to occur. For the present wall configuration, the node will be located at the outside surface (O) for winter analysis. For moisture accumulation in hot & humid climates, this node should be placed at the inside surface (I).

Let's reload the sample problem. You may accomplish this by implementing again the installation procedures for Program MOIST and the input files for the sample problem. This is accomplished by inserting the MOIST disk into your floppy drive, making this floppy drive the default directory, and then entering the command



INSTALL MOIST followed by the letter designating your hard drive. This will cause the original input files for the sample problem to overwrite the revised input files. During the installation process, ignore the warnings indicating that the MOIST program and input files are being overwritten.

Next go to building construction sheet. It should be the same as that given on page 32. Following the procedure given in the previous chapter, change the outdoor air flux

(VEO) to be equal to 0.114 m^3/h per m^2 (0.375 ft^3/h per ft^2). In addition, increase the thermal resistance (R) to 2.1 $m^2{\cdot}°C/W$ (12 $h{\cdot}ft^2{\cdot}°F/Btu$) for the non-storage layer to account for the additional thermal resistance of the air cavity. The parameter SIDE should already be O specifying an outside surface node. The Building Construction Parameter Sheet should now appear as that given below.

1	GYPSUM BOARD	2	SUGAR PINE
3	FIBER BOARD SHEATHING	4	EXTERIOR GRADE PLYWOOD
5	ORIENTED STRAND BOARD	6	MICROFINE PARTICLE BOARD
7	WAFER BOARD SIDING	8	STURDY BRACE BOARD
9	CELLULOSE INSULATION	10	FOAM CORE SHEATHING
11	GLASS FIBER INSULATION	12	KRAFT PAPER
13	ROOFING SHINGLES	14	PERMEABLE BOARD
15	BRICK	16	CONCRETE BLOCK
17	GLASS FIBER BOARD	18	CONCRETE
19	BUILT-UP ROOFING	20	GRAVEL
21	6-MIL POLYETHYLENE	22	BUILDING PAPER
23	EXTRUDED POLYSTYRENE	24	EXPANDED POLYSTYRENE
25	CEMENT PARGE COAT	26	STUCCO FINISH
27	ALUMINUM SIDING	28	AIR BARRIER

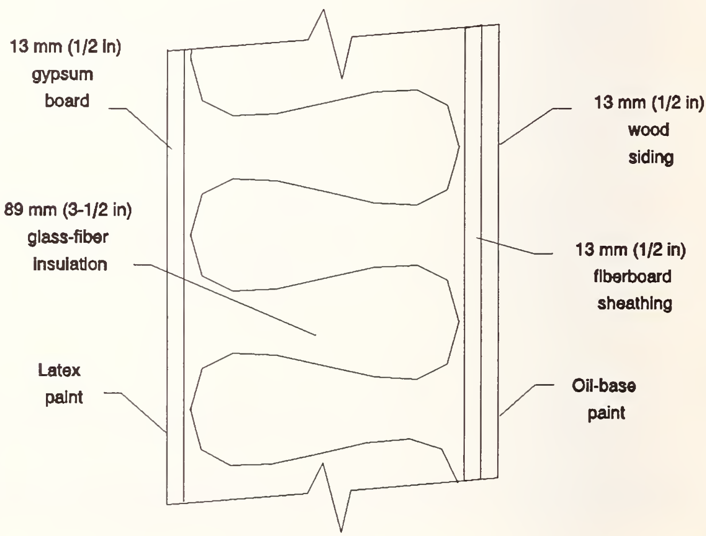
LAY	DES	L	T	MC	NX	R	M	VEI	VEO	SIDE
1	1	1.300	21.0	.5	2					
2						2.1	1900.0	.000	.114	0
3	4	1.300	21.0	7.0	2					

ENTER WHICH LAYER DO YOU WANT TO CHANGE (0 TO QUIT)

As an exercise, you may run this sample problem.

Chapter 7. Creating a New Building Construction

In this chapter, we will show you how to create a new building construction file for the wall construction given below.



From the MAIN MENU of Program MOIST, select option 3 to obtain BUILDING CONSTRUCTION. Then at the options menu for BUILDING CONSTRUCTION, select option 1 to CREATE A NEW BUILDING FILE. When the program prompts you for the number of layers in the construction, enter 4. A maximum of 10 layers can be simulated with MOIST. The program will next prompt you to enter parameters for each of the layers.

MOIST can treat a layer of the construction as either a "storage" or a "non-storage layer." The first and last layers must be storage layers.

In a storage layer, both the storage of heat and moisture are considered. The program subdivides a storage layer into equal-size subvolumes. The program performs a transient calculation of the heat and moisture transfer within each of the subelements. An initial temperature and moisture content must be specified to get the simulation started.

In a non-storage layer (e.g., air space), the storage of heat and moisture is neglected. The transfer of heat and moisture is assumed to be steady. Since the calculations are steady state, it is unnecessary to specify an initial temperature and moisture content. A non-storage layer may be convectively coupled to either the indoor or outdoor air.

For layer 1, when prompted to enter the type of layer, enter S for storage layer. When prompted to enter the material index, enter 1 for gypsum board. When prompted for the layer thickness, enter 1.3 cm (0.5 in). For initial temperature, enter 21 °C (70 °F). For initial moisture content, enter 0.5%. Lastly, enter the number of finite-difference nodes, which must be 2 or greater. However, the total number of nodes for all the layers must be less than 500. Since very little variation in moisture content is expected in the gypsum board, we can select the minimum number of nodes (2).

For layer 2, when the program asks for type, enter N for non-storage layer. For thermal resistance, enter 1.9 $m^2 \cdot °C/W$ (11 $h \cdot ft^2 \cdot °F/Btu$). For permeance, enter 1900 $ng/s \cdot m^2 \cdot Pa$ (33.1 $perm_{IP}$). For both convection coefficients, enter 0. For side, enter O to indicate an outside node.

For layers 3 and 4, enter the parameters given below:

Parameter	Layer 3	Layer 4
Type	S	S
Material Index	3	2
Thickness, cm (in)	1.3 (0.51)	1.3 (0.51)
Initial Temperature, C(F)	21 (70)	21 (70)
Initial Moisture Content, %	7	7
Nodes	4	7

After you enter the last parameter, the program will display the following table of parameters for the new construction. Check this table and make sure you entered the correct values. If you made a mistake, use the procedures discussed in Chapter 5 to correct an invalid entry.

```
  1  GYPSUM BOARD              2  SUGAR PINE
  3  FIBER BOARD SHEATHING     4  EXTERIOR GRADE PLYWOOD
  5  ORIENTED STRAND BOARD     6  MICROFINE PARTICLE BOARD
  7  WAFER BOARD SIDING        8  STURDY BRACE BOARD
  9  CELLULOSE INSULATION     10  FOAM CORE SHEATHING
 11  GLASS FIBER INSULATION   12  KRAFT PAPER
 13  ROOFING SHINGLES         14  PERMEABLE BOARD
 15  BRICK                    16  CONCRETE BLOCK
 17  GLASS FIBER BOARD        18  CONCRETE
 19  BUILT-UP ROOFING         20  GRAVEL
 21  6-MIL POLYETHYLENE       22  BUILDING PAPER
 23  EXTRUDED POLYSTYRENE     24  EXPANDED POLYSTYRENE
 25  CEMENT PARGE COAT        26  STUCCO FINISH
 27  ALUMINUM SIDING          28  AIR BARRIER


LAY  DES    L      T      MC    NX    R     M      VEI   VEO  SIDE
1    1    1.300  21.0    .5     2
2                                    1.9  1900.0  .000  .000    0
3    3    1.300  21.0   7.0     4
4    2    1.300  21.0   7.0     7

  ENTER WHICH LAYER DO YOU WANT TO CHANGE (0 TO QUIT)
```

Chapter 8. Achieving Convergence for Mathematical Solution

For each building construction that you simulate with Program MOIST, it is essential for you to carry out the procedures described below to insure convergence of the mathematical solution. Otherwise, the computer predictions may be in error.

We will illustrate the procedure using the sample problem (see page 7) using Washington, DC weather conditions. The easiest way to reload the original sample problem is to carry out the following steps: insert the MOIST program disk into your floppy disk drive, make this floppy drive the default drive, and enter the command INSTALL MOIST followed by the letter designating your hard drive.

After the above steps, the BUILDING CONSTRUCTION should be those given on page 31. The INPUT PARAMETERS should be the same as those given on page 25, except that the boundary file name should be changed to WYWASDC (Washington, DC) and the *convergence criteria* and the *maximum iterations* should be changed to the values recommended for applications without liquid in the pore structure of the materials (i.e., 0.1×10^{-3} and 50, respectively). The revised INPUT PARAMETERS are:

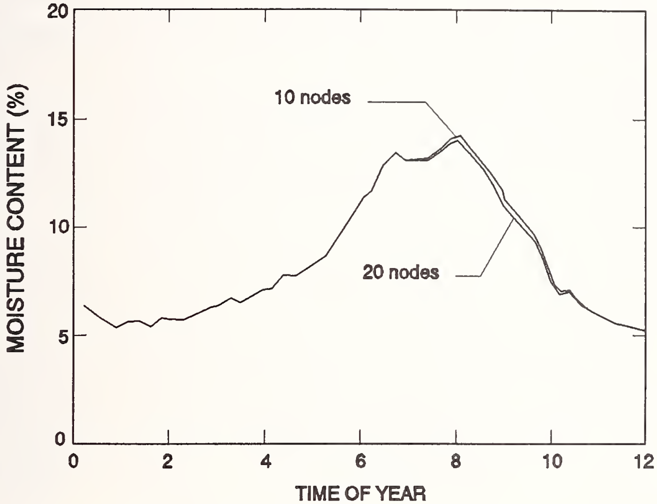
```
 1  TYPE SOLUTION? (ISOTHERMAL=1 NONISOTHERMAL=2)    2
 2  CONVECTION COEF AT INSIDE SURFACE               3.600
 3  CONVECTION COEF AT OUTSIDE SURFACE             12.400
 4  CONVERGENCE CRITERIA FOR MOISTURE SOLUTION     .1000E-03
 5  MAXIMUM ITERATIONS IN MOISTURE LOOP              50
 6  SOLAR ABSORPTANCE OF EXTERIOR SURFACE           .700
 7  SURFACE TILT (DEGREES)                          90.
 8  SURFACE AZIMUTH (DEGREES)                        0.
 9  INDOOR TEMPERATURE                             21.000
10  INDOOR RELATIVE HUMIDITY, PERCENT              35.000
11  BOUNDARY FILE TYPE (WYEC=1, SPECIAL=2)           1
12  BOUNDARY FILE NAME                             WYWASDC
13  INSIDE SURF PAINT PERMEANCE                    575.000
14  OUTSIDE SURF PAINT PERMEANCE                   115.000

 ENTER ITEM NUMBER (ENTER 0 TO QUIT)
```

Choosing Number of Nodes

MOIST predicts the temperature and moisture content of the layers of the construction as a function of time of year using a finite-difference model. In this finite-difference model, each layer of the construction is subdivided into equal-size subvolumes. A heat and moisture balance is performed on the nodes at the center of these subvolumes. The heat and moisture fluxes between nodes are predicted by linear approximations. As the number of nodes is increased, the approximate solution approaches the "exact" solution.

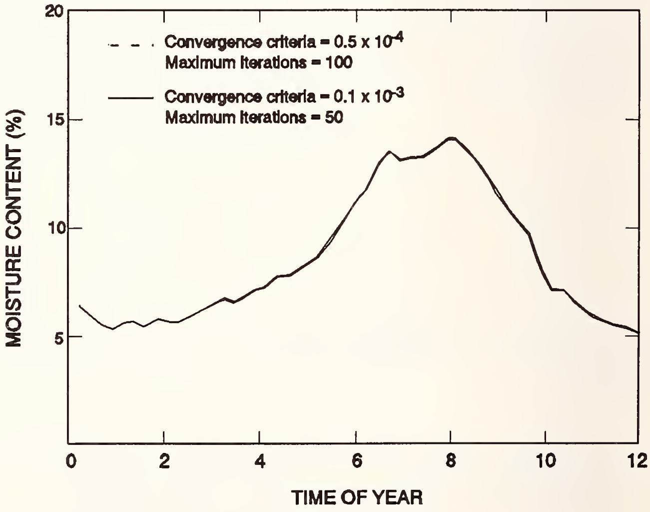
In materials with very little difference in moisture content across the layer, two nodes are sufficient to achieve convergence of the mathematical solution. Since very little difference in moisture content occurs across the gypsum board, two nodes are adequate. The number of nodes for the storage layers are given in the BUILDING CONSTRUCTION menu.

In the original sample problem, a large difference in moisture content is expected to occur across the plywood, and it is therefore necessary to determine a sufficient number of nodes for the plywood. This can be accomplished by carrying out computer simulations with an increasing number of nodes and comparing the predicted moisture content in the plywood. An adequate number of nodes is deemed to exist when the predicted moisture content of the plywood is nearly the same as a simulation with twice as many nodes. This process is illustrated in the following figure. Note that the moisture content in the plywood is very nearly the same for cases with 10 and 20 nodes. Therefore, 10 nodes is sufficient.



Choosing the Convergence Criteria and Maximum Iterations

First carry out a computer run with the recommended *convergence criteria* = 0.1×10^{-3} and *maximum iterations* = 50 for the case of liquid water not present in the construction layers. Then carry out another computer run with the *convergence criteria* decreased by a factor of two and *maximum iterations* increased by a factor of two. If the predicted moisture contents of the layers are nearly the same, then the recommended parameter values provide convergence. This process is illustrated in the figure below. Note that there is little or no difference between the moisture contents for the two simulations, thereby indicating that the recommended parameter values are adequate. In the event that the two simulations had produced different results, then you would continue to decrease the *convergence criteria* and increase the *maximum iterations* until there is very little difference between consecutive simulation results.



select option 1 to CREATE A NEW BUILDING FILE. When the program prompts you for the number of layers in the construction, enter 4. A maximum of 10 layers can be simulated with MOIST. The program will next prompt you to enter parameters for each of the layers.

MOIST can treat a layer of the construction as either a "storage" or a "non-storage layer." The first and last layers must be storage layers.

In a storage layer, both the storage of heat and moisture are considered. The program subdivides a storage layer into equal-size subvolumes. The program performs a transient calculation of the heat and moisture transfer within each of the subelements. An initial temperature and moisture content must be specified to get the simulation started.

In a non-storage layer (e.g., air space), the storage of heat and moisture is neglected. The transfer of heat and moisture is assumed to be steady. Since the calculations are steady state, it is unnecessary to specify an initial temperature and moisture content. A non-storage layer may be convectively coupled to either the indoor or outdoor air.

For layer 1, when prompted to enter the type of layer, enter S for storage layer. When prompted to enter the material index, enter 1 for gypsum board. When prompted for the layer thickness, enter 1.3 cm (0.5 in). For initial temperature, enter 21 °C (70 °F). For initial moisture content, enter 0.5%. Lastly, enter the number of finite-difference nodes, which must be 2 or greater. However, the total number of nodes for all the layers must be less than 500. Since very little variation in moisture content is expected in the gypsum board, we can select the minimum number of nodes (2).

For layer 2, when the program asks for type, enter N for non-storage layer. For thermal resistance, enter 1.9 $m^2 \cdot °C/W$ (11 $h \cdot ft^2 \cdot °F/Btu$). For permeance, enter 1900 $ng/s \cdot m^2 \cdot Pa$ (33.1 $perm_{IP}$). For both convection coefficients, enter 0. For side, enter O to indicate an outside node.

For layers 3 and 4, enter the parameters given below:

Parameter	Layer 3	Layer 4
Type	S	S
Material Index	3	2
Thickness, cm (in)	1.3 (0.51)	1.3 (0.51)
Initial Temperature, C(F)	21 (70)	21 (70)
Initial Moisture Content, %	7	7
Nodes	4	7

After you enter the last parameter, the program will display the following table of parameters for the new construction. Check this table and make sure you entered the correct values. If you made a mistake, use the procedures discussed in Chapter 5 to correct an invalid entry.

```
  1  GYPSUM BOARD              2  SUGAR PINE
  3  FIBER BOARD SHEATHING     4  EXTERIOR GRADE PLYWOOD
  5  ORIENTED STRAND BOARD     6  MICROFINE PARTICLE BOARD
  7  WAFER BOARD SIDING        8  STURDY BRACE BOARD
  9  CELLULOSE INSULATION     10  FOAM CORE SHEATHING
 11  GLASS FIBER INSULATION   12  KRAFT PAPER
 13  ROOFING SHINGLES         14  PERMEABLE BOARD
 15  BRICK                    16  CONCRETE BLOCK
 17  GLASS FIBER BOARD        18  CONCRETE
 19  BUILT-UP ROOFING         20  GRAVEL
 21  6-MIL POLYETHYLENE       22  BUILDING PAPER
 23  EXTRUDED POLYSTYRENE     24  EXPANDED POLYSTYRENE
 25  CEMENT PARGE COAT        26  STUCCO FINISH
 27  ALUMINUM SIDING          28  AIR BARRIER


LAY  DES    L      T      MC    NX    R     M      VEI    VEO   SIDE
1    1    1.300  21.0    .5    2
2                                    1.9  1900.0  .000   .000   0
3    3    1.300  21.0    7.0   4
4    2    1.300  21.0    7.0   7

  ENTER WHICH LAYER DO YOU WANT TO CHANGE (0 TO QUIT)
```

Chapter 8. Achieving Convergence for Mathematical Solution

For each building construction that you simulate with Program MOIST, it is essential for you to carry out the procedures described below to insure convergence of the mathematical solution. Otherwise, the computer predictions may be in error.

We will illustrate the procedure using the sample problem (see page 7) using Washington, DC weather conditions. The easiest way to reload the original sample problem is to carry out the following steps: insert the MOIST program disk into your floppy disk drive, make this floppy drive the default drive, and enter the command INSTALL MOIST followed by the letter designating your hard drive.

After the above steps, the BUILDING CONSTRUCTION should be those given on page 31. The INPUT PARAMETERS should be the same as those given on page 25, except that the boundary file name should be changed to WYWASDC (Washington, DC) and the *convergence criteria* and the *maximum iterations* should be changed to the values recommended for applications without liquid in the pore structure of the materials (i.e., 0.1×10^{-3} and 50, respectively). The revised INPUT PARAMETERS are:

```
 1  TYPE SOLUTION? (ISOTHERMAL=1 NONISOTHERMAL=2)    2
 2  CONVECTION COEF AT INSIDE SURFACE               3.600
 3  CONVECTION COEF AT OUTSIDE SURFACE             12.400
 4  CONVERGENCE CRITERIA FOR MOISTURE SOLUTION     .1000E-03
 5  MAXIMUM ITERATIONS IN MOISTURE LOOP              50
 6  SOLAR ABSORPTANCE OF EXTERIOR SURFACE           .700
 7  SURFACE TILT (DEGREES)                          90.
 8  SURFACE AZIMUTH (DEGREES)                        0.
 9  INDOOR TEMPERATURE                             21.000
10  INDOOR RELATIVE HUMIDITY, PERCENT              35.000
11  BOUNDARY FILE TYPE (WYEC=1, SPECIAL=2)           1
12  BOUNDARY FILE NAME                             WYWASDC
13  INSIDE SURF PAINT PERMEANCE                    575.000
14  OUTSIDE SURF PAINT PERMEANCE                   115.000

ENTER ITEM NUMBER (ENTER 0 TO QUIT)
```

Choosing Number of Nodes

MOIST predicts the temperature and moisture content of the layers of the construction as a function of time of year using a finite-difference model. In this finite-difference model, each layer of the construction is subdivided into equal-size subvolumes. A heat and moisture balance is performed on the nodes at the center of these subvolumes. The heat and moisture fluxes between nodes are predicted by linear approximations. As the number of nodes is increased, the approximate solution approaches the "exact" solution.

In materials with very little difference in moisture content across the layer, two nodes are sufficient to achieve convergence of the mathematical solution. Since very little difference in moisture content occurs across the gypsum board, two nodes are adequate. The number of nodes for the storage layers are given in the BUILDING CONSTRUCTION menu.

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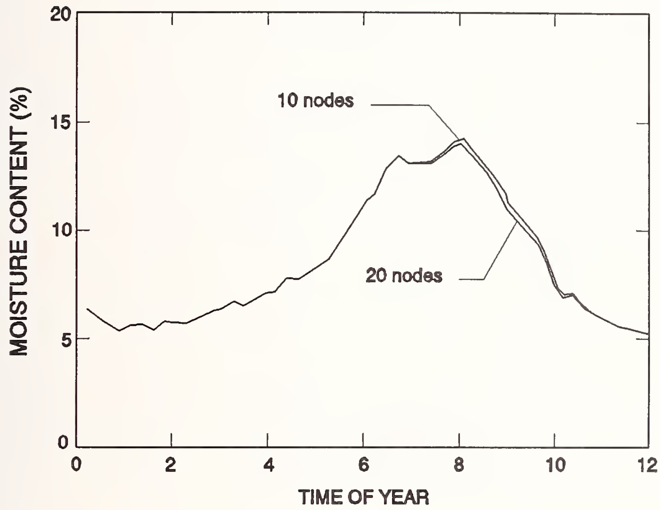
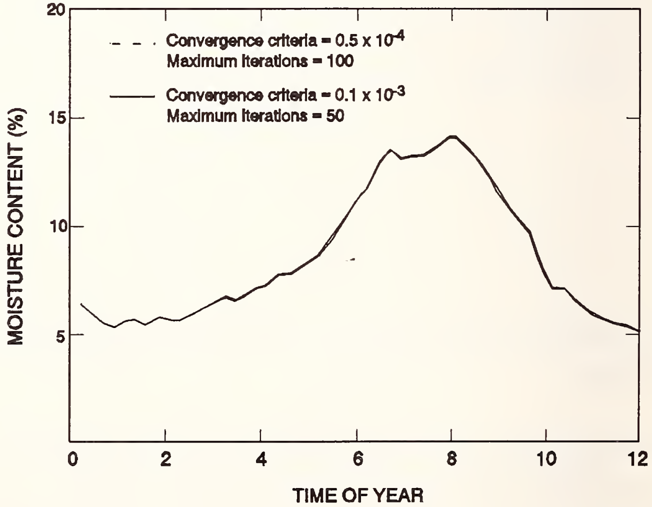


Choosing the Convergence Criteria and Maximum Iterations

First carry out a computer run with the recommended *convergence criteria* = 0.1×10^{-3} and *maximum iterations* = 50 for the case of liquid water not present in the construction layers. Then carry out another computer run with the *convergence criteria* decreased by a factor of two and *maximum iterations* increased by a factor of two. If the predicted moisture contents of the layers are nearly the same, then the recommended parameter values provide convergence. This process is illustrated in the figure below. Note that there is little or no difference between the moisture contents for the two simulations, thereby indicating that the recommended parameter values are adequate. In the event that the two simulations had produced different results, then you would continue to decrease the *convergence criteria* and increase the *maximum iterations* until there is very little difference between consecutive simulation results.



Appendix B

Listing of File RUN1.OUT

```
RUN1

  PROPERTY DATA

   1  GYPSUM BOARD
   .2465E-01   .9075E+01   .9354E+00   .1115E-13   .5000E+00   .6696E+03
   .1089E+04   .1603E+00  -.2347E+02  -.1480E+01   .1082E+01
   2  SUGAR PINE
   .1951E+00   .2116E+01   .7674E+00   .2787E-18   .7560E+00   .3652E+03
   .1633E+04   .9692E-01  -.2868E+02  -.9198E+00   .4576E+01
   3  FIBER BOARD SHE
   .3369E+00   .6488E+01   .8467E+00   .1301E-13   .7650E+00   .2659E+03
   .1298E+04   .5469E-01  -.2262E+02  -.4562E+01   .2953E+01
   4  EXTERIOR GRADE
   .3441E+00   .6177E+01   .8283E+00   .2787E-19   .6360E+00   .5094E+03
   .1214E+04   .1154E+00  -.2666E+02  -.6368E+01   .8889E+01
   5  ORIENTED STRAND
   .2121E+00   .3427E+01   .8106E+00   .2787E-19   .5720E+00   .6407E+03
   .1298E+04   .1177E+00  -.2768E+02  -.1468E+01   .3418E+01
   6  MICROFINE PARTI
   .2564E+00   .4860E+01   .8216E+00   .1022E-14   .4910E+00   .7625E+03
   .1298E+04   .1360E+00  -.2552E+02  -.3298E+01   .3817E+01
   7  WAFER BOARD SID
   .4601E+00   .1218E+02   .8630E+00   .2787E-19   .5280E+00   .7064E+03
   .1214E+04   .9086E-01  -.2804E+02  -.5720E+01   .9367E+01
   8  STURDY BRACE BO
   .1139E+01   .5060E+02   .9232E+00   .1301E-13   .7340E+00   .3988E+03
   .1298E+04   .7961E-01  -.2452E+02   .2399E+01  -.2539E+01
   9  CELLULOSE INSUL
   .5420E-01  -.3201E+00   .9275E+00   .2044E-10   .9470E+00   .8009E+02
   .1382E+04   .4327E-01  -.2398E+02   .1440E+01   .0000E+00
  10  FOAM CORE SHEAT
   .3636E+00   .1455E+02   .9023E+00   .4645E-14   .7000E+00   .9691E+02
   .1298E+04   .4846E-01  -.2585E+02  -.2782E+01   .2884E+01
  11  GLASS FIBER INS
   .1009E+00   .5356E+02   .9312E+00   .4645E-14   .9960E+00   .1147E+02
   .7118E+03   .4327E-01  -.2404E+02   .2572E+01   .0000E+00
  12  KRAFT PAPER
   .5190E+02   .2538E+04   .9020E+00   .2787E-19   .9000E+00   .8393E+03
   .1256E+04   .1592E+00  -.3224E+02  -.1168E+01   .3058E+01
  13  ROOFING SHINGLE
   .5190E+02   .2538E+04   .9020E+00   .2787E-19   .9000E+00   .1121E+04
   .1256E+04   .1038E+00  -.3224E+02  -.1168E+01   .3058E+01
  14  PERMEABLE BOARD
   .3360E+00   .6488E+01   .8467E+00   .1301E-13   .7650E+00   .2659E+03
```

```
 .1298E+04   .5469E-01  -.2449E+02   .0000E+00   .0000E+00
15  BRICK
 .7880E-02   .3771E+01   .8142E+00   .1626E-15   .5000E+00   .1922E+04
 .7955E+03   .7494E+00  -.2623E+02   .0000E+00   .0000E+00
16  CONCRETE BLOCK
 .1021E+00   .1010E+02   .7745E+00   .1626E-15   .5000E+00   .8490E+03
 .9211E+03   .1113E+01  -.2578E+02   .2538E+01   .0000E+00
17  GLASS FIBER BOA
 .1009E+00   .5356E+02   .9312E+00   .5295E-14   .9900E+00   .2643E+03
 .7955E+03   .4898E-01  -.2382E+02   .0000E+00   .0000E+00
18  CONCRETE
 .1253E+00   .1432E+02   .8279E+00   .8082E-17   .8000E+00   .2243E+04
 .9211E+03   .2163E+01  -.2664E+02  -.4404E+01   .5888E+01
19  BUILT-UP ROOFIN
 .5190E+02   .2538E+04   .9020E+00   .2787E-19   .9000E+00   .1121E+04
 .1465E+04   .1627E+00  -.3224E+02  -.1168E+01   .3058E+01
20  GRAVEL
 .1253E+00   .1432E+02   .8279E+00   .1301E-13   .7650E+00   .1442E+04
 .8374E+03   .1731E+01  -.2334E+02   .0000E+00   .0000E+00
21  6-MIL POLYETHYL
 .5190E+02   .2538E+04   .9020E+00   .2787E-19   .9000E+00   .8393E+03
 .1256E+04   .1592E+00  -.3518E+02   .0000E+00   .0000E+00
22  BUILDING PAPER
 .5190E+02   .2538E+04   .9020E+00   .2787E-19   .9000E+00   .8393E+03
 .1256E+04   .1592E+00  -.2936E+02   .0000E+00   .0000E+00
23  EXTRUDED POLYST
 .4194E+00   .1293E+02   .5247E+00   .2787E-19   .9000E+00   .4245E+02
 .1214E+04   .2890E-01  -.2707E+02   .0000E+00   .0000E+00
24  EXPANDED POLYST
 .4194E+00   .1293E+02   .5247E+00   .2787E-19   .9000E+00   .1602E+02
 .1214E+04   .3756E-01  -.2589E+02   .0000E+00   .0000E+00
25  CEMENT PARGE CO
 .6580E-01   .2815E+01   .7062E+00   .2322E-16   .5000E+00   .1922E+04
 .8374E+03   .1118E+01  -.2584E+02  -.2451E+00   .1019E+01
26  STUCCO FINISH
 .2465E-01   .9075E+01   .9354E+00   .1115E-13   .5000E+00   .6696E+03
 .1089E+04   .1603E+00  -.2564E+02   .0000E+00   .0000E+00
27  ALUMINUM SIDING
 .1009E+00   .5356E+02   .9312E+00   .2787E-19   .9000E+00   .8393E+03
 .1256E+04   .1160E+00  -.2495E+02   .0000E+00   .0000E+00
28  AIR BARRIER
 .5190E+02   .2538E+04   .9020E+00   .2787E-19   .9000E+00   .8393E+03
 .1256E+04   .1592E+00  -.2778E+02   .0000E+00   .0000E+00

INPUT PARAMETERS

1  TYPE SOLUTION? (ISOTHERMAL=1 NONISOTHERMAL=2)     2
2  CONVECTION COEF AT INSIDE SURFACE               3.600
3  CONVECTION COEF AT OUTSIDE SURFACE             12.400
```

```
 4  CONVERGENCE CRITERIA FOR MOISTURE SOLUTION     .1000E-02
 5  MAXIMUM ITERATIONS IN MOISTURE LOOP              20
 6  SOLAR ABSORPTANCE OF EXTERIOR SURFACE            .700
 7  SURFACE TILT (DEGREES)                           90.
 8  SURFACE ORIENTATION (DEGREES)                     0.
 9  INDOOR TEMPERATURE                             21.000
10  INDOOR RELATIVE HUMIDITY, PERCENT              35.000
11  FILE TYPE (WYEC=1, SPECIAL=2)                    1
12  BOUNDARY FILE NAME                             WYMADWI
13  INSIDE SURF PAINT PERMEANCE                     575.000
14  OUTSIDE SURF PAINT PERMEANCE                    115.000

 WALL CONSTRUCTION

 LAY    DES    L      T      MC      NX    R      M       VEI      VEO    SIDE
  1      1   1.300  21.0     .5      2
  2                                       1.9  1900.0    .000     .000     0
  3      4   1.300  21.0    7.0      2

 ANALYSIS INTERVALS

 COMPUTER ANALYSIS
 1  FIRST DAY......................................... 182
 2  LAST DAY.......................................... 546
 PRINTING AND PLOTTING
 3  FIRST DAY......................................... 182
 4  LAST DAY.......................................... 546
 5  INTERVAL (HOURS).................................. 168


 ITEMS SENT TO OUTPUT FILES

1 BOUNDARY CONDITIONS................................N
2 AVERAGE MOISTURE CONTENT OF LAYERS.................Y
3 SURFACE MOISTURE CONTENT OF LAYERS.................N
4 SURFACE RELATIVE HUMIDITY OF LAYERS................N
5 WEEKLY AVG SURFACE RELATIVE HUMIDITY OF LAYERS....N
6 ABBREVIATED HARDCOPY DOCUMENTATION ...............N
7 FULL HARDCOPY DOCUMENTATION........................Y
8 TIME AVG SURFACE HEAT FLUXES.......................N
9 SURFACE MOISTURE FLUXES............................N

DAY=188.00  TTIAV=  21.0  TTOAV=  20.1  TTSAV=  23.7
PPIAV=  .868E+03  PPOAV=  .162E+04

 NODAL TEMPS
 20.62178  20.55762  20.42251  20.35052
 13.47190  13.36887  13.00912  12.74954
```

```
  NODAL MOISTURE CONTENTS
      .344      .346      .347      .348
     8.824     6.245     6.865     8.180

  NODAL VAPOR PRESSURES
 .9829E+03 .9832E+03 .9815E+03 .9793E+03
 .9326E+03 .6523E+03 .7112E+03 .8334E+03

 QI=  .31636E+01    WI= -.64586E+05    QO=  .92202E+01    WO= -.39631E+05


DAY=195.00  TTIAV=  21.0  TTOAV=  20.6  TTSAV=  24.1
PPIAV=  .868E+03  PPOAV=  .164E+04

  NODAL TEMPS
  20.90529  20.89123  20.86059  20.84365
  19.22558  19.20079  19.10641  19.03681

  NODAL MOISTURE CONTENTS
      .335      .336      .337      .337
     6.276     5.664     6.603     7.792

  NODAL VAPOR PRESSURES
 .9663E+03 .9679E+03 .9697E+03 .9699E+03
 .9534E+03 .8356E+03 .1005E+04 .1191E+04

 QI=  .69330E+00    WI= -.55310E+05    QO=  .24719E+01    WO= -.58319E+05


DAY=202.00  TTIAV=  21.0  TTOAV=  21.2  TTSAV=  24.5
PPIAV=  .868E+03  PPOAV=  .195E+04

  NODAL TEMPS
  20.94782  20.94037  20.92473  20.91644
  20.12472  20.11201  20.07764  20.05701

  NODAL MOISTURE CONTENTS
      .325      .325      .326      .326
     5.859     5.497     6.595     8.565

  NODAL VAPOR PRESSURES
 .9331E+03 .9342E+03 .9354E+03 .9356E+03
 .9250E+03 .8494E+03 .1066E+04 .1382E+04

 QI=  .36724E+00    WI= -.36696E+05    QO=  .73289E+00    WO= -.10878E+06


DAY=209.00  TTIAV=  21.0  TTOAV=  22.3  TTSAV=  25.4
PPIAV=  .868E+03  PPOAV=  .215E+04
```

```
 NODAL TEMPS
 21.01413  21.01963  21.02813  21.03080
 21.28483  21.28788  21.24995  21.20872

 NODAL MOISTURE CONTENTS
     .334      .334      .335      .335
    5.721     5.346     6.634     8.472

 NODAL VAPOR PRESSURES
.9695E+03 .9714E+03 .9741E+03 .9748E+03
.9631E+03 .8791E+03 .1153E+04 .1470E+04

QI= -.27109E+00    WI= -.57067E+05    QO=  .14644E+01    WO= -.10805E+06
```

•
•
•

Appendix C

Listing of file RUN1.MC

```
.35     7.04
.34     6.36
.33     6.34
.33     6.27
.32     6.41
.32     6.43
.32     6.53
.33     6.50
.33     6.63
.32     6.81
.30     7.12
.30     7.68
.30     7.95
.31     8.02
.33     7.21
.27     8.63
.29     9.04
.27     9.90
.27    10.53
.28    10.99
.27    12.43
.30    12.40
.24    14.75
.25    15.29
.26    16.89
.27    17.45
.25    18.58
       •
       •
       •
       •
       •
       •
.29    19.28
.24    21.17
.21    24.34
.26    22.87
.28    24.09
.29    23.60
.24    24.86
.22    26.45
.31    25.16
.32    25.45
.32    25.10
.33    24.45
.42    22.28
.40    21.76
.34    20.21
.35    17.98
.48    16.48
.37    13.99
.41    12.08
.40    10.84
.37     9.39
.37     8.12
.36     7.26
.34     6.54
.35     6.08
```

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KEY WORDS (MAXIMUM 9 KEY WORDS; 28 CHARACTERS AND SPACES EACH; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES)

building technology, heat and moisture transfer, moisture control, moisture transfer, wall performance

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