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1-D hygIRC: A Simulation Tool for Modeling Heat, Air and Moisture Movement in Exterior Walls

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Introduction

1-D hygIRC is a user-friendly one-dimensional version of IRC's hygIRC, a state-of-the-art hygrothermal* computer model (see Construction Innovation **8**:3).[1] The basic component modules comprising 1-D hygIRC are: the recently benchmarked hygIRC solver; a climate database containing 30 to 40 years of hourly weather data for 19 Canadian and 6 US cities; a materials database containing the hygrothermal properties of 80 common construction materials as measured at IRC; a building envelope design tool integrated with the material properties database; and models to derive interior temperature and relative humidity conditions (see Figure 1). 1-D hygIRC also provides the user with easy-to-use tools for output analysis. Optional provisions have also been made for users to specify their own weather, interior conditions, or material property data, if they wish to investigate other parameters than those provided. The model simulates the hygrothermal response of each element to changing environmental conditions on either side of the envelope on an hourly basis (see Figure 2). This produces information on the temperature and relative humidity distributions within the wall assembly and the changes over time. Time series plots of temperature, moisture contents, and other output parameters can be viewed for the wall layers or the entire wall where applicable. 1-D hygIRC also contains the freeze-thaw cycles and RHT Index output measures developed for use with hygIRC (see Construction Innovation **8**:1).[2] Users can animate the results to give a picture of the wall response over time. This program is targeted to engineers, architects, building scientists, contractors, and other professionals. The framework of 1-D hygIRC was built to facilitate case studies allowing users to readily conduct parametric studies, studies where several parameters are changed one at a time to gauge the sensitivity of the wall response, or what-if scenarios such as "what if the stucco cladding was replaced with acrylic stucco?" Situations involving air leakage, water leaks and gravity, however, are still best handled using the 2-dimensional version of hygIRC needing the expertise of a researcher to set up the 'virtual wall' representation. The 2-dimensional version of hygIRC is more complex and it has not yet been adapted to the user-friendly modules developed for the 1-D version. The plan is to have 1-D hygIRC available for public release in January 2004. Interested readers are invited to check out IRC's Web site for further details about 1-D hygIRC pricing and availability (http://irc.nrc-cnrc.gc.ca/bes/index.html)

2-D hygIRC hygrothermal model on the world stage

As part of the European Union HAMSTAD (**H**eat, **A**ir and **M**oisture **STA**ndards **D**evelopment) strategic research project, 2-D hygIRC was chosen to provide benchmarking information to develop a European CEN (European Community for Standardization) standard for hygrothermal models. This standard has been proposed as a draft ISO standard that could be adopted as a CSA standard for the calculation, prediction and evaluation of moisture performance of building envelopes. For more information, visit the HAMSTAD Web site at:

http://www.buildphys.chalmers.se/research/HAMSTAD-e.htm

* Hygrothermal is derived from the combination of *hygro* from the Greek meaning moisture and *thermē* meaning heat.

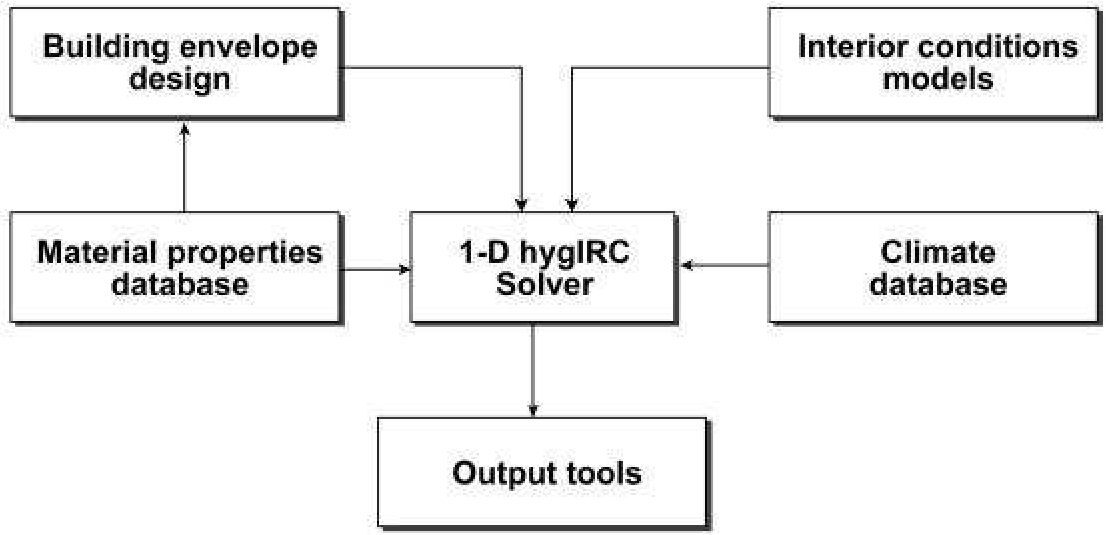

Figure 1. The Basic Component Modules making up 1-D hygIRC: the solver, the building envelope design tool, the climate database, the material properties database, tools for modeling the interior conditions, and the post-processor (output tools).

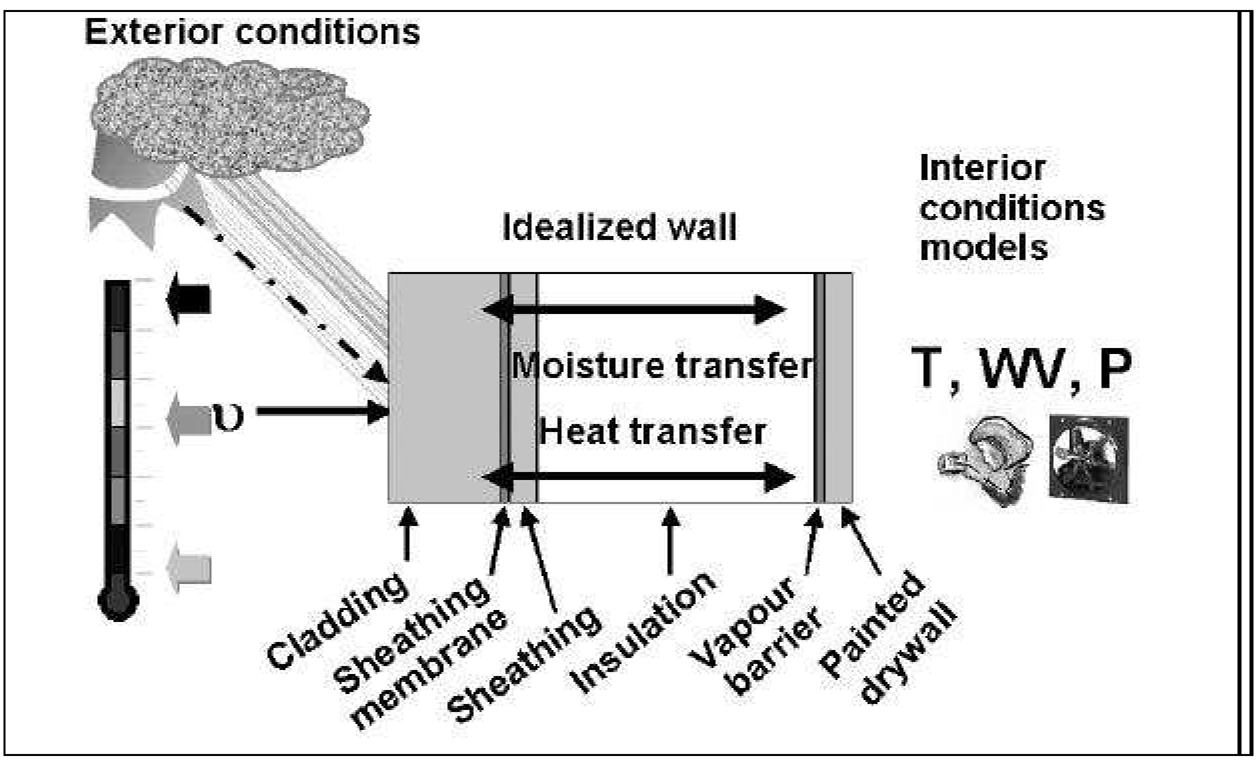

Figure 2. 1-D hygIRC is a one-dimensional simulation tool that models heat, air and moisture transfer through the various layers of 'virtual' building envelope components bounded on one side by the external environment and on the other by the indoor environment – 6 layers are shown here out of a possible 15†. The materials are selected from the materials database and the user supplies the dimensions.

† The convention used in 1-D hygIRC is that the left-hand side of the wall faces the exterior and the right-hand side faces the interior. The boundary conditions are applied accordingly.

Building Envelope Design

The building envelope design tools provide the user with a straightforward procedure for constructing models of virtual envelope sections to be analysed. The wall section is fixed at one metre in height and does not allow for variations from bottom to top (hence the term "1-D"). However, considerable complexity can be analyzed with multiple layers through the wall. Envelope sections are built, using a graphical interface, layer by layer (see Figure 3). The user selects the thickness and composition of each layer. Up to 15 layers can be accommodated. The envelope design tools are directly linked to the materials database, facilitating parametric analyses and what-if scenarios. Finally, wall orientation and inclination can be specified by the user. This is important, as these features will affect how much wind-driven rain and solar radiation will impinge on the outside surface for the chosen location. Orientation and inclination are easily manipulated using graphical tools.

The Climate Database

Users of 1-D hygIRC can select locations from the climate database from a list of 19 Canadian locations, including all the BSI hosting cities, and 6 US locations. For each location, 30 to 40 individual years of hourly weather data are available. The basic hourly elements are dry bulb temperature, relative humidity, wind speed and direction, solar radiation, rain, and cloud cover. Users can select individual years from the climate database or sequences of years, in chronological or non-chronological order, for multi-year simulations. The user always has the option of providing 1-D hygIRC with user-defined weather data, provided the input files conform to the hygIRC format. Graphical interfaces permit the study and selection of the weather patterns independently or in combination with the simulation results (see Figure 4).

The Materials Database

Apart from the solver, the most important component of 1-D hygIRC is the materials database. Over 80 common North American construction materials are included in the database. The material properties in the database include water vapour permeance, liquid diffusivity, air permeability, heat capacity, and thermal conductivity, among others needed for proper modeling of hygrothermal response.[3] These properties were all measured at IRC's thermal and moisture performance laboratory, which is primarily responsible for measuring the heat and moisture transport (i.e. hygrothermal) properties of conventional and new building materials. The laboratory has a longstanding reputation and responsibility to develop new national and international standard test procedures, from theory to application, and to maintain them. The laboratory participates in the international round robin tests to maintain its international standing and credibility. Provision has been made in 1-D hygIRC for the user to use other material properties if available provided they conform to the hygIRC format. The interface to the materials properties database is shown in Figure 5.

Models of Interior Conditions

By convention in 1-D hygIRC, the left-hand side of the envelope faces the exterior and the boundary conditions there are obtained from the climate database. The right-hand side of the envelope faces the interior. The interior conditions can be fundamentally important in determining the long-term performance of the envelope. For example, research has shown that wall designs that feature more vapour permeable layers towards the interior face of the wall can be more susceptible to indoor conditions, so these need to be realistic for any given climate. Several interior conditions models have been implemented in 1-D hygIRC to give the user a variety of options in modeling the interior boundary conditions.[4] As an option, third-party indoor conditions, obtained from measured data for example, can be used with 1-D hygIRC provided the input files conform to the hygIRC format. In 1-D hygIRC the interior temperature can be controlled by using either a seasonal heating schedule or a daily model based on the heating and cooling balance points of a hypothetical building (see Figure 6). The user determines the set points, thresholds and balance points. Indoor relative humidity can be either controlled or uncontrolled. If the relative humidity is controlled, then the user supplies the set points. Two models are provided in the case of uncontrolled indoor relative humidity, a statistically based model and an empirical model based on moisture generation rates (see Figure 7). The latter two approaches to generating indoor conditions result in indoor RH's that are responsive to local outdoor conditions obtained from the weather database.

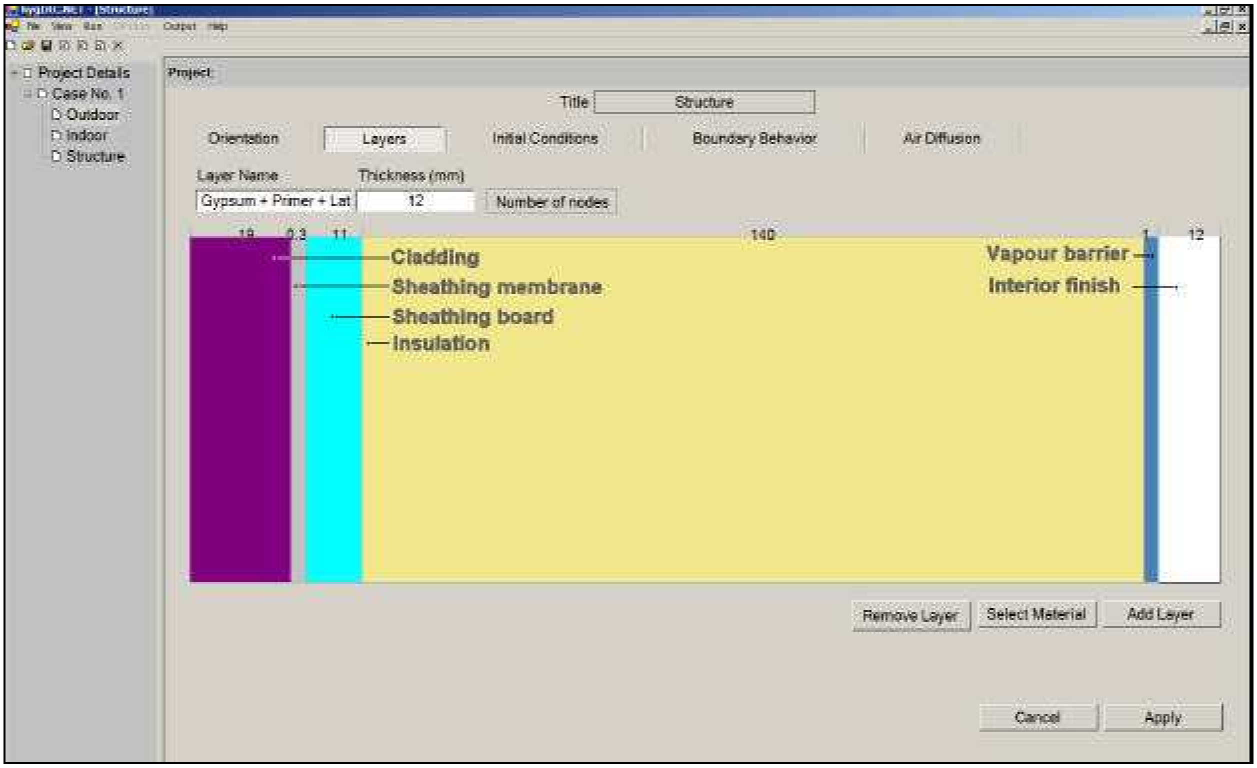

Figure 3. 1-D hygIRC provides the user with an easy-to-use graphical tool for constructed layered walls. The building envelope design tool is linked directly to the materials database.

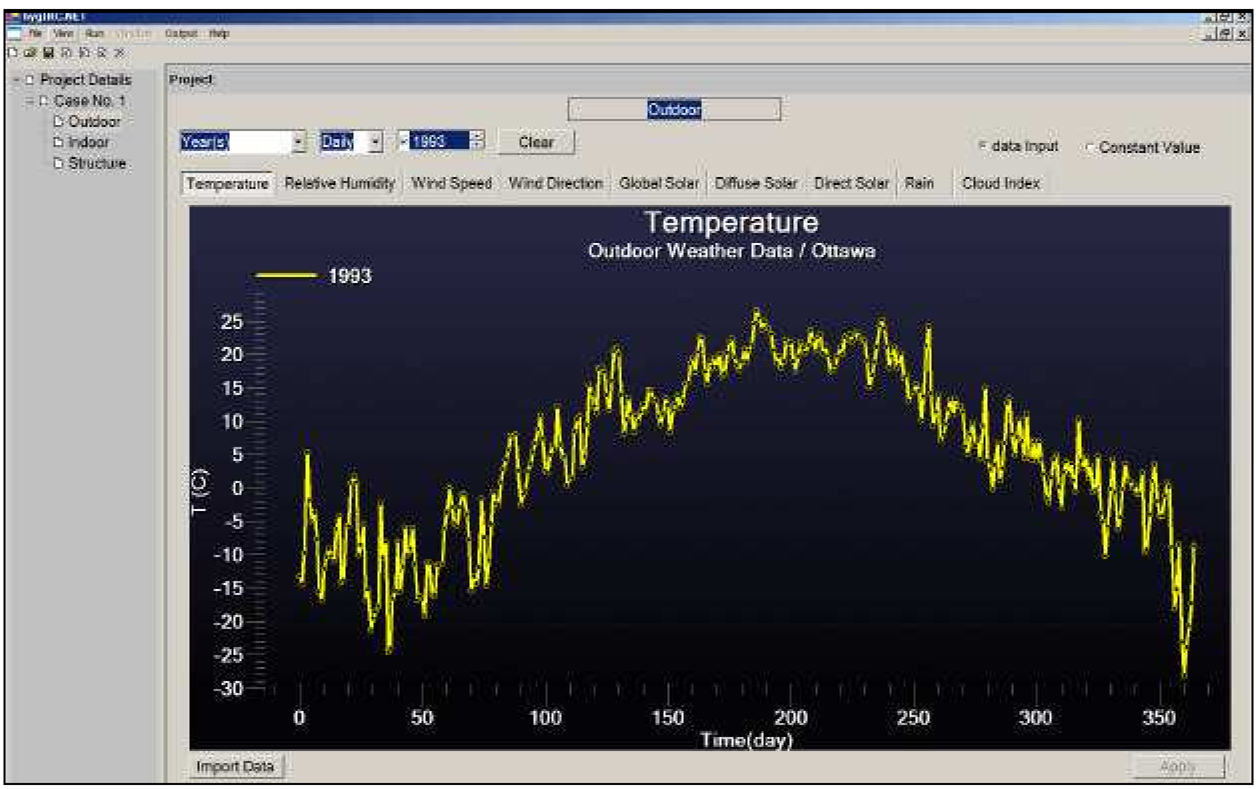

Figure 4. The interface to the climate database has tools to allow the user to choose individual years and sequences of years either sequentially or non-sequentially. All the climatic parameters used by hygIRC can be viewed in the climate database interface.

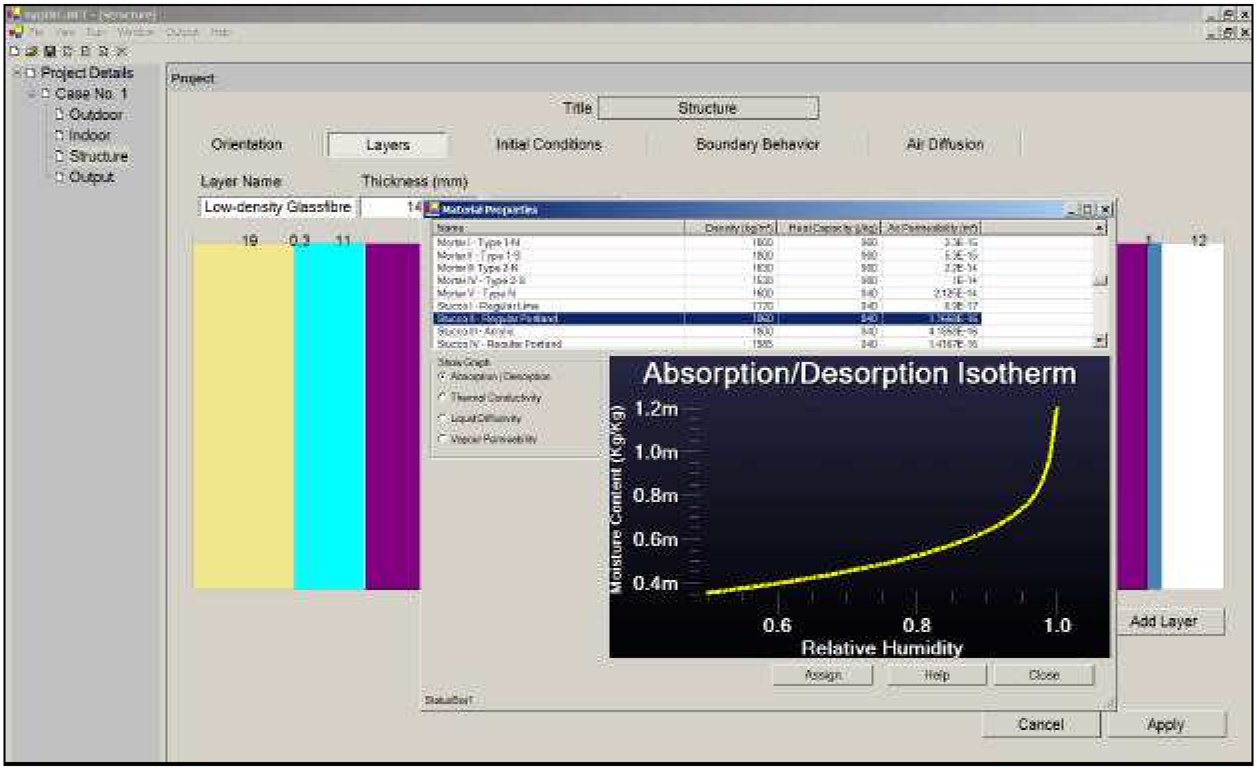

Figure 5. The material properties of over 80 common North American building materials can be easily reviewed in the interface to the material properties database. The user can view all the relevant hygrothermal properties of the material in question.

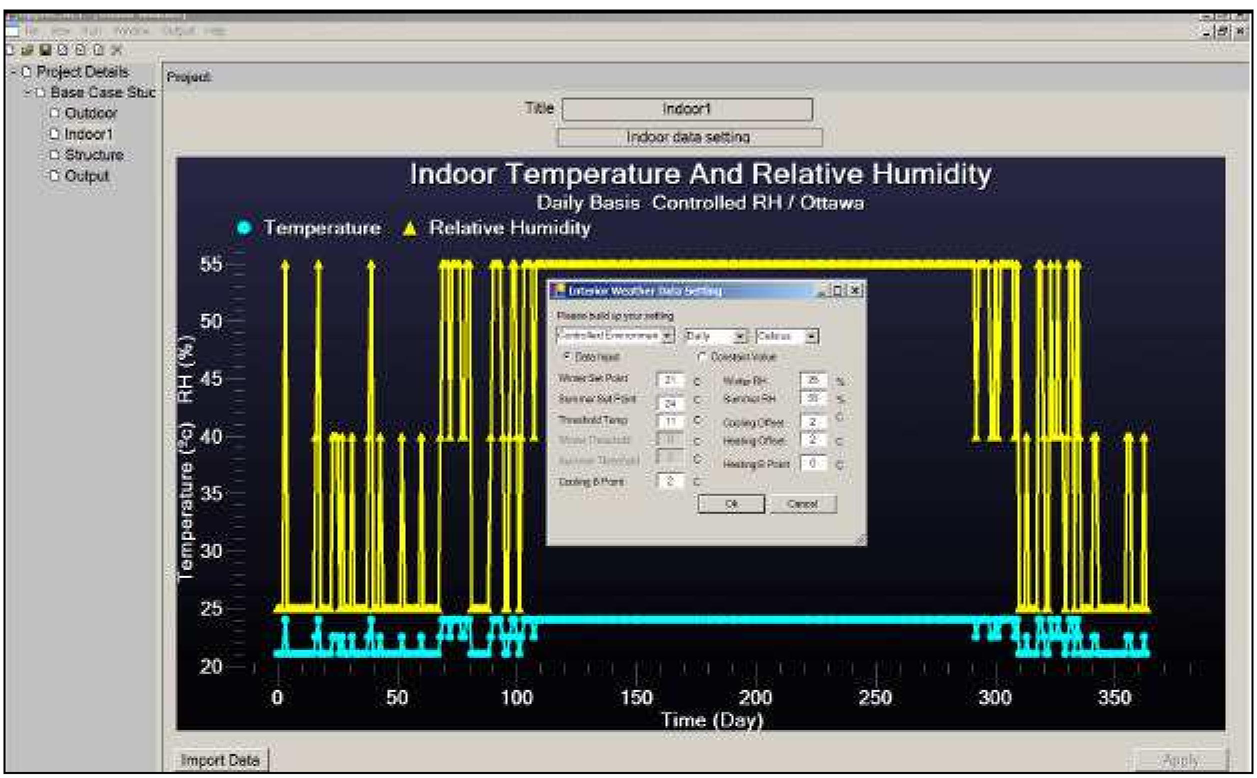

Figure 6. The interior condition models allow the user to set the interior temperature regimes using either a seasonal heating or daily balance point models. In this case the relative humidity is also controlled using set points.

The Solver

The kernel of 1-D hygIRC is based on 2-D hygIRC, IRC's state-of-the-art hygrothermal computer simulation tool.[5] hygIRC is a combined Heat, Air and Moisture (HAM) model and is also referred to as a hygrothermal model. The solver simultaneously solves the mass balance equations and the energy balance equations, mass being water and air. The moisture transport potentials used in the model are moisture content and vapour pressure. The temperature is the driving force for the energy transport. Moisture contents in the building envelope components are obtained by solving vapour diffusion and capillary liquid moisture mass balance. Temperature as well as heat fluxes through the envelope components are derived from the energy balance equation. 2-D hygIRC has been benchmarked at IRC by comparing the simulation results with the results of full- and mid-scale experiments.[6,7,8] In the benchmarking exercise a series of experiments was conducted in which the drying rates of oriented strand board alone or in combination with several sheathing membranes were systematically measured. Results from these experiments were compared with those derived from hygIRC simulations and subsequently used to help benchmark the model. The shape of the drying curves and the time taken to establish equilibrium moisture content show good agreement between the experiments and the simulations.

Running hygIRC Analyses

After specifying all the input, the user can start the simulation by clicking on **run simulation** in the hygIRC main dialog box. During the simulation, the program displays simultaneously two graphs (see Figure 8):

1. The total moisture content of the whole structure versus time in hours in real time for the duration of the simulation
2. The rain event versus time in hours in real time for the duration of the simulation.

Output Tools

For a simulation run, 1-D hygIRC calculates the hygrogthermal conditions for all the nodes in every layer of the envelope, for each hour. This leads to a large amount of output data. Of course, this output is always accessible to the user and it can be exported to various third-party programs. To facilitate the analysis of results, however, 1-D hygIRC has incorporated several features for post-processing analysis. The temperature, the moisture content and/or relative humidity, the heat flux, and freeze and thaw cycles can be examined at each node or for each layer. The output display interval can be varied, displaying every hour, day, week or year thereof. Charts displaying material layers and their boundaries or nodes are easily generated for single or multiple output parameters. Charts can be either snapshots of the entire wall or specified layers at a particular simulation time step or a time-series chart showing the entire simulation history for the element of interest (see Figures 9 and 10). An animation feature allows users to view a series of snapshots creating a movie of the time history hygrothermal response of the entire wall or specific layers. A novel output parameter developed at IRC, the RHT Index, is also included as an output parameter in 1-D hygIRC.[9] The RHT Index was specifically developed to characterize the simultaneous occurrence of moisture and temperature conditions that are prerequisites for typical deterioration mechanisms, such as corrosion and wood decay, and as such, RHT is an indicator of increasing risk of those deterioration mechanisms occurring (see Figure 11).

Future Prospects

1-D hygIRC is a computer simulation tool used to calculate the one-dimensional hygrothermal response of building envelopes. This computer model was designed to be user-friendly, providing practitioners, architects, air conditioning engineers, designers, and building material consultants with a tool to conduct heat and moisture transfer analyses for building analysis and design. The plan is to have 1-D hygIRC ready for public release in January 2004. Interested readers are invited to check IRC's Web site for further details about 1-D hygIRC and its price and availability (http://irc.nrc-cnrc.gc.ca/bes/index.html).

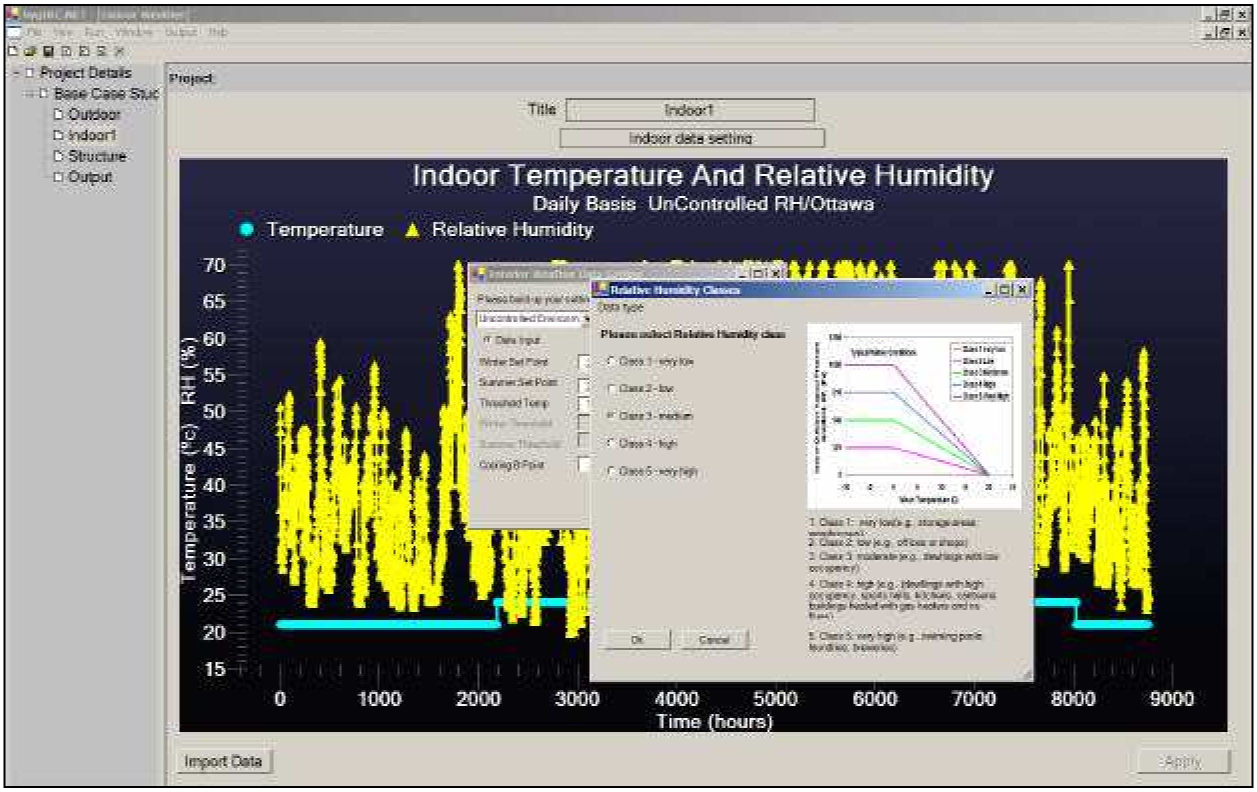

Figure 7. 1-D hygIRC also allows the relative humidity to be uncontrolled. Two models are provided; a statistical model and a model based on moisture generation rates. In this case a statistical model is assumed. The model assumes that the interior vapour pressure is equal to the exterior vapour pressure plus an amount determined by the occupancy and proportional to the mean monthly exterior temperature.

Figure 8. The screen shot shows the runtime operation of 1-D hygIRC. The real time history of the total moisture content for all the wall layers is shown here along with the real time history of rain events derived from the weather file.

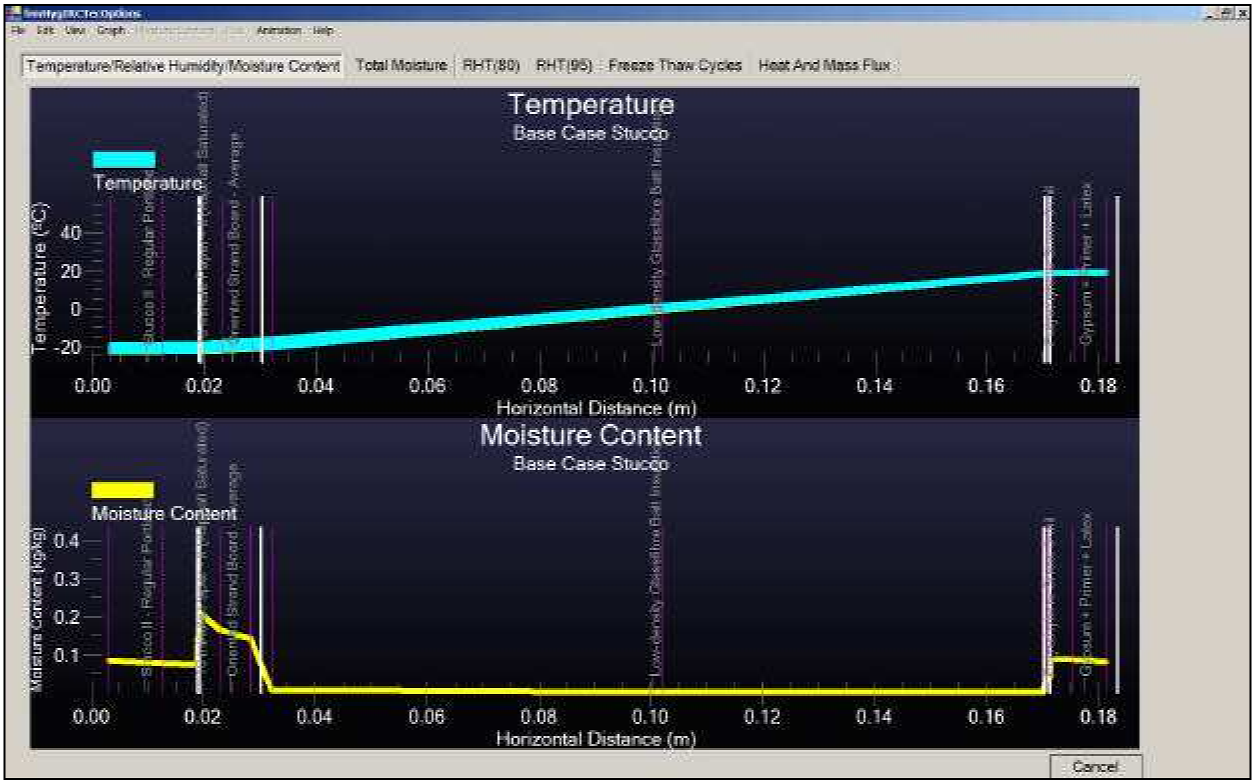

Figure 9. Output from 1-D hygIRC showing the final temperature and moisture content distribution through the entire wall section at the end of the simulation (a snapshot).

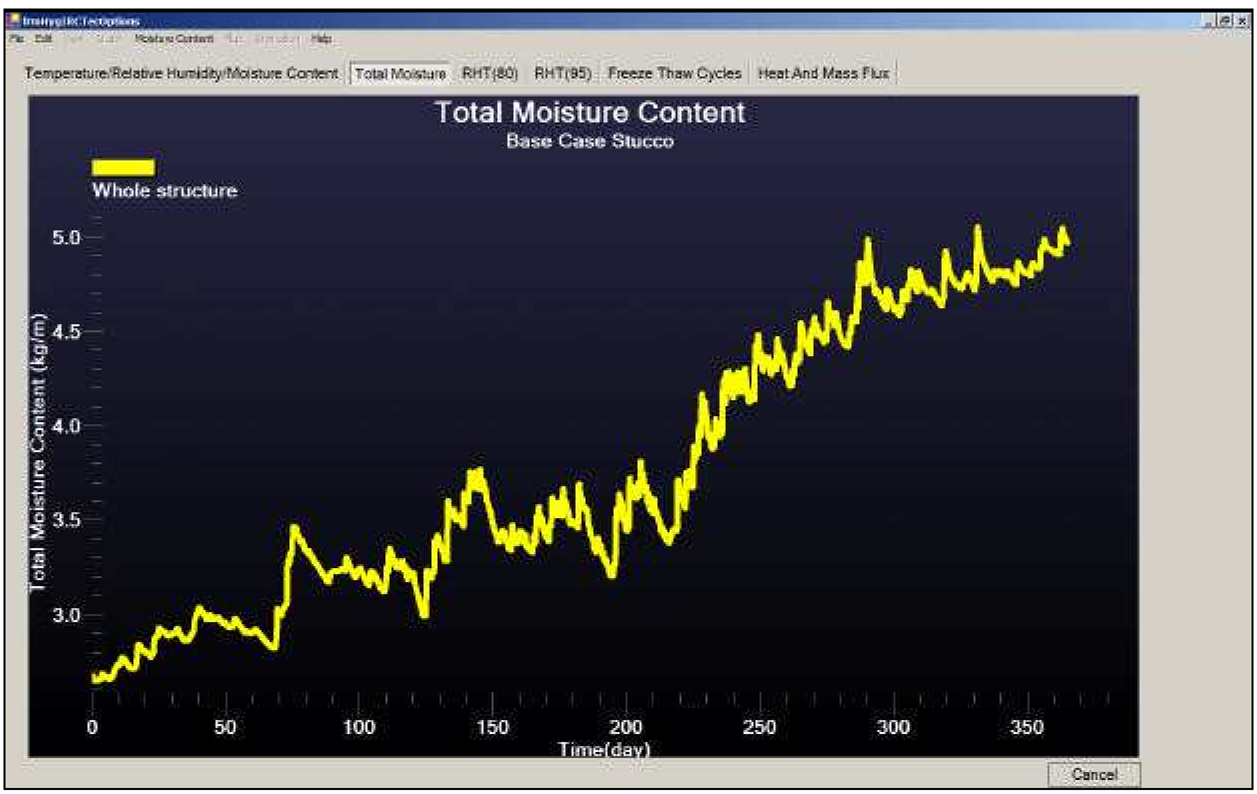

Figure 10. Output from 1-D hygIRC showing the variation of the total moisture content of one layer of the virtual wall through time (a time history).

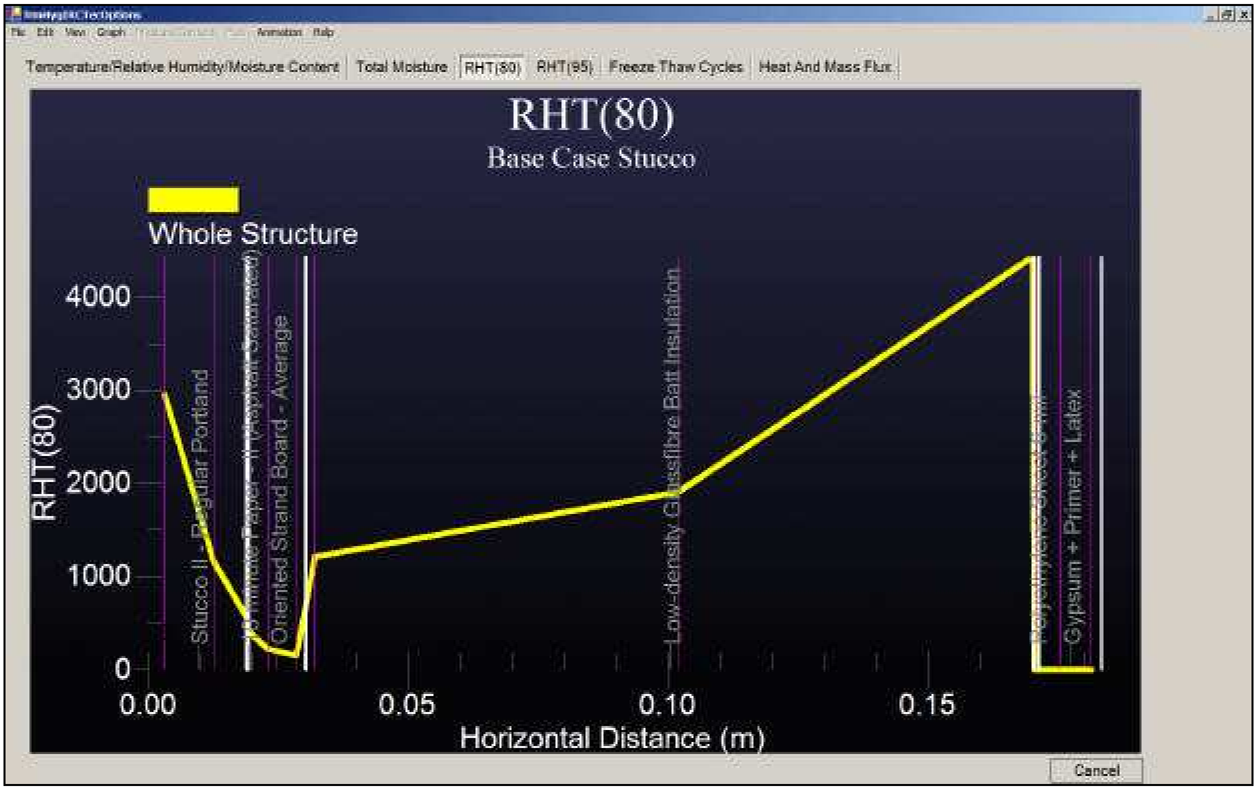

Figure 11. Output from 1-D hygIRC showing the final distribution of the accumulated total RHT (80) index through the entire wall section at the end of the simulation (a snapshot).

Further Reading

Full text versions for all of the cited articles are available on IRC's web site.

[1] CONSTRUCTION INNOVATION, Volume 8, Number 3, December 2003
http://irc.nrc-cnrc.gc.ca/newsletter/v8no3/design_e.html

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[9] Kumaran, M.K., Mukhopadhyaya, P., Cornick, S.M., Lacasse, M.A., Rousseau, M.Z., Maref, W., Nofal, M., Quirt, J.D., Dalgliesh, W.A. "An integrated methodology to develop moisture management strategies for exterior wall systems," 9th Canadian Conference on Building Science and Technology (Vancouver, B.C. 2/27/2003), pp. 45-62, February 2003 (NRCC-45987)
http://irc.nrc-cnrc.gc.ca/fulltext/nrcc45987/