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The effects of microclimate and time resolution of meteorological data on hygrothermal analysis of wood frame building facades

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THE EFFECTS OF MICROCLIMATE AND TIME RESOLUTION OF METEOROLOGICAL DATA ON HYGROTHERMAL ANALYSIS OF WOOD FRAME BUILDING FACADES

By

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THE EFFECTS OF MICROCLIMATE AND TIME RESOLUTION OF METEOROLOGICAL DATA ON HYGROTHERMAL ABALYSIS OF WOOD FRAME BUILDING FACADE

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Wu, Wai Ki Master of Applied Science, Building Science, Ryerson University, 2011

Abstract

When performing hygrothermal analysis for building envelopes, climate data is required as boundary conditions. This study investigates the effect of the microclimatic conditions using Toronto Pearson Airport and downtown hourly data. The results showed that the average water content of the wood frame building facade were similar throughout the study period. The high moisture content peaks reduced to average within days. The arithmetic averaged hourly weather data may also affect the analysis' results. 5-minute weather data is collected from the Ryerson weather network. The hourly data is constructed from the 5-minute data by arithmetic averaging. The simulation results from both dataset followed closely to each other throughout the study period. The averaging of hourly data removed some details from the raw meteorological data. However, it does not affect the overall trend of the climate condition and the impact to the hygrothermal analysis of building components is very limited.

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1 Introduction

Understanding the heat, air and moisture (HAM) transfer through the building envelope is essential for a designer to truly understand and evaluate the indoor environment and building envelope. Heat from the exterior climate results in extra loads to the heating, ventilation and air-conditioning (HVAC) system and increases the energy consumption due to extra heating or cooling of indoor space. The moisture of infiltration air may deposit in the building envelope which will affect the durability of the building. The indoor relative humidity will be affected by these moisture intakes. The HVAC system becomes necessary to remove the moisture and maintain human comfort. This results in negative impact to energy consumption. The moisture deposit in the envelope could respond with a time delay due to the temperature change of the envelope during the day. It may release to the interior space gradually and affect the indoor air quality (IAQ). The air leakage results in air drafts and occupant discomfort. These air infiltrations or exfiltrations can lead to discrepancies with the original HVAC design load calculation. This causes inefficiency in HVAC systems and disturbs the optimum efficiency of the system.

The whole building HAM response, human comfort, energy consumption and durability are all interrelated to each other. Human comfort is essential for health, productivity and social benefits. Building durability is important as it increases the service life of the materials used, reducing the impact of material usage and embodied energy during manufacturing. While removing indoor moisture (humidity) could contribute to 50% of the annual energy in warm and humid climates, the moisture response of the building would have an even larger impact on the overall energy consumption. Therefore a good understanding of HAM modelling would be necessary for this.

The development of this type of modeling has been greatly advanced in the past decades. A comprehensive list can be found at the US Department of Energy (DOE, 2011a). These tools are mostly designed for transient building energy simulation. These software tools mainly focus on the HVAC system. The tools can model individual components, systems and control strategies to obtain the energy consumption data. However, these tools are not designed to investigate the moisture transfer process in buildings.

Transient tools have been developed for simulation of HAM for building envelope (Blocken & Carmeliet, 2008), such as WUFI, DELPHIN, HYGirc and HEMFEM. They are commonly used in research projects and have limited commercial use. Recently the International Energy Agency (IEA) initiated a project to develop and evaluate whole building HAM models (Woloszyn & Rode, 2008). The goal is to combine the building simulation tool (EnergyPlus, TRNSYS) with the moisture analysis model into a single modelling tool. These coupled models can not only simulate the heating and cooling requirement for the indoor condition, but also calculate the moisture level in the indoor air and as well as account for the moisture storage. This moisture storage is modelled dynamically with the HVAC system. The moisture level of the building elements can also be assessed from the model.

Regardless of which tool is chosen for an analysis, the outdoor climate and indoor environment have to be defined as boundary conditions. The results of the calculation greatly depend on these boundary conditions and how they are defined.

The use of inappropriate weather data can lead to under-estimating moisture accumulation and drying potential of building envelopes, which directly influences the durability of buildings. For example, in 1998, Salonvaara and Karagiozis found the difference in moisture accumulation in brick cladding up to 30 times more when employing WYEC (Weather year for energy calculation) data than weather data by NOAA (National Oceanic and Atmospheric Administration) in their calculations (Salonvaara & Karagiozis, 1998). Wind speed, direction, localized gusting and turbulences in urban downtown centers greatly differ from those in rural/suburban areas, where weather stations are usually placed. These phenomena not only affect environmental loads on the building envelope, but also people’s comfort at the pedestrian level, which can be experienced as uncomfortable or even dangerous (Blocken & Persoon, 2009). Correspondingly, wind-driven rain (WDR) on building façades is not only one of the main moisture sources for building envelopes, but also an important factor in the dry and wet deposition of pollutants, façade surface soiling and façade erosion.

Both HAM and WDR calculations require data records of wind speed, wind direction and horizontal rainfall intensity as inputs for simulation in building envelope analysis. This meteorological data is recorded in weather stations situated across the city. In many cases, the weather station is located in the suburban region, while the subject building is located in the downtown city center. The effect of localized climate may affect the accuracy of the analysis. This study examines the extent of the impacts of this effect in the Toronto area.

Studies show that accuracy of the HAM simulation and calculated WDR amounts and intensities results are, to a large extent, determined by the time resolution of the meteorological input data (Blocken & Carmeliet, 2007b; Blocken, Roels, & Carmeliet, 2007). This study also examines the effects of time resolution of meteorological data in Toronto.

The goal of this study is to investigate the qualities in preparing the weather data which affect the hygrothermal analysis of building elements and the extent of the impacts.

2 Overview of HAM Modeling – Literature Review

In building envelope design and analysis, understanding the HAM performance is crucial. With the help of recent developments of high power computers and research in numerical modeling for HAM performance, numerical modelling of HAM phenomena becomes more readily available for research and design purposes. These numerical models require different boundary conditions in order to calculate the condition within the envelope. Figure 1 presents the types of the boundary conditions.

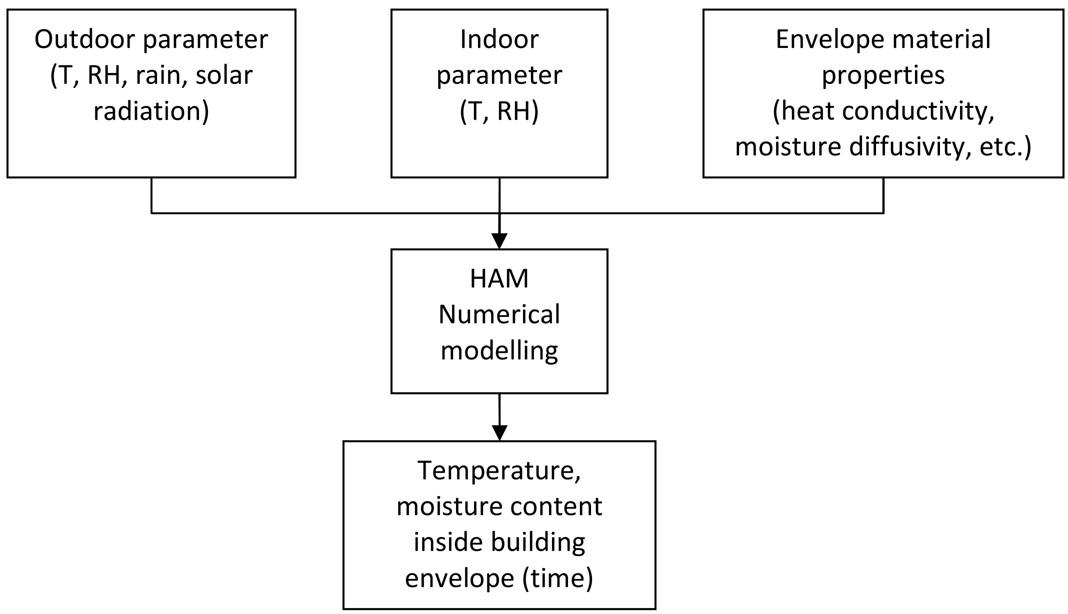


Figure 1: HAM modeling architecture

The indoor parameters are set to a range of temperatures and humidity levels to obtain optimum occupancy comfort by utilizing different types of heating and cooling systems. The material properties include the thermal conductivity, thermal storage, moisture diffusion coefficient and sorption isotherm.

The outdoor parameters represent the condition at the exterior of the building envelope. In general terms it means the weather conditions outside the building. There are different parameters in the weather data required for the HAM numerical modelling. Figure 2 describes the typical weather data items for HAM modelling. The dry bulb air temperature and solar radiation interrelated to the relative humidity (moisture in the air) and rain to establish a combined heat, air and moisture transfer across the envelope.

However, Figure 2 also shows that the rainfall does not directly contribute the moisture to the building facade. Instead it combines with wind speed and wind direction and forms the wind-driven rain (or driving rain). The wind travels in a horizontal direction, carries the rain drops and falls onto the building façade. The wind-driven rain describes the amount of the rain deposited on the facade.

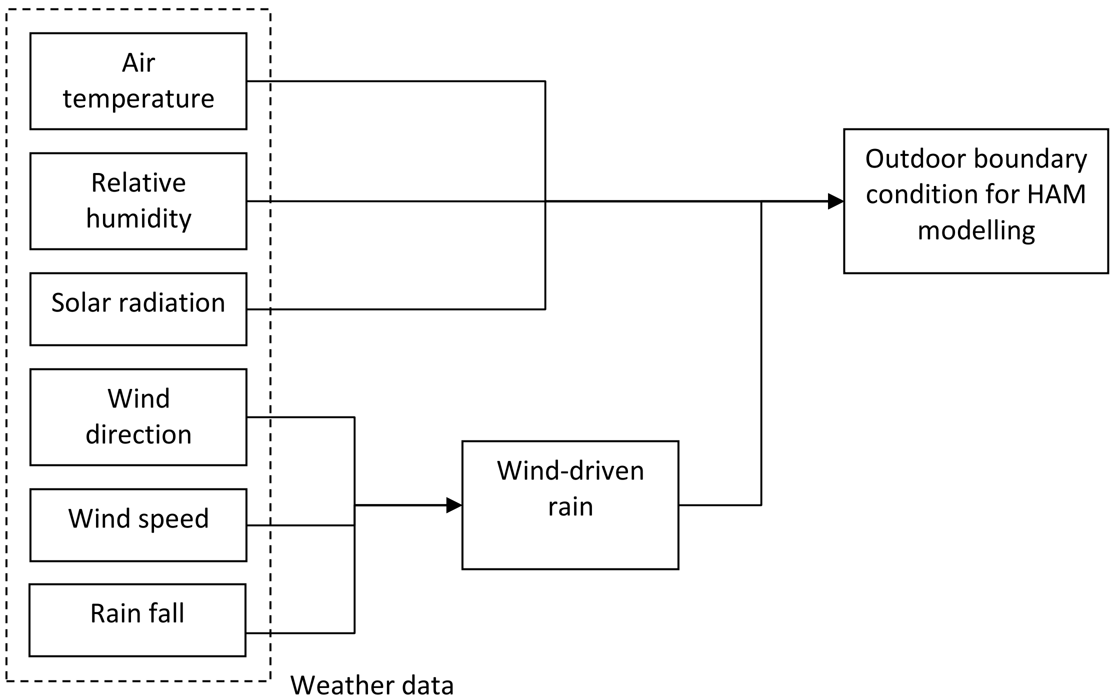


Figure 2: Composition of outdoor boundary condition (focus on wind-driven rain)

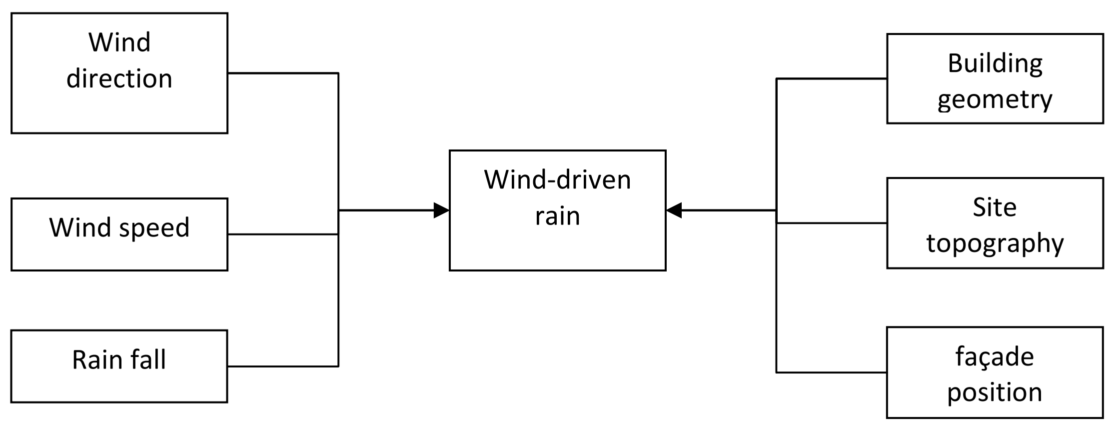


Figure 3: Parameters affecting formulation of wind-driven rain intensity

The quantification of wind-driven rain on building façades is not only based on three weather parameters. Instead, the building geometry, site topography, building façade position, and local turbulence intensity are all part of the equation (Figure 3). These variables make quantifying the WDR amount very complex. From previous work, there are three methods in quantifying the WDR intensity on building façades:

1) experimental method
2) semi-empirical methods
3) numerical methods

2.1 Significance of Wind-driven Rain in Building Science

Wind-driven rain is the most important moisture source in the hygrothermal performance of building façade (Abuku, Janssen, Poesen, & Roels, 2009). This moisture source can cause different forms of damage to the building façade. The moisture accumulation in porous exterior material can cause water penetration to the building envelope (Rousseau, 1983), damage by frosting (Maurenbrecher & Suter, 1993), discoloration of façade (Franke et al., 1998). The WDR runoff is also responsible for the soil pattern appearance on façade which causes extra maintenance costs (Blocken, Desadeleer, & Carmeliet, 2002; Charola & Lazzarini, 1986). All these issues cause damage claims and large repair and replacement costs to the owner (CWCT, 1994). Therefore, understanding the WDR effect in the hygrothermal performance of the building envelope is important (Blocken & Carmeliet, 2004; Dalgliesh & Surry, 2003).

There are two main directions for WDR study in building science: 1) quantifying the WDR intensity; 2) the hygrothermal response of the building due to WDR. In this study, the focus is on the hygrothermal response of the building with the effects of weather data quality.

2.2 Microclimatic Condition

When performing HAM and WDR analysis, the weather station which collects the data is usually located at a location different from the point of interest. For example, in Toronto, Toronto Pearson International Airport is the usual location of recording meteorological data. However, the microclimatic condition at Toronto city-center (an urban area) may be different from Pearson Airport (a suburban area). Wind speed, wind direction and rainfall are particularly important, as noted above. They could be very different due to the differences in geographical and built environment. The wind and its direction change when it channels through buildings in the downtown area. These qualities affect rain water disposition on the wall surface of buildings, and in turn may change the water content and energy performance of the building envelope. Previous studies show that the turbulence level in groups of buildings (urban environment) is very different from single building situations (Baskaran & Kashef, 1996). This is also confirmed by the pedestrian wind study showing that wind channels through buildings (Blocken & Persoon, 2009; Tominaga et al., 2008).

Studies carried out previously used meteorological data measured at the same location as the testing facilities (Abuku, Blocken, & Roels, 2009; Blocken et al., 2007). The weather stations used in these studies are situated next to the test building. This may apply to European cities in these studies where the weather stations are close to urban areas. Since the WDR intensity of the façade is greatly affected by the wind speed and wind direction, the first part of this project focuses on investigating the effects when using weather data from another geographic location, which is very typical in building science studies.

2.3 Time Resolution of Weather Data

The meteorological data collected from weather station consists of wind speed, direction and rainfall amount for calculating the WDR for HAM analysis. Currently the data is arithmetically averaged to hourly data (Blocken & Carmeliet, 2008). Studies show that hourly arithmetic average data would cause significant underestimation in the WDR applied to the façade (Blocken & Carmeliet, 2007b; Blocken et al., 2007). Their studies carried out at the test building near the institution at a suburban area. The authors suggested that a minimum of ten-minute average data is required to achieve acceptable results for quantifying WDR intensity.

Further study confirmed the ten-minute requirement of the data (Blocken & Carmeliet, 2008). Although hourly average data with weighted averaging technique can be used for analysis, hourly average data by arithmetic averaging technique should not be used except for a few special scenarios (Blocken & Carmeliet, 2010). Therefore, in this project, high resolution data of 10-minute averages or higher will be used.

The same authors highly recommended that high-resolution data (e.g. 10-min data) be used for more accurate simulation results in the guidelines that they developed for WDR (Blocken & Carmeliet, 2008):

> A good choice for the time resolution of wind and rain measurements is 10 min. Generally, hourly or daily data can be used instead, but only if they have been obtained from averaging 10 min measurement data with the weighted averaging technique. (p.635)

Currently most of the weather stations across the world provide arithmetically averaged hourly datasets for HAM software, commercial or research based (Blocken & Carmeliet, 2008):

> As mentioned before, most existing meteorological datasets for building applications contain at best hourly data. The use of such data for, e.g. HAM simulations is current practice. For example, the leading commercial and non-commercial advanced HAM codes WUFI (WUFI ORNL/IBP) (Kunzel, 1994; Kunzel et al., 2004), CHAMPS-BES (formerly called DELPHIN) (Grunewald, 1997; Grunewald and Nicolai, 2006), HYGirc (Cornick et al., 2003; Maref et al., 2004; NRC, 2007) and HAMFEM (Janssen, 2002; Janssen et al., 2007) that are used worldwide for hygrothermal building envelope analysis, contain and employ meteorological datasets for a large number of cities all over the world. Unfortunately, almost all of these datasets consist of arithmetically averaged hourly data, due to the lack of data at shorter time intervals. Efforts should be made to persuade national and international meteorological organizations and research

institutes to provide either higher resolution (10 min) meteorological datasets or weighted averaged datasets to the community. (p. 637)

Although there have been studies on acquiring more accurate data for WDR to be used as a boundary condition (Blocken & Carmeliet, 2007a; Blocken et al., 2007; Blocken & Carmeliet, 2008), studies on effects of time resolution in urban areas is minimal.

2.4 Research Problems

The above analysis presented certain unanswered questions in the boundary conditions for hygrothermal analysis for Toronto. There are four problems raised from the above:

1. Is there any effect of the microclimate of local environment to the hygrothermal analysis of building elements?
2. If there is, how much effect does it have on the results of the analysis?
3. Is there any effect of the time resolution of weather data to the hygrothermal analysis of building elements?
4. If there is, how much is the difference?

2.5 Research Objectives

For this project, the focus is on the use of outdoor climatic conditions in HAM modelling of buildings in Toronto. The objective is to demonstrate the significance of effects from the qualities of formulating and utilizing weather data for hygrothermal analysis of building elements. The study presents how different factors are affecting the HAM analysis and how severe the effect is from each factor to the result of the analysis. The study examines the factors individually and through detailed analysis, conclusions are drawn from the findings. The results are summarized at the end of the study.

2.6 Methodology

1. Microclimatic conditions in HAM modelling.

   The weather data file from different sources across Toronto is examined. The weather data from the suburban area (Pearson International Airport) is compared with the weather data collected from downtown Toronto. The HAM model of a typical wood frame residential construction is analysed to illustrate the differences in the building envelope. The result would reveal whether there is much difference in terms of HAM transfer across the building envelope.

2. Time resolution of weather data

   The second part of the project investigates the effect of time resolution of the weather data in HAM modelling. The time resolution of the weather data has significant impact in the calculated amount of wind-driven rain. The 5-minute weather data collected from Ryerson weather network is utilized. The 5-minute weather data is converted to hourly data with typical standard arithmetic methods. The two weather datasets are used in HAM modelling of the same building as in part one. The results would show the difference in average temperature and moisture states of the building envelope is very minimal.

The study utilizes different HAM modeling software for different parts of the project. Each software is examined in the study to determine the ideal tools for each analysis. The pros and cons of each software are presented in detail. Custom modification and development of software will be carried out if necessary. This includes additional modules developed for the software in order to carry out the required analysis in this study. The newly developed program or software is then examined in detail and verified before the analysis is carried out. This could ensure the software is designed properly to carry out the analysis and provide reasonable results.

The research is based on residential wood frame buildings in Toronto, Ontario. The climate in Toronto is characterized as cold winters and warm summers. The average July temperature in the summer is 20.8°C and in the winter is -6.3°C in January. The average Heating Degree Days is 4000. In this project, weather data from different sources is used. The Canadian Weather Energy and Engineering Datasets for Toronto Pearson Airport, as well as Toronto downtown (Downtown streets), are used in the project. The weather data collected from Ryerson University Weather Network is also utilized in the second part of the study.

3 Quantification of Wind-driven Rain

Wind-driven rain (WDR) is one of the most important moisture sources to a façade and it is one of the most important topics in building science (Blocken & Carmeliet, 2004; Choi, 1994). The reason is because besides vapour diffusion, this is the other source of moisture which is contained inside the pores of hygroscopic material in a much greater mass. In an ideal world, the WDR model would be applied as a boundary condition in a three dimensional format. The model would record the amount of rain that impacts on the façade, as well as run off, and that being absorbed. However just by the description above, it is already known that this level of detail is not practical even before any attempt. In real applications, there are several methods to obtain the useable data as boundary conditions for the hygrothermal analysis.

3.1 Measurements

Various designs of driving rain gauges have been attempt in the past few decades. The goal is to try to record the actual amounts of water impact on the façade in any given period of time. These measurement setups are mostly for research purposes only. In real applications, physical measurement data is unlikely to be available for analysis. Moreover, such measurements are very time consuming to obtain and analyze (Bitsuamlak, Gan Chowdhury, & Sambare, 2009), and have been found to be prone to error (Blocken & Carmeliet, 2006).

3.2 Simulations

With the help of advancements in computer power, Computational Fluid Dynamics (CFD) modelling of the wind blowing around the building with the rain drop trajectories becomes achievable. Previous studies have attempted to use such methods to evaluate the WDR amount on the buildings. This method requires detailed information about the buildings and the surrounding environment. The buildings or topography in the proximity area of the subject building will channel the wind into different directions. Hence, this data are is important for an accurate simulation. In practice, CFD analysis is very limited to research projects with simple buildings and surrounding environments (Abuku et al., 2009).

An alternative approach utilizing CFD modelling in wind-driven rain analysis is the numerical model developed by Choi (Choi, 1994) and extended by Blocken (Blocken et al., 2007) to include the time domain. The key feature is the introduction of two factors, specific catch ratio η_d (which relates to the rain diameter) and the catch ratio η (which relates to entire raindrop diameters). The simplified procedure is as follow:

1) Determine the wind flow pattern around the building using CFD modeling.
2) Introduce rain drops and determine trajectories with the wind motion by use of Lagrangian particle tracking.
3) The specific catch ratio η_d is calculated .
4) The catch ratio is calculated from η_d and the horizontal rain drop size distribution.
5) The catch ratio chart can be constructed for different regions of the building façade.

With the catch ratio chart, the amount of rain fall on the entire façade can be calculated for different time steps. According to the author(s), this method provides very close representation to the physical measurement result (Blocken & Carmeliet, 2007a).

3.3 Semi-empirical Models

Since the wind-driven rain is a combined effect between airflow and rainfall applied on the façade of the building, it is possible to introduce an empirical relationship between wind speed, direction and rainfall and the driving rain applied on the wall. In a simplified world, assuming the rain drop size and wind are all uniform, the amount of rain passing through an imaginary vertical plane can be simplified as follows:

$$R_{wdr} = R_h \cdot \frac{U}{V_t} \qquad \textbf{(1)}$$

where R_{wdr} is the WDR intensity, R_h is the regular rain fall, U is the horizontal wind speed and V_t is the rain drop vertical terminal speed. It is noticed that there is a proportional relationship between the U and V_t in the equation. An empirical constant f can be introduced to rewrite the equation as:

$$R_{wdr} = R_h \cdot U \cdot f \qquad \textbf{(2)}$$

This semi-empirical equation was first introduced by Lacy (Lacy, 1965) to define the driving rain intensity in an open field (imaginary vertical plain) given the wind speed and rainfall from weather data. The empirical constant f is also known as the Driving Rain Factor (DRF) (Straube, Onysko, & Schumacher, 2002). It is defined as: DRF = $1/V_t$. From experiments and field studies performed in Canada and Germany, and computer models, it is found that the value of DRF is between 0.2 – 0.25 for average conditions. However, it can vary from 0.5 for drizzle to as little as 0.15 for intense cloudbursts (Straube, 2010).

By using a WDR coefficient for the effect of wind deflection when approaching a building's surface and angle factor of the wind direction, a semi-empirical formula for the WDR can be formed as:

$$R_{wdr} = R_h \cdot U \cdot f \cdot \cos\theta \quad \textbf{(3)}$$

where angle θ is the angle between a line drawn perpendicular to the wall and the wind direction. This is the fundamental form of a semi-empirical formula to determine wind-driven rain to a building (Blocken & Carmeliet, 2004). In real situations, when the wind flow encounters a building, the wind flow will channel away from the face of the building and go around it. This airflow around the building phenomenon greatly affects the amount of rain deposition on the façade. The shape of building, height, upstream environment and topography will all affect the rain deposition on the façade. Different correcting factors have been introduced by different models and the goal is to address the effect of these variables. These factors are mainly collateral results from multiple field measurements (Blocken & Carmeliet, 2000; Henriques, 1992; Künzel, Kießl, & Krus, 1995; Sandin, 1988; Straube & Burnett, 1998), wind tunnel tests (Inculet & Surry, 1995) and computer modelling (Blocken & Carmeliet, 2000; Choi, 1994; Karagiozis, Hadjisophocleous, & Shu, 1997).

The common models that are frequently used are the following (Blocken & Carmeliet, 2010; Blocken, Dezsö, van Beeck, & Carmeliet, 2010):

1) Semi-empirical model in ISO Standard for WDR (ISO, 2009)
2) Semi-empirical model by Straube and Burnett (Straube, 1998)
3) Semi-empirical model from ASHRAE 160P 2009

3.3.1 ISO Standard 15927-3 2009

The ISO Standard 15927-3 2009 is under the title *"Hygrothermal performance of buildings – Calculation and presentation of climatic data – Part 3: Calculation of a driving rain index for vertical surfaces from hourly wind and rain data"*. The ISO Standard semi-empirical model uses two indices:

1) I_{wa} annual average index (average WDR exposure)

2) I_s spell index (maximum or peak WDR exposure)

In order to calculate the two indices, an airfield annual index I_A is calculated based on the quantity of driving rain that occurs on an open grass cover field at 10m high for one hour. The airfield spell index I_S is defined as a period during the WDR occurs where it is preceded and followed by 96 hours with I_A is zero.

To calculate the I_{wa} and I_s, four corrections factors are introduced:

- C_R - roughness coefficient
- C_T - topography coefficient
- O - obstruction factor
- W - wall factor

All the factors are tabulated in the ISO standard with detailed description. The final model for ISO Standard 15927-3 uses the following formula:

$$R_{wdr} = \frac{2}{9} \cdot C_R \cdot C_T \cdot O \cdot W \cdot R_h \cdot \cos\theta \quad \textbf{(4)}$$

3.3.2 Straube and Burnett Model

Straube and Burnett introduced driving rain factor DRF which account for the terminal velocity of the rain and rain deposition factor RDF (which is based on building geometry). The DRF is a function based on the raindrops' diameter. The model is simplified to:

$$R_{wdr} = DRF \cdot RDF \cdot U(z) \cdot R_h \cdot \cos\theta \cdot EHF \cdot TOF \quad \textbf{(5)}$$

where

U(z) is a power-law function which accounts for the mean wind speed profile.

DRF – driving rain factor

RDF – rain deposition factor

EHF – exposure and height factor

TOF – topography factor

3.3.3 ASHRAE Standard 160P 2009

AHSRAE Standard 160P *"Criteria for Moisture-Control Design Analysis"* is a standard which includes calculating the wind-driven rain load on a wall based on the wind speed, direction, and normal rain load. The standard describes that the design rain loads must be determined for walls exposed to rain. The amount of rain can be calculated by the following equation:

$$r_{bv} = F_E \cdot F_D \cdot F_L \cdot U \cdot \cos\theta \cdot r_h \qquad \textbf{(6)}$$

Where

F_E = rain exposure factor

F_D = rain deposition factor

F_L = empirical constant

U = hourly average wind speed at 10 m height, m/s

ϑ = angle between wind direction and normal to the wall

r_h = rainfall intensity, horizontal surface, mm/h

r_{bv} = rain deposition on vertical wall, kg/(m^2 h)

The exposure factor is tabled in the standard based on the terrain of the building and the height of it. The rain deposition factor is based on whether the wall is under a steep slope roof or low slope roof, and whether or not the wall material is subject to rain run off.

3.4 Selection of Method

The goal of this study is to examine the effects of microclimate conditions and time resolution of climate data in hygrothermal analysis. The ideal tool for this study would be the CFD model approach due to its level of detail and relative accuracy. However, this would require specific knowledge in CFD modelling and software tools for that. Due to the time and resource constraints of this project, the CFD model approach is not utilized for this project.

Field measurement approach in this study is not applicable as well. Since this study is a comparison with different weather data locations, driving rain gauges would be required to be set up and monitored at different locations. The driving rain measurement requires particular knowledge to select the proper equipment, setup and analysis of data. Otherwise the measured data would not be useable at the end and all the resources involved would be wasted. A separate study to setup the equipment and evaluate the measured data would be required before this study could be carried out. This could ensure the field measurement provides valid data for other research purposes. Therefore, the field measurement approach is not a viable option in this study.

The semi-empirical model is a more practical method for this study. The model ties very closely to the climate data recorded at the location, which is the focus of this study. It is a widely adopted method in practical analysis and the model can be easily incorporated into the hygrothermal analysis simulation software. The model is very easy to setup and can achieve a fairly accurate results (Straube, Onysko, & Schumacher, 2002). The learning curve is minimal as the factors are all tabulated with simple description and criteria. Therefore, the semi-empirical model was chosen to carry out the wind-driven rain analysis in this study.

The ISO model, Straube and Burnett model and AHSRAE 160P model are all very similar. The basic principles are based on the same equation with different factors to account for the building shape, height, and environmental conditions. In fact, the AHSRAE 160P model is largely adopted from the Straube and Burnett model. Since ASHRAE 160P is the latest North American standard, it will be more suitable for this study as Toronto is the location of interest, as it has also been used in previous study by Wu & Horvat (Wu & Horvat, 2010; Wu & Horvat, 2011).

4 HAM Modeling Software - Review

The HAM transfer is a transient problem and requires solving differential equations. Hence, computational solver is required to perform hygrothermal analysis. Commercial and research purpose software packages and tools are available for this kind of simulation. It is necessary to decide the proper tools that are most suitable to the nature and constraints of this project.

There are certain criteria in selecting the appropriate software tools:

- The software needs to allow users to create their own meteorological files for the analysis. Most commercial software packages have their own design year data sets for engineering calculations. Since this study is interested in analysis of two stations' meteorological data, the software should allow users to setup their own weather data file.
- The software needs to account for moisture storage and transport within the building envelope. Wind-driven rain acts as a major water source to the building envelope. The software tool is required to precisely account for the suction and transportation of the water within the material as well as for moisture buffering.
- The software is simple to use and able to extract the required result from different locations of the building envelope. The temperature, water content and heat flux should be able to be plotted among the two stations at any location within the building envelope.

In this section, several simulation tools will be discussed, focusing more on their fulfillment of the criteria listed above. A general overview of the tool will also be provided.

4.1 EnergyPlus

EnergyPlus is a whole building energy simulation program from the U.S. Department of Energy (DOE, 2011b). It is a combination of two building modelling software tools, BLAST and DOE-2 (Crawley, Pedersen, Lawrie, & Winkelmann, 2000). Basically, it is a simulation engine (or solver), which does not have graphical input of building geometry. Third party plugin software is available to utilize graphical software like Google SketchUp to import building geometry. EnergyPlus is capable of variable time steps, configurable modular systems with heat balanced zone airflow, ventilation, PV and solar thermal system simulation.

The energy model is coupled with moisture by Effective Moisture Penetration Depth (EMPD) models (Karagiozis & Gu, 2004). The model is a simplified, lumped approach to simulate surface moisture adsorption and desorption (Abadie, Debiois, & Mendes, 2005; Hens, 2005). It assumed that only a very thin layer of air near the interior surface interacts with the indoor air. This implies that water vapour diffusion between the indoors and outdoors through exterior walls is neglected. Previous works shows that such modelling is efficient in estimating the moisture buffering in the building material (Cunningham, 2003; Hagentoft, 2001). The EMPD model is later fully incorporated into EnergyPlus (Crawley, Pedersen, Lawrie, & Winkelmann, 2004)

4.2 IES Virtual Environment

IES (Integrated Environment Solution) Virtual Environment is a building simulation software which incorporate every aspect of a building environment, including HVAC, solar, lighting, climate, energy cost, carbon footprint and so on. It is the latest integrated software which combines almost all aspects in building engineering into a single software. The software allows user to construct the model of the building either through the build in module or import model from Google SketchUp or Autodesk Revit. The software even carries simulation functions for airflow around buildings. Although the software has fascinating features and capabilities, it does not process any moisture analysis capability. This feature is essential in the analysis of this project because the hygrothermal analysis of building envelopes is the most important indicator for the effect of climate data in water intake and storage of building components.

4.3 HAMBASE

HAMBASE is another MATLAB library that is designed for the HAM analysis by Eindhoven University of Technology (Netherlands) (De Wit, 2006). This model was based on the ELAN model first published in 1988 (De Wit & Driessen, 1988). The model later combined with the AHUM model (De Wit & Dozen, 1990), formed the WAVO model and utilizes MATLAB (De Wit, 2004). The model was worked on further and officially changed name to HAMBASE (Schijndel, 2004). The library includes a list of MATLAB files, which are functions required for the calculations (HAMLAB, 2011). Figure 4 shows the front interface of HAMBASE model. All the calculations are centralized to a single block in the middle. The single block is linked to the function that is coded in the .m files as per Figure 5. It is found that all the functions are coded in

.m files which reduced the flexibility for users to create their own models. Also, this configuration does not allow users to obtain result from other locations of the model easily. Users will need to trace all the code in the functions to identify the variables. The user will then need to create one's own functions to allow Simulink to export this data. This can be very time consuming and is not flexible enough for analysis.

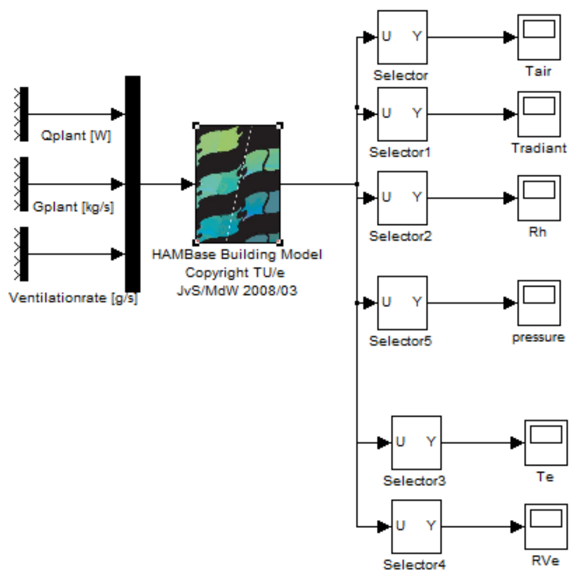


Figure 4: HAMBASE model (HAMLAB, 2011)

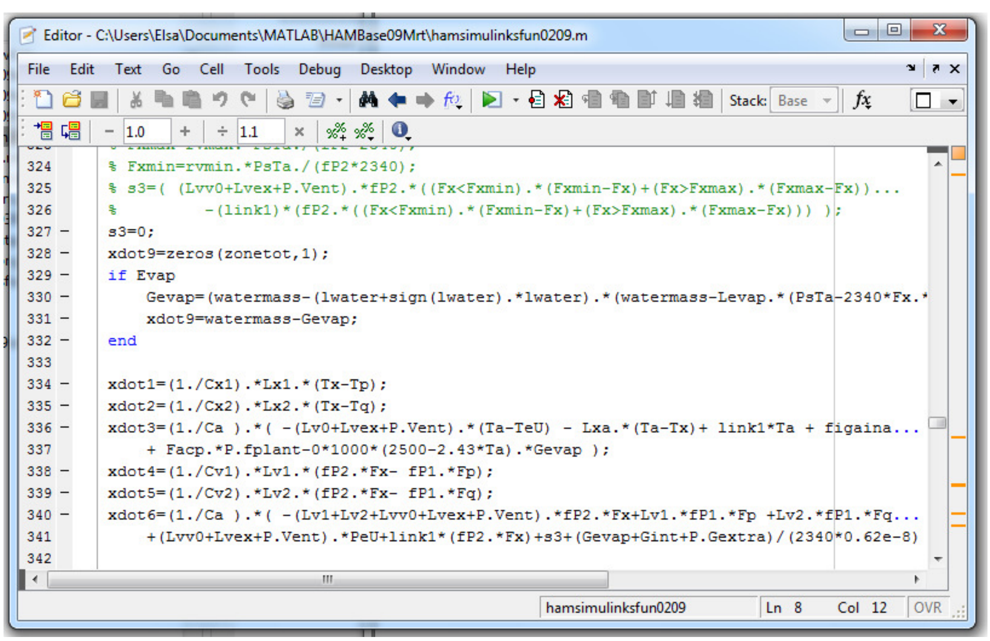


Figure 5: HAMBASE function (HAMLAB, 2011)

4.4 *WUFI (Wärme und Feuchte instationär)*

WUFI is a commercial software that can perform combined HAM analysis developed by IBP (Fraunhofer IBP, 2010) . The name WUFI in German is "**W**ärme **u**nd **F**euchte **i**nstationär" which translates to "Transient Heat and Moisture". The software can calculate the amount of heat and moisture transport at different layers of the wall system. It can be used to calculate the drying time for moisture in the cladding. The program can also calculate the effect wind-driven rain has on the façade. The software calculates the HAM in a transient format instead of the over simplified steady state calculations. WUFI performs the analysis on a per panel basis. Thus, users cannot obtain a whole building result from a simple case. The result will be per unit area of the envelope specified in the study. Each case in a file corresponds to a specific configuration of the envelope, including orientation, and materials. If users would like to perform a study for all four sides of the building, four cases with different orientation will be needed.

Figure 6 shows the input screen of wall construction. Source and sink (leaks) of air, heat and moisture can be introduced to different layer of the wall system. Materials can be selected from the material database. Users can also define their own material properties. However, the moisture transport properties have to be determined for proper analysis. At this time this function is experimentally collected by the WUFI laboratory in Germany. For North American materials, the data from the National Research Council of Canada is being used (Kumaran, 2002).

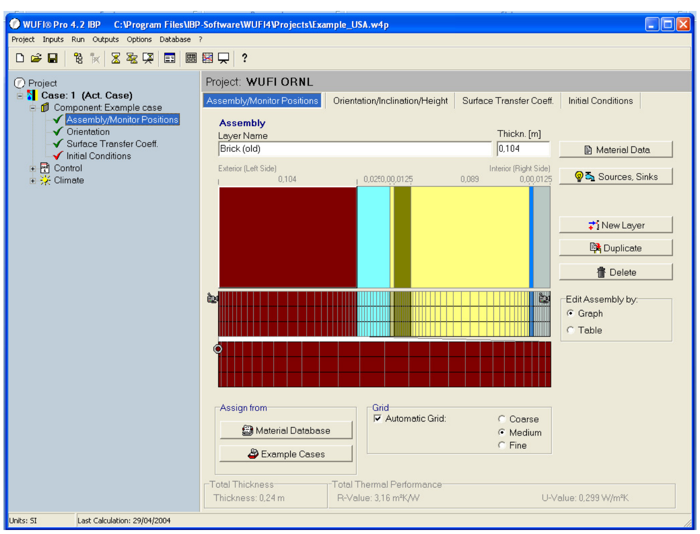


Figure 6: WUFI component setup interface (Fraunhofer IBP, 2010)

The control page will define the simulation period. In typical analysis, the goal is to investigate if there is any moisture accumulation within the building envelope to dangerous levels over the long term. Therefore, a long period of study time (beyond 15 years) is not unusual. The study time period depends on the purpose of the study and can be varied to suit the user's needs. The default calculation time step is one hour. Smaller time steps can be used; however, the climate data resolution has to match the time step for the analysis.

For the outdoor and indoor climate, the software has default weather data files for many cities around the world, and indoor climate profiles from different standards (Figure 7). The supplied weather data files are a year of statistically compile data with high chance of occurrence. The study for multiple years will repeat the year data set. Users can also provide their own climate data, with more than one year of data. The yearly weather data will be displayed when the proper data is imported (Figure 7). The following is a list of weather file formats accepted by WUFI:

*.WET *.TRY *.DAT *.WAC *.IWC *.WBC *.KLI *.AGD

For the indoor climate, WUFI provides a few indoor standards for the user to choose from. Users can also provide their own custom climate for their specific analysis needs, such as the environment of a cold storage.

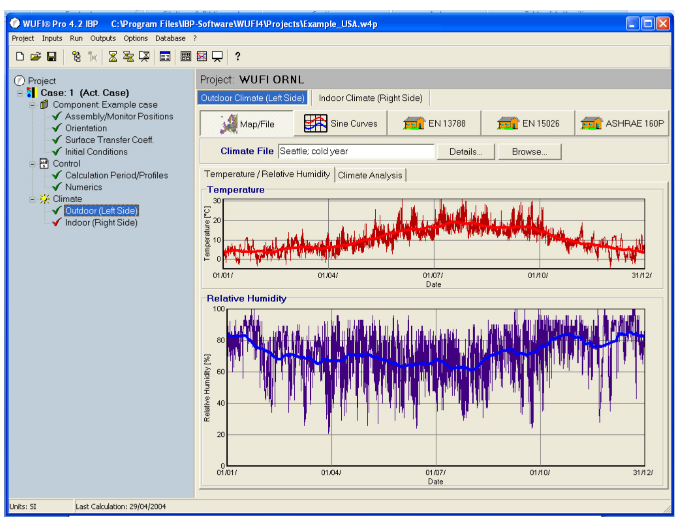


Figure 7: Weather data input (Fraunhofer IBP, 2010)

The most important output from WUFI is the water content of the envelope. Users can check the total water content of the wall or the individual layer. In typical cases, the goal is to ensure the water content is not maintained at a high level for prolonged period of time and does not have the trend of increasing over time. WUFI also outputs the heat transfer across the envelope. These data are all based on per unit area. Figure 8 shows an output of a one year analysis. It is noticed that the water content is high towards the end of the analysis and there is a trend of increasing water content. This shows that a longer study period may be required for verifying the findings.

All output data can be exported to .txt file format for further manipulation. WUFI allows certain extents of custom graph capability for output so users can customize the output graph to suit their own needs.

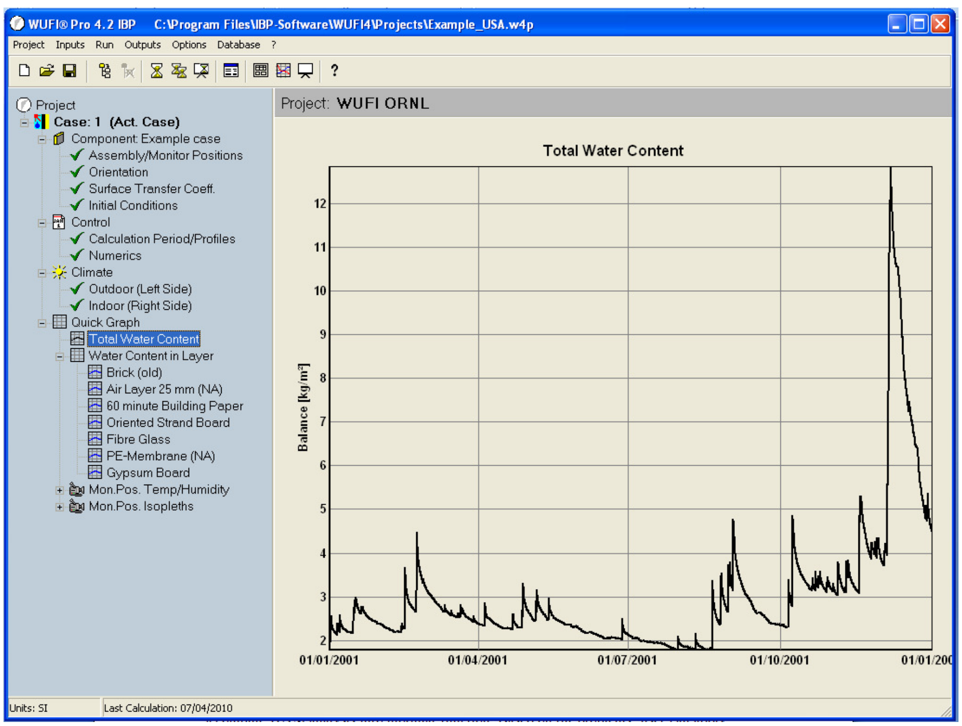


Figure 8: Total water content of the wall (Fraunhofer IBP, 2010)

4.5 HAM-Tools

HAM-Tools or International Building Physics Toolbox (Kalagasidis et al., 2007) is a set of MATLAB Simulink library toolboxes developed by multiple researchers from Chalmers University of Technology at Sweden and Technical University of Denmark. The toolbox idea is to break down a combined HAM analysis into modular functions (Figure 9). Based on the problems, users can apply individual modules to suit their own needs. The communications between each module are standardized so researchers can create their own customized functions universally. This creates a very flexible platform for researchers to analyze different HAM problems. The graphical interface of Simulink allows easy construction of the desired model.

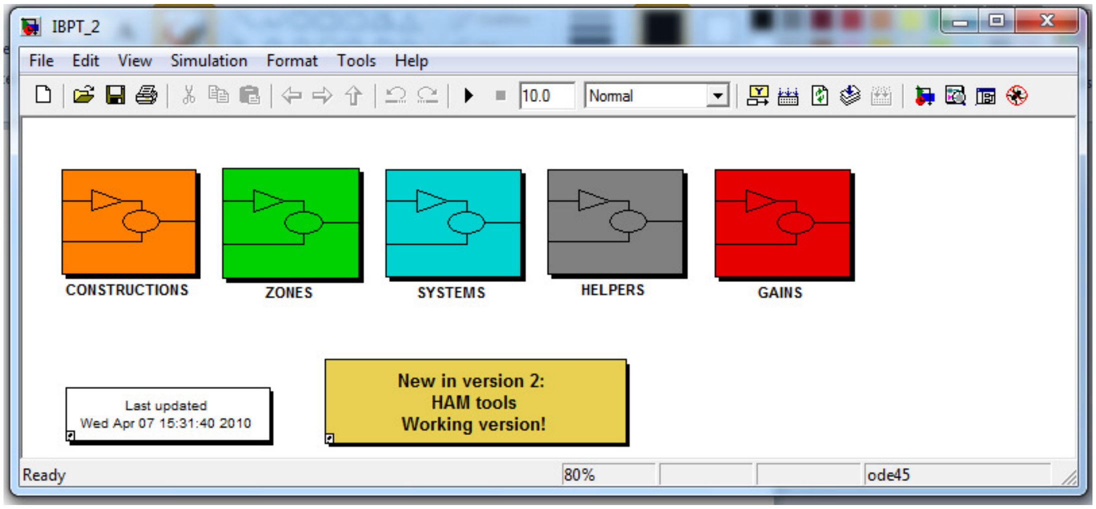


Figure 9: HAM-Tools library (IBPT, 2010)

Figure 10 shows an example of a combined HAM analysis for a building (IBPT, 2010). The building has two windows with a low sloped roof. Notice how individual components of the buildings are connected together. Each block contains a specific construction in multiple layers to perform the analysis. The data then passes through each block by an array. The array is predefined with data structure and type (Kalagasidis, 2003). Any external effect can be added to the house, for example; a heater or a vent to the exterior. The control of those features can also be implemented.

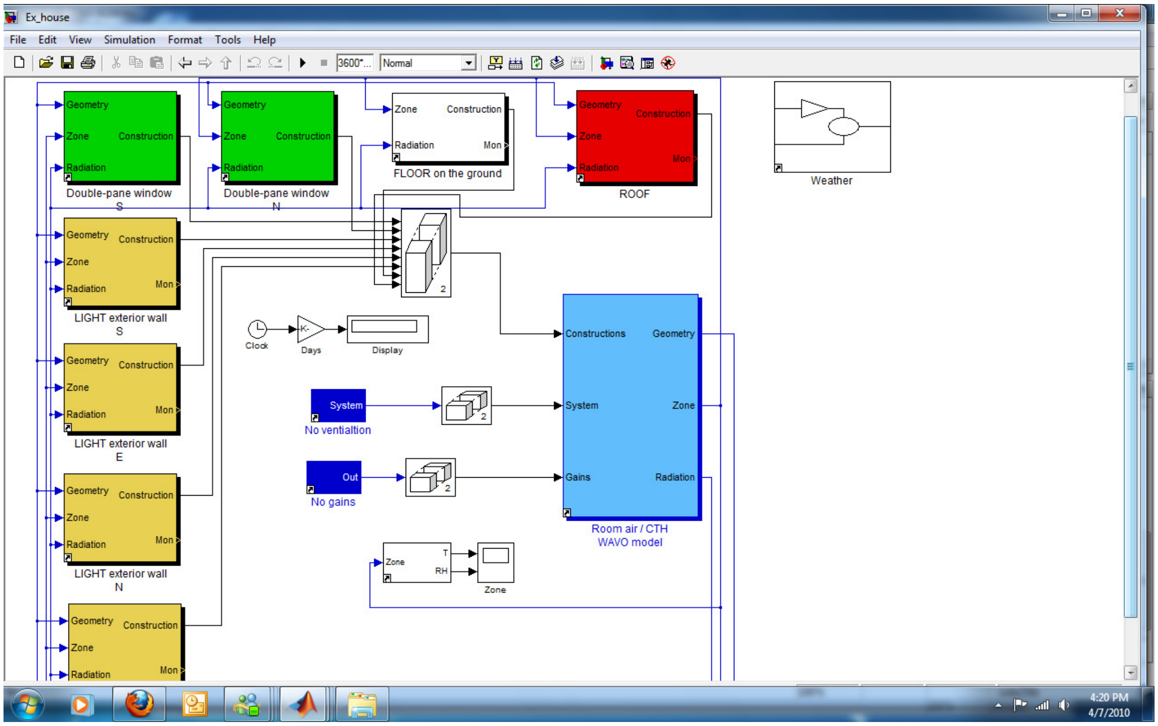
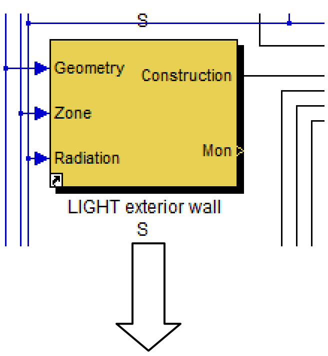
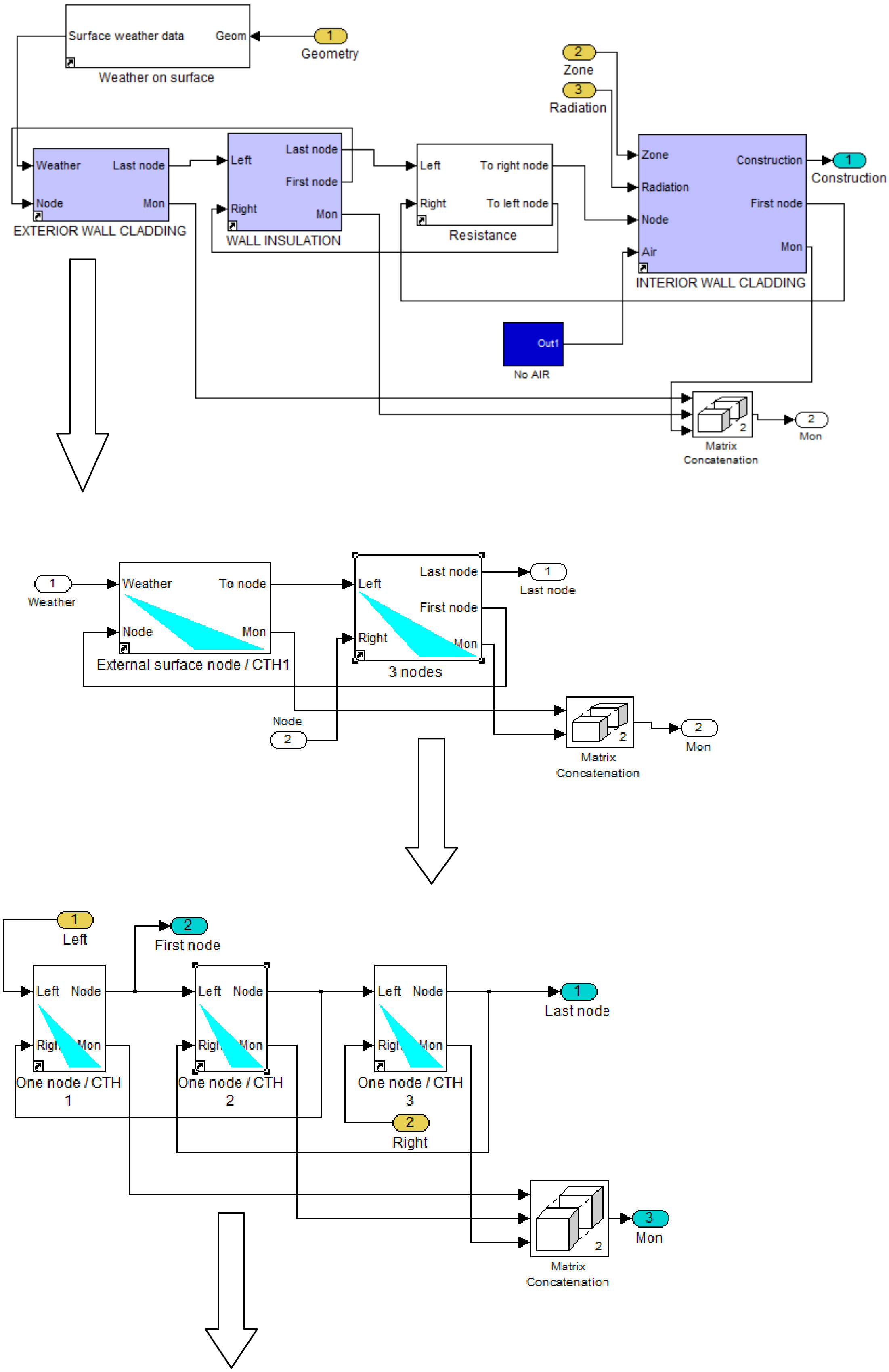


Figure 10: A house model constructed in HAM-Tools (IBPT, 2010)

Figure 11 shows the layers of construction in HAM-Tools. The Light Exterior Wall block in Figure 11 consists of four elements: exterior cladding, insulation, membrane, and interior cladding. The exterior cladding consists of the exterior surface node and the interior nodes. These nodes are equivalent to the elements in Finite Element Analysis. The interior node contains the heat and moisture transport function. So, each element will perform the heat and moisture transport calculation individually. This allows users to understand the HAM-Tools model easily.




Surface weather data
Geom
Weather on surface
1
Geometry
2
Zone
3
Radiation
Weather
Last node
Node
Mon
EXTERIOR WALL CLADDING
Last node
Left
First node
Right
Mon
WALL INSULATION
Left
To right node
Right
To left node
Resistance
Zone
Construction
Radiation
First node
Node
Air
Mon
INTERIOR WALL CLADDING
1
Construction
Out1
No AIR
2
Matrix
Concatenation
2
Mon
1
Weather
Weather
To node
Node
Mon
External surface node / CTH1
Last node
Left
First node
Right
Mon
3 nodes
1
Last node
Node
2
2
Matrix
Concatenation
2
Mon
1
Left
2
First node
Left
Node
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Mon
One node / CTH
1
Left
Node
Rigl
Mon
One node / CTH
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Matrix
Concatenation
3
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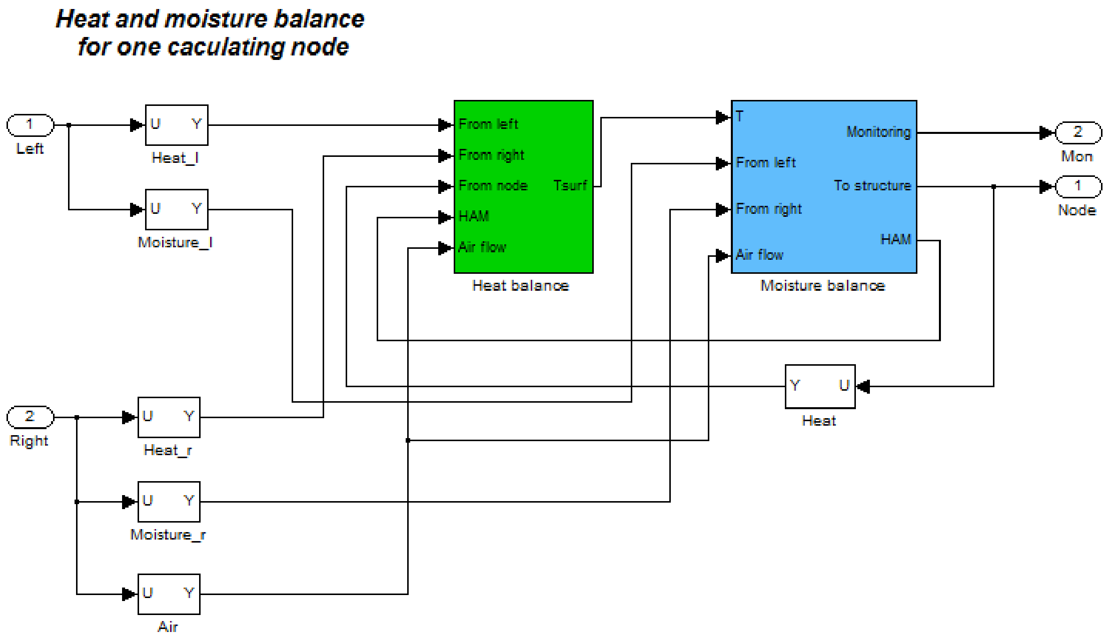


Figure 11: The layer construction of HAM-Tools tool box (IBPT, 2010)

For the data input of the model, users are required to load the data to the MATLAB workspace with the proper variable names. These include building details, dimension, location, orientation and so on. These data are typically stored in .m file. The weather data is required in .txt format with data requirements outlined by Kalagasidis (Kalagasidis, 2003). The material data requirements are also outlined in the above document. Users are required to define their own material data, including the moisture transport function and sorption function of individual materials.

The simulation time step is in seconds. Users can define any resolution of weather data. The calculation will use the time period data until the accumulated time is moved to the next time step in the weather data file.

The output of the software is very different from commercial software. There is no defined output from HAM-Tools. Users can set the scope at any location to monitor the data. Figure 12 shows the scope for the temperature and relative humidity and the display box from the "Light exterior wall N" block. The display can be changed to a file so an output file can be generated.

This output format is very flexible and allows users to explore results at any point of the analysis. However, this also means a user will need to setup the model accordingly to obtain those data. If there is a large number of monitoring points of interest throughout the model, this may be very time consuming. User will need a full understanding of the model construction and Simulink functions.

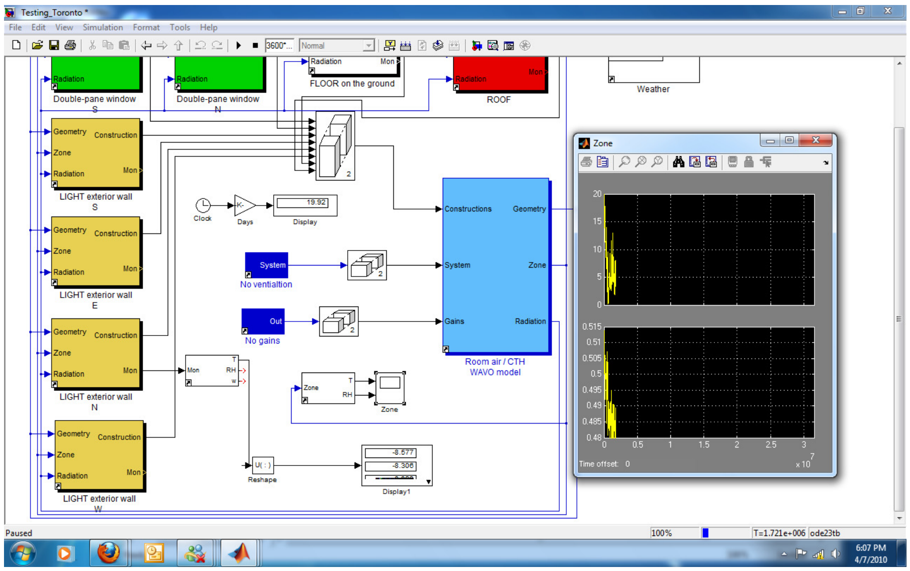


Figure 12: Output of HAM-Tools (IBPT, 2010)

4.6 Summary

The information regarding software packages is summarized in Table 1. Although EnergyPlus is very advanced in building energy simulation, it does not include the vapour transport component across the building envelope. The EMPD model only focuses on the moisture buffer of interior walls from the humidity of the interior air space. The water transport within the envelope cannot be modelled. The IES Virtual Environment carries a lot of building engineering analysis tools. However, it does not carry hygrothermal analysis functions, which is the most important function regarding this study.

Table 1: Comparison of various simulation software

Software Package	Summary of Software
Energy Plus	Energy Plus is an energy simulation software from the US Department of Energy. It is a very common tool for HVAC, air flow and energy use. It allows users to input weather data. It is more focused on the energy consumption of the whole building and not the moisture transport on building envelope.
IES VE	IES VE is a commercial software that can perform various kinds of simulation, including solar radiation, daylighting, and energy performance. However, it does not carry hygrothermal analysis capabilities, which is essential in this study.
HAMBASE	HAM BASE is a MATLAB program developed by de Wit at Eindhoven University of Technology from the Netherlands. It is a series of MATLAB programs and functions that can be used to simulate the whole building energy and moisture transport. The functions are coded in a MATLAB function and it is very difficult to trace the lead point for element to element. Extracting individual element states during the time of simulation is very difficult.
WUFI	WUFI is a commercial package for analyzing the moisture content within the building envelope. It allows users to setup their own weather file for analysis. It also calculates the energy transfer and moisture flux across different components in the building envelope.
HAM-Tools	HAM-Tools is a MATLAB Simulink library developed by Chamlers Institute of Technology from Sweden. It defines the calculation of the HAM of whole buildings in a series of modules. By connecting different modules in the graphical interface of Simulink, users can define all different scenarios of HAM analysis. It allows users the flexibility to define almost any scenario and condition. It also provides flexible input and output configurations. Users can select individual elements for monitoring. The analysis can be executed down to seconds. The boundary conditions can be input at any time resolution.

Based on the information found, it is decided that WUFI will be used for the study in microclimate effects on weather data. The ease of use and flexibility in weather data input makes it the ideal tool for this study. HAM-Tools is very flexible and versatile. WUFI provides an Excel spreadsheet program to facilitate users in generating their climate file. The readily available materials library allows for a vast variety in building envelope construction.

HAM-Tools would be the appropriate software to use for the time resolution of the weather data study. WUFI is not very flexible in reducing the simulation time steps because complete definition of solar radiation with the solar angle and wind-driven rain is required to form the .KLI weather file (Fraunhofer IBP, 2010). It also does not allow custom weather data with time resolution less than 1 hour. HAM-Tools is flexible in time steps of individual items of boundary conditions. Users can set the analysis time step to be in seconds with hourly and 5-minute weather data. Therefore, HAM-Tools will be the proper tools for the study.

5 Effects of Microclimate Meteorological Data

5.1 Introduction

When performing HAM modeling of buildings, meteorological data is required for the boundary conditions. This meteorological information is collected from weather stations located inside and around the city. Usually these weather stations are owned and operated by government bodies. Since the HAM modeling relies on accurate boundary conditions for the wind-driven rain, it is necessary to evaluate the impact of microclimate conditions.

5.2 Obtaining Meteorological Data

Environment Canada records and archives all meteorological data across Canada and makes it available for the public (Environment Canada, 2011). The data is organized in various formats, including hourly, daily, monthly and yearly time segments.

There are two different sets of data available from the website. The first one is called CWEEDS, Canadian Weather Energy and Engineering Data Sets. This data set contains information of 145 Canadian locations with up to 48 years of data, starting as early as 1953 (Environment Canada, 2011). This data set contains hourly data of the weather elements, including solar radiation, luminance, wind, temperature, sky index and so on. The data is organized in the WYEC2 format which is a standard weather data format adopted by Environment Canada (Environment Canada, 2008)(Appendix A).

The second type of data set is CWEC files, Canadian Weather for Energy Calculation. The data is prepared by National Research Council of Canada based on the statistics of 30 years of CWEEDS data. The data set contains 12 months of highest occurrence data from CWEEDS' database on long term statistics on individual data items. This data set will be used for simulation of typical weather of Canadian cities' weather. This data set is available for about 75 weather stations across Canada (Environment Canada, 2008). The CWEEDS is used in this study and the data from multiple years will be compared. In Toronto, there are weather stations at various locations. Table 2 shows weather stations with available CWEEDS data.

Table 2: Toronto weather station in CWEEDS files

Station Name	Station Identification Number	Solar Station Number	Latitude	Longitude
TORONTO	04714	6158350	43.67	79.38
TORONTO DOWNSVIEW AIRPORT	CAN72	6158443	43.75	79.48
TORONTO ISLAND AIRPORT	CANA2	6158665	43.63	79.4
TORONTO MET RES STN	04795	6158740	43.8	79.55
TORONTO PEARSON INT'L	94791	6158733	43.67	79.63

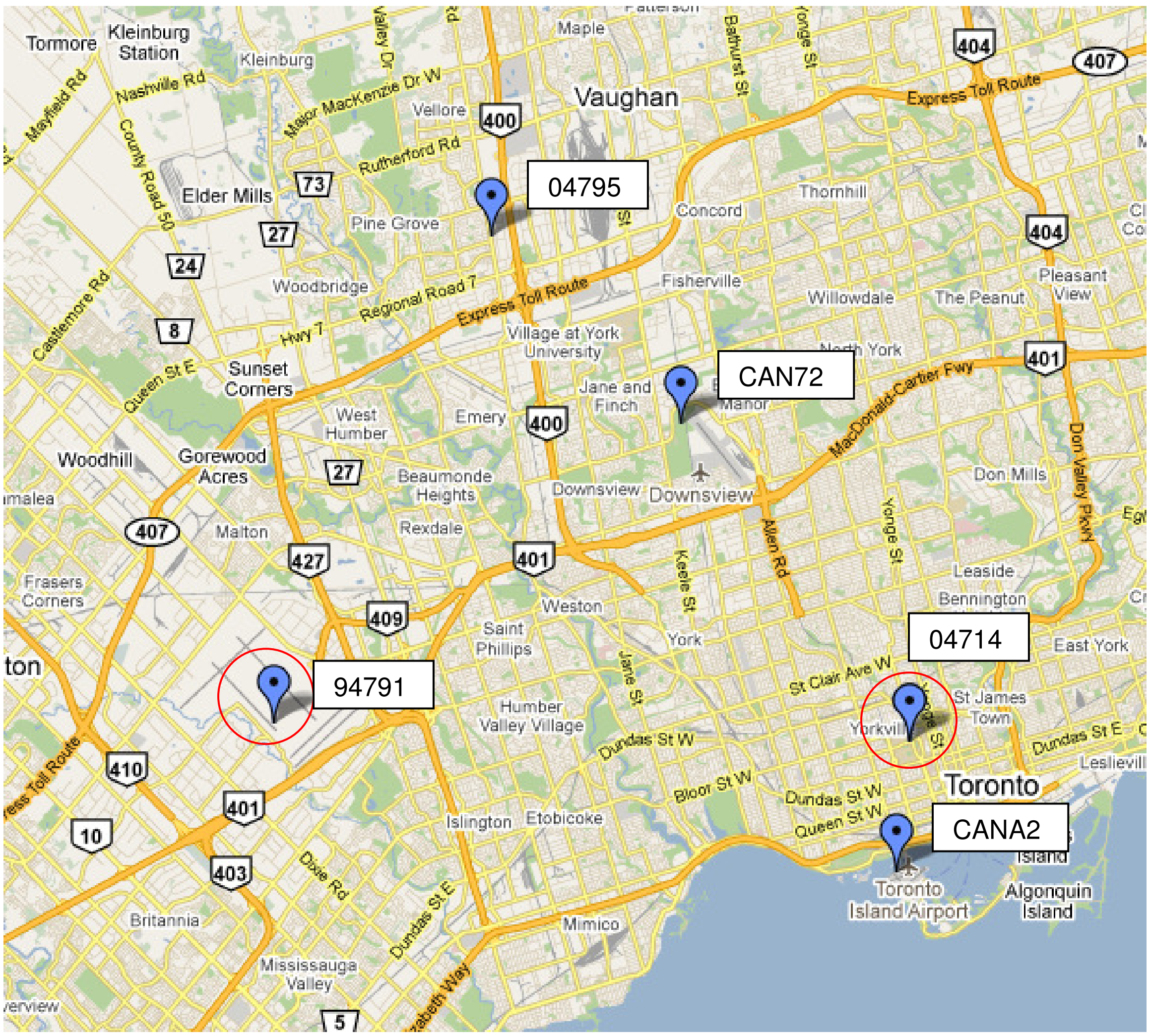
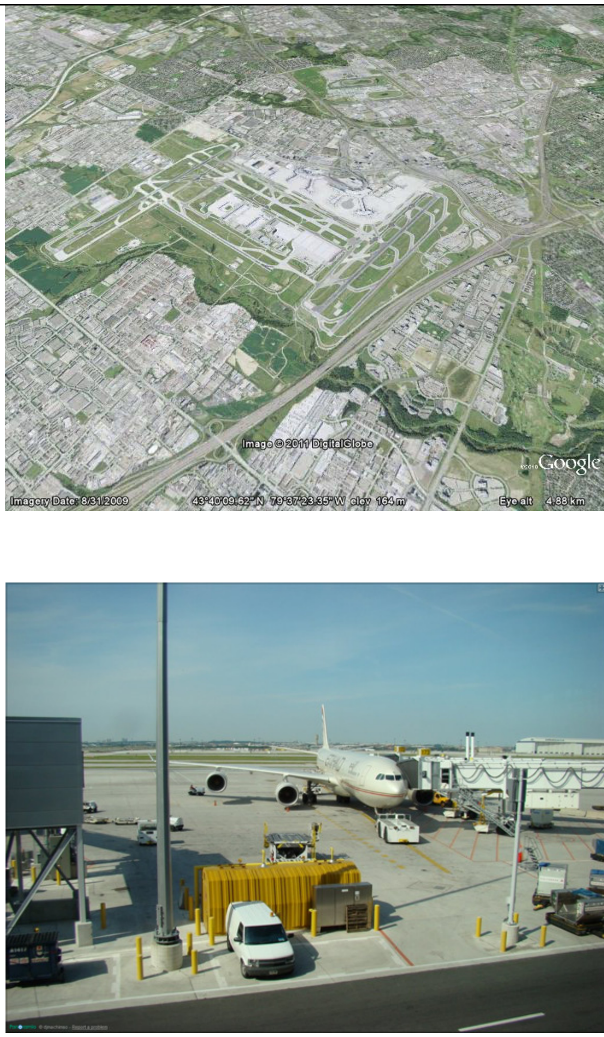


Figure 13: Locations of weather station in Toronto area.

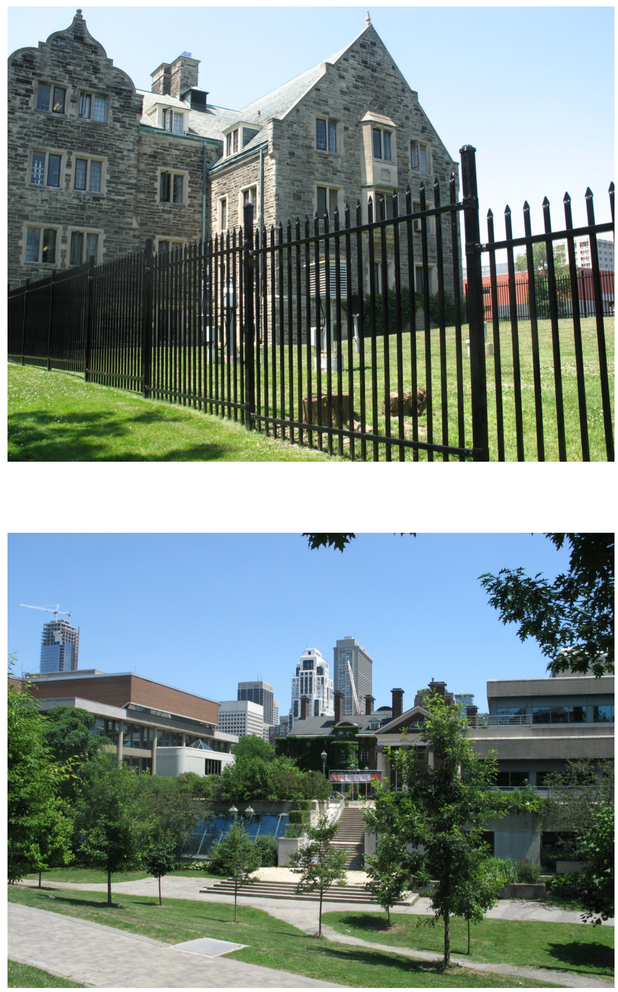
Figure 13 is the map of the weather stations listed above. It can be noticed that the Toronto weather station 04741 resembles closely to downtown environment (Trinity College, U of T) and it is also very close to the Ryerson University campus. The weather station 94791 at Pearson International Airport can represent the suburban climate. Therefore, the following two stations are chosen for comparison:

04741 – Toronto downtown Trinity College, University of Toronto

94791 – Toronto Pearson International Airport



Toronto Pearson airport



Downtown Toronto

Figure 14: Environment of weather station location

This study focuses on investigating the effect of location where weather data is collected, relative to the location of interest, therefore a suburban weather station versus a downtown building. Figure 14 shows the environment at the two weather station locations. From the pictures, it is noticed that there are significant differences between the environment of Pearson Airport and downtown Toronto. The downtown station is located in area similar to Ryerson University. There are mid to high rise buildings separated by green space. One could imagine the wind speed, wind direction at Toronto Pearson Airport and downtown. According to Environment Canada, both weather stations are situated at the ground level for measurement.

5.3 Hourly Rain Data

Sometimes, certain data items are not available at particular weather station due to the sensor type and equipment used at individual stations. Upon downloading the free CWEED files, it is discovered that the hourly rain data is not included in the CWEED files. Further investigation from Environment Canada reveals all other weather items that are not included in the data set have to be purchased with a fixed fee (Appendix B). This study is interested in the effect of micro-climatic condition and WDR, as it is one of the major factors in moisture build up in the envelope. Hence, rain data had to be purchased from Environment Canada since freely available CWEED data does not include that.

5.4 Organizing of Weather Data

The data from CWEEDS is organized in .txt file when downloaded from the website. Due to the large amount of data (500,000 to 2,000,000 lines of data for one weather station), the data has to be organized in a database format. An ACCESS database is setup to organize and manipulate the data to a useful format (Figure 15).

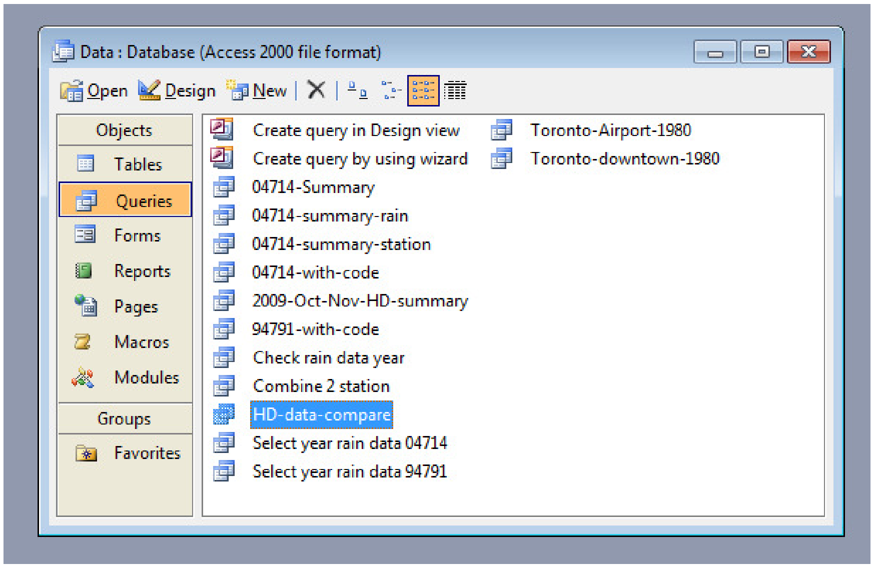


Figure 15: ACCESS database for weather data

The hourly rain data received from Environment Canada is in a completely different format compared to the CWEEDS data. The data in CWEEDS is organized vertically where hourly rain data file received is organized horizontally. Unfortunately, the attempt to convert the hourly rain data to useful format in ACCESS failed. Therefore, a custom program had to be created to convert data from the received .txt file to the same format as CWEEDS file before importing to ACCESS (Appendix C). The program reads a line of data from the original file. Then the line of data is broken down into multiple pieces of information, as follows:

Original file: Date, hour 1 data, hour 2 data……..

The "Date" and "hour 1 data" will be stored and write to target file in the following format:

Target file: Date, hour 1 data
Date, hour 2 data
…..

This file format will allow the hourly rain data to match the CWEEDS weather data set. This process is done in ACCESS.

5.5 Quality Assurance of Data

Once the data is transformed to a useful format, the data requires quality checks to ensure the data is complete and thorough. Upon further investigation, it is noticed that the hourly rain data for the Airport and downtown stations was not available from November to March due to servicing of rain gauge. The measuring equipment was taken off during this period of time (Appendix B). In order to perform the simulation in continuous form, the rain data between those months will be zeroed in the data for completeness of data.

Table 3: Number of data line with missing data of each year

	Station #		
Year	04714	94791	Total
1953		11	11
1954		10	10
1955	1	1	2
1957	2	2	4
1958	1		1
1959	11		11
1983		3	3
1985		3	3
1988		5	5
1989		4	4
1990	5	6	11
1992		3	3
1994	11	11	22
1995	27	31	58
1996	63	63	126
1997	12	12	24
1998	4	4	8
1999	7	7	14
2000	5	5	10
2001	5	5	10
2002	2	2	4
2003	1	1	2
2005	1	1	2

It is also found that data is missing intermittently from 1990 to 2001. Certain data items are missing for a period of few hours during a day (Appendix C). Table 3 summarized the total number of data lines with missing information throughout the dataset. This data inconsistency will affect the data analysis and accuracy of simulation. Linear interpolation can be carried out to repair the missing data. However, the data is missing in segments randomly scattered among those years. It is very time consuming to try to repair all data sets.

The criteria of selecting the data range are defined as following:

1. The data should be as recent as possible.
2. There should be minimal linear interpolation work to the dataset in order to maintain its originality.
3. The data range should be as large as possible for the simulation software to handle.

Based on the above criteria, it is decided to use the data from 1974 to 1989 for the study. It is estimated that 15 years of data would be enough to provide a consistent and accurate result. Also this is the limit of the chosen software in handling custom weather data files. This will be demonstrated later in the report. From 1974 to 1989, there are only 15 lines of data requiring linear interpolation. This range of the data is the ideal compromise between all the criteria above. The data is repaired based on linear interpolation method. Please refer to 0 for details.

5.6 Meteorological Data Analysis

The weather data between the Pearson Airport and downtown weather stations are analyzed before the simulation is performed. This allows for a preliminary overview of the difference in the weather data. When this analysis is paired up with the simulation results, a more thorough analysis and conclusion can be drawn. Since the focus of the study is on microclimatic conditions, temperature, dew point and wind-driven rain will be examined.

The dry bulb temperature and dew point temperature are compared between the Pearson Airport and the downtown stations. Figure 16 shows the comparison of 1978 data. It is found that there is minimal difference for dry bulb temperature and dew point temperature between airport and downtown data throughout the 1974 to 1989 data.

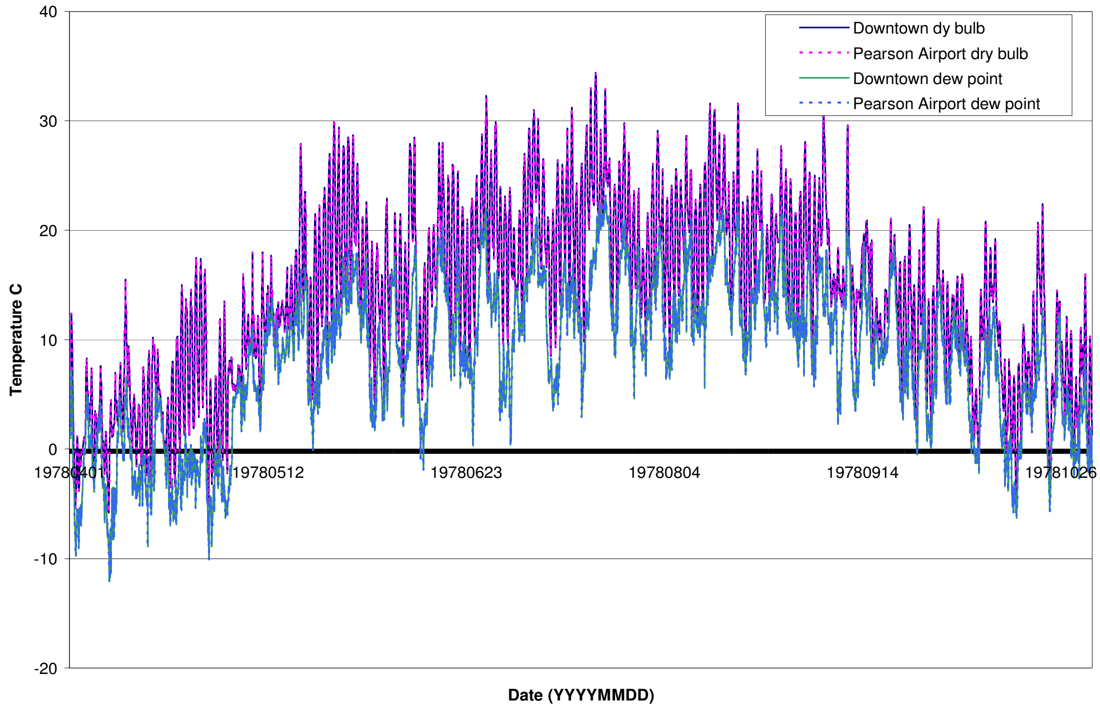


Figure 16: 1978 Toronto dry bulb and dew point temperature April 01 to November 30

Figure 17 shows the wind direction, the associated speed and frequency of the two stations, from 1974 to 1989. It is again discovered that there is minimal difference from the two sets of data. Figure 18 and Figure 19 show the wind direction with the corresponding rain event. It is noticed that the airport weather station presented more rain event than downtown weather station. The overall directions when the rain event happened are the same in both cases.

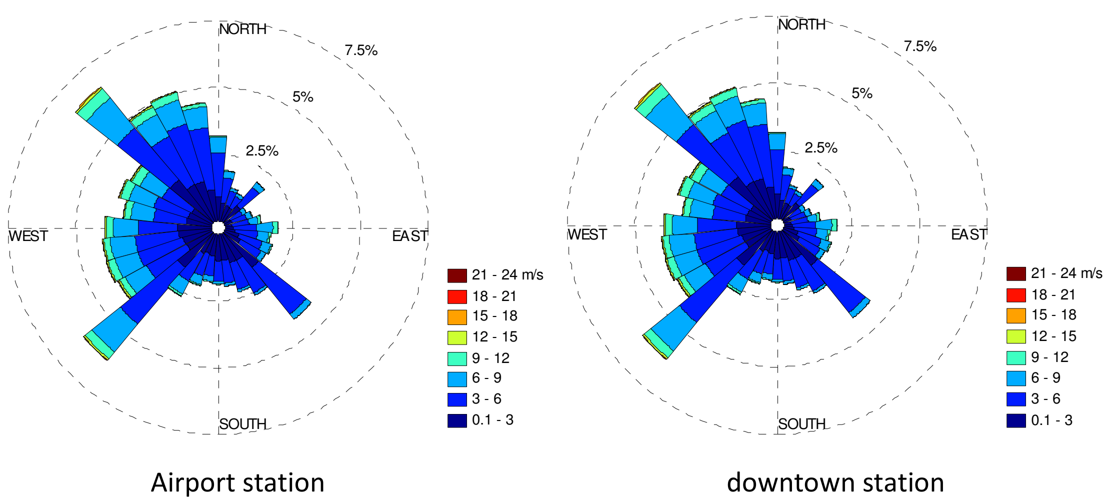


Figure 17: Wind direction, speed and frequency for airport and downtown weather station (1974-1989)

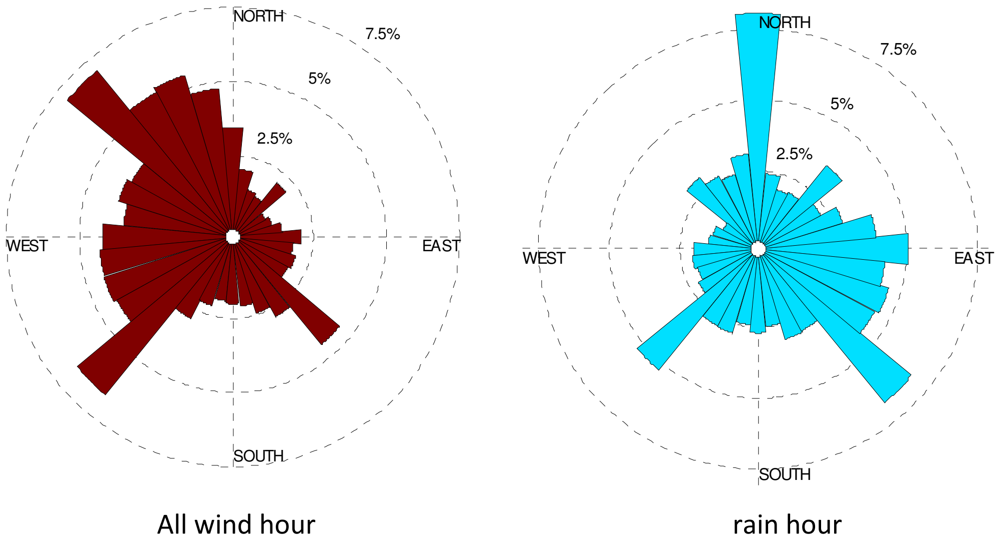


Figure 18: Wind direction, rain and frequency for airport weather station (1974-1989)

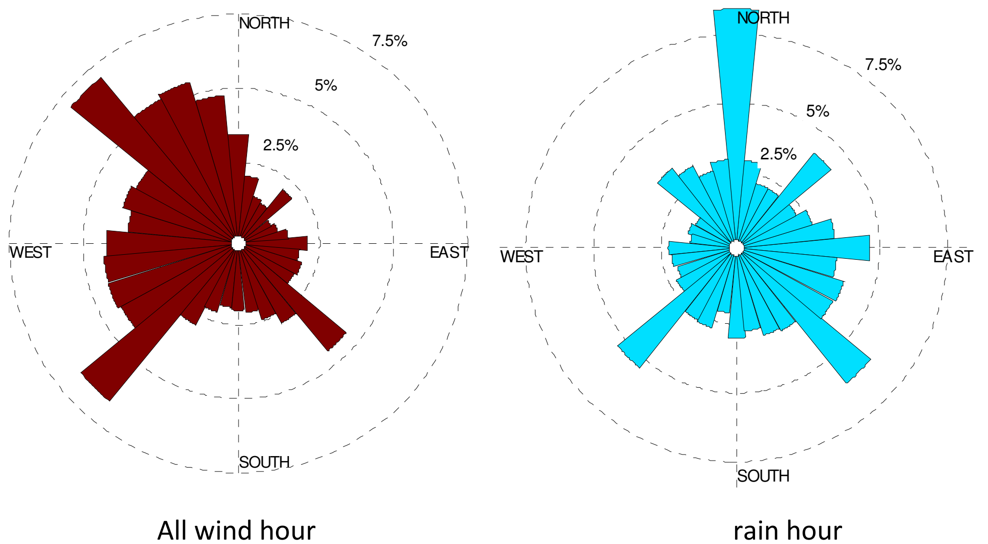


Figure 19: Wind direction, rain and frequency for downtown weather station (1974-1989)

Table 4 presents the accounting result of rainfall from the 1974 to 1989 data. The average rain fall from the airport data is 683mm and downtown data is 524mm. This shows that there is a slight difference between the two weather stations. These results lie relatively close to the average Toronto rain data of 700mm annually.

Table 4: Annual rainfall of weather station from 1974 to 1989

	Airport weather station	Downtown weather station
Total amount of rain from 1974 to 1989 (mm)	10250	7867.6
Average annual rainfall (mm)	683	524

5.7 Wind-driven Rain Intensity Analysis

In this study, it is assumed that the building is a two storey townhouse which is sheltered with buildings around it. The roof on the townhouse complex is low slope design. Hence the rain exposure factor and rain deposition factor of ASHRAE 160P model are:

F_E = 0.7

F_D = 0.5

Based on the formula in ASHRAE 160P model, the wind-driven rain is calculated for the average year in Figure 20: Wind-driven rain amount for the 1974 to 1989 data (from WUFI weather analysis). The data is obtained from the weather analysis function in the WUFI. It shows the average open field annual wind-driven rain index from 1974 to 1989. It is noticed that there is some difference in the amount of wind-driven rain from the two weather data sets, particularly in the west to north direction. This may suggest that moisture content analysis results of the envelope will be different using the two weather stations data. This will be verified in a simulation study later in the report.

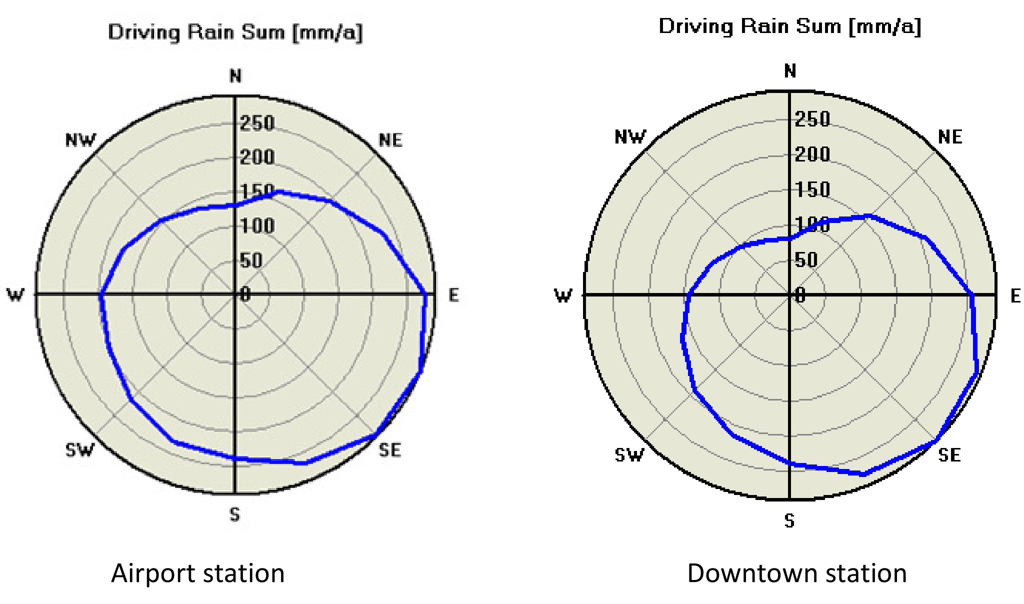


Figure 20: Wind-driven rain amount for the 1974 to 1989 data (from WUFI weather analysis)

5.8 WUFI Simulation with Airport and Downtown Data

In order to perform the comparison on the hygrothermal analysis, the WUFI simulations with the airport and downtown weather are required. Before the simulation can be executed, the boundary conditions and construction details have to be setup properly.

5.8.1 Building Envelope Construction

In this study, typical North American residential wood frame construction of the building envelope is used. The thickness of individual materials is detailed in Table 5 and Figure 21.

Table 5: Construction of building envelope

Material (outdoor to indoor)	Thickness
Brick	105mm
Air space	25mm
60 min building paper	0.1mm
OSB sheathing	12.5mm
Fiberglass insulation	89mm
Polyethylene vapour retarder (0.07 perm)	0.15mm
Gypsum board	12.5mm

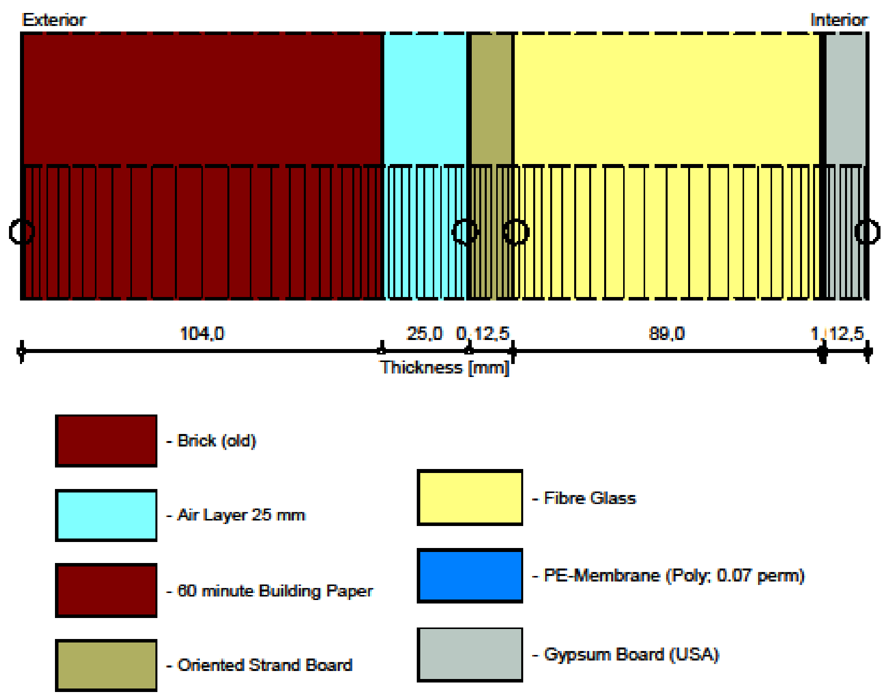


Figure 21: Wall construction for WUFI analysis

The detailed material properties, thermal and moisture transport characteristics can be found in Appendix E. Notice that the fibreglass insulation is only at 89mm thick, which is below current building code requirements. This is due to the WUFI's short list of materials in the library for North American construction. The thickness of the fibreglass can be changed. However, the sorption function has to be updated also, which must be determined through experiment. Since this is a comparison study, the fibreglass of 89mm is used as is in this study.

5.8.2 Orientation

It is assumed that the subject building is a townhouse with the front door facing south. Since the walls on the side of the townhouse are connected to the neighbouring house, only south and north façades are exposed to the exterior climate. The simulation will be executed on both the north and south façades individually to observe any significantly difference.

5.8.3 Exterior Climate

The WUFI software includes a utility program in Excel format for generating customized weather data files. User can copy and paste the data to different columns where the heading specifies the type of data in that column. It can generate the required weather data based on the meteorological data input from the user. For example, if the user specifies the measured rain data and solar radiation on the wall (users may have direct measurements of these qualities), WUFI can use this data and skip the calculation of solar radiation and wind-driven rain. If users provide data for global horizontal radiation, diffuse radiation and direct incident radiation, WUFI will calculate the solar radiation at different hours of the day based on the latitude and longitude of the building location.

However, this program is limited to around 60000 lines of data (the limitation of Excel spreadsheet size). This is equal to around 4.5 years of data, which is not enough to replicate the 15 year period that is interested in the study. In order to create a continuous file to simulate the whole period of time, a separate Visual Basic program (Appendix D) is designed and programmed to generate a weather file for 15 years of weather data (about 180,000 lines of data). It is noticed that 15 years of data is very close to the limit of the capability of WUFI, as the importing of the weather data file takes a very long time already. Any more data may create instability of the system due to lack of memory resources. This was another reason why 15 years of weather data is used in this study.

In this study, the following data items are provided to generate the .wac weather file for WUFI:

- Latitude
- Longitude
- Elevation
- Standard time zone
- Dry bulb temperature
- Relative humidity
- Global horizontal radiation
- Global diffuse radiation
- Direct incident radiation
- Wind speed
- Wind direction
- Rain

These data items are obtained from the ACCESS database that is created for this study. Data manipulation is required for the above items before data can be used to generate the .wac file. After the weather data is imported to WUFI, it allows the user to analyze the solar radiation and wind-driven rain amounts (Figure 20).

5.8.4 Indoor Condition

For the indoor conditions, WTA (International Association for Science and Technology of Building Maintenance and Monument Preservation) Guideline 6-2-01/E is used with medium moisture load (Figure 22). This is the default indoor condition set in WUFI. WUFI has other standard indoor conditions from different standards, for example DIN EN 13788 and EN 15026. The default is chosen for reference purposes since this study is comparing two different stations. There is no other source and sink for heat and moisture in this study. Initial conditions of the building envelope are set at 20^{o}C and 80% RH.

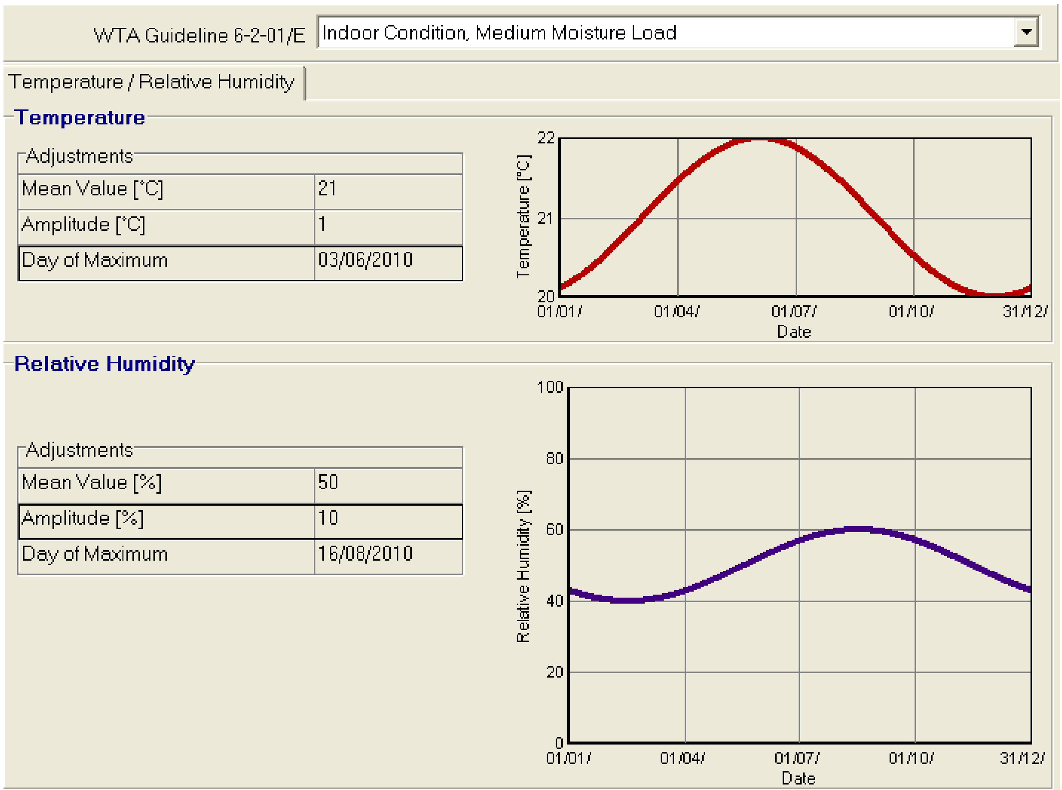


Figure 22: Interior condition if subject building

5.9 Simulation Results

This study is interested in the effect of microclimate conditions on the hygrothermal performance of the building envelope. From weather data analysis, it is found that the temperature has almost no difference but the wind-driven rain has shown some differences between the airport and downtown data. Hence, the result is focused on the moisture content of the building materials. The total water content of the north and south façades is shown in Figure 23 - Figure 26. It is noticed that there are some local peak differences in terms of the water content along the course of the study. The extremes for the two stations are summarized in the Table 6. It is noticed that the maximum and minimum water content among the different materials within the building envelope have minimal difference between the Pearson Airport data and downtown data. The total water content in the wall is different by about 75% on north façade and 30% for the south façade at maximum. The biggest differences are found in the brick at 85% at maximum.

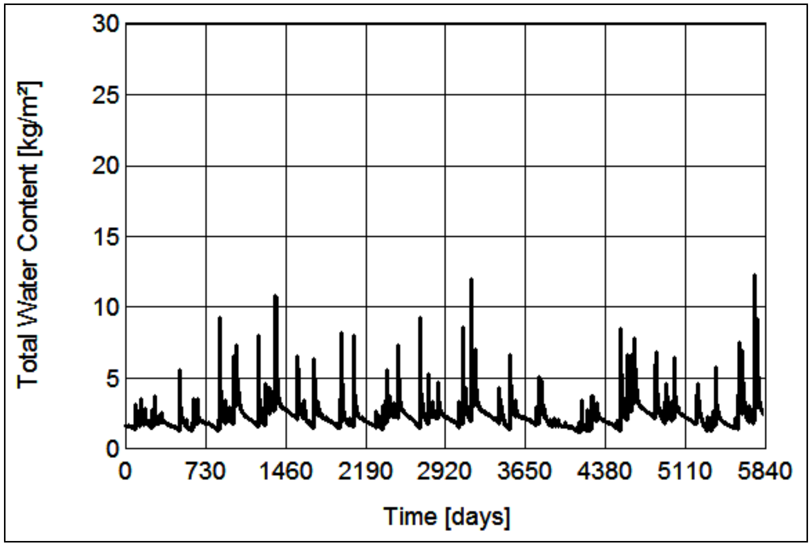


Figure 23: Total water content, downtown data, north façade

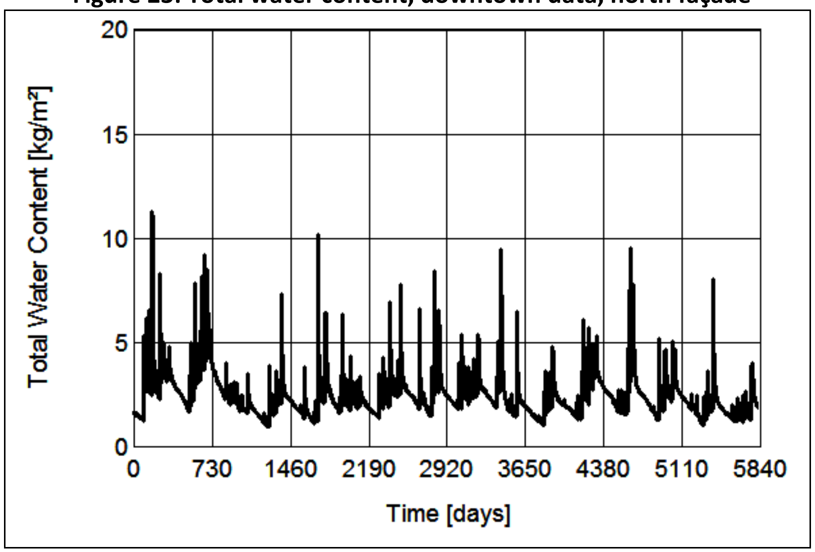


Figure 24: Total water content, downtown data, south façade

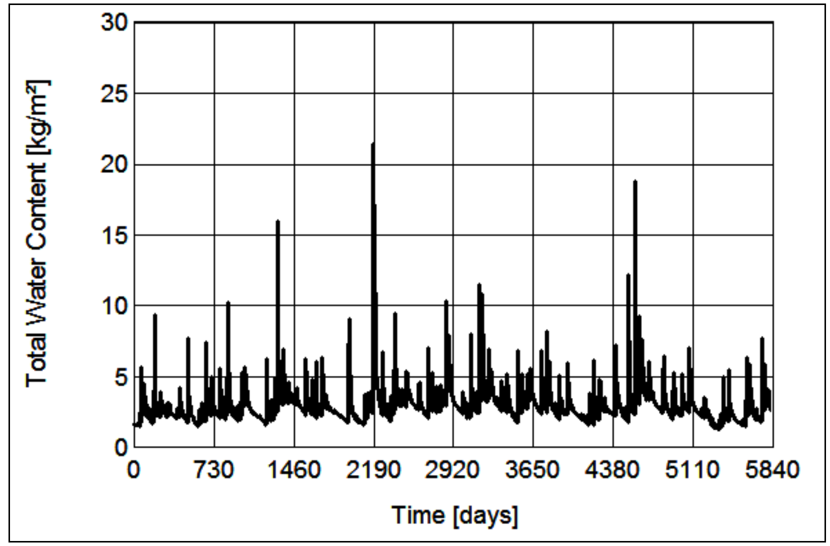


Figure 25: Total water content, airport data, north façade

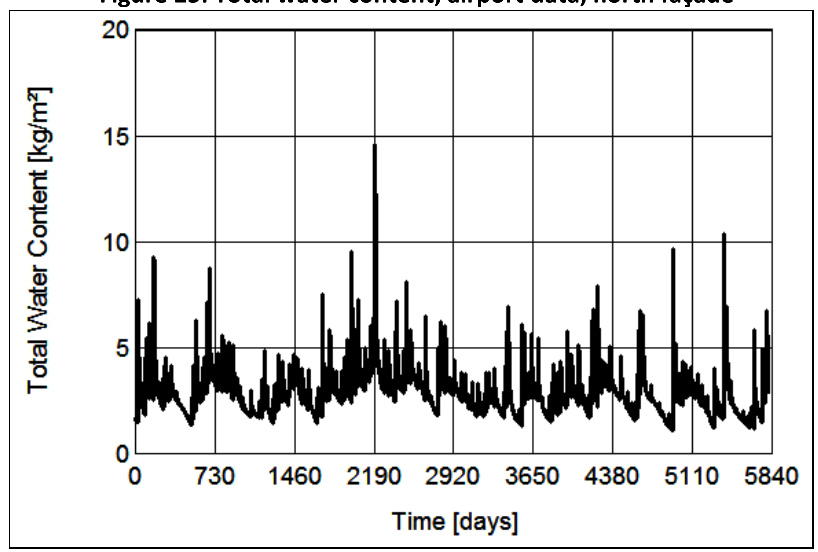


Figure 26: Total water content, airport data, south façade

Table 6: Water content of building envelope during the study period

	Pearson Airport				Downtown			
	North facade		South facade		North Facade		South façade	
Water content in kg/m^3	Min	Max	Min	Max	Min	Max	Min	Max
Brick	1.33	189.56	1.17	113.72	1.28	101.94	1.10	87.37
Air space	0.86	15.32	0.65	12.47	0.78	10.54	0.51	13.88
60 min building paper	0.00	0.02	0.00	0.02	0.00	0.01	0.00	0.02
OSB sheathing	62.82	196.71	55.83	202.61	60.79	179.71	50.74	221.53
Fiberglass insulation	0.44	7.10	0.5	10.34	0.37	6.12	0.43	8.61
PE membrane (0.07 perm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gypsum board	2.56	6.19	2.44	6.19	2.56	6.19	2.47	6.19
Total water content	1.27	21.44	1.13	14.61	1.19	12.3	0.97	11.27

Table 7 shows that the net total amount of heat flux and moisture flux passing through the interior and exterior surface. The south façade with downtown data has more heat transfer; whereas the north façade with airport data has more heat transfer. The total difference is less than 1% for 15 years.

Table 7: Heat flux and moisture flux exchange of the building envelope

	Pearson Airport		Downtown	
	North	South	North	South
Heat flux through exterior surface (MJ/m^2)	-1865.31	-1490.81	-1844.88	-1510.85
Heat flux through internal surface (MJ/m^2)	-1849.6	-1482.12	-1841.31	-1509.85
Moisture flux through exterior surface (kg/m^2)	1.12	1.7	0.76	0.56
Moisture flux through interior surface (kg/m^2)	0.23	0.53	0.14	0.44

The moisture flux difference is more significant in south exterior façade where airport data has almost 3 times of moisture flux compared to downtown data. In the interior façade, the north façade from airport data has two times the moisture flux compared to downtown data.

5.10 Discussion of Results

The study uses 15 years of meteorological data to compare the effect of microclimatic conditions in Toronto. Pearson Airport and downtown weather stations are chosen in this study to simulate the suburban data versus downtown urban data. From the total water content results as shown in Figure 23 - Figure 26, it is noticed that the average total water content between the airport and downtown data are fairly similar. It is noticed that there are some local maximums appearing in the airport data on both the north and south façades. However, from the simulation results, the water contributed by the wind-driven rain can be dried within a reasonable time frame without prolonged accumulation of water inside walls.

From Table 6, it is noticed that the maximum difference of water content is located on the brick layer of the wall system. This could be explained by any local wind-driven rain being absorbed in the brick layer and stored inside. From the data analysis in the previous chapter, it is noticed that there is a difference between the two datasets in terms of wind-driven rain based on the ASHRAE 160P.

Figure 23 - Figure 26 show the overall trend for the 15 years of study period. However, detailed observations cannot be retrieved from these figures. Hence, a sample year during the period is chosen to observe the difference in more detail. The water content in the brick during year 1988 is shown in Figure 27 - Figure 28. It is noticed that the water content in the brick layer reflects the difference of wind-driven rain events.

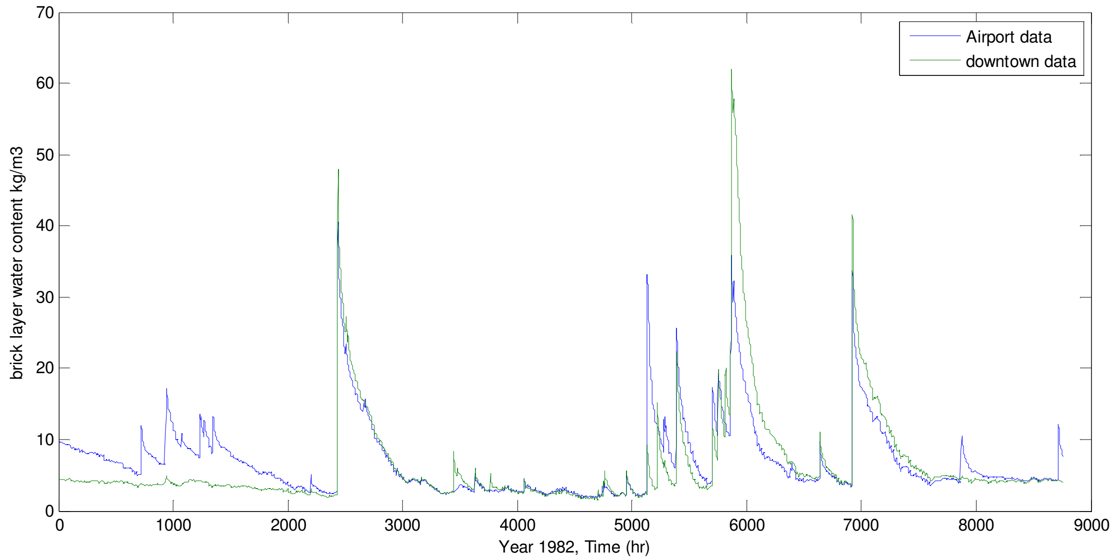


Figure 27: Water content of brick, south facing, 1988

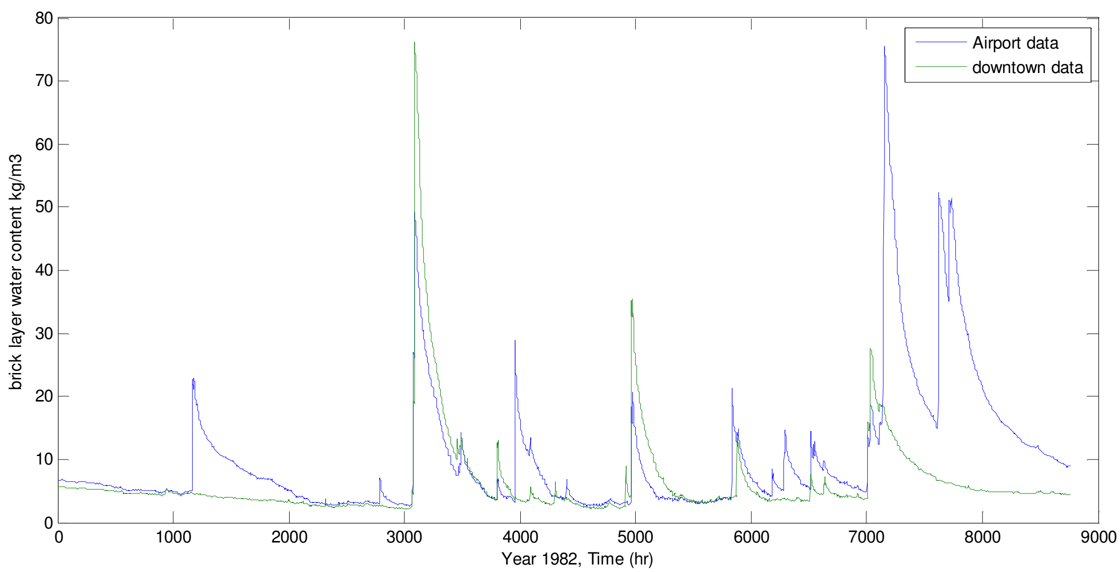


Figure 28: Water content of brick, north, facing, 1988

In the south facing wall results (Figure 27), the water content of the brick layer follows roughly the same path throughout the year. The peaks before hour 2000 are caused by the difference in the solar radiation. Table 8 shows the data from hour 1134 to 1147 and the global and diffuse radiation at the airport is almost 3 times the measurement of downtown at certain moment. Since all other weather measurements (temperature, RH, and rain) are similar during that time, the peaks prior to hour 2000 are caused by the difference in radiation difference.

Table 8: Difference of radiation reading (hour 1134 – 1147)

Hour	Airport station		Downtown station	
	Global direction radiation (W/m^2)	Diffuse radiation (W/m^2)	Global direct radiation (W/m^2)	Diffuse radiation (W/m^2)
1134	0	0	0	0
1135	0	0	0.55	0.55
1136	3.61	3.61	10.27	10.27
1137	44.72	44.72	43.33	43.33
1138	138.33	138.33	76.38	76.38
1139	253.88	253.88	106.11	106.11
1140	303.88	303.88	121.11	121.11
1141	322.22	322.22	136.38	136.38
1142	307.22	307.22	122.22	122.22
1143	155	155	95.55	95.55
1144	185.83	185.83	78.33	78.33
1145	109.44	93.33	39.44	39.44
1146	17.22	15.55	9.44	9.44
1147	0	0	0.55	0.55

After hour 2000, the peaks are caused by the rain event. Table 9 illustrates the rain events at hour 2212 and it shows that the amount of rain at the airport station is similar to that of the downtown station. As seen in Figure 27, there are peaks showing at about same period of time, which correspond to that of the weather data. The other peaks shown in Figure 27 are results of the similar rain events. There are times where the airport data result is higher than that of the downtown data results. However, the overall trend is very similar and the rain events also happen on similar days. As well, the peaks of moisture dry out within reasonable amount of time.

Table 9: Rain event from hour 2212 to 2224

	Airport station			Downtown station		
	Rain (mm)	Wind direction	wind speed (m/s)	Rain (mm)	Wind direction	wind speed (m/s)
2212	0.6	180	1.1	0	180	1.1
2213	1.8	50	1.7	0.4	50	1.7
2214	0	30	1.1	0	30	1.1
2215	0.2	310	1.9	0	310	1.9
2216	0	110	1.7	0.6	110	1.7
2217	1.1	130	1.1	0.2	130	1.1
2218	2.8	180	1.7	1.5	180	1.7
2219	1.8	110	1.9	4.9	110	1.9
2220	0.2	170	1.9	0.6	170	1.9
2221	1.5	140	2.5	0.9	140	2.5
2222	0.9	0	0	1.9	0	0
2223	1.7	130	2.5	1.1	130	2.5
2224	0.6	130	3.6	0.8	130	3.6

Figure 28 shows the moisture content of the brick layer in the north facing wall for the year 1988. The results indicate that there are more differences in moisture content as compared to the south facing wall. The difference showed in the figure before hour 2000 is caused by the difference in radiation reading (Table 8). In this case it is the radiation that affects the north surface. The peaks after hour 2000 are caused by the rain event. Table 10 shows the rain event from hour 3237 to 3241. It shows that the rain measurement is different between the two stations at different times. Combining the wind direction and wind speed, the airport data generates a higher wind-driven rain amount to the façade than that of the downtown station. This corresponds to the result showed in Figure 28. At hour 3000, the peak from airport data is about 50% higher than that of the downtown data. Although the overall moisture content of the brick layer in both sets of data follow similar paths throughout the year, there are more peaks along the year. These peaks are rain events happening at different times between the 2 sets of data. The figure shows that the moisture from the wind-driven rain event also dried out in a short time. The results from Figure 27 and Figure 28 correspond to the results shown in the Figure 23 to Figure 26. There are local differences between the two sets of data but the overall hygrothermal results are very similar.

From Table 6, it is also noticed that the difference in water content between the two weather stations diminishes towards the interior. This can be explained by the drying process in the wall system.

Table 10: Rain event from hour 3237 to 3241

	Airport station			Downtown station		
	Rain (mm)	Wind direction	wind speed (m/s)	Rain (mm)	Wind direction	wind speed (m/s)
3237	2.9	270	7.2	1	270	7.2
3238	10.6	280	6.1	5.1	280	6.1
3239	5.9	140	3.1	7.1	140	3.1
3240	0.6	140	1.9	1.6	140	1.9
3241	0	160	2.5	0.2	160	2.5

On the energy transfer aspect, the results show that there is minimal difference in terms of the energy in the two cases. The total energy difference is about 20MJ/m^{2}h, which is equal to about 5kWh/m^2 for 15 years. This works out to about 1.3MJ/m^2 per year or 0.333kWh/m^2 per year. For reference, a 2 storey townhouse uses about 15-20 kWh of electricity per day. The difference between the two stations is minimal in the total energy transfer.

It is noticed that there is about 400MJ/m^2 difference of heat flux between the north and south façades. This could be explained by the solar radiation from the sun. The south façade will receive more solar radiation due to the sun's angle facing toward the south throughout the year. The north façade will have more heat loss when the interior space is maintained at the desired temperature and humidity. This can indicate that the solar calculation of the simulation is executed properly.

Based on the above observations, the effect of microclimatic conditions in Toronto is not as significant as previous studies from Europe. There could be several reasons for this study result. The first is the annual rain fall amount in Toronto. According to Environment Canada, Toronto averages around 700mm of rain in a year. In Vancouver, average rainfall is 1230mm annually. In Netherlands, the annual average is 900-1100mm of rain. This could explain why the wind-driven rain effect may be less pronounced in the Toronto area.

Secondly, the urban area in downtown Toronto is not at the same level of density as compared to other large cities around the world, for example, New York, Chicago, Paris or Hong Kong. There are a few high-rise buildings in the commercial core and the rest of the area is scattered with low rise apartments, and single or two storey residential units. The effect of the microclimatic conditions is therefore diminished.

Since the weather stations in downtown are located in the relatively open field terrain next to Queen's Park, the meteorological data from these stations may not represent 100% of what the residential buildings experience. However, this data is the closest that the study could obtain. Ideally, the weather station would be located nex t to the test building; however it is not practical at this stage of study. Advanced CFD analysis could generate the required data but it is also time and resource demanding. Building data of the whole city will be required to generate accurate wind speed and direction. These data are often very difficult and impractical to obtain.

It is noticed that, the result and discussion of the study only apply to the Toronto area with typical residential building materials. For other types of constructions, further studies are required to formulate the observations as discussed above. The characteristics of the meteorological data are much localized. Results from this study may not apply to other locations.

All the above findings are published in the conference proceeding, titled “Simulation study of building envelope performance using microclimatic meteorological data” by the author of this study (Wu & Horvat, 2010).

6 Wind-driven Rain Module for HAM-Tools

The HAM analysis for the time resolution effect of the weather data is carried out by HAM-Tools utilizing MATLAB and Simulink. HAM-Tools is a library of Simulink model blocks that can be configured to analyze different scenarios in building science and hydrothermal performance. (Kalagasidis et al., 2007). The model blocks are very flexible and allow different customizations to suit individual cases.

One of the most significant advantages of HAM-Tools is the flexibility of time resolution of weather data and time step in the analysis. The access to this area is usually restricted in most simulation software. These two parameters are independent of each other. Users can provide hourly data and perform the analysis in minutes. The time step resolution usually does not affect the speed of the analysis.

6.1 Design Wind-driven Rain Module

HAM-Tools does not incorporate any rain modules in the model. It does not have the rain amount requirement in the weather data. In order to proceed with the analysis, a wind-driven rain module is designed for HAM-Tools. Since ASHRAE 160P was chosen to model the wind-driven rain intensity in this study, the model blocks will be designed based on that.

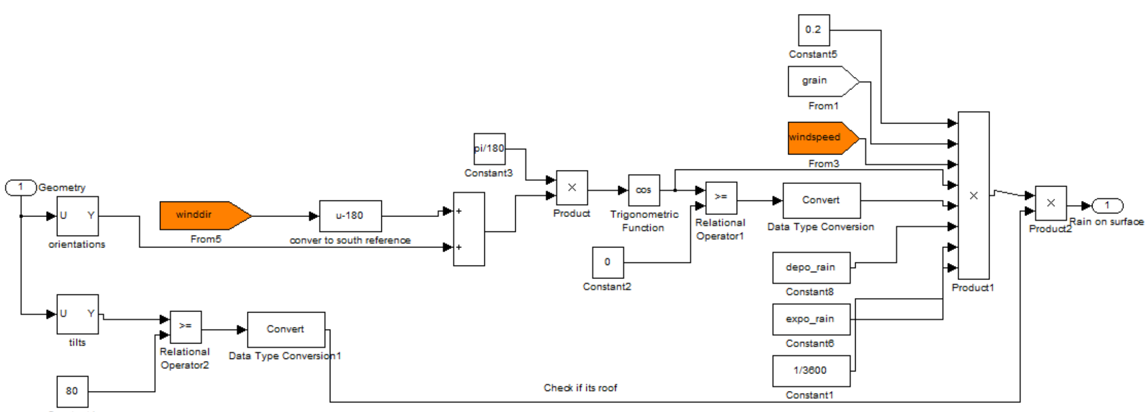


Figure 29: ASHRAE 160P wind-driven rain module for HAM-Tools

6.2 Design Concepts

In order to design the module, it is necessary to understand the structure of HAM-Tools in terms of moisture transport. Referring to Figure 11 in section 4.5, the wall construction is divided into different layers of blocks, with each block representing one material. For the layer without storage functions (such as the membrane, air), the resistance block is used. It is noticed that in the external surface block, it is further divided into an external surface node and 3 other nodes.

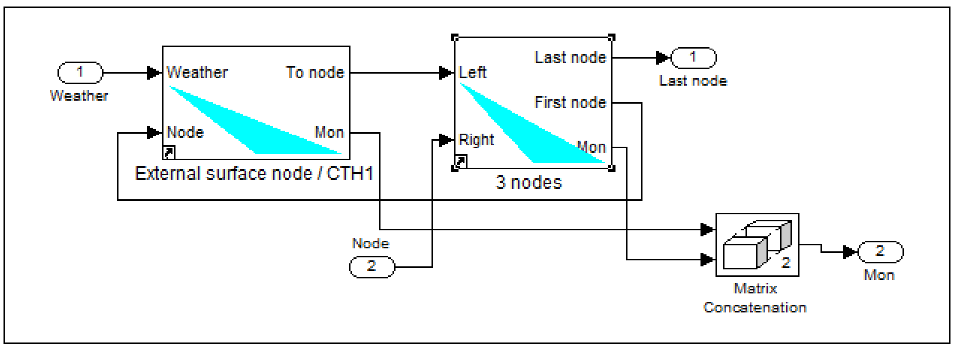


Figure 30: The construction of external surface block

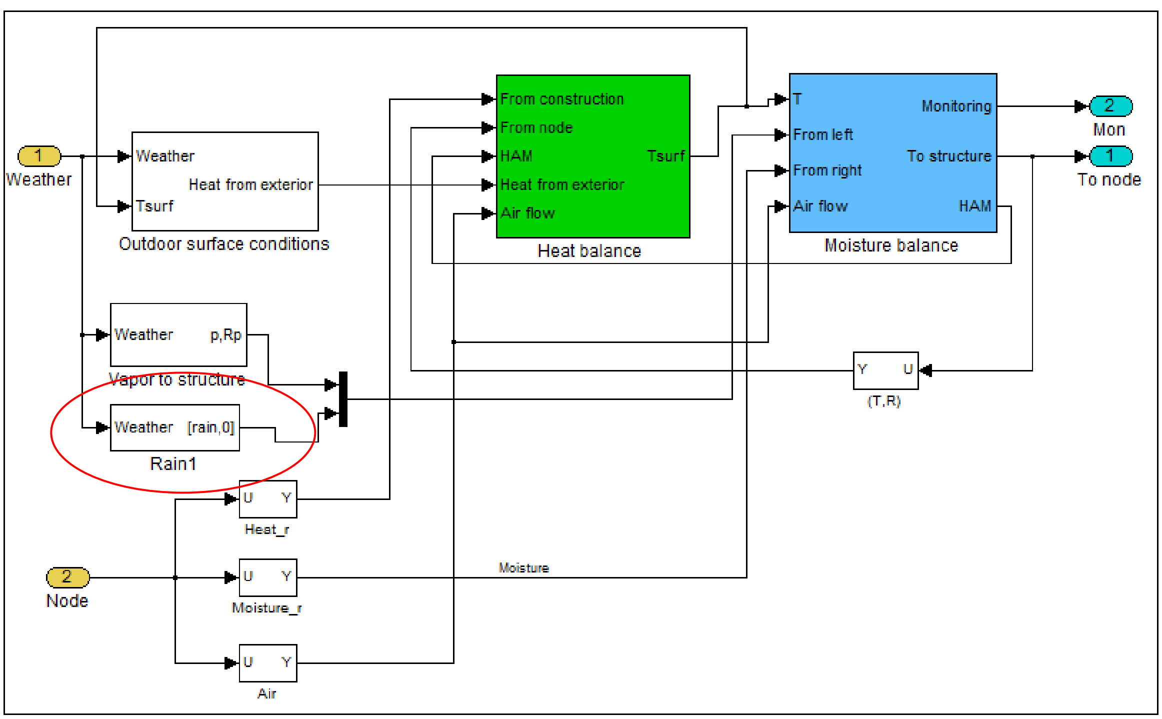


Figure 31: Heat and moisture balance of external surface node

As shown in Figure 31, the rain amount is input to the moisture balance through the “weather” port connected to the external surface block in Figure 30. From Figure 32, the weather input comes from the “weather on surface” model block.

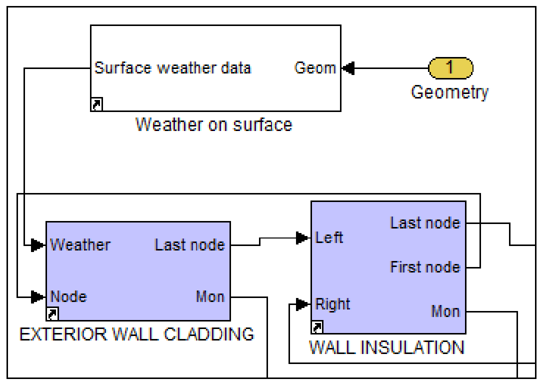


Figure 32: Weather on surface block to external surface block

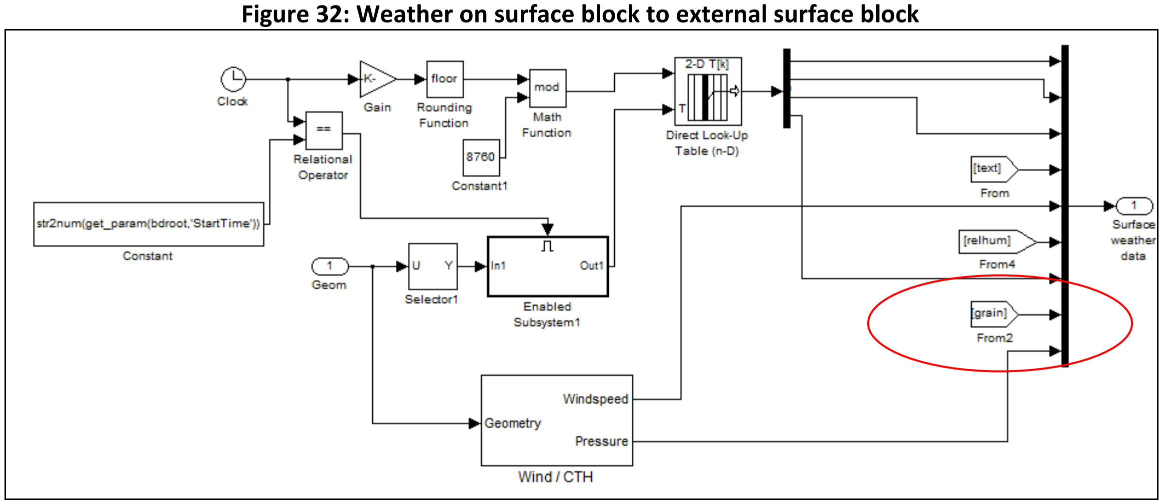


Figure 33: Design of "weather on surface" block

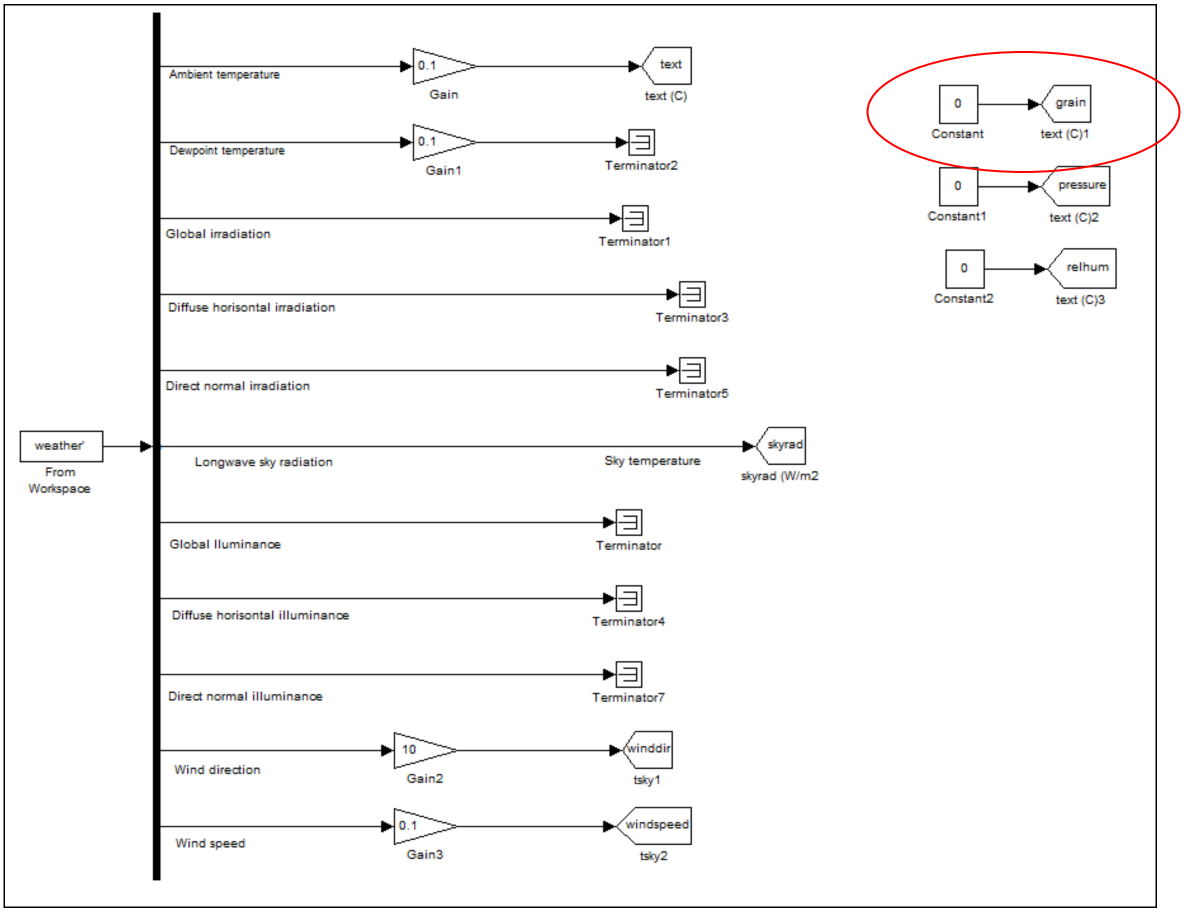


Figure 34: weather data reading block for HAM-Tools

Figure 33 presents the design of the "weather on surface" block. The "grain" is the variable for rain input to the "external surface" block. The "grain" is found in the "weather data reading" block (Figure 34) and it is set to zero at the moment. This is the reason why there is no rain data line in the weather file input requirement as stated in the current HAM-Tools documentation.

In order to allow rain input to the system, an additional item on the weather file for rain is required so that the horizontal rain data can be input to the Simulink models (Table 8). The unit of rain data is 10 mm/time unit from the weather data file and the data will be multiplied by 0.1 to correct the unit in the "weather data reading" block in Figure 35. This is the weather data file convention used in typical meteorological data from government.

Table 11: Addition of item 13, rain data to the weather data file

Column Number	Output number in Simulink	Description	Unit
1	-	Time	S
2	1	Air temperature	10°C
3	2	Dew point temperature	10°C
4	3	Global radiation on horizontal surface	W/m^2
5	4	Diffuse radiation on horizontal surface	W/m^2
6	5	Normal direct radiation	W/m^2
7	6	Incident long wave radiation	W/m^2
8	7	Illuminance, global	Lux
9	8	Illuminance, diffuse	Lux
10	9	Illuminance, direct	Lux
11	10	Wind direction	Deg
12	11	Wind speed	10m/s
13	**12**	**Rain, horizontal**	**10mm/hr**

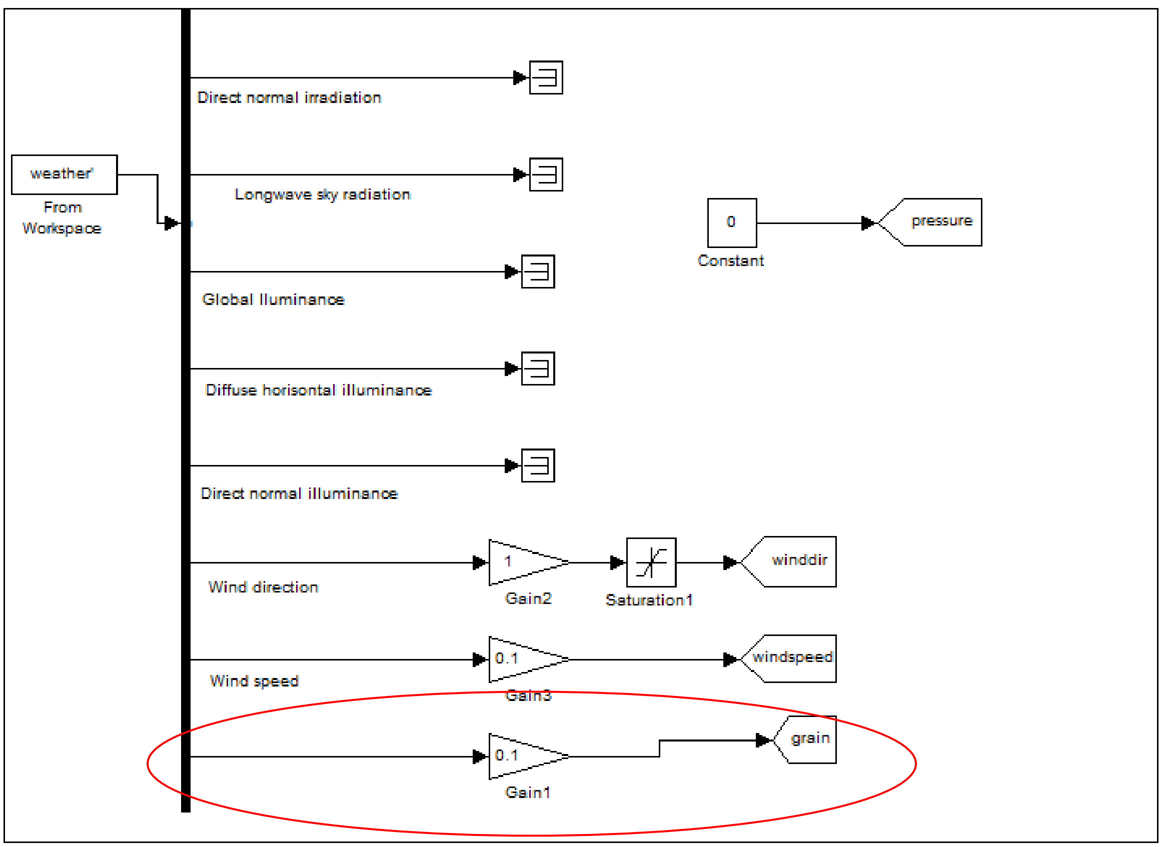


Figure 35: Adding rain input to weather data reading block

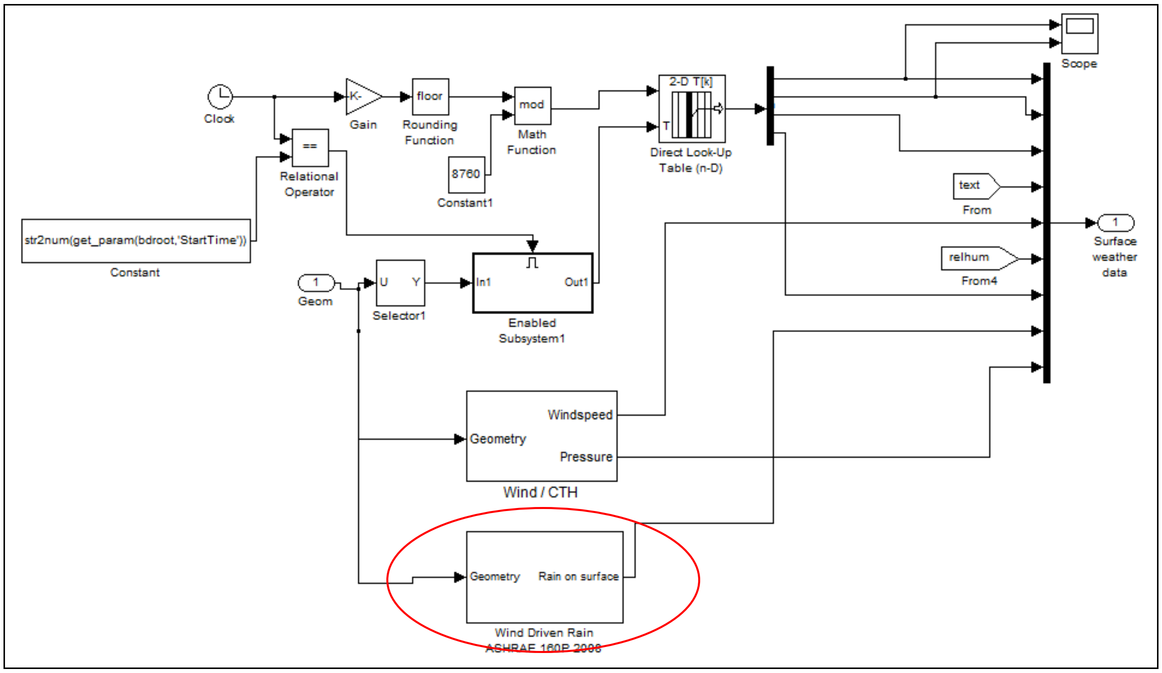


Figure 36: Adding the wind-driven rain module to weather on surface block

Once the "grain" is defined in the models, it can be used anywhere in the Simulink model. In order to formulate the wind-driven rain model for each external surface, the module receives the geometry data of the subject surface as input for the WDR calculation (Figure 36). This data includes the orientation, tilt angle to vertical and area. The output of the module will become the rain (liquid moisture) input to the heat and moisture balance at the external surface node.

With the rain data being read to the model, it is now required to calculate the wind-driven rain intensity to the wall surface. From ASHRAE 160P, the WDR is calculated as follow:

$$r_{bv} = F_E \cdot F_D \cdot F_L \cdot U \cdot \cos\theta \cdot r_h \qquad \textbf{(7)}$$

Where

F_E = rain exposure factor

F_D = rain deposition factor

F_L = empirical constant, 0.2 kg s/(m^3 mm)

U = hourly average wind speed at 10 m height, m/s

ϑ = angle between wind direction and normal to the wall

r_h = rainfall intensity, horizontal surface, mm/h

r_{bv} = rain deposition on vertical wall, kg/(m^2 h)

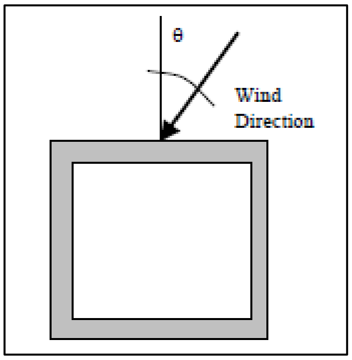


Figure 37: Definition of wind angle

The angle ϑ is defined as the angle between the normal of the building surface to the wind direction (Figure 37). It is found that in HAM-Tools, south is set as zero degrees, and counting in both directions, clockwise is negative and counter clockwise is positive. Therefore, north is 180^o, east is 90^o and west is -90^o. However, in normal meteorological data from weather stations, north is defined as 0^o and counting clockwise. Therefore, the wind direction conversion is required as shown in the Part A of Figure 38. First the wind direction is converted to south as 0^o. Then the angle ϑ is determined by the difference between the orientation of wall and the wind direction.

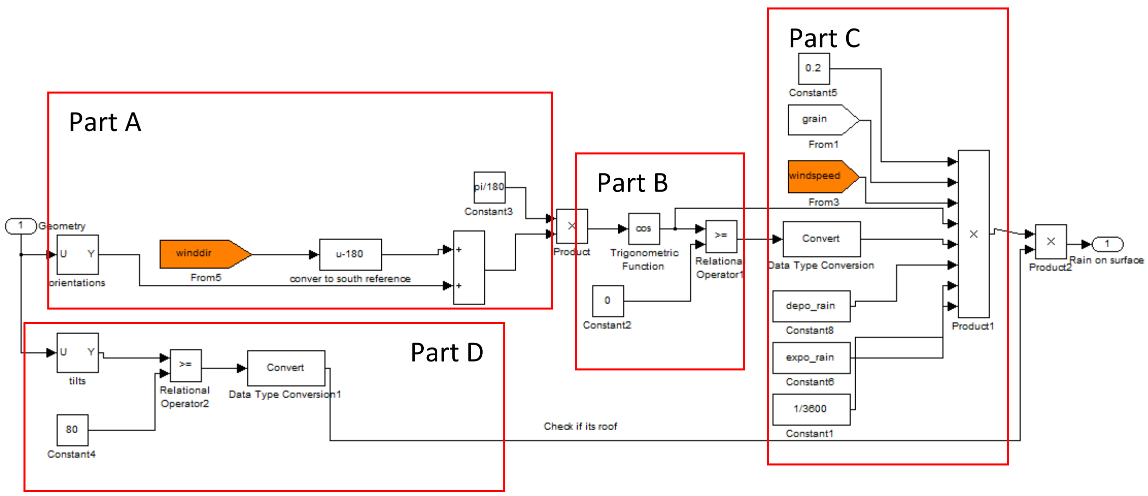


Figure 38: Design of wind-driven rain module in weather on surface block

Part B is to determine if the wall is oriented to the direction of wall. If the cosine of the angle is negative, which indicates the angle is bigger than 90^o, the wind is not blowing toward the wall. Instead, the wind is engaging at the back of the wall. In this case, the resultant angle factor is set to zero and the whole equation will become zero. Hence, no rain will be applied to the wall.

Part C is the multiplication of the rest of the parameter listed in the equation. The “grain” is the horizontal rainfall defined earlier. The rain exposure and deposition factors are also included here. These two parameters are input in the data input file at the beginning of the analysis. Since the analysis of HAM-Tools is based on seconds, the horizontal rain fall and WDR from the equation need to be divided by the time resolution of the weather data. For example, if the weather data is presented as hourly, the factor will be 1/3600 (1/300 for 5-minute data). This in fact divides the WDR to every second within that hour so the total amount of rain presented to the simulation model for that hour is consistent with the WDR analysis.

Part D is to verify if the surface is a roof. It uses the tilt angle of the surface as the criteria. If the surface is at an angle greater than the threshold reference to the vertical, it is classified as a roof. Since roofs are supposed to drain all the horizontal rainfall, there is no wind-driven rain analysis for roof surfaces.

6.3 Verification of Wind-driven Rain Module in HAM-Tools

The results from HAM-Tools and driving rain modules require verification before it can be used for analysis. The method employed in this study is to compare the results with a reference HAM simulation tool. If the results from the HAM-Tools are relatively close to the reference, it could be concluded that the driving rain module in HAM-Tools performs adequately for analysis.

In this study, WUFI is chosen as the reference tool for verification software due to its wide acceptance as a commercial solution for moisture analysis in building envelopes. The verification process is defined as shown in Figure 39. The process involves first using the same weather data, envelope construction and materials to perform HAM analysis without rain. This could provide a baseline to identify the differences in the two core models. Secondly, the same analysis is carried out in the two software tools including the driving rain input. The results from the analysis are examined to see if there is a significant difference between them. Modification to the driving rain module will be carried out until the confidence of the result is reached.

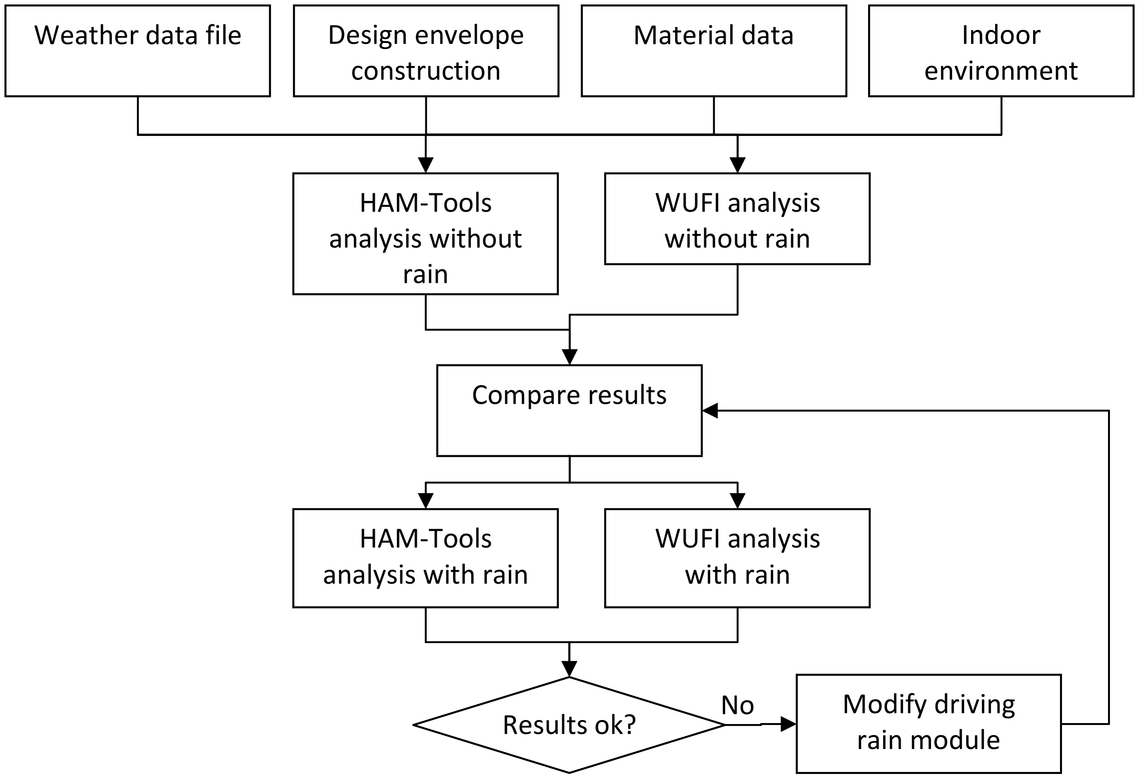


Figure 39: Verification process

6.3.1 Weather Data

In order to compare the results from the two different software tools, the same weather data has to be used in both cases to provide the same reference. In WUFI, the weather data file is embedded in the software in a format that cannot be extracted for use in HAM-Tools. In order to use the same weather data for both cases, a custom weather file has to be generated. Since the data from Environment Canada is readily available as shown in sections 5.2 to 5.5, the weather file uses those data for this verification purpose. Based on the previous analysis in the data error among CWEED data (section 5.5), the data year of 1988 is chosen to perform the analysis. The data is arranged accordingly in the required formats for WUFI and HAM-Tools for analysis.

6.3.2 Wall Construction and Material Data

In order to perform a direct comparison of the results, the same envelope construction using the same materials is required to perform the analysis. WUFI has a comprehensive list of materials while HAM-Tools only has a very short list of materials in the provided database (13 materials). The initial idea is to convert the material data from the WUFI format to the HAM-Tools format so that the same material data can be used.

There are various material parameters and coefficients required for HAM analysis. The basic material properties include density, porosity, heat capacity, heat conductivity and vapour diffusion resistance factor (reference to vapour diffusion of stagnant air). More advanced material properties include sorption isotherm or moisture storage (Figure 40), liquid transport coefficient and vapour diffusion coefficient (moisture dependent). The heat conductivity could also be moisture dependent. These parameters are applied depending on the material.

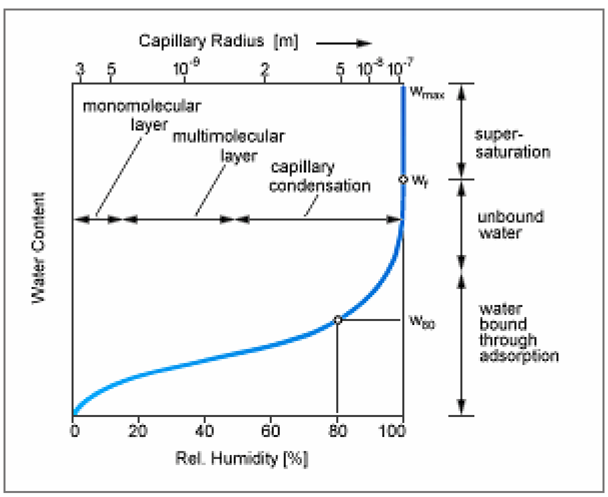


Figure 40: Sorption Isotherm of porous material (Fraunhofer IBP, 2010)

A material's sorption isotherm is one of the most important properties in hygrothermal analysis. It describes the equilibrium amount of moisture presented in porous materials at different levels of relative humidity. There are different regions within the process and the mechanism is drastically different. At low humidity levels, the water is adsorbed to the wall of the pores in the material in a single layer at a molecule level. As relative humidity increases, the single layer molecules build up to multi-molecules. When the humidity rises beyond 60%, capillary condensation causes extra moisture to condense at the pores. This will drastically increase the moisture content beyond linear behaviour. At near 100% relative humidity, the amount of saturated water in the material is defined as free saturation w_f or capillary saturation w_{cap}. It is noticed that w_f is not equal to the maximum water content (which is determined by the porosity). This is because at natural capillary action from surrounding humidity, there is still air within the pores of the material. For the region within $w_{f,}$, it is defined as hygroscopic region. Beyond that is called over-hygroscopic region.

It is noticed that the path of wetting and drying for porous material is not necessary the same. This is defined as hysteresis effect. However, it is assumed that the same path is followed in the modeling technique. This applied to both HAM-Tools and WUFI.

In WUFI and HAM-Tools, the moisture transport is broken down into vapour and liquid transport. The vapour transport is carried out by vapour diffusion and liquid transport is by capillary action. In WUFI, the liquid transport is using liquid transport coefficient D_w (m^2/s) as followings:

$$g_w = -D_w \cdot \nabla w \qquad \textbf{(8)}$$

where g_w (kg/m^2s) is the liquid moisture flux and w (kg/m^3) is the water content of the material. In this equation, D_w is function of w water content. WUFI has tabulated data provided for this coefficient. Figure 41 shows that the liquid transport coefficient varies with the water content of the material. In WUFI, there are two liquid transport coefficients, suction and redistribution. The D_W for suction is defined when there is free water presented at the material surface (which is the case of rain on façades). The D_w for redistribution is defined for the transport without the free water. Currently, there are only a few materials that have the liquid transport coefficient measured (Carmeliet & Roels, 2001). WUFI used an equation to approximate the D_w suction value. The D_w redistribution is approximated as 1/10 of the D_w suction.

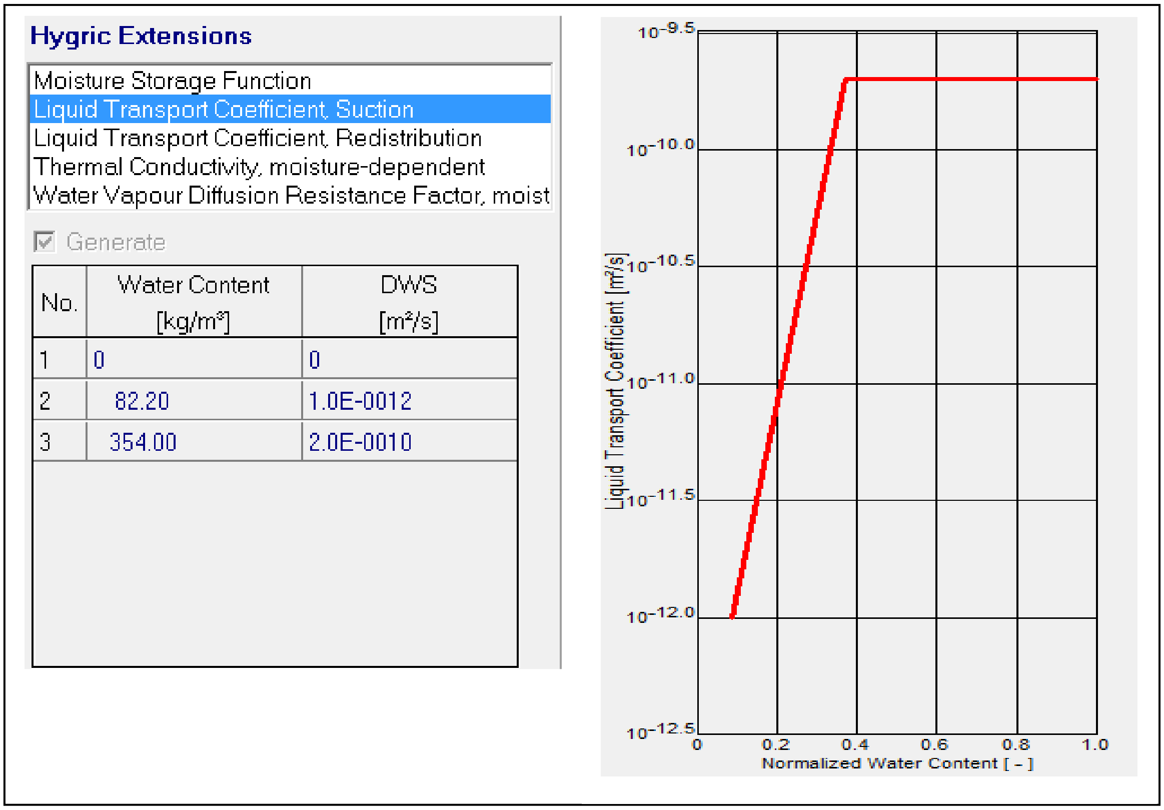


Figure 41: Liquid transport coefficient of Plywood in WUFI

In HAM-Tools, the liquid transport is governed as following:

$$g_w = K \cdot \frac{\partial P_{suc}}{\partial x} \quad \textbf{(9)}$$

where K (s) is the hydraulic conductivity and Psuc (Pa) is the suction pressure of the liquid water in the porous material. The suction pressure is created by water surface tension on the small pores inside the material and the smaller the diameter, the higher the pressure. The suction pressure is arranged with moisture content to form the water retention curve (Figure 42). Similar to sorption isotherm, the water retention curve processes hysteresis effect. In both WUFI and HAM-Tools, the assumption is to eliminate the hysteresis effect.

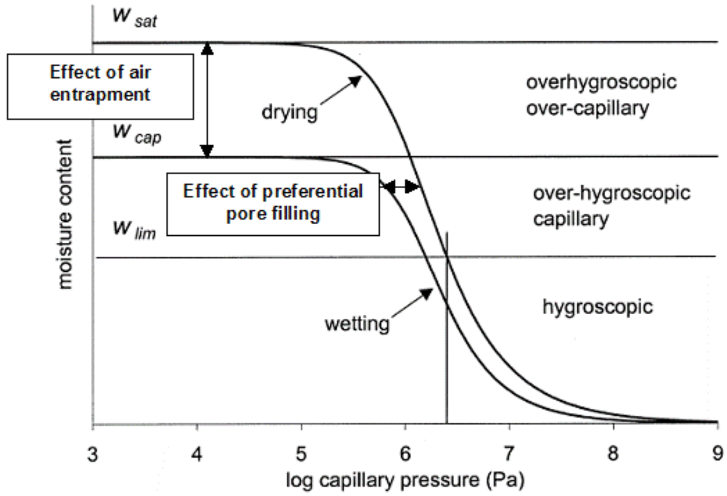


Figure 42: Water retention curve of porous material (BEESL, 2008)

In HAM-Tools, K is function of w water content. It is noticed that the liquid transport governing equation is different between WUFI and HAM-Tools. In WUFI, the system is based on the gradient of the water content. In HAM-Tools, the model is based on the suction pressure difference across the material thickness. In order to convert the Dw to K, the water retention curve of the material (Figure 42) is required to obtain the slope of the curve at various water content levels. This is another missing piece of information which cannot be found readily for the material in the database.

From the above analysis, it is noticed that utilizing the materials data from WUFI to HAM-Tools is not feasible and would generate more errors if not done properly with reliable data. It is, therefore, decided that the materials in HAM-Tools are used and subsequently find the corresponding material in the WUFI database with the closest match. Since this study is to look at relative differences between the two models, this method will be sufficient for the analysis.

HAM-Tools only has 14 materials in the materials database as shown below:

```
%Plaster board|Fiberglass Quilt|Wood siding|Timber flooring|Window
%glass|concrete|Foam insulation|Concrete on floor|Wooden panel|Roof
```

It is found that there is no reference to the source of the material data in the HAM-Tools library. Therefore, the wall construction design is chosen according to the name and some material properties in the database. Based on the materials available in the HAM-Tools database, a wood siding cladding and wood frame construction is used in this verification process.

Table 12 shows the designed envelope construction.

Table 12: Wood siding construction for HAM-Tools verification

Material (outdoor to indoor)	*Thickness*
Wood siding	12.5mm
Air space (ventilation gap)	25mm
60 min building paper (weather barrier)	0.1mm
Wood panel sheathing	12.5mm
Cellulose insulation	137.5 mm
Polyethylene vapour retarder (6 ng/s m^2 Pa)	0.15mm
Gypsum board	12.5mm

It is noticed that the material properties of wood siding cannot obtain a close match in the WUFI database. Since the wood siding is the cladding material which is exposed to the exterior environment, the hygrothermal properties are exceptionally important for this verification. Figure 43 shows the sorption isotherm of the wood siding in HAM-Tools and various wood products in the WUFI database. It is found that there are significant differences in the hygroscopic region between the WUFI and HAM-Tools materials. The hygroscopic region is where typical building material's moisture content is situated throughout the year. The sorption isotherm is the basis for other material parameters and coefficients. In order to obtain a meaningful comparison for this verification process, the material data has to be closely matched within this region. Therefore, a data adaption of the HAM-Tools material data is carried out.

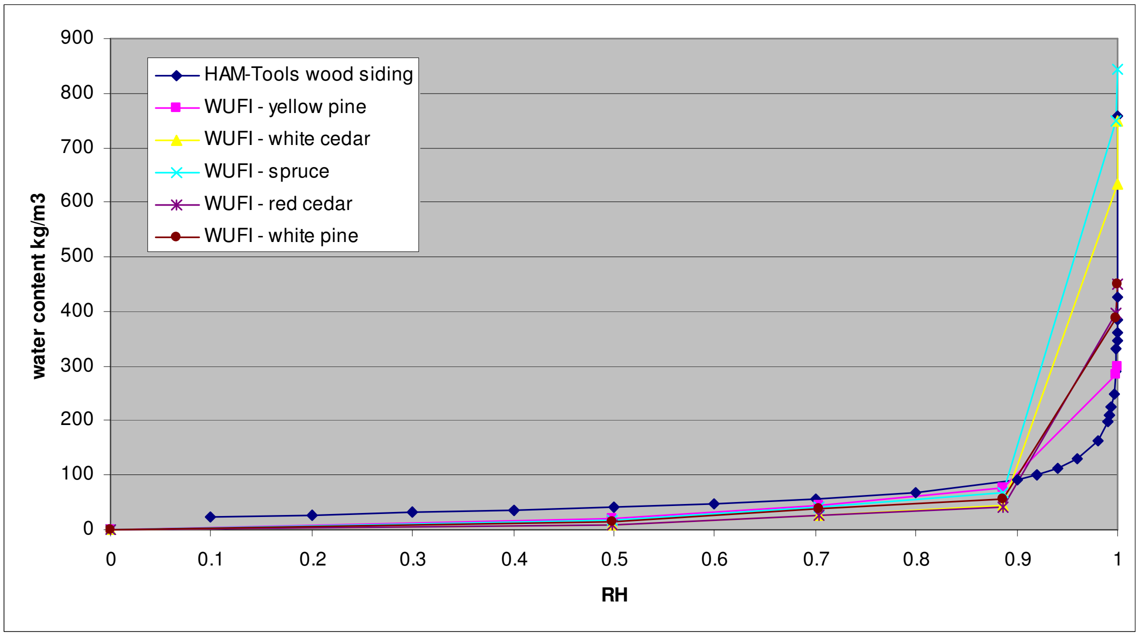


Figure 43: Sorption isotherm of materials in WUFI and HAM-Tools

Figure 44 shows the hygroscopic region of the same list of materials. It is noticed by shifting the wood siding data from HAM-Tools downwards, it could match the yellow pine data from WUFI closely. Table 13 summarized the general material properties of two materials.

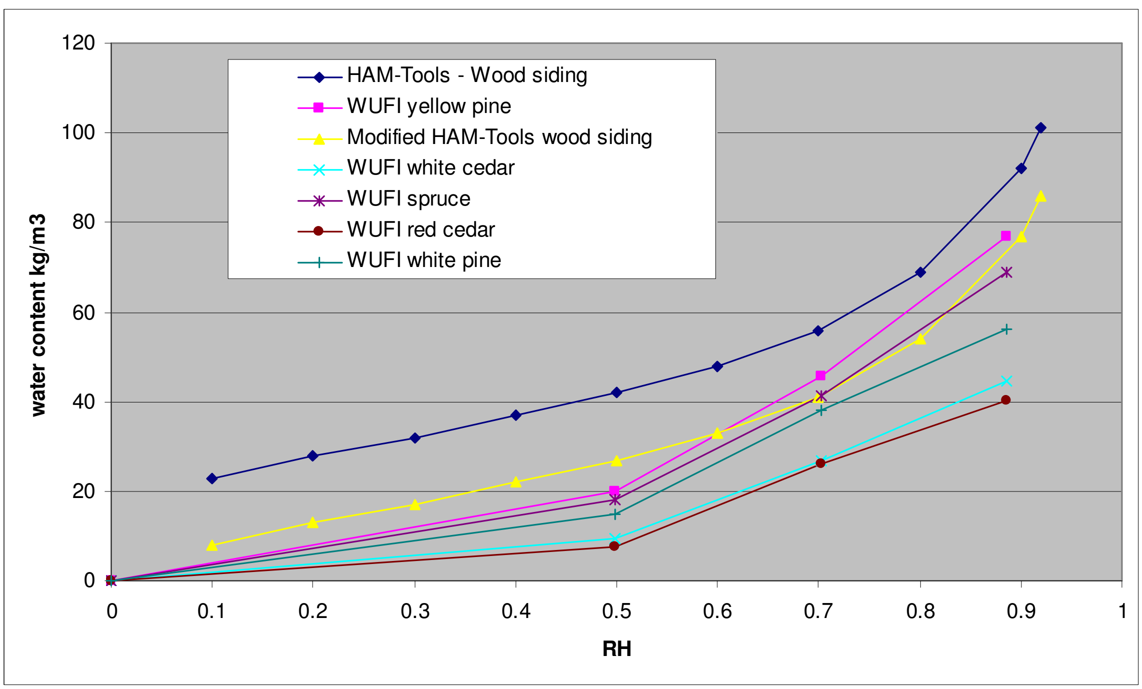


Figure 44: Sorption isotherm adaption for HAM-Tools material

Table 13: Material properties of cladding material

	WUFI yellow pine	HAM-Tools wood siding
Density (kg/m^3)	500	530
Porosity (m^3/m^3)	0.858	0.8
Heat capacity (J/KgK)	1880	900
Thermal conductivity (W/mK)	0.119	0.14

Since the sorption isotherm is adjusted for the wood siding material in HAM-Tools, other material properties which are related to the moisture content have to be updated accordingly. These include the moisture dependent vapour permeability and the moisture dependent hydraulic conductivity. The moisture content level in these parameters is shifted in the same way as the sorption isotherm. The final material data is summarized in Appendix G.

The wall construction in WUFI is set to the same as the HAM-Tools. Figure 45 shows the construction in WUFI with the thickness. These materials are chosen to have the closest match of material properties to the ones in HAM-Tools. The detailed material properties are attached to Appendix G.

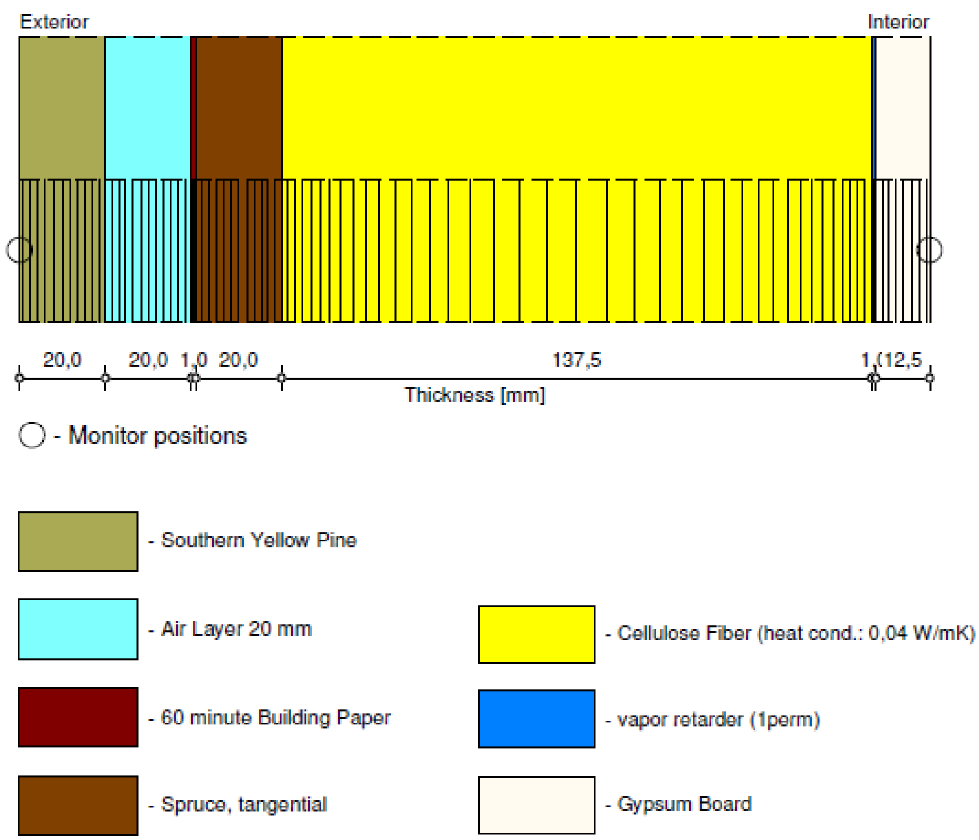


Figure 45: Wall construction in WUFI

From the above analysis, the material properties and wall construction for the verification are determined. This data provides a very close reference to assert the accuracy of the wind-driven rain module in the HAM-Tools.

6.3.3 Indoor Environment

The indoor environment of the two cases has to be the same to maintain the common reference of the analysis. In WUFI and HAM-Tools, they both commence the EN15026 standard. In this verification process, the regular humidity load setting is chosen.

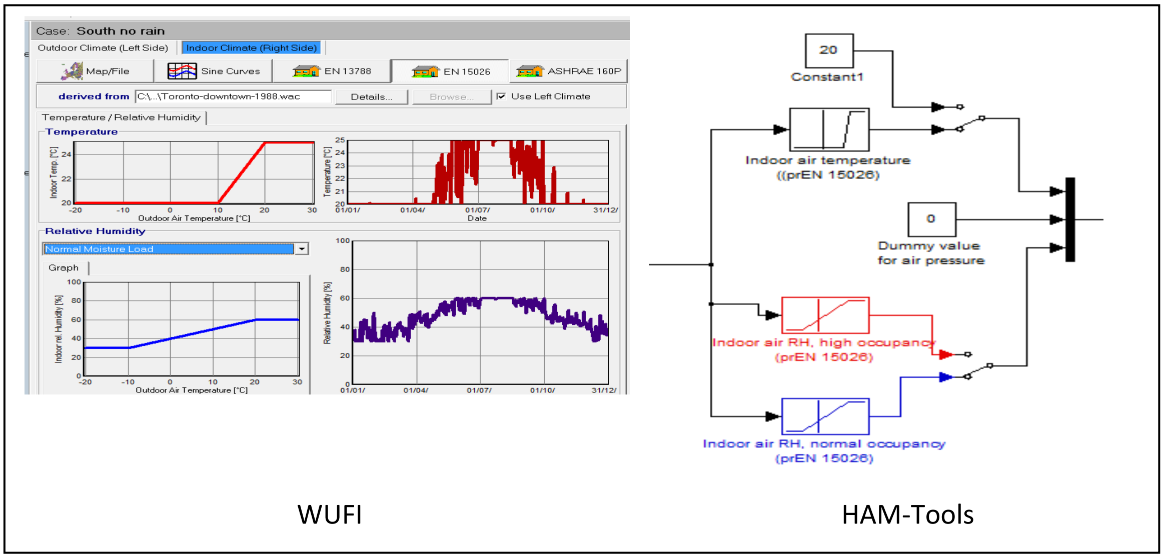


Figure 46: Indoor environment for verification

6.4 Analysis of Results (No Rain)

Using the input parameters specified is sections 6.3.1 to 6.3.3, the HAM analysis in WUFI and HAM-Tools is carried out. The first step is to compare the results between HAM-Tools and WUFI when there is no rain effect. The purpose is to provide a reference point for the verification process. Figure 47 shows the moisture content of the cladding material in WUFI and HAM-Tools without rain. The moisture contents in both WUFI and HAM-Tools follow the similar path for wetting and drying. It is noticed that with the modified sorption isotherm of the wood-siding in HAM-Tools, the result matches much closer to the WUFI result. There are still some differences between the results with the modified materials and the WUFI materials. This could be caused by the slight difference in material properties and the difference in the modelling technique.

Figure 48 shows the percentage difference of the HAM-Tools results with reference to WUFI results. It is noticed that the difference is relatively constant between 0 and 20% with modified HAM-Tools materials. The original wood siding in HAM-Tools generates 60- 100% difference compare to the WUFI results. These results provide a reference for the later analysis with rain effects on the cladding.

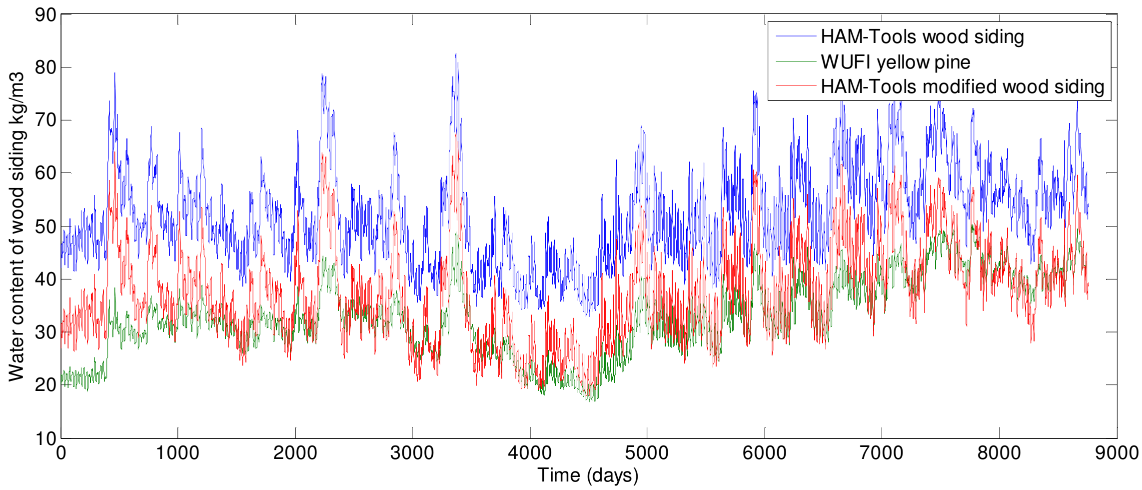


Figure 47: Wood siding moisture content from WUFI and HAM-Tools, south facing

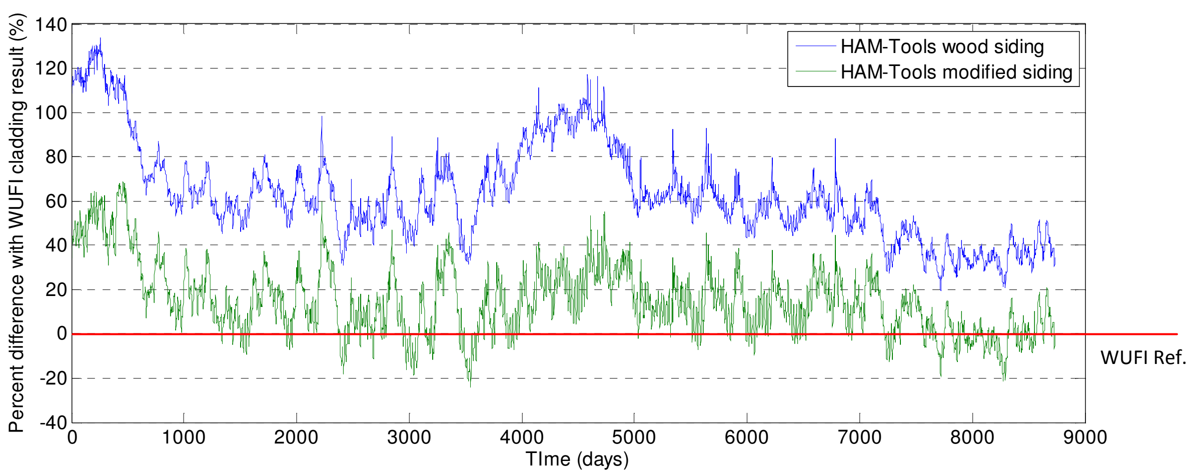


Figure 48: Percentage difference of the HAM-Tools result to WUFI data

6.5 Analysis of Results (with Rain)

With the reference of the verification complete, the rain effect is applied to the HAM analysis in WUFI and HAM-Tools with the newly developed wind-driven rain module. Figure 49 displays the resulting moisture content of the cladding material in the HAM-Tools and WUFI. Similar to the no rain effect case, the moisture content of the cladding in HAM-Tools follows the same path of wetting and drying to WUFI. There are some differences in terms of magnitudes along the study period. It is noticed that there are local peaks from the HAM-Tools results in comparison to the WUFI results. This shows that the HAM-Tools react to wind-driven rain more than that of WUFI. It is noticed that these peaks reduce quickly in a similar manner to the WUFI results and it indicates the cladding dried out in reasonably amount of time.

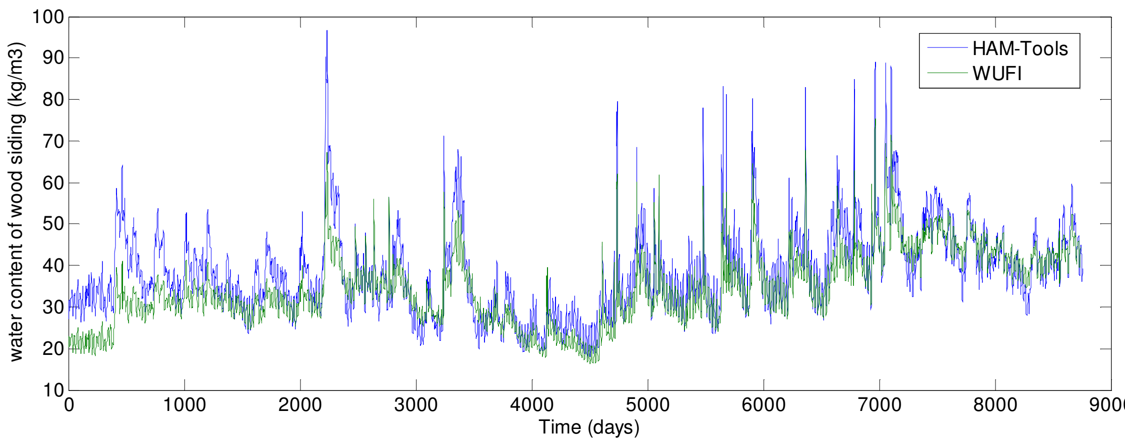


Figure 49: Water content of wood cladding between HAM-Tools and WUFI, south, with rain

6.6 Summary of Analysis

Figure 50 presents the percent difference in both rain and no rain cases with reference to WUFI results. Again, the percent difference in the rain effect case match closely with the no rain case. This observation indicates that the wind-driven rain module in HAM-Tools is incorporating the wind-driven rain effect to the cladding material while maintaining the model's integrity in the analysis.

From the above analysis, it is noticed that the wind-driven rain module can incorporate the rain effect to HAM-Tools without introducing significant error to the model. The wind-driven rain modules provided additional features to HAM-Tools and established a more complete HAM model for hygrothermal analysis. This is a significant step in HAM-Tools development as users can now obtain a complete picture of the moisture state of the building envelope.

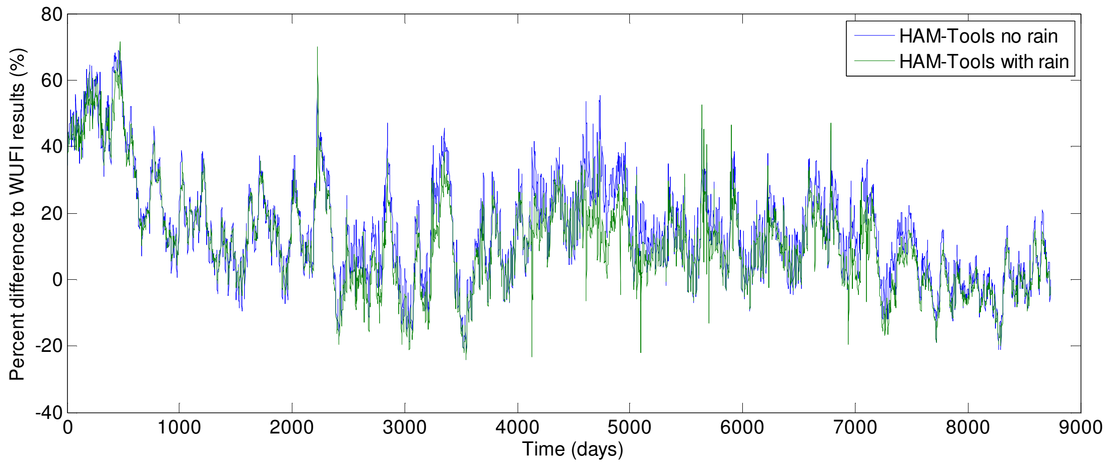


Figure 50: Percent difference with WUFI cladding result, south facing

With reference to the verification process as defined in Figure 39, it can be concluded that the wind-driven rain module developed in HAM-Tools performs successfully and does not jeopardize the integrity of the hygrothermal model in the software. This conclusion facilitates the second part of the study which involves the weather data with different time resolution.

7 Effects of Time Resolution of Weather Data

7.1 Introduction

Both HAM (Heat, Air and Moisture) and WDR (wind driven rain) calculations require data records of wind speed, wind direction and horizontal rainfall intensity as inputs. Studies show that the accuracy of the WDR amounts and intensities results are, to a large extent, determined by the time resolution of the meteorological input data (Blocken & Carmeliet, 2007b; Blocken et al., 2007). The same authors highly recommend that high-resolution data (e.g. 10-min data) be used for more accurate simulation results in the guidelines that they developed for WDR (Blocken & Carmeliet, 2008). However, the effect on HAM analysis in building envelope is not provided. Ryerson University has established a local weather station network to measure weather data at five minute interval. These data is valuable to compare the effect of data resolution on HAM analysis.

It is acknowledged that previous work on the quantification of WDR has been extensively covered by Blocken and the group. However, the research of those effects on hygrothermal performance of building envelope is very limited. This study attempts to investigate the effects of high resolution data on HAM transfer across the building envelope. The results from this study will reveal whether there is a significant difference in terms of moisture management performance and energy performance of the building envelope. This can subsequently show if previous study results, as mentioned above, apply to the Toronto area.

The meteorological datasets utilized in most hygrothermal analysis are hourly arithmetic averages from raw data at higher time resolutions. This raw data is usually not available for public access and only the averaged data is published for public use. However, from previous studies (Blocken & Carmeliet, 2004; Blocken & Carmeliet, 2007a), it is suggested that this technique could lead to errors in WDR analysis.

The effects of time resolution on weather data can be summarized as the Figure 51. The time step on the x axis is 10 minutes, total is 1 hr. ***U*** represents the wind speed and ***Rh*** indicates the horizontal rain fall (rain falls on a horizontal surface). The largest error occurring with arithmetic averages of raw data is the co-occurrence of high rain fall and high wind speed. In case a, high rain fall and high wind happened at time step 1 and 2. Arithmetic averaging of all 6 time steps will remove this high WDR intensity information. In case b, the high rain fall happens in low wind speed situations. The WDR intensity at that time step should be relatively low. However, the averaging of the weather data could increase the WDR significantly.

The study (Blocken & Carmeliet, 2006) suggested that 10 minutes data would be adequate for the WDR analysis. The author has also shown that if averaging to hourly data is required (due to ease of publishing and data file size), the meteorological data should be weighted average. This can ensure the accuracy of the WDR intensity calculated.

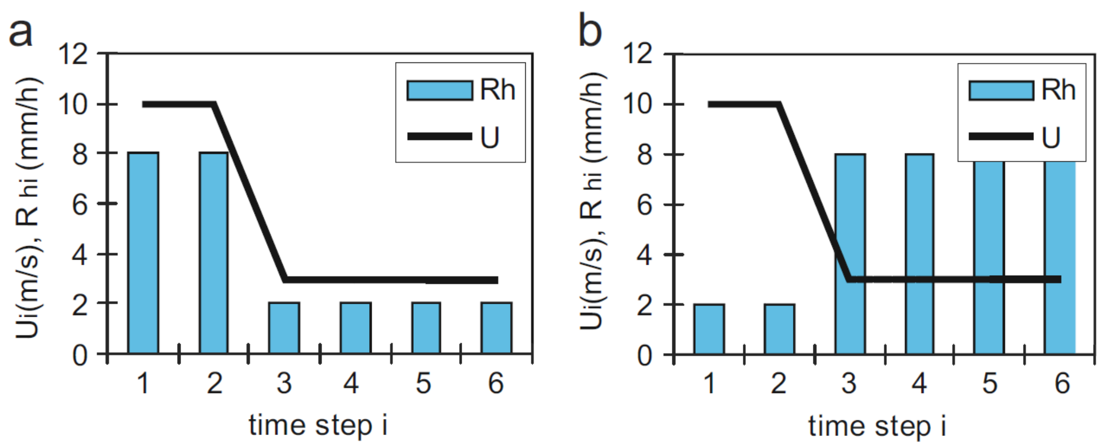


Figure 51: Illustration of time resolution effect on wind-driven rain (Blocken & Carmeliet, 2006)

7.2 High Resolution Weather Data

Currently most of weather stations across the world provide arithmetically averaged hourly dataset for HAM software, commercial or research based (Blocken & Carmeliet, 2008). This hourly data is averaged from the "raw data" at higher time resolutions at the weather station. The WYEC datasets from Environment Canada are also constructed utilizing this hourly average method. However, since the raw dataset could not be obtained from Environment Canada, an alternative source would be needed to obtain high resolution weather data.

7.2.1 Ryerson University Weather Network

Since July 2009, weather stations have been setup across Ryerson's campus. The weather stations obtain high resolution (5-minute) weather data for different faculty's research. At the time of this study, only a few months of data have been received, from January 2010 to May 2010. It is acknowledged that this short period of time may not be enough to provide in-depth analysis. However, this is the only data available at the time of study and the data should be able to provide enough details to draw a sound conclusion.

The data is collected in 5-minute intervals and includes the following parameters: dry bulb temperature, dew point, wind direction, wind speed and rain. These pieces of data are used to formulate the hourly data and are compared to the 5-minute raw data. The weather stations do not measure solar radiation due to the shortage of funds available at the time. Sensor for solar radiation was not obtained.

The received weather data is collected from the weather station situated at the roof of the Architectural Science Building. The weather station is a realistic representation of the downtown environment as shown in Figure 52. The sensors are located on the south west corner of the roof. There are 3 buildings surrounding the weather station in the near proximity. The engineering building on the east side is the closest one. The apartment building at the north side is further away. The Ryerson building on the west side is the furthest away and the south side is very open for two street blocks.

Figure 52: Weather station on roof of Architectural Building, Ryerson University

7.2.2 Construction of 5-minute Weather Dataset

In order to complete a heat, air and moisture HAM analysis for a wall structure, parameters missing in Ryerson Weather Network are required from other sources. These parameters included global radiation, diffuse radiation, normal direct radiation, and long wave radiation. In the Ryerson Weather Network, the weather stations do not include the solar radiation sensors. Hence the radiation data has to be appended from another source.

The radiation data is obtained from Environment Canada since they have a weather station in Toronto in close proximity of the Ryerson Weather Network. According to Environment Canada, weather station 04714 is located near the University of Toronto (Environment Canada, 2011). This location is a close representation of the weather station at Ryerson University. The WYEC dataset of that station is used as it summarizes the highest occurrences of weather data over 30 years. Since the radiation data is recorded hourly in units of energy, the radiation power (in watts) is calculated by dividing the time. The radiation power in watts is then applied to the each 5-minute data for that hour. In reality, the radiation power will be different from the beginning of the hour to the end of the hour. However, it will be too resource intensive to linearly interpolate each line of the 5-minute data for the solar radiation. Therefore, linear interpolation of the solar radiation data for the 5-minute data is not performed.

Table 14: Sample data for Jan 1st, 2010, 8:00am

Dry bulb (10°C)	Dew Point (10°C)	Global horizontal (W)	Diffuse (W)	Direct (W)	Incident (W)	Global Lux (lux)	Diffuse Lux (lux)	Direct Lux (lux)	Wind Dir (°)	Wind Spd (10 m/s)	Rain (10 mm)
11	-22.2	3.1	3.1	0.0	0.3	400	400	0	267	9	0
9.3	-24.7	3.1	3.1	0.0	0.3	400	400	0	274	11	0
9.9	-24.3	3.1	3.1	0.0	0.3	400	400	0	257	13	0
9.3	-24.9	3.1	3.1	0.0	0.3	400	400	0	351	13	0
9.3	-24.2	3.1	3.1	0.0	0.3	400	400	0	7	9	0
8.8	-24.7	3.1	3.1	0.0	0.3	400	400	0	222	7	0
8.5	-25.1	3.1	3.1	0.0	0.3	400	400	0	246	6	0
8	-25.8	3.1	3.1	0.0	0.3	400	400	0	337	7	0
8.5	-25.1	3.1	3.1	0.0	0.3	400	400	0	8	7	0
7.7	-26.3	3.1	3.1	0.0	0.3	400	400	0	323	11	0
7.7	-25.9	3.1	3.1	0.0	0.3	400	400	0	192	6	0
7.4	-26.4	3.1	3.1	0.0	0.3	400	400	0	354	9	0

The radiation power will be assumed to be equal from the beginning of the hour to the end of the hour and the calculated power is used in each 5-minute data line of that hour. Table 14 presents a set of sample data for January 1st, 2010 at 8:00am using above method. The *Global horizontal*, *Diffuse*, *Direct* and *Incident* information are from the solar radiation data from the WYEC dataset. The *Global Lux*, *Diffuse Lux*, *Direct Lux* information is also from the WYEC dataset. This is the luminance data for accessing daylighting in HAM-Tools. Although these are not used in this study, HAM-Tools require a complete set of weather data for input. Consequently, this data is also included.

7.2.3 Construction of Hourly Weather Data

Since this study is on the effect of time resolution on weather data, the hourly data has to be constructed from the same set of 5-minute data to ensure the data has the same reference. In order to closely represent the current practice of meteorological dataset formation, the hourly dataset is constructed by arithmetically averaging the 5-minute data. Special attention is required for averaging the wind direction. In real mathematical average, the angle of the wind will be added together and divided by the number of instance. However, angular quantity is not monotonically increasing. When it reaches 360 degrees it returns to zero. Therefore, regular arithmetical averaging is not applicable here. Instead, a vector average is used in this analysis which is standard practice in ocean climate by Nation Oceanic and Atmospheric Administration (NOAA, 2002). This technique breaks down the angle in cosine and sine components, adding the components together and performs arctangent to determine the resultant angle (Figure 53). The hourly wind direction is calculated by the above method from the 5-minute wind direction in that specific hour.

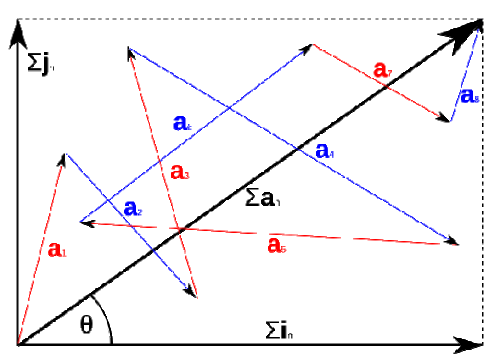


Figure 53: Addition of direction to form hourly direction data (Sjlegg,)

7.2.4 Quality Check for Data

Since only 5 months of weather data is received, it is not enough to complete a yearly weather data file for HAM-Tools. This has caused the simulation to halt even though the simulation period was set to the end of the received period. This is caused by some radiation and daylighting modules, which calculate the yearly parameters for the given surface before the actual simulation begins. Therefore, the yearly weather data file has to be completed. A Visual Basic script program is generated to fill the rest of the data line with zero. This could not be achieved in Excel because it has a 66,000 line limit in a spreadsheet. The program appends the rest of the data line with the proper time stamp in the first column. Refer to 0 for the details of the program.

The final hourly and 5-minute dataset is processed with a quality check for each line of item. The first check is to see if the data is out of range of the corresponding data item. The check is performed in ACCESS using a simple query similar to the one performed in section 5.5. The second test is to check if there is any missing data in the file. This utilizes a Visual Basic script program to compare the time stamp in each line of data to the next line (Appendix F). It is noticed that the data for March 13, 2010 2:00am is missing. This could be due to miscellaneous issues in the data acquisition process. The data is interpolated from the previous and next time step (Appendix F). This is important to have continuous weather data; otherwise, HAM analysis will be erroneous. If the software cannot find the weather data at the specific time step, the calculation will be halted.

7.3 Weather Data Analysis

The finished weather dataset is analysed before HAM analysis is performed. The preliminary analysis can reveal the significance of difference between the hourly and 5-minute weather data. This could allow further correlation with the HAM analysis results. Figure 54 shows the temperatures of the two sets of data and it is noticed that the difference is minimal between the hourly and 5-minute data. The hourly average temperature seems to be lagging compared to the 5-minute data, which is normal in arithmetic techniques. The effect of the time resolution is relatively minor.

Figure 55 shows the wind direction, speed and frequency of the weather data. It is noticed the wind is dominant from the north in both cases. The hourly average data has less south wind compared to the 5-minute data. For reference purposes, the data from Pearson Airport during that period of time is shown in Figure 56. It is noticed that there is more westerly wind in the Pearson Airport data than Ryerson station. This could be explained by the Ryerson weather station's location, which is located on the roof of the Architecture building. From Figure 52, it is observed that the weather station is partially surrounded by the buildings in the area.

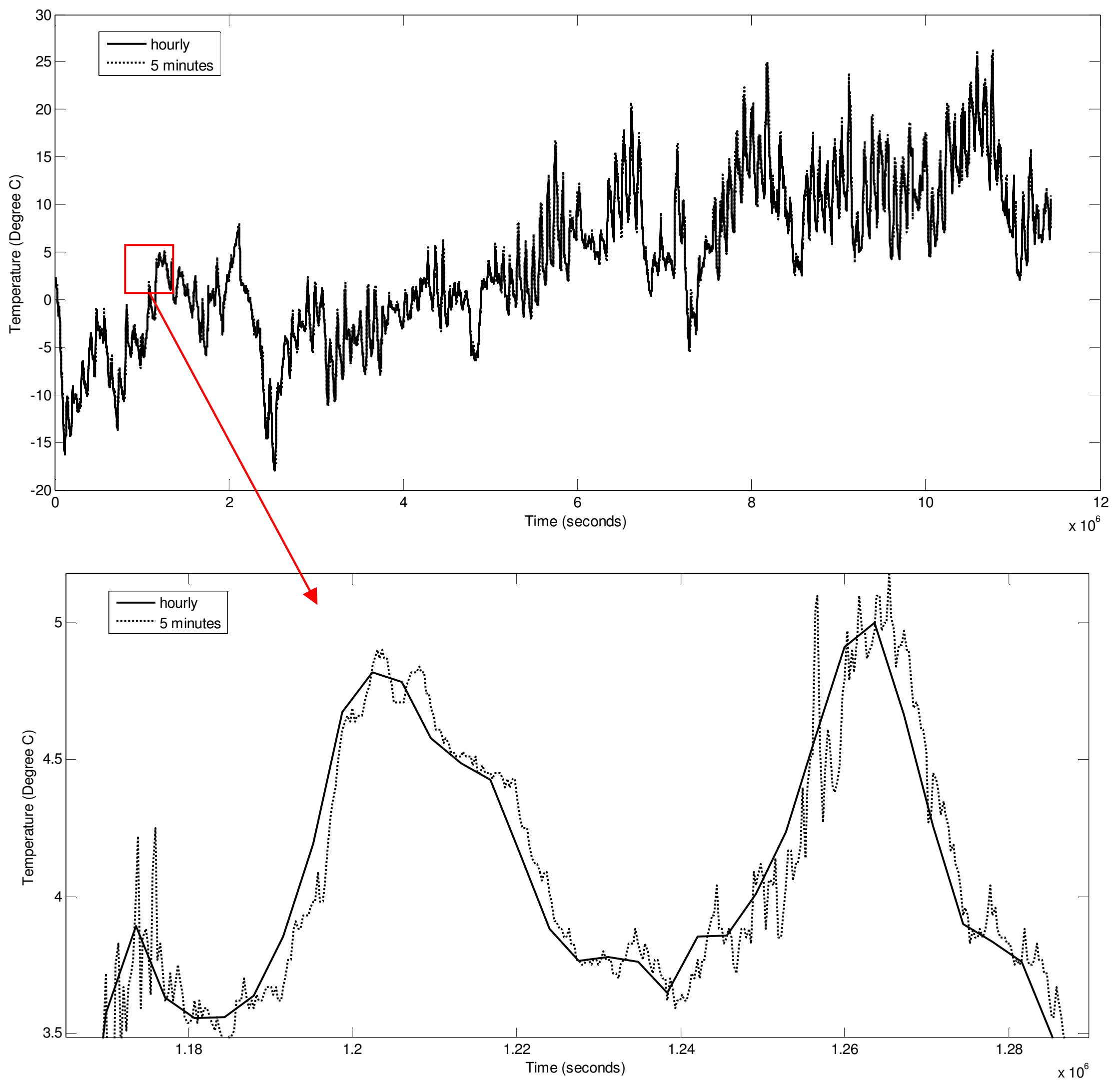
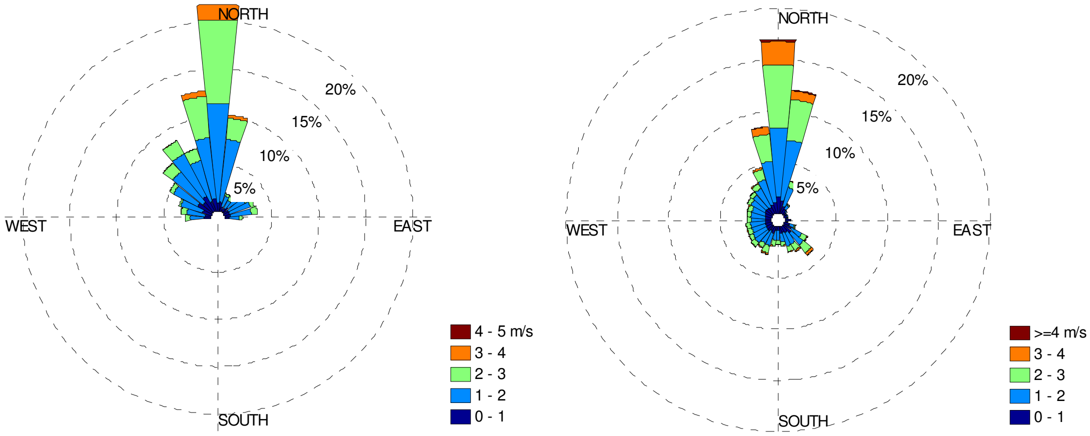


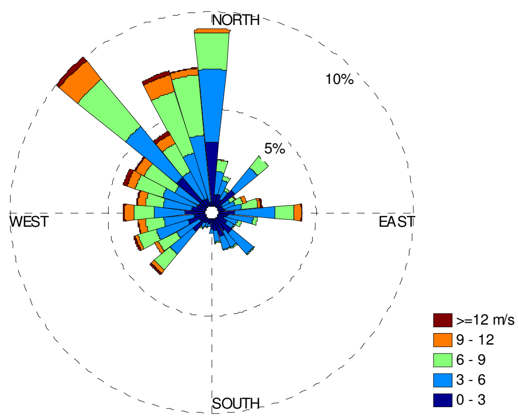
Figure 54: Temperature comparison between hourly and 5-minute data



Hourly data, average from 5-minute Ryerson

5-minute, Ryerson

Figure 55: Wind direction and speed (m/s) of hourly and 5-minute data (Jan 1 to May 13, 2010)



Pearson Airport 2010, Jan 1 to May 13

Figure 56: Wind direction and speed (m/s) from Pearson Airport

Figure 57 and Figure 58 show the wind hour and rain hour date of the two sets of data. The wind hour plots show that the wind is dominant from the north. In the rain hour plots, there are greater differences between the two sets of data. The hourly data shows that the rain happens with the north and north-west wind. In the 5-minute data, the rain happens in the north and south-east wind. This observation reveals the effect of averaging weather data. However, the rain hour plot does not present the magnitude of the wind and rain amounts in the event. It only accounts for the number of occurrences of rain events.

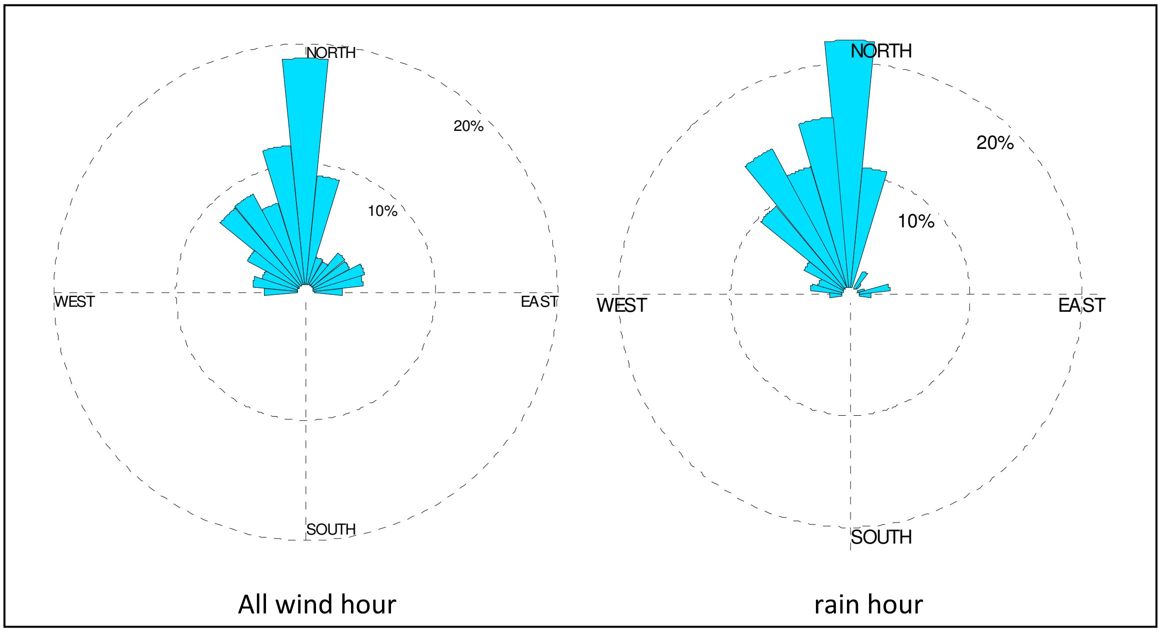


Figure 57: All wind hour and rain hour of hourly weather data

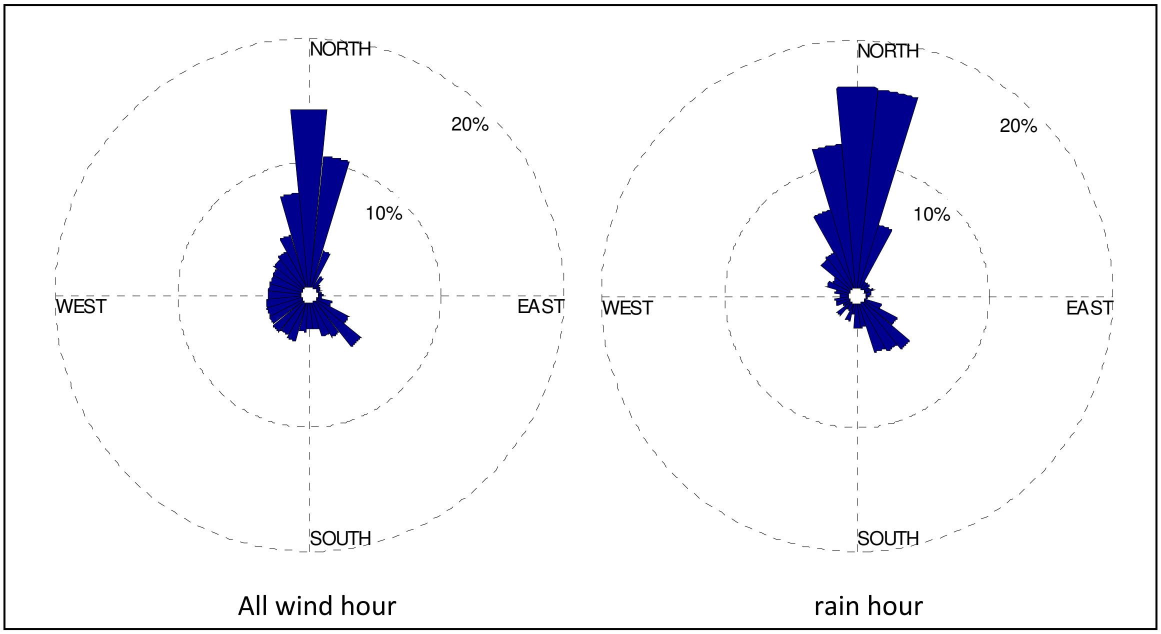


Figure 58: All wind hour and rain hour of 5-minute weather data

The total amount of rain from January to May is 149.8 mm. This amount is equivalent to approximately 25% of Toronto's average annual rain fall.

7.4 Wind-driven Rain Analysis

Before proceeding to HAM analysis, the wind-driven rain intensity is calculated and analysed. This could provide valuable information regarding the averaging process and its effects in the data. Similar to the previous sections (3.4), the ASHRAE 160P is used to calculate the WDR intensity.

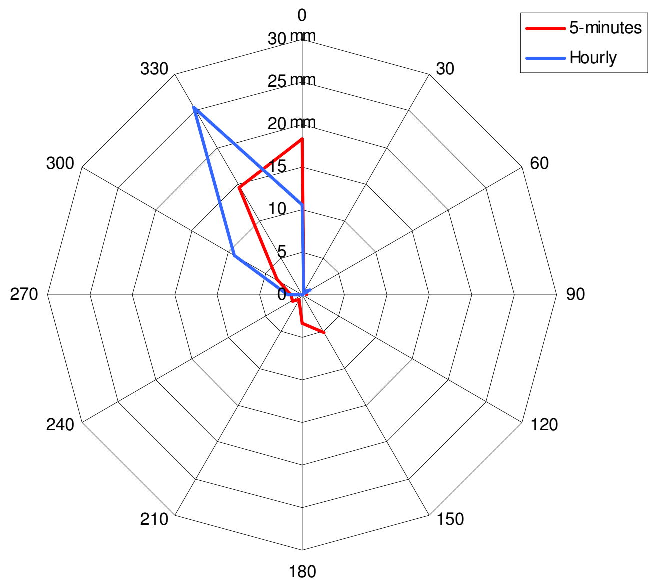


Figure 59: WDR comparison of hourly and 5-minute data (mm)

Figure 59 presents the driving rain intensity with the given weather data. This graph presents the overall intensity of driving rain at different directions. It is formulated using the AHSRAE 160P without the rain deposition and exposure factor. This is also commonly known as a driving rain intensity plot. It is noticed that overall, the driving rain is coming from north-west-north for both sets of weather data. The hourly data has slightly higher driving rain intensity than that of 5-minute data the 300 degree group. This could be explained by the averaging effect of the 5-minute data to formulate the hourly data. This result coincides with the previous analysis on the wind hour, rain hour. The overall wind is coming from north direction and the rain event happens during the north wind also.

7.5 HAM Analysis

In this part of the study, the 5-minute and hourly weather data is used in a hygrothermal analysis for a sample residential wall construction. The goal of the analysis is to investigate the effect of the averaging of weather data, provided the rest of the parameters are the same (boundary condition, wall construction, material, simulation time step). Since the weather data file requires flexible time step input, HAM-Tools would be the ideal tool to perform this task. From section 6, the wind-driven rain module is added to the tools and has been verified successfully. This provides a complete functionality to the simulation tool for hygrothermal analysis.

The weather data time step resolution is provided in hourly and 5-minute intervals. Therefore the reduction factor described in Figure 38 is set to 1/3600 and 1/300 respectively. Both analyses are performed with simulation time step in seconds to obtain the highest resolution and also eliminate the uncertainty generated from different simulation time steps.

7.5.1 Boundary Conditions

The exterior climate will be based on the weather dataset prepared from previous sections. The indoor climate will be using the EN15026 standard which defines the indoor temperature and relative humidity throughout a year. This is one of the standard indoor climate conditions available in HAM-Tools. In this study, it is assumed the building is a townhouse, where the north and south facing walls are subject to exterior climate.

7.5.2 Wall Construction

The wall construction in the study is a typical residential wood frame construction in North America. This is the same construction used in the verification process of the wind-driven rain module in HAM-Tools. The details of the material thicknesses are in Table 12. As mentioned in the previous section, there are very limited material selections from the HAM-Tools database. Introducing new materials to the database may generate unpredictable errors due to the material properties conversions as described in section 6.3.2. This wall construction has been proven in the verification process with the WUFI result. Therefore, the same construction is chosen here also.

The material data in this analysis utilizes the same ones from the verification process. The modified wood siding data is employed to ensure the result from the analysis does not generate significant errors. Figure 60 presents the final representation of the wall in HAM-Tools.

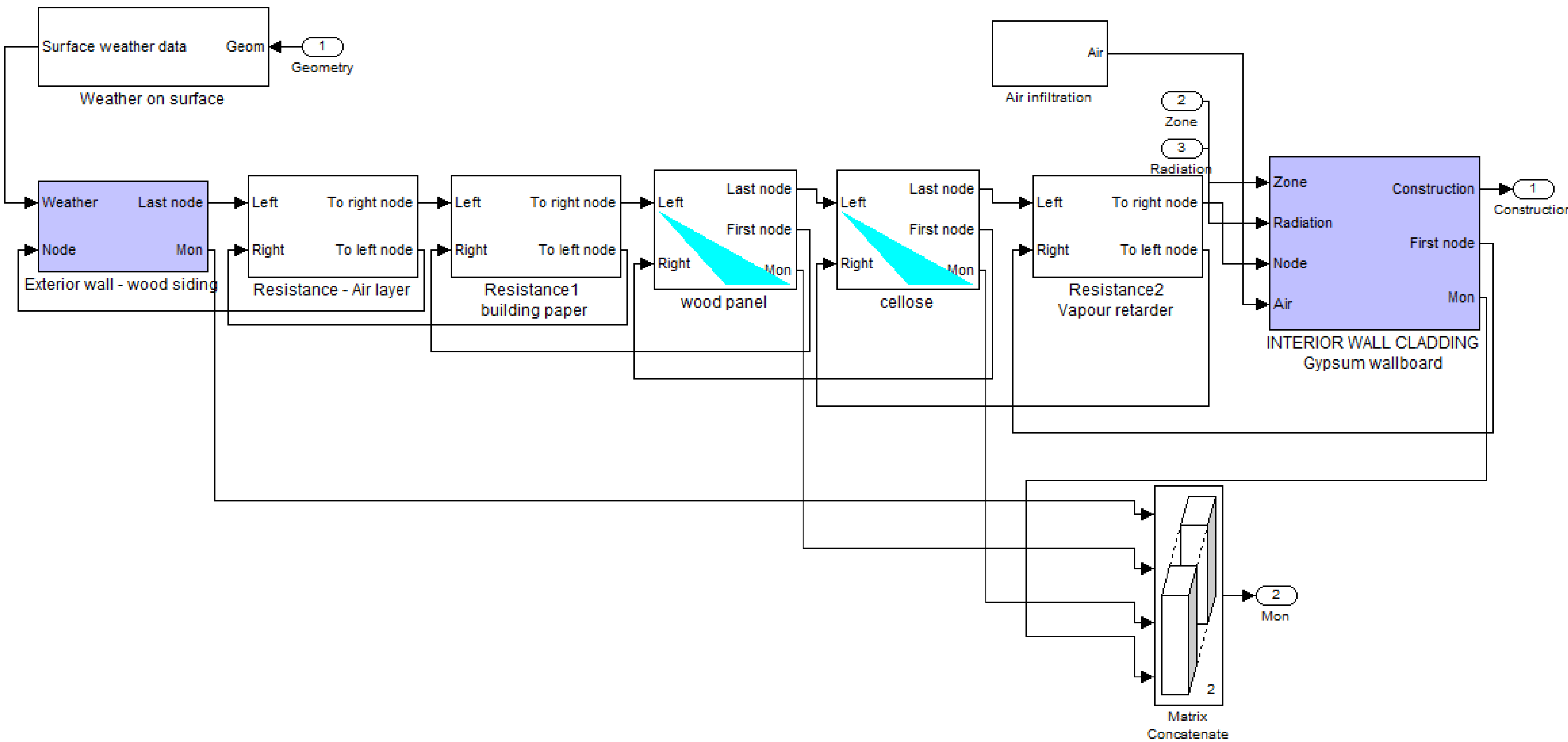


Figure 60: Model blocks of the wall construction in HAM-Tools

7.6 Simulation Results

The analysis is performed from January 2010 to May 2010. Since this study is interested in the hygrothermal performance of the wall with different resolution weather data, the moisture content of the material is of particular interest. The cladding material is exposed to the exterior conditions and therefore the wind-driven rain is the main contribution to the moisture of the wood siding material.

Figure 61 presents the moisture content of the wood siding in both 5-minute and hourly data. It is noticed that through the course of the analysis, the moisture content of both datasets follows the same course without significant difference.

The result from hourly data is below the result from 5-minute data throughout the course of the analysis with the exception of the very beginning. This can be correlated to the weather data analysis in Figure 57 and Figure 58. There are south wind and rain events in the 5-minute data and these events are removed in the hourly data after the averaging.

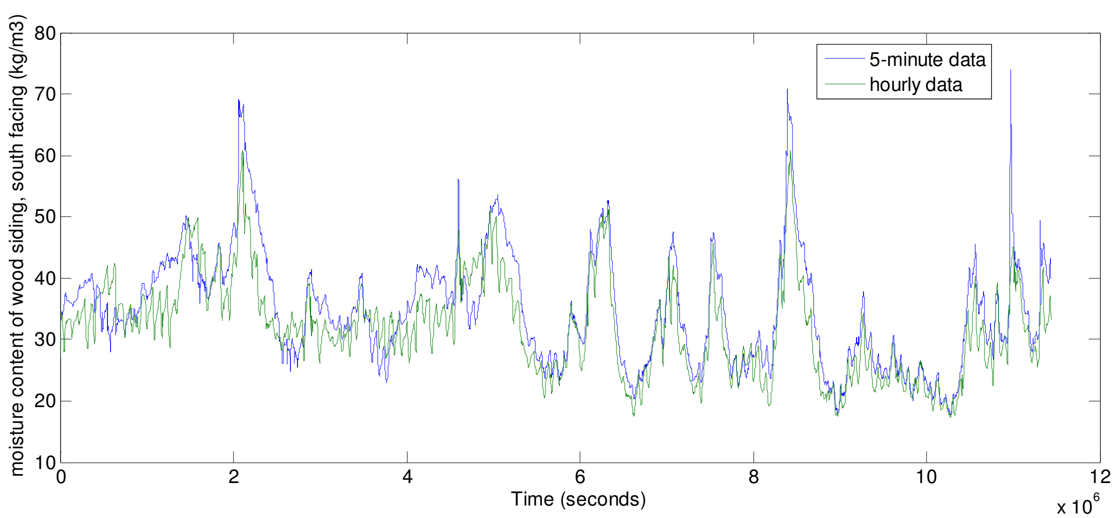


Figure 61: Moisture content of south facing wood siding

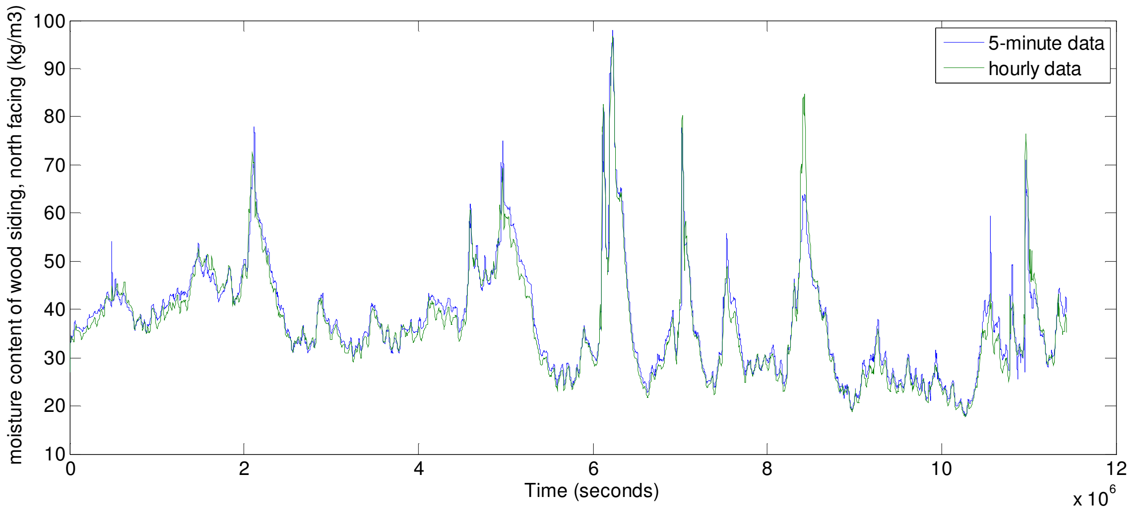


Figure 62: Moisture content of north facing wood siding

Figure 62 presents the water content of the wood siding of the north facing wall. It is noticed that the result from hourly data follow the same course of 5-minute data at a much closer formation compare to south facing wall (Figure 62). Throughout the course of the study, there are occasions where the 5-mintues data results are higher than the hourly data results and vice versa. These findings correspond to the analysis in the previous sections 7.3 and 7.4. Since both hourly and 5-minute data utilize the north dominant wind hour, rain hour and driving rain intensity, the moisture content results from both sets of data would coincide with each other closely.

Although there is more north-west wind in the hourly data as shown in Figure 57 compared to Figure 58, the difference is less significant shown in the moisture content results. This is because the wall orientation is set as north and any wind-driven rain events that happened away from the north direction are discounted by the *cos(Θ)* as describe in ASHRAE 160P standard.

Based on the above findings, the effect of averaging the weather data in hygrothermal analysis of building materials is revealed in detail. Without any hesitation, the averaging of raw weather data changed the integrity of the data. Certain details cannot be maintained to obtain the overall trend of the weather conditions. However, the extent is significantly less than that proposed by Blocken and his group (Blocken & Carmeliet, 2007a). Based on the analysis carried out in this study, the hygrothermal analysis can still be carried out with reasonable accuracy and detail, with arithmetic averaged hourly data.

Due to the limited material available in the HAM-Tools database, this study focuses on the wood siding material as the façade. Other façade materials like brick or concrete should be used to perform the analysis and compare the results with this study. However, separate studies would be required to confirm the conversion and formulation of material properties is successfully employed. This study only provides 5 months of high resolution weather data for the analysis. Longer study periods would be ideal to reinstate the findings from this analysis. The weather data in this study is only composed of Toronto data. Other locations with more intense annual rainfall, like Vancouver and European cities, could be used to verify the above findings.

The result from this study only applies to Toronto area. Other location, like Vancouver, cannot utilize the result without further investigation. Vancouver has double the annual rain fall compare to Toronto. The significant of effect in weather data resolution is unknown. Also, this study only focuses on the wall assemblies of the façade. Other components such as windows are not examined in this study. The hygrothermal response of these components could be very different from the wall assemblies. For example, the water leakage of a window could be almost instantaneous from the wind-driven rain, while wall assemblies have a delay in the hygrothermal response due to the moisture storage of material. Any underestimation of the wind-driven rain caused by averaging 5-minute data could be significant. Therefore, the result from this study could not be generalized to other building envelope components without further investigation to the specific application.

7.7 Summary of Results

This part of the study investigates the effects of using high resolution weather data in HAM and WDR analysis. The 5-minute data is collected from Ryerson University Weather Network and the hourly data is constructed by using arithmetic average. By analysing the hourly and 5-mintue data, it is noticed that the averaging introduced differences in the wind hour and rain hour plot. Although both sets of data have north dominant wind, the minimal south direction wind in the 5-minute data is eliminated in the hourly data. In the wind-driven rain analysis, the hourly data and the 5-minute data both have dominant north direction wind-driven rain with little difference. There is minimal difference in the south direction.

From the HAM analysis, it is noticed that there is minor differences in both the south and north wall in terms of water content between the 5-minute and hourly data. This result correlated to the weather data analysis. The difference between the results in the south facing wall is higher than that of north facing wall. This could be explained by the difference in the south direction wind and rain events between the 5-minute and hourly data. The overall water content of the wood siding in either data set follows a very similar path throughout the study period. There are some local differences; however, the overall trends are very similar. This shows that the averaging of weather data has impacts on WDR quantification, as stated in previous studies by Blocken (Blocken & Carmeliet, 2007a). However, the impact on the hygrothermal performance of the building facade is very limited in wood frame residential structures.

This study only investigates the HAM performance of wood frame residential wall. Further studies on other construction type would be beneficial to verify the above findings. Due to various technical issues, only 5 months of high resolution data is obtained in this study. Further study using longer duration of high resolution weather data would be useful to verify the above findings. Similar study at different location should also be carried out to compare with this study result.

The findings from this part of the study are summarized and published in the XII DBMC titled “Simulation study of building envelope performance with high resolution meteorological data” (Wu & Horvat, 2011).

8 Conclusion

This project attempts to demonstrate the effects of different factors in the generation of weather data for hygrothermal analysis. From the beginning of the study, it is presented that the microclimate conditions of urban areas and time resolution of the weather data are the two focuses in this study.

Before the simulation could be carried out, the tools had to be decided on. Different wind-driven rain approaches were analyzed and it was found that the semi-empirical model was the most appropriate for this study. AHSRAE 160P 2009 was selected as a reference for this study since it is a North American standard and the location of interest is Toronto.

Several software packages were evaluated for this study. It was concluded that WUFI was the most applicable tool for calculating the combined HAM for the airport and downtown weather data. The flexibility of HAM-Tools was most suitable for the high resolution data calculations.

The first part of the study aimed to investigate the effects of the microclimatic conditions in urban and suburban areas. The Pearson Airport data and downtown hourly data were used for the analysis.

The received weather data had to be organized in a database format so that it could be managed and converted into a useful format. Data quality assurance was also important because the completeness and consistency of data would affect the quality of the results. Errors in the data were detected and repaired. Fifteen years of data were selected to perform the analysis.

From analyzing the weather data between the airport and downtown weather stations, it was noticed that there were minimal differences in terms of dry bulb temperature and dew point temperature. The wind rose and rain hour were constructed and showed that the rain was concentrated on the south east direction. The wind-driven rain maps present some differences between the two sets of weather data. However, the difference was not very significant. This provided valuable information for analyzing the simulation results.

The simulation used 15 years of data from the two weather stations. The results showed that on average, the water content of the building envelope was the same throughout the 15 year period. Although there was high moisture detected in the building envelope scattered throughout the period, the drying process was quick and the water content of the wall returned to average reasonably fast. A sample year (1988) of results was plotted for detailed analysis. It was noticed that although there were differences in the peak moisture content, the overall moisture content of both sets of weather data followed closely along the same pattern. The energy difference between the two weather data sets was also minimal. This answered the first and second research questions listed in the beginning of the report. Although there was a difference in the hygrothermal analysis due to the effect of suburban and urban weather data, the difference in the analysis results was minimal in terms of moisture content and energy transport.

This observation can be explained by the annual amount of rainfall in Toronto, which is much less compared to Vancouver and some European cities. Also, the urban density of Toronto is much less compared to other cities in the world where similar data has been collected. This diminishes the effect of the difference between the two weather stations. Further studies with physical building measurement should be carried out to verify the findings.

The second part of the study focused on the time resolution of the weather data. The 5-minute weather data was collected from the Ryerson weather network on the roof of the Architecture building. The hourly data was constructed from the 5-minute data by the arithmetic averaging technique.

The hourly and 5-minute data were analysed before the simulation began. The wind rose plot showed that during the period, the wind was dominant from the north. The 5-minute data showed small amounts of wind from the south, and after averaging, the south wind was removed in the hourly data. The wind driven rain plots confirmed the above findings as the wind driven rain was dominant from the north in both sets of data, with minimal amounts from the south in the 5-minute data.

The hygrothermal analysis was carried out with HAM-Tools. A custom wind driven rain module was developed for the HAM-Tools as it does not carry such a function. The simulation results show that on the north façade, both the 5-minute and the hourly results followed closely to each other throughout the study period. For the south façade, the 5-minute data shows more difference to the hourly data than the north façade. This was due to the averaging of hourly data and the south wind being removed. However with this consideration, the results still closely match the hourly data. These findings fulfill the third and forth questions set out in the previous section. With no doubt, the averaging technique for hourly data removes some details from the raw meteorological data. However, it did not affect the overall trend of the climate condition and the impact to the hygrothermal analysis of building components was very limited.

This study successfully fulfilled the research questions laid out at the beginning of the report. Although this study showed that the current hourly data is adequate for HAM analysis, the results are limited to Toronto and similar climate. Any drastic difference in climatic conditions may have different results. As stated in the analysis, different location could have significant different climate. Vancouver has double amount of annual rainfall compare to Toronto. The result from this study cannot be directly applied to such location. This study investigated the hyrogthermal response of the wall. It does not apply to other part of the façade like windows. The effect of time resolution of weather data on these building components is unknown. Further investigation would be essential, and users should execute one's own judgement for the specific cases.

9 Future Studies

This first part of the study investigated the hygrothermal performance of wall structure utilizing the weather data from suburban and urban environment. The aim was to determine the impact on the analysis from the different environmental conditions. Further studies should be carried out in terms of total amount of energy (sensible and latent) difference with regards to energy cost. This could provide a clearer understanding of the impact from the two weather stations. Software packages such as Energy Plus can be used in this type of energy analysis.

Similar studies should be carried out at other locations, as different cities have different urban environments. The density of the city area may have different levels of impacts on the overall hygrothermal performance of the building envelope. While Toronto is a large city in Canada, it is very different comparing to other cities like Paris, New York, Hong Kong or Vancouver. Toronto has an annual rainfall of 650mm and Vancouver doubles that at 1150mm of annual rainfall. These weather conditions may have different levels of effects in the moisture analysis. Further investigation utilizing different locations should be employed.

For the second part of the analysis, more 5-minute data would be ideal to reinforce the findings in this study. The hourly data at the same time period from Environment Canada would be essential to ensure the weather data collected is within reasonable range. Different wall construction designs should be analyzed to support the results from this part of the study. However, this would require a separate study on converting the material properties to the HAM-Tools format.

To further improve this study, a test building should be constructed with the weather station beside it or in very close proximity. The test building will be wired with sensors to monitor the condition inside the building envelope. The measured data can then be compared with the simulation results, using the meteorological data from that station to verify the discoveries for the second part of the study. This could show whether the simulation can closely replicate the physical world. The same simulation could be executed with data from suburban weather station. It could reinforce the findings in the first part of the study.

Since physical measurement of meteorological data in urban environments might introduce errors due to other external variables in the surrounding environment, a CFD study at the test building should be carried out. Since the wind speed and direction are the main contributors to wind-driven rain on the building, this could support the validity of the physical measurements in such parameters. The building information (size, orientation) of the City of Toronto would be required for generating the CFD model. It may be very difficult and time consuming to gather this data as there is no central library for this information.

Appendix A CWEED CWES Data from Environment Canada

CANADIAN WEATHER
ENERGY AND ENGINEERING
DATA SETS
(CWEEDS FILES)

and

CANADIAN WEATHER
FOR ENERGY CALCULATIONS
(CWEC FILES)

UPDATED USER'S MANUAL

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prepared under the direction of
ENVIRONMENT CANADA - ATMOSPHERIC ENVIRONMENT SERVICE (AES)
[Currently known as the Meteorological Service of Canada (MSC)]
and THE NATIONAL RESEARCH COUNCIL OF CANADA

Revised on October 23, 2008

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Table of contents

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1 Introduction

1.1 What are the CWEEDS files?

The CWEEDS files are computer data sets of hourly weather conditions occurring at 145 Canadian locations for up to 48 years of record, starting as early as 1953, and ending for most locations in 2001. The primary purpose of these files is to provide long term weather records for use in urban planning, siting and design of wind and solar renewable energy systems, and design of energy efficient buildings. The general nature of the files, however, results in their widespread applicability to any sector which is weather-sensitive, such as transportation, air quality, agriculture, forestry, tourism, structural design, or general interest.

Users will likely find most value in providing the files as input into other software that processes the observational data in some way that provides more specific information germane to the user's requirements. For example, the information in the CWEEDS files can be used as input to design software that simulates building or solar energy system performance on an hourly basis. Other possibilities include the calculation of summary statistics regarding the wind energy potential at a location, or finding the means, variability, extremes, or frequency of other weather conditions or combination of conditions specifically tailored to suit an application.

There is virtually no limit to the variety of useful analyses that can be performed with the data in the CWEEDS files. The user will, however, need to provide the software which will perform apny additional analyses. Importing the data into a spreadsheet or data base program is a common way in which further analysis may be performed.

The CWEEDS CD-ROMs and disk only include compressed, formatted files of observed and estimated weather observations, utility software to uncompress and copy the files from the CD-ROMs, and documentation to explain the development, content, and format of the files.

Most of the 21 weather elements such as temperature and wind speed have been abstracted directly from the National Digital Climate Archives maintained by the Atmospheric Environment Service (AES) of Environment Canada in Downsview, Ontario. Nine of the weather elements relate to solar irradiance amounts and have been estimated for each hour for those elements and locations for which observations are not available.

The computer data sets are arranged so that one year of weather data for one location is contained in one file about one megabyte in size in the uncompressed, WYEC2 format described below. There are 48 files, for instance, totalling over 48 megabytes disk space in WYEC2 format for the full 1953-2001 CWEEDS period of record. In total, the full CWEEDS 4500 files comprise a little over 4.5 gigabytes.

A second set of files, called CWEC (Canadian Weather year for Energy Calculation), has been provided for convenience for a limited number of the locations. These files are described in Section 4.

1.2 Copyright and licensing information

PKUNZIP.EXE is licensed from PKWARE, Inc., by Environment Canada for the purpose of allowing the purchaser of the CWEEDS CD-ROMs to uncompress the CWEEDS files and make copies in the WYEC2 format on a floppy or hard disk. The remaining programs, files, and documentation on the CWEEDS CD-ROMs and floppy disk are copyrighted by Environment Canada. Normal copyright restrictions apply. Neither the compressed files, nor the uncompressed files once they have been extracted from the CD-ROM, may be reproduced, except for backup purposes, without the permission of Environment Canada.

1.3 The background of the CWEEDS files

Climatic information related to solar irradiance for building and solar energy systems was provided by the 1985 Environment Canada publication Solar Radiation

Data Analyses for Canada 1967-1976 (Volumes 1-6, Environment Canada, 1985). The increasing power, storage capacity, and cost-effectiveness of personal computers, accompanied by the sophistication of software used for building and energy system design has led to the requirement for ready access to long term hourly weather data sets. Environment Canada consulted with the user community in making decisions about the format and media used and obtained funding support from the Government of Canada Federal Panel on Energy Research and Development (PERD) to produce the CWEEDS files.

1.4 The format used for the CWEEDS files

The WYEC2 data format and units, described in Appendix A, was adopted for the CWEEDS files. WYEC2 (Weather Year for Energy Calculation, Version 2) has been devised by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) for providing WYEC2 data files for 76 cities including 5 in Canada (scheduled for release in June 1993). ASHRAE adapted the WYEC2 format from the TMY (Typical Meteorological Year) file format developed by Sandia National Laboratories in the US in the late 1970's.

The WYEC2 format is significantly different from the file format and organization of hourly data used by the AES internally in the National Digital Climate Archives. Users who have obtained hourly weather observations from AES previously should note the differences outlined below. For emphasis, the different aspects of the AES format are presented in italics.

> One record of the WYEC2 file format contains all the weather elements for one hour. Thus there is one record, comprising of the station identification, date-time stamp, and 21 observational elements and data flags, for each hour. (Note that this is different from the AES file format, in which each record contains all 24 hours of a given observational element for each day.)
>
> Hour "1" of the WYEC2 format is 1:00 AM and hour "24" is midnight, local standard time, including solar irradiance and minutes of sunshine. (In the AES format, the hours for a day range from midnight to 23:00 [11 PM]. The hours for all the AES elements are local standard time except for hourly solar irradiance amounts and minutes of sunshine which are referenced to local apparent [solar] time.)

2 Characteristics of the Weather Elements

The units, field number, data and flag positions, and the meanings of alphanumeric data and flags are presented in Appendix A. Additional clarification for some fields,such as how they were observed, estimated or modelled, or abstracted from the AES Climate Archives, appears below. In some cases, comments as to the representativeness of the observed values are provided as guidance to the user.

WBAN (field 001) number is an 5-character station identification number used in the WYEC2 format. It originated in the US and WBAN numbers were assigned to Canadian locations until recently. For locations for which no WBAN number has been officially assigned, an artificial identifier has been provided. These "unofficial WBAN" numbers all start with the characters "CAN". For those files in which the location for solar irradiance measurements is different from the location where the other hourly elements are observed (see discussion on solar irradiance, below), the WBAN number corresponds to the station at which solar irradiance is observed.

Solar global horizontal irradiance (field 102) observations are available for some of the period of record for 35 of the 143 CWEEDS locations. At 21 of the locations the solar irradiance observation site is coincident with the hourly weather observing site for part of the period of record. At the other 14 locations, the solar irradiance amounts were observed at a different AES observing site generally within 40 km of the hourly weather observing site. Appendix B provides the AES station number for the hourly weather observing site (WX.CSN) and the station number for the solar irradiance observing site (RAD.CSN).

The solar irradiance observations in the AES Climate Archives are referenced to local apparent (solar) time. The values were adjusted to local standard time for inclusion in the CWEEDS files by means of an algorithm developed by Perez (Morris et al., 1992; Perez et al., 1990).

The MAC3 model was used to estimate solar global horizontal irradiance for the 108 locations and times for which observations were unavailable (Davies et al., 1984; Environment Canada, 1985). Solar irradiance was estimated for some hours by the WON statistical model or linear interpolation when the MAC3 model failed, particularily when it could not be used due to missing cloud observations. The data flag with each field indicates whether the solar irradiance amount is observed or modelled. It is important to note that the modelling errors can be substantial for any given hour. The root-mean-square error for hourly solar global horizontal irradiance amounts are typically around 30% (Morris and Skinner, 1990). The long term average error however is 5% or lower. Thus it is unadvisable to use the modelled irradiance amounts if it is important to know the amount for a particular hour of a particular day.

A further note of caution: if the location of the solar irradiance observing site is different from the hourly weather observing site, then any given hourly irradiance amount may not be consistent with the cloud amount or opacity observations.

Direct normal irradiance (field 103) was estimated from the solar global horizontal irradiance using the MAC3 model for locations and hours for which observations of global solar horizontal irradiance were unavailable. An algorithm developed by Perez (Perez et al., 1990 and 1991, Morris et al., 1992) was used if the hourly observed global solar horizontal irradiance was available.

Diffuse horizontal irradiance (field 104) is observed at 5 locations. For other locations this element was estimated by the MAC3 model when the observations of the global solar horizontal irradiance was unavailable. An algorithm developed by Perez (Perez et al., 1991, Morris et al., 1992) was used if the hourly observed global solar horizontal irradiance was available.

Global horizontal illuminance (field 105), direct normal illuminance (field 106), and diffuse horizontal illuminance (field 107) were all modelled using an algorithm developed by McCluney (McCluney, 1984; McArthur, 1990; Morris and Skinner, 1990).

No estimates are available of the zenith illuminance (field 108). This field is always missing.

Minutes of sunshine (field 110), where observations are available are abstracted from the AES Climate Archives with adjustments made to convert the time base from local apparent (solar) time to local standard time. No values are estimated if observations are unavailable.

The units of Wind speed (field 209) observations are 0.1 m/s. Wind speed is provided in km/h in the AES Climate Archives. The observation is an estimate of the one-minute mean wind speed on each hour for the years before 1985 and a two-minute mean wind speed thereafter. Care is required in assuming wind speed and direction representativeness at nearby locations. Wind speed is sensitive to the height above ground and exposure of the anemometer.

Most of the anemometers at the locations in the CWEEDS files are mounted at 10m above ground in a flat, open exposure such as at airport locations. AES anemometers have not always been mounted at 10m above ground, especially before 1975. Information in the file AHISTORY.TXT provides a copy of anemometer height above ground for users interested in adjusting the wind speed to another height above ground. In general, significant caution is advisable in using wind speeds before 1975. Not only were the anemometers installed at heights other than 10m above ground more frequently before 1975 than after, but the station history files are often ambiguous as to anemometer height and location. The information provided in AHISTORY.TXT for some locations is an interpretation of conflicting or incomplete information in the AES station information files. Other non-standard anemometer locations, such as on top of aircraft hangers or the air traffic control tower, also occurred at some locations, mainly before 1975.

Anemometer exposure is also problematic. Most anemometers are located in a flat, open exposure, especially at major airports. However, some anemometers are located in more exposed locations, such as Cape St. James, BC, which is on an exposed headland on the open coast. Observed wind speeds are not representative of less windy, inland locations, or even other coastal sites not on an exposed headland. Other locations, such as Fort Simpson, NWT, are sheltered by trees, and not representative of nearby, more exposed locations. In general, wind speeds form observing sites are only representative of other nearby sites if the height above ground and exposures are similar.

Snow cover (field 212) is derived from daily snow depth observations. It is provided as a guide to estimating the surface albedo (reflectance) for calculations involving solar irradiance or natural illuminance on non-horizontal surfaces. Typical albedo values range from 0.2 for grass or gravel surfaces to 0.6 for snow surfaces. Freshly fallen snow may have an albedo value as high as 0.8.

3 How to Access and Use the CWEEDS Files

CD-ROM disk 1 provides CWEEDS files for Ontario, Quebec, Nova Scotia, New Brunswick, Prince Edward Island, and Newfoundland. CD-ROM 2 contains the files for BC, Alberta, Saskatchewan, Manitoba, the Yukon and the Northwest Territories. The files for each province or territory are located in subdirectory named accordingly. The files for each location are located in a subdirectory named with the WBAN number. There is one file for each year for each location.

The names of the provincial and territorial subdirectories are ONT, QUE, NB, NS, PEI, NFLD, BC, ALTA, SASK, MAN, YT, and NWT. The format of the names of the location subdirectories is WxxxxxW, where xxxxx is the WBAN number of the station. The names of the CWEEDS files themselves are WxxxxxW.Ynn, where xxxxx is the WBAN number and nn is the last two characters in the year. Thus BC\W94116W\W94116W.Y89 is the file for Penticton, BC, for 1989.

The files on the CD-ROM have been compressed using WINZIP.

4 Canadian Weather for Energy Calculations (CWEC) Files

The Canadian Weather for Energy Calculations (CWEC) files have been developped under the auspices of the National Research Council of Canada. They are derived using statistical criteria from long-term series of CWEEDS files.

The CWEC files are created by concatenating twelve Typical Meteorological Months selected from a database of, in most cases, 30 years of CWEEDS data. The method is similar to TMY procedure developed in the eighties by Sandia Laboratories. The months are chosen by statistically comparing individual monthly with long-term monthly means for daily total global radiation, mean, minimum and maximum dry bulb temperature, mean, minimum and maximum dew point temperature, and mean and maximum wind speed. The composite index used to select the most 'typical' months uses the following weights (in %)

Parameter	Dry Bulb Max	Dry Bulb Min	Dry Bulb Mean	Dew Point Max	Dew Point Min	Dew Point Mean	Wind Speed Max	Wind Speed Mean	Daily Solar Rad.
Weight	5	5	30	2.5	2.5	5	5	5	40

Additional consideration is given, in the selection process, to the statistics and persistence structures of the daily mean dry bulb temperature and daily total radiation. A complete description of the procedure used can be found in: D.L. Siurna, L.J. D'Andrea, K.G.T. Hollands, A Canadian Representative Meteorological Year for Solar System Simulation, Proceedings of the 10th annual conference of the Solar Energy Society of Canada (SESCI '84), August 2-6, 1984, Calgary, Alberta, Canada.

In the CWEC files, no missing values will be found in the following fields: extraterrestrial irradiance (101), global horizontal irradiance (102), direct normal irradiance (103), diffuse horizontal irradiance (104), weather (204), station pressure (205), dry bulb temperature (206), dew point temperature (207), wind direction (208), wind speed (209), total sky cover (210), opaque sky cover (211), snow cover (212).

The list of all available CWEC files is given in Appendix D. The years from which the CWEC typical months were chosen are listed in Appendix E.

5 Acknowledgements

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APPENDIX A - WYEC2 Format

Weather files in WYEC2 format consist of 8760 identical fixed format records (8784 records for leap years), one for each hour of each day of the year. Each record is 116 characters in length and is organized according to the table below. The flags associated with the data are described in the next section of the document.

All WYEC2 values are for Local Standard Time. Irradiance and illuminance fields contain data integrated over the hour, meteorological fields contain observations made at the end of the hour. For example, hour 12 contains irradiance/illuminance integrated from 11-12 and meteorological observations made at 12.

A file containing statistics about the WYEC2 file is assembled (number of missing records for each element and each year, yearly max and mean values of each element). The name of the file is xxxxx.STT, where xxxxx is the WBAN Station Number.

A file containing statistics about the radiation data is assembled. For this file

the year is divided into four periods centered around March 21 ("spring"), June 21
("summer"), September 21 ("autumn") and December 21 ("winter"). For each trimester
the max and mean of global irradiance, diffuse irradiance and direct irradiance are computed for each hour of the day. The file contains a summary with five columns: element, trimester, hour, max value and min value. The name of the file is
xxxxx.STR, where xxxxx is the WBAN Station Number. The easiest way to exploit the the information contained in this file is to retrieve it in a spreadsheet and plot
the various daily profiles. A visual inspection will then reveal if there is any major problem with the radiation data that were modelled.

Important note: CWEC files have always 8760 records. If the selected February month is from a leap year, it is truncated to 28 days.

Field Number	Data Positions	Flag Position	Data element and description Comments and warnings
001	001-005	--	WBAN station identification number Unique alpha-numerical five-character string to identify each station.
002	006-006	--	File source code A= AES Digital Archive of Canadian Climatological Data identified by element. B= Canadian Reference Year for Energy Calculations (CWEC) file derived from a compilation of the above.
003	007-016	--	Time, Yr Mo Day Hr (Yr 4 chars, Mo Day Hr 2 chars each) Mo is 1 to 12. Day is 1 to month length (28, 29, 30 or 31). Hr is 1 to 24. 1984051203 = 12 May 1984, 3 o'clock.
101	017-020	--	Extraterrestrial irradiance, kJ/m2 Amount of solar energy received at top of atmosphere during solar hour ending at time indicated in field 003, based on solar constant of 1367 W/m2. Nighttime values are shown as 0.
102	021-024	025-026	Global horizontal irradiance, kJ/m2 Total of direct and diffuse radiant energy received on a horizontal surface by a pyranometer during the hour ending at the time indicated in

			field 003. The values given in this field have been interpolated from Local Apparent Time to Local Standard Time but this is not reflected in the flags ("observed" values with a flag equal to blank are actually interpolated values).
103	027-030	031-032	Direct normal irradiance, kJ/m2 Portion of the radiant energy received by a pyranometer directly from the sun during the hour ending at the time indicated in field 003.
104	033-036	037-038	Diffuse horizontal irradiance, kJ/m2 Portion of the radiant energy received on a horizontal surface by a pyranometer indirectly from the sky during the hour ending at the time indicated in field 003. The values given in this field have been interpolated from Local Apparent Time to Local Standard Time but this is not reflected in the flags ("observed" values with a flag equal to blank are actually interpolated values).
105	039-042	043	Global horizontal illuminance, 100 lux 1056 = 105.6 klux
106	044-047	048	Direct normal illuminance, 100 lux 1056 = 105.6 klux
107	049-052	053	Diffuse horizontal illuminance, 100 lux 1056 = 105.6 klux
108	054-057	058	Zenith luminance, 100 Cd/m2 Not available, always missing.
110	059-060	061	Minutes of sunshine, 0-60 minutes The values given in this field have been interpolated from Local Apparent Time to Local Standard Time but this is not reflected in the flags ("observed" values with a flag equal to blank are actually interpolated values).
201	062-065	066	Ceiling height, 10 m 0000-3000 = 0 to 30,000 m 7777 = unlimited; clear
202	067-070	071	Sky condition

			Coded by layer in ascending order; four layers are described; if less than four layers are present the remaining positions are coded 0. The code for each layer is: 0 = Clear (less than 0.1 cover) 1 = Thin scattered 2 = Opaque scattered (0.1-0.5 cover) 3 = Thin broken 4 = Opaque broken (0.6-0.9 cover) 5 = Thin overcast 6 = Opaque overcast (1.0 cover) 7 = Obscuration 8 = Partial obscuration The flag is left as '9' only if all four layers are missing. It is written as 'E' if at least one of the layer has the flag 'E'.
203	072-075	076	Visibility, 100 m 120 = 12 km
204	077-084	085	Weather Eight single digit codes as explained below.
204a	077		Occurrence of thunderstorm, tornado or squall. 0 = None 1 = Thunderstorm - lightning and thunder. Wind gusts less than 50 knots, and hail, if any, less than 3/4 inch diameter. 2 = Heavy or severe thunderstorm - frequent intense lightning and thunder. Wind gusts 50 knots or greater and hail, if any, 3/4 inch or greater diameter. 3 = Report of tornado, funnel cloud or waterspout. If several phenomena occur simultaneously, the highest WYEC2 value is reported.
204b	078		Occurrence of rain, rain showers or freezing rain 0 = None 1 = Light rain 2 = Moderate rain 3 = Heavy rain 4 = Light rain showers 5 = Moderate rain showers

6 = Heavy rain showers
7 = Light freezing rain
8 = Moderate or heavy freezing rain

If several phenomena occur simultaneously, the highest WYEC2 value is reported.

204c	079	Occurrence of drizzle, freezing drizzle

0 = None
1 = Light drizzle
2 = Moderate drizzle
3 = Heavy drizzle
4 = Light freezing drizzle
5 = Moderate freezing drizzle
6 = Heavy freezing drizzle

If several phenomena occur simultaneously, the highest WYEC2 value is reported.

204d	080	Occurrence of snow, snow pellets or ice crystals

0 = None
1 = Light snow
2 = Moderate snow
3 = Heavy snow
4 = Light snow pellets
5 = Moderate snow pellets
6 = Heavy snow pellets
7 = Light ice crystals
8 = Moderate ice crystals

If several phenomena occur simultaneously, the highest WYEC2 value is reported, except for the values 1,2,3 which are reported before any other.

204e	081	Occurrence of snow showers or snow grains

0 = None
1 = Light snow showers
2 = Moderate snow showers
3 = Heavy snow showers
4 = Light snow grains
5 = Moderate snow grains
6 = Heavy snow grains

If several phenomena occur simultaneously, the highest WYEC2 value is reported, except for the values 1,2,3 which are the first ones to be reported.

204f	082		Occurrence of ice pellets, ice pellet showers, or hail 0 = None 1 = Light ice pellets 2 = Moderate ice pellets 3 = Heavy ice pellets 4 = Light hail 5 = Moderate hail 6 = Heavy hail 7 = Light ice pellet showers 8 = Moderate or heavy ice pellet showers If several phenomena occur simultaneously, the highest WYEC2 value is reported.
204g	083		Occurrence of fog, blowing dust or blowing sand 0 = None 1 = Fog 2 = Ice fog 4 = Blowing dust 5 = Blowing sand If several phenomena occur simultaneously, the highest WYEC2 value is reported.
204h	084		Occurrence of smoke, haze, dust, blowing snow or blowing spray 0 = None 1 = Smoke 2 = Haze 3 = Smoke and haze 4 = Dust 5 = Blowing snow If several phenomena occur simultaneously, the highest WYEC2 value is reported.
205	086-090	091	Station pressure, 10 Pa Pressure at station level 10150 = 101.5 kPa
206	092-095	096	Dry bulb temperature, 0.1 °C -152 = -15.2 °C

207	097-100	101	Dew point temperature, 0.1 °C -152 = -15.2 °C
208	102-104	105	Wind direction, 0-359 degrees 0 = north
209	106-109	110	Wind speed, 0.1 m/s Wind speed and wind direction both 0 indicates calm. 350 = 35.0 m/s
210	111-112	113	Total sky cover, 0-10 in tenths Amount of celestial dome in tenths covered by clouds or obscuring phenomena.
211	114-115	116	Opaque sky cover, 0-10 in tenths Amount of celestial dome in tenths covered by clouds or obscuration through which the sky and/or higher cloud layers cannot be seen.
212	117	118	Snow cover 0 = no snow or a trace of snow 1 = indicates more than a trace on snow on the ground

Flags

Flag characters indicate if the associated value is missing, was estimated or modelled or actually observed. Some fields have no flag, others have 1 or 2 character flags as follows:

Field	Flag type / comment
001-003	None (record identification fields)
101	None (calculated extraterrestrial irradiance is always present)
102-104	2 character (irradiance values)
105-212	1 character (all remaining fields)

1. One character flags. The following flags are used:

blank — Value was observed (that is, not derived with a model and not altered).
Exception: irradiance and minutes of sunshine flags are written as blank though they are interpolated to change the

time base from local apparent to local standard time.

A Value has been algorithmically adjusted (e.g. some values in Canadian Reference Years are smoothed at the beginning and end of months).

E Value was missing and has been replaced by a hand estimate.

I Value was missing and has been replaced with one derived by interpolation from neighboring observations.

M Value was missing and has been replaced with one derived with a model (model used depends on element).

Q Value is derived from other values (e.g. illuminance data which are not observed).

9 Value is missing; data positions contain 9s as well.

2. Two character flags for radiation values (on WYEC2 irradiance fields 102, 103 and 104), are a 1 character flag (as defined above) followed by a blank.

APPENDIX B - List of locations provided on the AES CWEEDS CD-ROM's.

STATION is the name of the AES station corresponding to the RAD.CSN.

RAD.CSN is the Canadian Station Number, an identification number assigned and used by AES, of the site where solar radiation is observed (it is not always the same site as where the other hourly observations are taken).

WX.CSN is the Canadian Station Number, an identification number assigned and used by AES, of the site where the hourly observations other that solar irradiance and minutes of sunshine are taken.

LAT is the latitude (°) of the site corresponding to RAD.CSN.

LONG is the longitude (°) of the site corresponding to RAD.CSN.

MLONG is the prime meridian (°) upon which the time zone is based. The difference in hours between Local Standard Time (LST) and Coordinated Universal Time (CUT) can obtained by the calculation LST = CUT - MLONG/15. For instance, if MLONG is 75°, and CUT is 11:00 then LST is 06:00.

SUN indicates the source of the minutes of sunshine, if available. W indicates that the observations are from the site corresponding to WX.CSN. R indicates RAD.CSN. A blank means no observations of minutes of bright sunshine are available.

RAD indicates by an R whether solar irradiance observations are available. A blank indicates no observations and all the irradiance fields are modelled.

FY is the last two digits of the first year provided on the CWEEDS

CD-ROM (i.e. 53 means 1953).

LY is the last two digits of the last year on the CD-ROM.

STATION	WBAN	RAD.CSN	WX.CSN	LAT	LONG	MLONG	SUN	RAD	FY	LY
ALBERTA										
CALGARY INT'L. A	25110	3031093	3031093	51.10	114.02	105.00	W		53	05
COLD LAKE A	25129	3081680	3081680	54.42	110.28	105.00	W		54	05
CORONATION	25113	3011880	3011880	52.10	111.45	105.00	W		53	94
COWLEY A	CAN43	3031920	3031920	49.63	114.08	105.00			53	59
EDMONTON INT'L. A	25142	3012205	3012205	53.32	113.58	105.00	W		61	05
EDMONTON MUNICIPAL A	CAN98	3012208	3012208	53.57	113.52	105.00	W		53	04
EDMONTON NAMAO	CANA6	3012210	3012210	53.67	113.47	105.00			56	94
EDMONTON STONY PLAIN	25145	301222F	3012205	53.55	114.10	105.00	W	R	61	05
EDSON	CAN46	3062241	3062241	53.58	116.42	105.00	W		60	69
EDSON A	CAN47	3062244	3062244	53.58	116.47	105.00	W		71	90
FORT CHIPEWYAN A	CAN52	3072658	3072658	55.35	114.98	105.00			68	78
FORT MCMURRAY A	25105	3062693	3062693	56.65	111.22	105.00	W		53	05
GRANDE PRAIRIE A	25115	3072920	3072920	55.18	118.88	105.00	W		53	05
HIGH LEVEL A	CAN53	3073146	3073146	58.62	117.16	105.00	W		71	05
LAC LA BICHE	CAN48	3063680	3063680	54.77	111.97	105.00			53	57
LAC LA BICHE AUT	CAN49	3063685	3063685	54.77	112.02	105.00			59	70
LETHBRIDGE A	94108	3033880	3033880	49.63	112.80	105.00	W		53	05
LLOYDMINSTER	CAN42	3013961	3013961	53.31	110.07	105.00			83	05
MEDICINE HAT A	25118	3034480	3034480	50.02	110.72	105.00	W		53	05
PEACE RIVER A	25101	3075040	3075040	56.23	117.43	105.00			59	05
PINCHER CREEK	CAN44	3035201	3035201	49.50	113.95	105.00			61	73
RED DEER A	25119	3025480	3025480	52.18	113.90	105.00			53	05
ROCKY MTN. HOUSE	CAN05	3015520	3015520	52.38	114.92	105.00			53	77
SLAVE LAKE	CAN50	3066001	3066001	55.30	114.78	105.00			72	91
SPRINGBANK A	CAN45	303F0PP	303FOPP	51.10	114.37	105.00			89	01
VERMILION A	CAN04	3016800	3016800	53.35	110.83	105.00			53	81
WAGNER	CAN51	3066920	3066920	55.35	114.98	105.00			53	69
WHITECOURT	CAN03	3067370	3067370	54.13	115.67	105.00			53	77
BRITISH COLUMBIA										
ABBOTSFORD A	24288	1100030	1100030	49.02	122.37	120.00	W		53	05
BEATTON RIVER A	CAN26	1180750	1180750	57.38	121.28	120.00			53	66
CAPE ST. JAMES	25342	1051350	1051350	51.93	131.02	120.00	R	R	57	91
CASTLEGAR A	94110	1141455	1141455	49.30	117.63	120.00	W		54	05
COMOX A	24292	1021830	1021830	49.72	124.90	120.00	W		53	05
CRANBROOK A	94157	1152102	1152102	49.60	115.78	120.00	W		70	05
FORT NELSON A	25218	1192940	1192940	58.83	122.58	120.00	R	R	53	05
FORT ST. JOHN A	25231	1183000	1183000	56.23	120.73	120.00	W		53	05
KAMLOOPS A	25220	1163780	1163780	50.70	120.45	120.00	W		53	05
KELOWNA A	CAN22	1123970	1123970	49.96	119.38	120.00	W		70	76
KIMBERLEY A	CAN25	1154200	1154200	49.73	115.78	120.00			53	68
LYTTON	CAN21	1114740	1114740	50.23	121.50	120.00	W		53	69
NANAIMO A	CAN20	1025370	1025370	49.05	123.87	120.00	W		54	67
OLD GLORY MOUNTAIN	CAN97	1145730	1145730	49.15	117.92	120.00			55	67
PENTICTON A	94116	1126150	1126150	49.47	119.60	120.00	W		53	05
PORT HARDY A	25223	1026270	1026270	50.68	127.37	120.00	R	R	53	05

PRINCE GEORGE A	25206	1096450	1096450	53.88	122.67	120.00	R	R	53	05
PRINCE RUPERT A	25353	1066481	1066481	54.30	130.43	120.00	W		61	05
PRINCETON A	CAN23	1126510	1126510	49.47	120.51	120.00	W		53	68
QUESNEL A	25224	1096630	1096630	53.03	122.52	120.00			53	05
SANDSPIT A	25346	1057050	1057050	53.25	131.82	120.00	R	R	53	05
SMITHERS A	25225	1077500	1077500	54.82	127.18	120.00	W		53	05
SMITH RIVER A	CAN27	1197530	1197530	59.90	126.43	120.00			53	68
SPRING ISLAND	CAN09	1037650	1037650	50.00	127.42	120.00			53	79
SUMMERLAND CDA	94152	1127800	1126150	49.57	119.65	120.00	R	R	53	05
TERRACE A	25229	1068130	1068130	54.47	128.58	120.00	W		55	05
TOFINO A	94234	1038205	1038205	49.08	125.77	120.00	W		60	05
VANCOUVER INT'L.	24287	1108447	1108447	49.25	123.25	120.00	W		53	05
VANCOUVER UBC	94238	1108487	1108447	49.25	123.25	120.00	R	R	53	05
VICTORIA GONZALES HTS	CAN18	1018610	1018610	48.42	123.32	120.00	W		53	67
VICTORIA INT'L. A	24297	1018620	1018620	48.65	123.43	120.00	W		53	05
VICTORIA MARINE	CAN19	1018642	1018642	48.65	123.43	120.00			70	83
WILLIAMS LAKE A	25247	1098940	1098940	52.18	122.07	120.00	W		61	05

MANITOBA

BRANDON A	14997	5010480	5010480	49.92	99.95	90.00	W		59	05
CHURCHILL A	15901	5060600	5060600	58.75	94.07	90.00	R	R	53	05
DAUPHIN A	25009	5040680	5040680	51.10	100.05	90.00	W		55	05
GIMLI	CAN96	5031038	5031038	50.63	97.02	90.00	W		72	90
GIMLI A	CAN63	5031040	5031040	50.63	97.05	90.00			53	71
ISLAND LAKE	CAN60	5061376	5061376	53.85	94.65	90.00			87	05
LYNN LAKE	CAN61	5061646	5061646	53.86	101.08	90.00	W		70	04
NORWAY HOUSE	CAN62	506B047	506B047	53.95	97.85	90.00			75	04
PORTAGE LA PRAIRIE A	94912	5012320	5012320	49.90	98.27	90.00			53	05
RIVERS	CAN59	5012440	5012440	50.02	100.32	90.00	W		53	69
THE PAS A	25004	5052880	5052880	53.97	101.10	90.00	R	R	53	05
THOMPSON A	15919	5062922	5062922	55.80	97.87	90.00	W		68	05
WINNIPEG INT'L. A	14996	5023222	5023222	49.90	97.23	90.00	R	R	53	05

NEW BRUNSWICK

CAMPBELLTON	CAN76	8100700	8100700	48.00	66.67	60.00	W		53	66
CHARLO A	14683	8100880	8100880	48.00	66.33	60.00	W		67	90
FREDERICTON CDA	14670	8101600	8101500	45.92	66.62	60.00	R	R	53	05
MIRAMICHI A	14631	8101000	8101000	47.02	65.45	60.00	W		53	05
MONCTON A	14625	8103200	8103200	46.12	64.68	60.00	W		53	05
SAINT JOHN A	14643	8104900	8104900	45.32	65.88	60.00	W		53	05
ST LEONARD	CAN78	8104928	8104928	47.16	67.83	60.00	W		86	94

NEWFOUNDLAND

ARGENTIA A	CAN85	8400100	8400100	47.30	54.00	60.00			53	69
BATTLE HARBOUR	CAN06	8500398	8500398	52.25	55.60	60.00			57	83
BONAVISTA	14522	8400600	8400600	48.70	53.08	60.00			60	94
BUCHANS A	CAN87	8400700	8400700	48.85	56.83	60.00			53	64
BURGEO	CAN88	8400798	8400798	47.62	57.62	60.00	W		67	90
CAPE HARRISON	CAN95	8500900	8500900	54.77	58.45	60.00			53	59
CARTWRIGHT	15503	8501100	8501100	53.70	57.03	60.00	W		64	05
CHURCHILL FALLS A	CAN83	8501132	8501132	53.55	64.10	60.00	W		69	92
COMFORT COVE	CAN89	8400798	8400798	49.27	54.88	60.00			67	82
DANIELS HARBOUR	15504	8401400	8401400	50.23	57.58	60.00	W		66	87
DEER LAKE A	14523	8401501	8401501	49.22	57.40	60.00			66	05

GANDER INT'L. A	14509	8401700	8401700	48.95	54.57	60.00	W		53	05
GOOSE UA	15601	8501910	8501900	53.32	60.37	60.00	W	R	53	05
HOPEDALE	15642	8502400	8502400	55.45	60.23	60.00			64	83
PORT AUX BASQUES	CAN90	8402975	8402975	47.57	59.15	60.00			67	91
ST. ANDREWS	CAN91	8403300	8403300	47.77	59.33	60.00			53	65
ST. ANTHONY	CAN92	8403400	8403400	51.37	55.58	60.00			53	65
ST. JOHN'S A	14506	8403506	8403506	47.62	52.75	60.00	W		53	05
ST. JOHN'S WEST CDA	14521	8403600	8403506	47.52	52.78	60.00	R	R	53	05
STEPHENVILLE A	14503	8403800	8403800	48.53	58.55	60.00	W		54	05
TWILLINGATE	CAN94	8404000	8404000	49.67	54.82	60.00			54	66
WABUSH LAKE A	15628	8504175	8504175	52.93	66.87	60.00	W		61	05

NORTH-WEST TERRITORIES

CAPE PARRY A	27202	2200675	2200675	70.17	124.68	105.00			57	05
FORT RELIANCE	CAN32	2201900	2201900	62.72	109.17	105.00			69	90
FORT RESOLUTION A	CAN33	2202000	2202000	61.28	113.69	105.00			60	69
FORT SIMPSON	CAN34	2202100	2202100	61.87	121.35	120.00	W		56	62
FORT SIMPSON A	CAN35	2202101	2202101	61.76	121.24	120.00	W		64	05
FORT SMITH A	26102	2202200	2202200	60.02	111.97	105.00	W		53	05
HAY RIVER A	CAN36	2202400	2202400	60.84	115.78	105.00			53	05
INUVIK UA	22258	2202582	2202570	68.32	133.53	105.00	R	R	58	05
NORMAN WELLS A	26202	2202800	2202800	65.28	126.80	105.00	R	R	56	05
SACHS HARBOUR A	CAN41	2503650	2503650	72.00	125.27	105.00			71	76
YELLOWKNIFE A	26110	2204100	2204100	62.47	114.45	105.00	W		53	05

NOVA SCOTIA

COPPER LAKE	CAN79	8201100	8201100	45.38	61.97	60.00	W		53	61
DEBERT	CAN80	8201400	8201400	45.42	63.45	60.00			53	60
EDDY POINT	CAN81	8201716	8201716	45.52	61.25	60.00	W		72	84
GREENWOOD A	14636	8202000	8202000	44.98	64.92	60.00			53	05
HALIFAX	CAN82	8202200	8202200	44.65	63.57	60.00	W		53	62
HALIFAX INT'L. A	14673	8202250	8202250	44.88	63.52	60.00			61	05
SABLE ISLAND	14642	8204700	8204700	43.93	60.02	60.00	R	R	56	91
SHEARWATER A	14633	8205090	8205090	44.63	63.50	60.00	W		53	05
SHELBURNE	CAN84	8205126	8205126	43.72	65.25	60.00	W		82	86
SYDNEY A	14646	8205700	8205700	46.17	60.05	60.00	W		53	05
TRURO	14675	8205990	8205990	45.37	63.27	60.00	W		61	76
YARMOUTH A	14647	8206500	8206500	43.83	66.08	60.00	W		53	05

NUNAVUT

ALERT	CANA4	2400300	2400300	82.50	62.33	60.00			64	05
BAKER LAKE	16903	2300500	2300500	64.30	96.00	90.00	R	R	63	05
CAMBRIDGE BAY A	26005	2400600	2400600	69.10	105.12	105.00	R	R	56	05
CAPE DYER	CAN39	2400654	2400654	66.58	61.62	60.00			60	89
CHESTERFIELD	16914	2300700	2300700	63.33	90.72	90.00			63	67
CLYDE	CAN93	2400800	2400800	70.49	68.52	75.00			85	93
COPPERMINE	CAN69	2300900	2300900	67.83	115.14	105.00	W		70	77
CORAL HARBOUR A	16801	2301000	2301000	64.20	83.37	75.00	R	R	56	05
ENNADAI	CAN37	2301100	2301100	61.13	100.90	90.00			56	69
EUREKA	CANA5	2401200	2401200	80.00	85.93	75.00	W	R	82	05
HALL BEACH A	16895	2402350	2402350	68.78	81.25	75.00		R	59	05
ISACHSEN	CANA7	2402600	2402600	78.78	103.53	105.00			70	78
IQALUIT A	16603	2402590	2402590	63.75	68.55	75.00	W		53	05

KUGLUKTUK A	CAN86	2300902	2300902	67.82	115.14	105.00	W		80	05
RANKIN INLET A	CAN38	2303401	2303401	62.82	92.10	90.00			81	05
REA POINT	CAN40	2403450	2403450	75.37	105.72	105.00			72	76
RESOLUTE	17901	2403500	2403500	74.72	94.98	90.00	R	R	63	05

ONTARIO

ARMSTRONG A	CAN08	6040325	6040325	50.28	88.90	75.00	W		53	67
ATIKOKAN	94932	6020379	6020379	48.75	91.62	75.00	W		67	88
BIG TROUT LAKE	15806	6010738	6010738	53.83	89.87	90.00	R	R	67	90
BUTTONVILLE	CAN17	615HMAK	615HMAK	43.87	79.37	75.00			87	05
CHAPLEAU	CAN67	6061358	6061358	47.83	83.43	75.00			66	75
EARLTON A	94797	6072225	6072225	47.70	79.85	75.00			53	05
GERALDTON	CAN10	6042715	6042715	49.70	86.95	75.00			68	76
GORE BAY A	94803	6092925	6092925	45.88	82.57	75.00			55	05
GRAHAM A	CAN64	6042975	6042975	49.27	90.58	75.00			53	66
HAMILTON A	04797	6153194	6153194	43.25	79.93	75.00			70	05
KAPUSKASING A	14899	6073975	6073975	49.42	82.47	75.00		R	53	05
KENORA A	14999	6034075	6034075	49.80	94.37	90.00			53	05
KINGSTON A	CAN15	6104146	6404146	44.22	76.60	75.00	W		70	94
KILLALOE	CAN68	6104125	6104215	45.57	77.42	75.00			53	71
LONDON A	94805	6144475	6144475	43.03	81.15	75.00	W		55	05
MOOSONEE	CANA1	6075425	6075425	51.27	80.65	75.00	W		57	93
MOUNT FOREST	94857	6145503	6145503	43.98	80.75	75.00	W		62	86
MUSKOKA A	04704	6115525	6115525	44.97	79.30	75.00			55	05
NAKINA A	CAN65	6045550	6045550	50.18	86.70	75.00			53	66
NORTH BAY A	04705	6085700	6085700	46.37	79.42	75.00	W		53	05
OTTAWA CDA	CAN14	6105976	6106000	45.38	75.72	75.00	R	R	53	05
OTTAWA NRC	04772	6106090	6106000	45.45	75.62	75.00	W	R	53	05
PETAWAWA A	CAN70	6106398	6106398	45.95	77.32	75.00			72	92
PETERBOROUGH A	CAN99	6166418	6166418	44.23	78.35	75.00			96	04
SAULT STE. MARIE A	94842	6057592	6057592	46.48	84.50	75.00	W		62	05
SIMCOE	94858	6137730	6137730	42.85	80.27	75.00			62	76
SIOUX LOOKOUT A	15909	6037775	6037775	50.12	91.90	90.00			53	05
ST. CATHERINES A	CAN16	6137287	6137287	43.20	79.17	75.00			72	05
STIRLING	CAN71	6158050	6158050	44.32	77.63	75.00			53	68
SUDBURY A	94828	6068150	6068150	46.62	80.80	75.00	W		54	05
THUNDER BAY A	94804	6048261	6048261	48.37	89.32	75.00	W		53	05
TIMMINS A	94831	6078285	6078285	48.57	81.37	75.00			55	05
TORONTO	04714	6158350	6158733	43.67	79.38	75.00	R	R	55	05
TORONTO DOWNSVIEW A	CAN72	6158443	6158443	43.75	79.48	75.00			58	64
TORONTO ISLAND A	CANA2	6158665	6158665	43.63	79.40	75.00			61	05
TORONTO MET RES STN	04795	6158740	6158733	43.80	79.55	75.00	R	R	53	05
TORONTO PEARSON INT'L	94791	6158733	6158733	43.67	79.63	75.00			53	05
TRENTON A	04715	6158875	6158875	44.12	77.53	75.00			53	05
WHITE RIVER	CAN66	6059475	6059475	48.60	85.28	75.00	W		53	75
WIARTON A	94809	6119500	6119500	44.75	81.10	75.00	W		53	05
WINDSOR A	94810	6139525	6139525	42.27	82.97	75.00			53	05

PRINCE EDWARD ISLAND

CHARLOTTETOWN CDA	14688	8300400	8300300	46.25	63.13	60.00	R	R	53	05
SUMMERSIDE A	14645	8300700	8300700	46.43	63.83	60.00	W		53	90

QUEBEC

BAGOTVILLE A	94795	7060400	7060400	48.33	71.00	75.00			53	05

BAIE COMEAU A	14627	7040440	7040440	49.13	68.20	75.00	W		65	04
CHIBOUGAMAU A	CAN74	7091401	7091401	49.82	74.42	75.00	W		72	81
CHIBOUGAMAU CHAPAIS	CAN75	7091404	7091404	49.77	74.53	75.00	W		83	91
GASPE A	CAN73	7052605	7052605	48.78	64.48	60.00	W		77	05
GRINDSTONE ISLAND	CAN13	7052960	7052960	47.38	61.87	60.00	W		69	82
KUUJJUARAPIK A	15701	7103536	7103536	55.28	77.77	75.00	W		53	05
KUUJUAQ A	15605	7113534	7113534	58.10	68.42	75.00	R	R	55	05
LA GRANDE IV A	CANA8	7093GJ3	7093GJ3	53.75	73.67	75.00	W		86	91
LA GRANDE RIVIERE A	73715	7093715	7093715	53.63	77.70	75.00	W		76	05
LAKE EON A	CAN07	7043740	7043740	51.87	63.28	75.00			56	76
MONT JOLI A	14639	7055120	7055120	48.60	68.20	75.00	W		53	05
MONTREAL INT'L. A	94792	7025250	7025250	45.47	73.75	75.00	R	R	53	05
MONTREAL JEAN BREBEUF	04770	7025260	7025250	45.50	73.62	75.00	R/W	R	53	05
MONTREAL MIRABEL A	75290	7035290	7035290	45.68	74.03	75.00	W		76	05
NITCHEQUON	15703	7095480	7095480	53.20	70.90	75.00	R	R	59	85
QUEBEC A	04708	7016294	7016294	46.80	71.38	75.00	W		53	05
RIVIERE DU LOUP	CAN12	7056615	7056615	47.80	69.55	75.00			66	79
ROBERVAL A	04752	7066685	7066685	48.52	72.27	75.00	W		58	05
SCHEFFERVILLE A	15619	7117825	7117825	54.80	66.82	75.00	R	R	62	93
SEPT-ILES UA	77912	7047912	7047910	50.22	66.25	75.00	R	R	53	05
SHERBROOKE A	04785	7028124	7028124	45.43	71.68	75.00	W		63	94
ST. HUBERT A	04712	7027320	7027320	45.52	73.42	75.00			53	05
STE. AGATHE DES MONTS	04790	7036762	7036762	46.05	74.28	75.00	W		67	91
VAL D'OR A	04730	7098600	7098600	48.05	77.78	75.00	W		55	05

NOTE: MONTREAL JEAN BREBEUF SUN = R UNTIL 1969, SUN = W FROM 1970

SASKATCHEWAN

BROADVIEW	25030	4010879	4010879	50.38	102.55	90.00	W		65	05
COLLINS BAY	CANA3	4061630	4061630	58.17	103.70	105.00			72	90
ESTEVAN A	24092	4012400	4012400	49.07	103.00	90.00	W		53	05
HUDSON BAY	CAN57	4083320	4083320	52.87	102.40	90.00			54	73
KINDERSLEY	CAN54	4043900	4043900	51.52	109.48	90.00	W		86	05
LA RONGE	CAN55	4064150	4064150	55.15	105.27	90.00			77	05
MOOSE JAW A	25018	4015320	4015320	50.33	105.55	90.00	W		54	05
NORTH BATTLEFORD A	25012	4045600	4045600	52.77	108.25	90.00	W		53	05
PRINCE ALBERT A	25013	4056240	4056240	53.22	105.68	90.00	W		53	05
REGINA A	25005	4016560	4016560	50.43	104.67	90.00	W		53	05
SASKATOON	25015	4057120	4057120	52.17	106.68	90.00			53	05
STONY RAPIDS A	CAN56	4067PR5	4067PR5	59.25	105.83	90.00			87	05
SWIFT CURRENT CDA	25028	4028060	4028040	50.27	107.73	105.00	W/R	R	55	05
URANIUM CITY A	CAN02	4068340	4068340	59.57	108.48	105.00			63	82
WYNYARD	25029	4019035	4019035	51.77	104.20	90.00	W		65	88
YORKTON A	25017	4019080	4019080	51.27	102.47	90.00	W		53	05

NOTE: SWIFT CURRENT CDA SUN = W UNTIL 1966, SUN = R FROM 1967

YUKON TERRITORY

BURWASH A	26325	2100182	2100182	61.37	140.05	120.00			67	86
DAWSON	CAN58	2100400	2100400	64.05	139.43	120.00			60	75
DAWSON A	CAN24	2100402	2100402	64.04	139.13	120.00			76	87
MAYO	CAN28	2100700	2100700	63.62	135.87	120.00			74	05
SNAG A	CAN29	2101000	2101000	62.37	140.40	120.00			53	65
TESLIN A	CAN30	2101100	2101100	60.17	132.74	120.00			55	05
WATSON LAKE	CAN31	2101200	2101200	60.12	128.82	120.00	W		53	92

WHITEHORSE A	26316	2101300	2101300	60.72	135.07	120.00	R	R	53	05

APPENDIX C – CORRESPONDANCE WBAN NUMBER / STATION NAME

WBAN	STATION NAME
04704	MUSKOKA A (ONT)
04705	NORTH BAY A (ONT)
04708	QUEBEC A (QUE)
04712	ST. HUBERT A (QUE)
04714	TORONTO (ONT)
04715	TRENTON A (ONT)
04730	VAL D'OR A (QUE)
04752	ROBERVAL A (QUE)
04770	MONTREAL JEAN BREBEUF (QUE)
04772	OTTAWA NRC (ONT)
04785	SHERBROOKE A (QUE)
04790	STE. AGATHE DES MONTS (QUE)
04795	TORONTO MET RES STN (ONT)
04797	HAMILTON A (ONT)
14503	STEPHENVILLE A (NFLD)
14506	ST. JOHN'S A (NFLD)
14509	GANDER INT'L. A (NFLD)
14521	ST. JOHN'S WEST CDA (NFLD)
14522	BONAVISTA (NFLD)
14523	DEER LAKE A (NFLD)
14625	MONCTON A (NB)
14627	BAIE COMEAU A (QUE)
14631	MIRAMICHI A (NB)
14633	SHEARWATER A (NS)
14636	GREENWOOD A (NS)
14639	MONT JOLI A (QUE)
14642	SABLE ISLAND (NS)
14643	SAINT JOHN A (NB)
14645	SUMMERSIDE A (PEI)
14646	SYDNEY A (NS)
14647	YARMOUTH A (NS)
14670	FREDERICTON CDA (NB)
14673	HALIFAX INT'L. A (NS)
14675	TRURO (NS)
14683	CHARLO A (NB)
14688	CHARLOTTETOWN CDA (PEI)
14899	KAPUSKASING A (ONT)
14996	WINNIPEG INT'L. A (MAN)
14997	BRANDON A (MAN)
14999	KENORA A (ONT)
15503	CARTWRIGHT (NFLD)
15504	DANIELS HARBOUR (NFLD)
15601	GOOSE UA (NFLD)
15605	KUUJUAQ A (QUE)
15619	SCHEFFERVILLE A (QUE)
15628	WABUSH LAKE A (NFLD)
15642	HOPEDALE (NFLD)
15701	KUUJJUARAPIK A (QUE)
15703	NITCHEQUON (QUE)

15806	BIG TROUT LAKE (ONT)
15901	CHURCHILL A (MAN)
15909	SIOUX LOOKOUT A (ONT)
15919	THOMPSON A (MAN)
16603	IQALUIT A (NU)
16801	CORAL HARBOUR A (NU)
16895	HALL BEACH A (NU)
16903	BAKER LAKE (NU)
16914	CHESTERFIELD (NU)
17901	RESOLUTE A (NU)
22258	INUVIK UA (NWT)
24092	ESTEVAN A (SASK)
24287	VANCOUVER INT'L. A (BC)
24288	ABBOTSFORD A (BC)
24292	COMOX A (BC)
24297	VICTORIA INT'L. A (BC)
25004	THE PAS A (MAN)
25005	REGINA A (SASK)
25009	DAUPHIN A (MAN)
25012	NORTH BATTLEFORD A (SASK)
25013	PRINCE ALBERT A (SASK)
25015	SASKATOON (SASK)
25017	YORKTON A (SASK)
25018	MOOSE JAW A (SASK)
25028	SWIFT CURRENT CDA (SASK)
25029	WYNYARD (SASK)
25030	BROADVIEW (SASK)
25101	PEACE RIVER A (ALTA)
25105	FORT MCMURRAY A (ALTA)
25110	CALGARY INT'L. A (ALTA)
25113	CORONATION (ALTA)
25115	GRANDE PRAIRIE A (ALTA)
25118	MEDICINE HAT A (ALTA)
25119	RED DEER A (ALTA)
25129	COLD LAKE A (ALTA)
25142	EDMONTON INT'L. A (ALTA)
25145	EDMONTON STONY PLAIN (ALTA)
25206	PRINCE GEORGE A (BC)
25218	FORT NELSON A (BC)
25220	KAMLOOPS A (BC)
25223	PORT HARDY A (BC)
25224	QUESNEL A (BC)
25225	SMITHERS A (BC)
25229	TERRACE A (BC)
25231	FORT ST. JOHN A (BC)
25247	WILLIAMS LAKE A (BC)
25342	CAPE ST. JAMES (BC)
25346	SANDSPIT A (BC)
25353	PRINCE RUPERT A (BC)
26005	CAMBRIDGE BAY A (NU)
26102	FORT SMITH A (NWT)
26110	YELLOWKNIFE A (NWT)
26202	NORMAN WELLS A (NWT)
26316	WHITEHORSE A (YT)
26325	BURWASH A (YT)
27202	CAPE PARRY A (NWT)
73715	LA GRANDE RIVIERE A (QUE)

75290	MONTREAL MIRABEL A (QUE)
77912	SEPT-ILES UA (QUE)
94108	LETHBRIDGE A (ALTA)
94110	CASTLEGAR A (BC)
94116	PENTICTON A (BC)
94152	SUMMERLAND CDA (BC)
94157	CRANBROOK A (BC)
94234	TOFINO A (BC)
94238	VANCOUVER UBC (BC)
94791	TORONTO PEARSON INT'L. A (ONT)
94792	MONTREAL INT'L. A (QUE)
94795	BAGOTVILLE A (QUE)
94797	EARLTON A (ONT)
94803	GORE BAY A (ONT)
94804	THUNDER BAY A (ONT)
94805	LONDON A (ONT)
94809	WIARTON A (ONT)
94810	WINDSOR A (ONT)
94828	SUDBURY A (ONT)
94831	TIMMINS A (ONT)
94842	SAULT STE. MARIE A (ONT)
94857	MOUNT FOREST (ONT)
94858	SIMCOE (ONT)
94912	PORTAGE LA PRAIRIE A (MAN)
94932	ATIKOKAN (ONT)
CAN02	URANIUM CITY A (SASK)
CAN03	WHITECOURT (ALTA)
CAN04	VERMILION A (ALTA)
CAN05	ROCKY MTN. HOUSE (ALTA)
CAN06	BATTLE HARBOUR (NFLD)
CAN07	LAKE EON A (QUE)
CAN08	ARMSTRONG A (ONT)
CAN09	SPRING ISLAND (BC)
CAN10	GERALDTON (ONT)
CAN12	RIVIERE DU LOUP (QUE)
CAN13	GRINDSTONE ISLAND (QUE)
CAN14	OTTAWA CDA (ONT)
CAN15	KINGSTON (ONT)
CAN16	ST. CATHERINES A (ONT)
CAN17	BUTTONVILLE (ONT)
CAN18	VICTORIA GONZALES HTS (BC)
CAN19	VICTORIA MARINE (BC)
CAN20	NANAIMO A (BC)
CAN21	LYTTON (BC)
CAN22	KELOWNA A (BC)
CAN23	PRINCETON A (BC)
CAN24	DAWSON A (YT)
CAN25	KIMBERLEY A (BC)
CAN26	BEATTON RIVER A (BC)
CAN27	SMITH RIVER A (BC)
CAN28	MAYO (YT)
CAN29	SNAG A (YT)
CAN30	TESLIN A (YT)
CAN31	WATSON LAKE A (YT)
CAN32	FORT RELIANCE (NWT)
CAN33	FORT RESOLUTION A (NWT)
CAN34	FORT SIMPSON (NWT)

CAN35	FORT SIMPSON A (NWT)
CAN36	HAY RIVER A (NWT)
CAN37	ENNADAI (NU)
CAN38	RANKIN INLET A (NU)
CAN39	CAPE DYER (NU)
CAN40	REA POINT (NU)
CAN41	SACHS HARBOUR A (NWT)
CAN42	LLOYDMINSTER (ALTA)
CAN43	COWLEY A (ALTA)
CAN44	PINCHER CREEK (ALTA)
CAN45	SPRINGBANK A (ALTA)
CAN46	EDSON (ALTA)
CAN47	EDSON A (ALTA)
CAN48	LAC LA BICHE (ALTA)
CAN49	LAC LA BICHE AUT (ALTA)
CAN50	SLAVE LAKE (ALTA)
CAN51	WAGNER (ALTA)
CAN52	FORT CHIPEWYAN A (ALTA)
CAN53	HIGH LEVEL A (ALTA)
CAN54	KINDERSLEY A (SASK)
CAN55	LA RONGE A (SASK)
CAN56	STONY RAPIDS A (SASK)
CAN57	HUDSON BAY (SASK)
CAN58	DAWSON (YT)
CAN59	RIVERS (MAN)
CAN60	ISLAND LAKE (MAN)
CAN61	LYNN LAKE A (MAN)
CAN62	NORWAY HOUSE (MAN)
CAN63	GIMLI A (MAN)
CAN64	GRAHAM A (ONT)
CAN65	NAKINA A (ONT)
CAN66	WHITE RIVER (ONT)
CAN67	CHAPLEAU (ONT)
CAN68	KILLALOE (ONT)
CAN69	COPPERMINE (NU)
CAN70	PETAWAWA A (ONT)
CAN71	STIRLING (ONT)
CAN72	TORONTO DOWNSVIEW A (ONT)
CAN73	GASPE A (QUE)
CAN74	CHIBOUGAMAU A (QUE)
CAN75	CHIBOUGAMAU CHAPAIS A (QUE)
CAN76	CAMPBELLTON (NB)
CAN78	ST LEONARD (NB)
CAN79	COPPER LAKE (NS)
CAN80	DEBERT (NS)
CAN81	EDDY POINT (NS)
CAN82	HALIFAX (NS)
CAN83	CHURCHILL FALLS A (NFLD)
CAN84	SHELBURNE (NS)
CAN85	ARGENTIA A (NFLD)
CAN86	KUGLUKTUK (NU)
CAN87	BUCHANS A (NFLD)
CAN88	BURGEO (NFLD)
CAN89	COMFORT COVE (NFLD)
CAN90	PORT AUX BASQUES (NFLD)
CAN91	ST ANDREWS (NFLD)
CAN92	ST ANTHONY (NFLD)

CAN93	CLYDE A (NU)
CAN94	TWILLINGATE (NFLD)
CAN95	CAPE HARRISON (NFLD)
CAN96	GIMLI (MAN)
CAN97	OLD GLORY MOUNTAIN (BC)
CAN98	EDMONTON MUNICIPAL A (ALTA)
CAN99	PETERBOROUGH A (ONT)
CANA1	MOOSONEE (ONT)
CANA2	TORONTO ISLAND A (ONT)
CANA3	COLLINS BAY (SASK)
CANA4	ALERT (NU)
CANA5	EUREKA (NU)
CANA6	EDMONTON NAMAO (ALTA)
CANA7	ISACHSEN (NU)
CANA8	LA GRANDE IV A (QUE)

APPENDIX D - AVAILABLE CWEC FILES

Station Name	WBAN	File Name	Based on years	Max % derived data
Abbotsford, BC	24288	W24288W.CW2	1960-1989	100
Comox, BC	24292	W24292W.CW2	1960-1989	100
Fort St John, BC	25231	W25231W.CW2	1960-1989	100
Kamloops, BC	25220	W25220W.CW2	1970-1989	100
Port Hardy, BC	25223	W25223W.CW2	1967-1991	10
Prince George, BC	25206	W25206W.CW2	1973-1989	25
Prince Rupert, BC	25353	W25353W.CW2	1963-1989	100
Sandspit, BC	25346	W25346W.CW2	1967-1992	10
Smithers, BC	25225	W25225W.CW2	1960-1989	100
Summerland, BC	94152	W94152W.CW2	1961-1989	10
Vancouver, BC	94238	W94238W.CW2	1960-1989	10
Victoria, BC	24297	W24297W.CW2	1960-1989	100
Calgary, Alta	25110	W25110W.CW2	1960-1989	100
Edmonton, Alta	25145	W25145W.CW2	1967-1991	10
Fort McMurray, Alta	25105	W25105W.CW2	1960-1989	100
Lethbridge, Alta	94108	W94108W.CW2	1960-1989	100
Medicine Hat, Alta	25118	W25118W.CW2	1960-1989	100
Estevan, Sask	24092	W24092W.CW2	1963-1989	100
North Battleford, Sask	25012	W25012W.CW2	1960-1989	100
Regina, Sask	25005	W25005W.CW2	1960-1989	100
Saskatoon, Sask	25015	W25015W.CW2	1960-1989	100
Swift Current, Sask	25028	W25028W.CW2	1960-1989	10
Churchill, Man	15901	W15901W.CW2	1964-1989	25
The Pas, Man	25004	W25004W.CW2	1972-1991	10
Winnipeg, Man	14996	W14996W.CW2	1960-1989	10
Kingston, Ont	CAN15	WCAN15W.CW2	1970-1994	100
London, Ont	94805	W94805W.CW2	1960-1989	100
Mount Forest, Ont	94857	W94857W.CW2	1962-1976	100
Muskoka, Ont	04704	W04704W.CW2	1953-1978	100
North Bay, Ont	04705	W04705W.CW2	1960-1989	100
Ottawa, Ont	04772	W04772W.CW2	1958-1983	10
Sault Ste Marie, Ont	94842	W94842W.CW2	1962-1989	100
Simcoe, Ont	94858	W94858W.CW2	1962-1976	100
Thunder Bay, Ont	94804	W94804W.CW2	1960-1989	100
Toronto, Ont	04714	W04714W.CW2	1960-1989	10
Trenton, Ont	04715	W04715W.CW2	1960-1989	100

Windsor, Ont	94810	W94810W.CW2	1953-1989	100
Bagotville, Que	94795	W94795W.CW2	1960-1989	100
Baie Comeau, Que	14627	W14627W.CW2	1965-1989	100
Grindstone Island, Que	CAN13	WCAN13W.CW2	1969-1982	100
Kuujjuarapik, Que	15701	W15701W.CW2	1960-1989	100
Kuujuaq, Que	15605	W15605W.CW2	1960-1989	100
La Grande Riviere, Que	73715	W73715W.CW2	1977-1989	100
Lake Eon, Que	CAN07	WCAN07W.CW2	1960-1976	100
Mont Joli, Que	14639	W14639W.CW2	1960-1989	100
Montreal Int'l., Que	94792	W94792W.CW2	1960-1989	100
Montreal Jean Brebeuf, Que	04770	W047704.CW2	1964-1986	10
Montreal Mirabel, Que	75290	W75290W.CW2	1976-1989	100
Nitchequon, Que	15703	W15703W.CW2	1959-1983	100
Quebec, Que	04708	W04708W.CW2	1960-1989	100
Riviere du Loup, Que	CAN12	WCAN12W.CW2	1966-1979	100
Roberval, Que	04752	W04752W.CW2	1960-1989	100
Schefferville, Que	15619	W15619W.CW2	1960-1989	100
Sept-Iles, Que	77912	W77912W.CW2	1973-1992	10
Sherbrooke, Que	04785	W04785W.CW2	1963-1989	100
St. Hubert, Que	04712	W04712W.CW2	1960-1989	100
Ste. Agathe des Monts, Que	04790	W04790W.CW2	1967-1989	100
Val d'Or, Que	04730	W04730W.CW2	1960-1989	100
Fredericton, NB	14670	W14670W.CW2	1960-1989	10
Saint John, NB	14643	W14643W.CW2	1960-1989	100
Greenwood, NS	14636	W14636W.CW2	1960-1989	100
Sable Island, NS	14642	W14642W.CW2	1969-1989	10
Shearwater, NS	14633	W14633W.CW2	1960-1989	100
Sydney, NS	14646	W14646W.CW2	1960-1989	100
Truro, NS	14675	W14675W.CW2	1960-1976	100
Charlottetown, PEI	14688	W14688W.CW2	1971-1989	10
Battle Harbour, NFLD	CAN06	WCAN06W.CW2	1958-1982	100
Gander, NFLD	14509	W14509W.CW2	1960-1989	100
Goose Bay, NFLD	15601	W15601W.CW2	1960-1989	10
St. John's, NFLD	14521	W14521W.CW2	1960-1989	10
Stephenville, NFLD	14503	W14503W.CW2	1965-1989	100
Inuvik, NWT (*)	22258	W22258W.CW2	1973-1992	25
Resolute, NWT	17901	W17901W.CW2	1963-1989	25
Yellowknife, NWT (*)	26110	W26110W.CW2	1960-1989	100
Whitehorse, YT	26316	W26316W.CW2	1970-1989	25

(*) Due to the unavailability of many measurements for this station, the Dew Point Temperature was not taken into account to select typical months. The weights normally attributed to the Dew Point Temperature in the selection process were transferred to the Dry Bulb Temperature.

APPENDIX E - MONTHS SELECTED BY CWEC WEATHER DATA ANALYSIS

CWEC weather files are made by concatenating individual months of real data chosen for their representativity. The table below provides the origin of the months chosen.

WBAN Station Name   Year of Origin

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
04704	Muskoka, Ont	65	70	63	63	55	53	69	58	78	57	54	64
04705	North Bay, Ont	65	82	88	63	87	84	69	89	79	89	71	68
04708	Quebec, Que	72	88	64	66	71	81	85	76	67	89	74	86
04712	St. Hubert, Que	62	70	61	69	71	69	68	71	72	64	74	77
04714	Toronto, Ont	69	65	64	64	63	70	81	89	78	69	83	61
04715	Trenton, Ont	69	88	88	67	70	79	63	89	80	86	83	88
04730	Val d'Or, Que	77	65	85	60	79	70	77	89	88	64	83	88
04752	Roberval, Que	77	61	85	63	71	60	85	85	72	75	84	88
04770	Montreal, Que	65	70	69	69	70	81	68	67	79	69	74	78
04772	Ottawa, Ont	66	80	64	64	68	70	77	81	79	69	74	60
04785	Sherbrooke, Que	86	70	85	77	85	70	84	71	80	64	89	83
04790	Ste. Agathe des Monts, Que	80	88	69	74	81	81	84	81	79	86	83	78
14503	Stephenville, NFLD	88	85	88	80	82	76	76	77	71	88	75	77
14509	Gander, NFLD	67	63	80	64	61	70	77	81	63	80	75	77
14521	St. John's, NFLD	78	85	77	74	66	88	64	69	71	65	74	75
14627	Baie Comeau, Que	75	76	85	66	81	69	78	89	72	81	87	65
14633	Shearwater, NS	73	71	88	89	84	84	81	80	67	73	84	65
14636	Greenwood, NS	72	70	69	69	61	84	83	80	80	81	84	67
14639	Mont Joli, Que	65	71	82	66	81	81	85	74	84	73	62	83
14642	Sable Island, NS	81	77	76	89	78	77	85	79	84	73	84	77
14643	Saint John, NB	62	88	69	84	75	81	85	71	60	77	74	67
14646	Sydney, NS	88	65	80	79	61	84	60	65	65	77	74	83
14670	Fredericton, NB	87	71	82	69	70	84	71	81	89	73	80	65
14675	Truro, NS	64	74	64	70	69	70	76	62	67	66	67	67
14688	Charlottetown, PEI	72	77	75	82	86	89	78	80	71	73	84	75
14996	Winnipeg, Man	67	82	84	68	73	86	81	72	82	89	77	75
15601	Goose Bay, NFLD	65	65	85	77	83	66	87	81	82	83	84	65
15605	Kuujuaq, Que	79	86	85	80	78	65	67	61	80	89	83	64
15619	Schefferville, Que	70	85	79	89	82	87	79	74	82	87	76	86
15701	Kuujjuarapik, Que	77	77	82	77	62	77	80	69	60	66	74	71
15703	Nitchequon, Que	73	75	61	80	77	66	82	60	73	66	70	59
15901	Churchill, Man	73	82	86	72	65	89	84	75	75	88	88	88
17901	Resolute, NWT	80	86	87	67	78	76	73	83	74	82	88	83
22258	Inuvik, NWT	92	87	82	83	75	91	91	87	88	84	87	79
24092	Estevan, Sask	85	70	72	71	73	77	77	65	70	66	88	67
24288	Abbotsford, BC	87	71	60	71	73	60	80	88	68	89	86	81
24292	Comox, BC	73	66	66	84	70	88	88	88	68	85	60	75
24297	Victoria, BC	70	60	66	84	82	60	80	66	68	89	72	81
25004	The Pas, Man	85	86	88	75	88	80	74	90	91	85	79	85
25005	Regina, Sask	88	61	72	71	60	89	80	79	73	71	88	88
25012	North Battleford, Sask	88	74	82	83	89	89	83	79	88	82	63	75
25015	Saskatoon, Sask	85	70	82	72	66	83	80	88	73	82	63	75
25028	Swift Current, Sask	88	71	76	63	73	73	76	60	73	73	88	88
25105	Fort McMurray, Alta	73	71	76	75	86	77	81	73	71	74	64	65
25110	Calgary, Alta	88	80	70	63	63	62	88	79	74	89	63	63
25118	Medicine Hat, Alta	67	80	85	64	89	80	77	73	73	73	64	65
25145	Edmonton, Alta	75	71	77	90	91	89	81	73	71	76	78	76
25206	Prince George, BC	88	76	77	74	88	77	86	89	82	81	74	82
25220	Kamloops, BC	88	71	80	85	88	88	87	84	81	85	71	80
25223	Port Hardy, BC	73	85	80	91	86	77	84	68	83	83	74	87
25225	Smithers, BC	62	60	60	74	82	66	75	72	62	70	63	67
25231	Fort St John, BC	75	74	80	73	69	67	88	84	70	77	60	62
25346	Sandspit, BC	82	68	68	70	91	81	69	88	88	77	89	85
25353	Prince Rupert, BC	70	71	80	73	67	63	63	68	80	82	63	78

26110	Yellowknife, NWT	86	75	78	73	70	72	65	73	81	65	69	63
26316	Whitehorse, YT	86	81	80	87	77	72	85	87	77	83	71	76
73715	La Grande Riviere, Que	83	86	79	77	78	77	89	86	88	89	87	77
75290	Montreal Mirabel, Que	77	83	80	79	81	81	84	81	79	86	83	83
77912	Sept-Iles, Que	92	75	80	89	87	81	78	75	84	73	75	82
94108	Lethbridge, Alta	62	85	77	84	89	62	79	88	80	82	67	88
94152	Summerland, BC	66	65	67	76	88	78	77	66	88	82	68	82
94238	Vancouver, BC	70	67	66	76	71	60	67	79	61	85	70	61
94792	Montreal Int'l., Que	66	70	61	79	71	70	77	78	79	86	84	78
94795	Bagotville, Que	75	64	68	70	65	87	78	86	65	85	67	71
94804	Thunder Bay, Ont	84	64	82	83	87	60	84	63	81	65	74	62
94805	London, Ont	62	88	89	88	63	70	81	66	80	83	69	75
94810	Windsor, Ont	65	77	89	63	63	62	73	56	72	83	79	73
94842	Sault Ste Marie, Ont	65	71	67	70	85	74	82	62	73	83	71	75
94857	Mount Forest, Ont	66	70	64	62	69	62	74	62	69	68	69	64
94858	Simcoe, Ont	62	73	62	71	63	62	71	66	66	69	65	64
CAN06	Battle Harbour, NFLD	78	63	75	70	67	78	77	77	63	80	73	64
CAN07	Lake Eon, Que	70	64	70	65	65	69	64	71	65	73	70	74
CAN12	Riviere du Loup, Que	78	70	75	71	68	70	66	70	77	73	70	67
CAN13	Grindstone Island, Que	76	71	77	69	69	81	72	75	77	69	75	77
CAN15	Kingston, Ont	91	89	74	71	70	77	77	91	92	91	73	77

Appendix B Communication with Environment Canada

The following is the email received from Environment Canada regarding the hourly rain data for the weather stations. It clearly stated that the rain data has to be purchased at a cost.

```
----- Original Message -----
From: Ontario Climate Centre <Ontario.Climate.Centre@ec.gc.ca>
Date: Monday, March 29, 2010 1:26 pm
Subject: RE: recent weather data
To: Wai Ki Wu <waiki.wu@ryerson.ca>

>
> Hourly rainfall is not an element available on the web site.  Daily
> precipitation is provided.  The hourly data can be purchased as a
> digital file for the fee $100 plus gst.  Payment can be made by
Visa
> or Mastercard, or a cheque made out to the Receiver General for
Canada
> can be mailed in with your request.
>
> Sandy Radecki
> Ontario Climate Centre | Centre Climatologique de l'Ontario
> Environment Canada | Environnement Canada
> 4905 Dufferin Street |4905 rue Dufferin Toronto, ON M3H 5T4
> ontario.climate@ec.gc.ca Facsimile | Télécopieur 416-739-4521
> Government of Canada | Gouvernement du Canada Website | Site Web
> www.climate.weatheroffice.ec.gc.ca
```

The following are the email received from Ontario Climate center regarding the rain gauge servicing during winter months.

```
Please note that hourly rainfall is not available for winter months.
The equipment is taken out of service during the season from November
to March.
-----Original Message-----
From: Wai Ki Wu [mailto:waiki.wu@ryerson.ca]
Sent: Thursday, March 11, 2010 3:01 PM
To: Ontario Climate Centre
Subject: *****SPAM***** Re: RE: Re: OCC 109
Hi
I found a way to make the data formatted to the way i want. However,
i found out there are some months are missing in data. For example,
for the Toronto city station 04714 (6158350) are missing data from
Nov 02, to March 31. I thought the data are complete for the year,
even there is no measurement.
Can you please take a look. I took a few years, for example, 1998 and
1999 are both missing the months listed above.
Rick
```

Appendix C Weather Data Error and Correction

The following script is the program to convert the rain data received from Environment Canada to the same format in freely downloaded CWEED format. The processed data is imported to the ACCESS database and combined to form the complete weather data.

```
Private Sub CommandButton1_Click()

    Dim header As String
    Dim value As String
    Dim strLine As String
    Dim day As Integer
    Dim daycount As String


    Set objFSO = CreateObject("Scripting.FileSystemObject")
    Set objfile =
objFSO.opentextfile("C:\Users\Rick\Documents\MASc\Conference Paper
1\HLY03_el123\rain-data.txt", 1)
    Set objTarget =
objFSO.CreateTextfile("C:\Users\Rick\Documents\MASc\Conference Paper
1\HLY03_el123\rain-data-target.txt", 1)

    Do Until objfile.atendofstream
        strCharacters = objfile.readline
        header = Mid(strCharacters, 1, 18)
        For i = 1 To 24
            day = (i - 1) * 7 + 19
            value = Mid(strCharacters, day, 7)
            daycount = CStr(i)
            If i < 10 Then
                daycount = "0" & daycount
            End If

            strLine = header & daycount & value


            objTarget.writeline (strLine)
        Next

    Loop

    objfile.Close
    Set objfile = Nothing

    objTarget.Close
    Set objTarget = Nothing
End Sub
```

The following table is to display the data lines in weather station 94791 (Pearson Airport) which has missing information between 1974 to 1989. The “99999” in the value field indicates the data is missing.

Date YYYYMM DD	Hour	Global Horizontal radiation	Direct normal radiation	Diffuse horizontal radiation	Dry bulb	Dew point	Wind direction	Wind speed
19830629	12	9999	9999	9999	219	81	130	47
19830629	13	9999	9999	9999	219	76	130	56
19830629	14	9999	9999	9999	222	67	140	53
19850626	9	9999	9999	9999	157	61	50	17
19850626	10	9999	9999	9999	162	59	290	25
19850626	11	9999	9999	9999	181	72	300	36
19880618	12	9999	9999	9999	240	35	310	25
19880618	13	9999	9999	9999	251	46	350	25
19880618	14	9999	9999	9999	247	60	170	53
19880618	15	9999	9999	9999	249	57	150	47
19880618	16	9999	9999	9999	252	46	160	47
19890630	13	9999	9999	9999	226	64	250	17
19890630	14	9999	9999	9999	237	84	120	17
19890630	15	9999	9999	9999	230	90	140	42
19890630	16	9999	9999	9999	233	93	130	42

The following table presents the same data which has been corrected by linear interpolation. The line above and below the missing data are shown to provide reference for linear interpolation.

Date YYYYMM DD	Hour	Global Horizontal radiation	Direct normal radiation	Diffuse horizontal radiation	Dry bulb	Dew point	Wind direction	Wind speed
19830629	11	3300	3525	268	215	78	140	42
19830629	12	3290.25	3435	355	219	81	130	47
19830629	13	3280.5	3345	442	219	76	130	56
19830629	14	3270.75	3255	529	222	67	140	53
19830629	15	3261	3165	616	227	69	140	56
19850626	8	1690	3151	205	144	62	60	25
19850626	9	2045.25	3076.5	274	157	61	50	17
19850626	10	2400.5	3002	343	162	59	290	25
19850626	11	2755.75	2927.5	412	181	72	300	36
19850626	12	3111	2853	481	181	62	120	25
19880618	11	3361	3196	599	224	26	90	11
19880618	12	3193.875	3210.5	537.375	240	35	310	25
19880618	13	3026.75	3225	475.75	251	46	350	25
19880618	14	2692.5	3254	352.5	247	60	170	53
19880618	15	2358.25	3283	229.25	249	57	150	47
19880618	16	2191.125	3297.5	167.625	252	46	160	47
19880618	17	2024	3312	106	244	43	140	47
19890630	11	3328	3518	304	211	76	0	0
19890630	12	3591	3560	315	219	57	310	11
19890630	13	3854	3602	326	226	64	250	17
19890630	14	4117	3644	337	237	84	120	17
19890630	15	3535	3737	365	230	90	140	42
19890630	16	2859	3504	319	233	93	130	42
19890630	17	2183	3271	273	233	93	130	36
19890630	18	1507	3038	227	225	97	140	36

Appendix D Programs for Weather Data Files

The following is the script file that generates the weather data file for WUFI. It rearranges the data from the Access database to the required format of WUFI.

```
Private Sub CommandButton2_Click()

    Dim strPath As String
    Dim strPathTarget As String

    strPath = Cells(13, 7)
    strPathTarget = Cells(14, 7)

    Set objFSO = CreateObject("Scripting.FileSystemObject")
    Set objfile = objFSO.opentextfile(strPath, 1)
    Set objfileTarget = objFSO.opentextfile(strPathTarget, 8, 0)

    Do Until objfile.atendofstream
        strLine = objfile.readline
        objfileTarget.writeline (strLine)
    Loop

    objfile.Close
    Set objfile = Nothing

    objfileTarget.Close
    Set objfileTarget = Nothing


End Sub
```

The following is the sample of the weather data file for WUFI.

```
WUFI®_WAC_02
10    Line Offset to 'Number of Data Columns'
Toronto Downtown
Description
-79.38      Longitude [°]; East is positive
43.67 Latitude [°]; North is positive
112.5 HeightAMSL [m]
-5.0  Time Zone [h from UTC]; East is positive
1     Time Step [h]
8760  Number of DataLines
7     Number of DataColumns
TA    HREL  ISGH  ISD   RN    WD    WS
-1.30 0.76  0.00  0.00  0.00  250   6.10
-1.60 0.82  0.00  0.00  0.00  260   6.70
-2.00 0.79  0.00  0.00  0.00  250   8.30
-2.60 0.74  0.00  0.00  0.00  260   7.80
-3.00 0.81  0.00  0.00  0.00  250   5.30
-3.20 0.74  0.00  0.00  0.00  240   6.70
```

Appendix E WUFI Input Files and Material Properties

The following pages are the boundary conditions and material properties for the model in WUFI.

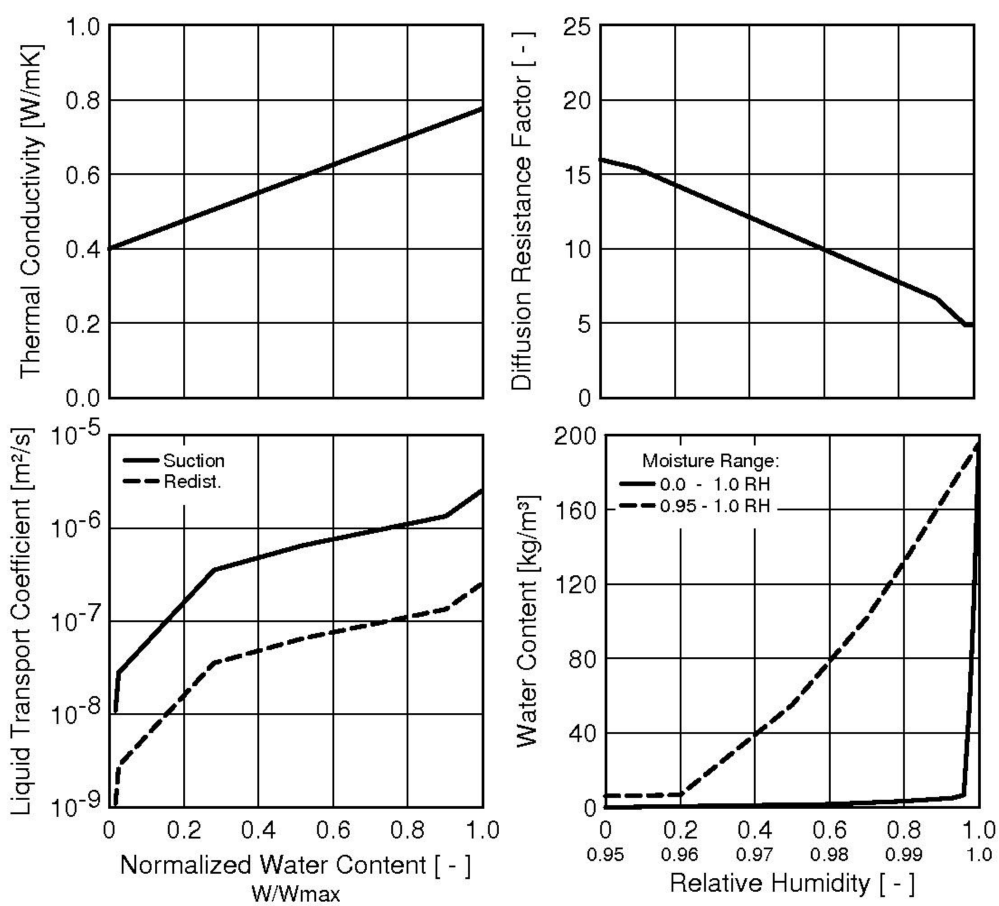
WUFI® Pro 4.2 IBP

IBP

Material : Brick (old)

Checking Input Data

Property	Unit	Value
Bulk density	[kg/m³]	1670,0
Porosity	[m³/m³]	0,196
Specific Heat Capacity, Dry	[J/kgK]	840,0
Thermal Conductivity, Dry	[W/mK]	0,4
Water Vapour Diffusion Resistance Factor	[-]	16,0
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	8,0



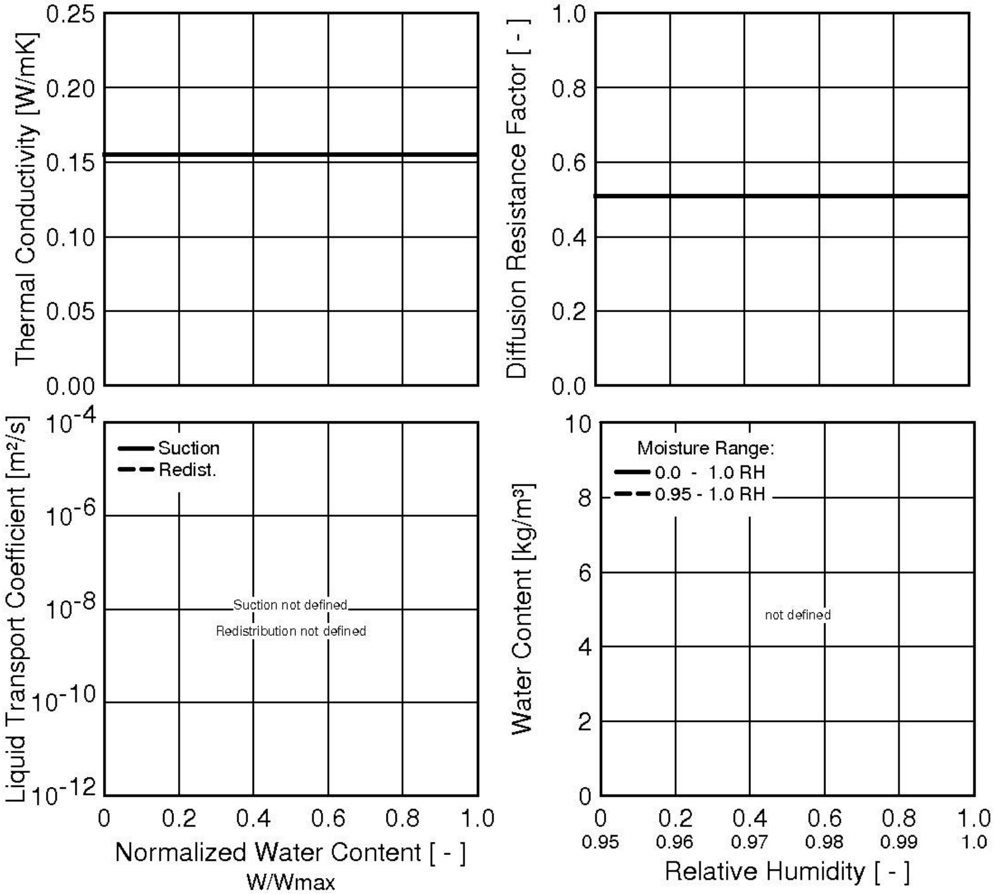
WUFI® Pro 4.2 IBP; Project: Test01.W4P; Test01, / Case 4: Toronto Airport 1974-1989 South; Date: 05/04/2010 10:06:16 AM Page : 3

WUFI® Pro 4.2 IBP

Material : Air Layer 25 mm

Checking Input Data

Property	Unit	Value
Bulk density	[kg/m³]	1,3
Porosity	[m³/m³]	0,999
Specific Heat Capacity, Dry	[J/kgK]	1000,0
Thermal Conductivity, Dry	[W/mK]	0,155
Water Vapour Diffusion Resistance Factor	[-]	0,51

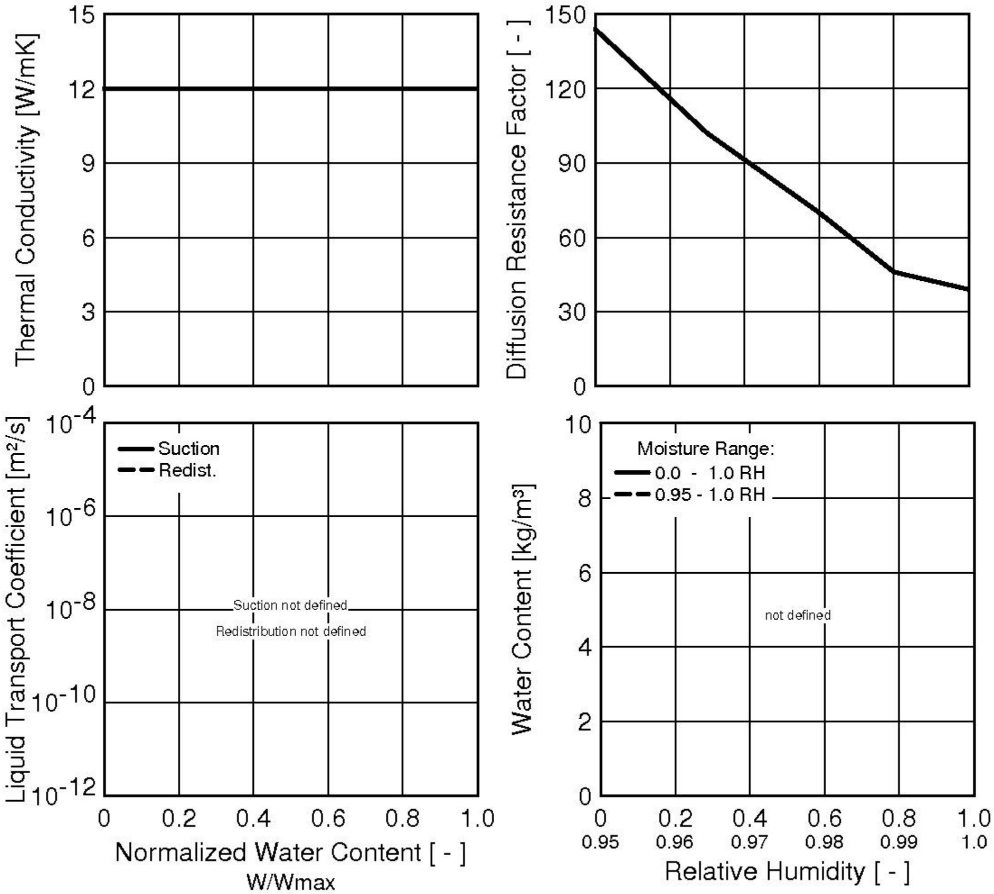


WUFI® Pro 4.2 IBP

Material : 60 minute Building Paper

Checking Input Data

Property	Unit	Value
Bulk density	[kg/m³]	280,0
Porosity	[m³/m³]	0,001
Specific Heat Capacity, Dry	[J/kgK]	1500,0
Thermal Conductivity, Dry	[W/mK]	12,0
Water Vapour Diffusion Resistance Factor	[-]	144,0

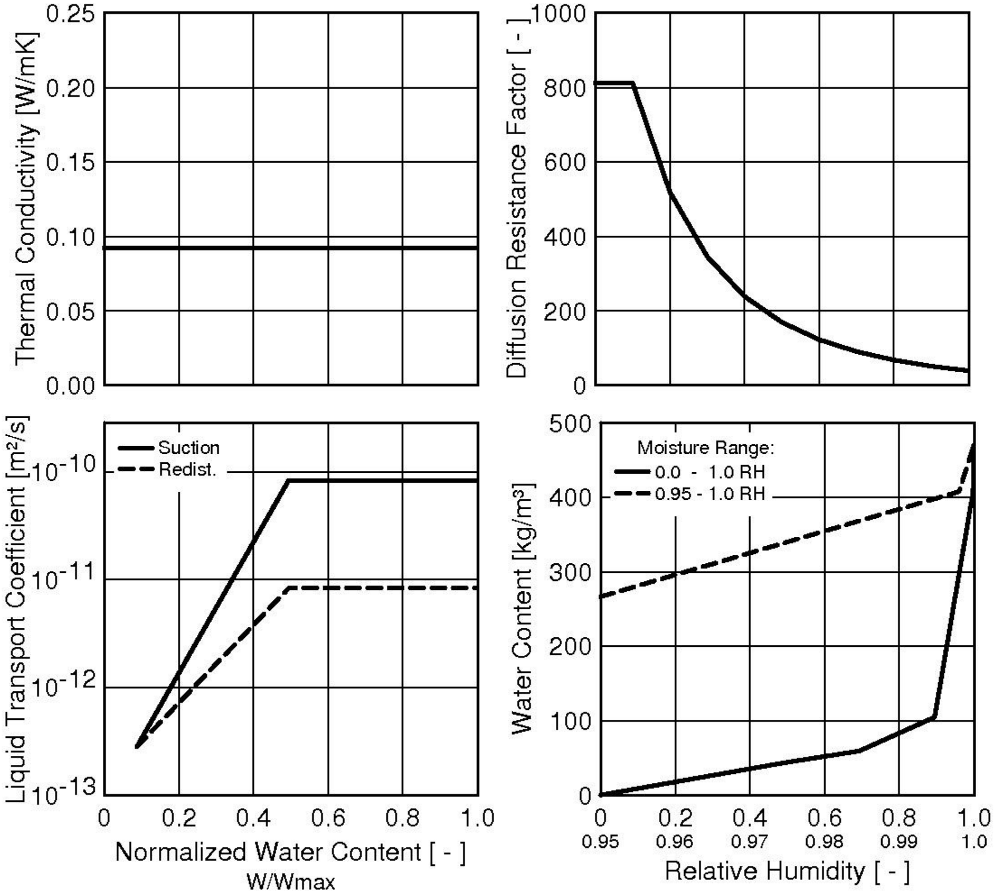


WUFI® Pro 4.2 IBP

Material : Oriented Strand Board

Checking Input Data

Property	Unit	Value
Bulk density	[kg/m³]	650,0
Porosity	[m³/m³]	0,95
Specific Heat Capacity, Dry	[J/kgK]	1880,0
Thermal Conductivity, Dry	[W/mK]	0,092
Water Vapour Diffusion Resistance Factor	[-]	812,8
Reference Water Content	[kg/m³]	83,3
Free Water Saturation	[kg/m³]	470,0
Water Absorption Coefficient	[kg/m²s^0.5]	0,0022

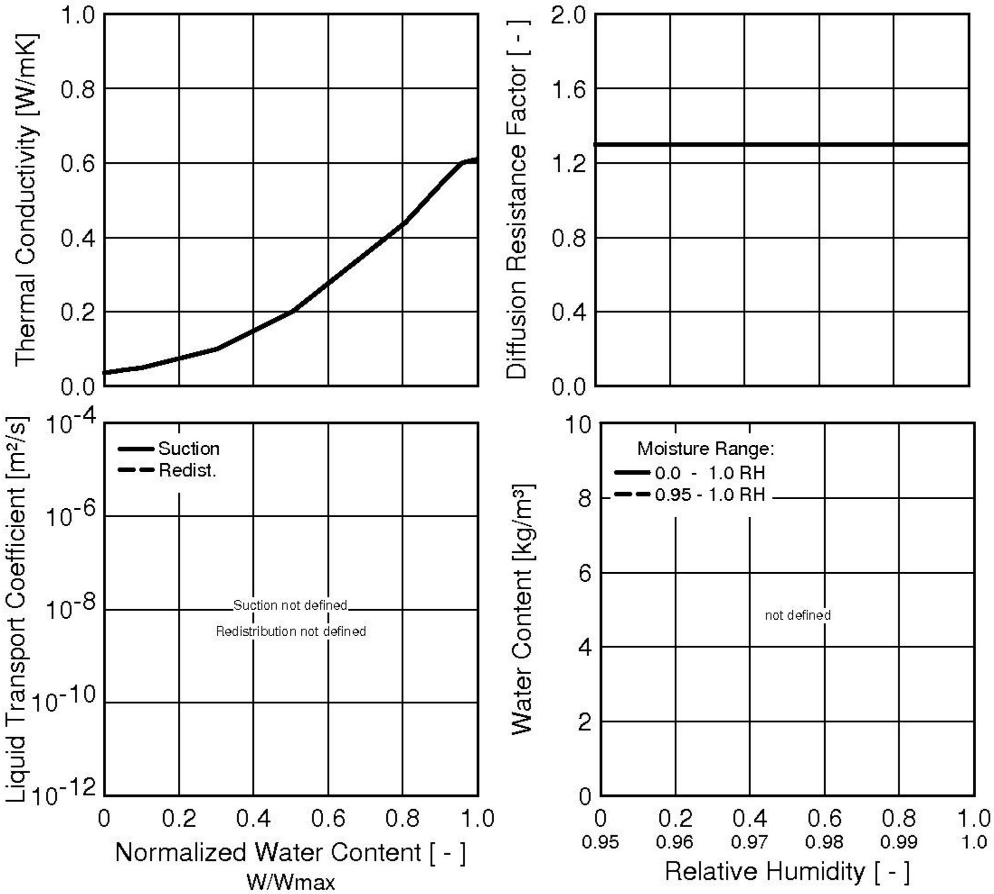


WUFI® Pro 4.2 IBP

Material : Fibre Glass

Checking Input Data

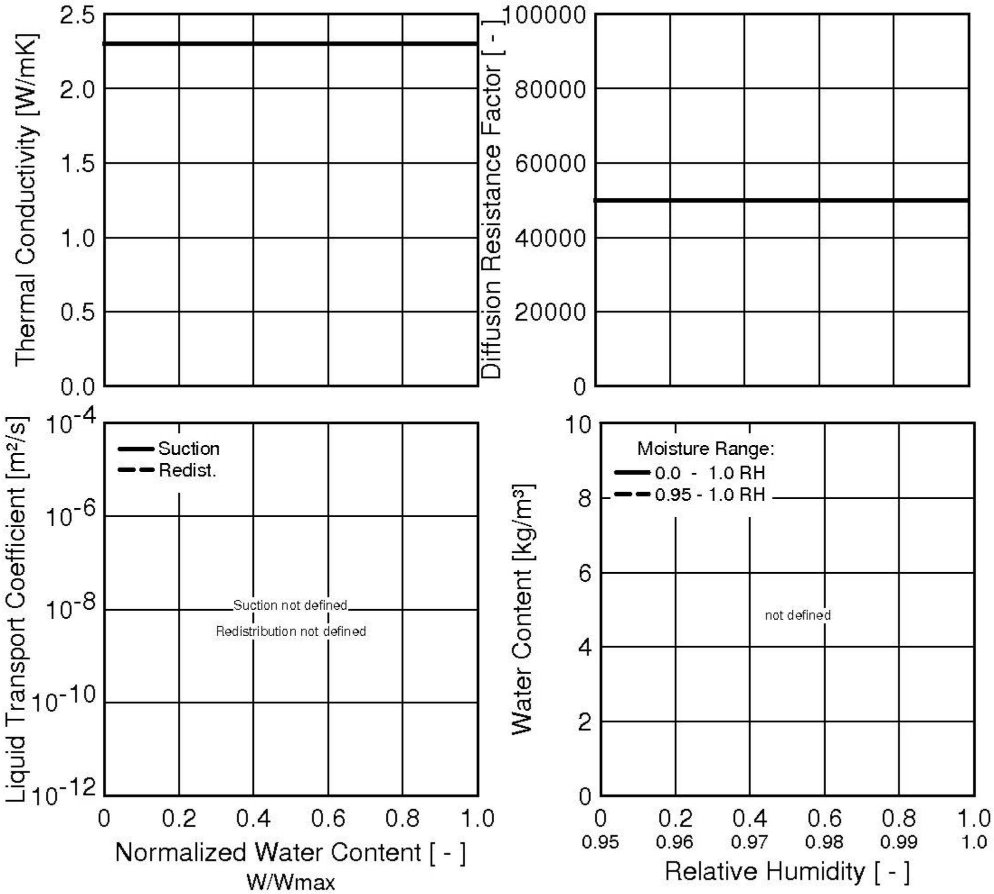
Property	Unit	Value
Bulk density	[kg/m³]	30,0
Porosity	[m³/m³]	0,99
Specific Heat Capacity, Dry	[J/kgK]	840,0
Thermal Conductivity, Dry	[W/mK]	0,035
Water Vapour Diffusion Resistance Factor	[-]	1,3



Material : PE-Membrane (Poly; 0.07 perm)

Checking Input Data

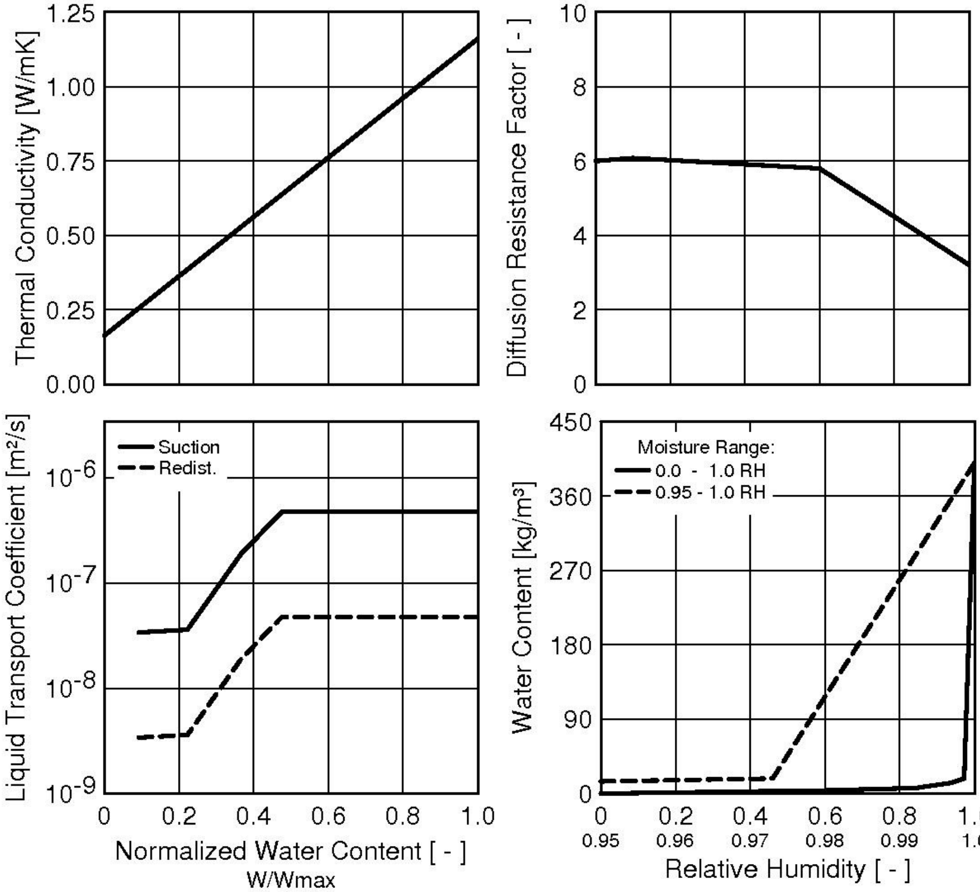
Property	Unit	Value
Bulk density	[kg/m³]	130,0
Porosity	[m³/m³]	0,001
Specific Heat Capacity, Dry	[J/kgK]	2300,0
Thermal Conductivity, Dry	[W/mK]	2,3
Water Vapour Diffusion Resistance Factor	[-]	50000,0



Material : Gypsum Board (USA)

Checking Input Data

Property	Unit	Value
Bulk density	[kg/m³]	850,0
Porosity	[m³/m³]	0,65
Specific Heat Capacity, Dry	[J/kgK]	870,0
Thermal Conductivity, Dry	[W/mK]	0,163
Water Vapour Diffusion Resistance Factor	[-]	6,0
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	8,0



Boundary Conditions

Exterior (Left Side)

Location: Toronto-Airport-1974-1989.wac
Orientation / Inclination: South / 90 °

Interior (Right Side)

Indoor Climate: WTA Guideline 6-2-01/E
Indoor Condition, Medium Moisture Load

Surface Transfer Coefficients

Exterior (Left Side)

Name	Unit	Value	Description
Heat Resistance	[m²K/W]	0.0588	External Wall
Sd-Value	[m]	----	No coating
Short-Wave Radiation Absorptivity	[-]	0.68	Brick, red
Long-Wave Radiation Emissivity	[-]	0.9	Brick, red
Rain Water Absorption Factor	[-]	0,7	According to inclination and constru

Interior (Right Side)

Name	Unit	Value	Description
Heat Resistance	[m²K/W]	0.125	External Wall
Sd-Value	[m]	----	No coating

Explicit Radiation Balance

Exterior (Left Side)

Name	Value
Enabled	no

Appendix F Ryerson Weather Data Repair

The following is the Visual basic program which appends the rest of the data to complete the yearly weather data file. The first column is the time stamp which is automatically generated.

```
Private Sub CommandButton4_Click()
    Dim strPath As String
    Dim strPathTarget As String

    Dim index As Long
    Dim increase As Integer
    Dim strLine As String
    Dim count As Long

    strPath = Cells(24, 7)
    strPathTarget = Cells(19, 7)

    Set objFSO = CreateObject("Scripting.FileSystemObject")
    Set objfile = objFSO.opentextfile(strPath, 8)
    'Set objTarget = objFSO.CreateTextfile(strPathTarget, 1)

    index = 11439600
    increase = 300

    Do Until index = 24751500
        index = index + increase
        strLine = index & Chr(9) & 0 & Chr(9) & 0 & Chr(9) & 0 &
Chr(9) & 0 & Chr(9) & 0 & Chr(9) & 0 & Chr(9) & 0 & Chr(9) & 0 &
Chr(9) & 0 & Chr(9) & 0 & Chr(9) & 0 & Chr(9) & 0
        objfile.writeline strLine
        count = count + 1
    Loop

    MsgBox count

    objfile.Close
    Set objfile = Nothing
```

The following is the Visual Basic program that is designed in conjunction with Excel to perform the quality check for the hourly and 5-minute data. The script will read the first item in the data line which is the time stamp and compare with the previous time stamp. If the difference is not the required one (3600s for hourly and 300 for 5-mintue), a message box will prompt the user for the error.

```
Private Sub CommandButton5_Click()

 Dim strPath As String
    Dim strPathTarget As String

    Dim index As Long
    Dim increase As Integer
    Dim strLine As String
    Dim count As Long
    Dim value As Long
    Dim previous_value As Long

    strPath = Cells(18, 7)
    strPathTarget = Cells(19, 7)

    Set objFSO = CreateObject("Scripting.FileSystemObject")
    Set objfile = objFSO.opentextfile(strPath, 1)
    'Set objTarget = objFSO.CreateTextfile(strPathTarget, 1)

    index = 0
    increase = 300
    previous_value = 0

    Do Until objfile.atendofstream
        strLine = objfile.readline
        splitLine = Split(strLine, Chr(9))
        value = CDbl(splitLine(0))
        If previous_value + 300 <> value Then
            MsgBox value
        End If
        previous_value = value
        count = count + 1
    Loop
    MsgBox count

    objfile.Close
    Set objfile = Nothing

End Sub
```

Based on the above script, it is found that the data from time stamp 6228000 is missing in the raw data received.

```
6227700.00  49.70 29.40 0.00  0.00  0.00  0.00  0.00  0.00  0.00  10
      30.00 2.00
6231600.00  49.70 29.10 0.00  0.00  0.00  0.00  0.00  0.00  0.00  8
      24.00 0.00
```

Since the data is from the beginning of the hour, the whole hour of data is constructed from the data before and after. It is noticed the from time stamp 6227700 to 6231600, the temperature is the same at 49.7°C, the wind is from 10 to 8 degree and the rain is from 0.2 to 0 mm. It is found that the chances are very limited. Therefore, the weather data is constructed using the 6227700 data. The 12 5-minute data is the same to ensure the averaged data to maintain the data integrity and minimize the difference introduced manually. The following is the after repaired data.

```
6227700.00  49.70 29.40 0.00  0.00  0.00  0.00  0.00  0.00  0.00  10
      30.00 2.00
6228000.00  49.70 29.40 0.00  0.00  0.00  0.00  0.00  0.00  0.00  10
      30.00 2.00
6228300.00  49.70 29.40 0.00  0.00  0.00  0.00  0.00  0.00  0.00  10
      30.00 2.00
6228600.00  49.70 29.40 0.00  0.00  0.00  0.00  0.00  0.00  0.00  10
      30.00 2.00
6228900.00  49.70 29.40 0.00  0.00  0.00  0.00  0.00  0.00  0.00  10
      30.00 2.00
6229200.00  49.70 29.40 0.00  0.00  0.00  0.00  0.00  0.00  0.00  10
      30.00 2.00
6229500.00  49.70 29.40 0.00  0.00  0.00  0.00  0.00  0.00  0.00  10
      30.00 2.00
6229800.00  49.70 29.40 0.00  0.00  0.00  0.00  0.00  0.00  0.00  10
      30.00 2.00
6230100.00  49.70 29.40 0.00  0.00  0.00  0.00  0.00  0.00  0.00  10
      30.00 2.00
6230400.00  49.70 29.40 0.00  0.00  0.00  0.00  0.00  0.00  0.00  10
      30.00 2.00
6230700.00  49.70 29.40 0.00  0.00  0.00  0.00  0.00  0.00  0.00  10
      30.00 2.00
6231000.00  49.70 29.40 0.00  0.00  0.00  0.00  0.00  0.00  0.00  10
      30.00 2.00
6231300.00  49.70 29.40 0.00  0.00  0.00  0.00  0.00  0.00  0.00  10
      30.00 2.00
6231600.00  49.70 29.10 0.00  0.00  0.00  0.00  0.00  0.00  0.00  8
      24.00 0.00
6231900.00  49.70 29.60 0.00  0.00  0.00  0.00  0.00  0.00  0.00  6
      22.00 0.00
```

The following is the repaired hourly data.

```
6224400.00  48.90 30.12 0.00  0.00  0.00  0.00  0.00  0.00  0.00
      356.23      24.83 12.00
6228000.00  49.70 30.12 0.00  0.00  0.00  0.00  0.00  0.00  0.00
      10.00 30.00 12.00
6231600.00  49.62 29.07 0.00  0.00  0.00  0.00  0.00  0.00  0.00
      355.18      23.08 2.00
```

Appendix G Material Data Adjustment for Ham-Tools

The following is the adjustment of the water content of vapour permeability and hydraulic conductivity for wood siding in HAM-Tools. The amount of adjustment of -15(s^{-1}) is based on the analysis in the report.

Vapour Permeability	
Original w	Adjusted w
28	13
42	27
69	54
92	77
120	105
162	147
176	161
198	183
236	221
332	317
345	330
362	347
386	371
426	411
758	743

Hydraulic conductivity	
Original w	Adjusted w
40	25
60	45
80	65
100	85
120	105
140	125
160	145
180	165
199	184
220	205
239	224
260	245
299	284
319	304
379	364
399	384
459	444
479	464
499	484
519	504
539	524
559	544
579	564
598	583
619	604
638	623
658	643
678	663
698	683
718	703
758	743

The following is the final material data for the wood siding used in the verification. The name is changed to “wood siding1” in the database so the original data can be maintained.

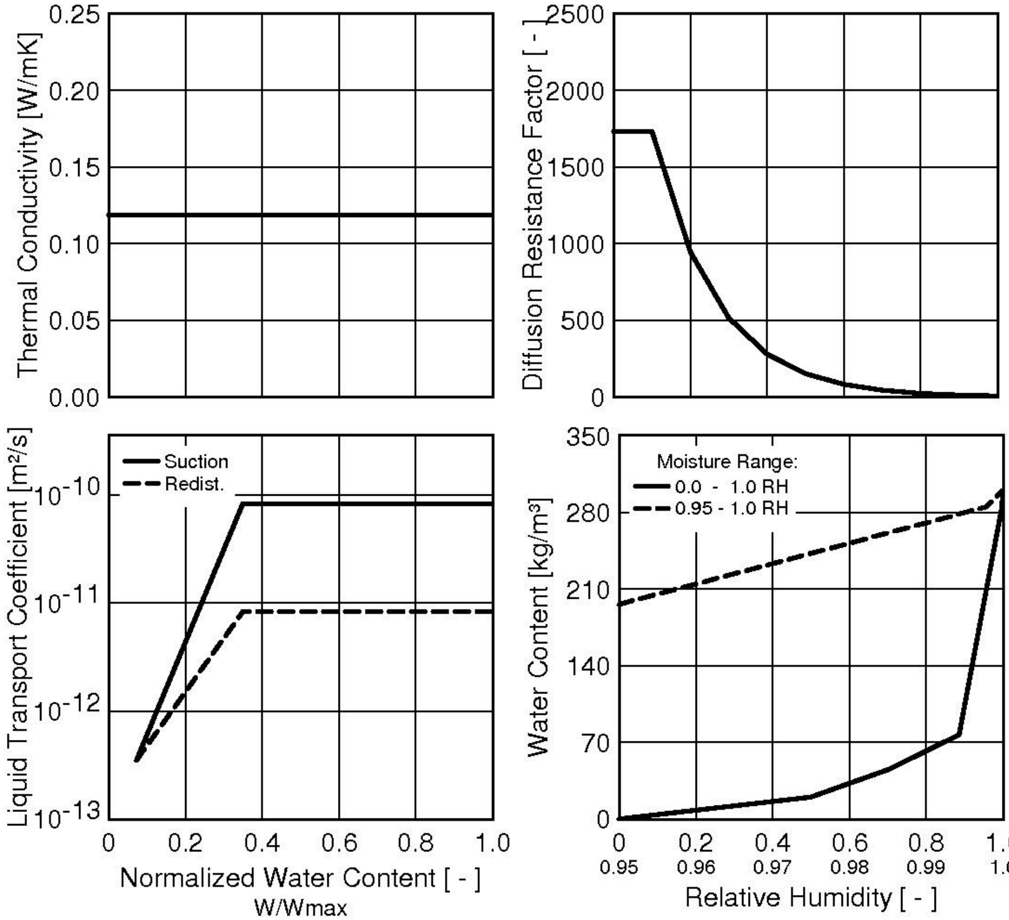
```
Mdata(19)=struct(...
'index',19,...
'name','Wood siding1',...
'dry_density',530,...
'lambda_dry',0.14,...
'lambda_T',0,...
'lambda_W',0.0005,...
'heat_capacity',900,...
'emissivity',0.9,...
'transmittance',0,...
'absorptivity',0.6,...
'porosity',0.8,...
'W_capillary',300,...
'WAC',0,...
'sorption_RH',[0.1000   0.2000   0.3000   0.4000   0.5000   0.6000
0.7000  0.8000   0.9000   0.9200   0.9400   0.9600   0.9800   0.9900
0.9920  0.9940   0.9960   0.9980   0.9990   0.9992   0.9994   0.9996
0.9998  1.0000],...
'sorption_W',[8 13  17  22  27  33  41  54  77  86  97  114 147 183
195 211 234 275 317 330 347 371 411 743],...
'delta_W',[28   42  69  92  120 162 176 198 236 332 345 362 386 426
758],...
'delta_p_W',[2.606E-12  2.608E-12   2.608E-12   2.605E-12   2.597E-12
2.575E-12   2.564E-12   2.545E-12   2.5E-12 2.319E-12   2.284E-12
2.236E-12   2.163E-12   2.022E-12   3.105E-15],...
'hyd_cond_W',[25 45 65 85 105 125 145 165 184 205 224 245 284 304 364
384 444 464 484 504 524 544 564 583 604 623 643 663 683 703 743],...
'hyd_cond_K',[8.22E-17  1.709E-16   2.95E-16    4.684E-16   6.679E-16
9.902E-16   1.512E-15   2.289E-15   3.428E-15   5.279E-15   7.983E-15
1.285E-14   2.84E-14    4.682E-14   1.256E-13   1.868E-13   5.071E-13
7.132E-13   9.473E-13   1.363E-12   1.854E-12   2.768E-12   3.921E-12
6.211E-12   1.038E-11   1.986E-11   3.825E-11   9.553E-11   2.88E-10
```

The following pages are the material properties from WUFI for the model at WUFI.

Material : Southern Yellow Pine

Checking Input Data

Property	Unit	Value
Bulk density	[kg/m³]	500,0
Porosity	[m³/m³]	0,858
Specific Heat Capacity, Dry	[J/kgK]	1880,0
Thermal Conductivity, Dry	[W/mK]	0,119
Water Vapour Diffusion Resistance Factor	[-]	1734,1
Reference Water Content	[kg/m³]	62,2
Free Water Saturation	[kg/m³]	300,0
Water Absorption Coefficient	[kg/m²s^0.5]	0,0014

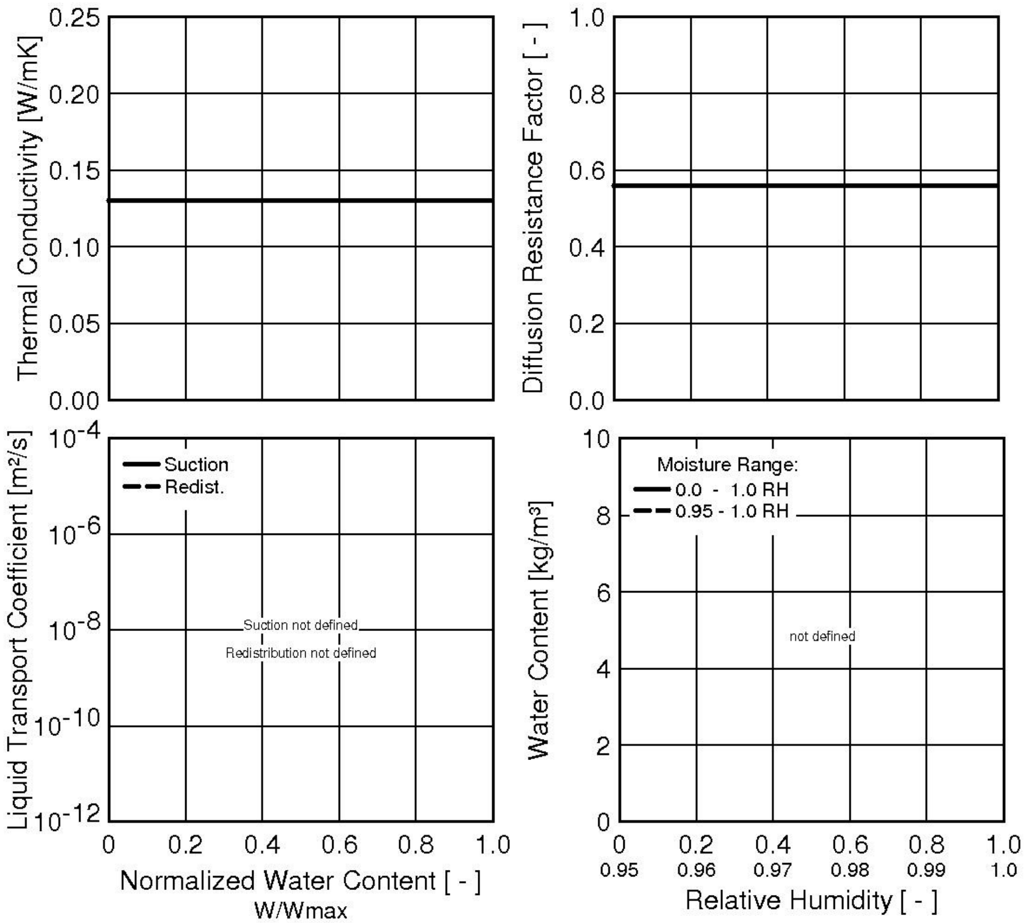


WUFI® Pro 4.2 IBP

Material : Air Layer 20 mm

Checking Input Data

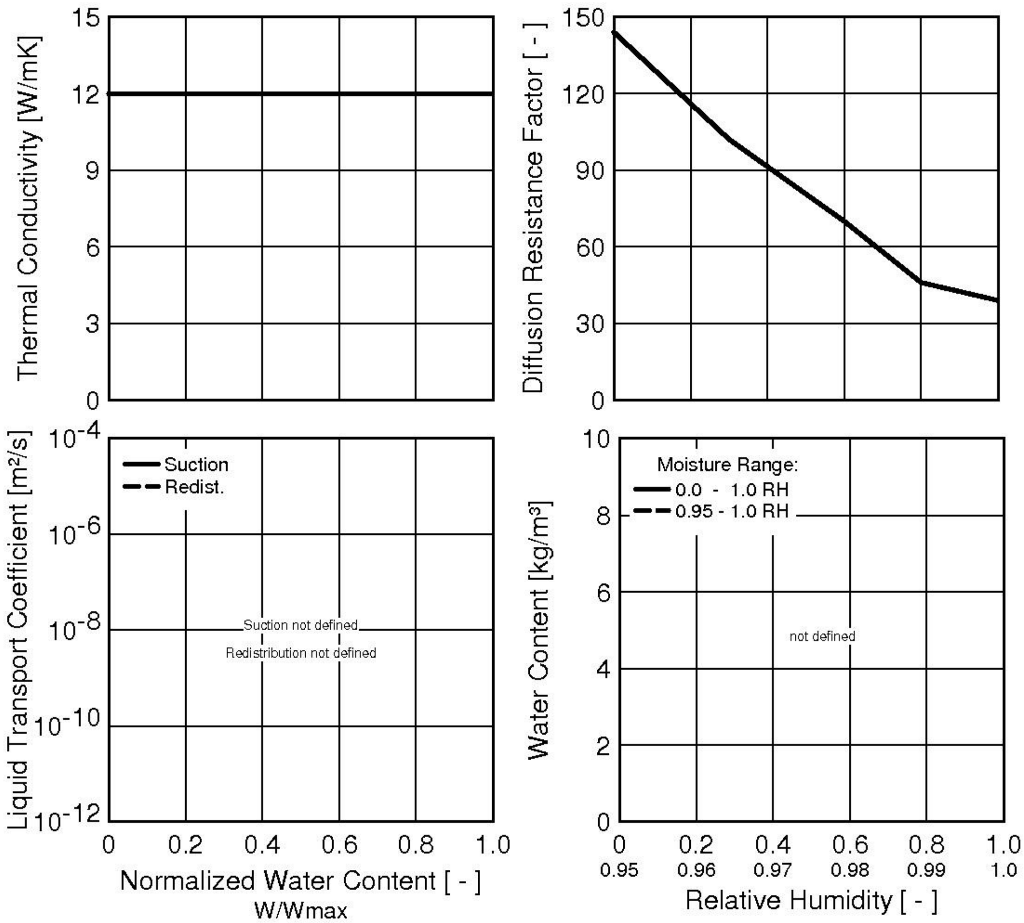
Property	Unit	Value
Bulk density	[kg/m³]	1,3
Porosity	[m³/m³]	0,999
Specific Heat Capacity, Dry	[J/kgK]	1000,0
Thermal Conductivity, Dry	[W/mK]	0,13
Water Vapour Diffusion Resistance Factor	[-]	0,56



Material : 60 minute Building Paper

Checking Input Data

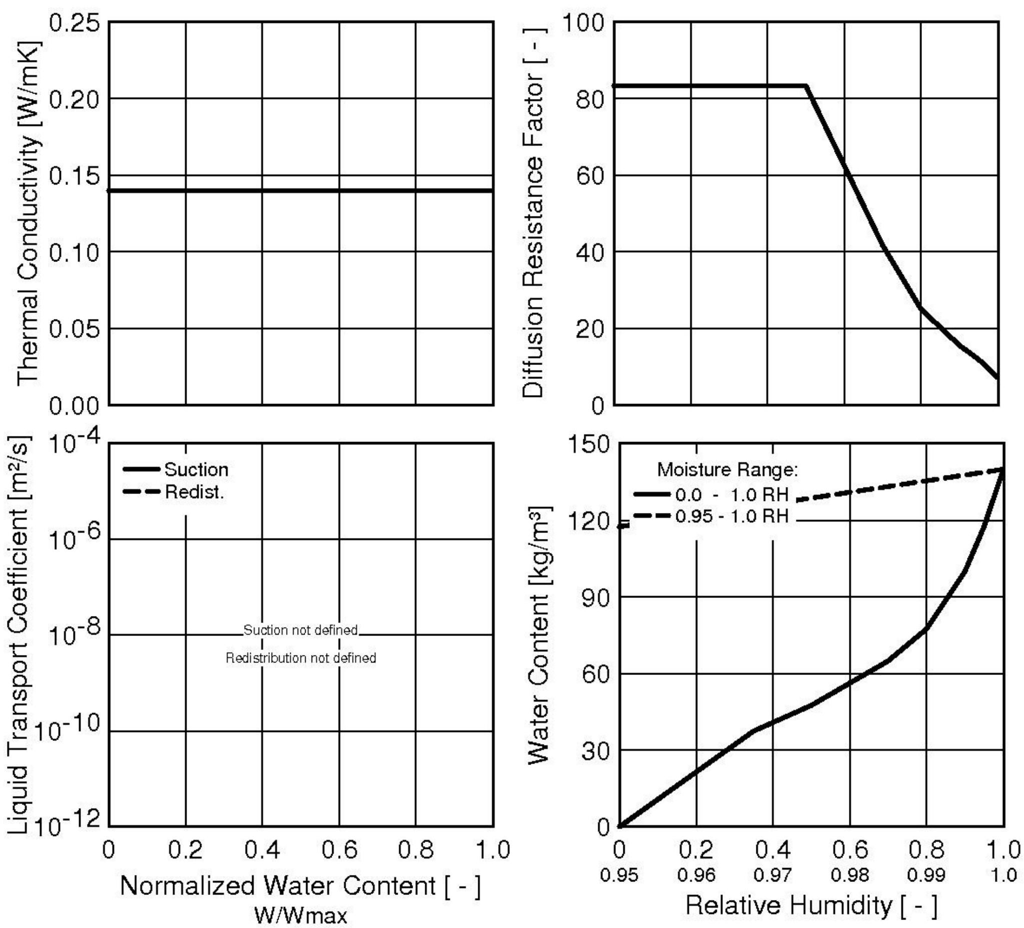
Property	Unit	Value
Bulk density	[kg/m³]	280,0
Porosity	[m³/m³]	0,001
Specific Heat Capacity, Dry	[J/kgK]	1500,0
Thermal Conductivity, Dry	[W/mK]	12,0
Water Vapour Diffusion Resistance Factor	[-]	144,0



Material : Spruce, tangential

Checking Input Data

Property	Unit	Value
Bulk density	[kg/m³]	430,0
Porosity	[m³/m³]	0,73
Specific Heat Capacity, Dry	[J/kgK]	1600,0
Thermal Conductivity, Dry	[W/mK]	0,14
Water Vapour Diffusion Resistance Factor	[-]	83,3

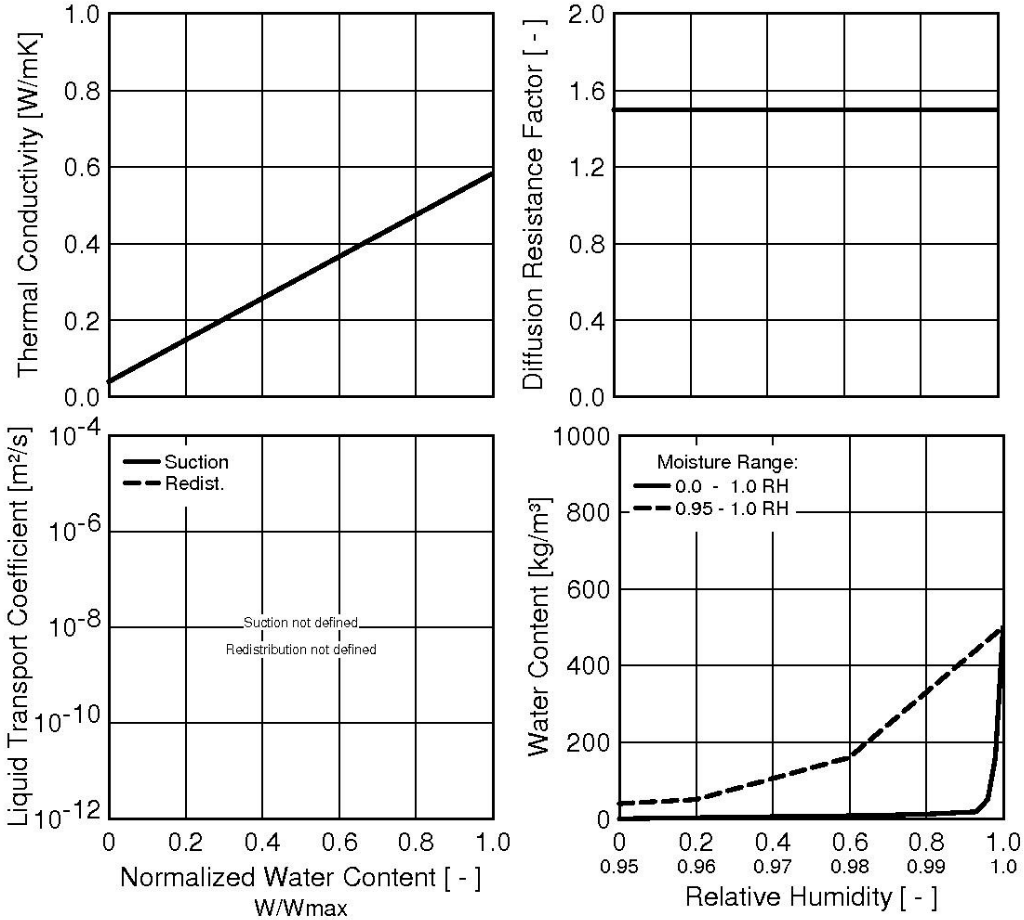


WUFI® Pro 4.2 IBP

Material : Cellulose Fiber (heat cond.: 0,04 W/mK)

Checking Input Data

Property	Unit	Value
Bulk density	[kg/m³]	70,0
Porosity	[m³/m³]	0,95
Specific Heat Capacity, Dry	[J/kgK]	2500,0
Thermal Conductivity, Dry	[W/mK]	0,04
Water Vapour Diffusion Resistance Factor	[-]	1,5
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	1,0



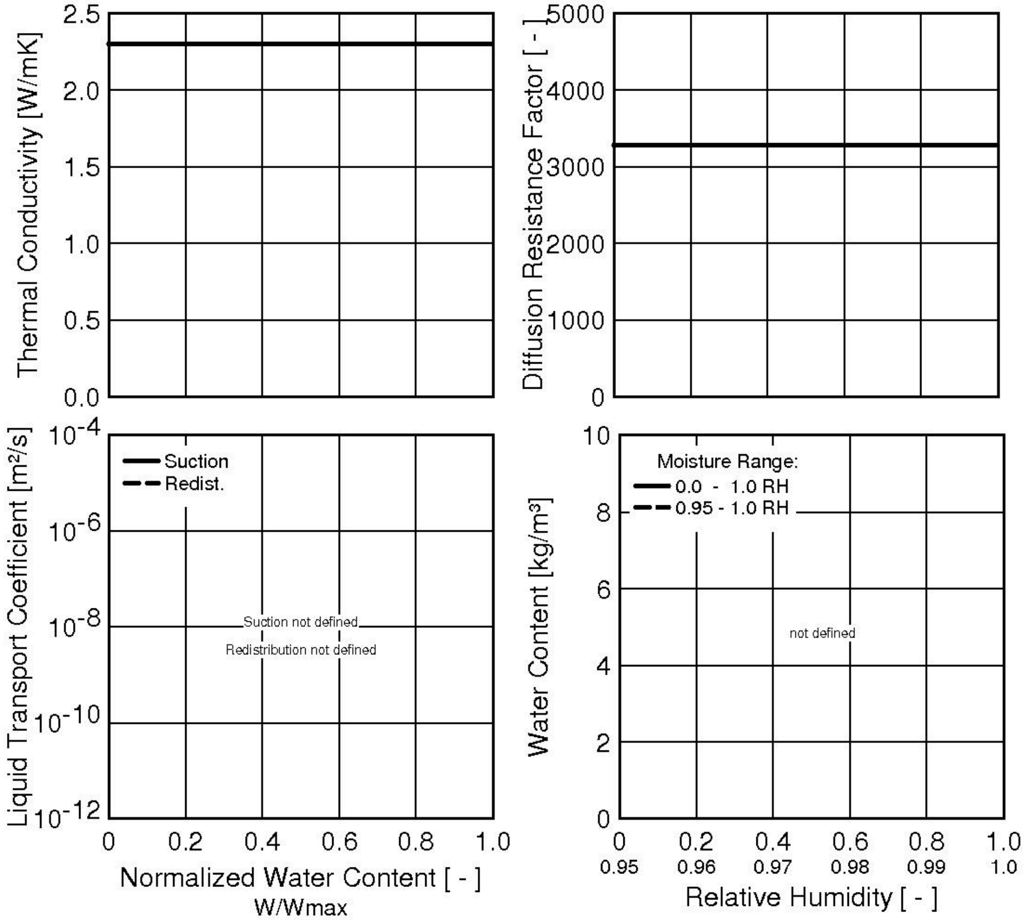
WUFI® Pro 4.2 IBP; Project: WUFI-verify.W4P; Case 1: South no rain; Date: 22/06/2011 5:00:20 PM Page : 6

WUFI® Pro 4.2 IBP

Material : vapor retarder (1perm)

Checking Input Data

Property	Unit	Value
Bulk density	[kg/m³]	130,0
Porosity	[m³/m³]	0,001
Specific Heat Capacity, Dry	[J/kgK]	2300,0
Thermal Conductivity, Dry	[W/mK]	2,3
Water Vapour Diffusion Resistance Factor	[-]	3280,0



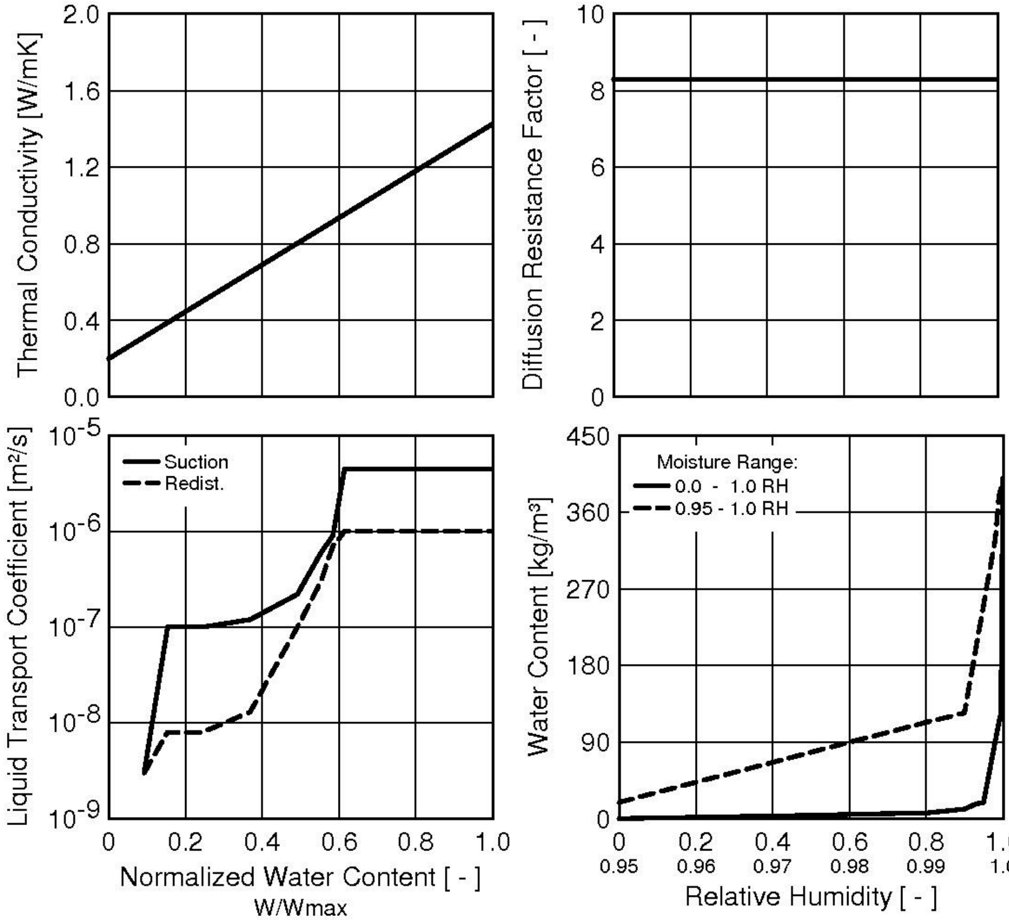
WUFI® Pro 4.2 IBP

IBP

Material : Gypsum Board

Checking Input Data

Property	Unit	Value
Bulk density	[kg/m³]	850,0
Porosity	[m³/m³]	0,65
Specific Heat Capacity, Dry	[J/kgK]	850,0
Thermal Conductivity, Dry	[W/mK]	0,2
Water Vapour Diffusion Resistance Factor	[-]	8,3
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	8,0



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