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Simulation Study of Building Envelope Performance Using Microclimatic Meteorological Data

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ABSTRACT

To accurately calculate heat, air and moisture (HAM) transfer in building envelopes, appropriate boundary conditions need to be specified. A previous study by Salonvaara and Karagiozis showed that calculations of moisture content in brick cladding could differ up to thirty times in magnitude when using different weather data sources. This study aims to investigate the effect of using urban (downtown) and suburban (Pearson Airport) weather data on HAM and wind driven rain (WDR) simulation. It was found that the temperature and humidity are very similar and WDR experienced differences between the two datasets. By utilizing WUFI for simulation of fifteen years of data, it was discovered that some WDR events peak at different times, however, the moisture can dry out in a reasonably short period of time. Also there are minimal differences in heat transfer between the two sets of data. Further, more detailed studies should be carried out with high resolution data to confirm such findings.

1.0 INTRODUCTION

The use of inappropriate weather data can lead to underestimating moisture accumulation and drying potential of building envelopes, which can directly influence the durability of building envelope components. For example, in 1998, Salonvaara and Karagiozis found the difference in calculations of moisture accumulation in brick cladding to be up to 30 times more when employing WYEC (Weather year for energy calculation) data than weather data provided by NOAA (National Oceanic and Atmospheric Administration) (Salonvaara & Karagiozis, 1998). 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. 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 (B. Blocken & Carmeliet, 2007; B. Blocken, Roels, & Carmeliet, 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, as opposed to currently most used arithmetically averaged hourly datasets provided by most weather stations across the world that is used in simulation software, commercial or research based usage (B. Blocken & Carmeliet, 2008).

When performing HAM and WDR analysis, the weather station is usually located at a different region from the location being studied. 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. For example, in Toronto, Toronto Pearson International Airport is the usual source of 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 rain amount are the particularly relevant. They can affect the rain water disposition on the wall surface of buildings, and in turn, may change the moisture content and energy performance of the building envelope.

This study attempts to compare test case simulation between weather data from the usual source at the Toronto Pearson Airport and Toronto downtown weather stations. The result from the study will reveal whether there are significant differences in terms of moisture management performance and energy performance of the building envelope. This could show if previous study results as mentioned above apply to the Toronto area.

2.0 OBTAINING METEOROLOGICAL DATA

Environment Canada records and archives all meteorological data across Canada and makes it available for the general public (*Canada's national climate archive,* nd). 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. The second type of data set is CWEC files, Canadian Weather for Energy Calculation. The data is prepared by the National Research Council of Canada based on the statistics of 30 years of CWEEDS data. The data set contains twelve months of the highest occurrence data from CWEEDS database on long term statistics on individual data items. This data set is used for simulation of typical Canadian cities weather. This study focuses on investigating the effect of the location where the weather data is collected, relative to the location of interest, on the simulated moisture result of the study lie. Originally, it was envisioned that the five minutes data from the Ryerson University urban weather network (established in July 2009). However, due to technical reasons, such data was not available. Therefore CWEEDS was used in this study. It was determined that the Toronto weather station 04741 has the closest resemblance of downtown environment (Charles St and Jarvis St) and it is also very close to the Ryerson University campus. The weather station 94791 at Pearson International Airport will be used to represent the suburban climate.

Due to various gaps in available data over certain years between two weather station, it was found that only the data from 1974 to 1989 was complete enough between two stations so it can be used in the study. It was also estimated that fifteen years of data would be sufficient to provide a consistent and sufficiently accurate result.

3.0 METEOROLOGICAL DATA ANALYSIS

The weather data between the Pearson Airport and downtown Jarvis weather stations were analyzed before the simulation could be performed. This allowed for a preliminary overview of the difference in the weather data. When this analysis was paired up with the simulation result, a more thorough analysis and conclusion could be drawn. Since the focus of the study is in microclimatic conditions, temperature, dew point, and wind driven rain are being examined. It is noticed that there is minimal difference for dry bulb temperature and dew point temperature between Airport and Jarvis data.

3.1 Wind Driven Rain

Wind driven rain WDR is one of the most important moisture source to a façade and it is one of the most important topic in building physics (B. Blocken & Carmeliet, 2004; Choi, 1994). Physical measurement of wind driven rain is very time consuming and prone to error (B. Blocken & Carmeliet, 2006). There are different approaches to obtaining the WDR data from the meteorological data. The common ones that are frequently used are the following (B. Blocken & Carmeliet, 2010):

1. Semi-empirical model in ISO Standard for WDR (ISO, 2009)
2. Semi-empirical model by Straube and Burnett (Straube, 1998)
3. CFD model by Choi (Choi, 1991), extended by Blocken and Carmeliet (B. Blocken & Carmeliet, 2002; B. Blocken & Carmeliet, 2007)

In addition to the above models for wind driven rain, AHSRAE Standard 160P (Draft 2008) *"Criteria for Moisture-Control Design Analysis"* is a proposed standard which include calculating the wind driven rain load on a wall based on the wind speed, direction, and normal rain load by the Equation (1).

$$R_{bv} = F_E \cdot F_D \cdot F_L \cdot U \cdot \cos\theta \cdot R_h \qquad (1)$$

where F_E is the rain exposure factor, F_D is the rain deposition factor, F_L is an empirical constant, U is hourly average wind speed at 10 m height, m/s, θ is angle between wind direction and normal to the wall, R_h is rainfall intensity on the horizontal surface, mm/h, R_{bv} is rain deposition on vertical wall, kg/(m^2 h). The exposure factor is tabled in the standard based on the terrain and the height of the building. The rain deposition factor is based on whether the wall is under a steep-sloped roof or low-sloped roof, or whether the wall material is subject to rain run-off.

At this stage of the project, the CFD model approach is out of the scope and resources available in this project. The Straube and Burnett model will require further investigation on the power-law function where specific information is unavailable at the moment (B. Blocken & Carmeliet, 2010). Since ASHRAE 160P is a North American standard, it will be more suitable for this study as Toronto is the location of interest, and therefore it will be applied here.

In this study, it is assumed that the building is a two storey townhouse which is sheltered by buildings around it. The roof on the townhouse complex is a low-sloped. Hence, the rain exposure factor is 0.7 and rain deposition factor is 0.5.

Based on the above formula, the wind driven rain is calculated for the same period of time, in the year of 1978 (shown as a sample in Figure 1). It was noticed that there are some differences in the amount of wind driven rain from the two weather data sets. At certain periods of time, for example, at 1700 hrs and 2700 hrs, the wind driven rain at Pearson Airport is significantly more than that of downtown. It was also noticed that the total number of rain events is minimal throughout the year. This may suggest that even though there are differences between the two weather station data, the effect of this moisture source to the building could be minimal. This is verified in a simulation study later in the report.

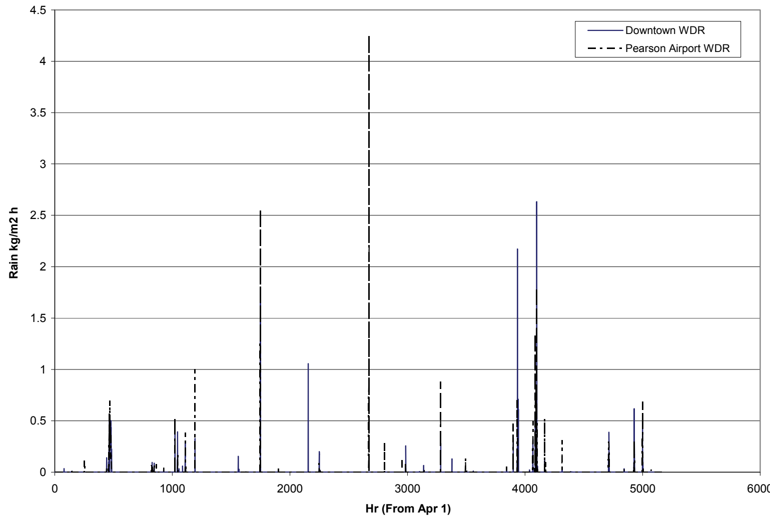


Figure 1: 1978 Toronto wind driven rain, north façade, townhouse

4.0 WUFI SIMULATION USING AIRPORT AND DOWNTOWN WEATHER DATA

In order to verify the effects of the suburban and urban meteorological data, a simulation study was carried out for the Pearson Airport and downtown Jarvis data. Several commercial and research purpose software packages are available for these simulation. 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 package has its own design year data set for engineering calculation that cannot be altered, and, thus, were not applicable for this study.
- The software needs to account for moisture storage and transport within the building envelope. It is noticed that there is minimal difference between the dry bulb temperature and dew point temperature. The other major difference is the wind driven rain which acts as a water source to the building envelope. The software tool is required to precisely account for the suction and transportation of the moisture within the material.
- The software is simple to use and able to extract the required result from different location of the building. The temperature, moisture content and heat flux should be able to be plotted among the two stations at any location within the building envelope.

WUFI (*IBP / software / WUFI*) was chosen for the simulation using Pearson Airport and downtown Jarvis weather data. The ease of use and flexibility in weather data input makes it the ideal tool for this study. 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 calculate the effect wind driven rain has on the façade. The software calculates the HAM in transient format instead of the over simplified steady state calculation.

In this study, the typical North American residential wood frame building envelope will be used. The cladding will be 105 mm clay brick. Then there will be 25 mm air space, building paper, 12.5 mm OSB sheathing, 89 mm fiberglass insulation, 0.15 mm polyethylene vapour retarder and 12.5 mm gypsum board wall.

4.1 Boundary Conditions

WUFI can generate the required weather data based on the meteorological data input from the user. In this study, the following data items were 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 pieces of data were obtained from the weather database that was created for this study. Data manipulation was required for the above items before data could be used to generate the .wac file. After the weather data was imported to WUFI, the software allowed the user to analyze amount of the wind driven rain (Figure 2). It was observed that the wind driven rain is more concentrated on the south east direction. The use of Airport data resulted in slightly higher amount of WDR over Jarvis data, especially in the west direction.

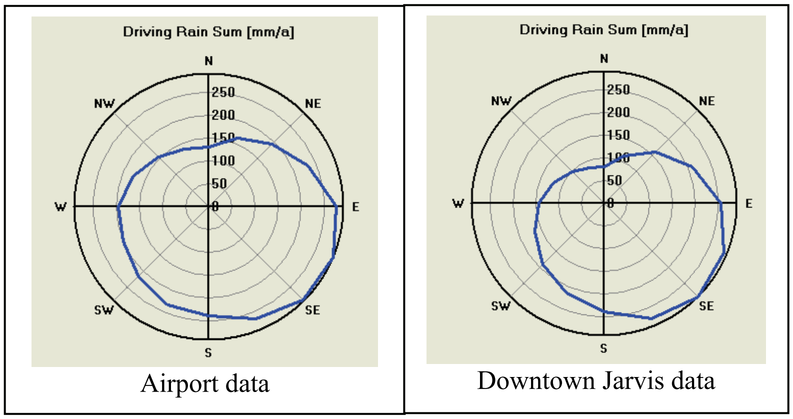


Figure 2: Wind driven rain compare

For the study, it was assumed that the subject building is a townhouse with the front facing south, therefore, simulation was executed only on the south and north façades which are exposed to exterior climate.

For the indoor conditions, WTA (International Association for Science and Technology of Building Maintenance and Monument Preservation) Guideline 6-2-01/E was used with medium moisture load. This is the default indoor condition set in WUFI. WUFI has other standard indoor condition from different standard, e.g. DIN EN 13788 and EN 15026. The default was chosen for reference purposes since this is a comparison study. There was no other source and sink for heat and moisture in this study. Initial conditions of the building envelope were set at 20^{o}C and 80% RH, which accounted for a 'new construction' moisture.

Table 1: Moisture content of building envelope during the study period

	Pearson Airport				Downtown Jarvis			
	North façade		South façade		North façade		South façade	
Moisture 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	0.00	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 moisture content	1.27	21.44	1.13	14.61	1.19	12.3	0.97	11.27

4.2 Simulation Results

The total moisture content of the north and south façades is shown in Figures 3&4. The extremes for the two stations are summarized in the Table 1. It was noted that the maximum and minimum moisture content among the different materials within the building envelope has minimal difference between the case that uses Pearson Airport data and the case that uses downtown Jarvis data. The total moisture content in the wall is different by about 75% on north façade and 30% for the south façade at maximum. The biggest differences were found in the exterior bricks at about 85% at maximum.

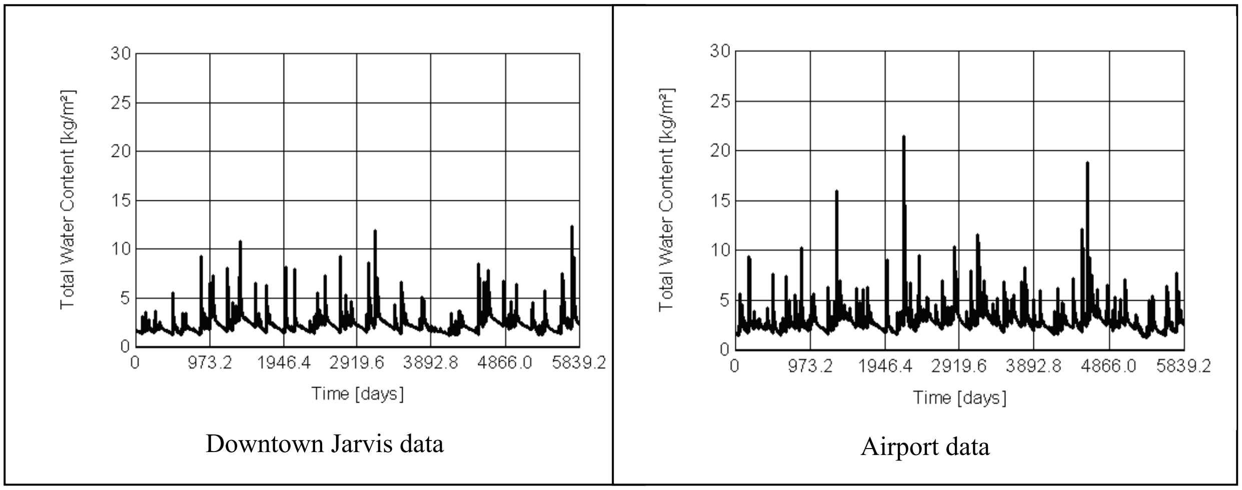


Figure 3: Total moisture content of north façade

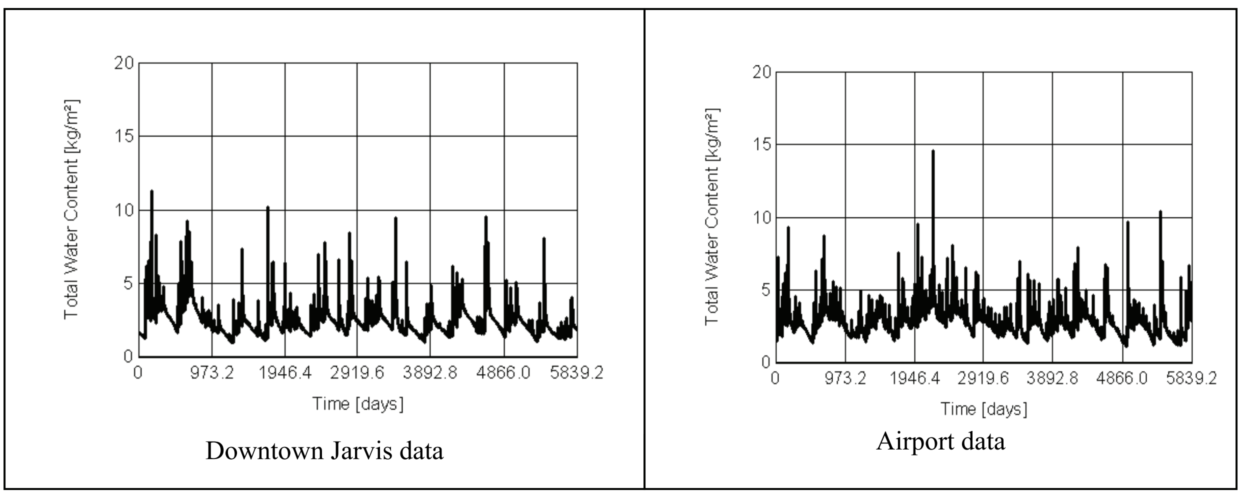


Figure 4: Total moisture content of south façade

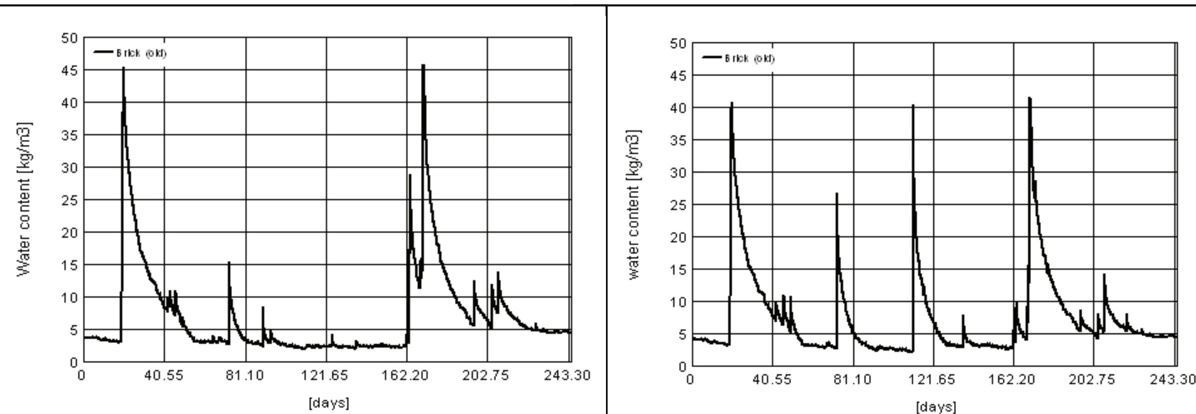
Table 2: Heat flux and moisture flux exchange of the building envelope

	Pearson Airport		Downtown Jarvis	
	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

4.3 Discussion of Results

The study uses fifteen years of meteorological data to compare the effect of microclimatic conditions on the results of building envelope performance in Toronto. Pearson Airport and downtown Jarvis weather stations were chosen in this study to simulate the suburban data versus downtown urban data. From the total moisture content results (Figures 3&4), it was noted that the average total moisture contents between two cases were fairly similar. There were some local maximums appearing in the case using the airport data on both north and south façade. However, from the simulation results, the moisture contributed by the wind driven rain can be dried within a reasonable time frame without prolonged accumulation of water inside the building walls.

From Table 3, it can be seen that the maximum difference of moisture content is located on the exterior brick layer of the wall system. This could be explained by direct exposure to WDR and moisture storage capacity of bricks. From the data analysis (Figure 1), it can be seen that there are differences in terms of wind driven rain based on the ASHRAE 160P (draft 2008). The comparison shows that at certain time there are significant differences in the wind driven rain of factors of 2 or 3 times. The moisture content in the brick during the same period of time is shown in Figure 5. The moisture content in the brick layer did reflect the scattered wind driven rain event throughout that year, with the airport data resulting in higher moisture content scattered throughout the year compared to downtown Jarvis data. The actual magnitude of the moisture content is based on the suction and sorption function of the cladding material.



Downtown Jarvis data | Airport data

Figure 5: Moisture content of brick during 1978 (April 1, to November 30)

On the energy transfer aspect, the result shows that there is minimal difference between the two cases (Table 4). The total energy difference is about 20 MJ/m^2h, which is equal to about 5kWh/m^2 for 15 years. This works out to about 1.3 MJ/m^2 per year or 0.333 kWh/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 transferred. There is approximately 400 MJ/m^2 difference of heat flux between the north and south façades. This could be explained by the solar radiation from the sun, and can also indicate that the solar calculation of the simulation was executed properly.

The most noteworthy observation is that the effect of microclimatic condition in Toronto is not significant as per previous studies from Europe. From their studies, wind driven rain is identified as the biggest moisture source on a building façade and they properly predict that the wind driven rain is crucial in studying the hydrothermal properties of the building envelope.

There can be several reasons for this study's result. First is the annual rain fall amount in Toronto: according to Environment Canada, Toronto averages around 700 mm of rain in a year. In comparison, in Netherlands, where above referred study was done, the annual average is 900-1100 mm of rain. In Vancouver, the average rainfall is 1230 mm annually. 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 big cities in the world, e.g. 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 apartment, single or two storey residential units. The effect of the highly urban microclimatic conditions is therefore diminished.

The third reason for such a result is that of the elevation of the weather station. Both weather stations are situated at an elevation of about 120m above ground. The meteorological data from these stations may not represent 100% of what the residential buildings at street level experience. However, these data is the closest that the study could obtain at the moment. Measuring the wind speed and direction at street level would be expensive on resources and is not practical for general usage. Advanced CFD analysis could generate the required data but it is also time and resource intensive. 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 should be noted that, the result and discussion of the study only applies to the Toronto area with typical residential building material. For other types of constructions, further studies are required to formulate the observation as discussed above. The characteristics of the meteorological data are much localized. Results from this study may not apply to other locations.

4.4 Future Work

At the time of this study, the five-minute data was not available from Ryerson weather station. Therefore the hourly data from Environment Canada station was used in this study. The five-minute data from Ryerson University urban weather network is needed to perform the analysis which can be compared with the hourly data within the same time period from Environment Canada. The simulation can then be carried out by HAM Tools (*International building physics toolbox.* nd). This could provide information regarding the effect of high resolution data to WDR and HAM performance of building envelope.

This study investigates the amount of energy and moisture transport differences between simulations using the data from the two weather stations. Further study should be carried out for the total amount of energy (sensible and latent) difference in terms of energy cost. This could provide a better understanding of the impact of having different data from the two weather stations. Software packages which focus on energy consumption can be used for this purpose e.g. Energy Plus.

One of the major drawbacks of this study is the positioning of the weather station. Since the weather station at downtown Jarvis is at an elevation of 120m above ground, the actual wind data on the subject building (low-rise) may not be fully relevant. To further improve this study, a test building should be constructed in the close proximity of the weather station. The test building should be wired with sensors to monitor the condition inside the building envelope. The measured data then can be compared with the simulation result utilizing the meteorological data from that station. This can show whether the simulation is capable of replicating the results of the physical world. The same simulation can then be executed with the data from suburban weather station which could reinforce the findings from this study.

Since physical measurement of meteorological data at street level is usually not practical, a CFD study at the test building should be carried out. This could verify the CFD data is representative of the physical measurements. The building information (size, orientation) of the city of Toronto will be required for generating the CFD model. It is very difficult and time consuming to gather this data as there is no central library for the required information.

5.0 CONCLUSION

This study aimed to investigate the effect of the microclimatic conditions in urban and suburban area and the effect of high resolution weather data on building envelope HAM performance simulation results. Due to unforeseeable circumstances in obtaining the five-minute data from Ryerson University urban weather station, the Pearson Airport data and downtown Jarvis hourly data was used for this study. Although this may have compromised the completeness of the research, this study still provided a significant indication that further study is required in this topic. For future work, the five-minute data has to be utilized to confirm the findings from this study.

Different wind driven rain approaches were analyzed and it was found that the semi-empirical model is the more common type. AHSRAE 160P (Draft 2008) was used in this study since it is a North American standard and the location of interest is Toronto.

From analyzing the weather data between Airport and Jarvis weather stations, it was noted that there are minimal differences in terms of dry bulb temperature and dew point temperature. The wind driven rain was calculated for a sample year and it was found that there are differences between the airport and Jarvis data. In some cases, the amount of WDR at one station is four times the amount measured at other one. This provided valuable information for analyzing the simulation results.

The simulation used fifteen years of data from the two weather stations. The results showed that on average, the moisture content of the building envelope were the same throughout the 15 year period. Although there was high moisture in the building envelope scattered throughout the period, the drying process was quick and the moisture content of the wall returned to average reasonably fast. For the same periods where the WDR were investigated, the simulation confirmed that the moisture content in the brick cladding reached the peak at WDR event. The energy differences between the two weather data sets were also minimal. This shows that the effect of suburban and urban weather data difference is minimal in terms of moisture and energy transport.

This observation can be explained by the annual amount of rainfall in Toronto, which is much less compared to Vancouver or 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 high resolution data and physical building measurement should be carried out to verify the findings.

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