Energy Efficient Door Design

Martin Liem

WOOD 493

A Report Submitted in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science in Wood Products Processing

In

The Faculty of Forestry

Prepared For:

Dr. Jack Saddler
Professor and Dean
Wood Products
Biotechnology
University of British Columbia

Dr. Peter Marshall
Associate Dean
Undergraduate Studies
University of British Columbia
EXECUTIVE SUMMARY

It is important to strive for greater energy efficiency when producing a product that will have a significant effect on a household’s overall energy consumption. The door manufacturing industry has been mandated by the Canadian federal government to authenticate that each product that they sell has a U-value no greater than 2.00 W/m²K. This regulation has caused door producers to re-evaluate their designs and certify only their most efficient designs before the enforcement date of January 1st, 2010. Currently only 11 solid wood exterior door designs offered by 2 manufacturers are listed under the CSA directory of certified exterior doors (CSA, 2009).

The purpose of this study is to determine the necessary features that a pre-hung door system is required to have in order to comply with the new building code. As it stands, solid wood doors will need to be built to a minimum thickness of 2-1/4”; use foam insulated cores; and / or incorporate the use of large sections of insulated glass units. This report will explain the specific requirements needed in order for an exterior door unit to qualify for sale within Canada. This study will detail a design brief outlining the key design characteristics that will help increase the energy efficiency of the design. A classical door design will then be evaluated by a thermal simulation testing software called THERM, which is the same method of product testing that is used by the engineering firms currently certifying fenestration products.
List of Key Words

Energy Star
Product Development
Energy Rating
CSA A453-95
Prototype
Door certification
Thermal efficiency
Air tightness
# TABLE OF CONTENTS

Executive Summary

List of Key Words

Table of Contents

List of Tables

List of Figures

Introduction

1.1 Project Scope

1.2 Topic Overview

2.0 Situation Overview

2.1 Reasons for Change

2.2 Heat Loss due to Air Infiltration

3.0 Certification Requirements

3.1 Minimum Requirements

3.2 Thermal Efficiency Requirements

3.3 Potential Building Code Changes

3.4 Air Tightness (A)

3.5 Water Tightness (B)

3.6 Wind Load Resistance (C)

3.7 Energy Rating (ER)
4.0 Thermal Properties of Materials

- 4.1 Thermal Conductivity
- 4.2 U-Value
- 4.3 R-Value
- 4.4 Thermal Properties of Construction Materials
- 4.5 Thermal Properties of Glazing Units

5.0 Door Design Aspects

- 5.1 Evaluation of a Door Unit
- 5.2 Insulated Door Slabs
- 5.3 Incorporating Glazing Units
- 5.4 Key Dimensions and Specifications
- 5.5 Threshold Clearance
- 5.6 Weather Stripping

6.0 Testing and Evaluation

- 6.1 THERM Finite Element Simulator
- 6.2 Window 5 Software
- 6.3 Results

7.0 Conclusion

References

Appendix A – Window 5 Report
LIST OF TABLES

Table 1: Energy Star Climate Zone Ratings ................................................................. 7
Table 2: Air Tightness ................................................................................................. 8
Table 3: Water Tightness Ratings ............................................................................. 9
Table 4: Suggested Minimum Ratings for Wind-driven Rain Resistance ............... 9
Table 5: Wind Load Ratings ..................................................................................... 10
Table 6: Thermal Conductivity of Construction Materials ...................................... 14
Table 7: Glass R-Values ......................................................................................... 15
LIST OF FIGURES

Figure 1: Climate Zones (NRCan, 2009) ................................................................. 4
Figure 2: Average Annual Energy Consumption per Household (Ugursal, 1997) ............ 5
Figure 3: Thermal Conductivity .............................................................................. 12
Figure 4: Door Diagram (Exterior View) .................................................................. 16
Figure 5: Door Slab Core Diagram .......................................................................... 17
Figure 6: French Door ............................................................................................. 18
Figure 7: Lock Side Corner Detail ............................................................................ 19
Figure 8: Cross-section Diagram – Sill ................................................................. 19
Figure 9: Types of weather stripping (Darling, 2008) ............................................. 20
Figure 10: Cross-section Diagram – Head Jamb .................................................... 21
Figure 11: Thermal Gradient (Threshold) .............................................................. 22
Figure 12: Window 5 Interface Screenshot ............................................................ 24
INTRODUCTION

The Canadian fenestration industry is presently under a significant strain to conform to strict certification requirements in order for their products to be approved for sale within Canada. The certification deadline for windows and sliding doors has already passed on January 1st, 2009; however, the certification deadline for swinging doors has been delayed until January 1st, 2010. Prior to the introduction of this regulation, the BC government promoted the sale of energy efficient windows by offering the added incentive of a PST exemption for multi-glazed windows (Bonney, 2008). Now that all windows sold in BC must be certified for energy efficiency, this PST exemption will be withdrawn as of March 31st, 2009. With the elimination of this tax advantage and the added costs incurred due to the certification requirement, this decision has been met with some fierce opposition by both consumers and manufacturers. By the end of this report, we will understand the reasoning behind this new regulation, as well as the implications this change will have on the various sectors within the window and door industry of Canada. Currently only 11 solid wood door designs offered by 2 manufacturers are listed under the CSA directory of certified exterior doors, compared to 144 steel doors and 14 fibreglass doors in the same listing (CSA, 2009).

1.1 Project Scope

Due to the high degree of relation between door and window products, this report will make a few references and comments regarding the window industry of Canada; however, for the purpose of maintaining a consistent flow of thought, this paper will primarily focus on the
door industry. In congruence with the nature of the wood products processing program, this project will further hone its focus by specifically concentrating on the design of a solid wood door rather than insulated steel and fibreglass doors, which are already able to reach higher insulation ratings (R-5 to R-6).

1.2 Topic Overview

This project will cover a few distinct topics regarding energy efficient door design. The first task of this report will be in explaining the moderately complex classifications and rating systems involved in the certification process. After achieving a clear understanding of what is outlined by the national building code of Canada, this paper will discuss the crucial differing characteristics of each material type that can be used to create a door unit; knowing this information will allow us to better understand the empirical differences between choosing alternative building materials for our design. The report will carry on by discussing a few design strategies that can improve the insulation rating of the door unit and then the final design will be evaluated using THERM and Window 5 thermal simulation software.
2.0 SITUATION OVERVIEW

The introduction of this new policy is a potent example of the federal government’s influence over Canadian businesses. The aim of this regulation is to ban the sale of less efficient exterior doors produced using less efficient materials; however, it also makes it infeasible for low-volume producers (i.e. custom window and door manufacturers) to neither pass on the certification costs to their customers, nor would they be able to persuade customers to accept exceptionally long lead times to allow for the certification process of their unique designs. Westwood Custom Windows and Doors Ltd. is one of at least a dozen custom manufacturers that indicated that they would be forced to shut down due to the introduction of the new regulation (Bonney, 2008). With plant closures and downsizing of these firms, upstream suppliers will also be affected by a slowdown in the demand for their products. Since a single small wood window and door manufacturer will purchase approximately 60,000 board feet of wood material per year, upstream suppliers will also sustain layoffs (Bonney, 2008). With the retraction of these smaller firms, the industry will be entering a period of consolidation.

2.1 Reasons for Change

This policy change is not new to the Canadian marketplace: In 2007, the federal government announced a ban on the sale of all incandescent light bulbs, which is expected to save an estimated six million tonnes of greenhouse gas (GHG) emissions from being released into the air on an annual basis, while saving the homeowner an average of $60 in electrical costs per year (CBC, 2007). With similar intentions and goals, the federal government expects that
the installation of certified doors and windows will reduce the average household’s energy consumption by up to 12% (NRCan, 2007). The majority of Canada experiences harsh summer and winter climates, with the only exception being Coastal British Columbia (See Figure 1). The interior provinces will typically have an average daily temperatures are near −15 °C in the winter, occasionally dropping below −40 °C (Wae, 2009). Summers on the west and east coasts will have average high temperatures in the low 20°C, whereas the interior provinces will average high temperatures ranging between 25 to 30 °C.

![Figure 1: Climate Zones (NRCan, 2009)](image_url)

Clearly, it is important to Canadians to own a properly insulated home. The amendments to the National Building Code of Canada will now ensure that the industry is producing products that are appropriate for our climate.
2.2 Heat Loss due to Air Infiltration

One other consideration that needs to be made when purchasing an exterior door is its ability to prevent air infiltration from the outdoors. The walls, windows and doors of a house forms what is called the “building envelope”. Any openings in this structure will reduce its energy efficiency by allowing heated air to escape the house during the winter months and cool air conditioned air to escape during the summer. The entry door can represent a significant weakness in the building envelope, as an improperly weather stripped threshold with a gap as small as 1/4” running along the bottom of a door is equivalent to having a hole in the wall that is 3 ½” in diameter. This single flaw in the building envelope can increase the energy costs of a household by as much as 8% (NRCan, 2009). With the average household consuming an average of 3240 GJ (See Figure 2) for space heating, proper weather sealing can save an average of approximately $200 - $300 per year depending on local energy prices. Therefore, it is quite clear that addressing construction issues such as this can be a worthwhile cause for a homeowner.

![Figure 2: Average Annual Energy Consumption per Household (Ugursal, 1997)](image-url)
3.0 CERTIFICATION REQUIREMENTS

Now that the fenestration industry has been forced into regulation, many of the companies that were unfamiliar with the realm of fenestration certification will now have to catch up to their more proactive competitors. This section will attempt to clarify a few of the important aspects related to certification that can be potentially confusing.

3.1 Minimum Requirements

The 2005 National Building Code of Canada (Division B, Section 9.6) requires all exterior wood doors to conform to the CAN/CSA-O132.2 guidelines (NRCC, 2005). In this edition of the Canadian building code, exterior doors are required to achieve a U-value\(^1\) no greater than 2.00 W/m\(^2\)K, which will need to be evaluated and certified by an accredited testing agency. In addition, doors and windows are also required to be evaluated based on air tightness, water tightness and wind load resistance, however the 2005 national building code does not specify a minimum requirement for doors and windows to attain during these evaluations.

\(^1\) U-value is an object’s area weighted measure of the thermal conductivity across its thickness. The value indicates the amount of heat (J) that is transferred per unit of time (s) measured over its total area (m\(^2\)) for a given temperature differential (°K).
3.2 Thermal Efficiency Requirements

The only firm requirement that the National Building Code of Canada has specified is that all window and door products manufactured for use in Canada must achieve a U-Value of 2.00 W/m²K. Natural Resources Canada has also developed a slightly higher standard, which is specific to each climate zone shown in Figure 1 and defined in the following table:

<table>
<thead>
<tr>
<th>Zone</th>
<th>Maximum U-Value (W/m²K)</th>
<th>Energy Rating Dimensionless*</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2.00</td>
<td>17</td>
</tr>
<tr>
<td>B</td>
<td>1.80</td>
<td>21</td>
</tr>
<tr>
<td>C</td>
<td>1.60</td>
<td>25</td>
</tr>
<tr>
<td>D</td>
<td>1.40</td>
<td>29</td>
</tr>
</tbody>
</table>

*ER = 57.76 SHGCW − 21.90 UW − 0.54 (L75 / AW) + 40

Source: (CSA, 2009)

3.3 Potential Building Code Changes

The state of the building regulations is currently under review by both Canadian and American institutions in order to develop a harmonized standard that can be accepted by both national building codes. Therefore, some BC manufacturers have opted to attain the higher standards set out by Energy Star in order be in a better position for when a final decision is made.
3.4 Air Tightness (A)

Although there is no specified minimum requirement set for the air tightness rating of a door, a physical test is still required and an evaluated value needs to be reported. In the testing of a door design, an actual sample is sent to the testing facility and the door unit is placed under a pressure differential of 35 Pa across the exterior and interior sides of the door. A higher A-Rating indicates that the door is more resistant to air infiltration.

Table 2: Air Tightness

<table>
<thead>
<tr>
<th>Air Tightness Rating</th>
<th>Max Air Leakage (m³/h)/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>2.79</td>
</tr>
<tr>
<td>A2</td>
<td>1.65</td>
</tr>
<tr>
<td>A3</td>
<td>0.55</td>
</tr>
</tbody>
</table>

Source: (NRCan, 2008)

3.5 Water Tightness (B)

Doors must also be evaluated for its resistance against water infiltration. A minimum water tightness rating is not set, however under unique circumstances a building inspector may request that the door unit exceed a specific water tightness rating. In this testing procedure, the interior side of the door is placed under a negative pressure (See Table 3), while the exterior side is sprayed with water. The performance rating is indicated based on the maximum negative pressure that the door can withstand before any water infiltration is observed. Water tightness ratings range from B1 to B7 – the higher the number, the more watertight the product.
Table 3: Water Tightness Ratings

<table>
<thead>
<tr>
<th>Water Tightness Rating</th>
<th>Pressure Differential (Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>150</td>
</tr>
<tr>
<td>B2</td>
<td>200</td>
</tr>
<tr>
<td>B3</td>
<td>300</td>
</tr>
<tr>
<td>B4</td>
<td>400</td>
</tr>
<tr>
<td>B5</td>
<td>500</td>
</tr>
<tr>
<td>B6</td>
<td>600</td>
</tr>
<tr>
<td>B7</td>
<td>700</td>
</tr>
</tbody>
</table>

Source: (NRCan, 2008)

The Canadian Mortgage and Housing Corporation recommend the following minimum water tightness ratings for the different areas within Canada:

Table 4: Suggested Minimum Ratings for Wind-driven Rain Resistance

<table>
<thead>
<tr>
<th>Region</th>
<th>Water Tightness Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Majority of Canada</td>
<td>B2</td>
</tr>
<tr>
<td>Queen Charlotte Islands</td>
<td>B5</td>
</tr>
<tr>
<td>Western Vancouver Island</td>
<td>B4</td>
</tr>
<tr>
<td>Eastern Vancouver Island, north coast of B.C.</td>
<td>B3</td>
</tr>
<tr>
<td>South-eastern Alberta, southern Saskatchewan</td>
<td>B3</td>
</tr>
<tr>
<td>St. Lawrence Valley, east Baffin Island, east New Brunswick, Nova Scotia, central Newfoundland</td>
<td>B3</td>
</tr>
</tbody>
</table>
3.6 Wind Load Resistance (C)

Doors are also required to be tested for their ability to withstand wind loads. This testing procedure simulates the effects of high wind load scenarios that can be experienced during a severe storm or hurricane. In this testing procedure a short burst of pressure is applied to the exterior side of the door unit and then it is inspected for permanent damage. Wind resistance ratings range between C1 to C5 – a higher number indicates a better resistance to impact wind loads.

**Table 5: Wind Load Ratings**

<table>
<thead>
<tr>
<th>Wind Load Rating</th>
<th>Wind Load Pressure (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>1.5</td>
</tr>
<tr>
<td>C2</td>
<td>2.0</td>
</tr>
<tr>
<td>C3</td>
<td>3.0</td>
</tr>
<tr>
<td>C4</td>
<td>4.0</td>
</tr>
<tr>
<td>C5</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Source: (NRCan, 2008)
3.7 Energy Rating (ER)

The energy rating (ER) value is calculated using the following formula (NRCan, 2009):

$$ER = 57.76 \text{ SHGCW} - 21.90 \text{ UW} - 0.54 \left(\frac{\text{L75}}{\text{AW}}\right) + 40$$

Where:

- SHGCW = total product solar heat gain coefficient, dimensionless
- UW = total product U-value in W/(m²•K)
- L75 = total airflow rate in m³/h at a pressure difference of 75 Pa
- AW = area in m² as per the reference sizes in Table 1.

Evaluating a door for its energy rating is purely optional for the manufacturer to determine. However, from the perspective of the homeowner, the energy rating (ER) is the bottom line figure to consider in comparing door units for its energy efficiency. The energy rating of a door unit is derived from:

- Solar heat gain
- Heat loss through frames, center and edge of glass
- Air leakage heat loss
- The addition of a constant +40 ER number
4.0 THERMAL PROPERTIES OF MATERIALS

This section will briefly discuss thermodynamics and its relevance to some common materials used in the construction of exterior doors. The thermal efficiency of a door is determined by two factors: material composition and thickness. Therefore, considering the material properties of materials used to construct a door will determine the thermal resistance. This section will introduce Thermal Conductivity, U-Value and R-Value in order to better understand the material comparisons that will be made at the end of this section.

4.1 Thermal Conductivity

Thermal conductivity is a material property represented by the corresponding SI units W/mK. The calculated thermal conductivity value is calculated based on the heat transfer (J) per unit of time (s) (Note: J/s = W), across a specific thickness (m) for a given temperature differential (∆T) measured in degrees Kelvin.

\[ \Delta T = T_{hot} - T_{cold} \]

Figure 3: Thermal Conductivity
4.2 U-Value

U-value is measured similarly to thermal conductivity, except it factors in one extra dimension – height. Therefore, U-value is represented in W/m²K, where the U-value indicates the amount of heat (J) that is transferred per unit of time (s) measured over its cross-sectional area (m²) for a given temperature differential (ºK). The U-value is an area-weighted average thermal conductivity over an object’s thickness and height. Because the cross-sections of windows and doors are quite irregular, an area-weighted value needs to be used.

4.3 R-Value

R-value is simply the inverse value of U-value (i.e. 1/U-value = R-value). This is the common builder’s terminology used to compare insulation value. In the context of this study, a U-value of 2.00 is equivalent to an R-value of 0.50. A typical 2”x4” wall space will be insulated with R-15 rated fibreglass batting, which will correspond to a U-value of 0.07.
4.4 Thermal Properties of Construction Materials

The thermal properties of the materials used for the construction of the door frame, slab and panels are under the greatest scrutiny since this is the greatest contributing factor to producing an acceptable U-value. Table 7 lists a few of the different types of materials that are used in the construction of a door:

Table 6: Thermal Conductivity of Construction Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal Conductivity (W/mK)</th>
<th>U-Value @ 2” Thick (W/m²K)</th>
<th>R-Value @ 2” Thick (m²K/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>250</td>
<td>4921</td>
<td>0.0002</td>
</tr>
<tr>
<td>Steel (1% carbon)</td>
<td>43</td>
<td>846.5</td>
<td>0.0012</td>
</tr>
<tr>
<td>Glass</td>
<td>1.05</td>
<td>20.67</td>
<td>0.0484</td>
</tr>
<tr>
<td>Vinyl</td>
<td>0.25</td>
<td>4.92</td>
<td>0.20</td>
</tr>
<tr>
<td>Oak</td>
<td>0.17</td>
<td>3.35</td>
<td>0.30</td>
</tr>
<tr>
<td>Pine</td>
<td>0.12</td>
<td>2.36</td>
<td>0.42</td>
</tr>
<tr>
<td>Douglas Fir</td>
<td>0.11</td>
<td>2.17</td>
<td>0.46</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>0.03</td>
<td>0.59</td>
<td>1.69</td>
</tr>
<tr>
<td>Air</td>
<td>0.024</td>
<td>0.47</td>
<td>2.12</td>
</tr>
<tr>
<td>Argon</td>
<td>0.016</td>
<td>0.31</td>
<td>3.18</td>
</tr>
</tbody>
</table>

Source: (TET, 2005)

As we can see from this table, a typical 2” thick door slab made of Douglas Fir, Pine, or Oak will not achieve the required U-value of 2.00 W/m²K – instead they will need to be a built to minimum of 2.17”, 2.36” and 3.35” thick respectively.
4.5 Thermal Properties of Glazing Units

Exterior doors will occasionally incorporate the use of glazing units (or “lites”) in its design, which would affect the overall U-value of the door unit. Typically, the U-value of an insulated glass unit will be superior to the solid wood frame it is installed in.

Table 7: Glass R-Values

<table>
<thead>
<tr>
<th>Type of Glass Unit</th>
<th>U-Value (W/m²K)</th>
<th>R-Value (m²K/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Pane regular glass</td>
<td>1.18</td>
<td>0.85</td>
</tr>
<tr>
<td>Clear Insulated Glass 7/8 inch overall thickness</td>
<td>0.48</td>
<td>2.08</td>
</tr>
<tr>
<td>Hard Coat Low-E insulated glass</td>
<td>0.41</td>
<td>2.45</td>
</tr>
<tr>
<td>Hard Coat Low-E insulated glass with argon</td>
<td>0.36</td>
<td>2.75</td>
</tr>
<tr>
<td>Soft Coat Low-E insulated Glass</td>
<td>0.29</td>
<td>3.50</td>
</tr>
<tr>
<td>Soft Coat Low-E insulated glass with argon</td>
<td>0.23</td>
<td>4.35</td>
</tr>
</tbody>
</table>

Source: (Carter, 2007)

Even the most superior door and window designs, incorporating the use of triple glazed, Low-E, argon filled glass units will only achieve an overall R-value between 3 and 4.5 (Jundt, 2009). Given that a standard 2”x4” framed wall will use R-13 to R-19 fiberglass insulation, the most energy-efficient door and window units are approximately 3 to 4 times less efficient than the wall they're installed in. Therefore, improving the efficiency of these weak points in the building envelope is critical to improving the home’s overall energy efficiency.
5.0 DOOR DESIGN ASPECTS

5.1 Evaluation of a Door Unit

In the previous section, we have learned how various types of materials will perform individually, while in this section, we will understand how they will contend as a whole. The overall U-value will be evaluated based on the area weighted contribution of each component of the door unit (NRCC, 2005). Sidelites and transoms\(^2\) are commonly paired with entry doors for aesthetic and design purposes (See Figure 4); however this can also work to the advantage of achieving a lower overall U-value, as the increased proportion of insulated glass units can offset some of the less thermally efficient sections made of solid wood.

![Door Diagram (Exterior View)](image)

Figure 4: Door Diagram (Exterior View)

\(^2\) A transom is a window installed above a door, forming part of a door unit.
5.2 Insulated Door Slabs

In section 4.4 we were able to establish that some solid wood doors will need to be built to exceptionally thick dimensions (2.36” and 3.35”) in order to achieve a U-value of 2.00, which would be impractical for most applications. To resolve this, the door slab can be constructed with an insulated core encased in a solid wood shell. A common insulating material used to fill a door cavity is expanded polystyrene, which is a rigid foam that has the ability to reach the target U-value of 2.00 with a mere thickness of 0.59”. Doors will typically range between 1 ¾” - 2 ¼” thick therefore the wood shell that will encase the foam insulation can add an additional 1.4” to the door thickness, which will bring the overall U-value of the door down to around 1.20 W/m²K – significantly lower than the target U-value.

Figure 5: Door Slab Core Diagram
5.3 Incorporating Glazing Units

As we have seen in section 4 of this report, incorporating the use of glazing units will often improve the overall U-value of the door unit. In addition, it will also allow for more light entry and thereby also increase the solar heat gain coefficient of the door.

![Door with Glass](image)

**Figure 6: French Door**

5.4 Key Dimensions and Specifications

In order to account for the dimensional changes in wood due to seasonal effects, the door design will need to incorporate specific clearances and offsets between particular elements of the door. The optimal clearance is typically set as narrow as possible to prevent as heat loss due to air leakage, but wide enough to allow for the expansion of the material during the wet
months of the year. Typically the door will have a 1/8” gap between the slab and the left, right and head jamb.

5.5 Threshold Clearance

The threshold of the door is typically set a bit higher in order to account for dirt and debris, unevenness of the floor as the door opens in and the possibility of the door being installed out of plumb. In the following diagram, the clearance has been set to a typical 1/4”.

Figure 7: Lock Side Corner Detail

Figure 8: Cross-section Diagram – Sill
The threshold is also the most difficult edge to weather strip. Because this area is prone to dirt and debris and wear, it is difficult to maintain a smooth and even surface for a door sweep to seal against. Also, the threshold should be free of any protrusions (i.e. door stops) so that there is less potential for an individual to trip over while passing through; this makes it difficult to find a weather stripping solution that will join well with the weather stripping surrounding the other three sides of the door.

5.6 Weather Stripping

Weather stripping bridges the gap between the door slab and the door jamb and sill. It provides a temporary seal around the doorway when the door is closed. There is a large variety of commonly available types of weather stripping, each offering different levels of the following characteristics: Air sealing effectiveness, durability; ease of operation, ease of installation and price.

![Types of weather stripping](Darling, 2008)
In the door design we will be evaluating, we will be employ the use of basic closed-cell foam to seal the gap 1/8” gap along the left, right and head jamb.

Figure 10: Cross-section Diagram – Head Jamb

The choice of weather stripping has a very minor effect on the overall U-value, but a more elaborate weather stripping option can be chosen to improve air and water infiltration resistance.
6.0 TESTING AND EVALUATION

The thermal evaluation of a door unit is quite a complex task considering that it is made of various types of materials and forms an irregular shape. Therefore, the certification process requires the use of computer simulation software to evaluate the U-value of a door unit. The thermal simulation modelling program that will be introduced in this section will be THERM and Window 5. THERM evaluates each cross-section’s specific U-value and then Window 5 calculates the area weighted average U-value.

6.1 THERM Finite Element Simulator

The sill, head, right and left jamb cross-sections need to be drawn and evaluated separately within this program. This program can accept AutoCAD DXF files as a graphic underlay which will allow us re-draw the components to scale.

![Figure 11: Thermal Gradient (Threshold)](image-url)
Each component material type needs to be defined (e.g. Wood, Butyl Rubber, etc.), which will have a corresponding thermal conductivity rating built into the program. Next, boundary conditions must be set in order to calculate the thermal gradient across the drawn cross-section (See Figure 11). The CSA standard requests for an interior temperature of 21 ºC and an exterior temperature of -18 ºC. With the boundary conditions set, the program can calculate the specific cross-section’s U-value.

6.2 Window 5 Software

Once each individual cross-section has been calculated, Window 5 software will accept these values and apply an area-weighted calculation of the overall unit’s U-value. According to CSA standards, all doors are evaluated with a nominal width of 1000mm by 2000mm high, regardless of the actual dimensions of the door. In the end, this software is will be able to produce a standardized report showing the door unit’s overall U-value as well as a piece by piece break down of the U-value contribution factors of the door slab and frame components (See Appendix A).
After designing and testing a classical solid wood door design with a 2” thick Douglas fir door slab, the resulting U-value that was calculated by the Window 5 software was 2.441 W/m²K. This result is not sufficient enough to pass the 2005 Nation Building Code, which is not a surprise based on our estimations made in Section 4.4.
7.0 CONCLUSION

In view of our results, wood door manufacturer will needs to consider incorporating insulating layers within the door slab as discussed in Section 5.2, or the extensive use of insulated glazing units (Section 5.3) in order to bring the overall U-value below 2.00 W/m²K. In order to meet the certification requirements set out by the 2005 National Building Code, products will also need to be tested for air tightness, water tightness and wind load resistance. While there minimum requirements have not been set for these rating schemes, it would be highly recommended that manufacturers strive to achieve the minimum standards suggested by Natural Resources Canada. Test products selected by certification agencies are chosen at random; therefore, the manufacturing process must be carried out in a controlled and repeatable manner.

Door manufacturers will also need to consider reducing the number of door designs that they are willing to offer; since each door configuration will need to be individually tested and certified, fixed design costs will rise and manufacturers will need to try to offset this increased cost over a larger customer base.

It will be a challenge for the existing wood door manufacturers to adapt to the new changes that are required of them following the turn of the decade; however, the firms that can endure this shakeout period will have a substantial market opportunity ahead of them.
REFERENCES


**APPENDIX A – WINDOW 5 REPORT**

Window 5.2a v5.2.17a Report  
ID: 1  
Name: Picture  
EnvCond: 1 NFRC 100-2001

Type: Fixed (picture)  
Tilt: 90  
Width: 1200.0 mm  
Height: 1500.0 mm  
Area: 1.80 m²

**U-value: 2.441 W/m²-K**  
SHGC: 0.602  
Vt: 0.648  
CI: 48.9

Data for Door Slab

<table>
<thead>
<tr>
<th>ID</th>
<th>Name</th>
<th>COG Area m²</th>
<th># Lay</th>
<th>Tilt</th>
<th>Uc W/m²2</th>
<th>SCc</th>
<th>SHGCc</th>
<th>Vtc</th>
<th>RHG</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Sample Slab</td>
<td>1.271</td>
<td>2</td>
<td>90</td>
<td>1.913</td>
<td>0.787</td>
<td>0.000</td>
<td>0.741</td>
<td>510</td>
</tr>
</tbody>
</table>

Frame and Glass Data for Door Slab '8 Sample Slab'

<table>
<thead>
<tr>
<th>ID</th>
<th>Name</th>
<th>D(mm)</th>
<th>Tsol</th>
<th>Rsol</th>
<th>Tvis</th>
<th>Rvis</th>
<th>Tir</th>
<th>Emis</th>
<th>Keff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9803</td>
<td>CLEAR5.LOF</td>
<td>4.7</td>
<td>.796</td>
<td>.074</td>
<td>.074</td>
<td>.888</td>
<td>.082</td>
<td>.000</td>
<td>.840</td>
</tr>
<tr>
<td></td>
<td>Air</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.049</td>
</tr>
<tr>
<td>9923</td>
<td>LOW-E_5.LOF</td>
<td>4.7</td>
<td>.676</td>
<td>.117</td>
<td>.105</td>
<td>.826</td>
<td>.115</td>
<td>.109</td>
<td>.000</td>
</tr>
</tbody>
</table>

Inside

Frame Data

<table>
<thead>
<tr>
<th>Location</th>
<th>ID</th>
<th>Name</th>
<th>Source</th>
<th>Frame Area m²</th>
<th>Edge Area m²</th>
<th>Uframe W/m²-K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Header</td>
<td>6</td>
<td>sample-head.T Therm</td>
<td>Therm</td>
<td>0.050</td>
<td>0.067</td>
<td>2.0070</td>
</tr>
<tr>
<td>Left Jamb</td>
<td>7</td>
<td>sample-jamb.T Therm</td>
<td>Therm</td>
<td>0.063</td>
<td>0.086</td>
<td>2.0400</td>
</tr>
<tr>
<td>Right Jamb</td>
<td>7</td>
<td>sample-jamb.T Therm</td>
<td>Therm</td>
<td>0.063</td>
<td>0.086</td>
<td>2.0400</td>
</tr>
<tr>
<td>Sill</td>
<td>8</td>
<td>sample-sill.T Therm</td>
<td>Therm</td>
<td>0.050</td>
<td>0.067</td>
<td>2.0010</td>
</tr>
</tbody>
</table>

Gas Data

<table>
<thead>
<tr>
<th>ID</th>
<th>Name</th>
<th>Type</th>
<th>Cond W/m-K</th>
<th>Visc kg/m-s</th>
<th>Cp J/kg-K</th>
<th>Dens kg/m³</th>
<th>Pran (x\ e^{-6})</th>
</tr>
</thead>
</table>

M. Liem
<p>| | | | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Air</td>
<td>Pure</td>
<td>0.0241</td>
<td>17.22</td>
<td>1006.10</td>
<td>1.2922</td>
<td>0.7197</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Tout | Tin | WndSpd | Wnd Dir | Solar | Tsky | Esky |   |   |   |
-----|----|-------|--------|-------|-----|-----|---|---|---|
-18.0 | 21.0 | 5.50  | Windward | 0.0  | -18.0 | 1.00 |

Solar | 32.0 | 24.0 | 2.80  | Windward | 783.0 | 32.0 | 1.00 |

Frame Library Data

<table>
<thead>
<tr>
<th>ID</th>
<th>Name</th>
<th>Source</th>
<th>U-value</th>
<th>Edge GlzSys</th>
<th>GlzSys Width</th>
<th>Abs</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>sample-head.T</td>
<td>Therm</td>
<td>2.0070</td>
<td>2.3500</td>
<td>N/A</td>
<td>1.934</td>
</tr>
<tr>
<td>7</td>
<td>sample-jamb.T</td>
<td>Therm</td>
<td>2.0400</td>
<td>2.3500</td>
<td>N/A</td>
<td>1.934</td>
</tr>
<tr>
<td>8</td>
<td>sample-sill.T</td>
<td>Therm</td>
<td>2.0010</td>
<td>2.3440</td>
<td>N/A</td>
<td>1.934</td>
</tr>
</tbody>
</table>

Divider Library Data

<table>
<thead>
<tr>
<th>ID</th>
<th>Name</th>
<th>Source</th>
<th>U-value</th>
<th>Edge GlzSys</th>
<th>GlzSys Width</th>
<th>Abs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

No Dividers for this Glazing System

Optical Properties for Glazing System '8 Sample GlzSys'

<table>
<thead>
<tr>
<th>Angle</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
<th>Hemis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vtc</td>
<td>0.741</td>
<td>0.740</td>
<td>0.736</td>
<td>0.729</td>
<td>0.719</td>
<td>0.691</td>
<td>0.620</td>
<td>0.470</td>
<td>0.236</td>
<td>0.000</td>
<td>0.640</td>
</tr>
<tr>
<td>Rf</td>
<td>0.174</td>
<td>0.173</td>
<td>0.174</td>
<td>0.178</td>
<td>0.187</td>
<td>0.213</td>
<td>0.278</td>
<td>0.424</td>
<td>0.671</td>
<td>1.000</td>
<td>0.255</td>
</tr>
<tr>
<td>Rb</td>
<td>0.166</td>
<td>0.165</td>
<td>0.166</td>
<td>0.169</td>
<td>0.178</td>
<td>0.203</td>
<td>0.266</td>
<td>0.404</td>
<td>0.648</td>
<td>1.000</td>
<td>0.244</td>
</tr>
<tr>
<td>Tsol</td>
<td>0.549</td>
<td>0.549</td>
<td>0.544</td>
<td>0.538</td>
<td>0.528</td>
<td>0.505</td>
<td>0.449</td>
<td>0.336</td>
<td>0.162</td>
<td>0.000</td>
<td>0.468</td>
</tr>
<tr>
<td>Rf</td>
<td>0.153</td>
<td>0.152</td>
<td>0.153</td>
<td>0.155</td>
<td>0.162</td>
<td>0.184</td>
<td>0.240</td>
<td>0.366</td>
<td>0.596</td>
<td>1.000</td>
<td>0.222</td>
</tr>
<tr>
<td>Rb</td>
<td>0.142</td>
<td>0.141</td>
<td>0.142</td>
<td>0.143</td>
<td>0.145</td>
<td>0.153</td>
<td>0.175</td>
<td>0.232</td>
<td>0.362</td>
<td>0.607</td>
<td>1.000</td>
</tr>
<tr>
<td>Abs1</td>
<td>0.140</td>
<td>0.141</td>
<td>0.143</td>
<td>0.147</td>
<td>0.153</td>
<td>0.160</td>
<td>0.169</td>
<td>0.179</td>
<td>0.176</td>
<td>0.000</td>
<td>0.157</td>
</tr>
<tr>
<td>Abs2</td>
<td>0.158</td>
<td>0.159</td>
<td>0.160</td>
<td>0.160</td>
<td>0.157</td>
<td>0.152</td>
<td>0.142</td>
<td>0.119</td>
<td>0.066</td>
<td>0.000</td>
<td>0.143</td>
</tr>
<tr>
<td>SHGCCc</td>
<td>0.684</td>
<td>0.684</td>
<td>0.680</td>
<td>0.674</td>
<td>0.663</td>
<td>0.636</td>
<td>0.573</td>
<td>0.443</td>
<td>0.228</td>
<td>0.000</td>
<td>0.592</td>
</tr>
</tbody>
</table>

Tdw-K : 0.475
Tdw-ISO: 0.635
Tuv   : 0.407

Temperature Distribution (degrees C)

| Lay1 | 15.4 | 15.1 | 37.5 | 37.8 |
| Lay2  | 9.9  | 10.3 | 39.3 | 39.0 |

M. Liem