Sustainability vs. Performance
Impact of reducing thickness of brick in veneer walls

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ABSTRACT:

The objective of this study was to investigate the effect of reducing the thickness of clay brick veneer on its water penetration performance and associated environmental impact. Thinner brick would mean reduction in material which would in turn impact transportation and installation. To examine the performance of thinner bricks, two brick samples were used for comparison: brick with standard 90mm width and brick with reduced width of 75mm. This change in width represents a 17% volumetric reduction in material used. Could this reduction in material be obtained without impacting the performance of the brick veneer?

The study at Ryerson compared the standard veneer brick with a thinner brick veneer by conducting water penetration tests on six wall specimens- three of each brick veneer. The initial results showed that thinner veneer allowed less water to penetrate through than the thicker one. Further tests were done specifically looking into the absorption characteristics of both brick samples. The water penetration tests were repeated to simulate different wind-driven rain conditions. Comparing the results from all the tests, it was observed that the thinner walls perform better. The lower water penetration of the thinner walls seemed directly linked to the fact that they have an IRA that is close to three times that of the standard bricks. This may result in better bond between mortar and brick which could result in less water leaking through the joints.

The investigation into the environmental impact of thinner brick veneer indicates that significant savings in energy, green house gases and other environmental aspects could be achieved if the thinner veneer is adopted Canada-wide.

This paper points to further studies that would be required to see the effect thickness has on brick veneer performance.

CONFERENCE THEME: Considering Research: Reflecting upon current themes in Architectural Research
KEYWORDS: clay brick veneer, water penetration, thickness, embodied energy, environmental impact

INTRODUCTION

Brick is one of the most commonly used cladding materials in single family houses in many regions of Canada. In addition to providing warmth and character to the building, brick also in modern buildings is used to act as a rain screen in the building envelope system. A rain screen may be defined as the outer leaf or cladding that "screens" the rain which works together with an inner leaf which acts as the drainage plane. The drainage plane and outer cladding are separated by an air space which helps with removal of water from behind the cladding and promotes faster drying of the wall (Brock 2005). Essentially the brick acts as a cladding element and does not support the primary structural loads.

For years bricks with a standard width of 90mm have been used in veneer construction. Can the thickness of the brick used as a veneer be reduced without affecting its performance? If the thickness is reduced how much can it contribute towards improving sustainability of the brick wall? The study focused on the brick veneer component of the building envelope as shown in figure1. Material reduction is an effective means of addressing sustainability as it directly impacts non-renewable resource consumption and the quality of environment that is impacted by production of materials. Reducing the width however begins to affect the effectiveness of the veneer to perform its function as a separator.

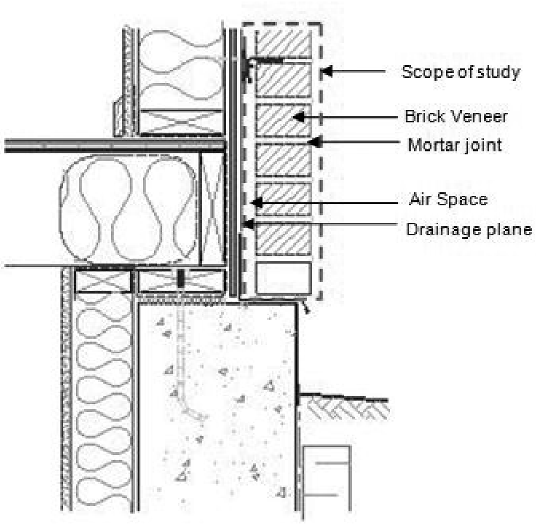

Figure 1: Typical Section- Brick Veneer wall at foundation showing scope of study. Source: (Wood frame envelopes 2001)

Regardless of the extent of impact on the sustainability of the wall, reduced thickness of brick is worth considering from the point of view of economics. This paper examines the two issues related to sustainability and performance as a veneer. There are many aspects to sustainability and performance. This paper focuses on sustainability from the point of view of environmental issues expressed through embodied energy and the performance from the point of view of the walls effectiveness as a rain screen. It identifies other issues related to sustainability and performance that are important and which may be considered in future studies.

1. STUDY APPROACH

The environmental impact of the reduction of brick width was calculated based on a simple model that relied on determining the reduction in mass and volume of the brick for a prototypical single family home. The reduction in mass and volume were determined and applied to standard values for the environmental impact of bricks available from literature. The environmental impact of such practices will vary widely from region to region depending on such issues such as local availability of material, transportation requirements, and sensitivity to impact on the natural environment. While the method used in this paper applies to buildings in Ontario, similar approach can be used to produce local results.

The performance of the brick veneer was measured by conducting tests on mock-up walls in the laboratory.

Water penetration tests and absorption tests according to ASTM standards and ISO protocols were conducted on two sample bricks described in Table 1 below-

Brick Sample	Size	Dimensions (mm)
Series"0"/ Standard	Cortes Max (3:1)	257 X 90X 79
Series"1"/ Thin	Premier Plus	257 X 75 X 79

Table 1: Details of brick samples

2. ENVIRONMENTAL IMPACT OF REDUCED BRICK THICKNESS IN A VENEER WALL

Reducing brick veneer thickness directly reduces the amount of material required for the same amount of surface coverage for its use in the building cladding. For a given area of finished wall, there are many benefits including:

Lesser use of resources

Lesser waste at the end of life cycle

Reduction in energy used to produce and transport the material

Higher efficiency in terms of installation due to better ergonomic considerations

Reduction in dead loads from the cladding

This paper focuses on the environmental impacts based on the life cycle assessment. The following sections examine the environmental impact from brick production.

2.1. REDUCTION OF MATERIAL

By reducing the thickness of a standard brick veneer from 90mm to 75mm, we reduce the total volume of the brick by approximately 17% i.e. a reduction of approximately 310cm3 per brick. To put this into perspective, this paper uses an example of a typical two storey detached house in Ontario with the following characteristics:

No. of storeys: 2

Height: 5 meters

Floor Area on two storeys: 250 m2

Total Area of opaque portion of cladding : 260 m2

The number of bricks required to clad 260 m2 would be approximately 10,800 brick units. If instead of the standard bricks the thinner bricks were used then, the amount of material saved would be approximately 3.3 m3. The reduced volume of bricks works out to approximately 1,800 bricks.

This is a significant amount considering the fact that in 2008 and 2009 (a year which was considered a low point in the housing market), there were approximately 200,000 and 150,000 new homes being built all across Canada respectively (CMHC 2010). This means saving of 360 (270 in 2009) millions bricks in 2008 or brick cladding for additional 33,333 (25,000) new homes.

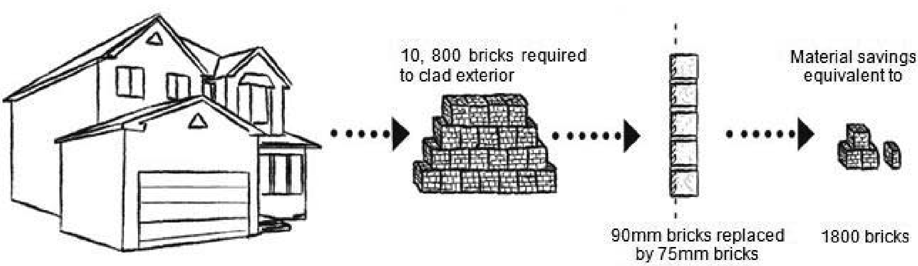

Figure 2: Amount of bricks saved in a typical single family detached house in Ontario, Canada.

2.2. REDUCTION CO2 EMISSIONS AND ENVIRONMENTAL IMPACT

One small step such as reducing the material used in brick production would also lead to saving large amounts of energy and reduce the amount of carbon dioxide emissions. The ATHENA institute has published a life cycle analysis report on brick and mortar products. The report considers different aspects from production to transportation and the impact each of these processes have on the environment in terms of energy consumption, emissions etc. (Venta 1998). The reduction in material consumption from previous example of a typical single detached house was analysed in terms of these aspects and the findings are discussed.

A sound indicator of a product's impacts on the environment is its embodied energy which is defined as the total energy consumed for various processes (extraction of raw material, production, transportation etc.) involved in creating a finished product. The embodied energy for clay bricks is 6.6 GJ/m3 of finished brick. The total embodied energy of the bricks on the house is approximately132GJ. Using thinner bricks would reduce this to 110GJ that is 22GJ of energy saved for a single detached house alone. If thinner bricks were used on all the new housing that was built in 2008, the total amount of energy saved would equal to 4488000 GJ of energy. This energy is sufficient to heat approximately 40- 50 single detached houses for a year (Natural Resource Canada 2010). Similarly other aspects that impact energy and environment that would be effected by reducing brick veneer thickness is shown in Table 2.

Environmental Aspects	Standard Brick	Thinner Brick	Reduction of
Non renewable energy consumption in GJ	57.2 GJ	48.1 GJ	9.1 GJ
Green house effect / CO2 emissions equivalent in kg	6582 kg	5530 kg	1052 kg
Acidification/ SOx equivalent in kg	7.4 kg	6.2 kg	1.2 kg
Nitrification equivalent in/ Ammonium in g	17.28 g	14.5 g	2.8 g

Table 2: Comparison of standard vs. thinner brick veneer in terms of energy consumption and emissions

It is clear from the above discussed example that a significant amount of energy can be saved by adopting thinner brick veneer. Several atmospheric emissions and effluents which cause environmental issues such as ozone depletion, acid rain, nitrification etc. can also be reduced. It should be noted that potential reduction in mortar use for thinner veneer wall was not included in the above estimates.

There are two ways in which the brick veneer may be considered to contribute to the thermal properties of the exterior wall. One is through the thermal resistance to conductive heat flow typically measured in terms of R-value. In a rain screen pressure equalized type of wall system assumed in this paper, the brick is simply a veneer between the pressure equalized cavity and the exterior. In this type of application the brick veneer's R-value is not effective and does not contribute much towards the total R-value of the building envelope .Therefore reducing the thickness of the brick would not have any significant impact on the heating/ cooling loads of a building from a conductive heat loss or gain point of view. The second way in which the brick affects the thermal properties of a wall is through its thermal mass. Some of the studies mentioned before have shown that the temperature of the cavity adjacent to the brick is affected by the heat storage due to the thermal mass of the brick. Reducing the thickness will reduce the thermal mass and therefore it may have a slight impact on the overall heating/cooling loads of a building.

From an overall perspective, considering all environmental factors such reducing need for natural material, emissions etc. this increase in heating/ cooling loads would be insignificant and it would still be worthwhile to reduce thickness of brick.

3. FACTORS EFFECTING WATER PENETRATION IN BRICK VENEER

Several studies on brick veneer were reviewed particularly focusing on factors that affect the performance in terms of durability, water penetration etc. It was important to understand these factors and their effects to analyse the results from the water penetration tests and assess why one wall performed better than the other. One of the most important criteria that decide the performance of a brick veneer wall is the amount of water that penetrates through the wall or gets absorbed by the wall. The following sections evaluate the effect of variables such as mortar joints, void area, initial rate of absorption etc. on water penetration.

3.1. INITIAL RATE OF ABSORPTION

To reduce water penetration in a wall, it is important to realise its flow pattern through a given surface. Water flows through the path of least resistance and so within a brick wall it flows through area of contact between brick and mortar (Whitlock 2003). This was proved in a study done by Thomas Hines when he claimed that neither the brick unit nor the mortar itself allows any significant leakage through their respective materials (Hines 1991). Most of the water migrates through minute, mostly invisible to the naked eye cracks that develop over a period of time. These cracks might form due to various reasons but a major deciding factor is the Initial Rate of Absorption (IRA) of the brick. It is the IRA which is directly responsible for the bond formed between the mortar and the brick when the wall is laid and the subsequent chemical reactions that occur. Higher the IRA, better the bond between brick and mortar.

3.2. MORTAR JOINTS

Mortar joints play a crucial role in a brick walls resistance to water presentation. Width of a joint affects leakage; thinner mortar joints perform better than wider joints. It is critical for the vertical joints to be completely filled even more than the horizontal joints as these joints do not undergo natural compression from the weight of the bricks above. Hence it is through these joints that most of the leakages occur. Width of the joint is another factor which affects leakages (Roller 1994).

3.3. WORKMANSHIP

While laying bricks, it is important that certain techniques are followed for proper bonding and minimising cracks. Good workmanship ensures a wall that is durable and works as a better rain screen. Bricks should never be tapped or moved once it has been laid on the mortar bed. Moving the masonry unit breaks the initial bond formed between the unit and the mortar causing cracks. It is also important that the joints be tooled as it provides a watershed surface and enhances the brick mortar bond. The compression applied while tooling produces a denser area near the wall surface and rids the mortar of any hidden cavities (Roller 1994).

3.4. VOID AREA

Increasing the number of voids or area of voids could be another approach to reducing material consumptions in brick production. From previous studies it has been concluded that increasing void area had no significant effect on water penetration, flexural bond or compressive strength. The flexural and compressive strength depends on the material used and the method of production. However in one of the studies it was concluded that higher void area amounted to higher consumption of mortar during construction (Sanders & Brosnan, 2007). Further investigation needs to be conducted to decide whether higher material consumption in brick production or higher mortar construction is better in terms of environmental and economic impacts.

4. LABORATORY TESTS

4.1. WATER PENETRATION TESTS

For this study, the two brick samples, a standard one and a thinner one were chosen. The standard brick will be referred to as Series "0" and the thinner one will be referred to as Series "1" from this point in the paper. Three mock up walls were built for each brick sample using Type N mortar. The wall specimens for Series "0" have been denoted as A0, B0 and C0 and the wall specimens for Series "1" will be denoted as A1, B1 and C1 henceforth. These walls had been initially tested two years ago and the results from the initial tests were used in the analysis.

The water penetration tests were carried out as prescribed by the ASTM E 514 standard. Each wall specimen was built to a size of approximately 1500mm X 1500mm and the face side was parged all around leaving a test area of about 1.08m2. The purpose of parging the side was so as to allow an air tight seal with the pressure/water chamber.

The test equipment consisted of the pressure/ water chamber and the water control panel. The pressure/ water chamber is attached to the face of the wall specimen and simulates pressure and rainfall similar to wind driven rain. The water control panel consists of all the controls that help monitor the flow of water into the chamber. It also consists of the water reservoir. As per the standard the water flow was maintained at 155l/hr and the pressure was maintained at 500 Pa for the initial set of testing. Figure 2 shows the entire test setup.

Each test was conducted for a period of four hours during which readings of water collected behind the wall were taken at half hour intervals. The wall specimen would be measures before and after the tests as the difference in weights would give us the amount of water that had been absorbed by the wall. After the initial round of tests, it was decided to test some of the walls again. The tests would be different this time as the initial moisture content in the walls would be higher.

After the initial testing of the walls as per ASTM 514 standards, a second set of tests was conducted by reducing the rate flow of water to 80l/hr. from 155l/hr. The flow was reduced to half of the original value in order to find the amount of water that higher pressure would drive through in the event that less water hits the facade. In reality the amount of water on a building facade would be much greater under such high pressure. For the third set of tests, the pressure was reduced from 500Pa (equivalent to wind speed of 100km/hr.) to 120Pa (equivalent to wind speed of 50km/hr.), as it is represents wind speeds prevalent during rain showers (Anand, Vasudevan & Ramamurthy 2003).

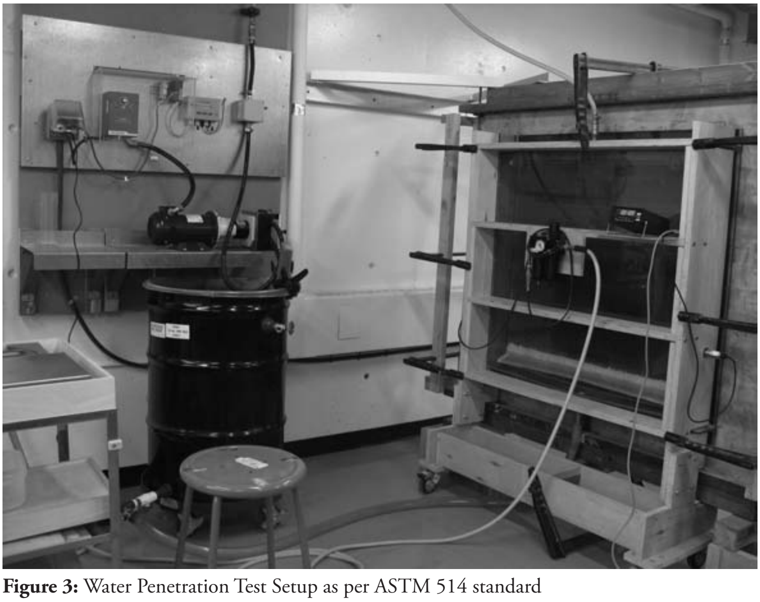

Figure 3: Water Penetration Test Setup as per ASTM 514 standard

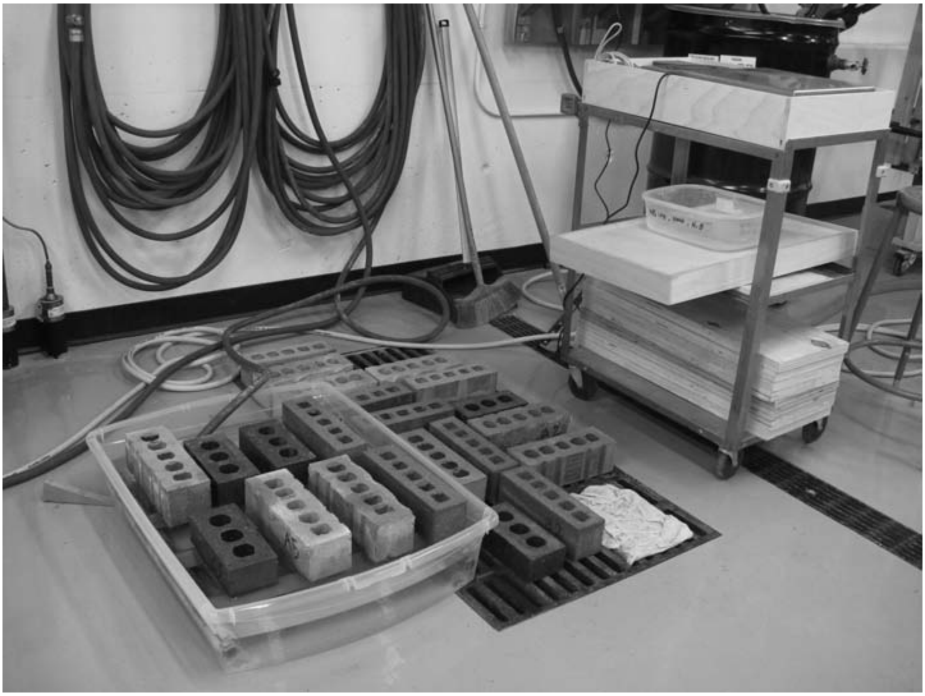

Figure 4: Absorption Test setup

4.2. PHYSICAL PROPERTIES AND VOID AREA MEASUREMENTS

Five specimens were randomly chosen from each type of brick for sampling and for the various laboratory tests as per ASTM C67 standards. The chosen specimens were checked for any visible damage like chipping, warpage etc. The specimens were each then properly marked and numbered. The following parameters were then measured- length, width, height, weight, face shell thickness and void area.

4.3. ABSORPTION TESTS

The absorption tests were carried out to evaluate the absorption characteristics of both bricks. After the initial water penetration tests it was noticed that Series "1" brick veneer walls absorbed quite a large amount of water. This result was quite unexpected and so it was decided to investigate the absorption properties of the bricks. As seen in figure 3 an absorption test set up was created using a rectangular tub and steel angles to hold the bricks in place. Five brick unit specimens were tested from each series

ASTM C67 and ISO 1418 standards were used to determine the absorption properties of the brick samples. All brick samples were checked for chips and loose debris and wiped clean before commencing the tests. To determine the Initial Rate of absorption of the bricks, each brick was first weighed to determine the dry weight, and then slowly immersed in to water for a minute. The brick was taken out, wiped off to rid of excess water and weighted to determine the wet weight of the brick. The difference in weight would give the amount of water absorbed by the brick in a minute. The same procedure was repeated for the remaining brick samples.

As for the partial and full submersion tests, the bricks were allowed to dry out completely in the lab for a few days before being subjected to testing. All the bricks were weighed before immersion into water and their dry weight was noted. These were 24 hour tests and the bricks were taken out at different intervals and readings were taken at - 5 and 20 minutes, 1, 2, 4, 8, 12 and 24 hours.

Water Flow		155l/hr.					78l/hr.		
Specimen		A	B			C	A	B	C
Pressure	No. of tests[1]	1	1	2	3	1	1	1	1
500Pa	Amount of water penetrated in litres	15.38	12.70	7.00	17.44	10.13	10.93	8.98	4.71
	Amount of water absorbed in litres	11.66	10.97	9.56	6.86	14.17	10.29	10.75	9.15
120Pa	Amount of water penetrated in litres	9.51	4.61			4.76			
	Amount of water absorbed in litres	6.86	8.23			5.72			

Table 3: Matrix showing amount of water penetrated and absorbed through wall specimens A, B and C of Sample "0" bricks

Water Flow		155l/hr.						78l/hr.		
Specimen		A		B			C	A	B	C
Pressure	No. of tests[1]	1	2	1	2	3	1	1	2	3
500Pa	Amount of water penetrated in litres	5.12	4.22	2.76	3.36	11.03	3.77	0.42	1.75	1.64
	Amount of water absorbed in litres	15.78	13.49	13.49	14.86	6.17	16.23	16.23	14.17	14.63
120Pa	Amount of water penetrated in litres	0.45		0.07			0.29			
	Amount of water absorbed in litres	11.20		9.15			8.23			

Table 4: Matrix showing amount of water penetrated and absorbed through wall specimens A,B and C of Sample "1" bricks

The two types of brick veneer walls show different levels of resistance to water penetration. While the difference in water absorbed and penetrated is not much in Series"0" walls, the difference is much bigger in Series"1" walls. The amount of water absorbed by Series "1" wall is around four times the water penetrated through them.

The results from the tests with lower water flow level and lower pressure showed a decrease in water penetration through the wall. The first drop of water was seen at the back of Series "0" walls within five minutes while it took approximately seven minutes in the case of Series"1". In case of lower pressure, it took longer for the first drops to appear- around ten minutes for Series"0" and fifteen for Series"1". Reducing the water flow by half reduced water penetration in series"0" walls by approximately one third of the penetration in the first set of tests. Sample C from series "0" and sample B from series "1" exhibited different behaviour to other two wall samples. Both these walls allowed less water through in comparison to the other samples. The amount of water penetrated through series"1" walls with lower pressure was negligible.

The Initial Rate of Absorption of Series"0" brick was found to be 13.5g/200 cm2/min while the Initial Rate of Absorption of Series "1" brick was found to be 40.6 g/200 cm2/min. This shows that the IRA of Series"1" bricks is three times as that of Series"0" brick. This could be the reason for better bond between mortar and brick in Series"1" wall specimens.

The results from the absorption tests helped determine the permeability and absorptive properties of the bricks. In the partial submersion test, it was noticed that the bricks from series "0" had not attained total saturation even after 24 hours as. At the same time bricks from series "1" absorbed much more water and also attained near saturation after four hours of partial immersion. In the full immersion test, Series "0" bricks absorbed water gradually and saturated within a period of one hour, hence while Series "1" bricks absorbed the maximum amount of water in the first five minutes of immersion and hence reached saturation point within 20 minutes. Also the total amount of water absorbed by the thinner bricks was actually more than one third of the amount of water in the thicker ones.

5. CONCLUSION

The study has demonstrated that there is great potential in adopting thinner clay brick veneer as a cladding material.

From an environmental perspective a lot can be gained by reducing the thickness of brick veneer. Lesser amounts of raw material such as clay and water would be required reducing the amount of natural material that needs to be extracted. The paper also proved that reduced thickness would not compromise the capability of the brick veneer wall to work as a rain screen.

The environmental study proved that the embodied energy of a house can be significantly reduced by 17% by slightly reducing the thickness of brick and this would multiply exponentially considering that thousands of houses are built in a year in Canada. Adopting thinner brick veneer would contribute to material reduction in other ways such as smaller foundations, less mortar etc. These possibilities have not been explored in this paper. Reduced carbon dioxide emissions would mean the brick production industry would reduce its contribution towards global warming. Similarly there would be a significant lowering of other emission like sulphur oxides, VOC's etc. Effluents such as ammonia which leads to nitrification of water bodies inhabitable are also reduced.

From the water penetration test it was clear that the thinner bricks allowed much lower amounts of water through than the standard bricks. It was observed in the initial tests when the moisture content in the walls were negligible, the walls absorbed more water than they allowed through.. Subsequent test results showed lesser amount of water was being absorbed with higher initial moisture content of the walls. Hence once the walls are wetted, the amount of water that penetrates the wall increases.

All the previous studies that were reviewed pointed out that the Initial Rate of Absorption plays a crucial role in the bond that is formed between the brick and the mortar at the time of laying the bricks. The results from the IRA tests showed that the IRA value of the thinner bricks was in fact approximately three times higher than that of the standard bricks. This can be confirmed from the fact that for all the water penetration tests, the water always appeared almost instantly through the joints in the standard bricks while it took a little longer in the thinner ones. This is a clear sign that there were cracks or minute openings in the joints of Series "0" walls.

Comparing with the results from the earlier study (Straka & Gorgolewski 2009), to the new results confirms the lesser water penetration compared to the other samples in the series. This was related to the fact that the same batch of mortar was used in both these walls. The results in the new tests also confirmed that these two wall specimens did perform better than the other walls. It was realised that all the walls from both brick samples performed better this time.

There are various clay products available, such as clay tile panels which are also designed as rain screen walls and seemingly used less materials. These panel systems however have much more complicated backup systems that cost more and utilise steel or aluminum framing which increases the embodied energy of these systems. These systems also tend to be much more expensive and require specialized labour. Due to these reasons, brick veneer is one of the most commonly used and cheapest form of cladding adopted in housing. Improving the design of the brick veneer is therefore an important and vast area of interest and from this study it has been proved that there is potential in thinner veneer walls.

6. CONCERNS REGARDING REDUCTION OF BRICK VENEER THICKNESS

Adopting thinner brick veneer would reduce the overall load on the structure of the building. This could possibly lead to more savings in material used in the foundation and framework. On the other hand, the number of anchors between the veneer and the frame might have to be increased to keep the veneer firmly attached to the frame (Straka & Gorgolewski, 2009). Further research must be done to investigate whether the thinner bricks can be used in multi residential apartment buildings of more than three storeys. Due to lesser thickness, thinner brick veneers might not be suitable for greater floor to floor heights as it may not be able to support its own weight. Reducing the thickness of the veneer may have negative effect on the thermal performance of the building envelope (Straube

J. F. 1998). Detailed analysis of rain screen brick veneer wall performance subjected to actual climatic conditions would have to be done in order to address the impact of thinner veneer on energy performance. The field study may be required as the cavity, its thickness and ventilation play a role in the wall thermal resistance. Other factors need to be taken into consideration is the effect reducing the thickness of brick has on fire resistance, sound transmission etc. (Straka & Gorgolewski 2009).

7. FURTHER STUDY

In terms of replacing standard brick veneer with thinner ones it is necessary to look into factors such as durability, sound transmission and fire resistivity. More research needs to be done on these factors and how they would be affected. Another important question would be the structural integrity of thinner veneer and its performance under the wind load. Both brick samples have different physical properties but are recommended for the severe weather in Canada.

REFERENCES

ASTM C67: S*tandard Test Method for Sampling and Testing Brick and Structural Clay Tile*. ASTM International.

ASTM E 514-90: *Standard Test Method for Water Penetration and Leakage through Masonry.* ASTM International.

Anand, K., Vasudevan, V. and Ramamurthy, K. 2003. *Water permeability assessment of alternative masonry systems.* Building and Environment.

Brock, L., 2005. *Designing the exterior wall- An Architectural guide to the Vertical Envelope*. John Wiley and Sons Inc: New Jersey.

Hines, S. T. 1991. *Relative permeance of mortar joints in masonry walls*. Ann Arbor: University Microflims International.

ISO 15148: *Hygrothermal performance of building materials and products- Determination of water absorption coefficient by partial immersion*. The International Organization for Standardization (ISO).

National Resources Canada Code. 2010. National Resources Canada: Ottawa.

Ritchie, T. 1960. *Rain Penetration of walls of Unit masonry*. Natural Resources Canada: Ottawa.

Ritchie, T., & Plewes, G. W. 1960. *Moisture Penetration of Brick Masonry panels*. American Society for Testing Materials Bulletin.

Roller, S. L. 1994. *Effect of Pressure on water penetration in brick masonry*. United Microfilms International: Ann Arbor..

Sanders, J. P., & Brosnan, D. A. 2007. *The Effect of Void Area on Brick Masonry.* Journal of ASTM International: Volume 4.

Straka, V. & Gorgolewski, M. 2009. *Water penetration through thinner brick veneer wall.* Ryerson University: Toronto.

Straube, J. F. 1998. *Moisture control and enclosure wall systems*. University of Waterloo: Waterloo.

Venta, G.J. 1998. *Life cycle analysis of brick and mortar products.* The ATHENA sustainable materials institute: Ottawa.

Whitlock, A. R. 2003. *Water penetration rate characteristics of masonry walls*. Ninth North American Masonry Conference: Clemson.

Wood frame envelopes- Best practise. Canadian Mortgage and Housing Corporation: Canada.

ENDNOTES

[1] The number of tests denotes the number of times each wall specimen has been tested.