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كفاءة تصميم واتجاه الشباك على الاحتياج الحراري السلبي بعيد المدى بالمباني السكنية

أمجد بن عبد الرحمن مغربي
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المستخلص العربي:
يختص هذا البحث بتقييم الأداء لمختلف أنواع الشبابيك (الفتحات) فيما يتعلق بالأداء الحراري السلبي (passive) لمنزل سكني نمطي بمدينة ووترلوو بكندا. عدد من أنواع الشبابيك (المفترضة) ذات الأداء الحراري العالي تم مقارنتها مع أنواع من الشبابيك العادية (الحالية) في محاولة لدراسة التقليل بعيد المدى من تكاليف استخدام الطاقة الإيجابية (active) لعدد من الشبابيك وثلاثة اتجاهات للفتحات تم دراستها متضمنة الاتجاه الجنوبي والشمالي والغربي باستخدام برنامج RetScreen PSH المختص بدراسة الاحتياج الحراري السلبي.
نتج عن الترقية من الشباك العادى إلى الشباك ذي الأداء الحراري العالي نتائج ملموسة للتقليل من الاحتياج إلى استخدام الطاقة الإيجابية وبالأخص عند توجيه المبنى باتجاه الجنوب. إضافة إلى ذلك، تم استرداد المبالغ التي تم إنفاقها لترقية الشباك إلى شباك ذي أداء حراري أعلى، نظرا للتقليل من احتياج الطاقة الحرارية الإيجابية، في أقل من عشرة سنوات. ويخلص البحث إلى أن ما يحدد الاختيار السليم – اقتصاديا- لعمل الترقية المطلوبة للشباك هما التكاليف الأساسية للترقية وعمر الشباك الافتراضي.

Abstract:
This paper describes research conducted to evaluate the efficiency of various window components with respect to solar heating demands of a prototype residential house in Waterloo, Canada. A number of proposed high performance window types are compared against base-case conventional windows in attempt to trace the long-cycle cutback in heating demands. Three window orientations including South, North and West facing were considered. RetScreen passive solar heating project model was used for this purpose.
The upgrade of windows has shown a dramatic cutback in passive solar heating demands with preference to South facing direction. Initial cost of window upgrade is reimbursed, due to reduction of active solar heating cost, in less than ten years depending on the type of window selected. It is concluded that the economical upgrade of a window depends on the initial installation cost required for the upgrade and the project life.

KEYWORDS: window, window orientation, solar, passive solar heating, cost.

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1. Introduction

Accessing thermal comfort solutions in architecture requires a number of strategies. Amongst these; efforts are focused on the utilization of active and passive heating and cooling techniques to achieve the desired level of occupant's comfort. With the arise debate concerning tumbling active energy techniques within buildings due to its economical causes associated with energy waste, passive solutions are increasingly implemented. Passive solutions are more environmentally friendly and have economical privileges comparing to former technique.

Passive heating occurs due to number of factors including solar gains and other radiating resources of heat around building. Alternatively, sources of heat within building are limited to heat transferred through thermal envelop, apertures, occupants as well as equipment (such as kitchen appliances). Amongst these, passive solar heating (PSH) is considered the most significant, i.e. heat penetrating through external doors and windows (1), (2), (3), (4), (5). Selection and orientation of windows will significantly control the annual heating demand (3). In addition, high-performance windows can require less than half the heating energy necessary for a space when compared to conventional windows (6). Beside pleasant living environment, passive solar designs can also provide a better use of natural daylight for lighting purposes (4). The design of window thus must be given greater concern being the prime source of passive heating compared to other building components.

The work in hand compares a number of window types (Appendix-a) for a proposed house at Waterloo, Canada. The site complex contains a number of prototype single family, one storey town house designed with passive solar principles (Figure 1). As shown in figure 1, the house contains a number of apertures (windows and patio doors) scattered at various elevations. Dimensions of these apertures are shown in Appendix-a.

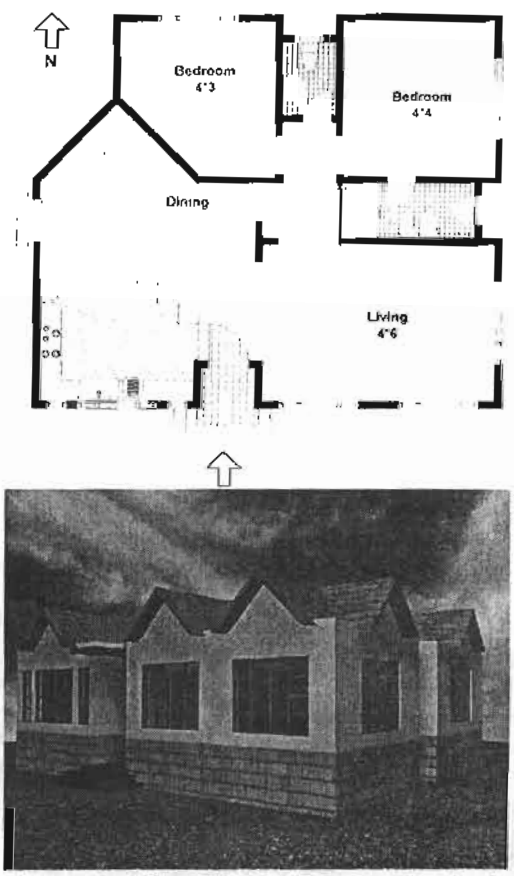


Figure 1. The proposed prototype single family, one storey town house, Waterloo, Canada

A number of detailed investigations are carried out concerning the use of high-performance windows in comparison with conventional window types. Full details of house components and apertures various specifications are examined using a project model named by RetScreen passive solar heating (7). The model is used to evaluate the energy production (or savings) and financial performance associated with energy efficient window use. Passive solar Heating systems along with the project model applications are discussed next. A full detail of the proposed house is highlighted later followed by the methodological approach and the discussion of the results.

2. Passive Solar Heating Systems

Passive solar heating is best applied to buildings where heating demand is high relative to cooling demand (2), (8). As mentioned earlier, the prime element in passive solar heating systems is windows. The transmission of solar radiation allows energy to enter the building and warm interior spaces whilst heat is not easily transmitted back outdoors. The phenomenon of greenhouse effect is particularly useful for supplying heating energy in the winter. Thus, window dimensions, components, thermal properties and orientations contributes significantly to the fraction of radiation piercing through (1),(2),(3),(5). Unfortunately, windows are not as thermally insulating as the building walls.

Buildings envelop acts as solar heat storage that reduces the need for heating in cold seasons. For buildings with modest window area, lightweight construction of wood or steel frame walls with gypsum board offers sufficient thermal mass to store solar gains and prevent overheating on cold sunny days. When compared to heavy materials such as stone or concrete, the former choice has significance in preserving heat while the later releasing it slowly overnight (9), (10), (11). The thermal mass of the building construction is crucial for passive solar heating systems with large window area. Other sources of heat are less effective in the contribution of heat when compared to solar heat (12).

3. Solar Heating Project Modsel

Solar energy contribution through an opening encounters a number of complications in the real environment. Some of these are related to the physics of heat transmitting through an opaque envelope and others are related to the aperture and surroundings. Calculation method or measuring technique selected is considerably important to decide the optimum technique for a specific task.

Theoretical approaches concerning passive solar heating can be used to evaluate the energy production (or savings) and financial performance associated with energy efficient window use. Maghrabi (13) has compared various measuring techniques and concluded that theoretical approach has an advantage at early stages of design where a number of cases could be examined, and parameters are controlled. The technique was led be many researchers as it is beneficial in time and cost. In this approach, assumptions are employed to answer some of the complexities accruing in practice since the full understanding of these complexities is not yet complete (14).

One of the models applied to assess the accuracy of the calculated energy flow is found in the work of Arasteh et.al.(5). The model examines the window configurations and its effectiveness with respect to energy and thermal comfort. Nevertheless, the model does not consider the annual energy cost saving. HOT2-XP is another energy model which is the quick entry version of Natural Resources Canada's (NRCan's) (15). The ER method is a Canadian standard that was developed based on hourly energy simulations (8). Additionally, REDFEN model solution is used to predict energy performance of fenestration on residential buildings (3). The work in hand was carried using RetScreen Passive Solar Heating Project Model (7).

The Model can be used to evaluate the energy production (or savings) and financial performance associated with energy efficient window use (7), (12). The model is intended for low-rise residential applications, although it can be used for small commercial buildings, and it applies anywhere in the world where there is a significant heating load. A number of projects are investigated using RetScreen project model including those found in Canada, USA, Germany, and recently in Japan. Validations of the project model in hand and various model equations involved are found in RetScreen PSH manual (12) for further investigation.

Basically, the model can be used to determine how efficient window use can affect building energy use in four ways:

1. Increased solar heat gains to the building through larger and better-oriented windows;
2. Reduced heat loss through more insulating windows;
3. Increased or reduced solar gains through the use of appropriate glazing; and
4. Reduced cooling energy demand due to improved shading.

3.1. Adjustment of Window Thermal Properties

The software incorporates database, which includes more than 1,000 windows that have thermal performance ratings. It adjusts the window thermal properties for the actual window sizes using method recommended by Baker and Henry (16). Dimensions of samples used to rate windows, according to Canadian standards, with respect to their U-values and solar heat gain coefficients (SHGC) are found in

Appendix-a. In the model it is assumed that all windows of the same orientation have the same SHGC unless different type of window was used (7), (12).

3.2. Heating Energy Savings

Two terms are evaluated each month to determine the net heating demand: heating demand (gross) and usable solar heat gains. Third term, internal gains, although part of each monthly evaluation, is assumed constant throughout the year. The model determines the difference in energy consumption between the proposed passive solar building and an identical building but without the passive solar features (i.e. the "base case"). The monthly heating demand and usable solar gains will be different between the base case and proposed buildings because of differences in window properties and orientations. Building monthly heating demand is assumed to vary linearly with outdoor temperature and is based on typical house heat loss coefficients.

The increase in solar heat gains obtained in the proposed case configuration is the sum of two terms: first, the associated increase in solar gains due to higher transmission of short-wave radiation through the glazing, and second, the re-distribution of window area that changes the total amount of solar energy captured by the windows due to their orientations. The seasons are considered six-month periods corresponding to the sun's movement.

The utilization factor is calculated according to methods developed by Barakat and Sander (17). Values for a 5.5°C temperature swing are used in the software program (this is likely the maximum swing that could be tolerated in a passive solar house) (7). The resulting utilization factor indicates the proportion of the transmitted solar gains that are utilized to offset heating load.

Heating energy savings are calculated for each month as the difference between the energy required to heat the building in the base case and in the proposed case. The energy savings over the heating season are the sum of the monthly energy savings:

3.3. Cooling Energy Savings

One of the tradeoffs associated with increased solar gains is the additional heat that may contribute to cooling energy demand in the summer months. To determine annual energy savings, the detrimental effects of increased solar heat gain must be assessed. For heating-dominated climates, the conductive heat gain through windows in the summer is very small relative to the solar gains and can be ignored (18); therefore the additional cooling requirement is determined only from the increased solar gain.

3.4. Annual Energy Savings

Annual energy savings, referred to in the model as renewable energy delivered, , are obtained by simply summing heating and cooling energy savings. Finally, the model also calculates the peak heating or cooling load (power) reductions, which indicate to the user opportunities to reduce the capacity of the conventional heating system or that of the air-conditioning system. Appendix-b demonstrates the flowchart of the PSH energy model(7).

4. The house

The proposed house consists of a living space, two bedrooms, dining, and other amenities including kitchen, bathroom, toilet and storage (Figure 1). As mentioned before, the house is designed with passive solar principles as an attempt to analyze the long term cutback in heating demands.

The insulation level used by the wall thickness and the thermal resistance of the insulation material used in the walls. At this proposed dwelling, a high insulation level building would have walls with at least 200mm of fibrous insulation (RSI > 4.5 $m^2 \cdot {}^\circ C/W$). Appendix-c shows the general parameters that are required to run the model.

As far as apertures were concerned, an attempt to intensively examine the various components of these apertures and how they contribute to the house efficiency with respect to passive heating demand. The regulations of Canadian Standard Association (CAN/CSA A440.2) (19) set the types windows with respect to their thermal properties. Apparently, there are three main types; single-glazed, double and triple-glazed. The sources of information for the window SHGC obtained from the project model data base matches those found in the ASHRAE Handbook-Fundamentals (20). The U-value is a measure of the heat transmission of the window (Appendix-a). It is assumed that all windows of the same orientation have the same U-values (12). Unit cost for each type of windows as they are involved in the process to acquire the life-cycle cost of energy demand for passive heating are entered in the model. The insulated glass units (IGU) is double-glazed with a single low-e film plus argon gas fill (DC-Le-A) and the high performance IGU is triple-glazed with double low-e films fill (TC-Le) are examined and compared against the double-glazed (DC) and single-glazed (SC) types. Low-e film material was proved to provide greater savings with respect to high solar heat (2).

The orientations examined are limited to the selected most appropriate window types obtained from the model. Allocating the house into three various orientations including south, north and west-facing as shown in Table-1. It is worth mentioning that about Sixty five percent of the window area is on the front elevation (Table 1). Heat generated by the sun could have disadvantages during summer for larger apertures. Nevertheless, since average temperature does not exceed 20C (Table 2) the additional heat provided by the sun can add little segment to air-conditioning loads. This problem can be alleviated by the use of shading elements.

Table 1. Various orientations examined with respect to window configurations

South facing		North facing		West facing	
Orientation	Elevation	Orientation	Elevation	Orientation	Elevation
South.	Front	North	Front	West	Front
South.	Front	North	Front	West	Front
South.	Front	North	Front	West	Front
North	Back	South	Back	East	Back
North	Back	South	Back	East	Back
North	Back	South	Back	East	Back
West	Right	East	Right	North	Right
East	Left	West	Left	South	Left
East	Left	West	Left	South	Left
East	Left	West	Left	South	Left

Window Configurations				
Type	Width (mm)	Height (mm)	Number	Total Area (m^2)
Casement	1,000	1,600	3	4.80
Fixed	500	1,600	8	6.40
Patio Door	1,200	2,000	2	4.80
Fixed	500	1,600	2	1.60
Casement	1,600	1,000	1	1.60
Casement	700	1,000	1	0.70
Patio Door	1,000	2,000	1	2.00
Fixed	500	1,600	4	3.20
Casement	700	1,000	1	0.70
Casement	1,000	1,600	2	3.20

Table 2. Various orientations examined with respect to window configurations

Months	Monthly Solar Radiations ($khW/m^2/d$)	Monthly Average Temperature (°C)
Jan	1.64	-10.5
Feb	2.7	-9.6
Mar	4.14	-3.6
Apr	4.99	4.4
May	5.78	11.1
Jun	6.22	15.7
Jul	6.11	18.5
Aug	5.1	17.3
Sep	3.68	13.1
Oct	2.54	7.2
Nov	1.45	0.9
Dec	1.26	-6.9

In conclusion, passive solar design in hand evolved proper orientation of buildings and proper location and surface area for windows as well as the correct use of energy efficient windows with varieties of thermal properties. Sensitivity analysis is performed to help determine which parameters are critical to the financial viability of a project and, meanwhile, to improve the performance of the building envelope with positive environmental benefits.

5. Methodological Approach

Window Type: Two different cases will take place comparing:

1. Single-glazes (SC) window type (base model) with respect to three window types (proposed models):
   a. Double-glazed Clear Window type (DC)
   b. Double-glazed, Low-e, Argon (DC-Le-A)
   c. Triple-glazed, Low-e, (TC-Le)
2. Double-glazed clear (DC) window type (base model) with respect to two other types (proposed models):
   a. Double-glazed, Low-e, Argon (DC-Le-A)
   b. Triple-glazed, Low-e, (TC-Le)
3. Orientation, as three orientations were examined for the selected model;
   a. Front elevation facing south
   b. Front elevation facing west
   c. Front elevation facing north

Initial cost of unit and installing at each window upgrade (Appendix-c) is considered in the project model to trace the year to positive cash flow and long cycle cut back in energy demands.

Table 3. Results of upgrading Single-glazed (base case) with respect to other window types

Year	Window Type: DC		Window Type: DC-Le-A		Window Type: TC-Le	
	Saving	Cumulative	Saving	Cumulative	Saving	Cumulative
#	$	$	$	$	$	$
0	(2,035)	(2,035)	(4,428)	(4,428)	(5,951)	(5,951)
1	706	(1,329)	780	(3,647)	780	(5,171)
2	741	(588)	819	(2,828)	819	(4,351)
3	778	190	860	(1,968)	860	(3,491)
4	817	1,006	903	(1,064)	903	(2,588)
5	858	1,864	948	(116)	948	(1,639)
6	901	2,765	996	880	996	(643)
7	946	3,711	1,046	1,926	1,046	402
8	993	4,703	1,098	3,024	1,098	1,500
9	1,043	5,746	1,153	4,177	1,153	2,653
10	1,095	6,841	1,211	5,387	1,211	3,864
11	1,149	7,990	1,271	6,658	1,271	5,135
12	1,207	9,197	1,335	7,993	1,335	6,470
13	1,267	10,464	1,401	9,394	1,401	7,871
14	1,331	11,795	1,471	10,866	1,471	9,342
15	1,397	13,192	1,545	12,411	1,545	10,887
16	1,467	14,659	1,622	14,033	1,622	12,510
17	1,540	16,200	1,703	15,736	1,703	14,213
18	1,617	17,817	1,789	17,525	1,789	16,001
19	1,698	19,515	1,878	19,403	1,878	17,879
20	1,783	21,298	1,972	21,375	1,972	19,851
21	1,872	23,171	2,070	23,445	2,070	21,922
22	1,966	25,137	2,174	25,619	2,174	24,096
23	2,064	27,201	2,283	27,902	2,283	26,378
24	2,167	29,368	2,397	30,298	2,397	28,775
25	2,276	31,644	2,517	32,815	2,517	31,292
26	2,390	34,034	2,642	35,458	2,642	33,934
27	2,509	36,543	2,775	38,232	2,775	36,709
28	2,635	39,178	2,913	41,145	2,913	39,622
29	2,766	41,944	3,059	44,204	3,059	42,681
30	2,905	44,848	3,212	47,416	3,212	45,893

Financial summary		Window Type: DC	Window Type: DC-Le-A	Window Type: TC-Le
Totlal initital cost		-2,035	-4,427.50	-5,951
Year to positive cash flow		2.80	5.10	6.60
Cumuative cashflow	After 10 years	6,841	5,387	3,864
	After 20 years	21,298	21,375	19,851
	After 30 years	44,848	47,416	45,893

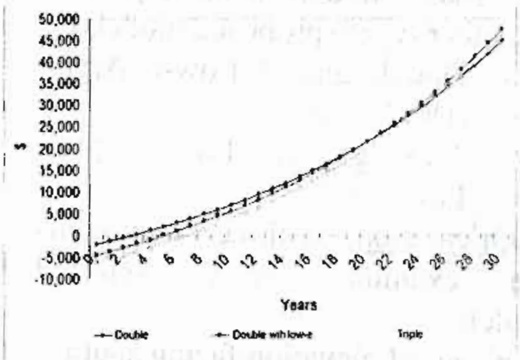


Figure 2. Regression curves of upgrading Single-glazed (base case) with respect to other window types.

6. Discussion

6.1. Window Type

1. Single-glazed (SC) as a based model: As shown in Figure (2) and Table (3), three cases took place for the proposed dwelling.

Table 4. Results of upgrading Double-glazed (base case) with respect to other window types.

Year	Window Type: DC-Le-A		Window Type: TC-Le	
	Saving	Cumulative	Saving	Cumulative
#	$	$	$	$
0	(2,393)	(2,393)	(3,916)	(3,916)
1	288	(2,105)	348	(3,568)
2	302	(1,803)	365	(3,203)
3	317	(1,486)	383	(2,820)
4	333	(1,153)	403	(2,417)
5	350	(803)	423	(1,994)
6	367	(436)	444	(1,550)
7	385	(50)	466	(1,084)
8	405	354	489	(595)
9	425	779	514	(81)
10	446	1,226	540	459
11	469	1,694	567	1,025
12	492	2,186	595	1,620
13	517	2,703	625	2,245
14	542	3,245	656	2,900
15	570	3,815	689	3,589
16	598	4,413	723	4,312
17	628	5,041	759	5,071
18	659	5,700	797	5,868
19	692	6,392	837	6,706
20	727	7,119	879	7,584
21	763	7,882	923	8,507
22	801	8,684	969	9,476
23	841	9,525	1,017	10,494
24	884	10,409	1,068	11,562
25	928	11,337	1,122	12,684
26	974	12,311	1,178	13,861
27	1,023	13,334	1,237	15,098
28	1,074	14,407	1,299	16,397
29	1,128	15,535	1,363	17,760
30	1,184	16,719	1,432	19,192

Financial summary		Window Type: DC-Le-A	Window Type: TC-Le
Totlal initital cost		-2,392.50	-3,916.00
Year to positive cash flow		7.10	9.20
Cumuative cashflow	After 10 years	1,226	459
	After 20 years	7,119	7,584
	After 30 years	16,719	19,192

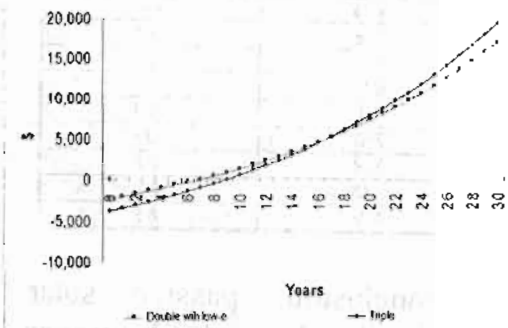


Figure 3. Regression curves of upgrading Double-glazed (base case) with respect to other window types.

There is a clear improvement for the upgrade from single-glazed (SC) to double-glazed (DC) window type. The initial cost of this upgrade was reimbursed three years later. In other words, the year to positive cash flow was shown roughly after two years and nine months after installation. Additionally, the cumulative cash flow after 10, 20 and 30 years was $6,841, $21,298 and $44,848 respectively. The fraction of cash flow is even more with the upgrade to type DC-Le-A or TC-Le. It is worth mentioning that after twenty year of use, the cumulative cash flow for the three upgrades reaches nearly $20,000 although the year to positive cash flow varies (Table 3). The regression curve of the year to positive cash flow ranged from two to six and half years for the three types. In one hand, the comparison shows an evident advantage to the upgrade. On the other hand, it shows that SC window type has a disadvantage to passive solar heating when implemented in these climatic regions.

In conclusion, with consideration to current climate conditions, the decision to implement SC window type is bounded with considerable fraction of uncertainty. This assures recommendations set by ASHRAE Fundamentals and Canadian standards concerning the implementation of this type where temperature degrees reaches below freezing point (8), (19), (21).

2. Double-glazed (DC) as a base model: The two proposed types are Dc-Le-A and TC-Le as shown in Figure (3) and Table (4). A number of results are derived from the comparison:
   - Initial cost for upgrade to Dc-Le-A type is $2,392. This number is increase with 40% when TC-Le type is selected.
   - Dc-Le-A has almost 2 years to cash flow privilege to the other type.
   - With respect to the cumulative cash flow, small fraction of improvement was recorded to TC-Le, after 20 years of use. This fraction is even increase with 25% when reaching 30 years as shown in Figure 3 and Table 4.
   - So, if the replacement of this window would occur after 20 years, it is more economical to use Dc-Le-A type since initial cost was less.
   - If replacement would occur later, then the proper decision for the proposed window type would be TC-Le as illustrated in Figure 3 and Table 4.

In conclusion, results had shown advantage improvement to the upgrade of windows specifically when considering the long-cycle saving.

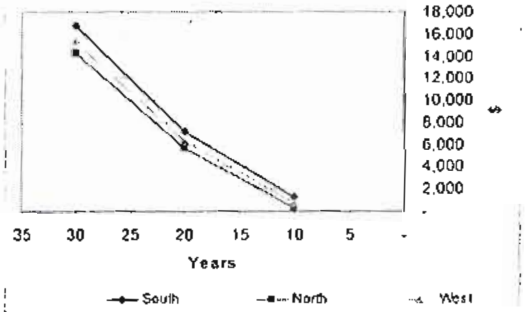
Table (5): Summary of cumulative cash flow with respect to various orientations involved

5.a: upgrade DC to DC-le-A

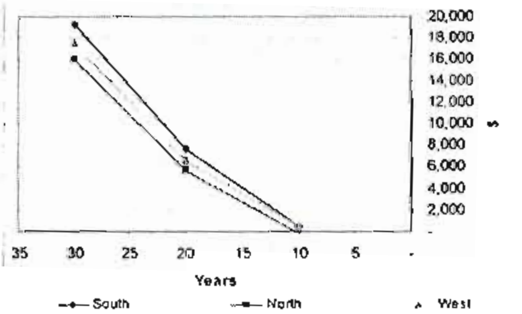
Financial summary		Orientation		
		South	North	West
Year to positive cash flow		7.10	7.20	7.2
Cumuative cashflow	10	1,226	328	735
	20	7,119	5,621	6,270
	30	16,719	14,244	15,265

5.b: upgrade DC to TC-Le

Financial summary		Orientation		
		South	North	West
Year to positive cash flow		9.20	9.20	9.1
Cumuative cashflow	After 10 years	459	(170)	392
	After 20 years	7,584	5,641	6,544
	After 30 years	19,192	15,925	17,431



4.a: upgrade DC to DC-le-A



4.b: upgrade DC to TC-Le

Figure (4): Regression curves of cumulative cash flow with respect to various orientations involved

3. Orientation: The orientation experiment was run considering Double-glazed (DC) as a base model. It is worthy mentioning that the above experiment concerning window type was run considering south facing orientation. In here, both upgrades will be examined each with three different orientations; south, north and west facing. A number of results were derived from the experiment (Figure 4), (Table 5):

- In 20 years, for an upgrade to DC-Le-A, directing building towards west resulted in reduced cumulative cash flow with nearly $849 compared to that of south facing. Likewise, north facing was reduced $1498 to that of south facing.
- In 20years, for an upgrade to TC-Le, directing building towards west resulted in reduced cumulative cash flow with nearly $1040 compared to that of south facing. Similarly, north facing was reduced nearly $1943 to that of south facing.
- The above figures substantially increased with nearly 65-68% and when compared after 30years of use.
- The year positive to cash flows were generally similar to the south facing model in both upgrades.

In conclusion, the above results obtained from the modeling south facing orientation would be more efficient with respect to passive solar heating in particular when compared to that of north. Thus increasing the number of opening for elevations facing south is preferable than any other location. In fact this is valid for cities locating north the hemisphere and above the equator. During summer seasons, treatments must be applied to apertures on southern direction to prevent overheating within buildings which will require passive or active cooling demands.

7. Conclusions

The prototype dwelling is designed with considerations to passive solar heating. Two base models for window types were selected and examined using RetScreen passive solar heating project model. Building orientations were examined for three different orientations including south, west and north facing. A number of Conclusions are derived from this study:

- Single-glazed windows recorded the poorest performance with respect to passive solar heating in buildings.
- South facing orientation is more efficient with respect to passive solar heating demands and north facing is less desirable.
- Initial cost of window upgrade is reimbursed, due to reduction of active solar heating cost, in less than ten years depending on the type of window selected.
- For an economical upgrading of a windows two issues must be considered; initial installation fees required for the upgrade and the project life.
- The use of double-glazed with a single low-e film plus argon gas fill and the high performance IGU is triple-glazed with double low-e films are recommended more than single-glazed or double glazed windows.
- Upgrading window from Double-glazed to DC-Le-A, , is more economical if the window is considered to last for 20 years and to TC-Le if replacement would occur after 30 years.
- Window design and orientation are effective for building designed with passive solar principles.

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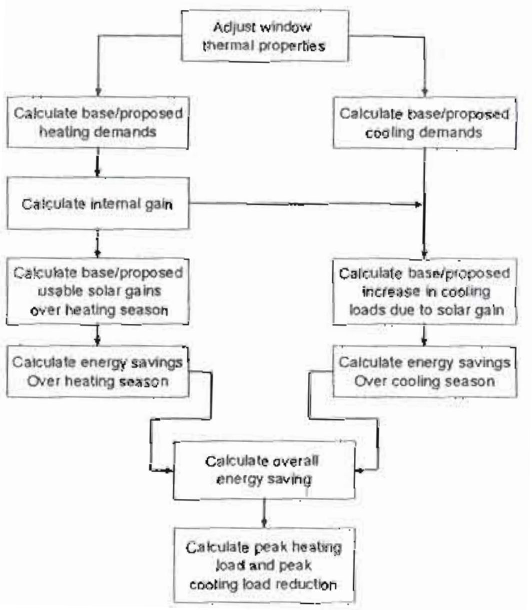
Appendix-a: The various window dimensions examined with respect to their U and SHGC values.

Orientation		Window Configurations					Single glazed clear (SC)						Double-glazed clear (DC)					
							Centre Glazing		Rated Window		Adjusted		Centre Glazing		Rated Window		Adjusted	
		Type	Width	Height	Number	Total Area	U_{cg}	$SHGC_{cg}$	U-value	SHGC	U-value	SHGC	U_{cg}	$SHGC_{cg}$	U-value	SHGC	U-value	SHGC
Orientation	Elevation		(mm)	(mm)		(m^2)	W/(m^2-°C)	-	W/(m^2-°C)	-	W/(m^2-°C)	-	W/(m^2-°C)	-	W/(m^2-°C)	-	W/(m^2-°C)	-
South	Front	Casement	1,000	1,600	3	4.80	5.91	0.86	5.14	0.63	5.40	0.71	2.82	0.76	2.69	0.50	2.73	0.59
South	Front	Fixed	500	1,600	8	6.40	5.91	0.86	5.55	0.75	5.34	0.69	2.82	0.76	2.78	0.66	2.76	0.60
South	Front	Patio Door	1,200	2,000	2	4.80	5.91	0.86	5.14	0.63	5.45	0.72	2.81	0.73	2.88	0.55	2.85	0.62
North	Back	Fixed	500	1,600	2	1.60	5.91	0.86	5.55	0.75	5.34	0.69	2.82	0.76	2.78	0.66	2.76	0.60
North	Back	Casement	1,600	1,000	1	1.60	5.91	0.86	5.14	0.63	5.40	0.71	2.82	0.76	2.69	0.50	2.73	0.59
North	Back	Casement	700	1,000	1	0.70	5.91	0.86	5.14	0.63	5.16	0.64	2.82	0.76	2.69	0.50	2.69	0.51
West	Right	Patio Door	1,000	2,000	1	2.00	5.91	0.86	5.14	0.63	5.39	0.71	2.81	0.73	2.88	0.55	2.86	0.61
East	Left	Fixed	500	1,600	4	3.20	5.91	0.86	5.55	0.75	5.34	0.69	2.82	0.76	2.78	0.66	2.76	0.60
East	Left	Casement	700	1,000	1	0.70	5.91	0.86	5.14	0.63	5.16	0.64	2.82	0.76	2.69	0.50	2.69	0.51
East	Left	Casement	1,000	1,600	2	3.20	5.91	0.86	5.14	0.63	5.40	0.71	2.82	0.76	2.69	0.50	2.73	0.59

Orientation		Window Configurations					Double-glazed, Low-e, Argon (DC-Le-A)						Trible-glazed, Low-e (TC-Le)					
							Centre Glazing		Rated Window		Adjusted		Centre Glazing		Rated Window		Adjusted	
		Type	Width	Height	Number	Total Area	U_{cg}	$SHGC_{cg}$	U-value	SHGC	U-value	SHGC	U_{cg}	$SHGC_{cg}$	U-value	SHGC	U-value	SHGC
Orientation	Elevation		(mm)	(mm)		(m^2)	W/(m^2-°C)	-	W/(m^2-°C)	-	W/(m^2-°C)	-	W/(m^2-°C)	-	W/(m^2-°C)	-	W/(m^2-°C)	-
South	Front	Casement	1,000	1,600	3	4.80	1.69	0.64	2.00	0.43	1.90	0.50	1.21	0.58	1.68	0.39	1.53	0.45
South	Front	Fixed	500	1,600	8	6.40	1.69	0.64	1.82	0.56	1.90	0.51	1.67	0.67	1.88	0.58	2.00	0.53
South	Front	Patio Door	1,200	2,000	2	4.80	1.41	0.40	1.88	0.31	1.69	0.35	1.09	0.37	1.60	0.28	1.39	0.32
North	Back	Fixed	500	1,600	2	1.60	1.69	0.64	1.82	0.56	1.90	0.51	1.21	0.58	1.39	0.51	1.50	0.47
North	Back	Casement	1,600	1,000	1	1.60	1.69	0.64	2.00	0.43	1.90	0.50	1.21	0.58	1.68	0.39	1.53	0.45
North	Back	Casement	700	1,000	1	0.70	1.69	0.64	2.00	0.43	1.89	0.44	1.21	0.58	1.68	0.39	1.67	0.40
West	Right	Patio Door	1,000	2,000	1	2.00	1.41	0.40	1.88	0.31	1.72	0.34	1.09	0.37	1.60	0.28	1.43	0.31
East	Left	Fixed	500	1,600	4	3.20	1.69	0.64	1.82	0.56	1.90	0.51	1.21	0.58	1.39	0.51	1.50	0.47
East	Left	Casement	700	1,000	1	0.70	1.69	0.64	1.82	0.56	1.82	0.56	1.21	0.58	1.68	0.39	1.67	0.40
East	Left	Casement	1,000	1,600	2	3.20	1.69	0.64	2.00	0.43	1.90	0.50	1.21	0.58	1.68	0.39	1.53	0.45

Appendix-b: Passive Solar Heating energy model flow chart (7).



Appendix-c: General parameters required to run the model.

Shading Factor	Elevations			
	Front	Left	Right	Back
Winter shading factor	50%	15%	30%	60%
Summer shading factor	10%	10%	80%	80%

Nearest location for weather data of Waterloo		Muskoka,ON
Latitude of project location	°N	44.97
Building front azimuth	°	180
Heating design temperature	°C	-24.2
Cooling design temperature	°C	26.9
Building floor area	m²	110
Mass level (Wood with gypsuim board)	-	Low
Insulation level	m².°C/W	4.5
Internal gains	kWh/d	2
Other cost (Contingencies)	%	10
Building has air-conditioning?		No
Heating fuel type		Propane
Modifiy window shading to the propsed case wiondow		No
Avoided cost of energy heating (Propane)	$/L	0.48
Retail price of electricity	$/kWh	0 065
Energy cost escalation rate	%	5
Inflation	%	3
Project Profile	Years	30
Heating system seasonal efficiency		0.9

Elevation	m²	SC	DC	(DC-Le-A)	(TC-Le)
Front Elevation	16.00	$ 100	$ 175	$ 250	$ 300
Left elevation	7.10	$ 150	$ 200	$ 275	$ 320
Right elevation	2.00	$ 150	$ 200	$ 275	$ 320
Back elevation	3.90	$ 150	$ 200	$ 275	$ 320
installation charges	29.00	$ 100	$ 100	$ 100	$ 100