Solar Energy Potential for the Northern Sustainable Houses

INTRODUCTION

Renewable energy technologies, such as solar photovoltaic (PV) or solar thermal systems, have the potential to offset the energy needs of housing in northern Canada. The annual total available solar radiation in the North is actually very similar to southern Canada's urban centres. Rising fuel prices and more competitive costs for solar technologies are driving interest in using on-site renewable energy generation to reduce fossil fuel dependency. Further, as fuel has to be imported to, and stored in, most northern locations, the environmental concerns associated with fuel spillage and pollutant emissions can be partly addressed by local solar energy generation.

In response to the high heating loads and costly energy, northern housing design has become more energy-efficient. However, at some point, there are diminishing returns associated with the application of energy-efficiency measures and it becomes more practical and affordable to consider ways to harness renewable solar energy to meet household needs. However, questions remain regarding the optimal orientation and surfaces of houses to capture solar energy in the North.

To explore the solar energy potential for northern housing, Canada Mortgage and Housing Corporation (CMHC) supported a modelling study of the four Northern Sustainable Houses (NSHs) that were constructed by northern housing providers to demonstrate culturally appropriate, energy-efficient housing options. The NSHs, designed, constructed and owned by housing providers in each of the three territories, were selected as illustrative case studies for optimizing the design and orientation of the roofs (upon which solar panels could be mounted) with respect to annual solar radiation exposure.

The Northern Sustainable Houses

There are four NSHs located across northern Canada (see table 1). The Dawson E/2 NSH, completed in 2008, and the Dawson E/9 NSH, completed in 2009, are both located in the same neighbourhood in Dawson City (64°N), Yukon. The Inuvik NSH, completed in 2011, is located in Inuvik (68°N), Northwest Territories. The Arviat NSH, completed in 2013, is located in Arviat (61°N), Nunavut.

Table 1 Northern sustainable house projects and climate data

Name	Location	Type	Solar hot water	Solar PV	Latitude, longitude	Heating degree-days[1]	Annual solar radiation[2]	Average annual wind speed[3]
Dawson E/2 NSH	Dawson, YT	Single	n/a	n/a	64.07°N, 139.43°W	8,120	13.7 MJ/m²	1.1 m/s at 10 m, 3.12 m/s at 30 m
Dawson E/9 NSH	Dawson, YT	Duplex	2 flat-plate panels	n/a	64.07°N, 139.43°W	8,120	13.7 MJ/m²	1.1 m/s at 10 m, 3.12 m/s at 30 m
Inuvik NSH	Inuvik, NT	Duplex	4 flat-plate panels	3.6 kW (8 panels)	68.36°N, 133.69°W	9,600	12.2 MJ/m²	2.7 m/s at 10 m, 4.56 m/s at 30 m
Arviat NSH	Arviat, NU	Single	n/a	n/a	61.11°N, 94.06°W	9,850	15.0 MJ/m²	7.55 m/s at 30 m

As a point of comparison, Ottawa has 4,500 HDD and 15.8 MJ/m² available solar radiation, wind speed of 3.9m/s at 10 m, 3.35 m/s at 30 m

[1] Degree-days below 18°C **(National Research Council of Canada, 2010)**
[2] Annual solar radiation for south-facing, and tilt = latitude - 15° **(Natural Resources Canada, 2013)**
[3] Average wind speed at 10 m (Natural Resources Canada, 2010) (Arviat not available); average wind speed at 30 m **(Environment Canada, 2003)**

All the NSH projects targeted significant energy savings while meeting the cultural needs of the communities where they are located. Higher levels of thermal insulation, heat recovery ventilation systems, high-efficiency space and water heating appliances and improved airtightness levels were included in each of the houses. For more information on the NSH projects, visit CMHC's website at www.cmhc.ca. To assess the impact of changes to the roof structures and orientation of the project on solar potential, Natural Resources Canada's RETScreen software was used in combination with knowledge of the specific construction characteristics of each of the houses.

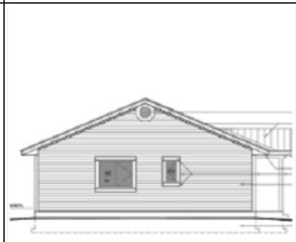
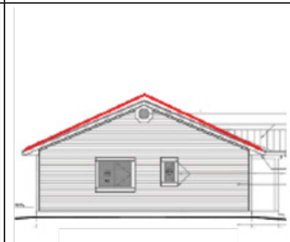
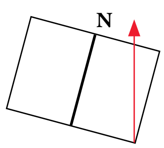
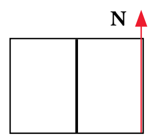
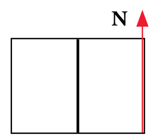
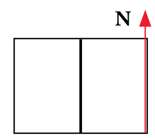
Dawson E/2 NSH

The Dawson E/2 NSH (see figure 1) in Yukon is a single-detached house with passive solar features. With its large roof almost facing south, the house has high potential for roof-integrated active solar technologies. The amount of solar energy falling on the roof structure was determined for two orientations and two roof slopes.

Table 2 summarizes the annual available solar radiation for the proposed scenarios. The new build design #2 option, while not quite realistic and much more expensive to construct compared to conventional roof structures, offered the highest potential solar yield. There could be racking installed on the roof that would allow the solar panels to be elevated to the desired tilt without changing the roof pitch, although wind loads and general aesthetics would need to be considered and the available solar collection area is reduced with a steeper tilt. Design options similar to the new build design #3 could possibly be more viable in the case of new build scenarios.

Figure 1 Dawson E/2 house

Table 2 Summary of different design scenarios for Dawson E/2 solar integration

	Retrofit of current build	New build design #1	New build design #2	New build design #3
Description	Existing orientation and roof angle, add panels to cover the roof	Orient main roof face to south, keep same roof angle	Orient main roof face to south, change roof angle or rack panels to optimal angle	Orient main roof face to south, change roof angle to maximum reasonable for roof-integrated panels
Tilt	 Original roof 22.6° (5:12)	 Original roof 22.6° (5:12)	 Modified roof 49° (latitude - 15°)	 Modified roof 30.3° (7:12)
Orientation of roof-slope face	 15° off south	 South facing	 South facing	 South facing
Available area on main roof	99 m^2	99 m^2	145 m^2	105 m^2
Average daily radiation available	3.27 $kWh/m^2/day$ 91% of max	3.29 $kWh/m^2/day$ 91% of max	3.61 $kWh/m^2/day$ 100% of max	3.43 $kWh/m^2/day$ 95% of max
Annual total radiation available on surface	1,295 MJ	1,303 MJ	2,079 MJ	1,420 MJ

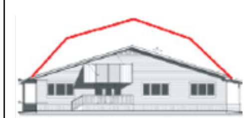
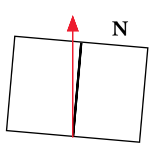
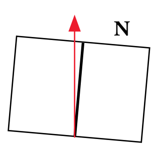
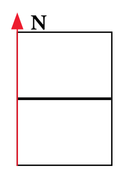
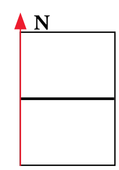
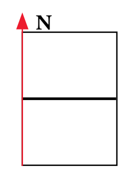
Dawson E/9 NSH

The Dawson E/9 NSH (see figure 2) in Yukon is a duplex with passive solar features and a two-panel solar hot water system on the south-facing porch roof. As the house is oriented with its roof areas facing east and west, there is not much potential for additional solar panels for the existing building except by increasing the area of the porch roof. Future construction of this design could consider orienting the house to have a south-facing roof area (or rotating the roof structure by 90 degrees) and by tilting the panels at an optimal angle.

Figure 2 Dawson E/9 house

Table 3 summarizes the available solar radiation (per unit area and annual total) for the proposed scenarios. The retrofit of current build option can be implemented without significantly altering the building design. Using all the available facade area to incorporate a larger porch roof, it could potentially quadruple the existing solar capacity. The three new build design options require rotation of the whole building (or just the roof structure) by 90 degrees to have the main roof facing south. This change alone will result in more than 11 times more available solar capacity due to the increase in available solar energy capture area. While the new build design #1 and #2 options are feasible in terms of the roof pitch, the new design #3 option is less realistic as it would be more expensive to construct.

Table 3 Summary of different design scenarios for Dawson E/9 solar integration

	Current build	Retrofit of current build	New build design #1	New build design #2	New build design #3
Description	Two solar hot water panels on the south-facing, 60° porch roof	Increase area of porch roof and add more panels to cover the available area	Orient main roof face to south, keep the existing roof slope at 4:12, install panels to cover the available area	Orient main roof face to south, change roof slope to 7:12, install panels to cover the available area	Orient main roof face to south, change roof slope to resemble a barn roof of 45° and 18.4°, install panels to cover the available area
Tilt	 Original porch roof 60°	 Original porch roof 60°	 Existing roof 18.4° (4:12)	 Modified roof 30.3° (7:12)	 Modified roof 45° and 18.4°
Orientation of roof-slope face	 5° east or west of south	 5° east or west of south	 South facing	 South facing	 South facing
Available area on main roof	11 m^2 (2 panels)	43 m^2 (8 panels)	142 m^2	157 m^2	52 m^2 at 45° 104 m^2 at 18.4°
Average daily radiation available	3.58 $kWh/m^2/day$ 100% of max	3.58 $kWh/m^2/day$ 100% of max	3.19 $kWh/m^2/day$ 89% of max	3.43 $kWh/m^2/day$ 96% of max	3.59 $kWh/m^2/day$ for 45° 3.19$kWh/m^2/day$ for 18.4° 100% and 89% of max
Annual total radiation available on surface	39 MJ	155 MJ	454 MJ	537 MJ	518 MJ

Inuvik NSH

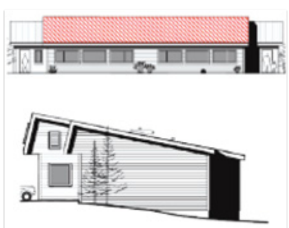
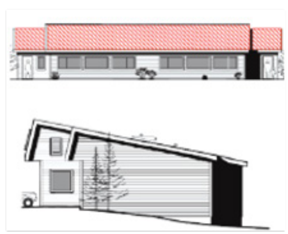
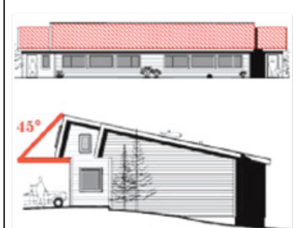
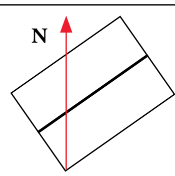
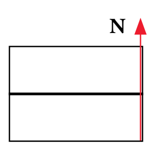
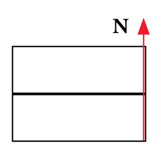
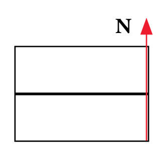
The Inuvik NSH (see figure 3) in the Northwest Territories is a duplex with passive solar features, a two-panel solar hot water system and a 1.7-kW solar electric system for each unit, all of which are installed on the southeast-facing roof. Future construction of this design could include orienting the duplex south and changing the tilt of the roof.

The existing solar panels are mounted at 75 degrees on the main roof. There are also two side roofs set back from the main roof that could accommodate more solar panels; but will be partly shaded during the day.

Table 4 summarizes the available solar output for the proposed scenarios. Decreasing the roof angle where the solar panels are mounted by extending the soffit will increase the available solar energy capture area, but would also provide more shading to the south-facing windows and thus less passive solar gains. By using both

Figure 3 Inuvik NSH

Table 4 Summary of different design scenarios for Inuvik NSH

	Retrofit of current build	**New build design #1**	**New build design #2**	**New build design #3**
Description	Eight photovoltaic panels and two solar hot water panels per housing unit on the main roof at 75°; main roof oriented at 35° east of south	Orient main roof face to south, keep the existing roof slope and add more panels to cover the side roof	Orient main roof face to south, change existing roof slope to 60° and add more panels to cover both the main roof and the side roof	Orient main roof to south, change existing roof slope to 45°, add more panels to cover both the main roof and the side roof
Tilt	 Original roof 75°	 Original roof 75°	 Modified roof 60°	 Modified roof 45°
Orientation of roof-slope face	 35° east of south	 South facing	 South facing	 South facing
Available area on main roof	32 m^2 (main roof only)	43 m^2 (main roof area and sides)	47 m^2 (main roof area and sides)	58 m^2 (main roof area and sides)
Average daily radiation available	3.33 $kWh/m^2/day$ 91% of max	3.53 $kWh/m^2/day$ 96% of max	3.66 $kWh/m^2/day$ 100% of max	3.60 $kWh/m^2/day$ 98% of max
Annual total radiation available on surface	108 MJ	149 MJ	171 MJ	207 MJ

the main roof and the side roofs, orienting the house to face south, and decreasing the roof angle to 60 degrees, the new build design #2 option was found to offer close to optimal solar energy potential and would lead to 1.6 times more solar potential (MJ/year) than the current build condition.

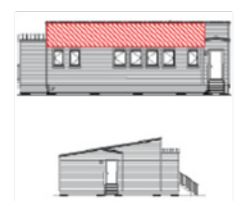
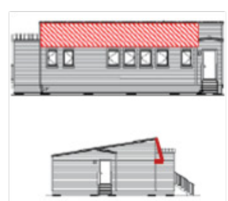
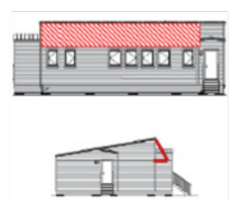
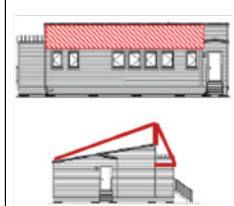
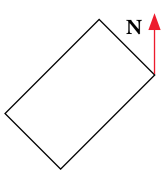
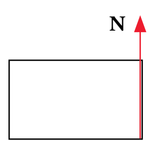
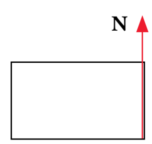
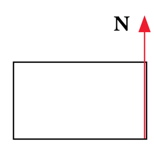
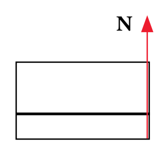
Arviat NSH

The Arviat NSH (see figure 4) in Nunavut is a single-detached house with passive solar features, designed to be 'solar ready' with available facade area.

The house was designed to be solar ready and the original design called for future solar panels on its southeast facade (45 degrees east of south). In the current design, the main

Figure 4 Arviat NSH

Table 5 Summary of different design scenarios for Arviat NSH

	Retrofit of current build	New build design #1	New build design #2	New build design #3	New build design #4
Description	Add one row of panels above windows to cover the southeast-facing facade	Orient main facade to south, add one row of panels above windows	Orient main facade to south, add a 75° roof overhang and add panels to the overhang	Orient main facade to south, add a 60° roof overhang and add panels to the overhang	Orient main facade to south, change roof to 60° and 4:12 and add panels to the south-facing roof
Panel tilt	 Original vertical facade with original 2:12 roof	 Original vertical facade with original 2:12 roof	 Add awning at 75° with original 2:12 roof	 Add awning at 60° with original 2:12 roof	 Modify roof to 60° (south) and 4:12 (north)
Orientation of facade/roof-slope face	 45° east of south	 South facing	 South facing	 South facing	 South facing
Available area on main roof	22 m^2 (facade)	22 m^2 (facade)	23 m^2	25.5 m^2	46.6 m^2
Average daily radiation available	3.82 kWh/m^2/day 81% of max	4.26 kWh/m^2/day 91% of max	4.59 kWh/m^2/day 98% of max	4.70 kWh/m^2/day 100% of max	4.70 kWh/m^2/day 100% of max
Annual total radiation available on surface	84 MJ	94 MJ	105 MJ	120 MJ	219 MJ

facade where the solar technologies could be integrated is oriented 45 degrees east of south. The impact of design changes on solar energy potential is shown in table 4. The new build design #1 option orients the main facade to face south and shows an 11% increase in total annual radiation available. As the optimal tilt angle for Arviat is less than 90 degrees, the new build design #2 and #3 options explored adding a sloped overhang on the available facade area at 75 and 60 degrees, respectively. As a result, the new build design #3 option increased the total annual available solar radiation by 35% compared to the retrofit of current build option. The awning could also provide shading for the windows during the summer, reducing the potential for overheating. The new build design #4 option investigated the effect of expanding the south-facing area by increasing the slope of the north roof. As long as the roof pitch remains feasible for construction, this option was projected to offer 2.6 times more radiation than the retrofit of current build option.

CONCLUSIONS

The findings of the study demonstrate the sensitivity of the annual solar energy potential of houses in the North to their orientation and the tilt angle of the roofs that receive solar energy. Although the houses are located in different cities across the North, the findings were relatively consistent. For instance, while it is advantageous from a solar gain point of view to have the longest axis of a house oriented east-west (that is, 90 degrees to south to provide the most opportunity for one of the roof surfaces to face south); being off by 15% did not have a significant impact on solar potential. However, being off by 90 degrees could reduce the annual solar radiation falling on the roof surface by 30% or more. With respect to roof tilt angle, it was found that moving from a relatively low slope (for example, 4:12) to higher slopes tends to increase the annual solar energy potential of south-facing roof surfaces. However, as the slope approaches 90 degrees, the annual solar potential begins to decline due to the higher angle of the sun to the vertical surface during the summer when solar energy potential peaks. The study demonstrates the need to carefully model solar potential at the design stage so the house orientation and solar energy receiving surfaces can be optimized.

Implications for the northern housing industry

The results of this study demonstrate that while there is significant potential to capture solar energy to help offset the energy needs of northern housing, actual solar energy capture is very sensitive to the orientation of the house on the site and the angles that the solar capture surfaces present to the sun. Therefore, to optimize the solar energy potential of houses in the North, careful attention must be paid to the planning and design of both houses and communities.

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Housing Research at CMHC

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