ERG/200702

Solar energy and multi-storey residential buildings

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26 March 2007

Summary

This report considers the limitations on solar energy in new, multi-storey residential buildings. In a time of rising energy demand and faltering production, the decisions made with respect to building design will be felt for many decades to come. Buildings can improve their energy security by reducing their heating demand and replacing imported energy supplies with indigenous ones.

The findings in this report are preliminary; however, they show that:

- Buildings of between four to seven stories have the potential of meeting all of their space and water heating requirements from solar energy.
- Reducing heating demand can increase the number of stories heated with solar energy.
- Seasonal storage will be necessary for any building expecting to use solar energy if it is to be used as a predominant source of space heating.
- A building of 26 stories in height will gain no more than a fraction of its heating supply from the sun.
- For solar heating to work in a 26 storey building, it would be necessary to incorporate technologies, such as the "solar wall", into its design.

1 Introduction

Energy security, the physical availability of supplies to satisfy demand at a given price (1), has become one of the dominant issues in the opening decade of the twenty-first century. As world demand for energy continues to increase, prices will inevitably rise and many people will find themselves facing stark choices with respect to energy-related activities such as transportation, food supplies, and residential heating (2).

Meeting a jurisdiction's energy security needs can be achieved through three steps: *review* (an analysis of existing sources of energy, infrastructure, and types of demand), *reduce* (the development of wedges to reduce energy demand), and *replace* (the application of wedges that replace imported energy sources with indigenous ones) (3).

The residential sector is a particular interest to anyone living in a northern country such as Canada, where a review of residential energy consumption shows that the majority of buildings are heated by natural gas and fuel oil (4). Residential energy demand can be reduced through better building practices and living in higher-density apartment buildings (5). Replacing existing energy sources with indigenous ones that are ideally renewable is easier to achieve when a building is being designed rather than after-the-fact, this is also true with solar energy applications.

This paper examines the space and water heating energy requirements of multi-storey residential buildings and how roof-top mounted solar energy collection systems could meet some or all of this demand. The paper determines the maximum height of a building located in Halifax.

2 Multi-storey residential energy demand

Multi-storey residential buildings—such as apartments and condominiums—are intended for multiple households. Data shows that multi-storey residential buildings are usually more efficient than single-attached or single-detached residential units; for example, see (6).

According to a CMHC study of 40 different multi-storey residential buildings, the average energy demand for all energy-related activities in household suites constructed after 1981 was 212 kWh/m^2 (7). The same study showed that suites in privately owned condominiums consumed 35 percent more energy than suites in buildings with social or non-profit ownership. The CMHC study also suggests that low-energy apartments with an energy demand of 150 kWh/m^2 is achievable (7).

Energy activities in the residential sector are divided into five components: space heating, water heating, appliances, lighting, and space cooling. NRCan maintains statistics on the energy activities in the residential sector of each province; by applying these statistics to the average energy consumption of a household, it is possible to determine the average consumption of each component. The average consumption by activity for suites in multi-storey residential buildings in Nova Scotia is shown in Table 1.

Table 1: Annual energy consumption in multi-storey residential building suites (6)

Activity	Percentage of consumption	Consumption by activity	
		Existing (212 kWh/m^2)	Low-energy (150 kWh/m^2)
Space heating	61.4%	130.17	92.1
Water heating	22.7%	48.12	34.1
Appliances	11.8%	25.02	17.7
Lighting	4.1%	8.69	6.2
Space cooling	0.1%	0.21	0.2

Space and water heating are responsible for about 84 percent of the energy demand in a suite in a multi-storey residential building. Table 2 shows the energy costs associated with an existing and a low-energy apartment using electric heat.

Table 2: Energy costs for a 100 m^2 suite

	Existing	Low-energy
Heating demand (kWh/m^2)	178.3	126.2
Demand in 100 m^2 suite (kWh)	17,829	12,615
Electricity cost (at $0.11/ kWh)	$1,961	$1,387

The average monthly space and water heating demand can be calculated for the heating season[1] from the average daily temperature and the heating degree days. Table 3 shows the monthly energy demand for an apartment suite in Nova Scotia with either existing or low-energy demand.

[1] The heating season consists of those months with an average temperature below 18°C; in Halifax, the heating season is from October to May, inclusive.

Table 3: Monthly energy demand (kWh/m^2) for a suite in Nova Scotia[2]

	Daily average temperature (8)	Heating degree days	Percentage of heating demand	Heating demand (kWh/m^2)	
				Existing	Low-energy
October	9.97	249	6.7%	12.8	9.0
November	4.80	396	10.7%	17.9	12.7
December	-0.14	562	15.2%	23.8	16.8
January	-3.92	679	18.4%	27.9	19.7
February	-3.70	608	16.4%	25.4	18.0
March	-0.14	562	15.2%	23.8	16.8
April	4.71	399	10.8%	18.0	12.8
May	10.03	247	6.7%	12.7	9.0

3 Solar potential

As fuel prices increase and the prospect of shortages loom large, energy security will become a dominant issue, to both the public and politicians. Meeting the energy security challenge will require detailed reviews of how and where energy is used, programs to reduce energy consumption, and finally, technologies to replace imported energy sources with indigenous ones.

In the Canadian residential sector, the focus must be on space and water heating, as these are vital to anyone wanting to living in a northern climate. All new buildings must be constructed to the highest possible standards to reduce their energy consumption, thereby reducing the quantity of replacement energy.

Finding replacement sources becomes problematic in a province like Nova Scotia as there are a limited number of alternative sources of energy: coal has environmental consequences, hydroelectricity is completely spoken for, and biofuels are limited in their availability. One possible alternative that will have to be utilized is solar.

Solar energy for heating can be captured in a number of ways, from simple building orientation to solar thermal collectors attached to the building. Two solar thermal technologies common to heating applications in buildings are evacuated tube and flat plate collectors. Variations in

[2] The daily average temperature data in Table 3 is the 10 year average for each month (1990 to 1999).

flat plate collector designs can be used to improve performance, such as glazed apertures and selective surface treatments; however, evacuated tube collectors have been found to be more effective during low light or low ambient air applications—something common during Canadian heating season.

Figure 1 shows the annual solar energy potential for Halifax: the incident radiation, evacuated tube, and flat plate data is the estimated energy available on a one square metre surface.

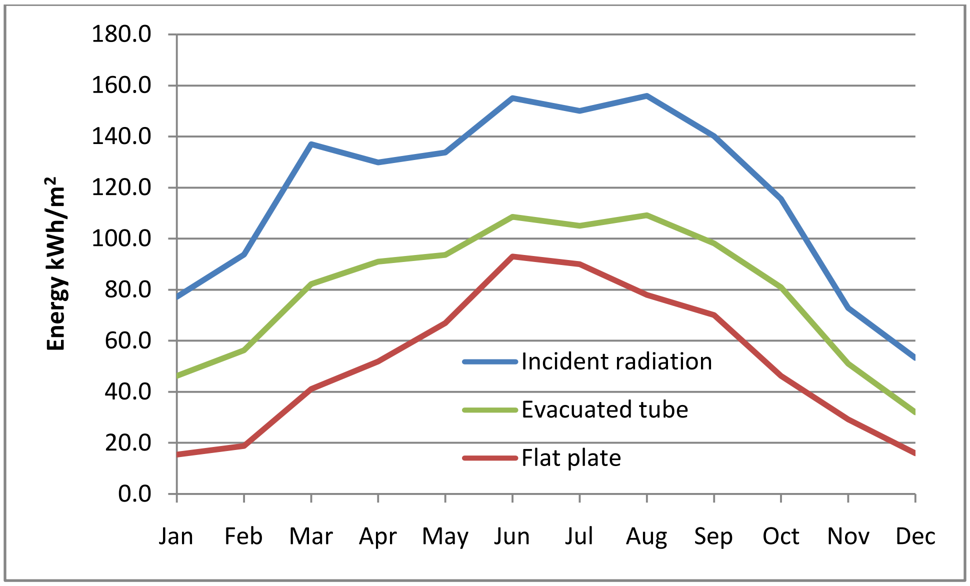

Figure 1: Solar energy potential in Halifax

The total annual solar incident radiation for Halifax is approximately 1,400 kWh/m^2; these estimates indicate that evacuated tube solar panels could supply 950 kWh/m^2, while flat plate panels could supply 600 kWh/m^2.

4 Maximizing solar gain in multi-storey buildings

Solar energy can be used to replace some or all of the energy required in a suite in a multi-storey building. As the amount of solar energy increases, the reliance on unreliable supplies of costly imported energy will decrease, thereby improving the energy security of the building's tenants. This section considers the number of stories that could be heated from solar energy.

For the purposes of this analysis, it is assumed that the multi-storey building is a rectangular-box shaped building (i.e., a cuboid), with a normalized footprint of one square metre and a solar panel on the roof of the building also normalized to one square meter. To obtain the total energy (demand or supply) for an actual building would require multiplying these results by the area of the building's roof surface.

Under ideal conditions, an evacuated tube supplying 950 kWh/m^2 (the annual estimate for Halifax) would be able to meet the annual heating requirements for 5.3 floors of existing apartments with heating loads of 178.3 kWh/m^2. However, this calculation does not taken into account that the supply of solar energy varies throughout the year.

Table 4 shows the maximum number of stories that could be heated using evacuated tube or flat plate panels throughout the heating season. The number of stories is determined for both panel types by dividing the energy available from each panel by the demand. For example, in January, the evacuated tube and flat plate would produce 46 kWh/m^2 and 15 kWh/m^2, respectively; since the demand is 27.9 kWh/m^2, the panels could meet the heating requirements of slightly more than one-and-a-half stories for the evacuated tube and about half-a-storey for the flat panel.

Table 4: Maximum number of stories

Period	Demand (kWh/m^2)	Energy from m^2		Number of stories	
		Evacuated tube	Flat plate	Evacuated tube	Flat plate
October	12.8	81	46	6.3	3.6
November	17.9	51	29	2.8	1.6
December	23.8	32	16	1.3	0.7
January	27.9	46	15	1.6	0.5
February	25.4	56	19	2.2	0.7
March	23.8	82	41	3.4	1.7
April	18.0	91	52	5.0	2.9
May	12.7	94	67	7.4	5.3

There are three points to note about the number of stories shown in Table 4:

- Buildings constructed to the maximum number of stories (7.4 with evacuated tube or 5.3 with flat plate panels) would require backup energy sources to meet their heating requirements for the other months of the heating season.
- Buildings constructed to the minimum number of stories (1.3 for evacuated tube or 0.5 for flat plate panels) would have excess energy during most of the heating season.

- It is assumed that the daily amount of solar energy meets the daily energy demand. If the daily demand exceeded the available solar energy, some form of backup energy source would be required.

Solar energy is available throughout the year, if it could be captured and stored in the form of heat during times of excess, it could be used during times of demand.

4.1 Storage

Storage of solar energy is achieved by increasing the temperature of a storage material, which is later cooled as the solar energy is extracted (9) (10). The effectiveness of a material to store thermal energy is a function of its heat capacity. Typical thermal storage materials include:

- Masonry – poured concrete, brick, stone, or ceramic tile can be easily incorporated into a design and posses quality thermal properties. Such applications are not capable of providing seasonal storage.
- Water – the heat capacity of water makes it attractive for thermal storage. The potential for using water as storage is limited due to difficulty of incorporating large volumes into a building design.
- Phase-change materials (PCMs) – materials that have the ability to change phase as they absorb and release heat can be attractive for thermal storage. PCMs typically provide greater heat storage capacities per unit volume than materials that rely on mass, however similar to water, these materials can be difficult to incorporate into a design.
- Borehole thermal energy storage (BTES) – through borehole heat exchangers, the earth can be used to store large quantities of solar energy. An example of this application is the Drake Landing Solar Community in Okotoks, Alberta. BTES holds great potential for seasonal storage of solar energy.

Due to fluctuations in the amount of solar energy available throughout the year, solar thermal collection systems are typically limited by storage potential. Large volumes of thermal mass are required to make solar energy available from day to day or month to month.

4.2 Solar potential using storage

The use of solar energy and storage for heating multi-storey residential buildings is considered in this section. In all cases, it is assumed that the storage system is 50 percent efficient, meaning that only half the energy collected by the solar panels is effectively transferred and stored for use at a later date. The simulations are run over nine years, from June 1990 to May 1999, with the heating degree days obtained from Halifax's annual temperature data; the maximum heating degree days occurred in January 1991. Initially, all storage units are uncharged, with no energy available for heating purposes.

4.2.1 Existing suites

Existing suites have an average energy demand of 212 kWh/m^2 and heating requirements of 178 kWh/m^2. During the non-heating season months (June through September), the heating load is 4 kWh/m^2.

Figure 2 shows the results of the nine-year simulation for a building with four stories of suites. The maximum heating demand occurs in January 1991 with a demand of 147.2 kWh/m^2 (36.8 kWh/m^2 per suite). The heating supply, obtained from the storage and the available solar energy, always exceeds the heating demand, and continues to grow over time; the supply has a wave-shape as it increases in the non-heating season and decreases during the heating season.

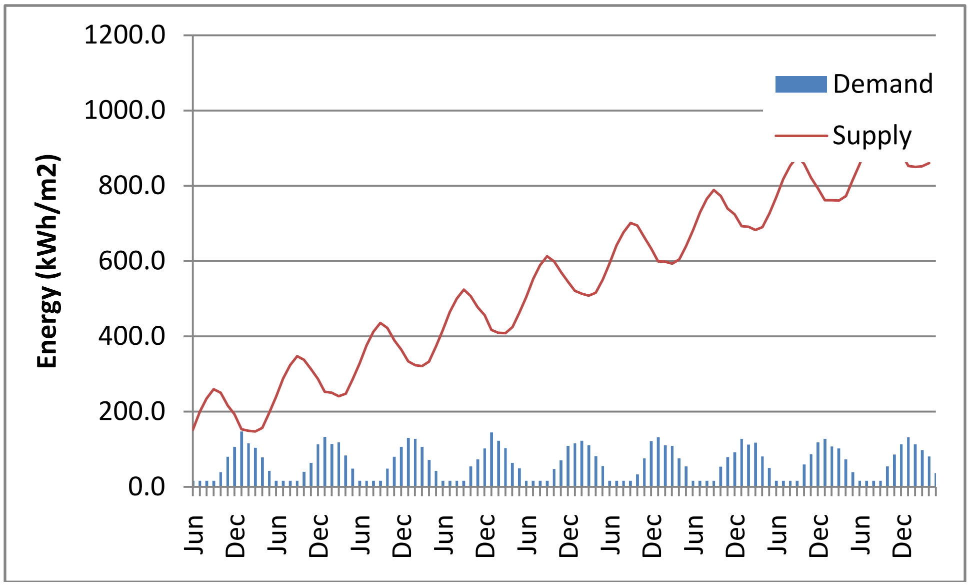

Figure 2: Four floors of heating: existing suites

Figure 3 shows the effect of constructing a five-storey building consisting of suites with existing energy demand. In this case, the heating demand exceeds the supply; over time the storage is depleted, requiring an increasing amount of backup supply.

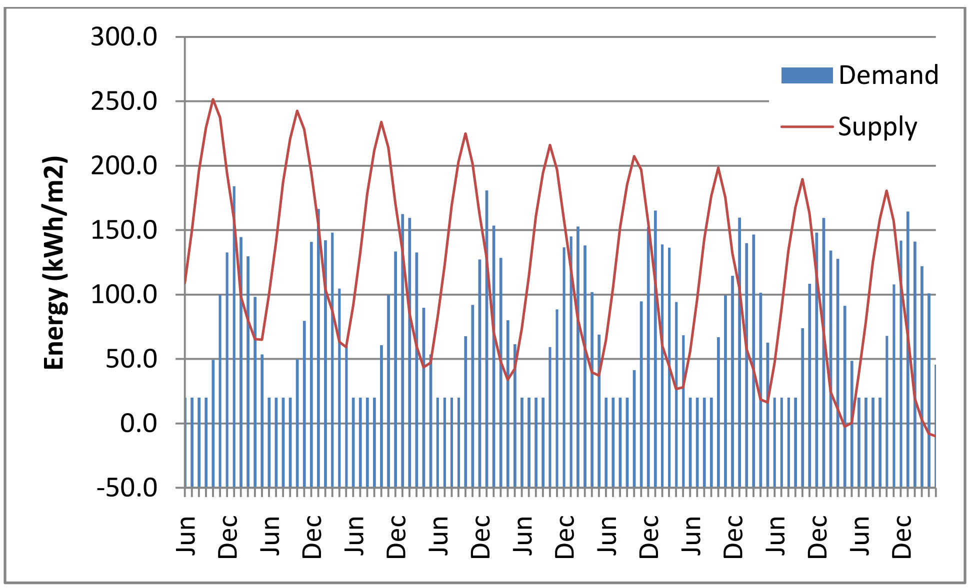

Figure 3: Five floors of heating: existing suites

4.2.2 Low-energy suites

Low-energy suites have an energy demand of 150 kWh/m2 and a heating demand of 126 kWh/m2. The non-heating season load is 2.8 kWh/m2.

Figure 4 shows the results of the nine-year simulation for a building of six stories. The maximum demand occurs in January 1991 with a heating requirement of 156 kWh/m2 (26 kWh/m2 per suite). The heating supply exhibits a wave-like shape as the storage increases during the non-heating season and decreases during the heating season. Supply exceeds demand and grows over time.

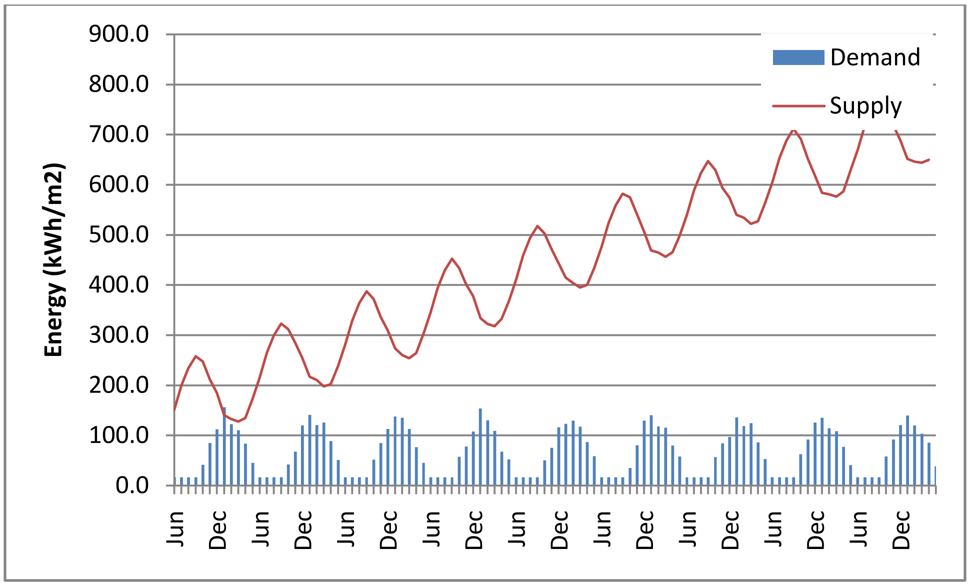

Figure 4: Six floors of heating: low-energy suites

Figure 5 shows the heating requirements for a seven-storey building consisting of low-energy suites. Over time, supply is unable to meet demand, depleting the storage and requiring more backup each heating season.

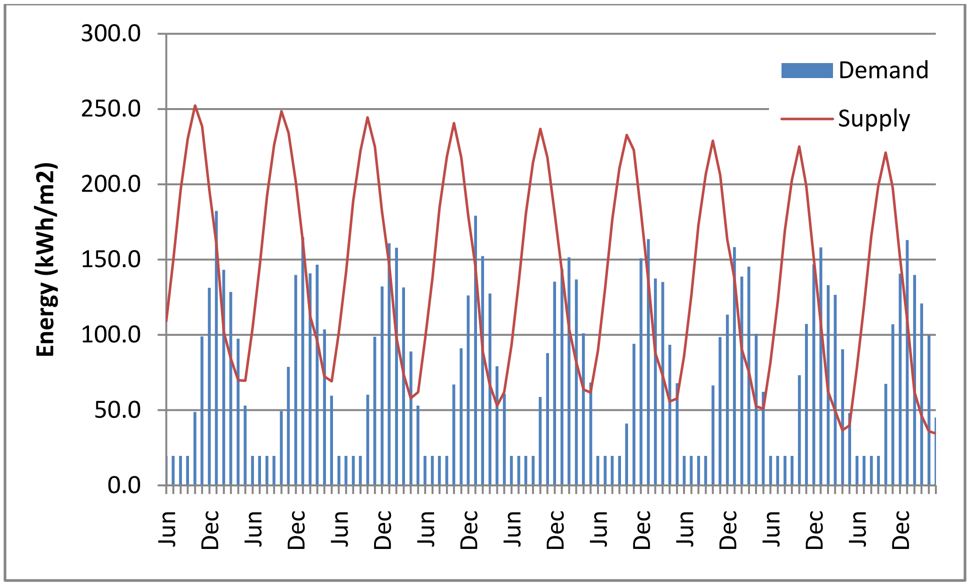

Figure 5: Seven floors of heating: low-energy suites

5 Concluding Remarks

Space and water heating are necessities of life for anyone living in a northern country such as Canada. However, as energy costs increase because of rising demand and supply shortfalls, it will become more difficult for many Canadians to heat their homes. To maintain national energy security will require Canadians to reduce consumption and replace imported energy supplies with ones that are both indigenous and, ideally, renewable.

Multi-storey apartment buildings are one way in which energy consumption can be reduced. However, if the building continues to use imported, fossil energy sources, it does little to enhance the energy security of its occupants. Solar energy is a renewable energy source that can replace non-indigenous energy sources in multi-storey apartment buildings.

This paper has considered the amount of solar energy required to meet the energy needs of a typical suite in an apartment building in Halifax and from this, derived the ideal maximum number of stories that can be heated by the sun. By using thermal storage systems to capture solar energy throughout the year, the number of stories can be increased.

The paper found that the maximum number of stories that can have their energy needs met by solar energy varies, depending upon the heating demand of the building. It appears that in suites built to today's standards about four stories could be heated, while newer building technologies might be able to reach six stories. Buildings of greater height will require other energy sources to make up the shortfall. To reach the maximum number of stories, it is necessary for the building to maintain some form of seasonal storage, capturing solar energy as heat throughout the year and releasing it during the heating season.

The paper considered the use of roof mounted solar panels only; it did not consider the use of wall-mounted solar energy capture systems (for example, see (11)). Although wall-mounted systems can be retrofitted to buildings, they are best added during the construction of the building, as this simplifies the overall design.

Energy security will be one of the dominant factors in the twenty-first century. Buildings constructed today must be built with energy security in mind, failure to do so will simply make the building too costly to occupy as energy prices continue their inexorable rise.

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