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# Energy performance enhancement in multistory residential buildings

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## HIGHLIGHTS

- Solar potential and energy consumption of multistory buildings is investigated.
- Integration of PV panels in façades is considered due to the reduced roof surface per dwelling unit.
- Apartment buildings are more energy efficient for heating and cooling than single houses.
- With optimal roof design, a building of three stories can reach a net-zero energy status.
- Above three floors, facades should be exploited to enhance energy production.

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## ABSTRACT

This paper presents a study of energy performance enhancement methods in multistory residential buildings. The study is carried out for Montreal location, Canada (45°N). All configurations considered assume a suburban environment that allows high solar exposure and no obstruction from adjacent buildings or external surrounding objects such as trees. Energy performance is measured by the balance between energy consumption, on the demand side, and electricity production by means of integrated PV systems, on the supply side. The present study considers enhancement of the supply side by increasing electricity generation potential.

Apartment buildings are designed to be highly energy efficient and to conform to passive solar design principles. The buildings investigated include – low rise (3–5 floors), mid-rise (6–9 floors) and high-rise (up to 12 floors), with eight apartments per floor. All Integration of PV systems in façades, in addition to roof surfaces, is considered, in view of the reduced availability of roof surface per dwelling unit. The results of simulations employing the EnergyPlus building simulation program indicate that apartment buildings are relatively energy efficient for heating and cooling, while allowing a high level of residential density, but their solar potential is limited. Under the present study, a building of three stories can generate about 96% of its total energy use, if the roof design is optimized for solar energy generation. Above 3 floors, additional measures are required to enhance energy production. Implementing PV systems on 50% of south façade and 80% of east and west façades surface areas, in addition to enhanced roof surface design (folded-plate), enables electricity production of up to 90% of energy use of a 4-story building reducing with increasing height to 50% for 12 stories.

The study indicates that investment in advanced design of façades (such as folded-plate curtain walls) can substantially increase electricity production and achieve net zero and surplus energy status in building over eight stories high.



## 1. Introduction

Attempts at mitigating environmental impact of human activities should target high-density urban complexes, where half of the world's population is concentrated [1]. Since a large portion of total energy consumption is attributable to buildings (30% of Canada's total energy consumption, and over 50% of Canada's electricity consumption [2]), reduction of energy consumption in buildings, and transforming them into energy producers, is a high priority objective in limiting their environmental impact.

Implementation of energy efficiency measures in buildings enables reduction of energy consumption by up to 35% [3]. Energy

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efficiency measures are not sufficient, however, to address an expected increase in future energy demand of the building sector. Coupling energy efficiency measures with increased renewable energy production techniques enables generating the amount of some or all of a building's energy consumption, thus reducing dependence on fossil fuel. Initiatives to implement stringent energy efficiency measures and to enhance energy production are starting to take shape internationally [3,4]. Policymakers around the world are embracing the concept of net zero energy buildings, which generate energy to counterbalance their consumption, as a vital strategy to meet energy and carbon emission goals [5,6].

Net zero and surplus energy single-family houses and neighborhoods can be realized through careful design of such houses and their positions with respect to each other [7–9]. However, the density of such neighborhoods is limited, reaching a maximum of 26 units per acre, particularly if solar access principles are respected [8].

Achieving net zero energy buildings in a higher density context is more challenging. High-density conurbation has some significant economic and environmental advantages, such as efficient land use, efficient transport and infrastructure and reducing greenhouse gas emission (e.g. [10–13]) however it also has the negative effect of reducing building potential to capture and utilize solar energy.

Multistory buildings can offer substantial solution in accommodating the increased density of modern cities while maintaining energy efficiency, in addition to playing an important role in the topography of these cities. These solutions are becoming widely adopted in North American cities where denser and taller housing buildings in cities and town centers play an increasing role. For instance, in Canada, multistory residential buildings represent a significant percentage of the housing stock (about 31%) and are responsible for 24% of the overall annual energy use within the residential sector [14].

Disadvantages of such buildings are associated with reduced potential for solar capture. Roof and exposed façade surfaces for active collection of solar energy for electricity and/or hot water generation are significantly reduced. Therefore there is a need to understand the performance of these buildings, and to develop strategies for increasing their potential to generate electricity.

Research conducted to assess the performance of multistory buildings in general, and residential in particular, is scarce, their important role notwithstanding. Lack of data on multistory performance is a major problem in developing design strategies for such buildings [15]. Most reported studies concentrate on mapping the energy use of existing multistory residential buildings, focusing mainly on their energy use for heating, cooling, hot water and in few cases daylighting availability, as well as outlining efficiency measures that can be implemented in such buildings (e.g. [14,16–19]).

Very few guidelines exist, on the architectural design of multistory buildings, to improve their energy efficiency and solar potential. The design of multistory buildings tends to encourage maximizing the ratio of floor area to envelope area [15]. This approach, while having some cost benefits and positive effect on heating/cooling consumption, is incompatible with passive solar design strategies, compromising the potential of building to gather and exploit solar energy in passive heating, daylighting, and installation of solar collectors for domestic hot water and electricity generation. To accommodate energy efficiency in multistory building design, building shape, including the design of façades and roofs, should be considered and optimized since the early design stage. Failing to do so would result in the mechanical and electrical systems having to compensate for design shortfalls [20]. On the other hand, the potential of these buildings to generate electricity by means of building integrated PV (BIPV) systems has not been systematically studied. For instance, Pelland and Poissant [21] conducted a study of BIPV potential in Canada, however the study excluded the potential of apartment buildings. Increasing the potential of energy generation of multistory buildings is of primary importance in achieving net zero energy higher density status.

The current research investigates the energy performance of multistory buildings, in terms of consumption for heating and cooling and potential electricity generation employing PV systems integrated in roofs and/or façades, at varying density levels. The study focuses on residential apartment buildings of different heights, ranging from low rise of 3-floors and up to12-floors. The study aims at improving the balance between energy consumption and generation in multistory building, employing different scenarios to increase the electricity generation of these buildings.

The main contribution of the current study consists in providing insight on the design of energy efficient multistory buildings, as well as suggesting some basic guidelines of key parameters to consider in attaining net zero energy multistory building design. This study constitutes the first stage in the design and analysis of mixed-use high performance neighborhoods, and therefore it is concerned with new construction, where design parameters can be controlled and a systematic design methodology can be developed. New constructed multistory building is a fast growing sector especially in North America [22].

## 2. Methodology

### 2.1. General

The objective of this research is to investigate the effect of increasing residential density in multistory buildings on the overall solar potential and energy use of these buildings. Solar potential relates primarily to the potential of roofs and façades to capture solar radiation for the generation of electricity, employing BIPV systems.

Montreal (45°N) is adopted as the pilot location of the study, to represent northern cold climate of mid-latitude. Buildings are designed to conform to passive solar design principles and to be highly energy efficient (e.g. insulation of 7 K $m^2$/W for walls and 10 K $m^2$/W for roofs, triple glazing low-e argon fill windows, airtight construction, etc.). Details of the characteristics of these apartment buildings are given in Table 1. Moreover, the multistory buildings investigated are assumed to have maximum solar exposure, with no shading from surrounding elements or buildings.

Total energy consumption in units is obtained by assuming energy use for appliances, for lighting and for domestic hot water (DHW) based on energy use in energy efficient houses and net zero energy houses (NZEH) [23]. Lighting energy consumption in rear apartments, where daylighting is limited, is based on the Comprehensive Energy Use Database of the Office of Energy Efficiency of Natural Resources Canada [24]. This database relies on data collected from surveys and other sources (manufacturers, electricity distribution companies, government surveys, etc.) [25]. Elevators are considered in buildings with 5 floors and above. Average energy consumption of elevators is based on 8 h of elevator operation per day [26]). A heat pump with a coefficient of performance (COP) of 4 is assumed to supplement the passive and active solar heating systems. This COP rating falls within the range of commercially available heat pumps (about 3.5 to 4) [27].

Simulations are performed employing the Energyplus software [28], to compute energy generation of the BIPV systems integrated on the south and near south facing surfaces (see below) and heating and cooling energy consumption.