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Technoeconomic assessment of the impact of window shading retrofits on the heating and cooling energy consumption and GHG emissions of the Canadian housing stock

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ABSTRACT

This study evaluates the economic feasibility and the effect of window shading retrofits on the heating and cooling energy requirement of the Canadian housing stock based on detailed energy simulations conducted using the Canadian Hybrid Residential End-Use Energy and GHG Emissions Model (CHREM).

The study found that adding 1/2 in. light aluminum VB on the indoor side of windows with automatic control based on zone temperature would result in substantial reduction in energy and GHG emissions in the Canadian housing stock. Other types of window shading devices may be effective in reducing the cooling energy consumption, but they result in an increase in overall energy consumption when both heating and cooling season performance is taken into consideration.

The economic feasibility of VB depends largely on the fuel mix and cost of fuels used as well as the tolerable payback period and expected fuel cost escalation rate. Thus, the economic feasibility is different for each province.

1. Introduction

As one of the countries with the highest per capita energy consumption, there is pressure on Canada to reduce its energy consumption and associated GHG emissions. Being responsible for about 16% of the total national end-use energy consumption and 15% of the total GHG emissions [1], the Canadian residential sector offers a large potential to reduce energy consumption and the associated GHG emissions.

A variety of strategies are available to reduce energy consumption and GHG emissions in the residential sector through energy retrofits such as improving end-use energy efficiency, improving envelope and window characteristics, and introducing renewable energy sources and alternative energy conversion technologies.

Since solar gain through glazing is commonly the largest and most variable heat gain in residential buildings, it has major and conflicting implications on heating and cooling energy consumption and peak loads: while allowing solar gains to offset the heating loads, windows can also represent a major source of heat loss in the winter, as their insulating value can be, depending on the window type, much lower than that of the surrounding walls. Also, the heat gain that is beneficial during the heating season adds to cooling loads during the cooling season. Without appropriate solar gain control strategies, building peak cooling loads and increased cooling energy can offset any benefit from thermally improved envelopes. Control of solar gain using exterior and interior shading devices is not only necessary in highly glazed, poorly insulated buildings, but is critical in existing building retrofits and design of new energy efficient buildings.

Shading devices can be classified into three categories: exterior, between-glazing and interior shading devices. They can be fixed or controllable. Exterior shading devices are effective to reduce solar heat gain and cooling load before the sun strikes the window [2] while most homeowners use some form of interior window treatment, such as drapes, blinds, or shades. While internal devices can reduce heating energy requirement during the winter, they trap heat on the interior of the glass so they may cause overheating during the summer increasing cooling loads. Studies on the effect of blinds and their position on the heating and cooling energy requirements of a building show that existence of a blind can reduce overall energy consumption [3–6]. Lomanowski et al. [3,4] found that to reduce cooling energy requirement the optimum blind position is

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the outdoor side while indoor side blinds are effective to reduce heating energy requirement.[1]

Shading devices can be either fixed or moveable. Fixed systems are commonly used for solar shading, while operable systems are more common to control thermal gains, protect against glare, and redirect daylight. The use of fixed blind systems generally requires higher energy consumption than moveable blind systems because as they decrease the cooling load and cooling energy use, they also reduce the possible benefit for heating with solar gain when there is a heating load. Moveable systems follow the dynamic exterior thermal and luminous conditions. Manually operated systems are generally less energy efficient and unreliable [7–9].

A simulation study examined the impact of manual control (lowered/retracted) of window blinds on annual energy consumption of a single south-facing room in Toronto, Canada [10]. Four blind control strategies were considered: 'permanent' (always closed), 'none' (always open), 'manual' (based on solar thermal gain and illumination), and '7 months' (blinds always closed April–October, and always open November–March). The study found that a blind system by itself, without a proper control, could result in an increase in energy consumption.

Automated shading systems reduce energy use and control interior conditions without relying on occupants as they close automatically when the indoor light level or temperature exceeds the control set point and re-open later to admit useful light. Automated systems can achieve savings in both cooling loads and lighting energy and have better thermal and daylighting performance than both fixed blinds and manually controlled blinds [8,9].

An experimental study in Montreal showed that the use of automated Venetian blinds can decrease the energy cost by 30% during the winter and by 50% during the summer [11]. However, automatic systems can produce discomfort in occupants who dislike the feeling of not having personal control over the system. Also, automated devices are often high-maintenance, and therefore expensive, solutions. Other studies conducted in a variety of climatic conditions found similar results. In an extensive experimental study conducted at a full-scale demonstration facility in Oakland, CA over a 1.5 year period to assess the energy saving potential of automated Venetian blinds operated in synchronization with daylighting controls concluded that an integrated system could achieve energy savings of 7–15% and 19–52% for cooling and lighting energy, respectively, compared to a fixed 45° angle setting of the blinds [12]. Utilizing a sophisticated adaptive controller incorporating fuzzy logic and genetic algorithm capable of prediction and adapting to user behavior and room characteristics for the integrated operation of blinds, electric lighting, and HVAC systems in an occupied office building in Lausanne, Switzerland [13] achieved a reduction in energy consumption of 25% over 94 days in winter compared to a conventional system. In a similar study conducted in Manglore, South India, Kurian et al. [14] found that fuzzy-based blind and artificial lighting control could achieve 20–80% of annual energy savings compared to the base case of manual blind systems without daylighting control. Similarly, Kim et al. [7] found that for an office building in Seoul, South Korea, optimal control of blind systems based on heat gain and daylight outperforms manual control.

Since adding internal and/or external shading devices to windows has a direct impact on their thermal performance, as well as the heating and cooling energy consumption and associated GHG emissions, a detailed study was conducted to assess the technoeconomic feasibility of controlled and fixed internal, between-glazing and external Venetian blind (VB) type window shading retrofits for the existing Canadian housing stock (CHS). Venetian blinds were selected for this study because compared to overhang or canopy type external shading devices, Venetian blinds are more practical as retrofit applications. They can also be installed readily on the inside of windows, and both inside and outside Venetian blinds can be automatically controlled. Between-glazing type VB require the replacement of the entire window.

The main results of this study are presented here while detailed results are given in Nikoofard [15]. The effect of window type upgrades are discussed elsewhere [16,17].

2. Methodology

Due to the substantial regional differences in climate, primary fuel availability, fuels used in electrical generation, as well as the construction, heating/cooling equipment and appliance characteristics, the suitability and feasibility of policy tools and strategies that involve solar technologies differ dramatically in Canada from region to region. Therefore, this study was conducted using the Canadian Hybrid Residential End-Use Energy and Emission model (CHREM) [18–20]. CHREM is statistically representative of the Canadian housing stock (CHS). It is based on the Canadian Single-Detached and Double/Row Database (CSDDRD) [19,21], and utilizes the high resolution building energy simulation program ESP-r [22] as its simulation engine. CSDDRD was developed using the latest data available from the EnerGuide for Houses database, Statistics Canada housing surveys, and other available housing databases and consists of close to 17,000 houses representative of the CHS. CHREM consists of six components that work together to provide predictions of the end-use energy consumption and GHG emission of the CHS. These components are [18–20,23]:

- The Canadian Single-Detached and Double/Row Housing Database (CSDDRD).
- A neural network model of the appliances and lighting (AL) and domestic hot water (DHW) energy consumption of Canadian households.
- A set of AL and DHW load profiles representing the usage profiles in Canadian households.
- A high-resolution building energy simulation software (ESP-r) that is capable of accurately predicting the energy consumption of each house file in CSDDRD.
- A model to estimate GHG emissions from marginal electricity generation in each province of Canada and for each month of the year.
- A model to estimate GHG emissions from fossil fuels consumed in households.

The validity of CHREM was verified and it was concluded that CHREM can confidently be used to study the impact of energy efficiency and renewable energy technologies in the CHS [20]. The methodology that is used in carrying out this research is depicted in Fig. 1.

2.1. Parametric study

Before applying the various window shading upgrade scenarios to the CHREM, a parametric study was conducted to determine the specific variables and the value ranges of the variables that have a significant effect on the energy performance of the upgrade.

To conduct the parametric study, a one-storey detached house commonly found in Canada was used as the "case study house", which was first modeled and simulated without any shading upgrade to provide the "base case" energy requirement. Then, the

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[1] 'Space heating/cooling energy requirement' is the amount of energy required to maintain the temperature of a house at the required level. It does not include the efficiency of the space heating/cooling equipment.