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Energy performance of a solar mixed-use community

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ABSTRACT

This paper explores a solar mixed-use community that combines residential and commercial buildings. The pilot location of this study is Calgary, Canada (52° N), representing northern, cold climate. Energy performance of the neighbourhood is estimated in terms of energy consumption and generation potential by means of building integrated PV systems. In addition, the analysis takes in to account the overall primary energy demand and greenhouse gas emissions. EnergyPlus is employed to simulate the overall energy consumption of the neighbourhood. Investigation of different options of mechanical systems is carried out using TRNSYS. Designing and analysing energy performance of a mixed-use community as an integrated system presents an opportunity to explore sharing of energy resources and interaction with the utility grid.

1. Introduction

Net zero energy buildings have the potential to alleviate the negative environmental impact of the built environment including the reduction of greenhouse gas (GHG) emissions. The principle of net zero energy has been extensively applied to buildings. These are buildings that generate annually as much energy from renewable energy sources as they consume (Torcellini & Crawley, 2006). The design of net zero energy solar buildings involves a twofold approach of enhancing energy efficiency while optimizing active solar energy production using photovoltaic technologies and thermal collectors. Reduction of energy consumption can be achieved through several measures, including enhanced HVAC efficiency measures. In addition, use of energy for heating can be significantly reduced by means of solar heat gains. A well-designed passive-solar building may provide 45–100% of daily heating requirements (ASHRAE, 2007).

Applying the net zero energy concept at urban scale can provide opportunities for seasonal storage, implementation of smart grids for power sharing between housing units, controlling peak electricity production timing and reducing utility peak demand. Additional advantages of net zero energy neighbourhoods include enabling design flexibility and increasing available surface areas for the integration of photovoltaic systems.

A small-scale, low-density residential neighbourhood of single-family houses can reach net-zero energy status assuming a careful design of building shapes and orientation (Hachem, Athienitis, & Fazio, 2012a). A mixed-use neighbourhood, which combines residential and commercial buildings (retail, office, residential, hotel, recreation or other functions (Niemira, 2007)) is significantly less amenable to achieving such status. Mixed-use communities have several economic and environmental advantages that lead to reduced levels of greenhouse gas emissions (Coupland, 1997; Grant, 2007; Rabianski, Gibler, Tidwell, & Clements, 2009). Such neighbourhoods are considered as part of a strategy to achieve sustainable developments (Grant, 2007; Hoppenbrouwer & Louw, 2005). Despite this fact, quantification of the performance of mixed-use neighbourhoods is not currently available. Moreover, comprehensive design guidelines for achieving high-energy performance mixed-use neighbourhoods are sorely lacking. A systematic design and analysis of energy and GHG emissions of these neighbourhood designs has yet to be completed.

This paper presents a concise summary of the design of an energy efficient solar mixed-use community, and its performance estimated in terms of energy consumption and generation potential assuming building integrated PV systems. In addition the paper examines the impact of various mechanical systems on the overall neighbourhood energy performance and on its carbon emissions.

The effect of neighbourhood is taken into account both in the simulations and the analysis of the results. The study forms part of a large scope research programme aimed at assessing the effects of multiple design parameters on energy performance of such

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communities, and the development of guidelines for their design. This base case design is intended as a reference against which the effects of modifications to selected design parameters are to be assessed. This complex research programme includes different categories of parameters that will be investigated in order to develop guidelines for the design of archetypes of high performance multifunctional communities. These categories include: overall design; energy options and additional categories such as environmental impact, sustainability and “resilience” parameters. The design category will encompass parameters such as pattern of the communities (circular, linear, hexagonal, etc.), density (on per capita basis and number of buildings), and design of the centre and its effect on transport (e.g. number of vehicle trips per day). Energy related parameters would include shift of load and generation, district energy, storage, cogeneration, and energy use for transport under different design parameters.

2. Design of the base case

The neighbourhood design developed and analysed in this paper represents the first stage towards proposing a design procedure for high performance solar mixed-use communities.

In view of the absence of general guidelines for the design of multifunctional high-energy performance, the design presented in this paper is based on various assumptions of design guidelines for shaping a sustainable neighbourhood. The main criteria for the selected guidelines relate to reducing dependency on cars (i.e. walkability), determining the minimal required density for a viable community, and maintaining a balance between the built area and green public land and street area. These assumptions are briefly described below.

The base case development illustrating the design procedure reflects a Northern cold climate and is assumed to be located in Calgary, Canada (52° N). The general design of the community layout relies on traditional neighbourhood developments guidelines (TND) (TND, 2014), combined with the fused grid street system of the Canadian Mortgage and Housing Corporation (CMHC) (CMHC, 2011). A TND, known as a village-style development, includes a variety of housing types, a mixed land use, an active centre, a walkable design and often a public transit option within a compact neighbourhood (TND, 2014). The TND guidelines are used to define the approximate relative land areas for each of the functions, as summarized below.

CMHC fused grid system is designed to allow mixed-use, densification, and efficient public transport (CMHC, 2011), and therefore can constitute a basis for the design of a new sustainable neighbourhood.

Employing the guidelines aforementioned, a land area of 16 ha is determined with a geometry based on the assumption of a ½ km maximum walking distance from the centre of the development (Kemp & Stephani, 2011). The land partition employs a mixture of fused grid and TND designs: the built area constitutes 64% of the land, streets use about 24% of the land, and the remaining 12% represents the green public area. Residential areas form about 80% of the total built area (including surrounding land), with the remainder (approximately 20%) as a mixture of viable commercial space and civic functions. The residential buildings include single detached houses, attached houses, and mid-rise apartment buildings (3–5 stories). The main commercial amenities included in the neighbourhood are: office building, retail area and grocery store, in addition to a primary school. The commercial and civic functions are concentrated in the core of the development (Rowley, 1996).

The density is based on the assumption of a minimal number of 4000 residents, to achieve a viable mixed-use neighbourhood (Barton et al., 2010). The total number of residents is employed to determine the number of residential units, assuming an average of 4 persons per unit. A total of 1003 residential units are designed, including 180 houses and 27 apartment buildings with varying number of apartments.

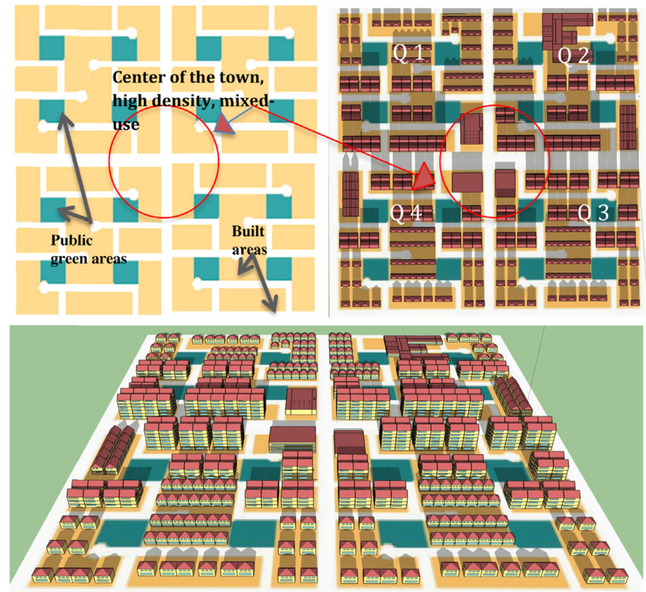

Fig. 1. Neighbourhood design.

A variable residential density is adopted in the design of this neighbourhood. The dense area (125 units/ha) is designed around the centre of the development, while the low-density areas (25–50 units/ha) are located towards the outskirts.

2.1. *Buildings design*

2.1.1. *Residential*

Residential units are designed as two-story detached and attached houses (180 m^2 and 120 m^2 respectively) and apartments in low-rise buildings (3–5 floors). The houses are designed to optimize passive solar design (Hachem, Fazio, & Athienitis, 2013) with south-facing windows occupying about 35% of the south façade. Other thermal characteristics are presented in Table 1.

The apartments have a floor area of 110 m^2 (average apartment size in Canada (Armstrong, Swintona, Ribberink, Beausoleil-Morrison, & Millette, 2009)) (Fig. 1).

2.1.2. *Commercial buildings*

Below is a summary of the main design considerations for each of the commercial buildings employed in the design of this neighbourhood. Fig. 2 illustrates a schematic of each of these buildings.

2.1.2.1. Office building. Guidelines that assist in determining office areas in a neighbourhood with a given population are lacking. This is due to the large number of factors that should be considered in planning such areas in an urban development (e.g. type of business, area required for a business, local employees, etc. (Kyle, Baird, & Spodek, 2000)). For this hypothetic neighbourhood a mid-size 3-story office building of 3600 m^2 (i.e. 1200 m^2 per floor) is assumed. The building envelope is designed as specified in Table 1. Assumptions for electrical loads are specified based on ASHRAE recommendations (ANSI et al., 2007).

2.1.2.2. Primary school. The single story 4500 m^2 school building is designed to specifications for a primary school for a population of 4000 persons. This is based on an estimated number of pupils

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