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Impact of neighborhood design on energy performance and GHG emissions

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HIGHLIGHTS

- Energy use and GHG emissions of different neighborhood designs are investigated.
- Improving buildings energy performance reduces energy use and GHG emissions by 75%.
- Density as isolated factor has limited effect on transport on per capita basis.
- Distance to central business district impacts transport GHG emission significantly.

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ABSTRACT

This paper presents an innovative and holistic approach to the analysis of the impact of selected design parameters of a new solar community on its environmental performance, in terms of energy efficiency and carbon footprint (green-house gas (GHG) emissions). The design parameters include energy performance level of buildings, density, type of the neighborhood (mixed-use vs residential), location of the commercial center relative to residential areas and the design of the streets. Energy performance is measured as the balance between overall energy consumption for building operations (assuming an all-electric neighborhood) and electricity generation potential through integration of PV panels on available roof surfaces. Greenhouse gas emissions are those associated with building operations and transport.

Results of simulations carried out on prototype neighborhoods located in the vicinity of Calgary, Alberta, Canada indicate that, while adopting high-energy efficiency measures can reduce the buildings' impact by up to 75% in terms of energy consumption and GHG emissions, transport still has a large environmental impact. The parameters of highest impact on transport and its associated GHG emissions are the design of the neighborhood and the distance to the business center. Density, as isolated parameter, has a modest effect on the selected mode of transportation, in terms of using private or public transportation.

While this study relates to a specific location and a range of design assumptions, the methodology employed can serve as a template for evaluating design alternatives of new sustainable developments and their environmental impact.

1. Introduction

Energy consumption by the building and transportation sectors accounts for large portions of the global energy consumption of urban areas, and for the associated greenhouse gas (GHG) emissions. Buildings are responsible for more than 40% of overall energy consumption, and about a third of greenhouse gas emissions, in both developed and developing countries [1]. On the other hand, the transport sector plays a crucial role in world energy use and emission of GHGs. For instance, in 2004, transport energy consumption accounted for 26% of global energy use [2]. This was associated with GHG emissions that constituted about 23% of world energy-related GHG emissions [3]. Mitigating the negative impact of the built environment requires a holistic approach that combines reduction of energy used by transportation and buildings with increased exploitation of renewable energy sources. While extensive initiatives are in progress worldwide to increase energy efficiency of buildings, efforts and regulations to control transport consumption are lagging.

Design of urban forms has significant influence on energy consumption by both buildings and transport. For instance, the global spreading of suburban low-density developments in Europe, the

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US and other countries counteracts the efforts to decrease energy consumption, by both transport and buildings [4–11]. These neighborhoods are often characterized by detached houses, which are generally the most energy intensive residential buildings. Moreover, they are designed at a distance from the city center and job/amenities facilities, resulting in an increased travel distance and associated energy consumption and GHG emissions by transport [5].

Travel patterns are dependent on many factors including distance to destinations, such as home, work, transit, green spaces/nature, as well as for daily activities [12,13]. The distance factor affects significantly the decision of people to use private or public transportation [13]. For example, in neighborhoods located farther from downtown, people tend to choose private over public transport, due to shorter automobile routes, less developed transit infrastructure, and other factors, such as time traveled or passenger comfort [14].

Car dependency reduction is an important and in many situations a feasible strategy to reduce cities' overall energy consumption and GHG emissions [15,16]. Several studies were conducted to understand the effect of various neighborhood patterns on mode of transportation. For instance, an extensive study of 370 large American cities [17] indicates that the vehicle miles traveled (VMT) can be reduced trough compact communities, decreased number of roads, increased options/infrastructure for active transportation and community-based retail with restricted parking lots. Per capita VMT is considered the most influential single parameter in the transport sector, affecting environmental degradation and resource depletion [18,19]. In addition, land use, coupled with transportation choices, have the potential to shape travel behavior and reduce dependency on fossil fuel [12].

A comprehensive literature survey reveals that most of the existing research concentrates on one or the other of these sectors – transport or building operations. Moreover, research into energy efficiency in buildings often concentrates on individual buildings, neglecting the impact of the neighborhood design on the energy performance of buildings and of the neighborhood as a whole [20,21].

Existing research that tackles both building and transport sectors, focuses mainly on relationships between building density and transport energy consumption within dense urban areas. This research is ambivalent, as to the impact of densification strategies on the reduction of transport energy consumption. For instance, several studies emphasize the strong relation between compact dense developments and the reduction in energy consumption in both building and transport sectors [22–24,7]. Other research contradicts these findings, stating that there is no significant impact of urban density, as an isolated factor, on car travel [25,26].

There is a need, therefore, to understand the environmental impact of buildings and transportation, and to quantify this impact, to serve as a guide for future efforts and policies to achieve more sustainable communities. This paper explores the effects of some design parameters on the energy use and GHG emissions of a large-scale solar community. This solar community adopts passive solar principles, for the design of buildings, their orientation and their situation with respect to each other [27], in addition to utilizing available roof areas for the integration of photovoltaic panels. The studied parameters include parameters related to the characteristics of the neighborhood and to the spatial design of this neighborhood. The neighborhood characteristics include the energy efficiency of buildings, the density of the community and the type of neighborhood (residential as compared to mixed-use). The impact of spatial design is investigated through parameters such as the location of the central business district and the design of streets. The response variables are energy performance and GHG emissions of the studied neighborhoods. Energy performance refers to the balance between the total energy consumption by building operations and renewable energy production potential of the neighborhood, employing building integrated PV systems (BIPV). The paper aims at providing an insight into the most significant environmental impacts of selected design parameters, and understanding how different community types affect GHG emissions by buildings and by transportation.

2. Methodology

The environmental impact of different design parameters of a large-scale neighborhood of land area 64 hectares is investigated. This hypothetical neighborhood is designed, based on various design considerations including maximizing solar capture and utilization, as described below (Section 2.1). The design takes into account the density, in terms of number of people and number of residential units per hectare. The pilot location of the study is Calgary (Alberta, Canada; 52°N), representing a mid-high latitude, cold climate zone. Below is a summary of the design process of this neighborhood followed by a presentation of the parametric investigation employed in the study.

2.1. Neighborhood design

2.1.1. Overall design considerations

The mixed-use neighborhood is designed employing guidelines of traditional neighborhood developments (TND), the Canada Mortgage and Housing Corporation (CMHC) fused grid, and various design guidelines for shaping sustainable neighborhoods. A TND, known as a village-style development, includes a variety of residential building types, a mixed land use, an active center, a walkable design, and often a transit option within a compact neighborhood scale area [28]. The site layout is based on the CMHC fused grid [29]. The fused grid can be a comprehensive basis for the design of a new energy efficient sustainable neighborhood, because it is designed to allow mixed-use, densification and efficient public transportation. In the design of this neighborhood, basic assumptions are selected to reflect actual Canadian neighborhoods, representative of the studied location, in terms of type of residential buildings, area of residential units, average density, and other factors. For actual application of such neighborhood design, local regulations should be implemented. Additional specifications are presented below.

The land partition employs a mixture of fused grid and TND designs. The built area constitutes 64% of the land, streets occupy about 28%, and the remaining 8% is green area. The residential area forms about 80% of the total built area, with the remainder (approximately 20%) assigned to viable commercial space and civic functions. The residential buildings include single-family detached houses, attached houses, and mid-rise apartment buildings (3–5 stories). The main commercial amenities include office buildings, retail area and grocery store, in addition to a primary school.

The residential neighborhood assumes the same design specifications mentioned above, however it excludes the commercial and public buildings (the central business district-CBD) from the 64-hectare area of the neighborhood. Fig. 1 presents the overall neighborhood design associated with a low-density, mixed-use scenario.

2.1.2. Buildings design assumptions

2.1.2.1. Residential buildings.

• Houses

Two types of houses are designed, a detached house of a total of 180 m^2 and attached houses of 120 m^2 each. The area is based on average detached and attached houses in Calgary [30]. Occupancy