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Multistory building envelope: Creative design and enhanced performance

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ABSTRACT

The paper presents a comparative study of three strategies in the design of the building envelope of multistory residential buildings combining enhanced energy performance and architectural innovation. The first strategy, serving as base case, employs a high performance flat façade, applied to a building of square layout. The second strategy introduces multifaceted facade geometries, comprising plates of varying tilt angles, to the same building layout, in order to assess the impact of envelope geometry on energy performance. The third approach investigates the impact on energy performance of varying building layouts as applied to flat and multifaceted facades. British Columbia (Canada) serves as location of the study, representing northern climate conditions.

For all three design approaches, the most important stage towards achieving high performance is to design an energy efficient building envelope. Comparison of energy performance of complex façade geometries to the base case, indicates that these geometrical patterns do not significantly compromise the thermal performance of the building, while enabling a considerable increase in the electricity generation potential by integrated photovoltaic systems. In folded-plate façade systems, this increase in PV potential is observed on per unit area basis as well as per total façade area. In addition, some of these façade patterns allow time spread of useful electricity generation of the BIPV systems. Combining folded façade geometry with building layouts that allow large south and near south exposure has the potential of enabling energy positive status. While the paper focuses on residential buildings, the methodology can be applied to any type of high-rise building.

1. Introduction

Building envelope design plays a significant role in the energy performance of multistory buildings. A holistic design approach of energy efficient buildings, that adopts passive strategies for building envelope design, has significant impact on improving the overall building energy performance, including large scale buildings (Sozer, 2010). A high-performance facade that integrates daylighting, shading, and natural ventilation systems, has the potential to significantly reduce energy consumed by building operations (Sadineni and et al., 2011). Moreover, building envelope forms a major factor of a building aesthetic and visual impact. Flexibility in envelope design to meet various visual and functional aspects, is an important component that can encourage architects, clients and other stakeholders to opt for one system over others. There is a need therefore to demonstrate that this flexibility of design not only does not compromise energy performance, but in fact has the potential to enhance it. There exist however some challenges in integrating energy performance considerations into more traditional architectural requirements such as aesthetics, functionality, and structure (Wingate, 2012). To meet these challenges, performance criteria need to be considered simultaneously with other architectural criteria at early design stages (Medio and Murphy, 2008).

There exists a large body of research carried out on various aspects of the enclosure of different building types, including multistory buildings (Quesada et al., 2012). Most of these focus on the impact of specific components of the façade on specific and overall performance criteria of the building (such as daylighting, heating and cooling). A number of conceptual design elements of the building envelope have been identified to be implemented in planning and design of buildings. These design elements include building orientation, geometry/shape, materials of which the envelope is made, thermal resistance, window to wall area ratio, shading devices, thermal mass, renewable energy integration, and air infiltration (Hemsath, 2013; Hayter et al., 2000; Bambardekar et al., 2009; Attia et al., 2009; Samuelson et al., 2016). Research conducted on curtain wall systems and double-skin facades includes studies of heat flow, effect of shading devices, effect of tilt and size of such devices on the overall energy performance (Hwang and Tan, 2012; Knaack, 2007; Oesterle, 2001), as well as the impact of geometrical configurations of the building envelope itself on the overall energy performance and daylighting (Hachem et al., 2014; Hachem and Elsayed, 2016).

Recently, research on double-skin facades (DSF), including their thermal characteristics and performance is starting to draw more interest (Joe et al., 2014). These facade systems are comprised of two

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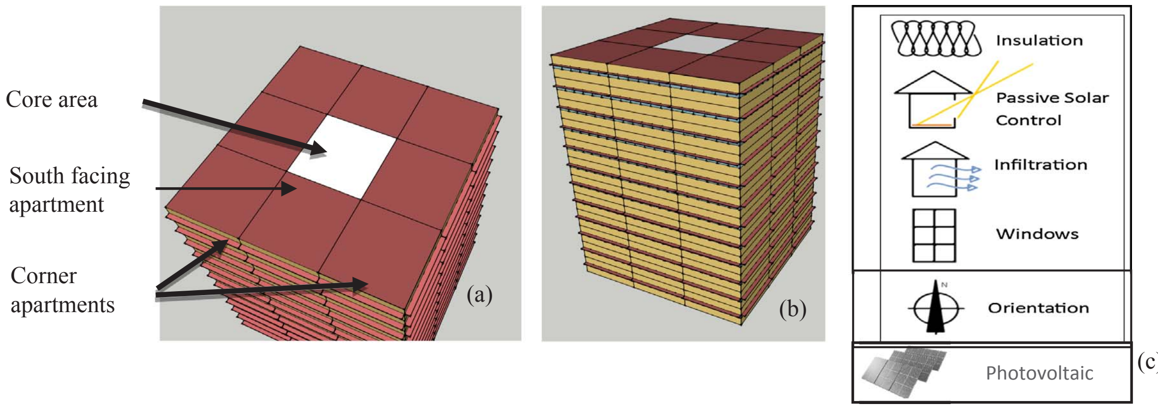

Fig. 1. Base case square layout apartment building, (a) apartment partition, (b) overall view, (c) main parameters investigated (see below for description) for the flat façade model.

skins, separated by an air cavity. There are several sub-categories of double-skin facades, classified by the method of subdivision of the air gap, both vertically and horizontally (Knaack, 2007). This system constitutes buffer zone between the interior and the exterior environment (Boake et al., 2003), and can be used to provide means to ventilate the cavity to the exterior or to preheat air supplied to the indoor space to supplement space heating (Hensen et al., 2002; Yun et al., 2007). Studies carried out on DSF systems indicate the potential of these systems to increase the energy efficiency of the building, to maintain a high thermal comfort level of the occupants, to allow optimal design of daylighting while allowing more possibilities to integrate efficient shading devices (Trubiano, 2013). The performance of such systems is governed by a number of design parameters including window glazing types, cavity design and airflow within the cavity (e.g. Hachem and Elsayed, 2016; Boake et al., 2003; Barbosa and Ip, 2014; Gratia and De Herde, 2007).

Recent developments in solar technologies, such as building integrated photovoltaic (BIPV) systems and thermal collectors enable building envelopes to play the role of energy generators in addition to maintaining energy efficiency (Hestnes, 1999). This role is rendered more relevant by the efforts to reach self-sustainable buildings and communities. Multistory buildings have inherently a reduced potential for solar electric and thermal generation, as compared to low-rise buildings, due to reduced roof area per overall occupied floor area, combined with reduced efficiency of PV integrated in vertical facade surfaces (Hachem et al., 2014). An increasing number of studies are performed to optimize integration of solar panels in the building envelope, including the integration within shading devices and light shelves (Walter, 2015; Josco, 2015). Successful integration of solar collectors includes enhancing architectural quality of solar collectors, including shape, size and colors (Probst and Roecker, 2007; Tripanagnostopoulos et al., 2000). Manipulating façade geometry, on the other hand, can have a number of benefits including the increase of energy generation potential of PV façade integrated panels, as compared to vertical flat surfaces (Hachem and Elsayed, 2016).

The research presented in this paper aims at highlighting creative methods in designing facades of high-energy performance multi-story residential buildings, ranging from the components of the envelope, both glazed and opaque areas, to geometrical design of facades and plan layouts. The paper includes a discussion of some of the geometrical principles and patterns developed in previous research, aimed at investigating the impact of double-skin envelope with outer skin having a variety of folded plate geometries on energy performance of a high-rise office block (Hachem and Elsayed, 2016). The explored parameters related to the outer skin surface geometry and to the associated air cavity depth between the two skins of this façade system. Results of the mentioned work indicate that although deviation from the basic flat façade leads generally to an increase in heating load, this is counterbalanced by a reduction in cooling load, and a considerable increase in energy generation potential from façade integrated photovoltaic systems.

The present paper deals with residential buildings where architectural design of such building types is generally more conservative than that of office or public buildings, due largely to market constraints. The focus of the paper is thus to demonstrate a holistic approach to envelope design of residential buildings, employing various design strategies, which enable flexibility in geometric and components design without compromising energy efficiency or functional comfort and enhanced aesthetic and visual opportunities.

2. Approach

The paper discusses three main strategies in the design of building skin of residential multistory buildings aimed at enhancing their energy performance. It presents examples of energy performance based on extensive research and simulations carried out on various patterns of multistory building facades. The first design approach applies a flat, double-skin façade (DSF) to a building of square layout, focusing on the main parameters in the design of such façades. The second strategy adopts a multifaceted folded plate geometry for the outer skin of a building of the same square plan as the first approach, to investigate the effects of modifying the geometry of the envelope on energy performance. The third strategy focuses on manipulating the plan layout of the building to maximize the performance of flat and selected folded facades.

2.1. Assumptions

The building studied in this research is a 12-story apartment building located in the Vancouver area (BC, 49°N, Canada). Each floor is composed of 8 apartments of 90 m^2 floor area each, and a central service core that contains elevators, stairs, mechanical and electrical rooms. The base case has a square layout (Fig. 1) and it serves as the basis of the analysis for the first two design strategies. In the third approach the layout itself changes into other shapes, discussed below. The size of the apartments, occupancy and appliances are assumed based on existing residential blocs in the studied location (RDH, 2012), and various norms and standards.

All presented design strategies assume a modular double-skin façade system of specific characteristics as detailed below. Double-skin façade construction consists of an outer skin and inner skin separated by an air cavity, referred to as “Channel “or “corridor”, which can be designed to be closed or to allow the movement of interior or exterior air through the façade system (Arons et al., 2001).

This research assumes that the two skins are continuous over the building face and the cavity is divided horizontally at each floor plate