INTEGRATED DESIGN CONSIDERATIONS FOR SOLAR COMMUNITIES

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ABSTRACT

This paper presents design considerations for an integrated design of solar communities highlighting the interactive nature of various design parameters to improve the energy performance of these neighborhoods. These considerations are illustrated through practical design examples of different neighborhood scenarios and individual buildings, based on extensive studies and analysis of energy performance of a wide spectrum of buildings and neighborhoods. The examples fall under two general categories – design at the neighborhood level, and design at the individual building level. Neighborhood design is illustrated by examples of homogeneous residential neighborhoods consisting of 2-storied housing units and of a mixed-rise neighborhood. Design of individual buildings focuses primarily on design of the envelope – consisting of roof and façades – for maximizing energy generation potential, as a function of height and relative position to adjacent buildings. In addition to examples of application of the design considerations, the paper outlines the process of design of solar communities and the role of simulations in the design process.

KEYWORDS:

Integrated Design Process, Solar Potential, Passive solar design, Building integrated photovoltaic, Solar neighbourhood design.

1. INTRODUCTION

The design of new communities often lacks an integrated approach, with buildings designed without much consideration for energy implications of their urban and environmental context, including site layout, their setting within this site and their relation with other neighboring buildings. For instance, in mixed-use neighborhoods, high-rise buildings may be designed right next to low-rise buildings, resulting in negative effect on solar access and on the feasibility of integrating solar technologies, and consequently on the overall energy performance of the neighborhood. While this may be unavoidable when erecting new buildings within existing neighborhoods, such negative effects can be avoided or mitigated in the design of new neighborhoods, by the implementation of an integrated design process.

The concept of integrated design may refer to a variety of design aspects (e.g. Zimmerman, 2006; AIA 2007, Boecher et al. 2009). A more recent application of the concept and

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practice of integrated design relates specifically to energy efficiency and high performance buildings (e.g. Brown and Cole, 2006). Integrated design approach is essentially an iterative multiple objective optimization process, which considers different aspects (constraints) of a project (Eisenberg and Reeds, 2003; Dekay and Brown, 2013). Such approach, applied on a community level, should consider a building as an interdependent system, as opposed to an assemblage of separate components (site, structure, systems and use). Integrated design of a neighborhood aims at optimizing the whole neighborhood as distinct from optimization of isolated buildings.

Numerous existing studies focus on integrated design approach for buildings and building systems, including building structure, interior space and mechanical services. A number of studies outline the impact of integration of façade systems with building systems on enhancing energy performance and on cost savings (e.g. Goia el al, 2010; Annex 44 – IEA, 2010; Oesterle et al, 2001; Costa, et al, 2000). Other studies highlight the effect of fundamental design strategies such as building orientation and building envelope design (including window area, glazing type, shading devices and control) on sizing mechanical equipment (Zelenay et al, 2010; Carmody et al., 2004, Hausladen et al., 2008). Guidelines for integrated design strategies and applications to buildings are being developed as well (e.g. ASHRAE 2010).

Design strategies that target the overall design of neighborhoods, where site design and buildingdesign are considered in an iterative holistic approach, are rather scarce. Such considerations influence the design of site layout, positioning and shape of streets, zoning in this site, buildings' shapes, orientations and envelopes, in combination with other energy efficiency measures. Predetermined site and street layouts may impose constrains on the orientation of buildings, and consequently their potential to capture solar energy for daylighting, passive solar heating and cooling, as well as potential electricity and heat generation by means of solar technologies. Such constraints are taken into account in the optimization process, which forms the core of the integrated design, with the objective of maximizing the overall performance of the neighborhood at minimal cost. Adopting such considerations in the design of mixed-use communities can provide opportunities for district heating and/or cogeneration of heat and power, seasonal storage, implementation of smart grids for power sharing between housing units, controlling peak electricity production timing and reducing utility peak demand. *This research is concerned primarily with integrated design consideration to improve the energy performance of neighborhood designs. The term "solar community" implies therefore a community where solar energy performance is a primary design consideration.*

An integrated design process of a solar neighborhood should start, when applicable, by first optimizing the site layouts, the road layouts and the partition of land. The next step consists of optimizing the general building shapes. Buildings are designed to conform to the site layout while maximizing environmental inputs, such as solar energy capture and utilization, thus reducing energy consumption. When the flexibility of neighborhood design allow it, some iteration of reshaping of site parameters (e.g. street shape and lot divisions) as well as building parameters (shape, envelope, energy generation technologies etc.) can be undertaken to optimize the functional layout of buildings, building envelope and integration of the envelope systems with the building systems.

Modeling is a vital element in the iterative integrative design of solar communities (AIA, 2012). The modeling involves a systematic approach to predict the dynamic response of buildings and their systems and the interaction with on-site renewable energy generation

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(Athienitis et al, 2010). It is recommended to employ simulation programs at early design stages of energy efficient buildings and neighborhoods in order to attain the performance goals. More advanced models may be needed in later stages to enable detailed analysis.

As part of a wide-scope ongoing research program, a detailed investigation has been carried out into the parameters affecting the response of a wide range of energy efficient residential units and neighborhood configurations, as well as multistory apartment buildings (Hachem et al, 2011a, 2011b, 2012a, 2012b, 2013, and 2014). This paper focuses on the implications of the main findings of this research for integrated design considerations in planning solar energy optimized communities, and highlighting the interactive nature of such considerations. In addition to examples of application of the design considerations, the paper outlines the methodology of applying simulations in the design process. While the presentation focuses on residential buildings, with some examples of applications to office /commercial buildings, the methodology and results can be applied to other types of buildings.

The following tools and databases have been employed in the investigation. The effects of design parameters on energy performance are assessed through simulations employing the EnergyPlus software (EnergyPlus, 2010). Geometric data of investigated configurations, required for the simulations, are generated by *Google Scketchup* (Google SketchUp Plugins, 2011). The weather data for Montreal, Canada (45°N) are employed to represent a northern mid-latitude climate zone. A whole year weather data set is used to estimate annual electricity generation of the BIPV system as well as energy demand for heating and cooling. The shading algorithm of EnergyPlus handles mutual shading by buildings. The TRNSYS PV model (or equivalent one-diode model) provided by EnergyPlus is employed in electricity generation simulations of the BIPV systems with approximately 12.5% efficiency, under standard conditions.

The paper consists of three main parts. The first part presents a number of neighborhood scenarios wherein design considerations are proposed to integrate site layout and building shapes in order to improve the overall energy performance. The second part presents examples of integrated design considerations on the level of buildings. The third part focuses on the role of simulations in the integrated design process of solar optimized neighborhoods. The goal of the examples provided in this paper is to illustrate the process of integrating the design of building parameters (such as building shape, envelope design, building systems) with site parmeters (such as road design, site layout), and how this may affect the performance of the neighborhood as a whole. The paper is intended to provide practical design guidelines for professionals (e.g. architects, urban designers, developers) involved in the design process of energy efficient solar neighborhoods.

2. INTEGRATED DESIGN AT THE NEIGHBORHOOD LEVEL

Buildings ranging from two-story family houses to multistory buildings (residential and/or commercial) are considered in the design of the studied communities. Neighborhood characteristics take into account common municipal regulations that determine practical issues, such as minimum distances between detached units and road width. Residential neighborhood patterns are characterized by the shapes of housing units, their density and the road layout. Indepth analysis of shape parameters and neighborhood analysis can be found in Hachem et al. 2011b and 2012a. The following features characterize residential units and apartments:

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- Townhouses are designed to accommodate a single family of 4 persons. Apartments are considered to have the same floor area and capacity.
- The housing units are designed to be highly energy efficient and comply with basic passive solar design principles (Hachem et al, 2012a). Windows constitute 35% of equatorial and near-equatorial façades[1]. The windows on the remaining façades are limited to the minimum functional area for a northern cold climate, (≤4% of the façades; (Chiras, 2002)).
- In townhouses, building integrated photovoltaic systems (BIPV) are assumed to cover the total area of equatorial and near-equatorial facing roof surfaces, considered optimal for capture of solar energy for electricity generation. In multistory buildings, PV system is assumed to cover 50% of near equatorial façade area, starting from the third floor up, in addition to roof surfaces (Hachem et al, 2014).

This section includes 3 main scenarios of communities. The first scenario illustrates a complete new neighborhood design, including the design of road layouts and partitioning of the lots. The second scenario assumes predefined shapes of street layouts and examines tradeoffs in design to achieve better solar exposure. The third scenario consists of a mixed-use development where townhouses coexist with tall buildings. This scenario discusses considerations in the design of tall buildings, and distance between buildings at different heights and their relative positioning.

Scenario 1: design of site layout in residential neighborhood

This scenario is illustrated by an example based on an ongoing project for the design and construction of a mixed-use development, composed of two-storied residential units and high-rise commercial and residential buildings. The makeup of the development, in terms of occupancy, density, total floor area of residential and commercial use, is prescribed, and there are some restrictions on the relative positioning of commercial and residential zones, but the site layout and relative positioning of buildings allow some flexibility. The residential neighborhood presented in Figure 1 forms part of the development shown in Figure 8, which illustrates design of mixed-use neighborhood design under scenario 3, below. The example demonstrates how an initially proposed design is modified to provide improved solar access for passive and active energy efficiency.

The initially proposed design – option (a) (Figure 1a) – does not take into account energy efficiency considerations. Housing units have small south façades as compared to the east/ west façades (Aspect Ratio-AR of around 0.6). This design layout leads to limited solar radiation on south-facing surfaces (refer to Figure 9 for the effect of aspect ratio on energy performance). The average heating load of the houses with small south facades, is increased by about 20%, as compared to houses with same layout (attached) and floor area but with a ratio of south façade to the orthogonal façade of 1.3 (Hachem et al, 2013). Additional impacts of the house design of option (a) include restricted south roof area available for the integration of PV systems, which reduces electricity generation potential, as well as restricted daylight penetration. Further discussion of this effect is presented in section 3.

1. Since the study presented in this paper is conducted for the northern hemisphere, the terms "equatorial facing" and "south facing" are equivalent and are employed interchangeably.

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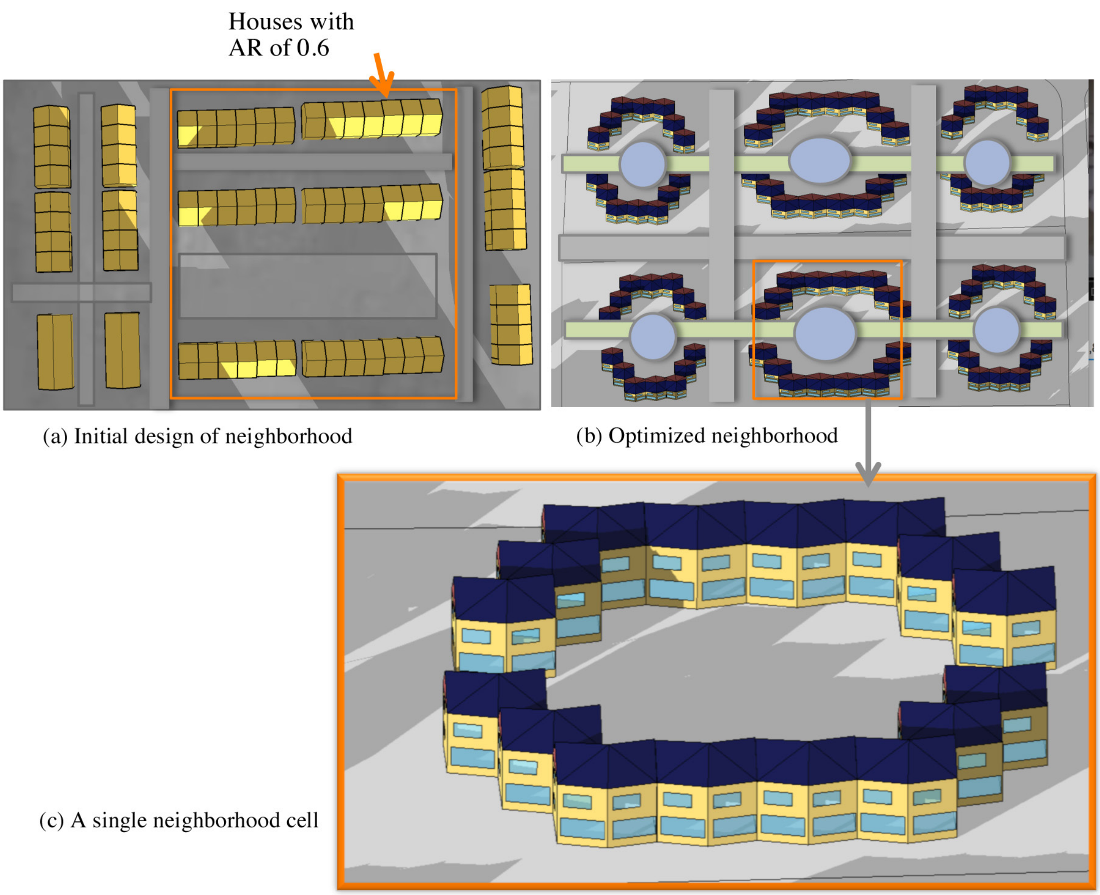
In the solar optimized neighborhood – option (b) (Fig. 1b) – all houses have aspect ratio of 1.3. The site, employing an enhanced arrangement of houses, can realize the same density as the initial proposal, while ensuring better solar exposure. The design is based on the principle of integration of optimized solar exposure with increased density.

The improved design demonstrates a considerable reduction of heating loads, while increasing the potential of electricity and useful heat generation (if BIPV/T systems are adopted instead of BIPV systems). In addition to maximizing the energy efficiency and increasing the general solar potential, townhouses are designed to encourage social interaction among inhabitants. Courtyards are created between the multiplexes, to allow safe and enjoyable space for children to play and for people to socialize.

FIGURE 1: Optimizing housing design for solar exposure, (a) initial design of the neighborhood, (b) optimized design, (c) single neighborhood cell



Scenario 2: Prescribed road layout

This scenario relates to the interaction of predetermined site layout and road design, with building shapes and positioning. Two sets of examples are provided. The first set, depicted in Figures 2 and 3, represents housing units along a generally east-west oriented, straight or curved road. The second set of examples shown in Figure 4, are of inclined road with different angles of inclination relative to east-west axis.

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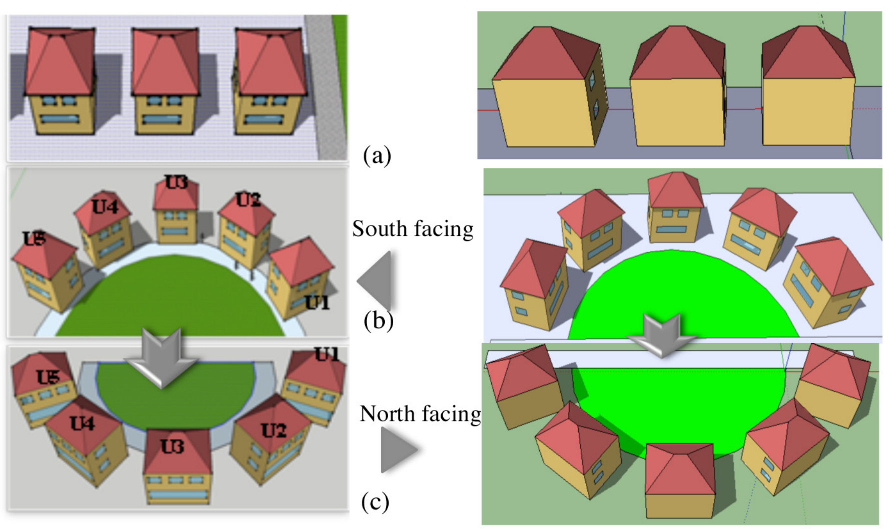
East-west facing road

The site layout represented in the first set of examples (Figure 2) is characterized by a straight road running along the east-west axis (Fig. 2 a, d), a curved road, oriented toward the south (Fig. 2 b, e) or toward the North (Fig. 2 c, f). In the first category of design (Fig 2 a-c), the building positions follow the shape of the road, while complying with passive solar design principles and rule of thumbs. For instance, the houses are oriented such as to have the longest façade and a large window area toward the south or near south. Employing these considerations, the effect of road curvature on heating, cooling and energy generation of the building is not significant (less than 3%) as compared to an ideal situation such as presented in Figure 2a – where all houses have southern exposure.

In the second category (Figs. 2 d-f), the houses are designed with the long façade and the large windows facing the road, regardless of passive solar design principles. Consequently, in some cases large windows are designed on the north façade, such as in configurations 2d and 2f. These design considerations affect significantly the performance of the overall neighborhood, were in cases like these depicted in Figure 2d and 2f, the average heating load of the neighborhood is increased by up to 50-60% as compared to the corresponding configurations with solar design principles in 2a and 2c, respectively.

FIGURE 2: Design around curved roads, (a) respecting solar design principles; (b) designs facing the road.



This example demonstrates that simple design considerations such window location and arrangement of houses, if taken into account from the early design stage, can affect significantly the performance. These are issues that can be easily overcome by adopting a process that integrates solar design principles and rules of thumb, with the site topography.

Rectangular layout is generally considered the optimal shape for energy efficiency. In urban context, however, this shape may not be optimal (e.g. around curved roads, see Fig. 3), due to the site shape, road layouts, or simply for aesthetic and functional considerations. Non-rectangular and particularly self-shading shapes (like variations of L shape) offer flexibility in architectural as well as solar design, but their efficient design is influenced by several

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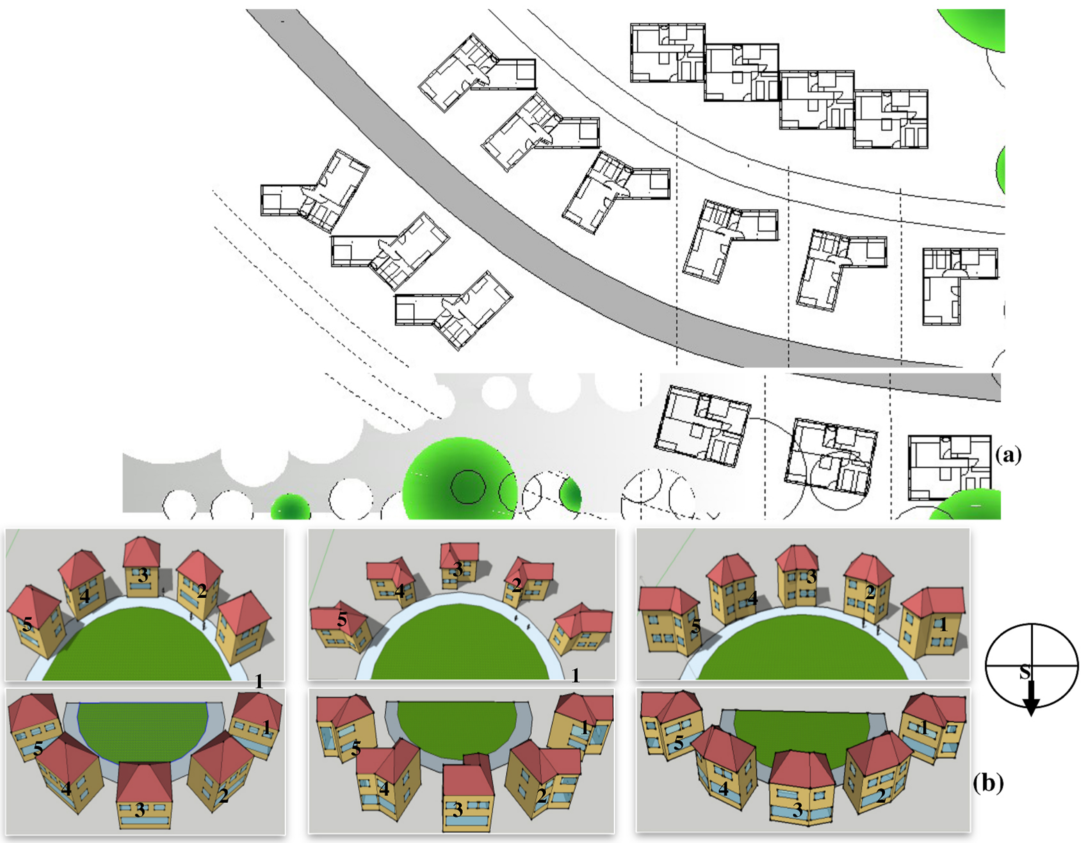
parameters (Hachem et al, 2013). Figures 3 show example of such scenarios where L shape variations are designed around curved roads.

Interaction of site layout and units configurations may result in shift of peak electricity generation among units in the neighborhood. Depending on the design of the building, the difference in peak electricity generation time can reach 6 hours relative to solar noon. Spread of peak generation time improves electricity supply efficiency by providing a more even electricity generation profile, thus imposing less demand on the electric grid. This can be economically beneficial, since the cost and price of electricity often vary with time of day. Shifting peak generation time towards peak demand time can lower net energy cost and also reduce net peak demand from the grid.

FIGURE 3: (a) Plan view of different houses design around curved roads, (b) Different house shapes around cul –de- sac scenario.



Inclined road

In cases where the road layout is not conducive for optimal orientation, tradeoffs can be made to optimize the buildings for solar access. Below is an example of tradeoff between land use and energy efficiency (heating and cooling loads). In alternative 4a, rectangular buildings are oriented south regardless of the road orientation, the second alternative – 4b – consists of rectangular buildings oriented toward the road, the third – 4c – provides a compromise, where part of the building is oriented toward the road while the other part is south facing.

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Analysis of these three configurations, at different angles of orientation of the street (rotated 15° to 60° east or west relative to south) shows that beyond an angle of orientation of 30°, configuration 4c offers a good compromise between energy performance and land use. This is illustrated in the graph of Figure 5, for a road inclination of 45° west of south. The graph shows that the first alternative is the best in terms of energy demand but worst in terms of land use. Thesecond alternative involves the highest energy consumption, requiring about 36% more energy for heating than the first configuration, but optimal in land use. The third represents a good compromise, where land use is not increased significantly as compared to the second alternative, while heating and cooling loads are almost identical with the first alternative (see Fig. 5).

FIGURE 4: Design of houses with respect to an inclined road of 45°; (a) south facing rectangular houses; (b) rectangular houses oriented toward the road; (c) L-variants with the wings oriented towards the road.

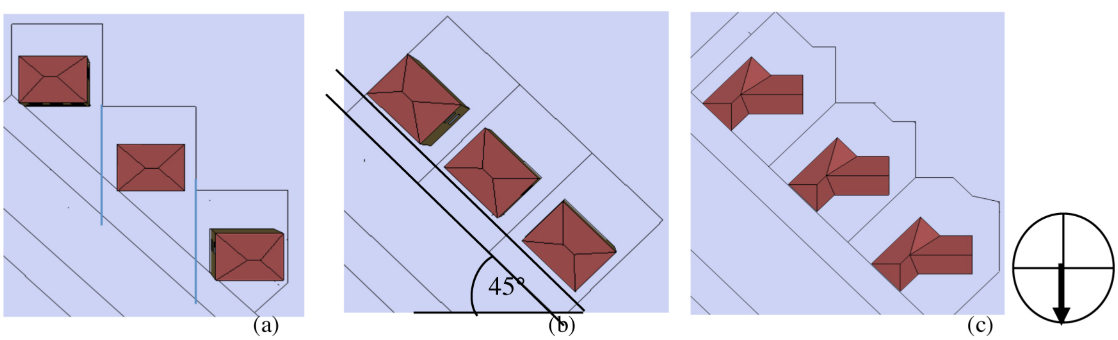
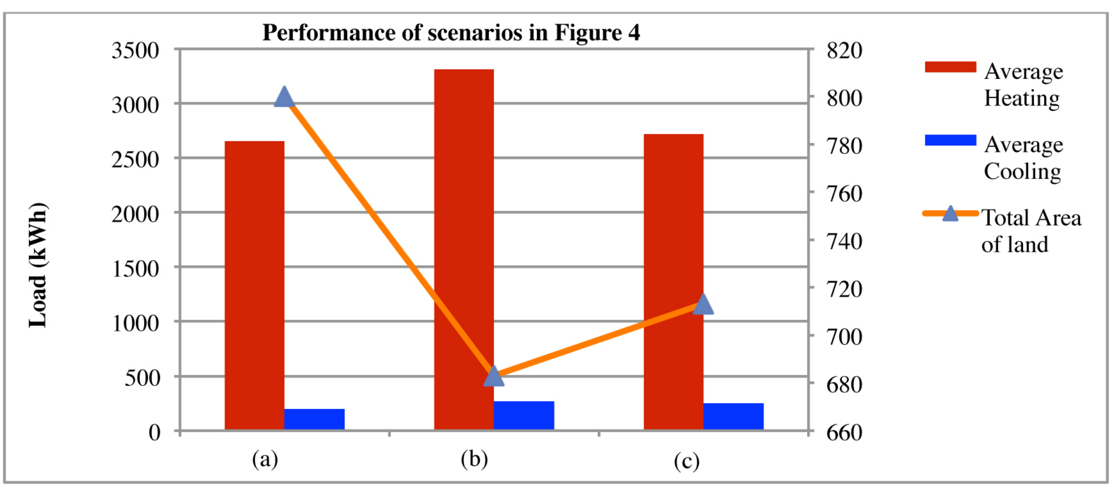


FIGURE 5: Performance of the scenarios presented in Figure 4.



Scenario 3: Mixed height development

Mutual shading effects in mixed-height neighbourhoods

This scenario presents a case of combined high-rise and low-rise building configurations, such as is commonly found in existing neighborhoods, especially in cities. This may lead to serious reduction in solar access of some buildings, due to mutual shading. Distance between

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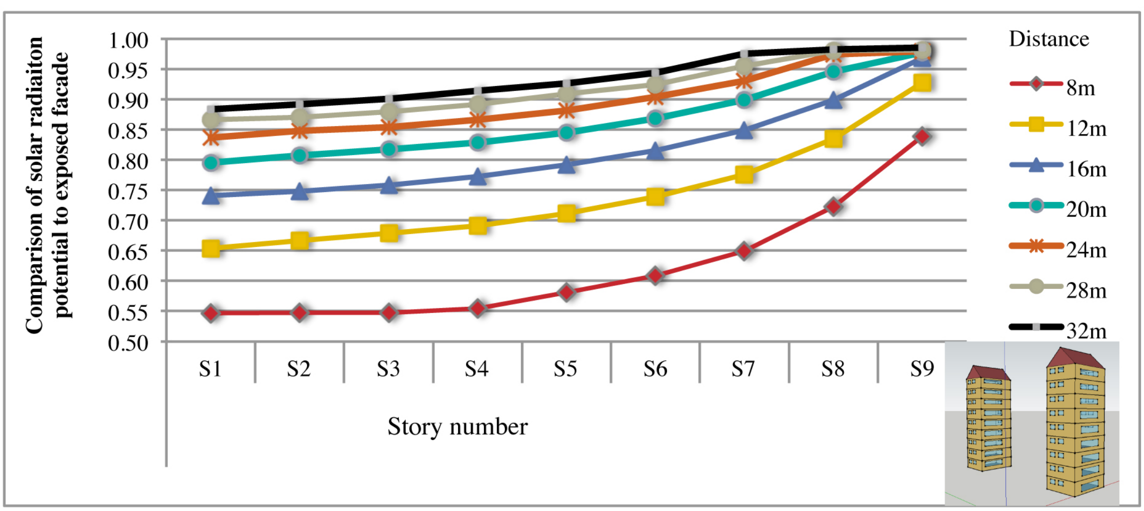
buildings and their orientation play a major role and should be determined as a function of the height of these buildings, within imposed constraints (such as density). This effect seems not fully appreciated, even by designers of new developments. For instance, in residential neighborhoods consisting of rows of houses with the same height (e.g. two-story houses), distance between rows can be manipulated to reduce shading, and for maximum daylight penetration and solar heat gain. Usually, at mid-latitudes, a distance equal to twice the height of the shading buildings can eliminate shade. Design of interior space can compensate for constraints on these distances.

In mixed-height neighborhoods, the complexity of design increases. Shading effects on solar radiation and on heating load are illustrated in Figures 6 and 7. Figure 6 presents the effect of shading by a 9-story building on solar radiation incident on the south façade of a building of similar height positioned to the north, at varying distances. The incident radiation effect gives an indication of passive heat gain potential and of energy generation potential. Figure 7 presents the effect on heating load of shading of a 9-story building by a building of varying height positioned at varying distance to the south. It should be borne in mind, however, that this is only the study of the effect of a single shading building situated on the south the shaded building. The effect is expected to be amplified in case where other adjacent buildings cast shade form other directions, in addition to this studied effect.

FIGURE 6: Mutual shading of two identical buildings 9 stories high; Shading building is on the south of the shaded buildings.



Mixed-use neighbourhood design example

The configuration presented in Figure 8 is a schematic representation of a new large scale mixed neighborhood proposed to be built in the near future, in Ontario, Canada. It can be observed from Figure 8a, representing the proposed initial design, the extent of shade that is cast by the tall buildings on the townhouses designed on the north of the development. The height of these buildings (about 18 floors) and their position (on the south side of the site) reduces significantly the potential of the townhouses to generate electricity and useful heat, as well as for passive heating. For instance, assuming that BIPV/T systems are integrated within the total south or near south facing areas of the roofs, the potential generation can be reduced by about 50% for the houses that are directly next to the tall buildings. In addition,

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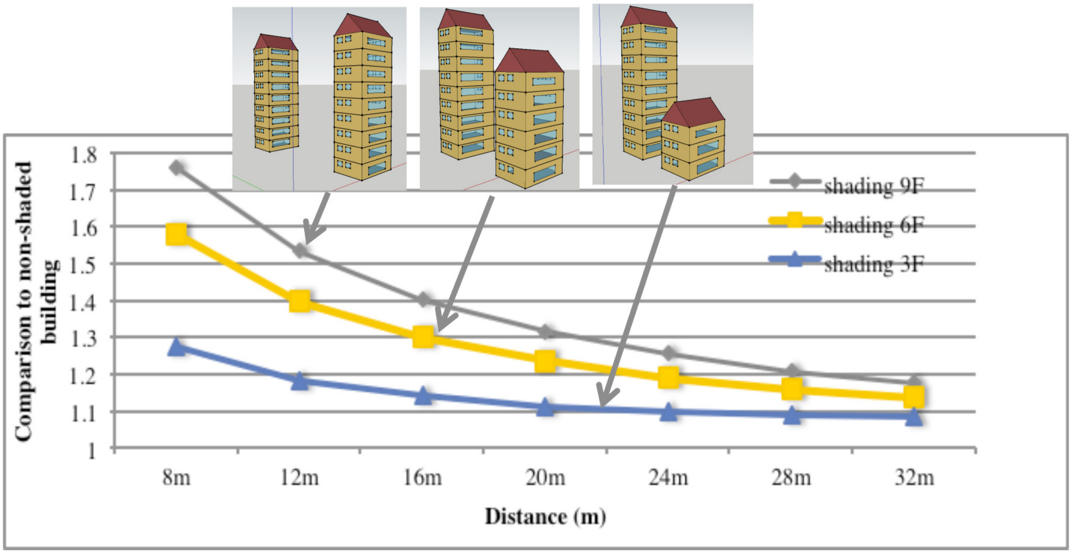
FIGURE 7: Comparion of average heating load in 9-story buildings, with different shading scenarios and at various distances.



the position of these high-rise buildings with respect to each other affects significantly the solar radiation on their façades. This is critical for multistory buildings, since façades have the largest potential to integrate solar technologies, due to limited roof surface (see section 3).

In redesigning this mixed use neighborhood (Fig. 8b), the position of tall buildings on the south, and of houses on the north of the development, cannot be changed, for considerations concerning the neighboring development (primarily commercial considerations). In addition, the density of the layout, the overall land area as well as major street layouts are fixed and cannot be changed in the redesign. Design modifications aimed at improving solar performance are therefore focused on rearranging the position and shape of the tall buildings, and their relation with the townhouses. Additional improvements of the community design, not directly associated with the topic of this paper, are related to functionality and improving life quality. For instance, the redesign substantially increases the green areas by introducing parks and green roof design, reducing exterior parking areas, and improved usage of the land.

Redesign of the residential zone itself is illustrated in scenario 1 above. Design modifications to the high-rise buildings consist primarily of reducing the maximum height while adding some mid-rise buildings in order to maintain the total functional area, as well as modifications to the shapes and positioning of the buildings. This redesign enables to optimize the near south façades of the high-rise buildings and to eliminate the shade cast on these façades, as well as reduce shading of townhouses. Depending on the design of façades, potential electricity and heat generation of the high-rise buildings can increase by some 250% relative to the initial configuration, if PV systems are implemented on south flat facades (Fig. 8b). Improved design of façades is discussed in section 3.

This example demonstrates that design of mixed solar neighborhoods should integrate a number of design issues. These integrated design considerations include shade reduction, maximizing solar potential, optimizing the shape of buildings and their positioning with respect to each other. The objective is to maximize the overall energy generation potential while reducing energy consumption of the buildings, as demonstrated in section 3, while avoiding compromising functinality and quality of life.

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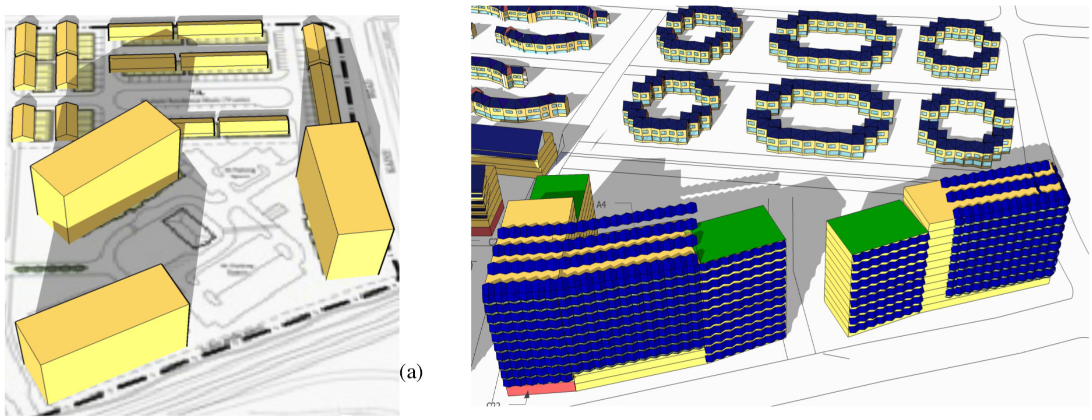
FIGURE 8: Mixed -use design, (a) proposed design, (b) redesigned community.



(a) (b)

3. Integrated design of buildings

This section focuses on the design of building envelope and integration of building envelope systems with the building systems. Design of building envelope should be an integral part of the design of the site. Building envelope can be designed to actively generate electricity and heat that can be directly linked to the building systems. On the other hand, operation of the building and its energy demand can dictate the size of PV system and consequently, depending on the performance goal (e.g. net zero energy status, positive energy, etc.), the shape of building envelope to accommodate this system. These points are discussed below through examples illustrating different concepts. The examples and the analysis of results are relevant to midlatitude climate. Different solutions would be appropriate in different climates.

Relation between site layout and building design

As discussed in the previous section, site layout, and the position of roads within this site, as well as the position of existing neighboring buildings can affect the design of a planned building. This effect is manifested in four major design decisions: orientation of the building; external dimensions and geometrical shape of the building; fenestration position; and internal layout. All these design decisions are interrelated and affect significantly the performance of the building.

The orientation of a building affects heating and cooling load significantly (Hachem et al, 2013). It also controls the position and design of windows and of the internal layout. Orienting the building so as to maximize south facing elevations is beneficial in two important ways: reducing heating and cooling loads, as well as governing timing and amount of electricity and hot water generation potential by solar collectors. Figure 9 illustrates the effects of different south façade ratio on heating and potential electricity generation by BIPV systems.

The floor depth (perpendicular to south façade), as well as the internal layout can affect the effective distribution of daylight and solar heat gain, and will thus influence the energy demand for heating and lighting. To maximize daylighting and passive heat gain during the day it is recommended that living zones (living rooms, dining rooms and kitchen) are located along the south façade.

In cases where a development does not allow adequate southern exposure, more creative ideas can be called upon, and in these cases the role of architects can prevail. For instance L

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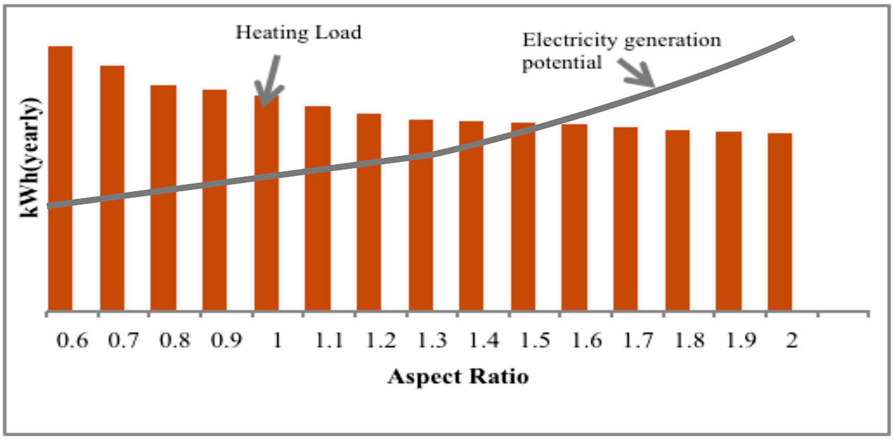
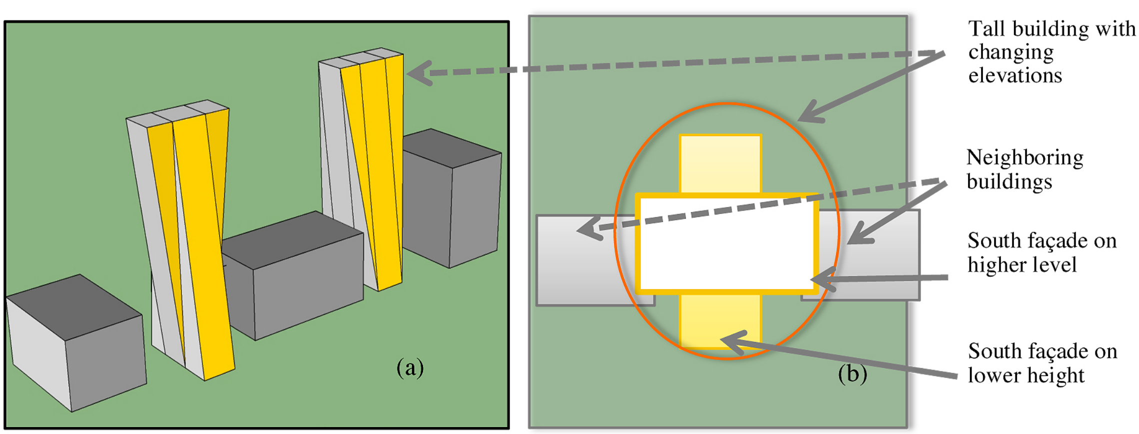
FIGURE 9: Influence of aspect ratio of south façade to lateral façade on the trends of heating load and electricity generation potential.



shape variations designed around a curved road such as presented in section 2 above (scenario 2). While these L shape variations can be designed to have an energy efficiency comparable to a rectangular shape (difference of about 6-8% in heating energy consumptions, Hachem et al, 2013) these shapes can offer various advantages in term of solar energy generation potential due to their increased roof area and their multiple orientations.

In high-rise buildings, façades play a major role in potential energy generation. In mixed-rise neighborhoods, where south façade widths of high-rise buildings are constrained by neighboring lower buildings, these constraints can be mitigated through varying the layout (dimensions, orientation) with height as more space becomes available above a certain height. This concept is roughly illustrated in Figure 10 below. Tall buildings designed with the long east/west façades change proportions or orientation at higher elevations, reaching a full south exposure.

FIGURE 10: Scematic illustrating a conceptual design of tall building to change the façade exposure with height; (a) 3D view of the development, (b) Plan view.



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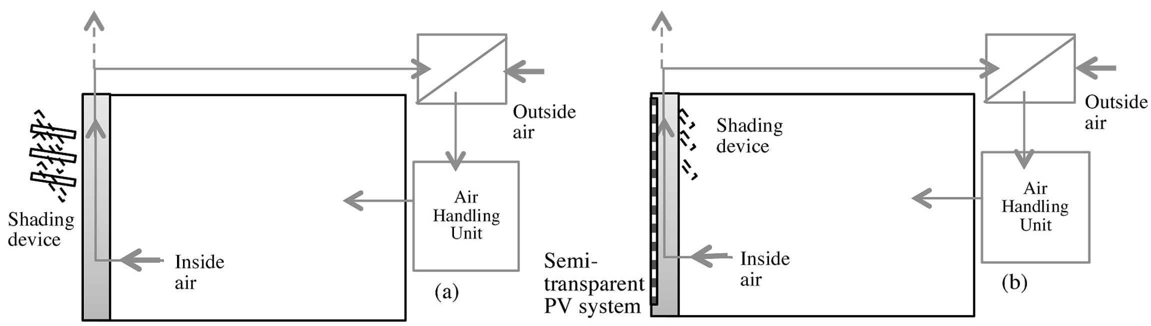
Building envelope as integral part of building systems design

Integration of façade systems and /or roof systems with other building systems provides an opportunity for improved performance and cost savings. A high-performance façade, which integrates daylighting, shading, and natural ventilation systems with electrical lighting and HVAC controls, contributes to reduction in the overall energy requirement for lighting, heating and cooling. In addition, such façades allow for lowering of peak heating and cooling loads, thus facilitating smaller HVAC system and/or low-energy alternatives. Reducing the size of such systems results in increased energy saving, reduced initial costs, and HVAC system operation and maintenance savings (Zelenay et al, 2011). Figure 11a presents an illustration of an integrated design of a façade system (including shading device and ventilation) with the HVAC system, and potentially with the lighting system. Dimming artificial lights based on daylight availability can lead to reduction of energy use for lighting by up to 30%. This is very significant especially in office buildings.

FIGURE 11: Illustration of an integrated design of a façade system with the HVAC system, (a) ventilated façade, (b) with semitranspartn PV.



Similarly to the concept presented above, semitransparent PV/T system (STPV/T) can be designed as an integral part of the façade. Figure 11b presents the option of replacing the outer skin of the façade with a STPV/T system. These systems can be particularly advantageous when integrated in the façades of mid to high- rise buildings, since higher buildings provide the opportunity to reduce shading from the surroundings (street elements, trees, etc.) and from adjacent buildings. This system allows transmission of daylight combined with some shading control and electricity generation (Robinson et al, 2008). Design of such systems with provision of air circulation behind the STPV/T panels system is a technology that combines STPV modules and heat extraction devices to produce simultaneously power and heat (Tripanagnostopoulos, 2001). It can assist in reducing the temperature rise of the STPV cells, and thus increasing the overall efficiency of the system, while collecting useful heat for space heating.

In the design of roofs, a similar principle of integrating PV/T systems can be applied, as shown in Figure 12. Heat extraction from the PV rear surface is usually achieved using circulation of a fluid (air or water) with low inlet temperature in an open-loop or closed-loop configuration. For example, in an open loop air system, outdoor air is passed under envelope-integrated PV panels, cooling them and recovering useful heat that would otherwise be lost to the outdoor environment. This heat can be used for space heating and/or domestic hot water (DHW), either by direct means or through a heat pump.

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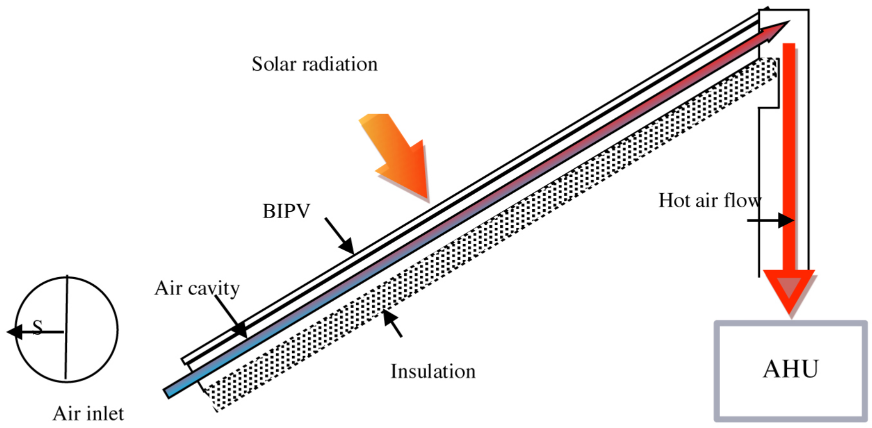
FIGURE 12: Cross-section illustrating an open loop BIPV/T system.



Design of building envelope for energy production

For neighborhoods to achieve high performance (net zero energy or energy positive status), buildings should be optimized for solar capture and energy generation. Integrated design process should consider the building envelope as energy generator, and therefore designs this envelope as a function of design objectives (e.g. maximizing generation vs. costs). The examples aim to illustrate the principles of applying BIVP to building envelopes. Detailed analysis of these systems are presented in Hachem et al., 2012b. These examples and principally results of the analysis are relevant to mid-latitude climate.

Example of application in houses

Roofs represent the optimal surfaces to integrate BIPV/T systems in houses and other low-rise construction. The design objective is to maximize energy generation, within cost constraints, the goal being to achieve or surpass net zero energy status for the house based on optimized design decisions concerning energy efficient building envelope, appliances and equipment. Roof shape and surface area can be manipulated to accommodate a BIPV/T system that generate the energy required to reach the design goal.

The house shown in Figure 13 is designed as a single family, 2-story house, with advanced energy efficiency measures and optimal solar exposure (AR=1.3). This house requires a gable roof with the BIPV/T system covering the total south facing roof area to achieve net zero energy status. Another alternative of the same house which adopts a hip roof design, with a side angle of 45° (Fig.13a), fails to achieve net zero (generating some 60% of the total energy use, (Hachem et al, 2011a).

Multi-faceted roofs, such as folded-plate and split-surface roof configurations, such as illustrated in Figures 13c-13e, can significantly increase electricity production and heat generation, primarily through increased effective surface area. Dividing the gable shaped roof surface into three plates with varying tilt/orientation angles can increase electricity generation by up to 17%. Replacing the gable roof with a folded-plate surface increases electricity generation potential by up to 30%. Varying surface orientations in such roof designs enables spread of peak electricity generation over up to 3 hours, potentially reducing the impact on the electric grid.

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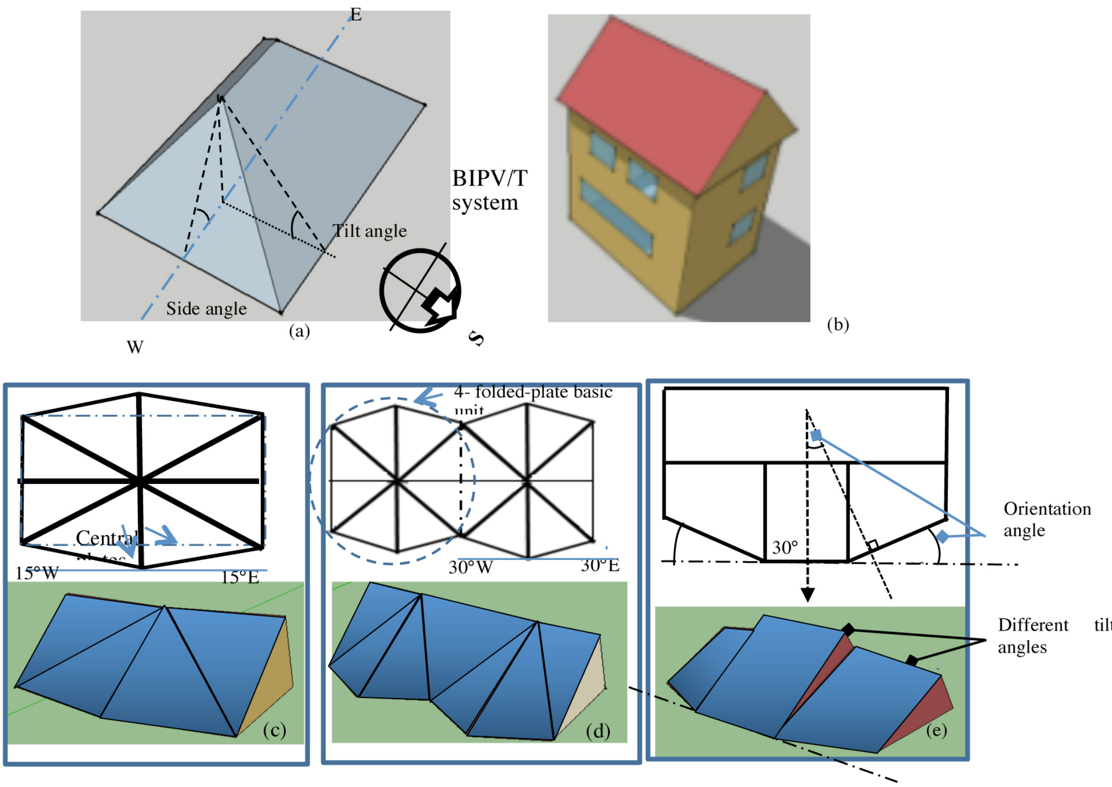
FIGURE 13: Roof designs, (a) Hip roof with side angle of 45°, (b) gable roof, (c) folded-plates design with a single unit, (d) folded-plates roof with 2 basic units, (e) Split-surface roof configuration (Hachem et al, 2012b).



Example of application in multi-story buildings

Multi-story buildings can offer substantial solution in accommodating the increased density and mixed-use living while maintaining energy efficiency.

Such buildings, however, have reduced potential for solar capture. Roof surfaces for active collection of solar energy for electricity and/or hot water generation are significantly reduced relative to the overall occupied area. Figure 14 presents a typical example of the variation with height of available south facing roof area, assuming a gable roof design, and of façades, assuming 50% of the combined areas of east, south and west facades, of a typical apartment building. This graph shows that the availability of area to integrate PV systems in the roof becomes insignificant relative to energy demand as the building height increases. Although the graph represents a specific design (floor plan), the correlation may vary quantitatively not qualitatively for different design.

There is need therefore to reconsider the way multistory buildings are designed. Building envelope and especially façades in tall buildings, should be designed to maximize electricity generation of the building in addition to fulfilling other functions of weather protection, daylight penetration, and visual aspects.

The example presented in Figure 15 proposes folded-plate curtain wall systems as a façade surface to increase the potential of PV system integration, and to improve their performance (Hachem et al, 2013b). This folded-plate curtain wall consists of the juxtaposition of a number of single folded-plate units, where PV or semi-transparent PV panels are integrated in the inclined panels. A BIPV/T system can be designed as well following the same principle.

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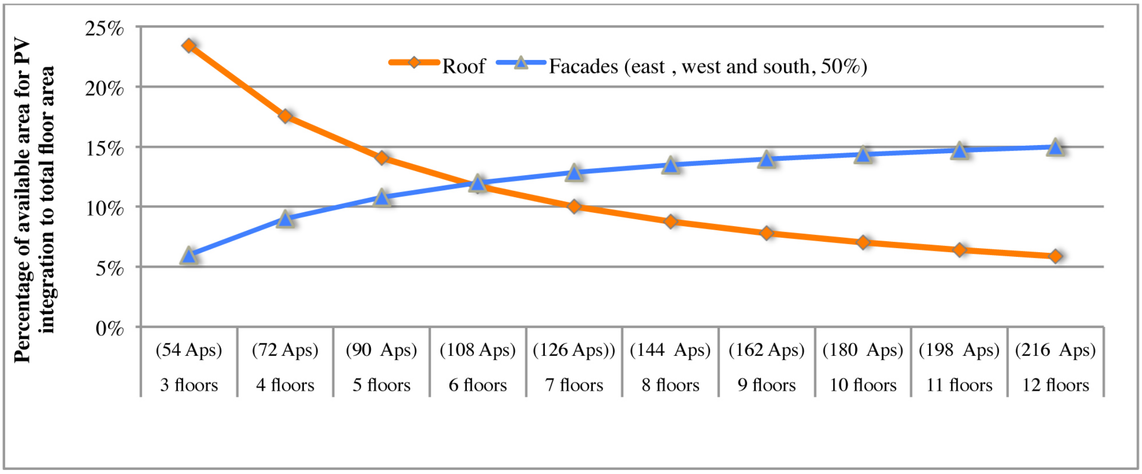
FIGURE 14: Correlation between south roof area of a gable roof design, 50% of the combined areas of east, south and west facades, and the total floor area of a multistory building of varying heights.



The basic unit is composed of 4 plates; the upper plates are used to integrate the PV systems, while the lower plates comprise the vision part (see detail in Fig. 15). The configuration combines a tilt angle of 60° and orientation angles of 20° east and west of south[2].

Depending on its geometrical design, this system may increase the potential electricity generation (and similarly the heat generation) of the façade by as much as 250% as compared to a flat vertical façade, as shown in recent studies (Hachem et al, 2013b). The graphs in Figure 16 show the performance, in terms of energy generation to consumption ratio, of a residential building of varying heights. The performance of folded-plate PV system applied on the façade of a multistory residential building is compared with the performance of south facing BIPV applied on a gable roof of the associated buildings. The graphs demonstrates that such folded-plate PV system applied to the façade of a multistory residential building enables reaching net zero or energy positive, starting with a height of 8 floors and above while for the same 8-story building, roof will not generate more than 30% of the total energy use. BIPV applied to both roof and façades achieves energy surplus status for all building heights of the specific design. This is particularly applicable for mid-rise apartment buildings between 3- and 8-story buildings.

Optimizing building shape for increased electricity generation

The design of a building, including floor plan, facades and roofs, is governed by a combination of performance goals. Different goals may be assigned (consciously or intuitively) different weights and the final design will depend heavily on this weight assignment. The example presented below of a 3-story office building is based on an office building of the ongoing project of Fig. 8, but with particular weight on energy performance in order to highlight the way in which energy considerations influence the design.

2. The orientation angle of a surface, relative to south, can be defined as the angle between south and the projection on a horizontal plane of the normal to this surface. Tilt angle of a surface is the angle between the normal to this surface and a vertical axis.

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FIGURE 15: Application of folded-plate curtain wall system on multistory apartment building.

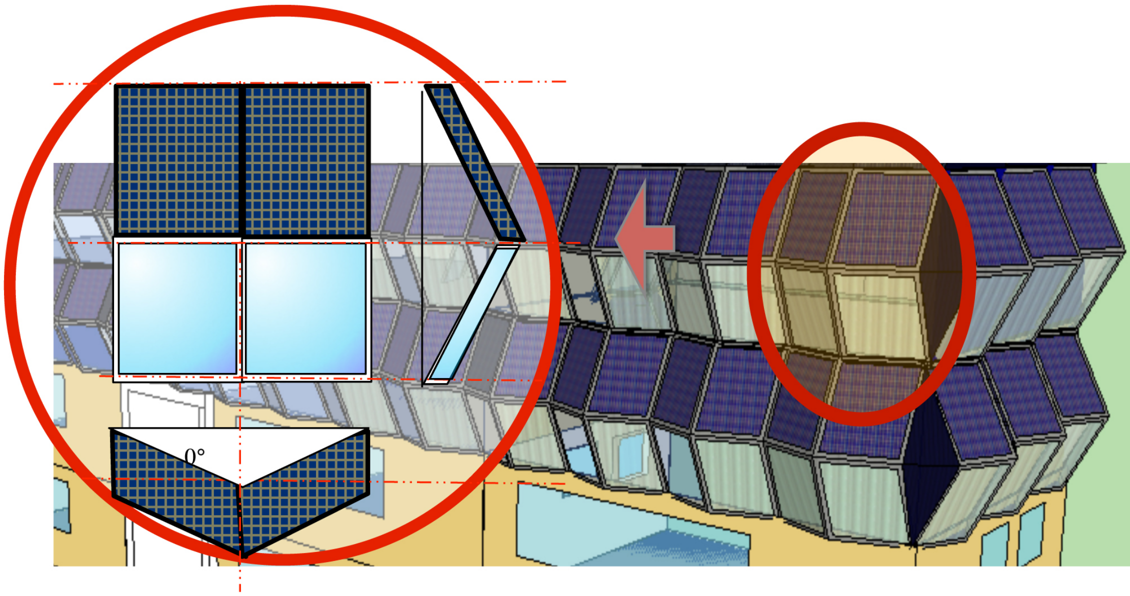
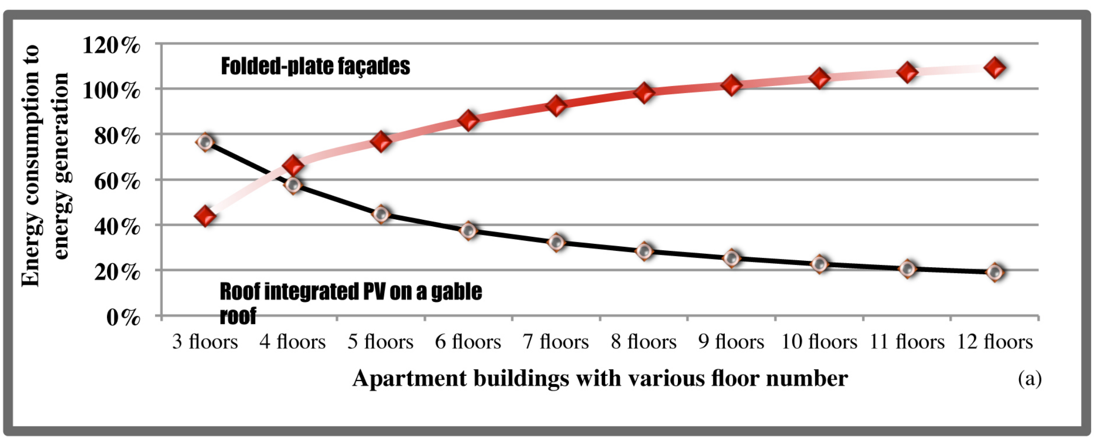
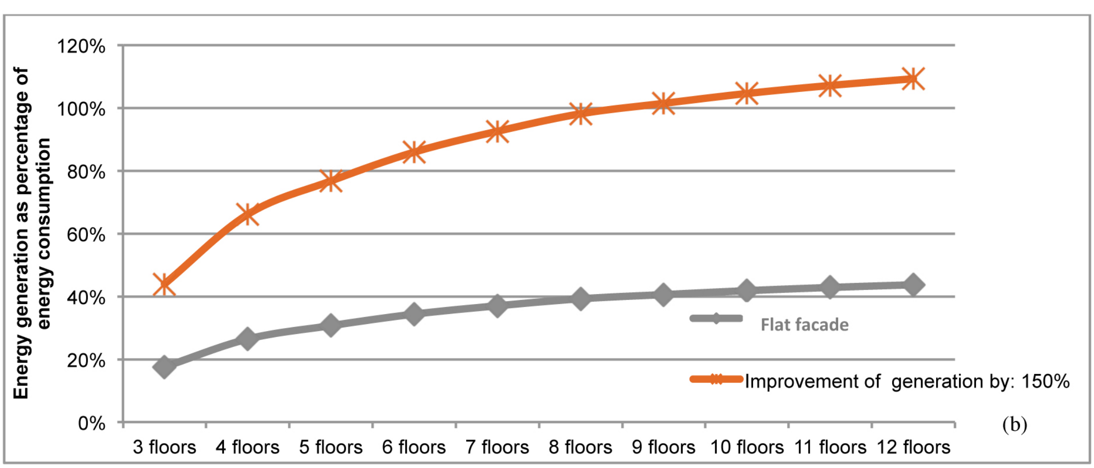


FIGURE 16: (a) comparison of energy performance of folded-plate PV façade of a multistory residential building with south facing BIPV applied on ta gable roof design option of the associated buildings, (b) comparison to a flat facade.





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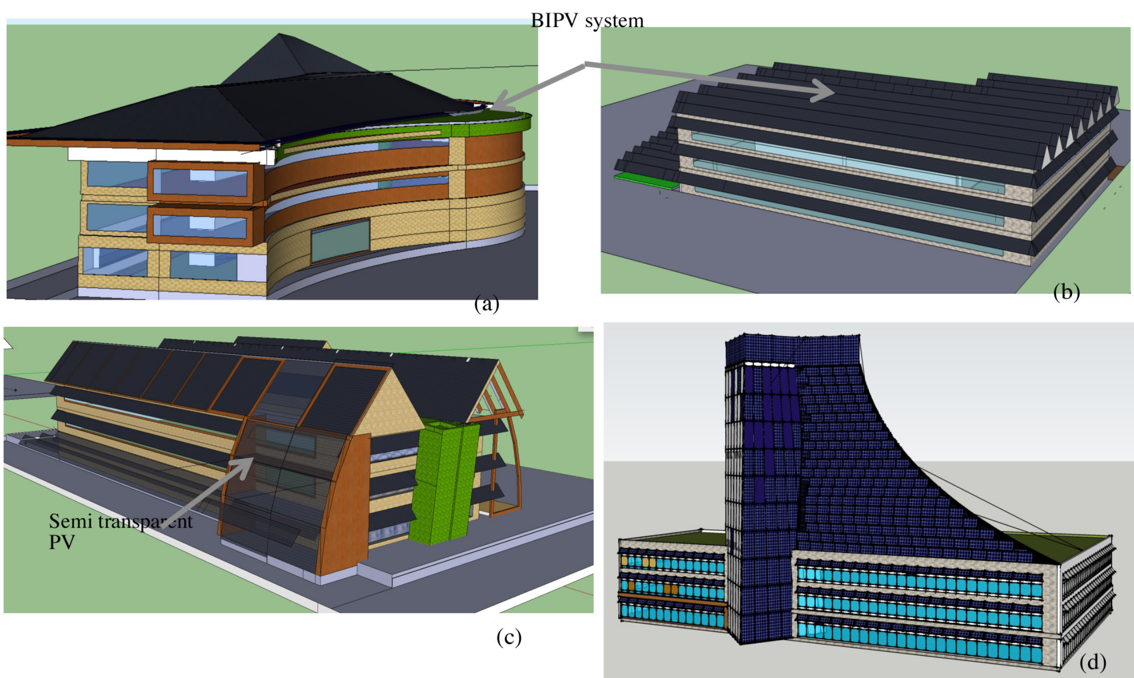
This example demonstrates an integrated design process that considers the design of building shape, building envelope and building energy performance in parallel, since the early design stages, and therefore, enables the incorporation of a properly sized PV or PV/T system. In some cases radical change of the envelope can be envisaged during the design process, as indicated in Figures 17b and 17d.

For a given preliminary building specifications, the process consists of first reducing significantly the energy consumption, and then redesigning the envelope/shape to enable generation of the total energy use of the building. For each alteration of building envelope, the energy performance is simulated to analyze the effect simultaneously.

Preliminary analysis indicates that energy efficiency measures and advanced lighting, in addition to the implementation of heat pump with a coefficient of performance (COP) of 4 to assist heating and cooling, can reduce the energy intensity to about 60kWh/m^2 per year. These results are comparable to some published data on energy efficient office buildings in Canada (e.g. NRCan, 2012). The design shows that although with such small intensity, there is challenge to achieve net zero energy status due to the reduced available surface for the integration of PV system, and hence there is a need to adjust the building shape.

Figure 17 presents design alternatives that progressively increase energy performance status. In alternative 16a the roof design is amplified to include a large PV. The system can generate about 65% of the total energy use of the building. Alternative 17b employs enlarged roof surface and additional overhangs to integrate PV system, in addition to supplementary PV canopy on the west. This alternative increases the generation potential to 95% of the energy use of the building. The third and fourth options offer energy positive potential. Selection of the optimal alternative is, obviously, subject to additional criteria, such as daylighting, aesthetical considerations, cost analysis, etc. It should be mentioned for instance that

FIGURE 17: Four alternatives of the design of an office building to achieve net zero or energy positive status.



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the electricity need for lighting in such office is about 8% larger than for heating, and can be reduced to be equal or slightly less than the space heating using different lighting strategies. Therefore designing the envelope to increase daylighting should be a part of the integrated design objectives with appropriate weight assigned.

4. SIMULATION AS TOOL IN INTEGRATED DESIGN PROCESS

This section presents a methodology for employing energy simulations in the design process of solar community. Simulation of building /neighborhood performance is an indispensable tool for achieving a high-energy performance neighborhood. Modeling should be considered as a part of the integrated design process, from the early design stage. It allows exploring different design solutions and their immediate effect on the performance of buildings and assemblages of buildings.

At the early design stage, when the shapes of buildings are being determined, simulation can assist in determining basic parameters such as optimal window size, thermal mass, and PV optimal location. Presently available simulation tools are limited in their capability to model basic design characteristics for the development of solar communities. Depending on their features and the flexibility of data input and output, some tools that are geared for more advanced stages, can be employed at the early stages. These early models can be continuously updated to allow for more complex geometries, detailed HVAC-systems, energy-generation systems, natural ventilation, as well as user behavior (occupancy, manual shading, internal gains, such as gains from occupant, lighting and electrical equipment, etc.).

Simulation

Data generation for Simulation Software

Before starting the modeling process, some assumptions must be made on the functional aspects of various buildings (residential, commercial, mixed-use, etc.). At the early modeling stage, detailed floor plans are unknown. However, floor area, building usage, and rough building geometry are known. Floor plans define the location and size of various functions such as living areas, bedrooms, offices (in office buildings), corridors, elevators, mechanical and electrical equipment and storage rooms. The main data that should be provided at the early simulation stages include:

- Generating geometric data for whole building simulation program from given coordinates of housing units using appropriate graphic software (e.g. Google Sketchup) or purposedeveloped tool.
- Providing data for whole building simulation software including weather data, building materials, glazing properties, HVAC, control systems, etc., as required by the relevant software.
- For the first stages, assuming simple models of HVAC systems (For instance, EnergyPlus provides HVAC templates, which allow simplified mechanical system modeling process). More detailed data can be added to the basic model later on in the process.

Running Simulations

Integrated design process of a neighborhood involves a large number of simulation runs and data analyses in order to achieve the high performance goals. Some simulations issues include:

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- Simulations time step: Simulations should be performed at relatively small time step (≤1hr).
- Data processing and analysis: Raw data obtained from simulations (for instance hourly data in spreadsheets) should be processed to provide significant design related information. The processing can be automated. Relevant design data include:
    - o Computation of relevant information such as heating and cooling loads for specified design dates and total annual values;
    - o Passive energy inputs: Solar radiation on south facing and near south facing façades (yearly and for specific design days); heat gain from windows (for specific design days and/or specific periods); Energy generation outputs such as thermal heat and electricity generation from BIPV/T systems and peak generation time (yearly generation, seasonal, and specific design days).

Design stages

The design methodology can be divided into 4 main stages, and iteration is often required between these stages. The stages are summarized below and illustrated in the flowchart of Figure 18.

- The first stage consists of designing the overall layout of the neighborhood, according to specifications (such as density, use (mixed-use, residential), etc.). Road design, lot allocation and positioning of buildings should be considered and designed in parallel, with a view to maximize solar potential. A number of neighborhood alternatives should be prepared to test and compare various options.
- The second stage is to perform preliminary simulations of solar access/energy performance of the neighborhood (or representative parts of the neighborhood) of the initial design alternatives. This will indicate whether geometries of the buildings and their positions are optimized to take advantage of available insolation, and to identify serious shading problems. Iterations between stage 1 and 2 can be performed until reaching some solar optimized alternatives.
- Based on best performing alternatives developed in stage 2, general concepts of roof and façade designs are further improved to maximize the potential of buildings to generate energy (electricity and heat), while increasing their energy efficiency.
- The last stage consists of complementing the design of the envelope and its geometry by fine- tuning technologies. This may involve additional iterations of the envelope designs to enable full integration of energy efficiency technologies (HVAC etc.) and energy generation technologies (PV, PV/T).

CONCLUDING REMARKS

This paper illustrates the process of integrated design of residential and mixed-use neighborhoods through examples that apply the principles of this process to specific scenarios. The examples include design issues on the level of neighborhood planning, in cases where roads and lot divisions are prescribed and in a case allowing flexibility in selection of these parameters. Neighborhoods with mixed height and heterogeneous buildings are presented in addition to homogeneous neighborhoods of 2-story residential units. Examples of integrated design at the level of individual buildings focuses on the integration of building envelope design

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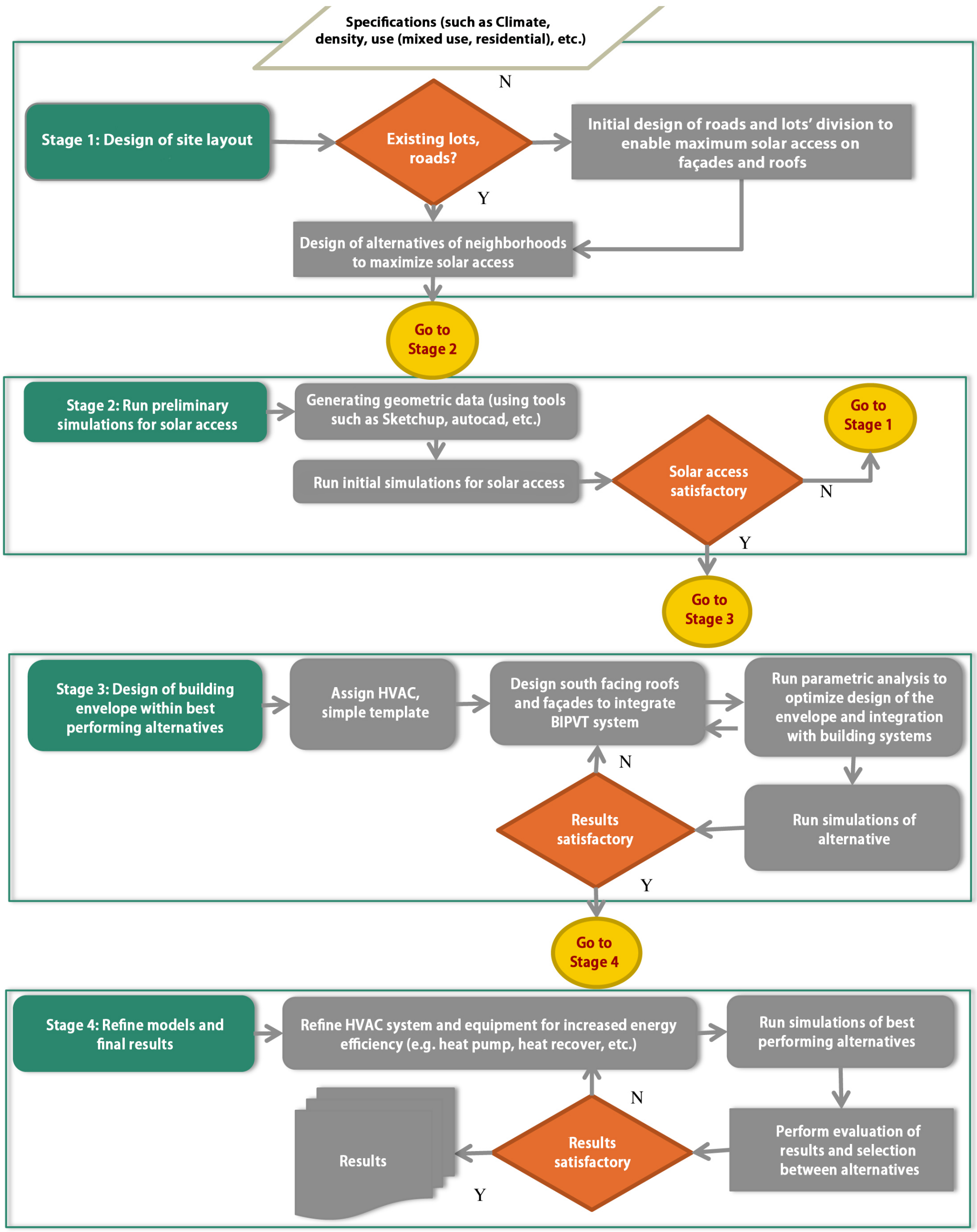
FIGURE 18: Flowchart depicting the general outline of integrated design process of a solar optimized neighborhood.



with the building systems, as well as demonstrating advanced envelope design for integrating energy generation technologies to offset building energy demand.

The examples are based on extensive studies, simulations and analyses, carried out to assess the effects of numerous design parameters on the energy performance of a variety of buildings (including single houses, townhouses, apartment buildings and offices) and neighborhood scenarios. Some of the main results of these studies are included in this paper. For instance – parameters such as the positioning of houses in a residential neighborhood, the

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interaction with the building envelope design and the positioning of the fenestration – have major effect on heating load (by as much as 50%). In the design of neighborhoods with buildings of varying height the correlation between distance and height of buildings have significant effect on energy consumption and on energy generation potential of solar technologies.

The design of building envelope should be integrated with the building systems in order to reduce energy consumption (heating, cooling, lighting, etc). In addition it can be exploited for integration of energy generation technologies such as PV systems or hybrid PV/thermal system. The objective of maximizing energy production at minimal cost can produce highly attractive and imaginative envelope configurations. Examples of such solutions are folded-plate PV (or semitransparent PV) integrated facades, which have the capacity of substantially increasing generation relative to a regular flat façade.

Topics presented in this paper are related to solar energy optimization issues. In the design of high performance neighborhoods that aspires to achieve net zero or energy surplus status a holistic approach should be adopted. The neighborhood should not be considered as a sum of its constituent buildings, but should consider the interaction between these buildings and its effect on the overall neighborhood performance. For instance, manipulation of buildings' positioning and orientations can be exploited to enhance both level and timing of electricity generation, so as to reduce load mismatch and enhance grid interaction, by shifting the time of electricity generation toward peak energy use. Although some of these decisions may influence the performance of individual buildings, it can positively affect the overall performance of the neighborhood. Other design-integrated considerations that can be addressed when designing a neighborhood is the planning of centralized heat and power generation, seasonal storage, and implementation of smart grids for power sharing between buildings of different types functions (e.g. office and residential that have peak loads at different times). Other issues of the design of high performance communities relate to the viable scale of these communities and the phasing of the construction of the community, since this can rule the design and construction of centralized systems to serve a number of buildings designated to be built at the same phase. On the other hand a neighborhood design should account for energy consumption that are not only relate for building operations, such as infrastructure and transportation.

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