Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 122 (2017) 301–306

Energy Procedia

www.elsevier.com/locate/procedia

CISBAT 2017 International Conference – Future Buildings & Districts – Urban Form, Energy and Technology, CISBAT 2017 6-8 September 2017, Lausanne, Switzerland

Defining density and land uses under energy performance targets at the early stage of urban planning processes

Shanshan Hsieh[a,b,c,*,†], Nils Schüler[c,†], Zhongming Shi[a,b], Jimeno A. Fonseca[a,b], François Maréchal[a,c], Arno Schlueter[a,b]

[a]*Future Cities Laboratory, Singapore-ETH Centre, 1 Create Way, Singapore 13892, Singapore*

[b]*Architecture and Building Systems, ETH Zurich, John-von-Neumann-Weg 9, Zurich 8093, Switzerland*

[c]*Industrial Process and Energy Systems Engineering Group, Ecole Polytechnique Fédérale de Lausanne, Sion 1950, Switzerland*

Abstract

The energy demand of cities is highly influenced by urban planning parameters such as urban density and land use. These parameters are mostly determined during early stages of planning. However, the relationships between urban planning parameters and energy systems of districts are rarely incorporated. This paper aims to identify trade-offs between urban density, land use and share of renewable energy sources (RES). For this, we used a Mixed Integer Linear Programming formulation. The model is applied to a real case study of urban planning in Singapore. The results show that when the required share of RES increases from 20% to 70%, the maximum achievable density (floor area ratio) decreases from 32.2 to 2.9 with purely residential land use. While maximizing the self-consumption of electricity produced by PV panels, the resulting land uses are more diverse. These results provide urban planners with constraints from the perspective of energy performance of a district.

Peer-review under responsibility of the scientific committee of the CISBAT 2017 International Conference – Future Buildings & Districts – Energy Efficiency from Nano to Urban Scale

Keywords: urban planning; urban energy system; land use; self consumption; optimization; MILP; district cooling network

* Corresponding author.
† These authors contributed equally to this work.
E-mail address: hsieh@arch.ethz.ch

1876-6102
Peer-review under responsibility of the scientific committee of the CISBAT 2017 International Conference – Future Buildings & Districts – Energy Efficiency from Nano to Urban Scale
10.1016/j.egypro.2017.07.326

1. Introduction

The immediate importance of environmental targets and urbanization pose serious challenges for designing future cities. Energy system designers need to set limitations to attend a growing energy demand while addressing aspects of sustainability [1]. In this context, the renewable energy potential and the efficiency of energy systems may define the maximum energy that could be supplied to urban areas.

Extensive research has been focusing on establishing the links between urban planning and design parameters and building energy demand reduction at the district scale [2]–[4]. The urban form not only influences the energy demand of buildings but also the performance of energy supply systems. For instance, tall buildings could increase shading on other building surfaces for solar energy harnessing. Furthermore, the photovoltaic (PV) electricity production determines the amount of renewable energy supplied to districts in cities, and this would constrain the population density and distribution of buildings if certain environmental targets are imposed. Some studies have tested such constraints on land uses [5] and density [6] imposed by urban energy supply systems. In a densely populated city like Singapore, space availability is one of the key drivers for conversion technology selection. Rooftop areas are limited due cooling tower installations that could otherwise be used to install solar panels. In this context, district cooling with centralized cooling plants has the advantage of increasing chiller conversion efficiencies and rooftop areas for solar panels. In the Master Plan of Singapore, land uses and urban density (floor area ratio (FAR)), are the two main parameters that could restrict the performance of energy systems.

This paper identifies the relationship between urban planning parameters and energy and environmental targets. This entails setting up thresholds of urban density and land use that attain a maximum penetration of renewable energy sources (RES). Section 2.1 describes the case study and inputs of the MILP formulation. Section 2.2 describes the MILP formulation. Section 3 compares the different optimization objectives and metrics. Section 4 concludes with highlights, shortcomings, and potential future work.

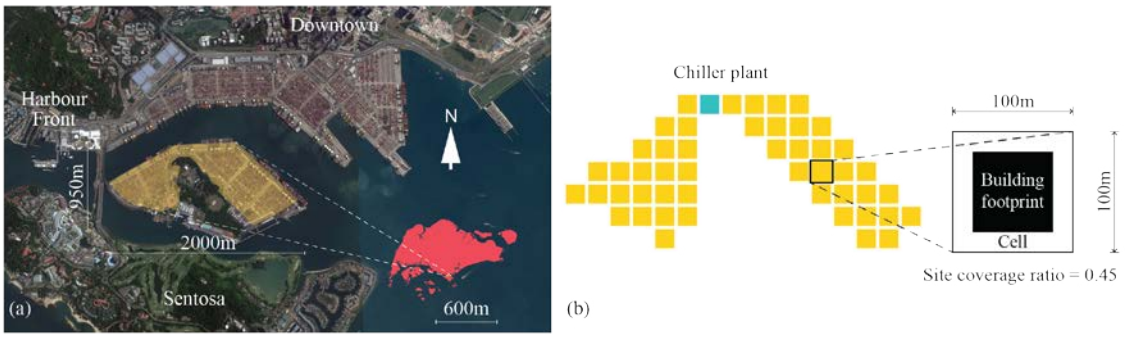

Fig. 1 (a) Real map of the case study site and (b) abstracted map with layout of the cells and the building footprint (podium pattern) in each cell.

2. Material and method

2.1 Description of case study

The authority of Singapore is planning to relocate the Tanjong Pagar container terminal (Fig. 1a) leaving a greenfield of 200 hectares for development. The site is located right off the gateway of the central business district. The project will become part of the major access point to the sea from the center of the city. In this study, a part of the buildable area of the site was divided into 49 homogenous cells (squares) with a size of 100 meters by 100 meters (Fig. 1b). Based on a survey to 602 blocks in six mixed-use Singapore regional centers, we gave the blocks a podium building pattern, which is referred in Fig. 1b. We further assumed all the blocks in the case study site adopt this building pattern with a site coverage ratio of 0.45. For land uses, we adopted the most common ones of the Singapore Master Plan in this research, which are residential, office, and commercial. Industrial use is less likely to appear on this site, therefore, was not included. The respective hourly energy demand profiles for weekdays and weekend days in Singapore are depicted in Fig. 2 [7]–[10]. Since Singapore is located in the tropics, it is assumed that the space