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Effects of air infiltration modeling approaches in urban building energy demand forecasts

Gabriel Happle[a,b,], Jimeno A. Fonseca[a,b], Arno Schlueter[a,b]

[a] *Future Cities Laboratory, Singapore-ETH Centre, 1 Create Way, CREATE Tower, Singapore 138602*
[b] *Architecture and Building Systems, Institute of Technology in Architecture, ETH Zurich, Stefano-Franscini-Platz 1, CH-8093 Zurich, Switzerland*

Abstract

The air infiltration rate is a highly sensitive variable that influences heating and cooling demand forecasts in urban building energy modeling. This paper analyses the effect of two different simplified modeling techniques of air infiltration - fixed air change rate vs. a model based on wind pressure and air temperatures - on the heating and cooling demand in a district. The urban energy simulation toolbox City Energy Analyst (CEA) is used to simulate a case study in Switzerland, comprising of 24 buildings of various functions. Results indicate that despite the large differences for individual buildings, a fixed infiltration rate model could be sufficient for early design studies of district energy systems, as the impact on the sizing of district energy systems remains relatively low. This comparison will contribute to the continued development of urban energy simulations that are robust, as well as computationally fast.

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1. Introduction

Urban Building Energy Models (UBEM) such as the City Energy Analyst (CEA) [1,2] are powerful tools to estimate future energy consumption in urban areas and identify opportunities to improve the performance of buildings and infrastructure. The approach of UBEM is to apply physical models of heat and mass flow in and around buildings to predict operational energy uses as well as indoor and outdoor environmental conditions for groups of buildings [3]. UBEM are expected to become a planning tool for utilities, municipalities, urban planners for applications like planning and optimization of district energy systems [3]. Infiltration has a significant effect on the energy performance of buildings [4]. Infiltration models used in building-scale models span from constant air changes per hour [5] for single zone buildings to co-simulation with multi zone air flow networks [6] or computational fluid dynamics [7]. Several

* Corresponding author.
E-mail address: happle@arch.ethz.ch

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studies on infiltration models at the building scale are discussed in the literature [5]. To the knowledge of the authors there are no studies comparing infiltration models of UBEM at the time of writing. The objective of this paper is to compare two different building infiltration models and their impact on district-scale energy demand. The heating and cooling energy demand of a cluster of buildings is simulated with a static infiltration model (DIN 1946-6) and a dynamic infiltration model (EN 16798-7), while all other parameters are kept constant. The aggregated heating and cooling demand of the buildings and the metrics relevant for district energy system planning are compared.

2. Method

The CEA [8] is an UBEM that uses archetypes to describe physical properties of 3D buildings. In CEA hourly heating and cooling energy demand is calculated with the single-zone resistance-capacitance model of EN ISO 13790 [9,10]. Solar heat gains are calculated via an urban radiation simulation and internal gains are calculated as mean weighted value per hour for buildings with more than one building function from the standard schedules in [11]. Ventilation and infiltration air flows an their respective temperatures are used in the calculation of the hourly air heat transfer coefficient between the indoor and outdoor air temperature nodes in the resistance-capacitance model. Simple control strategies of heating, cooling and ventilation systems, such as schedules setback temperatures are implemented in the calculation procedure. The following sections introduce the two infiltration models used for this study as well as the control algorithm for mechanical and natural ventilation in CEA.

2.1. Model A: Static infiltration rate

The static infiltration based on the air tightness of the envelope is calculated with Eq. 1 from DIN 1946-6 [12].

$$q_{V:inf} = f_{system} * V_{zone} * n_{50} * (f_{location} * \Delta p_{dim}/50Pa)^n \quad [m3/h] \tag{1}$$

Where $f_{system} = 0.5$, $f_{location} = 1$, and $n = 0.667$ are extracted from [12]. A design differential pressure $\Delta p_{dim} = 5Pa$ is suggested for a multi-storey building shielded from wind [12].

2.2. Model B: Dynamic infiltration rate

In contrast to the static infiltration model, the dynamic model takes into account the outdoor and zone air temperature and the wind speed on site. The dynamic infiltration is calculated according to an iterative procedure described in EN 16798-7 [13]. The calculation procedure is based on the formulation of all air volume flows into and out of a zone, including infiltration, as a function of the unknown zone reference pressure (gauge). For the CEA tool only the calculation of air flows through leakages (infiltration) is implemented. All other air flows (mechanical and window ventilation) are assumed to be balanced and do therefore not have an impact on the zone pressure (see section 2.3). The infiltration air volume flows are summed up according to their direction, converted to mass flows and the mass balance is iteratively solved as a function of the unknown zone reference pressure, see Eq. 2.

$$q_{m;V;lea;in} + q_{m;V;lea;out} = 0 \quad [kg/h] \tag{2}$$

The air flows through each default leakage path, defined in [13] are depending on the path pressure difference, which is calculated from the unknown zone indoor pressure, the wind pressure and the stack effect due to the temperature difference between the zone and the environment, Eq. 3.

$$q_{V;lea;path,i} = f(u_{site}, T_e, T_z, h_{path,i}, C_{p:path,i}, C_{lea;path,i}) \quad [m3/h] \tag{3}$$

According to the standard calculation procedure [13] five standard leakages paths are considered. They are located at the roof and the building facade facing the wind at 0.25 and 0.75 of the building height, as well as at the facade not facing the wind at 0.25 and 0.75 of the building height. For the wind pressure coefficient $C_{p;path,i}$ standard values for different expositions, heights, and cross ventilation properties are provided in [13]. The path's leakage coefficient $C_{lea;path,i}$ is a fraction of the total leakage coefficient according to the fraction of envelope are represented. The total

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