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3D Data Models for Urban Energy Simulation

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Abstract

Sustainable use and management of energy resources is a challenging task for growing urban population. Especially, an urban environment in temperate continental climate consumes high energy resources for their space heating and domestic hot water demands. Assessment of thermal energy requirements for future energy demands is fundamental to sustainable urban environment. Thermal energy demand can be simulated using physical and empirical laws from building physics domain. Physical laws compute thermal energy consumption based on heterogeneous datasets from various data sources. These datasets may include information from cadastre, building registers, inhabitant census, 3D building models, ground surveys and meteorological databases. Furthermore, depending upon availability, accessibility and level of detail, specific simulation methods are usually employed for evaluation of energy consumption at different spatial scales. This paper attempts to identify input data parameters which could facilitate validation and calibration of thermal energy demand based on input data sensitivity using simulation methods.

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Keywords: urban energy data model; CityGML; heating energy demand; data sensitivity; level-of-detail

1. Introduction

The building and urban energy simulation tools and programs such as ESP-r, EnergyPlus, INSEL and CitySim use physical and statistical models to estimate the thermal demands at building and city-scale based on heterogeneous datasets from various urban energy related data sources. Apart from the thermal demand simulation of buildings, models are also being developed to predict household electricity demands [1]. However, simulation results of disaggregated urban energy flow modelling study by Perez et. al. indicates that a space heating service in

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buildings consumes large proportion of total energy demand [2]. Therefore, calibration and validation of thermal energy demand simulation methods is fundamental in order to know uncertainty in methods and sensitivity of methods towards input data parameters, respectively. Moreover, discrepancies observed between the simulated and monitored energy consumption values allows to identify critical input data parameters which are affecting the simulation results. The impact of parameters can be tested by specifying a test workbench. A workbench would account for metadata information of input data quality, resolution, its source and the default assumption in values. Consequently, accuracy of predicted thermal energy demand can be stated as a function of particular affecting data parameter. For the implementation of test workbench, spatio-temporal input datasets are required to be structured into a conceptual data model along with its metadata information including source, quality and method of determination. Perez et. al. have presented a conceptual data model for overall energy flow simulation in urban areas and also stated its utility for input data sensitivity analysis [2]. Based on the review of previous research studies in the context of data modeling for simulation methods, the objectives of article are defined as follows:

- To characterize the input data requirements for thermal simulation methods.
- To identify input data parameters for thermal energy demand calculations.

2. Related Works

The process of urban energy related data sources identification, data acquisition and preparation of input data files for simulation is certainly a resource and time consuming task. The approaches presented in the past replaces the simple input data files preparation task for simulation by a conceptual input data model formulation [3]. The input data model formulation and also subsequent specification of test workbench require review of possible urban energy related data sources and data availability and accessibility constraints for simulation methods.

2.1. Data Sources and Requirements

In general, urban energy related data sources can be classified into three main categories: Primary, Geomatic and Building Physics. The required data values are either present with these data sources (measured or default benchmark data) or can be derived mathematically from the geo-physical properties of buildings. Figure 1 gives an overview of energy-related data sources and attributes associated with these data sources. The primary data sources such as building registers and censuses provide basic information about the building construction year and its type, number of floors / measured building height and number of dwellings. A meteorological data (measured/qualified product) about ambient air temperature, wind speed and direction is often readily available per case study site at hourly or monthly time step. However, the solar heat gains per surface are computed from the measured global irradiance on horizontal surface and surface orientation using diffuse irradiation models. The required spatio- semantic attributes such as gross volume, surface type (roof, wall, and ground) and sun-wind exposed surface area are mathematically derived from the building geometry encoded in CityGML model. On the other hand, the building physics attributes are the default benchmark data for given building archetype as specified in the building and environment standards/norms (e.g. IWU for Germany) [4], [5]. In Starter Project Energy Atlas Berlin, key data indicators/indices have been defined and classified broadly according to the geometry and spatio-semantic metrics [6]. These metrics typically account for the set of attributes derived from the CityGML model, cadaster and statistical data for estimation of thermal energy consumption values. In another study of thermal energy demand calculations for a residential site Scharnhauser Park near Stuttgart, input data for simulation method have been categorized as the geometry, physical and weather data [7]. However, in order to explain the uncertainties in simulation results sub-classification of input data is necessary. An approach of data sub-classification has been proposed in Section 3.

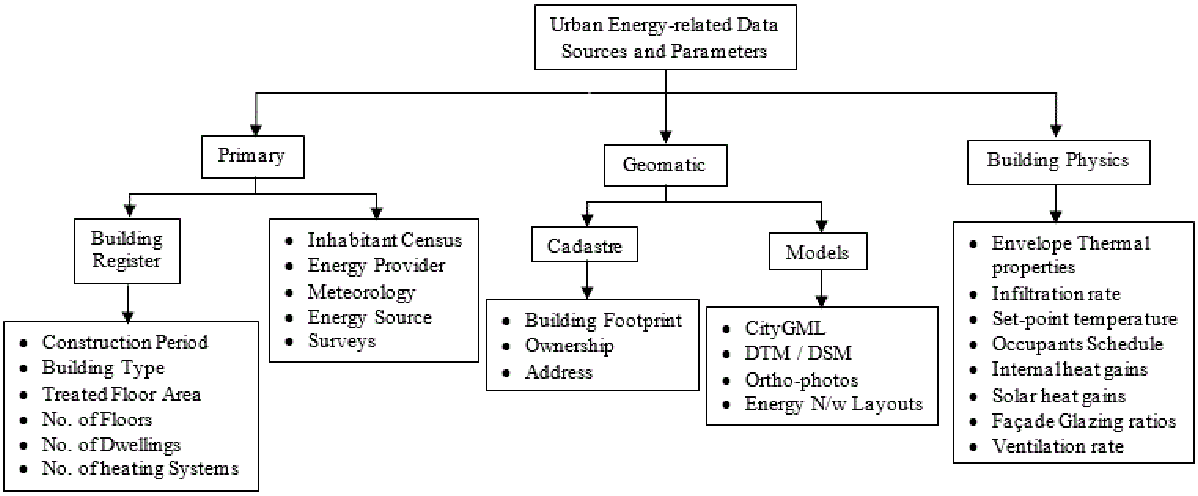

Figure 1 Urban energy related data sources

2.2. Simulation Methods

A typical statistical energy consumption can be calculated using its correlation with the building characteristics, heated floor area and the demographic factors. A typical generalised statistical approach predicts the energy consumption based on the building archtypes, construction year, default values of heat transfer coefficients and the number of buildings in a district [8]. Most of the statistical demand simulation studies have been materialised into statistical models such as the regression models [9] and the gaussian mixture models [10]. The physical simulation methods depend upon the comprehensive model of building dimensions and detailed input data. Starting with the simplest degree-day model, annual energy demand is correlated with the building thermal envelope parameters considering only transmission losses through the envelope [11]. The monthly energy balance simulation method calculates the heating energy demand considering the transmission & ventilation losses and solar radiation & internal gains through the envelope [12], [13]. The dynamic building thermal energy demand simulation method based on the VDI 6020 standard requires hourly weather data and detailed geometrical modeling where a building is discretised into “thermal zone” areas for hourly investigation of multi-zone convective and radiative interaction. The degree day and energy balance models have been validated with varying data inputs to test the impact of input parameters on simulation results [7], [11]. The uncertainties in energy balance model have been investigated with respect to geometric and thermal uncertainties [14]. A heated area, volume, building height and window ratio parameters have been identified in geometry category while ventilation rate parameter in thermal category. A input data model formulated for energy balance model has been presented in Section 4.

3. Characterization of Data

Figure 2 shows the characterization of input data defined in context of thermal simulation to be performed, number of attributes and the level-of-detail of geometry required. A required data for simulation can be characterized or sub-classified according to the geometry levels-of-detail, semantic typification of physical attributes and temporal granularities in measured attributes. The modelling of energy demand using the statistical to physical range of simulation methods can be intuitively associated with the 2.5D LoD to LoD3 geometry range and data availability to accessibility range of building physics attributes. However, uncertainty quantification of underlying parameters of simulation model, LoD sensitivity analysis and accuracy assessment of attributes can be performed using the metadata nomenclature (specifying the source, timestamp, determination method and quality) associated to critical data parameter for studying the reliability of simulation results. In particular, using metadata approach, impacts of variations in critical LoD sensitive data (e.g. building volume, thermal zones, building height) and

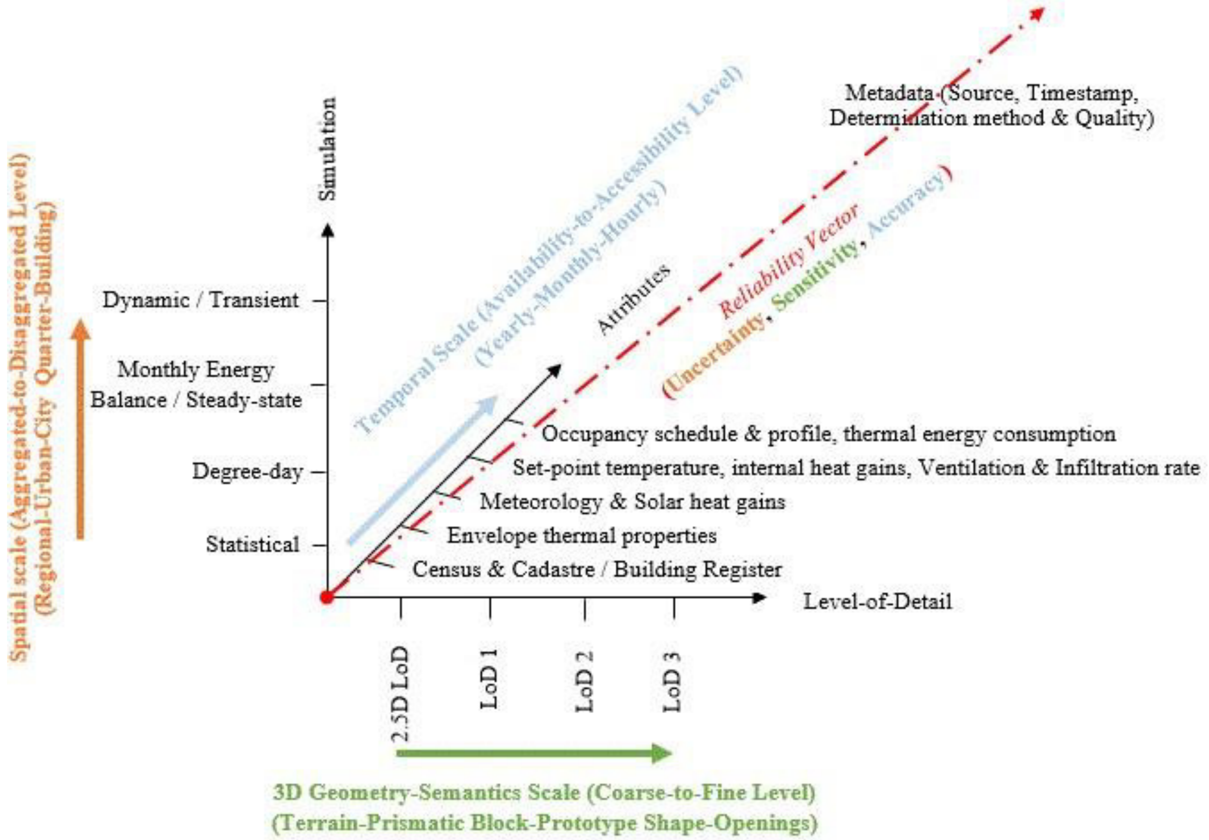

Figure 2 Data characterization for thermal simulation methods

physical data (e.g. window ratio, refurbishment year, U-values, air change rate) parameters on simulation results can be readily identified by specifying a test workbench.

4. Formulation of data model for identified parameters: SimStadt Platform

SimStadt is a modular platform for simulation of thermal energy demand and photovoltaic potential at urban scale [15]. It consists of preprocessing workflow steps (Geometry, Physics, Usage and Weather processing) which derive simulation relevant parameters from CityGML model, building physics & usage library and from readily available qualified weather databases. Presently, monthly energy balance simulation method (based on European DIN V 18599-1 standard) is implemented as simulation workflow step to estimate space heating and cooling demands of given case study. The input data parameters derived in preprocessing workflow steps are used to formulate an input data model for simulation method (Figure 3). The simulation results are associated to respective buildings for visualization of heating demand for a given case study site.

5. Conclusion and future work

A critical review of the data requirements for urban energy simulation methods is presented with a focus on characterization of input data requirements and identification of critical data parameters. A general approach of data characterization and formulation of input data model is demonstrated for monthly energy balance simulation method which is implemented as simulation workflow in SimStadt platform. Keeping in view the challenges of data sensitivity analysis, automation in input data preparation tasks and structured coupling between processing & simulation steps (Figure 4), the present work could be extended for following research interests:

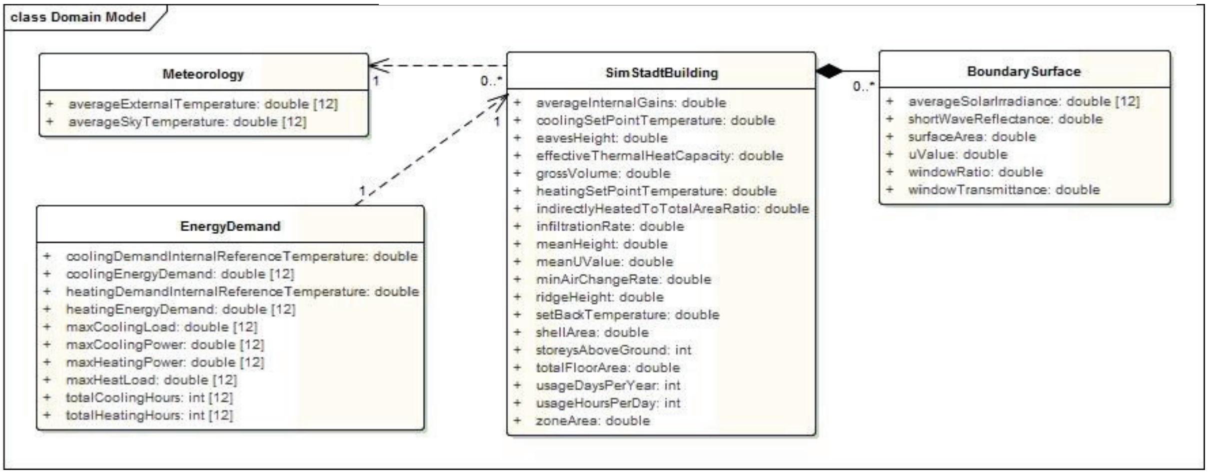

Figure 3 Input data model for monthly energy balance simulation method

- A metadata approach in data sensitivity and uncertainty analysis could be helpful to identify the compatible geometrical level-of-detail for particular simulation method and also to improve the accuracy of simulation results by assessing variations in input data parameters.
- An input data model could be extended for range of statistical and physical thermal simulation methods. Moreover, the scope and modularity of SimStadt platform could be further improved by formulating input data models for electricity & domestic hot water demand modeling and also for radiation simulation methods.
- A simulation data can be structured into a database according to given input data model. The defined interfaces to the simulation programs can also make use of this centralized database for their input requirements and the results stored in a database can be readily fetched for visualization purpose.
- The interface definition for simulation programs could also be useful in specifying orchestration of simulation functionalities between these programs which could lead to the realization of co-simulation framework for well-defined use cases.

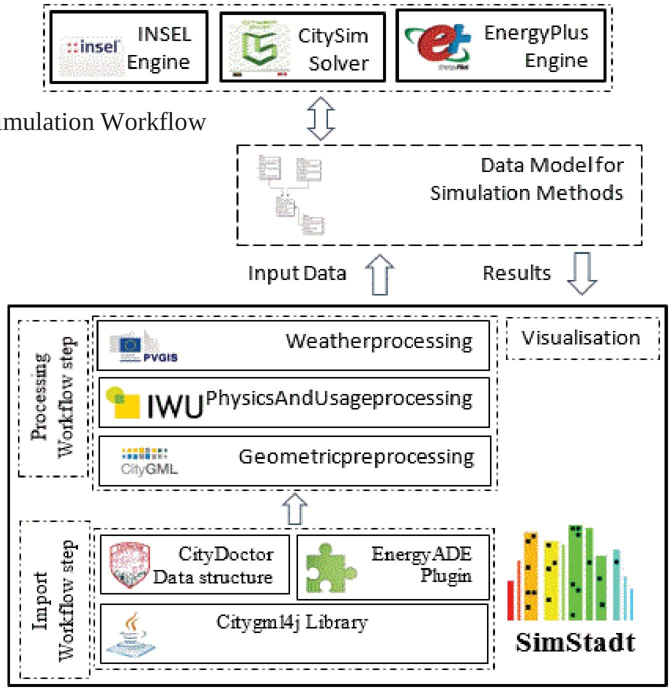

Figure 4 Proposed concept for automation and coupling between processing & simulation workflows

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