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CITYSIM SIMULATION: THE CASE STUDY OF ALT-WIEDIKON, A NEIGHBOURHOOD OF ZÜRICH CITY

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As research in building energy demand simulation is reaching maturity, there is now a growing interest in the evaluation of the energy need of larger and/or pre-existing urban areas [1, 2, 3], to evaluate the energy performance associated with alternative development or improvement scenarios. These past years, the urban energy use simulator CitySim was developed at EPFL based on multiple physical models. CitySim can compute an estimation of the on-site energy use for heating, cooling and lighting; however for this it needs a complete physical description of the buildings in the form of an XML input file. To simulate just a few buildings, it is convenient to simply enter this information manually through a graphical user interface; but when buildings are counted in hundreds or thousands, a more efficient method is required: data handling in databases. This paper describes the methodology used to take best advantage of PostgreSQL and QuantumGIS to manage the inputs needed by CitySim and the large amount of results produced. It describes the database structure used for the case study and the working principle of the Java tool that links the database and CitySim. The methodology was successfully applied to simulate a case-study neighbourhood of Zürich City and produced useful energy demand graphs.

Reference

Laboratoires

LESO-PB - Solar Energy and Building Physics Laboratory

Documents

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CITYSIM SIMULATION: THE CASE STUDY OF ALT-WIEDIKON, A NEIGHBOURHOOD OF ZÜRICH CITY

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ABSTRACT

As research in building energy demand simulation is reaching maturity, there is now a growing interest in the evaluation of the energy need of larger and/or pre-existing urban areas [1, 2, 3], to evaluate the energy performance associated with alternative development or improvement scenarios. These past years, the urban energy use simulator CitySim was developed at EPFL based on multiple physical models. CitySim can compute an estimation of the on-site energy use for heating, cooling and lighting; however for this it needs a complete physical description of the buildings in the form of an XML input file. To simulate just a few buildings, it is convenient to simply enter this information manually through a graphical user interface; but when buildings are counted in hundreds or thousands, a more efficient method is required: data handling in databases. This paper describes the methodology used to take best advantage of PostgreSQL and QuantumGIS to manage the inputs needed by CitySim and the large amount of results produced. It describes the database structure used for the case study and the working principle of the Java tool that links the database and CitySim. The methodology was successfully applied to simulate a case-study neighbourhood of Zürich City and produced useful energy demand graphs.

INTRODUCTION

The urban population is forecasted to increase to almost 70% by 2050, and the energy consumption in cities is likely to follow that trend if no remedial actions are taken. It is therefore necessary to identify solutions that lead to significant reductions of resource consumption whilst maintaining good quality of life standards for urban inhabitants. To this end, computer modelling at the urban scale is an invaluable decision support tool for urban planners and designers. However, with computer modelling tools, such as CitySim [1], the amount of data required for the simulation of an ensemble of buildings is proportional to the number of buildings involved, likewise for the results produced. At the urban scale, an efficient storage of the significant quantity of data needed and produced by the simulation of hundreds or thousands of shelters can only be realized by the use of databases (MySQL, PostgreSQL, Access or others). This article presents the creation of a database model for urban energy simulation using PostgreSQL, its link to the urban energy simulator CitySim and finally the case study of a zone of 123 buildings in the Alt-Wiedikon district of Zürich.

PostgreSQL database

Database management systems (DBMS) and geographical information systems (GIS) provide excellent tools for data management, and some start to integrate simulation modules [4, 5]. These modelling capabilities are limited, but we suggest that their usage in conjunction with urban energy use simulation programs is very promising. PostgreSQL is a complete and open-source DBMS, offering the wide range of usual SQL functionalities for data handling. It is also completed by the spatial data module PostGIS, which provides geometrical data types (such as points, lines, polygons and collections of these) and a multitude of related functions to access, edit and process spatial data. To these internal functionalities are added importation tools, APIs for access through self-written programs and various open source software offering for example graphical user interfaces. The open source GIS software QuantumGIS can be used to access, visualise and modify data in a PostgreSQL database, and to produce map representations of any parameter linked with a geometry.

CitySim

These past years, the urban energy use simulator CitySim was developed at EPFL [1]. Comprised of multiple physical models coupled together, CitySim can compute an estimation of the on-site energy use for heating, cooling and lighting with an hourly time step. A radiation model first computes the irradiation incident on each surface of the zone, direct from the sun, diffuse from the sky and reflected by other surfaces. The results of this model, together with predictions of longwave radiation exchange, are input to a thermal model determining the thermal exchange through buildings' envelopes and computing the heating or cooling energy needs to maintain predefined temperature conditions inside. Finally, energy systems providing heating, cooling and electricity can also be defined. The corresponding models compute what energy was provided to meet (or not) the associated demand at each time step, thus determining the new state of the model at the next time step. However, a complete physical description of the scene – in the form of an XML input file and a climatic data file – is needed for the simulation. The climate data includes hourly temperature, wind and irradiation values, completed with geographic coordinates and the definition of far field obstructions (which is used in a pre-process to the radiation model). The building models describe the envelope of each building (the thermal properties of each façade, the layered composition of the walls, the proportions of window and the physical properties of the glazing), as well as the infiltration rate and, when possible, the presence of occupants. This may be completed by simple models of energy systems such as solar panels, boilers and HVAC. In order to create a CitySim model, this information on each building must be encoded in the dedicated XML input file mentioned above.

METHODOLOGY

The methodology starts with the definition of a database model for the storage of the data needed and produced by CitySim, follows with the description of a Java tool developed to connect the database with CitySim and ends with a case study of 123 buildings in the Alt-Wiedikon neighbourhood in Zurich (Switzerland).

Alt-Wiedikon case study (data source)

The Alt-Wiedikon residential neighbourhood in Zurich (Switzerland) was selected as case study. In order to obtain a description of the 123 buildings in the zone of Alt-Wiedikon in a reasonable time, the following data sources were used:

- Cadastral maps, usually available in digital format, provide reliable 2D representations of buildings' footprints and were thus used as a basis to define the building entities to be modelled. The altitude and average height of each building was extracted from digital surface and terrain models (DSM and DTM).

- The buildings' register contains varying quality data about the geographical location, address, main allocation, construction date, renovation date, energy systems, etc. of buildings. In the absence of more detailed knowledge, the construction characteristics can be extrapolated from these parameters.

- A company census, containing sensitive data related to the kind, location, activity and number of employees of all firms in the area will be used in the future to estimate the number of occupants in buildings.

- A visual survey helped complete the physical model of the buildings in the area with estimates of the glazing ratio, window type and frame material of each building and allowed us to check the status and relevance for simulation of each building (demolished, garage, etc.).

It appears that sufficient data is available to create a first rough but extensive model of any urban zone in Switzerland. However, organising this data into a coherent simulation model is a highly time-consuming task if no appropriate tools are used, and research simulation tools are usually not adapted to perform this task.

Database use and data model

The use of DBMS has several advantages: 1) the disparate original source files (.shp for maps, .xls or other for text data) can be loaded as simple tables in a temporary database, 2) a dedicated data model can be designed as an intermediary data model to bridge the conceptual gap between CitySim's specific input file format and the data sources, and 3) SQL and spatial functions enable one to combine the different data sources, based on common identifiers and on spatial location, in order to retrieve the necessary data and fill-in a CitySim-dedicated database.

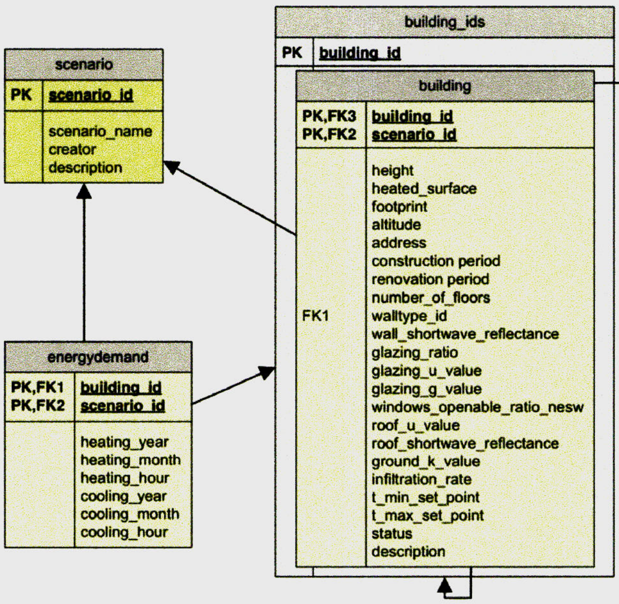

Figure 1: Schema of the data model of the CitySim database. If a building is not redefined in a scenario, its "base case" version is used. Thus the energydemand table refers to the scenario table and to the building_ids table, which contains all existing "building_id" independently of the scenario.

The data model designed for this purpose is presented in Figure 1; it is mainly composed of a central "building" table including the essential data such as the cadastre footprint of the building, the average height, the construction and renovation periods and the number of floors. The “building” table then refers to a "walltype" table and a "scenario" table. The "walltype" table lists all defined construction types, whose physical compositions are stored in the "layer" and "material" tables. The "scenario" tag defines case-study modifications of the base case (or scenario 0) model. Finally, an "energydemand" table contains the simulation results for heating and cooling demands of each building in each scenario. The energy systems are not defined within this data model, which presently focuses on energy demand.

The footprint and average height are imported from cadastre files. The buildings’ register fills in the period of construction, the treated floor area and optionally the address, the number of floors and the energy system used for heating. The wall types are chosen in a list of typical values according to the building’s construction and renovation periods. Glazing ratios, U-values and openable ratios are based on results from the visual survey. The other parameters use default values: windows g-value of 0.7, roof U-value of 0.3 W/m^{2}K, ground conductance of 3 W/m^{2}K, infiltration rate of 0.4 h^{-1}, minimum and maximum set point temperatures of 21°C and 26°C, short wave reflectance of the façades of 0.2.

Java connection tool

Once all the necessary data is gathered in the database, creating a CitySim input file for simulation and storing the results back in the database is a well-defined task that can be automated. For this purpose, a small Java program was written to access the database, retrieve the relevant data and transform it in a comprehensive CitySim model. For each building, the 2D footprint is extruded in a 2.5D model based on the altitude and average height of each building. As heat losses or gains are usually negligible between touching buildings, the shared surfaces are considered adiabatic and the corresponding façades are cut accordingly. Each building surface (wall, roof or ground) is then attributed a construction wall type or a U-value, a glazing ratio and physical properties, and a reflectance based on the attributes in the building table. Each building is also attributed with minimal and maximal set point temperatures and an infiltration rate. The model is finally written in a CitySim input XML file. The Java program then launches a simulation by calling the CitySim solver with the input file and a climatic data file produced with Meteonorm [6] and describing a typical year in Zürich. Once the simulation has ended, the result file containing heating and cooling demand for each hour of a typical year is read, prepared and inserted in the “energydemand” table of the database. Simple SQL views joining the “building” and “energydemand” tables can then be defined in the database to present a scenario’s results.

RESULTS

Our structure now enables us to quickly modify or correct our model and to simulate large urban zones in a relatively short time (the simulation takes less than twenty minutes for a hundred buildings on MacBook Pro 2.3Ghz with 4 Gb of RAM). QuantumGIS was used to access our database and produce meaningful representations of the results (figures 2 and 3).

Base case simulation

Figure 2 shows the heating and cooling demands resulting from the CitySim simulation of the neighbourhood. The total simulated heating need of the zone in the base case scenario is of 28 GWh per year, and 2 GWh for cooling. From an inspection of the database, we noted that the