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INTEGRATION OF OUTDOOR HUMAN COMFORT IN A BUILDING ENERGY SIMULATION DATABASE USING CITYGML ENERGY ADE

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Abstract

Handling data needed by Building Energy Simulation (BES) tools can be a tedious task, especially at the urban scale. Besides BES, users often have different needs (building energy use, human comfort, integration of renewables, urban planning…) in mind when using simulation tools, but often have access to the same dataset. To simplify and harmonize the process of obtaining a homogeneous dataset, we make use of a PostgreSQL database in the CityGML file format using the Energy Application Domain Extension (ADE), which can be accessed remotely to retrieve data. CityGML with Energy ADE is an open data model with the objective of having a common platform to store and exchange 3D information and energy data between municipalities, professionals and researchers. The structure of the CityGML covers the following modules: geometry, construction, occupancy and energy systems. However, in the CityGML structure an important parameter to describe the city livability is missing: the outdoor human comfort. Considering this, we propose to further develop the database, by adding outdoor human comfort parameters and results. A case study of the Ecole Polytechnique Fédérale de Lausanne (EPFL) campus will be set-up, stored in the database and simulated with the software CitySim. The resulting human comfort indices will further be sent back to the improved database for an offline analysis with GIS tools. With this new development, the CityGML with Energy ADE can benefit from information on the urban microclimate and its impact on people activities and wellbeing.

Keywords:
CityGML; Outdoor Human Comfort; Urban energy and sustainability; PostgreSQL

1 INTRODUCTION

The outdoor human comfort and the energy demand of buildings are essential parameters to quantify the sustainability and livability of a city. Sustainable development should work at several scales, creating a dynamic interaction between pedestrians, buildings and the whole city.

When focusing on City Energy Modelling, unlike Building Energy Modelling, each urban simulation engine generally has its own tailor-made data model, and there is nowadays no way of communication between these models. To address this issue, since May 2014, an international consortium of urban energy simulation developers and users (11 European organisations (Hochschule für Technik Stuttgart, Technische Universität München, Karlsruhe Institute Technology, RWTH Aachen University, HafenCityUniversität Hamburg, European Institute for Energy Research, Ecole Polytechnique Fédérale de Lausanne, Centre Scientifique et Technique du Batiment, Electricité de France, Sinergis, M.O.S.S Computer Grafil Systeme) representing 5 urban energy platform developments (CitySim, SimStadt, Energy Atlas, Modelica library AixLib, Sunshine platform)) is establishing an Urban Energy Information standard, as Application Domain Extension (ADE) of the CityGML urban information model. CityGML is a XML-based open data model for the

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storage and exchange of virtual 3D city models, issued by the Open Geospatial Consortium (OGC) [1]. CityGML is organized around a CityGML core model, prolonged by Application Domain Extensions (ADE) for different purposes such as: geometry, construction, occupancy and energy systems. However, these modules do not address one important part of the livability in cities: the outdoor human comfort.

The human comfort, defined as the condition of mind which expresses satisfaction with the thermal environment [2], can be used as an indicator to quantify the urban microclimate, and provide guidelines for a sustainable urban development. The main meteorological parameters that affect the outdoor human comfort are: the air temperature, the wind speed, the solar irradiation, the relative humidity and the mean radiant temperature. The Mean Radiant Temperature (MRT) describes the heat radiation exchange between the human body and its environment, and it is defined as “the uniform surface temperature of an imaginary black enclosure in which an occupant would exchange the same amount of radiant heat as in the actual non uniform space” [2]. The MRT is used to quantify the outdoor human comfort: it is an input parameter in the calculation of the Physiological Equivalent Temperature (PET) [3] and the Predicted Mean Vote (PMV) [4], and is directly used to analyse the outdoor microclimate. The MRT is sensitive to the urban environment, as well as on the impact of short and long wave radiation received by pedestrian.

Several softwares exist to quantify the Mean Radiant Temperature:

- ENVI-met and the post-processing tool called BioMet, also able to quantify Predicted Mean Vote (PMV), PET and UTCI (Bruse, 2014).
- RayMan model, that calculates radiation fluxes and thermo-physiologically indices, as PMV, PET, Standard Effective Temperature (SET*) (Matzarakis et al., 2007) UTCI and Perceived Temperature (Matzarakis, 2015).
- SOLWEIG (SOlar and Long Wave Environmental Irradiance Geometry) that quantifies PET and UTCI (Lindberg,2015).

Several case studies were already performed with the previous software [5] [6] [7], but a common platform able to store and exchange the results is missing.

To achieve this, we propose to use a PostgreSQL database to handle data on urban areas. Cities are composed of a very large number of surfaces with various and complex properties. With a database, it becomes easier to extract, share and store this big amount of information.

This paper starts with a brief introduction of the specificities of the CityGML Energy ADE standard, defines the methodology used to extract data from the PostgreSQL database and shows the methodology to create a new outdoor human comfort module (feature type) in the CityGML Energy ADE. The new feature type, in CityGML data model, is an interchange platform with the punctual calculations of the Mean Radiant Temperature obtained by the software CitySim. The case study of the EPFL campus in Lausanne is used as demonstration case study for the analysis of the Mean Radiant Temperature, which are inserted in dedicated tables in the PostgreSQL database.

2 MATERIALS AND METHODS

The methodology aims to present a gateway between CitySim and CityGML Energy ADE data models, by the creation of a new feature type describing the outdoor human comfort. In previous research, a gateway between CitySim data model and CityGML Energy ADE was established, using the EPFL campus in Freiburg and Lausanne (Switzerland) as case study [8] [9].

2.1 CityGML with Energy ADE data model

CityGML with Energy ADE is composed of the following four interrelated modules, linked to the 3D information in the CityGML core through references:

- Building, Zones and Boundaries: where the information concerning buildings geometry, thermal zones, opening and schedules are stored.
- Construction and Layers: data concerning the physical characteristics of the envelope, such as material, and their physical and optical properties (emittance, absorptance, transmittance, and reflectance).
- Occupancy Module: describes the usage of the building, the presence of occupants, and the consequently usage of facilities and appliances.
- Energy System Module: describes the energy demand, supplied by different energy systems (conversion, distribution and storage).

The four modules are completely independent of each other. They may also not be present or be linked together through references. In the following methodology, we propose to create a new feature type in the module “Energy System Module”, called Outdoor Comfort, which contains the information of Mean Radiant Temperature and Models of Comfort. The reason for the comfort feature type to be located in the Energy System Module is due to the concept that for a person to maintain the required comfort, he or she has to exchange energy with the environment. The results of the Mean Radiant Temperature, as calculated by the software CitySim, are stored in the CityGML Energy ADE data model.

2.2 Mean Radiant Temperature

The calculation of the Mean Radiant Temperature in CitySim is based on the Integral Radiation Measurements [10]: a pedestrian is designed as a cylinder, with the base inscribed in a circle of 0.17 m. It is further located in the outdoor environment, positioned at a height comprised between 1.1 and 1.5 m, corresponding to the centre of gravity of a human body [11]. The geometrical and physical characteristics of the pedestrian described in the CitySim XML data model as follows:

<Building Name="Pedestrian1" id="52" key="p1" Vi="0.0306780338" Simulate="true" mrt="true" mrtEpsilon="0.97">

where *mrt="true"* describes if the calculation of the Mean Radiant Temperature is performed (True) or not (False); *mrtEpsilon="0.97"* is the emissivity of pedestrian, with the standard value corresponding to 0.97.

The geometrical characteristics are described hereafter:

<Building>
<Zone>
<Occupants … />
<Wall…>
<V0 x="0.11" y="0.00" z="1.10"/>
<V1 x="0.17" y="0.00" z="1.10"/>
<V2 x="0.17" y="0.00" z="1.50"/>
<V3 x="0.11" y="0.00" z="1.50"/>
</Wall>
</Zone>
</Building>

where the vertex (V0, V1, V2 and V3) are defined per each spatial coordinates x, y and z.

2.3 PostgreSQL Database

PostgreSQL is an object-relational database management system developed in the past decades as open-source software. The compatibility with geographical information systems and the ability to create new tables from existing ones are some of the interesting features of Postgres [12].

The database server Postgres together with the PostGIS add-on were installed on a Linux machine at EPFL. Data such as the building physical characteristics (material types, wall types, height, dimensions…) as well as ground surfaces were inserted in a dedicated database following the requirement by the CityGML structure.

A Java program (named CitySim Database Linker) extracts the necessary data to create an input XML file for the CitySim simulation. The simulation is then performed and the results produced (energy demand, mean radiant temperature, irradiation on buildings, etc.) can then be fed back in the database.

A geographical information system such as QGIS, can then be used to visualize the results from the database by colouring the footprint of the buildings.

2.4 The Case Study: EPFL campus

The main campus of the Ecole Polytechnique Fédérale de Lausanne (EPFL) is located near the Leman Lake and the city of Lausanne; it is one of the largest universities in Switzerland, and hosts around 15.000 people (including students and professional) each day. To illustrate the previously presented methodology, a selected area of the campus was defined (Figure 1): this area is located in the Northern part of the campus and composed of six interconnected buildings (BM, BP, CM, GC, GR and LE). It presents three different types of ground covering (grass, clay soil and asphalt) and three cherry trees in the “bocce court”. The Mean Radiant Temperature is punctually calculated on a grid of 10 meters, between 1.1 and 1.5 meters above the ground.

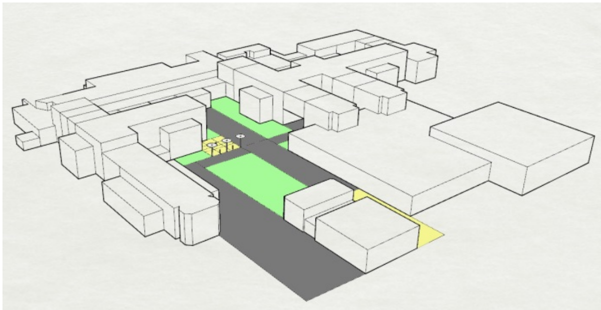

Fig. 1: Study area in the EPFL campus of Lausanne, located on the Northern part of the university. Each ground material is defined: grass (Green), asphalt (Grey) and clay soil (Yellow).

The MRT is quantified for a typical meteorological year (TMY), by the weather data provided by the software Meteonorm [13] for the meteorological weather station of Pully (VD).

3 RESULTS AND DISCUSSION

3.1 CityGML with Energy ADE data model

A focus on the actual Energy System Module is shown in Figure 2, the proposed methods will relate the *“ADEElement”_CityObject* with a new *“featureType”* called *OutdoorHumanComfort* (Figure 3). The new “*featureType”_OutdoorHumanComfort* contains:

- *type: ComfortType*
- *data: TimeSeries [0..1]*
- *metabolicActivity: Measure [0..1]*
- *clothingCoefficient: Measure [0..1]*

The “*enumeration” ComfortType* contains the following methodology to analyze the outdoor human comfort: Mean Radiant Temperature, COMFA model, Index of Thermal Stress (ITS),

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Physiological Equivalent Temperature (PET), Standard Effective Temperature (SET*), Universal Thermal Climate Index (UTCI), Discomfort Index (DI), Wet Bulb Globe Temperature Index (WBGT) and Thermal Sensation.

The group *metabolicActivity:Measure* includes the pedestrian metabolic activity, expressed in W/m^2; as an example 58 W/m^2 corresponds to seated, relaxed [14]. The group *clothingCoefficient*, expressed in clo, describes the clothing insulation of the studied pedestrian, as an example the clothing ensemble “Shirt, trousers, jacket, socks and shoes“ corresponds to 1 clo (or 0.155 m^2·K/W).

Figure 3 shows the proposed application Schema of the EnergyADE with the new *“featureType”_OutdoorHumanComfort:* the new feature type is directly related to the *“ADEElement”_CityObject*, and contains the *type:ComfortType* that is readable in the green box *“enumeration”ComfortType* where the Mean Radiant Temperature and the other selected outdoor standards are defined.

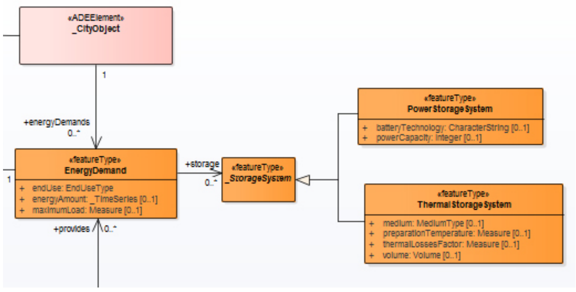

Fig. 2: Application Schema of the EnergyADE data model, detail on the Energy System. For the entire schema, please refer to wiki.energy.sig3d.org.

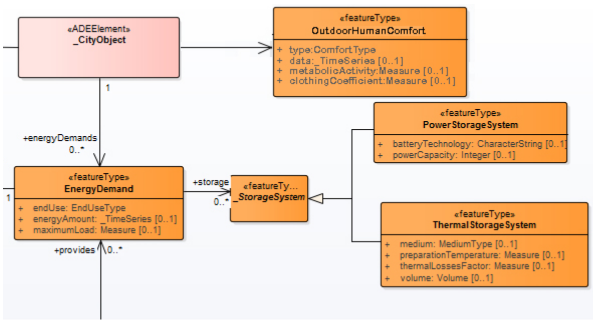

Fig. 3: Focus on the Application Schema of the EnergyADE data model, detail on the Energy System with the new feature Type Outdoor Human Comfort.

Based on the following methodology, in the CityGML data model the pedestrian is represented as a new object member called “Building” and its geometrical characteristics are described as following:

<cityObjectMember>
<bldg:Building>
<bldg:lod2Solid>
<gml:Solid>
<gml:exterior>
<gml:CompositeSurface>
<gml:surfaceMember>
<gml:Polygon gml:id=" b52_p_w_105">
<gml:exterior>
<gml:LinearRing>
<gml:posList>
0.11 0.00 1.10
0.17 0.00 1.10
0.17 0.00 1.50
0.11 0.00 1.50
0.11 0.00 1.10
</gml:posList>
</gml:LinearRing>
</gml:exterior>
</gml:Polygon gml:id="b52_p_w_105">
</gml:surfaceMember>
</gml:CompositeSurface>
</gml:exterior>
</gml:Solid>
</bldg:lod2Solid>
</bldg:Building>
</cityObjectMember>

3.2 Mean Radiant Temperature

The Mean Radiant Temperature calculated by CitySim will be defined as follows in the CityGML data model:

<energy:OutdoorHumanComfort>
<energy:ComfortType>MeanRadiantTemperature </energy:ComfortType>
<energy:Data>
<energy:RegularTimeSeries>
<energy:id>1</energy:id>
<energy:temporalExtent>TMY</energy:temporal Extent>
<energy:timeIntervalunit="hour">1</energy:timeI nterval>
<energy:values uom="°C">10 10 11 15 15 16 18 20 22 22…>
</energy:values>
</energy:RegularTimeSeries>
</energy:Data >
</energy:OutdoorHumanComfort>

In the previous method, the MRT values are calculated for each hour of a Typical Meteorological Year (TMY).

3.3 PostgreSQL Database

Finally, once all the information is calculated, the data can be used to populate the corresponding table in the database. An additional table relating to the MRT was added (Figure 4).

Since the pedestrian is described as a building (Sect. 3.1), the mean radiant temperature calculated for this individual corresponds to the same “object” identified with building_id and hence also relates to the building table.

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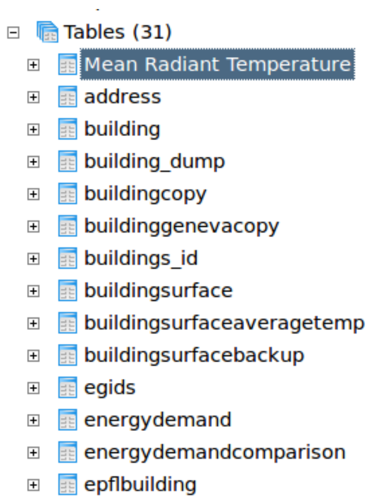

Fig. 4: Structure of the database with Mean Radiant Temperature.

3.4 The Case Study: EPFL campus

The Mean Radiant Temperature in a selected area of the EPFL campus in Lausanne was defined, showing its variation by the urban environment during the different periods of the year. The Mean Radiant Temperature is influenced by the built environment (shadowing provided by the neighbouring buildings, according to their orientation), by the soil covering (clay soil, grass and asphalt) and by trees. Figure 5 shows the Mean Radiant Temperature in three different locations of the site:

- A, Clay soil, with SVF=0.66.
- B, Soil covered by asphalt, under the Cherry Tree, with SVF=0.85.
- C, Soil covered by asphalt, with SVF=0.94.

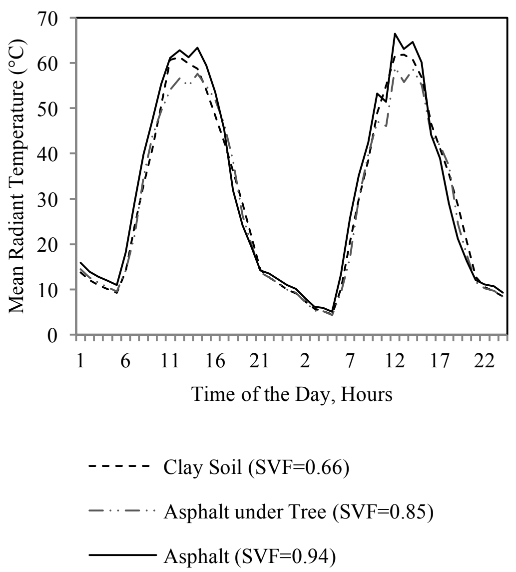

Fig. 5: Mean Radiant Temperature for two summer days, 21st and 22nd June, defined in three different positions of the site.

The highest MRT is for a pedestrian located on the asphalt, and with low shadowing protections; on the contrary the lowest MRT is defined for a pedestrian located under the cherry tree: this is related to the vegetation, which by the evapotranspiration maintains a lower temperature compared to artificial surfaces, and it reduces the short and long wave radiation received by the pedestrian. During the night time, the MRT is similar in all locations (and slightly lower than the air temperature) showing the high impact of the solar irradiation on the calculation of the MRT.

4 CONCLUSIONS

The presented methodology makes use of the CityGML data model to store and share simulations results concerning the outdoor human comfort; in this paper a methodology to include the Mean Radiant Temperature in the CityGML data model was defined. The Mean Radiant Temperature in a selected area of the EPFL campus was calculated, showing the impact of the built environment and the ground covering in the MRT variation during the year. Information on the case study (the EPFL campus in Lausanne) was added to a PostgreSQL database installed on a server at EPFL. A Java program was then used to extract information from this database to build a model of the campus containing the required information to perform a simulation with CitySim.

This paper presented the first steps to include the outdoor human comfort in the CityGML data model, the next steps of the project will include:

- The ability to store and share the output data provided by the following standards: COMFA model, Index of Thermal Stress (ITS), Physiological Equivalent Temperature (PET), Standard Effective Temperature (SET*), Universal Thermal Climate Index (UTCI), Discomfort Index (DI), Wet Bulb Globe Temperature Index (WBGT) and Thermal Sensation.
- The capacity to store the output data provided by the following software: ENVI-met, RayMan and SOLWEIG.

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