CityBEM: Monthly Heating and Cooling Energy Needs for 3D Buildings in Cities

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Syed Monjur Murshed
European Institute for Energy Research, Germany
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Background

- In the context of **smart and low carbon cities**, increasing energy efficiency, reducing GHG emission, etc. play an important role.

- **Buildings** are responsible for 40% of energy consumption and 36% of CO$_2$ emissions in the EU (EU 2011).

- **Building Energy Models** (BEM) can help to investigate detailed measures e.g., refurbishment plans, etc.
  > several such **models** (statistical vs. engineering), **standards**, **tools/software** exist to calculate energy (heating and cooling) needs
  > models are prepared and applied at different **spatial** and **temporal** extents and/or scales
  > one of the widely used standard is **ISO 13790:2008** (ISO 2008)
Background

ISO 13790:2008 using non-GIS data

+ Widely used standard, applied in different countries (Vollaro et al. 2014, Vatieres et al. 2013, Kim et al. 2013, etc.)
+ Internal validation of model

- Considers single building
- Cannot perform citywide calculation

ISO 13790:2008 using 3D city models

+ With the availability of 3D city models and different LODs, ISO standard is applied (Eicker et al. 2012, Nouvel et al. 2015, Agugiaro 2016) in many cities

- Only heating energy demand is calculated
- Mostly on residential districts
- Robust validation is missing
Objectives

- Implement the **ISO 13790:2008 standard** using the 3D city models to calculate the monthly building **heating and cooling energy needs in cities** => CityBEM

- Use open source and mostly publicly available datasets, tools and software to develop the CityBEM

- Perform a **quick and robust calculation** at a city scale

- Perform a 3-step **validation** of the CityBEM model
CITYBEM: AN OPEN SOURCE IMPLEMENTATION AND VALIDATION OF MONTHLY HEATING AND COOLING ENERGY NEEDS FOR 3D BUILDINGS IN CITIES


Resource Urbanisms
Asia's divergent city models of Kuwait, Abu Dhabi, Singapore and Hong Kong


https://lsecities.net(objects/research-projects/resource-urbanisms)
ISO standard is structured into 4 main blocks:

1. definition of **building boundaries** for conditioned and unconditioned spaces

2. identification of the **zones** (single vs. multi zones)

3. definition of the **internal conditions** for calculation of external climate, and other environmental data inputs (heat transfer losses, heat gain, etc.)

4. calculation of energy needs for heating and cooling, for each time step and building
4. calculation of energy needs for heating and cooling, for each time step and building

7 main calculation steps:

\[ Q_{ht} = Q_{tr} + Q_{ve} = (H_{tr} + H_{ve}) \cdot (\theta_{int, set} - \theta_e) \cdot t \]

\[ Q_{gn} = Q_{int} + Q_{sol} = (\Phi_{int} + \Phi_{sol}) \cdot t \]

\[ Q_{C, nd} = Q_{ gn} - \eta_{ls} \cdot Q_{ht} \]

\[ Q_{C, nd, interm} = a_{C, red} \cdot Q_{C, nd} \]

\[ Q_{H, nd} = Q_{ht} - \eta_{gn} \cdot Q_{gn} \]

\[ Q_{H, nd, interm} = a_{H, red} \cdot Q_{H, nd} \]
Methodology: input data

Building geometry
- Wall area N, S, E, W
- Volume
- Floor area

Building typology
- Window area N, S, E, W
- U values wall, roof, window, ground
- G values window
- Thermal bridges
- Infiltration
- Ventilation
- Internal gain

Weather conditions
- Monthly temperature
- Monthly wind speed
- Monthly solar irradiance
Methodology: software architecture

ESRI Shapefile

FME

CityGML

PostgreSQL

PostGIS

3DCityDB

Meteonorm

Weather data

.csv file

read

Python script

read/write

+ SQL queries

Shapefile

.FME

conversion

.CityGML

.import/export

PostgreSQL database

+ PostGIS extension

FZK Viewer

pgAdmin

PostgreSQL Tools

eclipse

QGIS

Trademark

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Results

Heating energy need in 4300 buildings in Karlsruhe Oststadt

Heating energy need (kWh/m²/year)

- 15 - 50
- 51 - 100
- 101 - 125
- 126 - 150
- 151 - 200
- 201 - 300
- 301 - 510

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Results

Annual cooling energy needs in the buildings in 5 building typologies in Kuwait

AbdullahAlSalem  Jleeb  Sharq
NWSulaibikhat  Qortuba

Annual cooling energy needs

- < 180 kWh/m²
- 180 - 205 kWh/m²
- 205 - 230 kWh/m²
- 230 - 255 kWh/m²
- 255 - 280 kWh/m²
- > 280 kWh/m²
Results

Annual cooling energy demand in the 20 typologies
Validation

A 3 steps validation was performed

> Compare results with that in literature
> Compare with ISO 13790:2008 appendix values
> Compare with a simulation software

TRNSYS: TRaNsient SYstems Simulation
Performance/test

- The CityBEM monthly model is tested in several European and Asian urban cities, with varying number of buildings in both LOD1 and LOD2 data.
- The model proves very efficient and quick in displaying results in the virtual machine.
  > around 3 minutes to run on about 4300 LOD2 buildings, 8 minutes on 12000 LOD2 buildings, 28 seconds on 600 LOD1 buildings, etc.

Limitation

- CityBEM requires a geometrically and topologically correct CityGML dataset.
- User and their behavior are assumed constant in all buildings.
Ongoing research

- Calculation of energy use, considering the heating, cooling and ventilation system (HVAC)
- Hourly or seasonal energy need /use
- Sensitivity of the critical model input parameters
- Simulation of energy saving potential or building refurbishment plans, through a Graphic User Interface (GUI)
- More realistic representation of building using LOD3 or LOD4 models (multi-zone building)
- Integration/Testing of CityBEM with EnergyADE 0.8 DB schema (next presentation!)
References

- Zangheri, P., R. Armani, M. Pietrobon, L. Pagliano, M. F. Boneta & A. Müller. 2014. Heating and cooling energy demand and loads for building types in different countries of the EU. Report in the frame of the EU project ENTRANZE
Thank you!

Contact: murshed@eifer.org
European Institute for Energy Research