

## **Urban Energy Information Modelling: An interactive platform to communicate simulation-based high fidelity building energy analysis using Geographical Information Systems (GIS)**

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### ABSTRACT

This paper presents a novel approach to urban scale energy information modeling that integrates 24x7 high fidelity energy demand data from every building on a 28-acre urban neighborhood located in Pittsburgh, Pennsylvania, USA. The simulation input parameters are in accordance with ASHRAE 90.1-2010 and DOE reference buildings 2004. The 28-acre site is zoned for mixed use development comprising residential, commercial and retail land use types. The simulated data is represented on an interactive platform using Geographical Information systems (GIS) to provide multi-dimensional visualization of the complex relational data.

### INTRODUCTION

Whole Building energy simulation during the design stage nowadays is becoming a common trend among building designers who are concerned about energy conservation. This task applies to new construction as well as retrofit projects to address sustainability issues with regard to reducing carbon footprint while maintaining healthy and productive environments.

A bigger challenge is emerging in practice to address the total energy consumption profile on a neighborhood or city level rather than just at the building level. For cities with a dense urban environment, the energy consumption by the building sector is more than two-thirds of the total energy consumption of the city (NewYork, 2010). This is the case with almost every city not only in the United States but almost all the cities in developing and third world countries.

A building-by-building energy consumption model would be a starting point for analysis by urban design planners (Howard B. et al., 2012). This building-by-building energy consumption can be an important data source by the utility companies to optimize energy supply and mechanical engineers to design efficient systems. The first part of the research involves urban energy modeling of a 28-acre mixed-use redevelopment. The second part is to convey this to the clients, the design team and related parties for decision making using Geographical Information Systems (GIS).

The concept of adopting GIS to present building simulation results is fairly new in the building

simulation industry. This research not only focuses on data representation, but also serves as a decision making support tool. The GIS map provides information on the macro to micro level building energy consumption (energy consumption across the site to individual building energy consumption), the energy use intensity (EUI) of each building as well the EUI and the peak heating and cooling loads for the entire site as well as each individual building. The energy simulation also provides the hourly energy consumption to study the actual peaks which occur during a 24-hour period. This information is extremely important to mechanical engineers for HVAC plant sizing, devise options for thermal and district tri-generation systems compared to stand alone systems. For the design team, the mapping information is particularly important in terms of design improvisation and optimization of energy consumption by using sustainable design strategies. According to (Howard B. et al., 2012), combined heat and power systems (CHP) can function effectively by re-using the waste heat from the site. This is possible due to the close spatial proximity of the site to the CHP systems. Spatially distributed energy use information can help the design team identify cost-effective engineering opportunities. Therefore, information on site heating and cooling loads can help identify cost effective energy supply systems on an urban scale.

The GIS mapping is intended to be a powerful tool for the stakeholders that will help them with the decision for energy plant sizing, energy use, return on investment and comparative estimates of MTCO<sub>2</sub> associated with district thermal and district tri-generation (heat, cool and electric power) versus stand-alone systems.

### OBJECTIVES

This paper presents a detailed analysis of baseline energy simulation of the 28-acre urban mixed-use redevelopment of the Lower Hill District in Pittsburgh, Pennsylvania, USA. Comparative analysis are performed to study the simulation model input parameters using DesignBuilder default assumptions and the Department of Energy (DOE) reference model input parameters. The output of the baseline energy simulation analysis, which are modelled based on DOE reference building, is

mapped using GIS, which serves as a tool for data representation and communication from a macro level to micro level of individual buildings. At the macro level, the map provides information on the entire site energy consumption, energy use intensity (EUI) which is broken down to block level information for different building types, which is further broken down to the micro building level information which in addition to the total energy consumption and the EUI, provides energy end-use details and hourly energy consumption.

### BUILDING ENERGY SIMULATION AND GIS MAPPING PROCESS

A Baseline energy simulation is conducted for the mixed-use redevelopment that comprises 35

buildings of land use types namely: multi-family units, townhouses, offices, retail spaces, community centre and a hotel using EnergyPlus simulation engine with DesignBuilder as the interface. The data from the simulation is processed for analysis using Microsoft excel. The processed data are mapped on Arc Map for every building as building attributes. These building attributes can be viewed as a HTML pop-up window in Arc Scene as shown in Figure 2. Figure 1 shows the site plan of the Lower Hill District indicating the different land uses along with the surroundings in context.



Figure 1 Site map of the Lower Hill District, Pittsburgh, Pennsylvania

### **GIS representation as a Decision Support Tool**

The platform used for effectively conveying the simulated data is Arc Map and Arc Scene version 10.0. The simulated data for each building is mapped in Arc Scene that enables 3D building visualization as well as graphical data representation.

Firstly, the GIS map is created using the 2D layers of the land parcels, roads, topography, building blocks, and hydrology for the city of Pittsburgh. These layers are downloaded from the Allegheny County, Pennsylvania GIS website. The layers are then imported into Arc Map to create a 2D base for the building blocks. In order to model a realistic topography for the base, a triangulated data structure

(TIN) layer is created using the 2D contours and the extrusion function in Arc Map.

The 3D models of the buildings on the Lower Hill district site are imported from the Sketchup file provided by the urban planning firm Urban Design Associates (UDA). The 3D models of each building is exported as a collada file from Google sketch up. The collada file is imported into Arc Scene as a geodatabase which is created for every building.

Once the 3D map is created in Arc Scene, the data from the energy simulation is imported as building attributes into Arc Map as well as Arc Scene to be able to switch from 2D and 3D. Each building contains the attributes: building name, total

conditioned area, annual energy consumption, energy use intensity, annual and monthly peak demand. The simulated data are processed using Microsoft Excel. Arc GIS provides a feature to directly import this Excel format data into the 3D map as building attributes. The building attributes are designed to be viewed as a HTML pop up window in Arc Scene for every building as shown in Figure 2.

This visualization aid is available to all project decision makers for easy and clear access to all the simulated data. Currently, this data is available on Arc Scene, which is a stand-alone software. As a continuation to the process of making simulated data easily accessible to project partners, the next step involves making the data available online.

### Further development using GIS CLOUD

Making the map available online can be achieved using GIS cloud. According to the developers of GIS cloud computing, "GIS is a technological field that incorporates geographical features with tabular data in order to map, analyze and assess real world problems" (giscloud.com, 2012). GIS helps in merging large amounts of data and cartography into a single map which serves as a decision tool. Although GIS software was completely stand-alone previously, the recent introduction of GIS online and GIS cloud technologies has enabled sharing the data analysis and mapping the data.

GIS cloud is the first web based GIS powered by cloud computing (giscloud.com, 2012). Since this is an integrated feature with ARC GIS, it is cost efficient, easy web publishing, improved collaboration and also provides cloud security.

Currently all mapping on GIS cloud is in 2D format. The maps are directly imported from Arc Map with the individual layers as cloud data. The 3D components such as buildings and other land features can be coded into the GIS cloud website using JavaScript API. The use of JavaScript API for the development of GIS cloud is detailed completely in the GIS cloud developers manual. Figure 3 indicates a mock up of the GIS cloud website with the 35 buildings of the Lower Hill District Redevelopment site along with its surroundings building. The format and layout of the website is in accordance with the current version of GIS cloud website which is used for 2D mapping and data representation. The 3D features are intended to be incorporated into the same website.

Figure 3 illustrates the simulated data information that can be visualized on the GIS cloud map online. The building data (e.g. building type, building area, number of residential units) and simulated data (e.g. annual end use energy consumption, peak design loads, energy use intensity) associated with each building can be selectively displayed. The GIS cloud maps can be viewed by anyone who has been provided with a link to the map and can be controlled for private and public use.

The simulation results can be viewed as time based, building type based and scale based data. The time based output provides monthly, daily and hourly natural gas and electricity consumption for every building on the site. The scale based output provides data from a macro level (site scale) to a micro level (building scale). The building type output provides details on the energy consumption, and peak loads by the various building types.

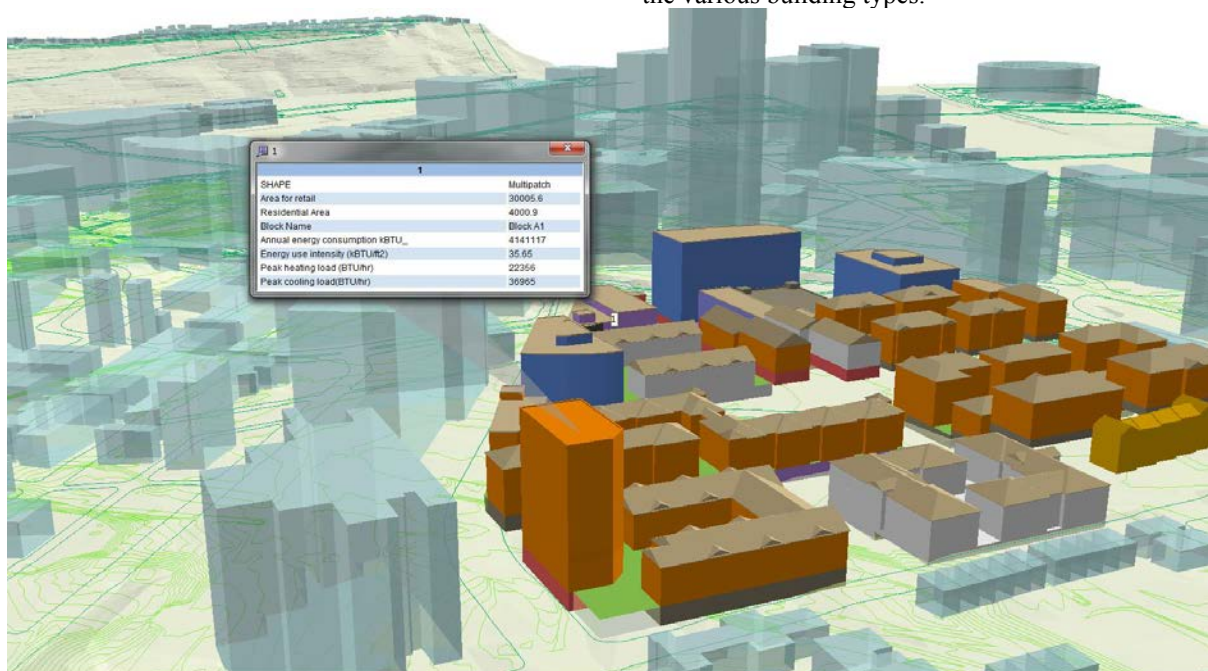


Figure 2 3D view of the Lower Hill District with building attributes displayed as a HTML pop up window in Arc Scene

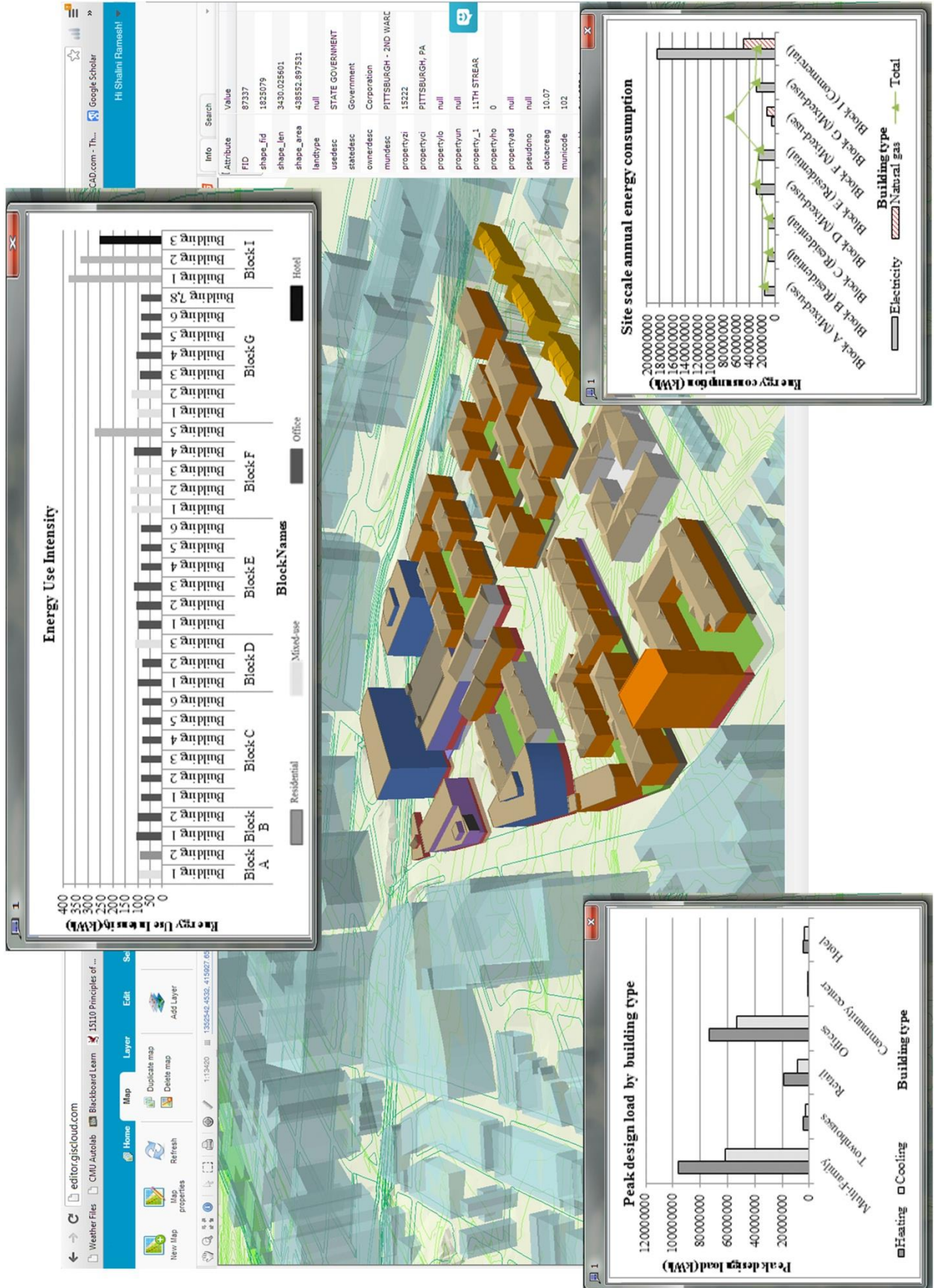


Figure 3 Mock-up of the GIS cloud website for displaying simulated data on a macro and micro level

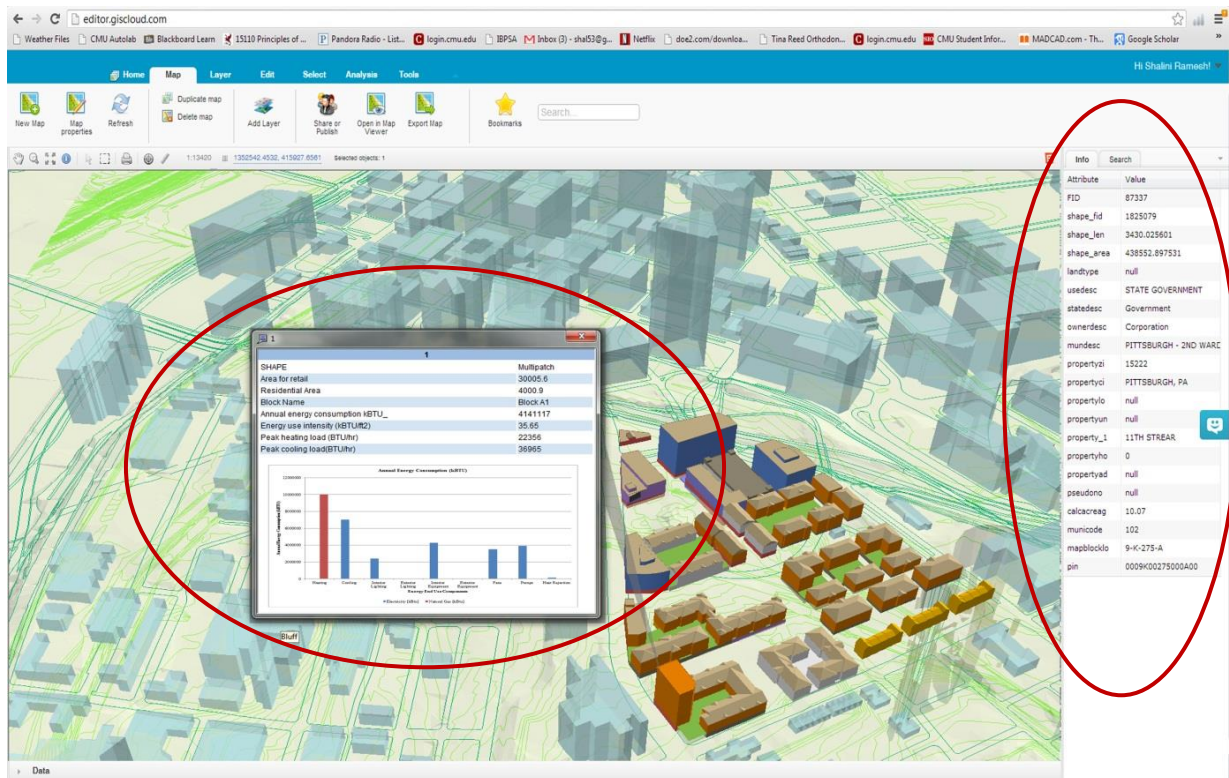


Figure 4 Mock-up of GIS cloud website indicating the two information display windows (HTML pop up and side bar)

Figure 4 illustrates the two windows that can be used to display simulated data information. The HTML pop up window can be used to display graphical information such as visualizing peak loads, and energy use intensities, across the entire site. The site bar is used to display individual building information. Therefore, the data display can be

organized concurrently as macro level display data as well as building level display.

Figure 5 represents the Google Earth image of the Lower Hill District. Urban planners and designers use this as a visualization tool for the design development and design decision making with the surrounding context in view.

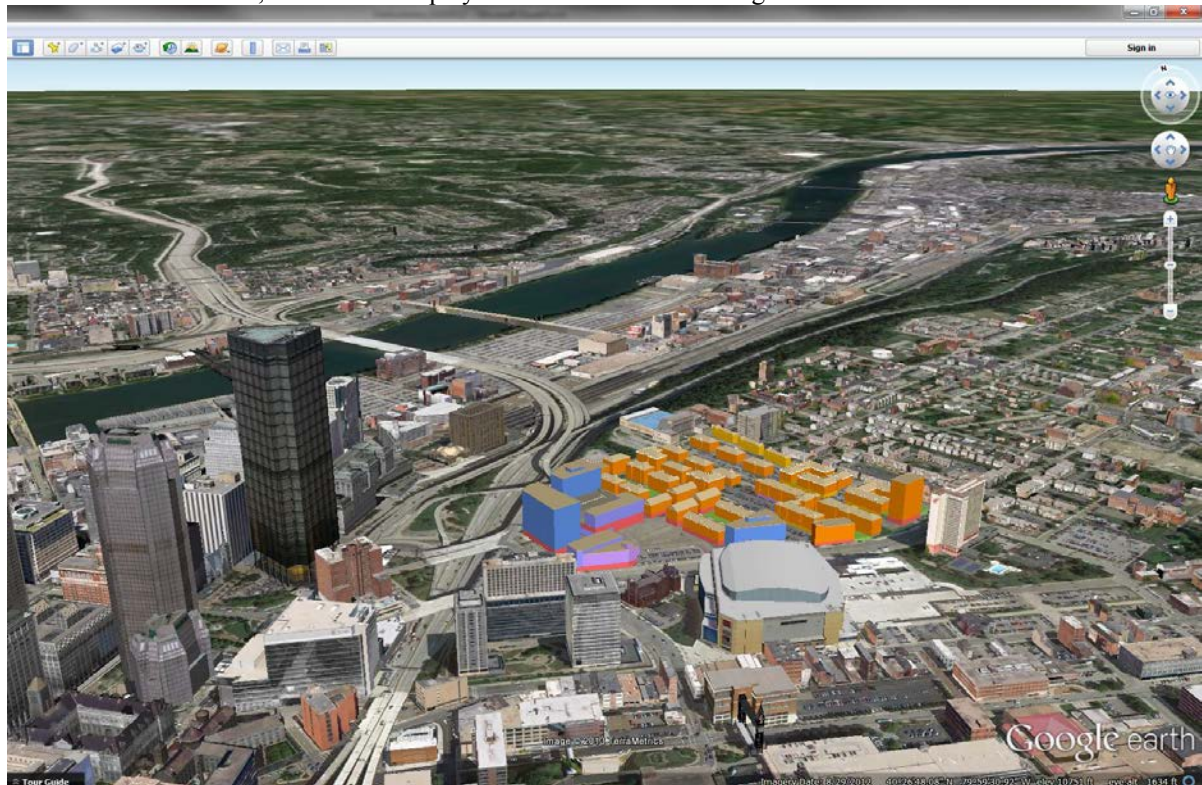


Figure 5 Google Earth representation of the Lower Hill District

### SIMULATION INPUT PARAMETERS

Figure 6 provides detailed information on the various sources that is used to populate the model input parameters. The sources used for the baseline model simulation are ASHRAE 90.1.2010, DOE reference buildings for mid-rise residential, high-rise

commercial, stand-alone retail and small hotel, EnergyPlus TMY3 weather file for Pittsburgh and specifications from UDA such as site zoning, building geometries, building areas for each residential unit, offices and retail spaces, number of residential units and building heights.

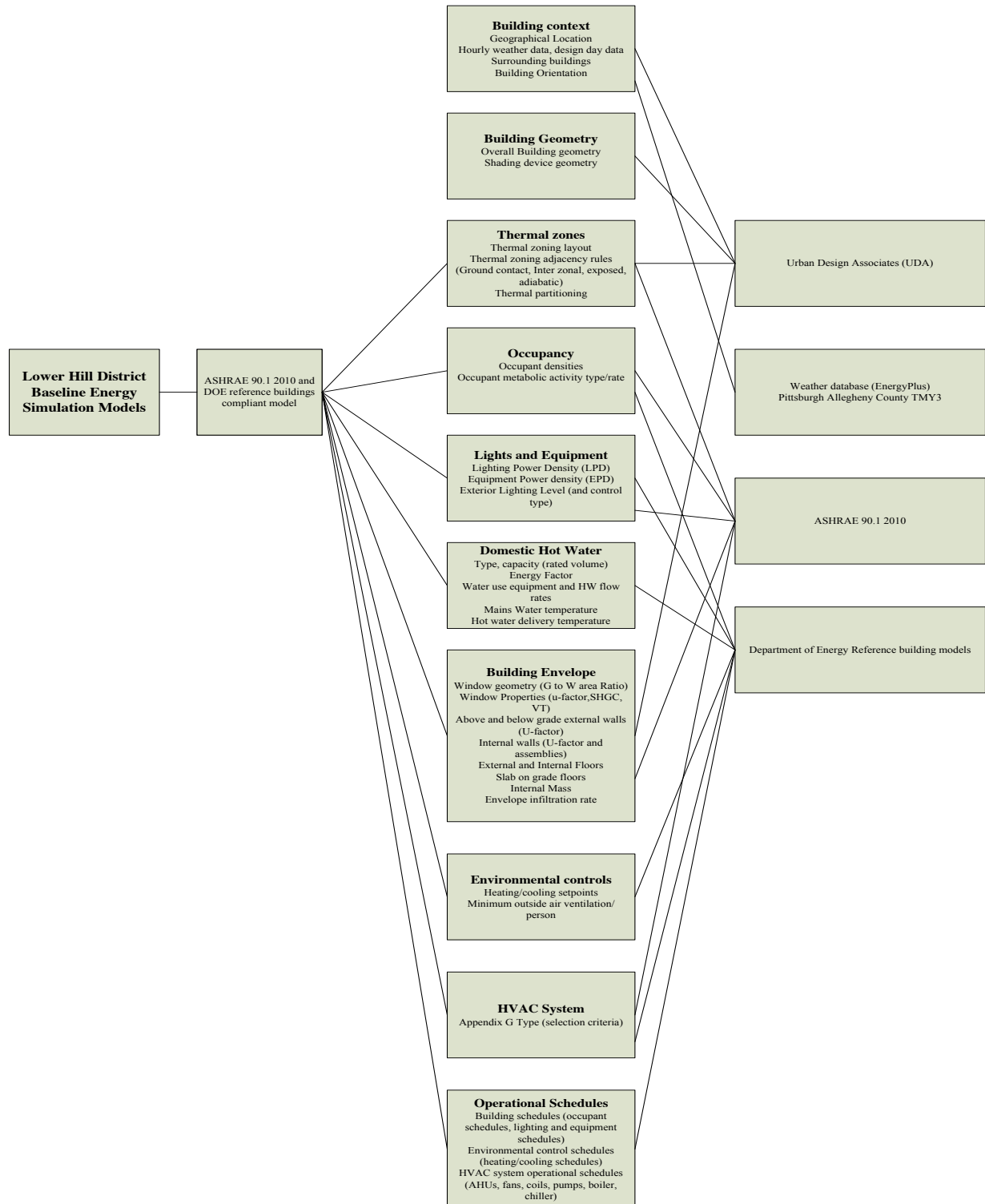


Figure 6 Chart indicating various modelling input parameters and the sources for the input parameters; adapted from (Karaguzel & Lam, January 2012)

## SIMULATION RESULTS

On a macro level, results of the energy simulation of the 35 buildings provide an overview of the energy consumption, peak energy demand loads and the energy use intensities for the whole site. The estimated Annual Energy Consumption using DOE reference input parameters is 39,992,955 kWh. The Net Conditioned area is 195,084m<sup>2</sup> out of the gross floor area of the buildings which is 259,870m<sup>2</sup>. The Energy Use Intensity (EUI) for the overall site is 214.6 kWh/m<sup>2</sup> based on the net conditioned floor

area. On a micro level, detailed simulation results and analyses are available for every building type (residential, commercial, retail), scaled down to individual block/building scale.

Figure 7 illustrates how the site scale data is organized from a block level zooming down to building level. The chart indicates the peak heating and cooling loads profile across every block and the block/building which have the highest peaks.

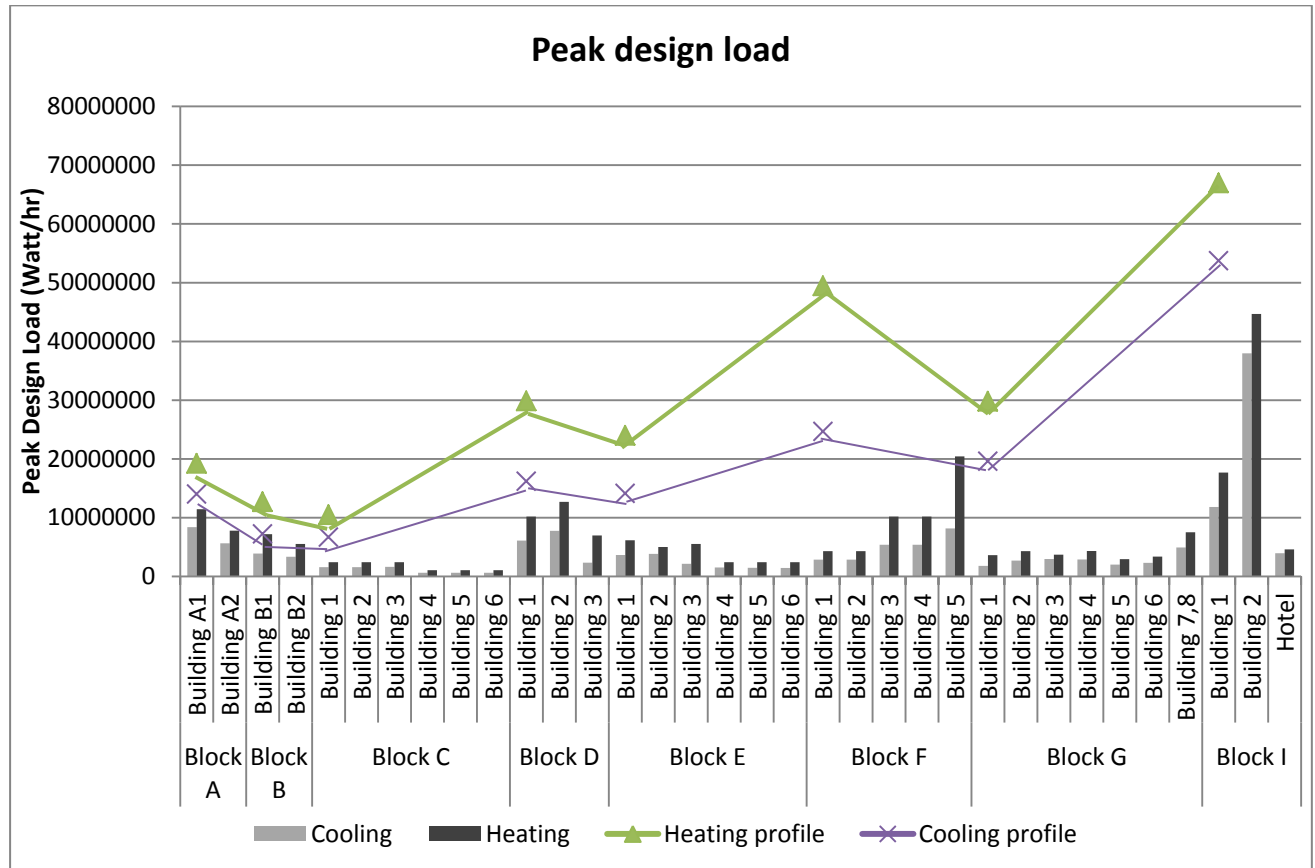


Figure 7 Peak design loads for heating and cooling on a block and building level

## IMPORTANCE OF THE DECISION SUPPORT TOOL

As discussed in the earlier sections, the GIS cloud platform helps to effectively communicate all the urban level simulated data systematically. The GIS cloud platform serves as an effective decision support tool for assessing potential project impacts in terms of energy consumption and carbon emissions. From previous research, it is known that district systems can be designed to function effectively when the loads can be accurately aggregated from all buildings on an urban scale, with time-based high fidelity data. The GIS tool helps in analysing the peak loads for heating and cooling on an urban scale and accessing the feasibility of district systems with respect to sizing and installation of CHP systems. . The tool

also helps in analysing potential neighbourhood parties that may be interested in investing in the district systems to get an optimal load for the maximum benefits from the district system. It also helps in accessing the complexity, economic opportunities, risk and feasibility of inter-related energy plant parameters to the project stakeholders, i.e., investors and developers as well as the design team.

When dealing with urban scale projects, communicating numeric data can be a cumbersome process and has a high probability of errors. Putting together all the simulated data in a structured database with graphical representation serves as the most effective method of communication. This visual method of representing simulated data will enhance

the decision making process at the micro and macro design levels.

## CONCLUSION

This paper presents an urban scale whole building energy simulation and high fidelity data representation of the annual energy consumption, energy use intensities, and peak heating and cooling loads from a macro to micro level. From the process of building simulation to data visualization the following conclusions are drawn:

- For simulation input parameters, managing the sources of input parameters consistently is extremely important to achieve simulated data that closely replicates reality. The inputs are recommended to be drawn from sources such as building codes and standards or well established research data. It is important not to assume that defaulted parameters in given software are recommended parameters, but need to be checked against relevant standards and references before performing any simulation.
- Daily, weekly, monthly, seasonal and annual load characteristics have a significant impact on the mechanical equipment performance, which affects economics and equipment configurations. Providing the high fidelity simulated data from a macro to a micro level helps in first order feasibility assessment of energy production, distribution and storage alternatives as well as performing comparative economic cost-benefit calculations.
- Communication of urban scale simulated data can be a very cumbersome and error prone process. By using, the structured database in GIS coupled with cloud based web communication features to enhance accessibility will reduce data management errors and serve as a powerful decision support tool for city planners, mechanical system designers and other project partners.

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