Dynamic Energy Mapping Project Outline

July 28, 2015

Contents

Abstract

This document provides an approach of adding the "time" dimension to an Energy Map. The approach is demonstrated with a model of a conceptual urban setting created in CityEngine based on the extracted topological and density pattern from an existing urban design project. The buildings in the conceptual model is then assigned an energy profile of certain DOE Commercial Benchmark Building Reference model based on its building type. Hourly energy demand profile of heating and cooling end use is then obtained from the EnergyPlus Reference models. The energy consumption data is classified into groups with consideration of building energy design context and the data distribution properties. A corresponding color coded energy profile is then generated and imported to CityEngine. 8760 color coded 3D map images was then extracted from CityEngine with Python script. A data reading, ploting, color-coding calculation and a user interface for visualizing the images and dynamic data plot with sliders is implemented using Python and related packages. The tool is anticipated to provide decision support for community energy management and planning, demand-side strategy design and district system sizing.

The document will also briefly discuss one of the testbed for data classification and visualization.

1 General Introduction

1.1 Project Overview

(include some specific information of the project, more like the type of description in the abstract.)

1.2 Definition of Energy Map

1.2.1 Energy Thematic Map

In a restricted sense, Energy Map is an instance of a thematic map that depicts energy information. It is an abstract representation of some energy feature in an urban environment. It is useful in providing energy related qualitative or quantitative insight.

The energy topics depicted in an Energy Map can be classified into four major categories: energy supply, energy demand, energy related building design / urban planning, and energy related environmental impact. One common sub-category of the supply side topics concerns the locations and evolving process of energy infrastructures such as power plants, energy transmission pipelines, energy refining facilities and market hubs. EIA state energy profile map [13], U.S. natural gas pipeline map [10] are under this sub-category. Other supply side topics include total energy production [7]; total energy source production like global coal production map [11]; sustainable energy potential map of wind, solar, biomass, geothermal energy potential [22] and hidropower potential [8]. Common demand side topics include: energy demand for one or more enduses [23], energy source demand like coal demand [12] and energy cost [3]. The design side topics concerns building physical conditions like Calgory Heat Map [18], design policy information like climate zone map [5] and energy code adoption map [6]. The energy behavior environmental impact map include both the impact of building or energy infrastructure to environment and the environment change to buildings or infrastructures. The carbon emission map as [1] is an instance of the former and the "Energy Sector's Vulnerabilities to Climatic Conditions" Map is an example of the latter [4].

It is necessary to mention some unfortunate terminology overloading involved in the topic of Energy Map. The term "Heat Map" used in this discussion refers to the Energy Map with building heating energy as its theme, not to be mis-interpreted as the color-coded representation of matrix values as in this definition [25].

The history of thematic map dates back to early 17th century, and from then on maps can present spatial patterns of some feature in addition to merely recording locations of geographic features [27]. Over a century later, spatial analysis emerges and map starts to assisting geo-data analysis. Finally after the born of modern computer and the development of database, map becomes a more powerful information system that undertakes more complecated tasks including data aggregation, managing, query and presentation. This gives Energy Map a much broader meaning.

1.2.2 Geo-database of Building Energy

In a broader sense, Energy Map is a hibernation of two types of databases: building energy database, a subset of the BIM (Building Information Model), and Geographical Information System (GIS). The basic functions of an Energy Map includes 1) storing energy data in

an organized fashion, that facilitate easy analysis and query of energy data and 2) provide reports in the form of graphs, tables, animations etc that conveys numerical information in a way that best support pattern recognition and decision making.

This definition can be considered as a superset of the thematic map definition, so the energy topics inherits those representable in the thematic energy map. Some examples of the Energy Maps under this "database" definition include: National Heat Map that records and presents heat demand density of buildings and building sectors, Renewable Energy Potential Map that uses GIS tool in renewable and residual energy potential assessment [24], a site selection model that evaluates different choices of power plant location [28], and "Heat maps" with information of heat sources and sinks that supports district system expanssion design [14].

1.2.3   Coupled Geo-database and Energy Simulation Platform

"Geodesign is a design and planning method which tightly couples the creation of design proposals with impact simulations informed by geographic contexts" [15]. It is a performance based approach in urban and environmental planning. Traditionally, each performance metric is represented with a choropleth map layer. By stacking different layers together, the performance metrics are aggregated for each location on the map and a judgement of design alternatives are formed based on the aggregated performance metrics [17]. However, some of the performance metrics are requires complicated calculation or simulation to retrieve. Hence the new development of Dynamic Energy Map would not only records temporal and spatial information but also provide stooth connections to urban level energy simulation tools that calculates energy performance metrics of different design alternatives on the fly which effectively automates the geo-design work flow.

1.3   Why "time" dimension is important for an Energy Map

1.3.1   Strong Temporal Variation of Energy Demand

Building energy demand is strongly dependent on weather condition, building type, size, building physical design, building mechanical system and appliance quality and building operation schedules. The aggregation of all parameters results in a great variance in the range and extreme value of energy consumption. Weather condition have strong seasonal pattern and day-night pattern. This type of variation takes the form of a global influence on building heating or cooling load. Building operation schedules vary greatly from building to building as a result of difference in building type and occupant behavior. Different operation scheduces indicates the arrival of peak demand within a mixed-use urban environment are not simultaneous. Difference in building type also suggest difference in indoor environment requirement such as ventilation rate, lighting intencity etc., indicating a dramatic variation in energy consumption data distribution among buildings in the community. Upon these considerations, a simple annual or monthly average cannot effectly represent the real energy consumption behavior of an individual building and the whole urban environment. In order to present this complecated behavior of time-depandent energy demand, the time dimension is necessary.

1.3.2 Close Match of Supply Side to Demand Side Improves Community Scale Energy Performance

As a result of the finiteness of fossil fuels, the using of renewable energy begins to come into play. In 2013, renewable energy account for 9% of the primary energy source of residential and commercial buildings [9]. Electricity generated from sustainable sources normally do not have much storage capacity, hence in order to meet the energy demand with renewable electricity, a better understanding of the spatial-temporal pattern of energy demand is important [21].

Demand-driven energy supply is necessary to reduce energy waste and achieve better total community energy performance, and in order to match the supply side to the complicated behavior of the demand side, understanding the spatial-temporal pattern of the energy demand in the early design and planning stage is important.

1.3.2.1 District Energy System Sizing

A district energy system consists of a power plant, a series of buildings as terminal energy users and a network of pipelines that transmit energy from the power plant to end-users. Commonly used media for energy transmission include steam, hot water or chilled water [2]. A district energy system helps reducing negative environmental impact by harvesting residual energy in the form of rejected heat or coolth in the process of electricity generation or other industrial processes. It can adapt to a broader range of fuel choices including natural gas, oil, coal, biomass and garbage. This makes it more flexible and more competitive in the market [19]. Other non-environmental benifits include reducing the space dedicated to mechanical system and improve design flexibility in buildings, reducing harmful gas production from stand-alone boiler conbustion.

Dynamic Energy Map supports district energy system design by 1) revealing the non-coincident peak demand of heat or coolth 2) providing the aggregated demand for better decision making.

Obvious mathematical concepts become more obscure when it comes to real life problems. It is well understood that linearity holds for expectation not max, i.e. the sum of max values of each distribution does not equal to the maximum of the sum of each distribution. However this mistake is not rare in the sizing of a district system. One common approach of sizing a district system is to add up the capacities of each terminal devices. However, the size of each individual device is the peak demand of that building with some amount of extra capacity accounting for unexpected situations. Since the peak demand of individual buildings do not occur at the same time, the end result of summing up the max demand at each end point exceeds the actual total demand peak of the community, hence with this approach, the whole district system becomes too oversized, which make the whole system less efficient. Dynamic Energy Map can reveal the problem of such approaches. Further, it can provide the correct pattern of the aggregated demand for system sizing.

1.3.2.2 Community Energy Planing

Community Energy Planing / Management is a combination of community level design and energy management strategies aiming at providing quality of life in an urban environment with minimized energy consumption and environmental impact [20]. The awareness of the importance of the environmental design on energy performance and quality of life is reflected

in design concepts such as New Urbanism, smart growth and transit-oriented growth. These concepts advocates a compact urban growth that minimizes car usage by creating mixed-used communities, well-functioned road, complete public transportation system and diverse housing choices [26]. Dynamic Energy Map will make these effort visible.

The

Dynamic Energy Map can be used in comparing the energy impact of mixed-used community versus unitary-used community.

1.4 General Description of Dynamic Energy Map

Within the current context, "dynamic" refers to changing over time, hence Dynamic Energy Map is an Energy Map equipped with temporal information. As a result of the "dynamic" property, one assumption about Dynamic Energy Map is that at least one of the energy related variables depicted in the map should change over time. Due to the fact that there are two versions of definitions for Energy Map, there are also two versions of corresponding Dynamic Energy Map.

1.4.1 Thematic Map Time Series

In a restricted sense, where an Energy Map is defined as a thematic map focusing on energy topics, Dynamic Energy Map is just a series of maps, each of which is a thematic Energy Map representing the status of energy information happened at a certain time spot. Also with the convention that thematic maps are ordered in increasing time order. The purpose of such a Dynamic Energy Map is to facilitate the comparison of thematic maps at different time steps. Baring this in mind, it makes more sence to apply a universal map symbol and breakpoints to the sequence of thematic maps in this version of Dynamic Energy Map.

1.4.2 Spatial-Temporal Energy-geo-database

In a broader sence, where Energy Map is defined as energy-geo-database, Dynamic Energy Map is an energy-geo-database with "time" being one of its data entries. One major purpose of Dynamic Energy Map under this definition is to enable search, filter and query of the energy data by "time" field, thus presumably, time should act as one of the indexes in the database that facilitates faster search and query of the time data. The second task of Dynamic Energy Map is to provide more powerful reporting tools than normal Energy Maps that accounts for the difficulty and complexity of spatial-temporal data visualization aiming at better conveying the dynamic spatial pattern.

1.4.3 Performance Based Geo-design Support Platform

When Dynamic Energy Map becomes a platform coupled with Energy Simulation tools, design alternatives would be evaluated and compared at each given time spot or time window according to the design context.

2 Objective and Problem Definition

2.1 Exploring potential use cases of Dynamic Energy Map

One major objective of this study is to explore the application of Dynamic Energy Map with a use case senario of supporting district energy system design, community energy management and geo-design approach.

2.1.1 Support District System Design

2.1.2 Support Community Energy Management

Community Energy Management is a combination of urban planning, transportation management and infrastructure design.

2.1.3 Support Geo-design

2.1.4 Definition of Dynamic Energy Map according to the use cases above

According to the use cases above we selected the heating and cooling demand as the major variable in discussion. We define "Local" Dynamic Energy Map for Community level design support as:

- A database holding 8760-hour meta data of energy demand of buildings in a moderate sized community served by a district system [2].

- An interface that has multi-dimensional graphical display of the meta data in conveying spatial-temporal pattern of the energy behavior of the district.

  - 1D: data plot for providing quantitative information
    The Local Dynamic Energy Map displays the aggregated hourly energy demand of the whole community and major building sectors throughout the year. It enables comparison of different urban design alternatives in terms of total demand and demand variation. These information supports district system planning by optimizing the load of buildings in a mix-used community so that they have a stabler demand profile.

  - 2D/3D: graphical display of spatial relationship of energy data
    The Local Dynamic Energy Map applies a graduated symbol or color to buildings in the community aiming at providing the intuition of the building energy demand behavior within a community. It helps identify the rank of energy demand in a community and provides a guidance in energy cascading design.
    For univariant map senario, we suggest the variant size symbol according to the study of Garlandini et al. [16]. For bivariant map senario, such as the case for the current study, when heating demand and cooling demand are depicted on the map together, we suggest a two dimentional color ramp.

  - 1D + 2D/3D: interactive graphical display of spatial-temporal pattern of energy data.

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