Dynamic Energy Mapping Project Outline

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Contents

1 General Introduction

1.1 Project Overview

Buildings alone account for 40% of the total energy usage in the United States. However if the indirect energy impact of the built environment as a whole was considered, the community design induced energy and environmental impact could exceed this already high ratio: 60% - 75% of the energy consumption is connected to the spatial layout of built environment [18]. In a broader sense, the energy resources distribution influences the layout of human activities [18]. More specifically, built environment influence the energy throughput in the form of land use design and infrastructure layout [13].

Community Energy Management (CEM) is a combination of community level design strategies and energy management strategies aiming at providing quality of life in an urban environment with minimized energy consumption and environmental impact [13]. It contains "land use planning", "transportation management", "site planning" and "local energy supply and delivery planning" [13].

Energy Mapping makes the community energy planning alternatives visible to planners and policy makers [2]. Energy Map, or energy master plan [14] contains the information of energy demand and supply in the form of energy intensity [2], renewable energy, residual energy [3] and decentralized energy network [5]. It facilitates the matching of energy demand and supply in the aspect of spatial, temporal and quality [3].

The current challenge of the Energy Mapping approach is its lack of temporal information of energy supply and demand, creating barriers for the matching of demand and supply in the a time-of-use fashion [2].

A Dynamic Energy Map aggregates the time-of-use energy information to the traditional Energy Mapping practices. It acts as a geo-database that holds 1) hourly energy profile data for each building and the aggregated energy profile data for the whole community; 2) hourly energy supply data of community decentralized energy sources [2]. With the Dynamic Energy Map, the temporal behavior of the demand and supply of heating, cooling and electricity are revealed and are available to be compared, analyzed and updated. Dynamic Energy Map is also connected to simulation software, and can act as a key component of Geo-design that encompasses "geo-spatial modeling, impact simulations, and real-time feedback to facilitate holistic designs and smart decisions" [9]. The development of data-driven approaches and machine learning methods could also be coupled and can perform more complicated analysis of spatial-temporal behavior of energy data and provide more informative design or management support.

1.2 Objective and Problem Definition

The objective of the project is to 1) implement a Dynamic Energy Demand Map with hourly thermal energy consumption data for each building and the whole community 2) use it to optimize the arrangement of land use pattern to improve the energy performance in terms of aggregated thermal energy demand variation and 3) support sizing of a district thermal energy supply system.

The community model is created in City Engine [10] based on the land use pattern of a mixed-use redevelopment project at Lower Hill District, Pittsburgh, PA [19]. The model contains 68 buildings, comparable to a typical service area of a district thermal energy system (combined heating and cooling), about 50 to 150 buildings [12].

The hourly heating (gas) and cooling energy (electricity) consumption profile is retrieved from DOE Commercial Benchmark Building simulation [16]. An interface was designed to combine the 8760 heating-cooling energy choropleth map images from City Engine and the 8760 hourly heating-cooling energy data from EnergyPlus to form a Dynamic Energy Map. The interface provides users with the functions of 1) navigating through the dynamic map images, 2) dynamic data plots of single buildings, building sectors and aggregated community thermal energy demand.

1.3 Related Concepts

Some related key concepts will be discussed in this section include district energy system, Energy Map and Dynamic Energy Map.

1.3.1 District Thermal Energy System

A Decentralized Energy System is a “local or sub-regional supply of energy from a local source.” [17]. It brings the energy generation near to the energy end users and reduces the energy transmission and distribution loss [5]. A district energy system is one form of decentralized energy generation. It can produce thermal energy in a central plant and deliver the thermal energy to local buildings through a closed-loop pipeline network. Thermal energy are delivered in the form of steam, hot water or chilled water [2]. The central power plant can take on one of the following forms: 1) thermal power plant that only generates thermal energy, which can be either heating or cooling energy 2) co-generation system, or combined heat and power (CHP) system, that generates electricity and reuses the reject heat from electricity generation to serve space heating and service hot water to local buildings [12] 3) tri-generation system, where the central plant uses the heat generated by CHP plant to produce chilled water and supply both heating and cooling energy [4]. Corresponding to the different types of power plant, the network delivering thermal energy can be classified as 1) district heating network that only delivers steam or hot water 2) district thermal network that delivers both heating energy in the form of steam or hot water and cooling energy as chilled water.

There are several advantages of adopting a district thermal energy system: the central power plant can use a broader range of fuel choices including natural gas, oil, coal, waste, and renewable energy sources in the generation of thermal energy. This makes the district thermal energy system more flexible and more competitive in the market and increases the energy system resilience [12]. It reduces the transmission loss of thermal or power (if the central plant is a CHP plant or CCHP plant) by bringing energy production closer to energy end use [5]. It has high energy generation efficiency as a result 1) it can utilize high efficiency large-scale energy generation equipment and 2) it provides better "load matching" [12]. It also reduces the space and cost dedicated to installation and maintenance of HVAC systems in single buildings and reduces harmful gas emission [12].

1.3.2 Heat Map

Heat map is defined as "a spatial plan of existing and planned building heat demand, and decentralised energy networks and generation equipment" [5]. It is also a GIS "live database" that allows new development information to be incorporated. It is a key component to the DE energy master plan [5].

1.3.3 Energy Map

Energy Map is a generalization of a heat map that includes energy supply, demand and infrastructure information of various energy forms and technologies. It is also a combination of building energy database, a subset of the BIM (Building Information Model), and a Geo-database or Geographical Information System (GIS).

Energy Map can help to envision the community or city level energy demand reduction with high performance building design [1]. It can be used in supporting district heating system design [5, 11] by visualizing the heat sources and sinks.

1.3.4 Dynamic Energy Map

Dynamic Energy is a Energy Map equipped with temporal information of energy supply and demand. It enables spatial-temporal comparison, aggregation and query of energy demand and supply. When coupled with Energy simulation tools, design alternatives would be evaluated and compared at each given time spot or time period. By performing advanced data analysis method, the dynamic map makes patterns that are omitted in static maps visible and analyzable. Both aspects enable more detailed energy analysis and design support.

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

1.4.1 Strong Temporal Variation of Energy Demand

Different building types often indicates different energy demand profile. For example, the residential building heat demand profile has two major peaks, morning and evening, and is relatively low for the rest of the day. For office buildings, there is a peak heat demand in the morning and a relatively high heat demand through the day time but drops in the evening. Hospitals usually have a more flattened demand throughout the day. Within a mixed-used urban environment, the arrival of peak demand for different buildings are usually not simultaneous [5].

In the design of a district energy system, mixing building types with different time-of-use energy profile can be helpful in creating a less variate aggregated energy demand. This allows the central power plant in a district thermal energy system to a have higher utilization rate and reduces the need for backup plant that accounts for high peak demand [5].

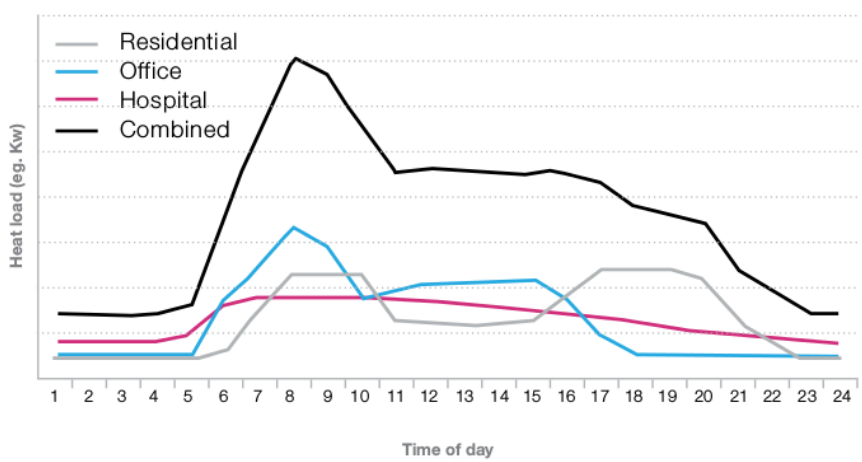

Figure 1: Mixing Load of Different Building Type [5]

1.4.2 Aggregation of Peak Value Becomes Tricky for Data with Time Variation

One common mistake for sizing a district thermal energy system is to add up the peak demand of each terminal users. Since the peak demand of individual buildings do not occur at the same time, the end result of summing up the peak demand at each end point exceeds the actual total demand peak of the community, hence with this approach, the whole district system becomes excessively over-sized, which reduces the whole system efficiency. Dynamic Energy Map can reveal the problem of such approaches by directly providing the aggregated thermal energy demand for the community and for single buildings or building sectors. It allows a side by side comparison of single building demand and aggregated demand and eliminates the misunderstanding of the demand aggregation. With the direct information of aggregated thermal energy demand, it also assists actually sizing a district thermal energy system.

2 Related Works

Section 2.1 and section ?? provide an overview of the existing instances of static energy maps and dynamic energy maps. Section ?? and ?? provides some supporting evidences for certain design choices. Section ?? provides some information on potential technologies for further development. (?? are not written)

2.1 Static Energy Map

2.1.1 Calgary Energy Map

One of the early instances of Static Energy Mapping practices is the Energy Mapping Study of City of Calgary in 2008, carried out by Canadian Urban Institute. It aims at providing insights to achieve the goal of reducing 50% of Green House Gas (GHG) emissions by 2050 [1]. It depicts 1) how building design strategies and land use planning can influence the city level energy use intensity 2) the availability of alternative energy sources and the opportunities to combine building level sustainable design technology with the community level energy system design.

Calgary energy map first compares energy use intensity (the annual total demand for thermal energy of space heating cooling, hot water and electricity per unit area [1]) in GJ/ha between two development cases: "business as usual" case and "ultra-high efficiency" case (Figure 2). The comparison demonstrated a 34% reduction in energy use intensity from the former to the latter [1].

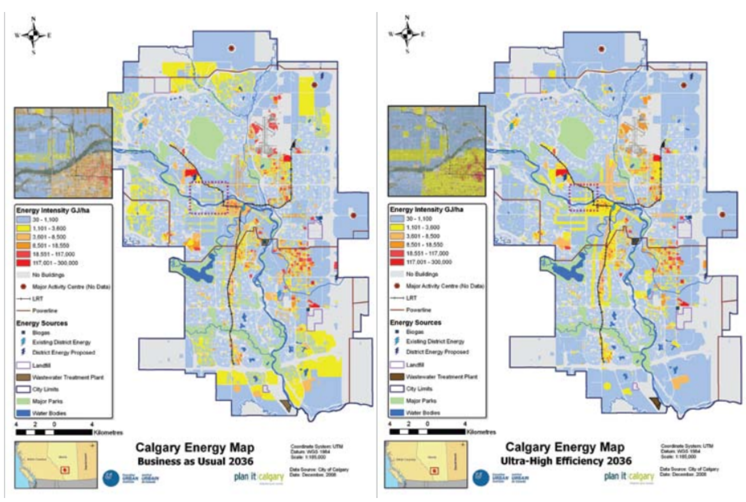

Figure 2: Calgary Energy Map (Business as Usual, Ultra-High Efficiency) [1]

It also shows alternative energy sources of district energy, solar hot water, solar air, energy sharing and PV installation on the map (Figure 3). By overlaying the alternative technology map and the "ultra-high efficiency" map, it highlights the opportunities of using alternative renewable energy sources and district energy system to further improve the energy performance of high energy demand areas after high performance building design was applied [1].

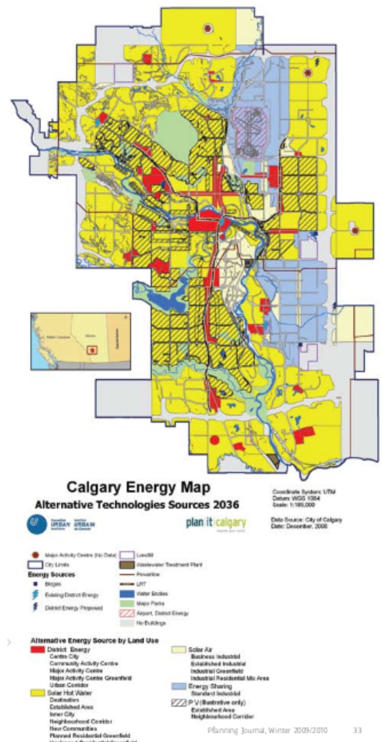

Figure 3: Calgary Energy Map Alternative Energy Source [1]

2.1.2 UK Heat Map

Under the goal of supplying 25% of the total energy with decentralized energy (DE) by the year 2025, the Decentralised Energy Master Planning Program (DEMaP) was conducted between 2008 to 2010 to "identify opportunities for district heating networks through heat mapping and energy masterplanning" [14]. In this study, the term DE only refers to "combined heat and power systems connected to district heating networks" [5].

London Heat Map is a publicly accessible interactive map developed as part of the DEMaP project. It is completed for the London Boroughs in 2012. It can act as a starting point of Energy Master Plan for local authorities, and can assist developers to make connections to existing DE networks to meet policy requirements (London Plan DE policy) [5, 14]. Point features of high heating energy consumers and suppliers, existing and emerging energy networks are depicted on the interactive map. High DE potential regions ("focus area" [5]) are identified and depicted on the map to highlight the opportunities of utilizing the heat supply in the community planning and development (Figure 4). The "live-database" property of London Heat Map allows new data of energy consumption be uploaded by users.

The criteria applied for identifying focus area include: 1) near to existing or emerging DE network, 2) high heat demand density 3) anchor load building, 4) diverse heating demand profile 5) has public ownership with policy concerns to make connections to the DE network [5]. The physical constraint are also considered in finalizing the high DE potential regions.

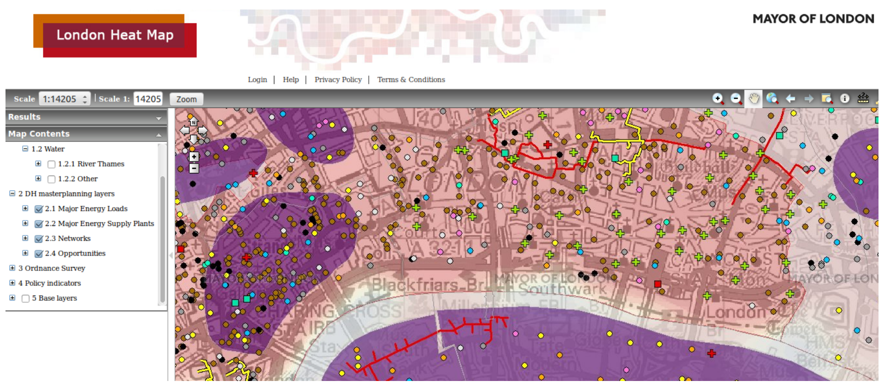

Figure 4: London Heat Map [15]

National Heat Map (Figure 5) is another UK energy mapping project that focuses more on the industry side [5]. It is a "high resolution web-based" heating energy interactive map, developed by the Department of Energy and Climate Change (DECC). It aims at "support planning and deployment of local low-carbon energy projects in England" [7]. Power plant developers can use this map to consider the feasibility for a CHP plant under policy requirements [5]. Heating demand density (kWh/m^2) of four major building sectors: public buildings, commercial buildings, industry buildings and residential buildings, together with the total demand is plotted on the map as a 2D raster image with a discrete color scheme from blue to red representing low to high heating demand. Heat source of CHP stations and thermal power stations are plotted as point features in the map. Address level heat demand data in csv format is also available for local authorities upon request [6].

The "Water Source Heat Map" (Figure 6) is an added layer group to the existing National Heat Map with information about the the heat potential of the 4041 waterways in England. Heat potential of waterways are represented in temperature, surface area, flow rate and heat capacity (kJ/m^3 for coastal and estuary, kW for canal, river and settlement). It aims at supporting the plan of water-based thermal system as water-based heat pump [8]. The

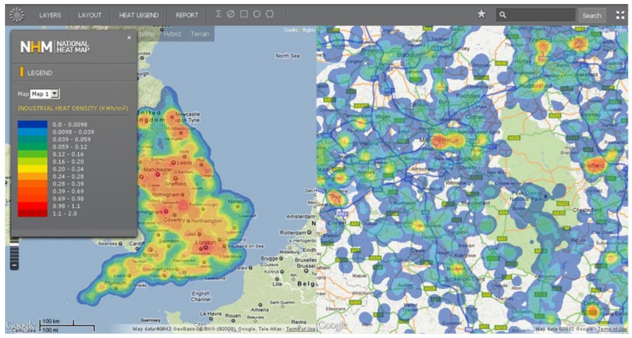

Figure 5: National Heat Map [20]

map revealed the large thermal capacity of water bodies that could serve over one million buildings in the UK [8].

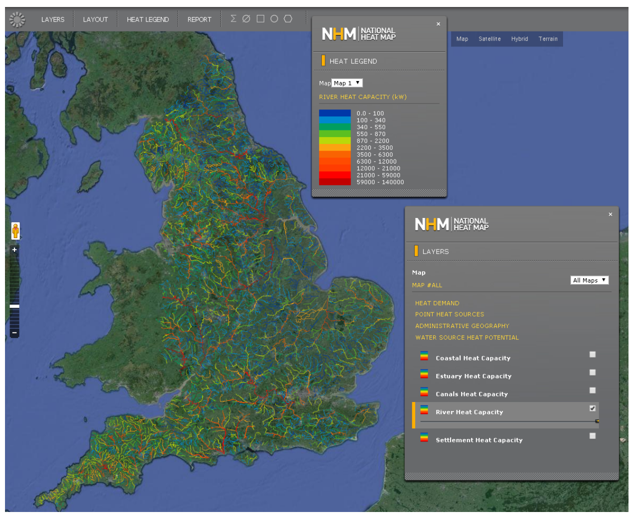

Figure 6: Water Heat Map [8]

2.1.3 Energy Potential Mapping

Dobbelsteen et al. described a framework of Energy Potential Mapping (EPM) that aggregates information of energy supply, demand and infrastructure on the same map with demand and supply represented in the same unit of GJ or GJ/ha [3].

In 2010, a "Heat Mapping" study under the framework of EPM was launched by TU Delft aiming at visualizing heat demand and supply and infrastructure with the same unit that facilitates easy comparison and facilitates the matching of supply and demand [3]. The map is presented with aggregated supply and demand in a 3D Heat Map. The absolute quantity of each type of demand and supply is represented with extruded height in the

3D map. Demand is represented with a transparent 3D feature, and each supply source is represented with solid 3D feature in a different color [3].

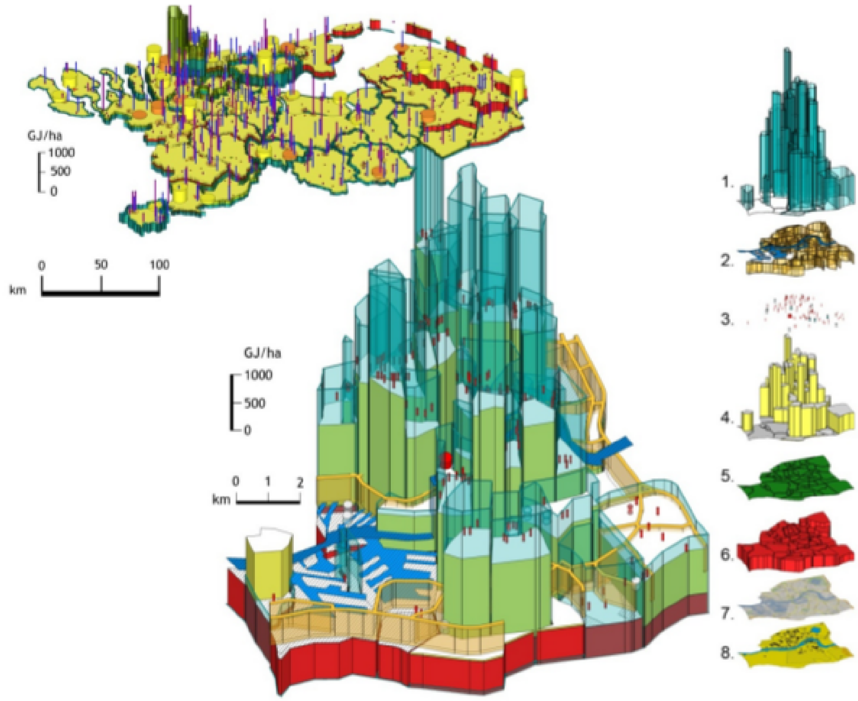

Figure 7: Heat Mapping of Netherlands and Rotterdam [3]

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