EnergyFlowVis:
Visualizing energy use flows for UBC Campus

CPSC 547, 2020: Project proposal

Claude Demers-Belanger (claude.demers-belanger@ubc.ca)
Sanyogita Manu (Sanyogita.Manu@ubc.ca)

1. Introduction

UBC campus is akin to a small town with over 350 institutional buildings (over 1.4 million square meters of institutional floor space), a hospital, a secondary school and five residential neighborhoods. In 1997, UBC was the first Canadian university to implement a campus-wide sustainability policy. Since then, UBC has developed several strategies to further the cause of reducing GHG emissions, one of them being energy efficiency measures for the built environment. This work falls under the scope of the UBC Energy and Water Services (EWS) Unit, which is responsible for managing and operating the buildings on campus. Since buildings are one of the most important utility assets, they need to be monitored closely to assess performance and implement efficiency programs. To achieve this, building management systems (BMS) have been installed in 152 buildings on campus. BMS monitors and controls the various mechanical heating, ventilation, and air conditioning (HVAC) systems in these buildings using a network of sensors and controllers. Commercial BMS systems come with their own data visualization tools, which have certain limitations. In addition to not being able to store historical data, these tools cannot be customized to add visualization capabilities specific to the tasks identified by the user, in this case the EWS. So, over a period of time, EWS has developed its own custom applications by consolidating all the BMS data on the Skyspark platform.

We propose a problem-driven design study that focuses on visualizing energy-use flows for the UBC-Vancouver campus. This will enable EWS to understand the energy flows (1) from different energy sources to a building or a zone and (2) from a building, or a zone with a building, to end-uses and specific equipment. Examples of sources are electricity, natural gas, thermal power, and biomass, while those of end-uses are cooling, heating, lighting, and appliances.

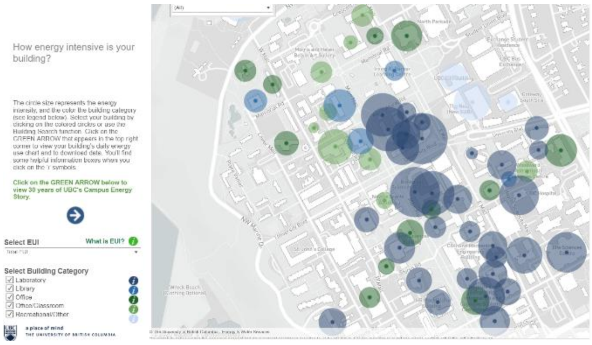
We both have several years of experience working with such data in the research (Sanyogita) and consultancy (Claude) realms, so this project engages us at a personal level. In addition to these motivations, we are a part of the Energy, Technology, and Architecture (ETA) Lab team. ETA Lab is an interdisciplinary research group that tackles research problems related to energy use in the built environment. This project, therefore, aligns perfectly with the Lab's research activities.

2. Related work

We have stated in the preceding section that each BMS has its own commercial toolkit for visualizing the monitored data. Since the BMS sensors are limited in terms of their capacity to store historical data, it is likely that the corresponding visualization tools do not offer the functionality to display energy flows. For this reason, we have excluded such tools from this review.

Currently, EWS has two different ways to visualize the energy use dataset [1]. One of them shows a bubble chart spread on a Campus map where the bubble position encodes the location of the building, the size encodes the amount of energy consumed and the color encodes the type of building (Figure 1). Users can see the total and daily (time series) energy consumption for each building by clicking on the corresponding bubble. The objective of this dashboard is to help the users identify the energy consumption for all buildings in the dataset, together and individually. The other dashboard is a set of bar charts that show historical annual data of the whole campus for GHG emissions, annual usage, annual cost, water usage and savings. Both dashboards are designed with Tableau. They do not give any information on "how" the energy is consumed in these buildings in terms of end-uses.

According to the researchers we interviewed, this functionality or visualization would be extremely useful in making energy management decisions.



How energy intensive is your building?

The circle size represents the energy intensity, and the color the building category (see legend below). Select your building by clicking on the colored circles or use the Building Search function. Click on the GREEN ARROW that appears in the top right corner to view your building's daily energy use chart and to download data. You'll find some helpful information boxes when you click on the 'i' symbols.

Click on the GREEN ARROW below to view 30 years of UBC's Campus Energy Story.

Figure 1: Campus bubble chart of annual energy use

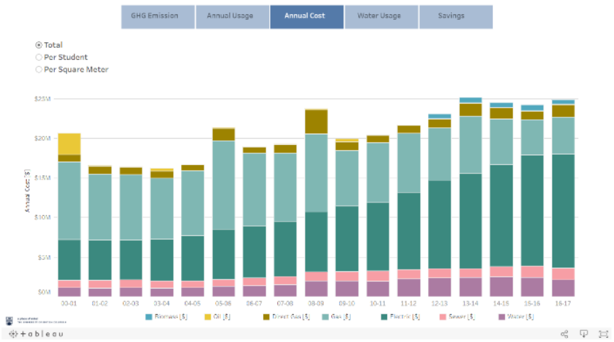


Figure 2: Bar chart of annual energy cost for the whole campus

The primary objective of our review of existing literature was to understand how flow data was visualized across domains that were peripherally related to ours. We found that flow diagrams were used extensively to visualize flow of materials [2]–[5], flow of energy from primary source to end-uses or demand drivers from a global [6], [7] and country-level perspective [8], [9] to provincial scale [10], [11]. We also found several examples where flow diagrams were used to examine the interaction between two or more resources, such as the energy-water or energy-water-food nexus [12]–[14]. We came across fewer examples of flow diagrams being used to visualize money and associated goods flows between sectors [15] or energy and exergy flows for sub-systems in industrial processes [16].

The use of flow diagrams in the building energy efficiency domain seems to be limited. Belzer [17] developed separate flow diagrams for commercial and residential buildings sectors to depict flows of energy from source to end-use in these two sectors. We also came across energy flow charts that visualize the flow of energy use related annual metrics (total energy use, CO2 emissions, utility cost) between source and individual buildings on a campus [18]. The same authors propose two other applications of flow diagrams to show (1) building-level energy flow, and the associated cost [19] and (2) energy and mass flows in HVAC sub-systems [20]. We see another application of the latter in [21]. It is interesting to note that the last two examples are reminiscent of the first ever (arguably) flow diagram made by Captain Henry R. Sankey and published in 1898, "the thermal efficiency of steam-engine" to represent the flow of heat energy in a steam engine.

3. Data and Task Abstraction

As a first step towards task abstraction, we met with multiple stakeholders. First, we met with researchers from the ETA Lab to discuss what information they would need to extract from building data to make better decisions. Then, we met with a UBC Community Energy Coordinator to ask similar questions.

After combining the answers and summarizing, we concluded that researchers and energy managers want to see a detailed breakdown of how energy is consumed on campus, starting at the building level and then disaggregated by end-use down to the equipment level. Access to this information will help them to make better decisions in terms of modifying end-uses through demand-side management as well as enable better informed energy retrofits. They also wanted to be able to compare energy flows for different buildings or different time periods for the same building. time periods. Our task, therefore, is to design a system that will enable these users to explore the flows between sources and end-uses and allow comparisons between different scenarios.

To do this, we will use the EWS energy and water Skyspark dataset. First, the consumption data are table data, where each building that have a BMS (137 buildings) will have an electric consumption meter, a gas consumption meter, and a water consumption meter. These meters log data every few seconds for each of the buildings. Also, for most buildings, we have data on equipment operation that will be used to calculate energy use. Therefore, the dataset that links between equipment, buildings, sensors, and end-use is a network. Finally, each sensor logging data at a specific sampling rate will represent table data as well.

4. Solution

From our limited study of related works, we found that the Sankey diagram was the preferred idiom for visualizing energy flows. They have been used to encode a similar use case with institutional buildings in [18] as shown in Figure 3. In another example, the Sankey diagram is used to visualize country-level projections (for 2050) of energy flows for a specific combination of energy efficiency and behavior related scenarios (energy pathways) (Figure 4). This visualization is a part of a tool that enables users to understand the impact of selecting a given energy pathway on the national carbon footprint [22].

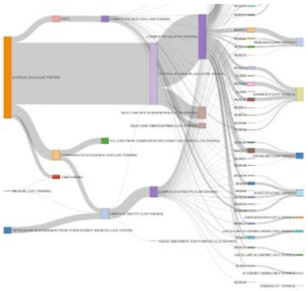


Figure 3: Sankey diagram showing annual CO2 emissions

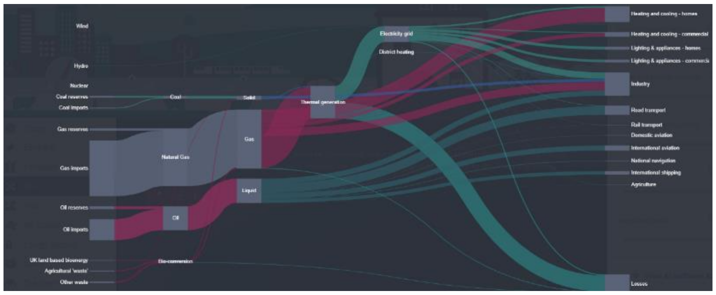


Figure 4: Country level energy flow chart for 2050 based on a user-selected energy pathway

We will design our version where the energy will flow from the energy type (water, gas, electricity) down to the building level, then to end-use, and potentially, to the equipment level. Once we have an efficient design, we will need to find a way to compare two scenarios (i.e., building vs. building or season vs. season) using Sankey diagrams. The end system will be interactive, but we have yet to solve this interaction problem to answer our primary tasks. Figure 5 shows the flow of information we are designing.

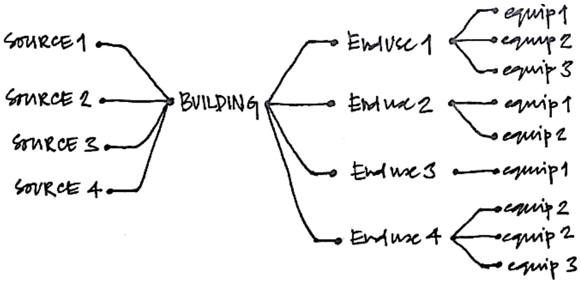


Figure 5: A conceptual schematic of the overall energy flow between sources and end-uses for a building

5. Milestones

We have complementary skill sets, and we would like to use that to our advantage to complete this project. Sanyogita will focus on designing the visualization and Claude will work on its implementation. These scopes, however, will overlap to some degree. We both will work on the final deliverables, such as reports and presentations, together. We have provided an estimate for the hours for each task and the scope in Table 1. This will evolve and change as we continue to work on the project.

Table 1: Project timeline and scope

Task	Hours	Deadline	Description
Pitch	10	October 1	Explore the dataset and related work, work on task and data abstraction, prepare slides and video
Project meetings	10		Internal discussions and brainstorming sessions, meetings with the users – ETA Lab and EWS, meetings with Tamara
Proposal	14	October 23	Study related work, work on task and data abstraction, ideate potential solutions, write the proposal
Design	45	November 20	Finalize task and data abstraction, study related work in detail, study relevant vis idioms, develop design schematics and mock-ups, work on uses cases and interaction scenarios
Implementation	45	December 7	Convert data from Skyspark to Database format, Create Synthetic data if necessary, Validate metadata of sensor for energy consumption calculation, Programming, Testing, User testing.
Project update	10	November 17	Prepare slides
Peer reviews	2	November 19	Unstructured User study with ETA lab members.
Final presentation	10	December 10	Prepare slides, rehearse
Final paper	20	December 14	Detailed project write-up

6. References

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