

EnergyFlowVis:

Visualizing energy use flows for UBC Campus

CPSC 547, 2020: Project proposal

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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. Background

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 (Figure 2). 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.

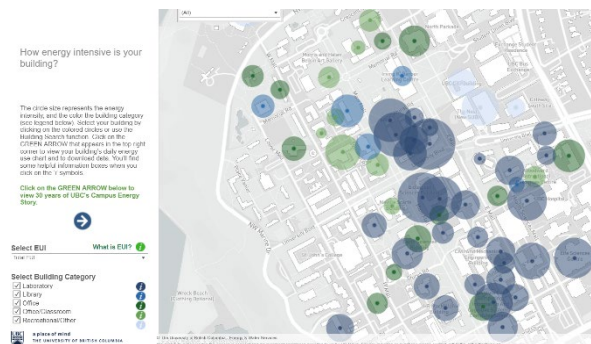


Figure 1: Campus bubble chart of annual energy use

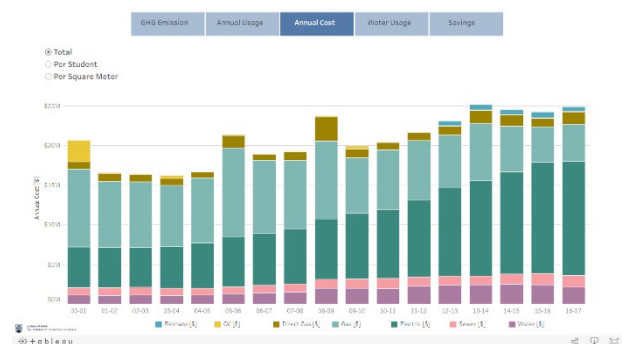


Figure 2: Bar chart of annual energy cost for the whole campus

2.1 Related work

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.

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].

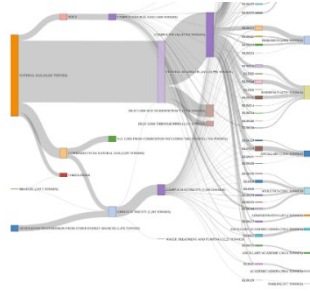


Figure 3: Sankey diagram showing annual CO2 emissions

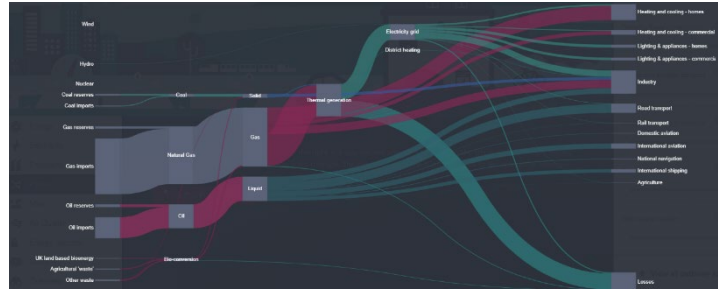


Figure 4: Country level energy flow chart for 2050 based on a user-selected energy pathway

3. Data and Task Abstraction

3.1 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.

The result was that those stakeholders wanted to understand how energy was consumed on energy going from the source of energy to the consumer. They wanted as much granularity as possible. The ultimate goal would be to know where to focus their effort to reduce consumption on campus. For example, this information could be an input in the campus retrofit plans, to help prioritize efforts from the biggest return on investment to the smallest.

The main requirements tasks that we articulated based on our discussions with the stakeholders are as follows:

- 1 Have the ability to track the flow of energy from source to consumer
- 2 Have the ability to navigate between campus level to building level consumption
- 3 Have the ability to compare different buildings together
- 4 Have the ability to compare different time periods for the same building

Based on these tasks, the focus of this project is to design a system that will enable the user to use data within the three levels of actions:

- Analyze -> Consume -> Discover
 - Requirement 1
- Search -> Explore
 - Requirement 1 and 2
- Query -> Identify, Compare and Summarize
 - Requirement 1,2,3 and 4

3.2 Data abstraction

The data used in this project is accessible publicly. EWS gives access through the SkySpark platform to UBC's energy and HVAC data. The data has two type: Network & trees and Tables. The building sensors are organized in a tree dataset where the sensors are linked to an equipment, an equipment type and a building (Figure 5). In some cases, the sensors are linked to a room or an area of the building. Also, each sensor will have a table associated to him where the data is organized in a time series. For example, you can find under the building "CIRS", equipment type "Utilities", equipment "Elec Main Meter", the sensor "CIRS Elec Main Meter Energy" that logs data every 15 minutes (Table 1).

Table 1: Timeseries example for sensor "CIRS Elec Main Meter Energy"

Timestamp	CIRS Elec Main Meter Energy (kWh)
2019-01-09T23:45:00-08:00 Los_Angeles	11
2019-01-10T00:00:00-08:00 Los_Angeles	13.5
2019-01-10T00:15:00-08:00 Los_Angeles	16
2019-01-10T00:30:00-08:00 Los_Angeles	12
2019-01-10T00:45:00-08:00 Los_Angeles	11.5

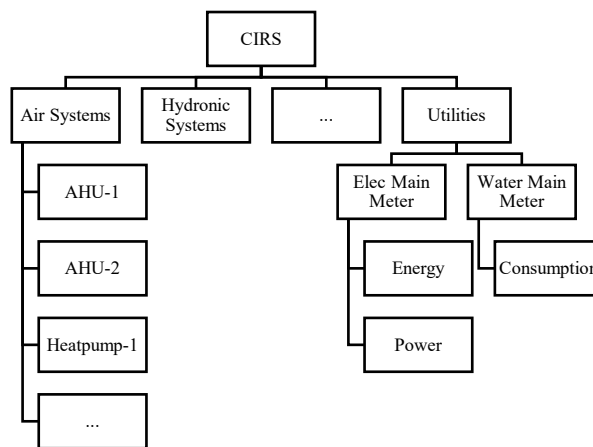


Figure 5: Example of sensor tree for the CIRS building

Our project will focus on a subset of buildings that have energy consumption smart meters (92 buildings) where we will convert the raw data into consumption only data. As the Skyspark data is heavily focused on HVAC equipment, our project will also put emphasis on this part of the buildings’ consumption. For some of the HVAC equipment, we have energy sensors however, for other equipment, the consumption will be derived from calculation (i.e. time the machine is turned on). Therefore, the tree in Figure 6 will be the processed format of the data.

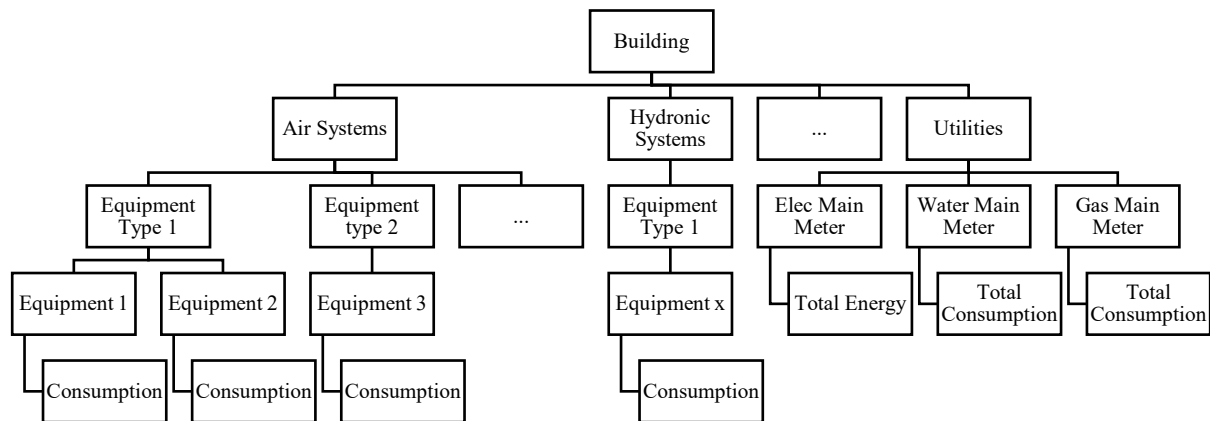


Figure 6: Processed data tree format

To visualize the data, we will also consider building clusters to group the buildings. They will be separated between:

- Laboratory
- Library
- Office
- Office/Classrooms
- Other

Also, the equipment types will be limited to:

- Air Handling Units (AHU)
- Heat pumps
- Heating Plants
- Cooling plants
- Cooling towers
- Fans
- Roof Top Units
- Heat Recovery
- Unit Heater
- Chiller
- Others

The energy end-use will be broken down in 7 categories [23]:

- Space heating
- Space Cooling
- Combined heating and cooling
- Lighting
- Emergency Lighting
- Other

4. Solution

We are proposing a Python based web application that will allow the users to visualize energy flows based on the EWS energy data. We have developed design mock-ups that will give an idea of the structure of the application and will help us to explain some of the navigation scenarios.

The application interface (Figure 7) is divided into two main sections: Panel 1, on the left, is a collection of input fields that will allow the user to query and filter the data for visualization; Panel 2 on the right has the main view window where the result of the user's query will appear in the form of an energy flow diagram. In addition to these panels, we will also provide a collection of tabs on top of the main view for a more high-level filtering of data; these levels are analogous to the different scales that are generally used to explore or analyze energy data for the built environment, namely:

- Neighborhood (in this case, the UBC campus) which is a large cluster of buildings based on their geographic location and proximity to each other,
- Building cluster, by which we mean a smaller subset of buildings grouped by different criteria. One of the criteria we will use is building use type. Other existing visualizations on EWS data group the buildings in five clusters based on this criterion: Laboratory, Library, Office, Office/Classroom and Recreational/other. We will keep these clusters to be consistent. The other criterion that might be useful is the age of the building. We have information about the year in which the buildings in the dataset were constructed. We are contemplating if we should allow dynamic binning of the buildings/data by allowing the user to create “building age” bins or to pre-bin the data.
- Individual building

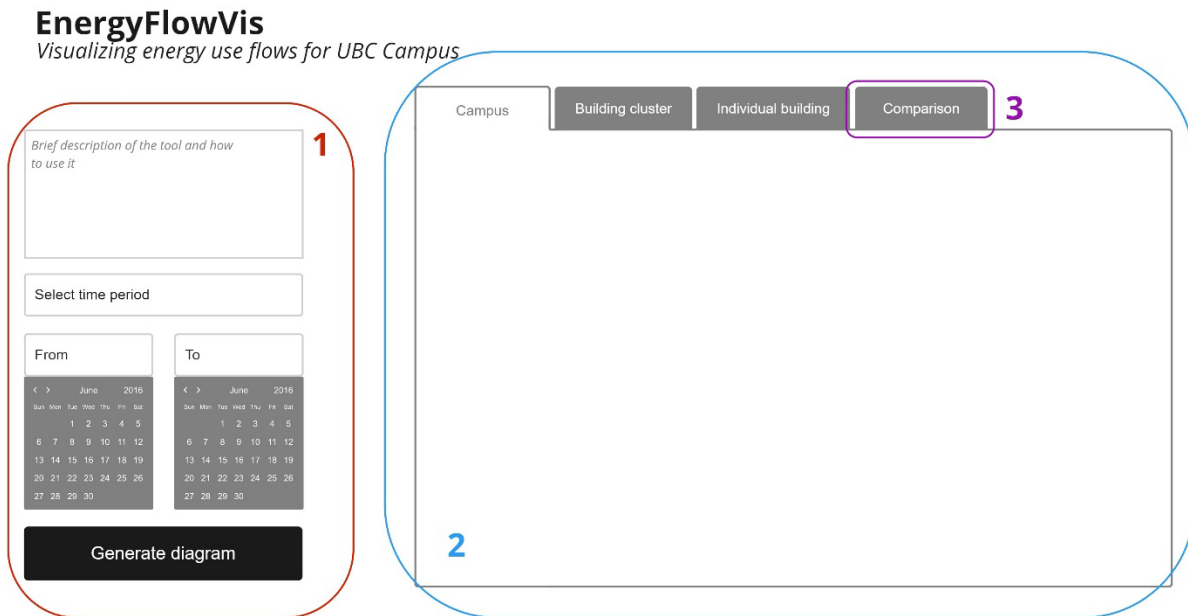


Figure 7: a mock-up of the EnergyFlowVis interface

The input fields in panel 1 will change for each tab and there are several questions that this poses for us in terms of the design and the functionality of this application. We have elaborated them as follows:

- For the “Campus” tab (Figure 1), the user will be able to select the time period. The primary design choice in this case is the granularity of the time stamp used for selecting the period starting from an option where

the user could input the exact date in the “from” and “to” fields (most flexible) or input the month and year to selecting a calendar year (least flexible).

- For the “Building cluster” tab, we will have to modify the input fields by offering the user a selection of the cluster type (building use type, building age, etc.) and a selection of a specific cluster within the selected cluster type. We will also provide the ability for select the time period.
- For the “Individual building” tab, the input fields will be changed to offer an alphabetical list of all the buildings in the database for selection along with the time period input.

We also want to offer comparison between two or more energy flow diagrams for the following scenarios:

- Compare campus level energy flows between two different time periods.
- Compare one building cluster between two different time periods.
- Compare the same time period between two different buildings clusters.
- Compare an individual building two different time periods.
- Compare the same time period between two different buildings.

We have yet to decide how we will design this functionality in terms of navigation. One way to do this is to offer a separate “Comparison” tab (#3 in Figure 1) and then provide all the relevant input fields in panel 1. The other option is to offer additional inputs within the “Campus”, “Building cluster” and “Individual building” tabs. We are currently weighing the merits and demerits of these options.

4.1 Energy Flow diagrams

We have developed several mock-ups of the energy flow diagrams using synthetic data as a first step towards developing the design language for the diagrams. Figure 8 shows a campus-level energy flow diagram which was generated to assess the effectiveness of this design idiom for a more complex data set with several overlapping energy flows and many nodes. The issue of occlusion (of a flow/stream by another) was resolved by reducing the transparency of the layers on top in this case. The other design choice to be made is the way the node data is displayed. In this diagram both the node labels and the quantity are visible. For instances where node labels are long, we may have to find another way to display them.

We have also explored different color encoding for the nodes and the flows. In Figure 8, the flows in a single hue (grey) and the nodes appear in different hues. In option (a) from Figure 9, the nodes appear in different hues and the flows use the source node’s color, which in option (b) the flows use the target node’s color. Our initial impression is that the single hue flows (Figure 2) seem to show the flows clearly even for a dense dataset, while the other options seem to be too bright and might result in very “busy” diagrams, especially for large datasets.

In order to allow comparison between two or more flow diagrams, we are exploring the possibility of using juxtaposition (side-by-side views, similar to Figure 9) and superimposition (Figure 10). There are merits and demerits to both approaches. Superimposition allows easy comparison between the energy flows in the two layers. It will likely make the transition between displaying one set of flows to adding a second set of flows on top smoother. However, it should be noted that in the diagram we have used here as an example [24], the grey colored flows are the benchmark to which the scenario indicated in the colored flows is compared, so the latter is more prominent than the former and is always less quantitatively so there is no occlusion. It is unlikely that superimposition will support more than two layers of flow diagrams. Juxtaposition, on the other hand may make it difficult to compare the flows and nodes in fine detail especially if the changes between the diagrams are pronounced (different nodes or large differences in the flow quantities). But it also reduces threats to effectiveness by removing any possibility of occlusion and making it viable to compare more than two flow diagrams at a time.

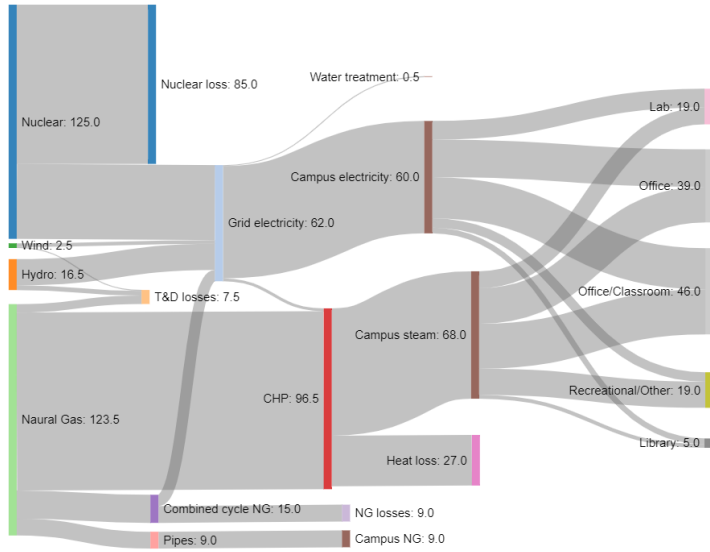
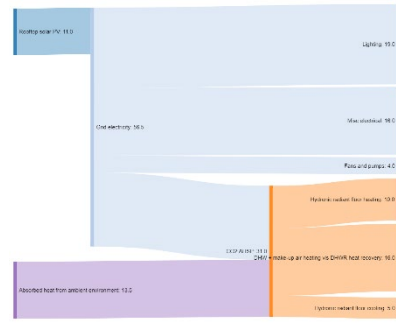
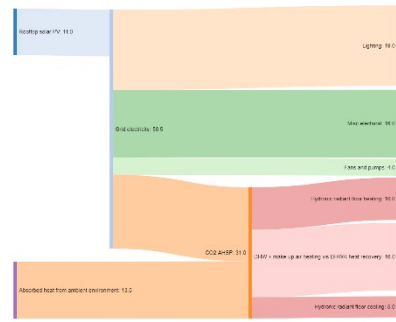


Figure 8: Mock-up of the EnergyFlow diagram for data aggregated at campus level



(a)



(b)

Figure 9: a mock-up of color encoding options and an example of juxtaposition (side-by-side view) of two energy flow diagrams

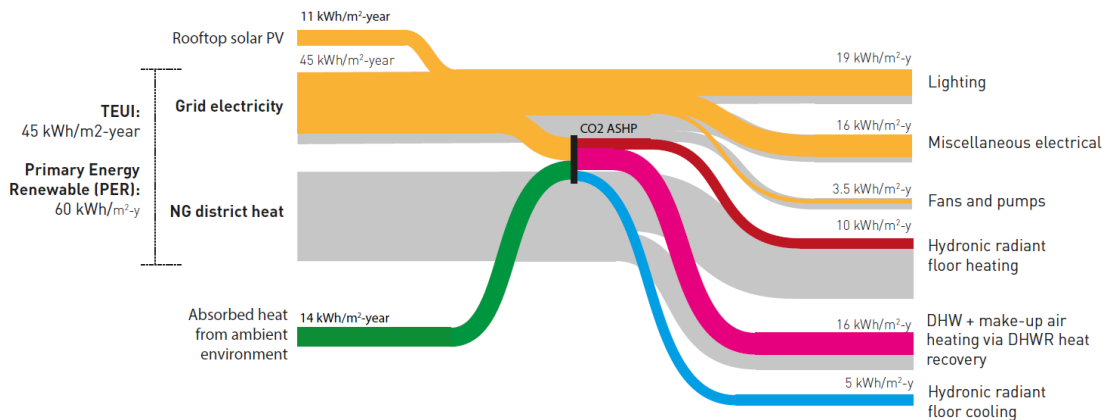


Figure 10: An example of superimposition of two energy flow diagrams

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 2: Project timeline and scope

Task	Hours	Deadline	Description	Completion (hours)
Pitch	10	October 1	Explore the dataset and related work, work on task and data abstraction, prepare slides and video	10
Project meetings	10		Internal discussions and brainstorming sessions, meetings with the users – ETA Lab and EWS, meetings with Tamara	5
Proposal	14	October 23	Study related work, work on task and data abstraction, ideate potential solutions, write the proposal	14
Design	45	November 25	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	15
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	10
Project update	10	November 17	Prepare text/slides	10
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	

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