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EEB Hub Regional Sankey Diagram: Philadelphia Authority for Industrial Development Historical and Forecast Energy by Planned Use at the Philadelphia Navy Yard

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**EEB Hub Regional Sankey Diagram:
Philadelphia Authority for Industrial Development Historical and Forecast
Energy by Planned Use at the Philadelphia Navy Yard
LLNL-TR-643762**

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Executive Summary

The Energy Efficient Buildings Hub (EEB Hub) is a DOE-funded center, focused on improving the energy use in commercial and large-scale residential buildings. One of the Hub's goals has been to develop the means and methods to reduce energy use in commercial buildings by 20 percent by 2020. Understanding energy use in buildings is a key component to managing energy use at multiple scales, from the building to the city, to the region. Sankey diagrams are an accessible tool to visualize energy flows, and help identify opportunities to deploy energy saving technologies.

A campus-level Sankey diagram was previously generated from 2010-2011 data for ~100 metered Navy Yard buildings to quantify natural gas and electricity usage by principal building activity [4]. As these properties are renovated, the energy consumption and building principal activities are being updated and modified.

To depict the multi-year time lapse of regional electricity distribution in the Navy Yard, LLNL generated Sankey diagrams using data from 36 properties (buildings, developments, equipment) used to develop Philadelphia Authority for Industrial Development's (PIDC) Navy Yard Master Energy Plan (NYEMP). The diagrams presented in this report depict ~10 building use types and the yearly changes in forecasted usage in GWh from 2011 to 2022.

The forecast captures increases in regional energy use from planned building additions and renovations and yearly increases for existing buildings. From 2009 to 2022, there is approximately 5.6 million square feet of planned additions and renovations. The largest addition of properties are for office (~ 2.3 million square feet for dedicated office, and larger for shared office space) and residential space (~1 million square feet). Until 2014, the largest user of energy is for flex space, reaching a forecasted 11.4 GWh. In 2015-2016, the largest forecasted user is for a data center reaching ~25.7 GWh. After 2016, the largest consumers are either for office space (reaching 63.2 GWh forecast in 2022), or heavy industry (68 GWh forecast in 2022).

Introduction

The Navy Yard

The Navy Yard is on 1,200 acres containing roughly 282 existing buildings (233 historic structures), 7 miles of waterfront, and more than 10,000 employees working in more than 6.5 million square feet of facilities [2]. There are commercial, Naval, and industrial facilities. Establishments currently based at the Navy Yard include the EEB Hub, Penn State, Urban Outfitters, GlaxoSmithKline, Tasty Baking Company, Unique Industries, WuXi AppTec Laboratory Services, Rhoads Industries, and Iroko Pharmaceuticals.

Philadelphia Authority for Industrial Development (PIDC) and the Navy Yard Master Plan

PIDC manages the independent unregulated electric distribution grid that serves the Navy Yard. They led efforts to develop a 10 year Energy Master Plan that implements smart grid technologies to reduce the need for off-site external energy consumption. The plan is also organized around stakeholder involvement around distributed generation and energy efficiency.

PIDC contributed to the 2013 Navy Yard Master Plan update which addresses infrastructure improvements and additions, recreation, residential and commercial development, and research space. The plan integrates sustainable design including green spaces, carbon footprint reduction, redevelopment of existing sites, LEED designed buildings, mass transit, and storm water retention.

EEB Hub and Penn State University

The EEB Hub, located in the Philadelphia Navy Yard, was created by the U.S. DOE as an energy regional innovation hub. One of the Hub's goals has been is to develop the means and methods to reduce energy use in commercial buildings by 20 percent by 2020. Understanding energy use in buildings is a key component to managing energy use at multiple scales, from the building to the city, to the region.

Previously, EEB Hub requested qualitative visualizations of regional energy flows for the Navy Yard. These energy flows or Sankey diagrams are an accessible tool to help identify opportunities to deploy energy saving technologies. LLNL generated a campus-level Sankey diagram using metered natural gas and electricity data for the fleet of ~100 buildings in the Navy Yard. The Sankey showed energy flow from natural gas and electricity to end use based on the principal activity of the building. The energy consumption and building principal activities are being updated and modified as properties in the Navy Yard get renovated.

Analysis

To provide a transient aspect to regional energy use, LLNL developed annual Sankey diagrams showing actual usage from 2009 to mid-2011 and forecast usage from mid-2011 to 2022. The main source of data is contained in a spreadsheet used to develop Navy Yard Master Energy Plan (NYEMP). The data for four quarters each year is organized by the usage in MWh, substation (SS 93 and SS 664) that supplies electricity, and by building use type (residential, industrial, office, data center, etc.).

Existing property at the start of the NYEMP consumed an estimated amount of electricity, known as the baseline, from 2009 to mid-2011. The forecast analysis beyond 2011 assumes a 1% annual usage increase for the baseline for most¹ properties. The forecast also accounts for approximately 5.6 million square feet of planned building renovations and property (buildings, developments, equipment) additions in the Navy Yard starting in 2011. Tables A1 and A2 show the Watt per square foot for each building type. Other assumptions about the forecast analysis are in Appendix A.

Figure 1 shows the location of the two substations in the Navy Yard (yellow dots) and the areas of the Navy Yard they cover. Loads from SS 93 are all industrial, while those for SS 664 are generally commercial.



Figure 1. Map of the Navy Yard and substation locations. Property data for the Sankey diagrams are fed by substations 93 and 664, shown as yellow dots. The green shaded area is served by substation 93 and substation 664 serves the brown shaded area. [5]

¹ Except East End development and equipment

Data from 2 substations and 36 properties were grouped into 10 building use types (industrial, residential, etc.), some of which are a combination of others. We chose building use as the Sankey diagrams “end flow” because in a previous report, regional Sankey diagrams were organized by building type and end use [4]. In that report, the Commercial Buildings Energy Consumption Survey (CBECS) was used to approximate end-use energy loads for a given building type since sub-metering was not available.

Figure 2 shows the annual cumulative (both substations) forecast total in GWh from 2011-2022. Each Sankey diagram shows the split of distribution from SS93 and SS664 to baseline and each building type. Figure 3 and 4 depicts estimated energy use in 2009 and 2010 respectively. Similarly, one Sankey diagram per year from 2012 to 2022 (figures 6 through 16) shows forecast energy usage. 2011 had a combination of estimated energy usage and forecast for added property. The captions for each figure note the approximate square footage of property that is being added.

The forecast captures increases in regional energy use from planned building additions and renovations and yearly increases for existing buildings. The largest addition of property is ~ 2.3 million square feet for office space (larger for shared office space) which is forecasted to be the largest energy consumer, reaching 63.2 GWh forecast in 2022. The second and third largest consumers in 2022 are expected to be for heavy industry (68 GWh) and a data center (25.7 GWh), both of which are energy resource intensive. The fourth largest consumer by 2022 is forecasted to be for residential use which accounts for ~ 1 million square feet of added space.

Data used to generate the Sankey diagrams are shown in Appendix A. Table A1 shows use forecast in GWh organized by year and building use for properties from substation SS664, and table A2 shows properties from substation SS93. Table A3 shows total forecast usage when combining SS93 and SS664.

The Sankey diagrams are semi-automated to retrieve data from a spreadsheet. As the understanding of the Navy Yard energy use is updated and refined, Sankey diagrams can be updated and modified relatively easily.

It should be noted that data is organized such that the information given here may also be available in the NYMP, and specific details about each property remain confidential.

Results: Forecasted usage and Sankey diagrams

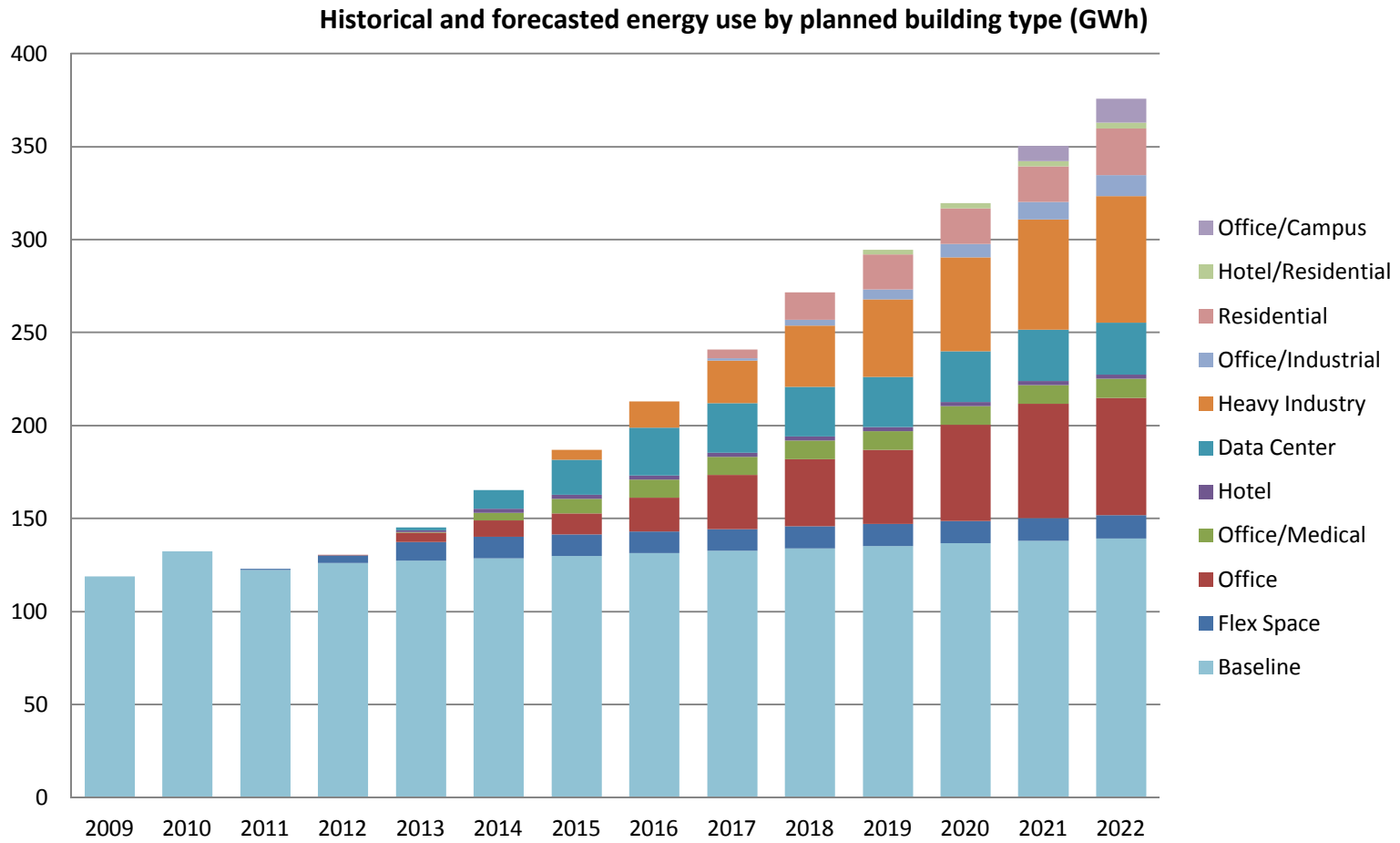


Figure 2. 2009-2022 Baseline and Forecast Usage (GWh) by building end use for Navy Yard substations SS93 and SS664.

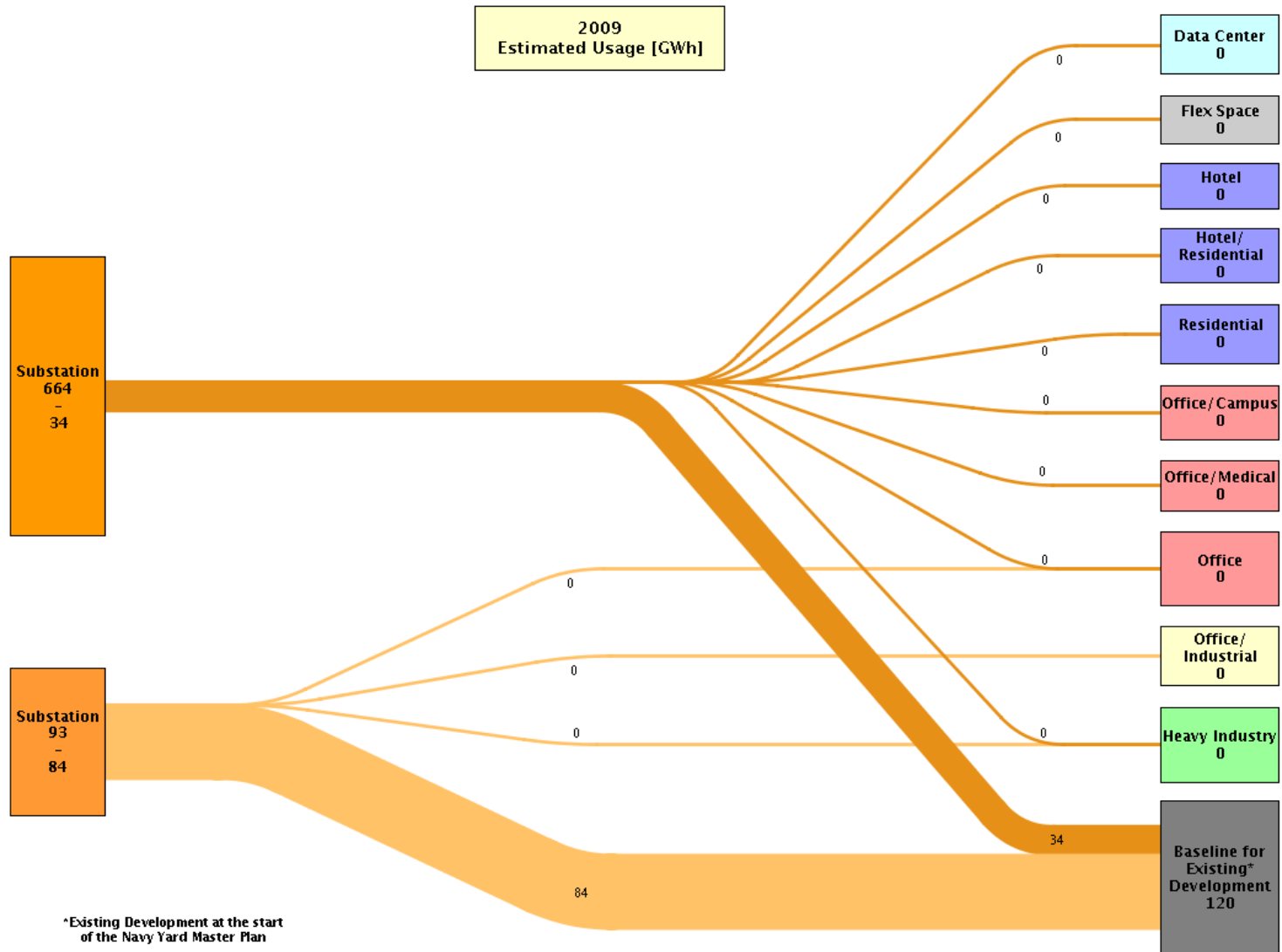


Figure 3. 2009 Energy Usage (GWh) for Navy Yard substations SS93 and SS664. No property additions are forecasted.

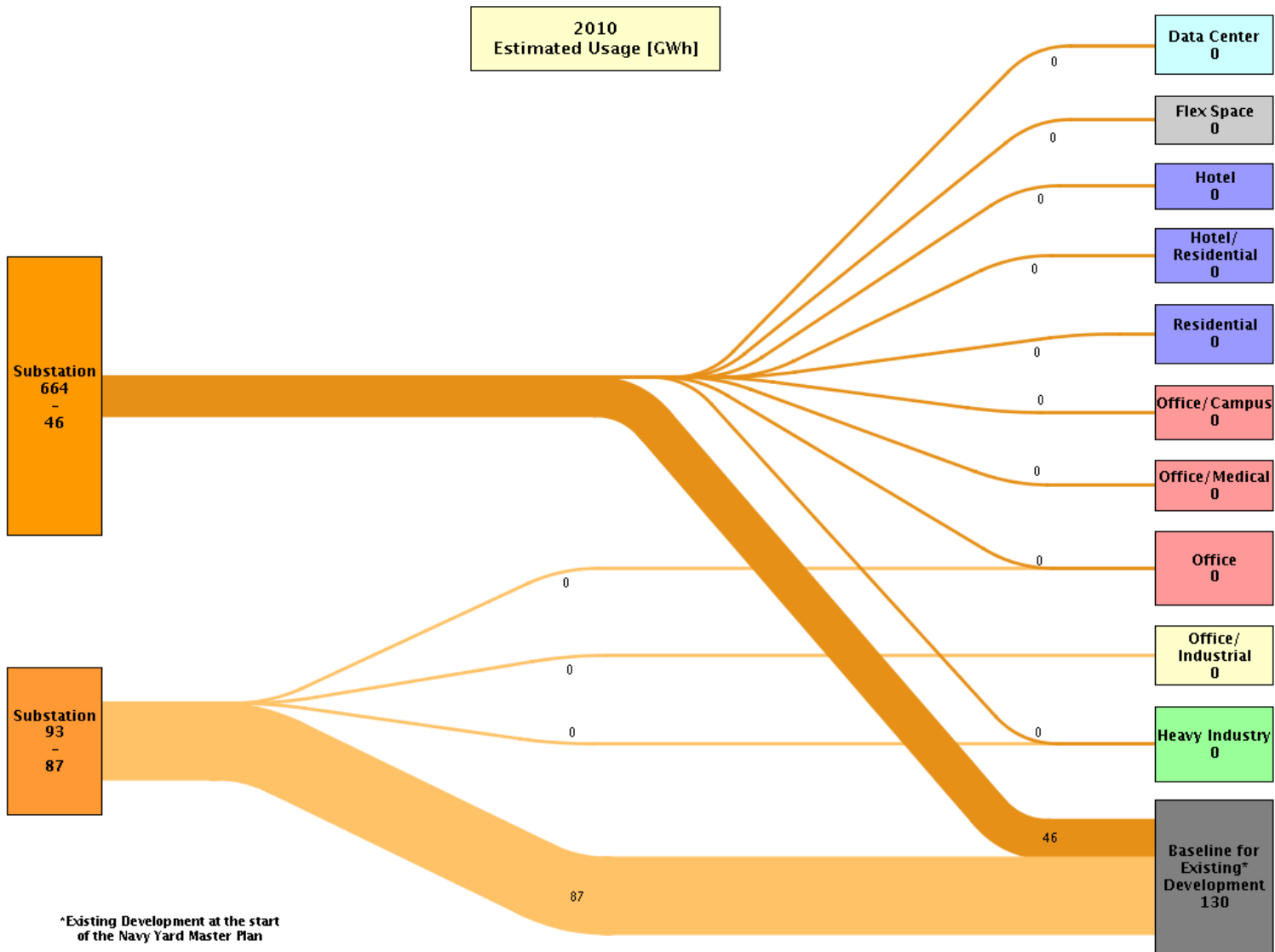


Figure 4. 2010 Energy Usage (GWh) for Navy Yard substations SS93 and SS664. No property additions are forecasted.

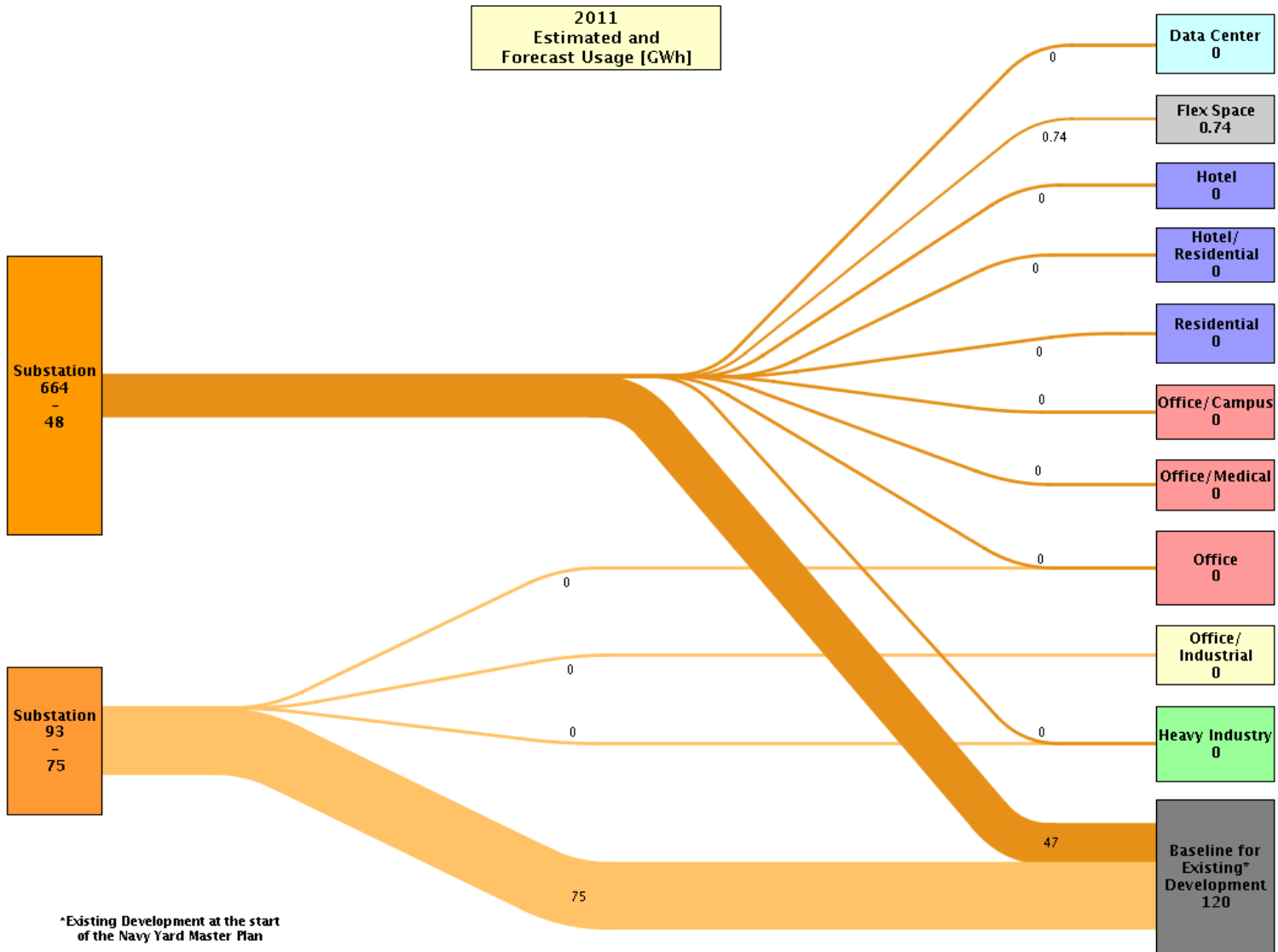


Figure 5. 2011 Energy Usage (GWh) for Navy Yard substations SS93 and SS664. Additions to SS664 usage include 200,000 sq. ft. of flex space.

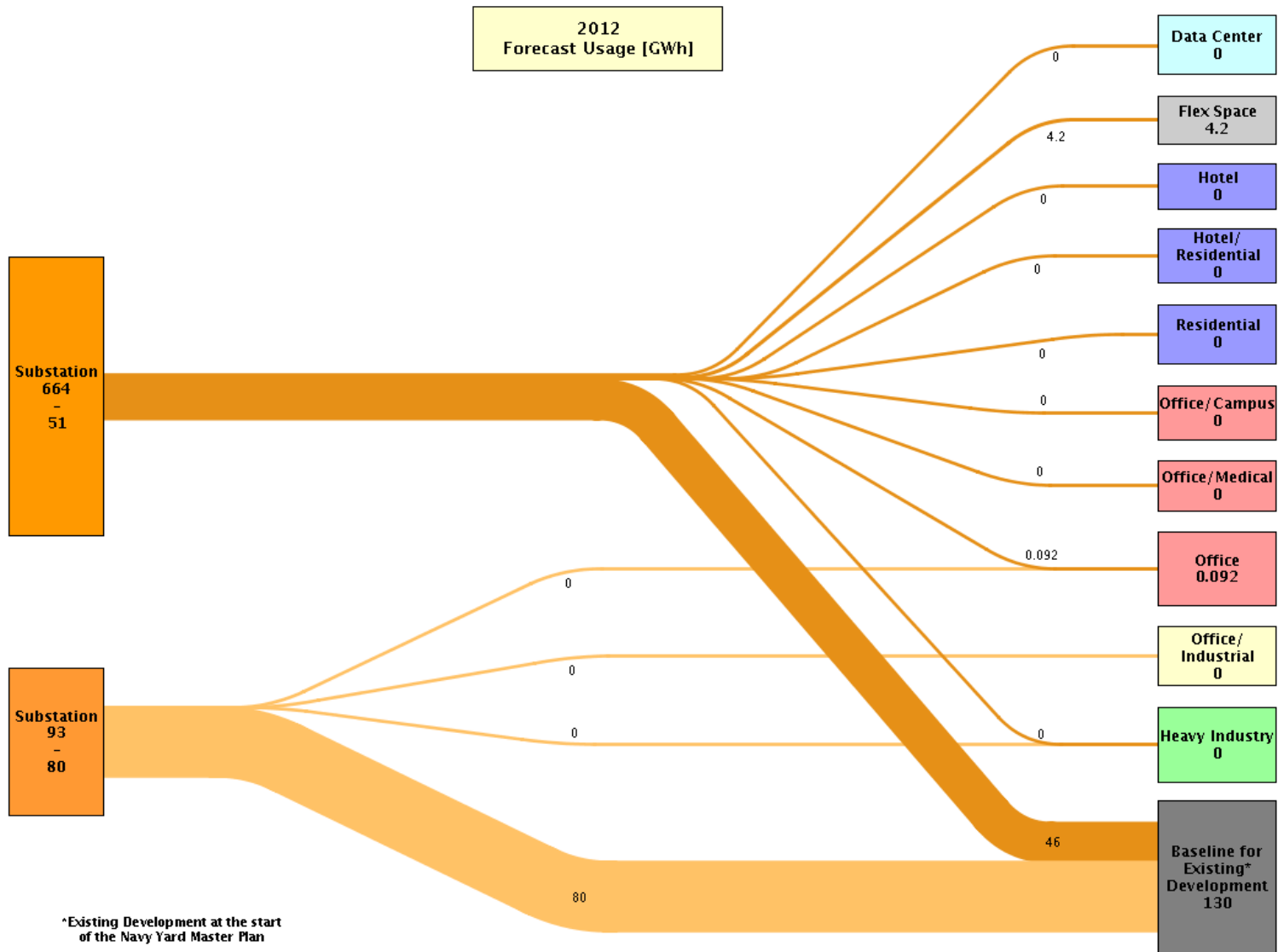


Figure 6. 2012 Energy Usage (GWh) for Navy Yard substations SS93 and SS664. Additions to SS664 usage include 2,125,000 sq. ft. of office space.

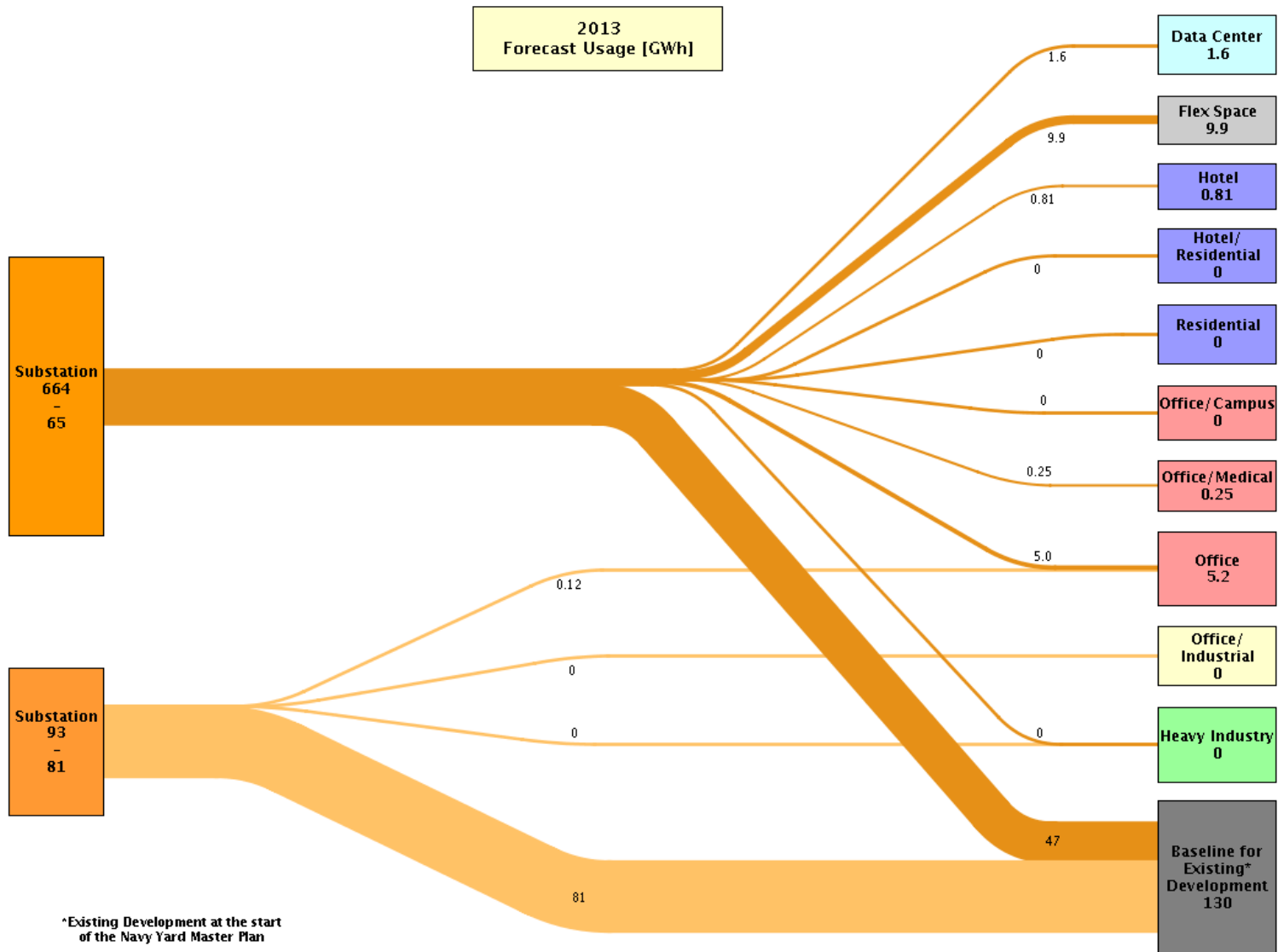


Figure 7. 2013 Energy Usage (GWh) for Navy Yard substations SS93 and SS664. Additions to SS664 usage include offices (50,000 sq. ft.), hotel (100,000 sq. ft.), and office/medical (236,000 sq. ft.). Additions to SS93 consist of 207,000 sq. ft. of office space

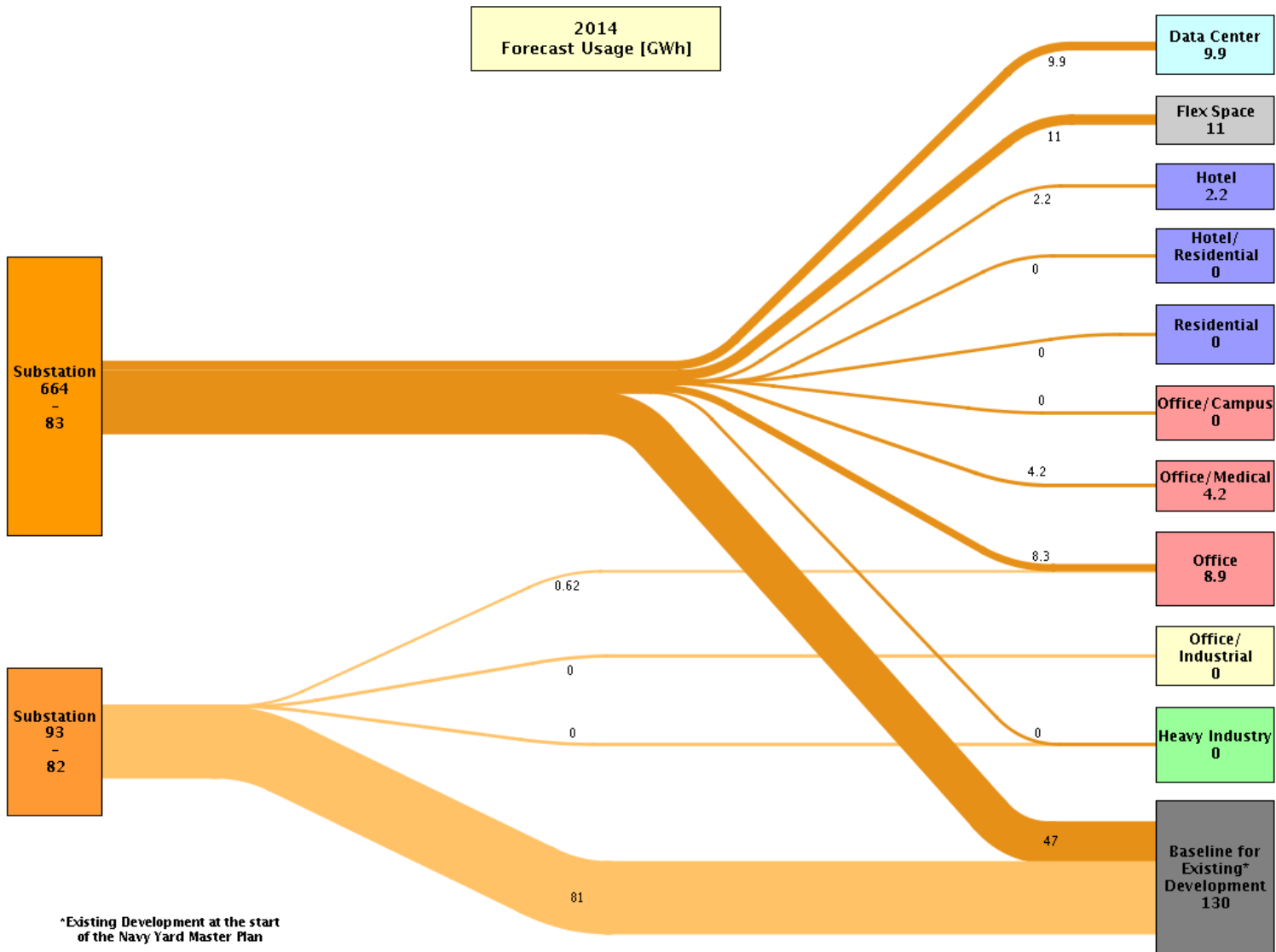


Figure 8. 2014 Energy Usage (GWh) for Navy Yard substations SS93 and SS664.

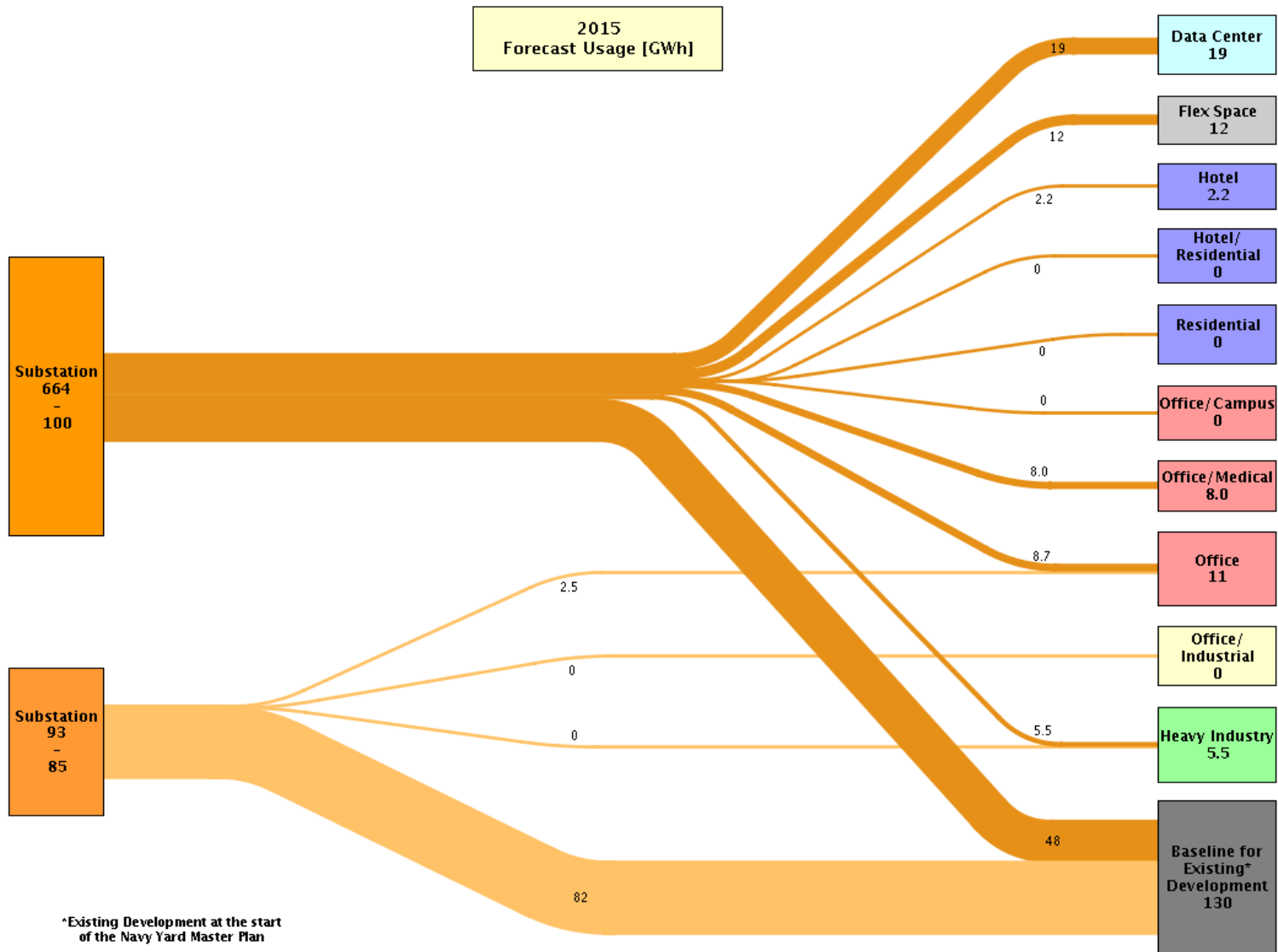


Figure 9. 2015 Energy Usage (GWh) for Navy Yard substations SS93 and SS664. Additions to SS664 usage include 750,000 sq. ft. of heavy industrial space.

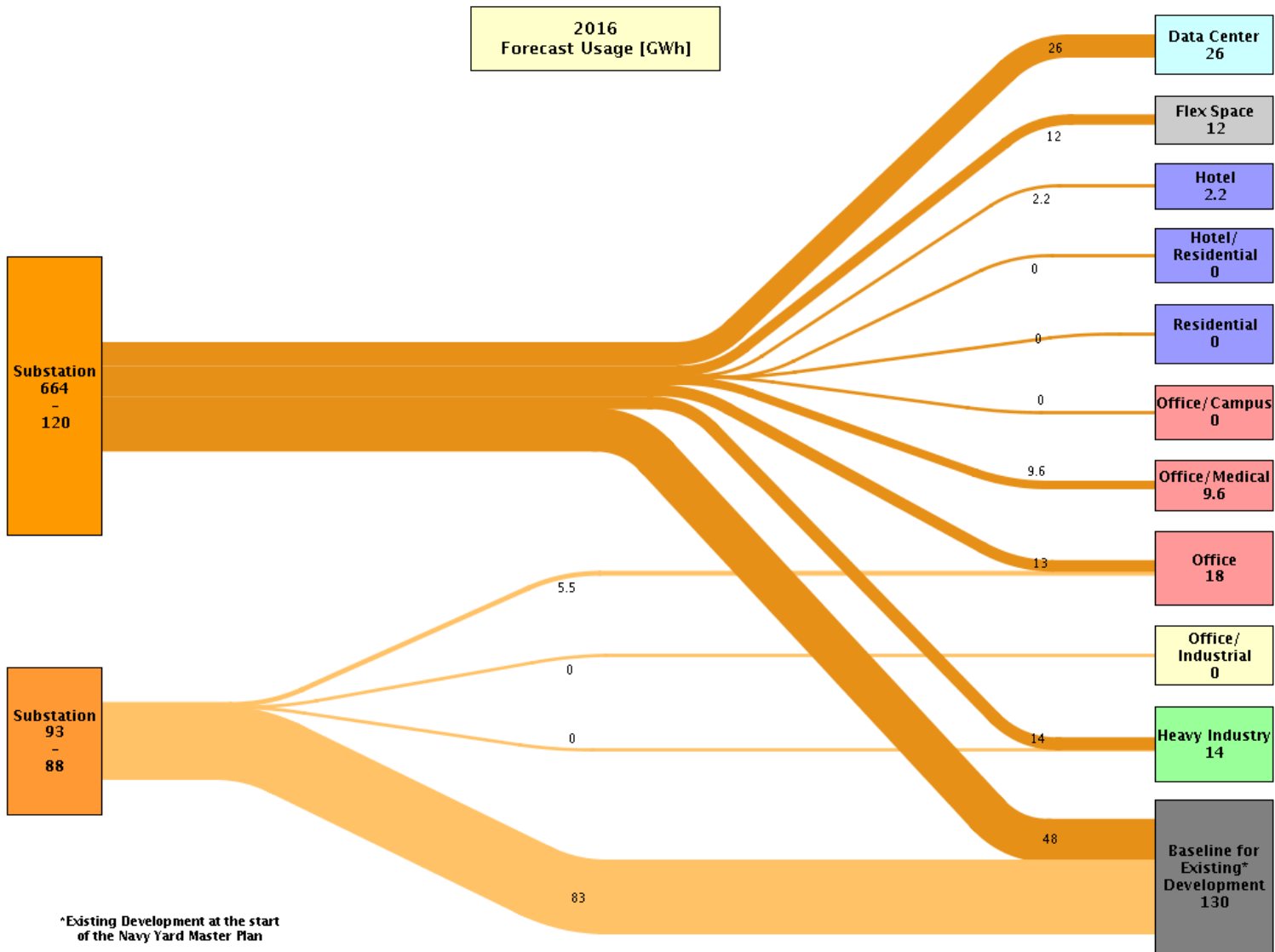


Figure 10. 2016 Energy Usage (GWh) for Navy Yard substations SS93 and SS664.

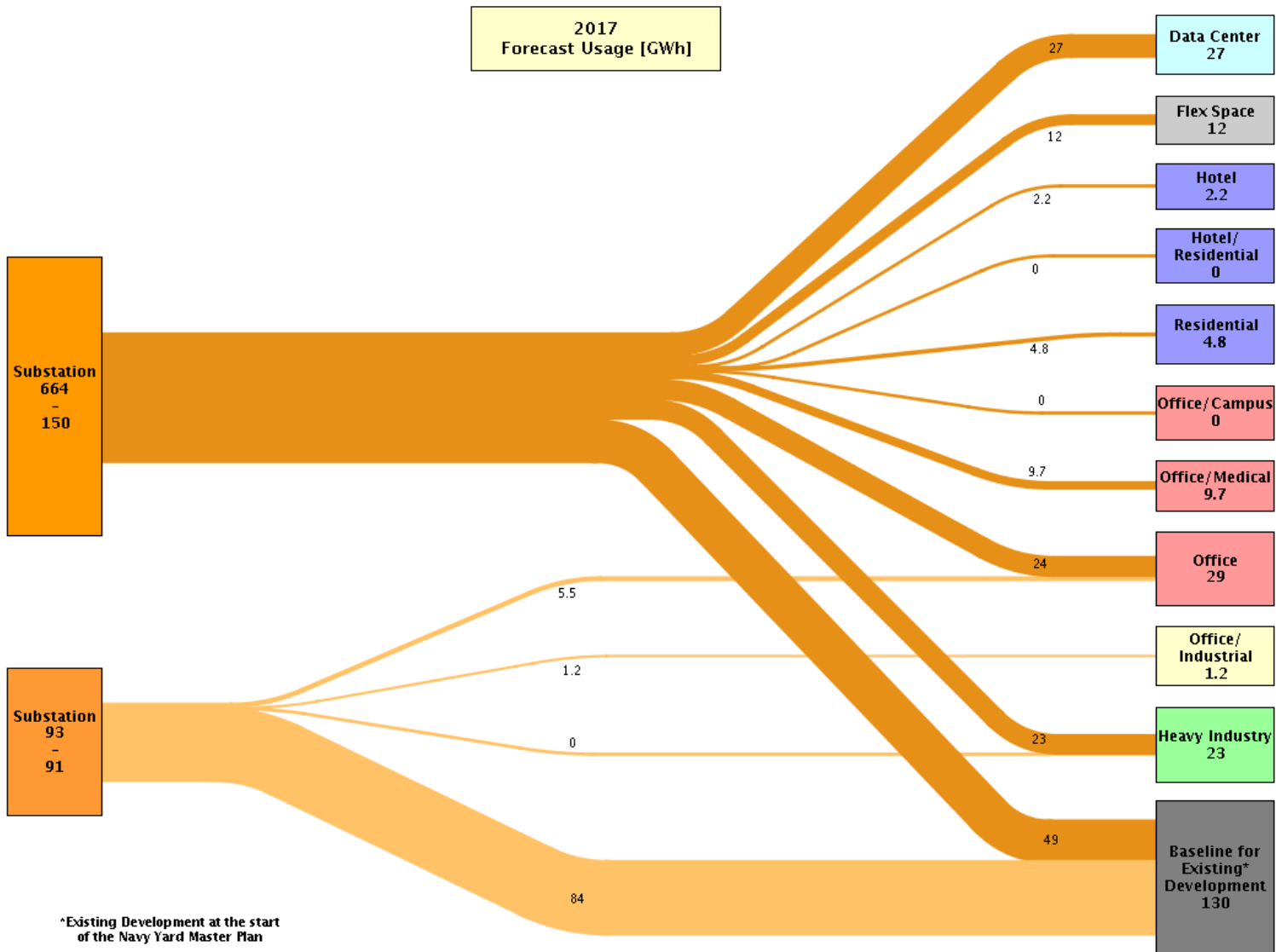


Figure 11. 2017 Energy Usage (GWh) for Navy Yard substations SS93 and SS664. Additions to SS664 usage include 1,070,000 sq. ft. of residential space. Additions to SS93 consist of 300,000 sq. ft. of office/industrial space

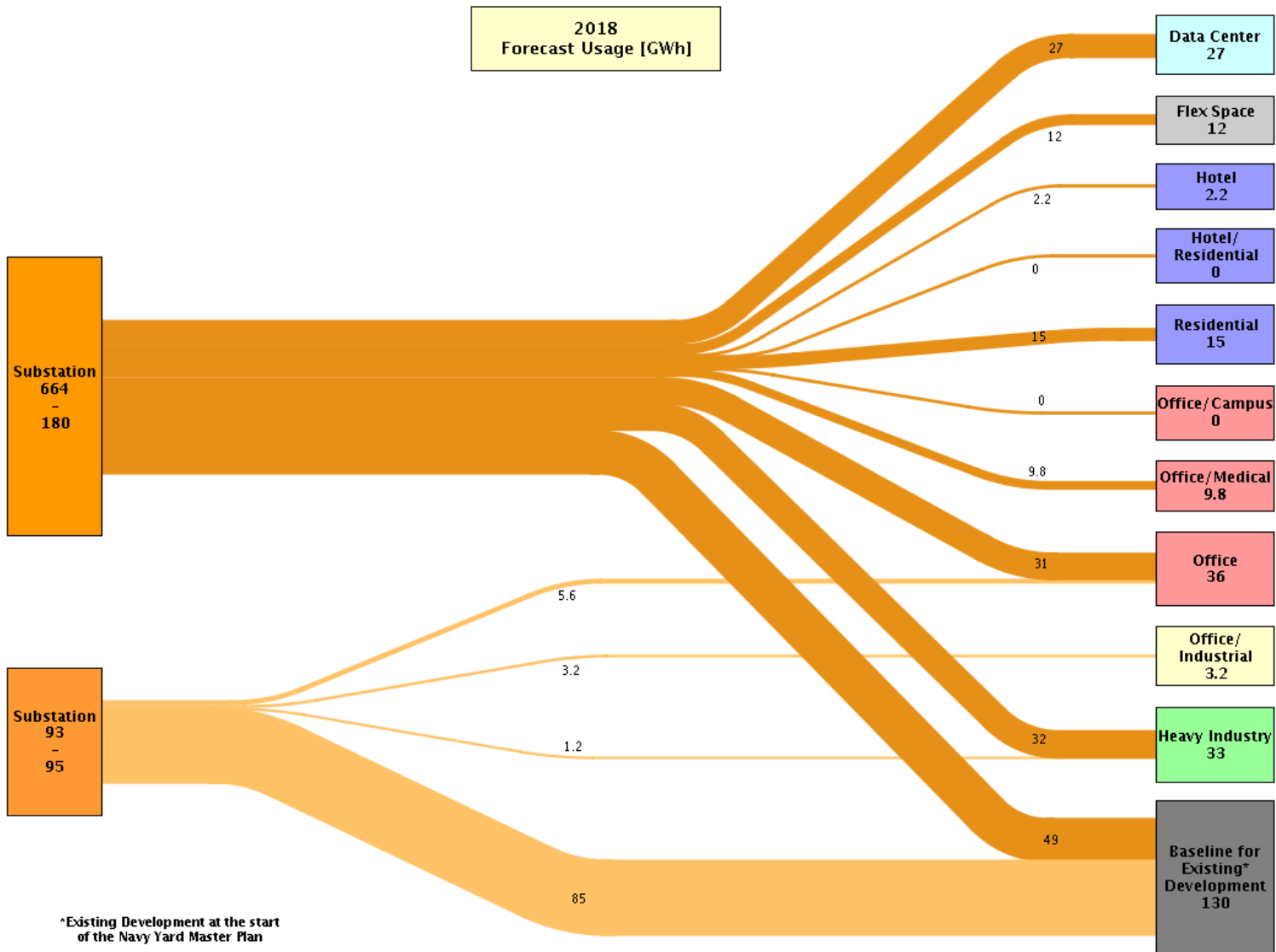


Figure 12. 2018 Energy Usage (GWh) for Navy Yard substations SS93 and SS664. Additions to SS93 consist of an electric oven for heavy industrial purposes.

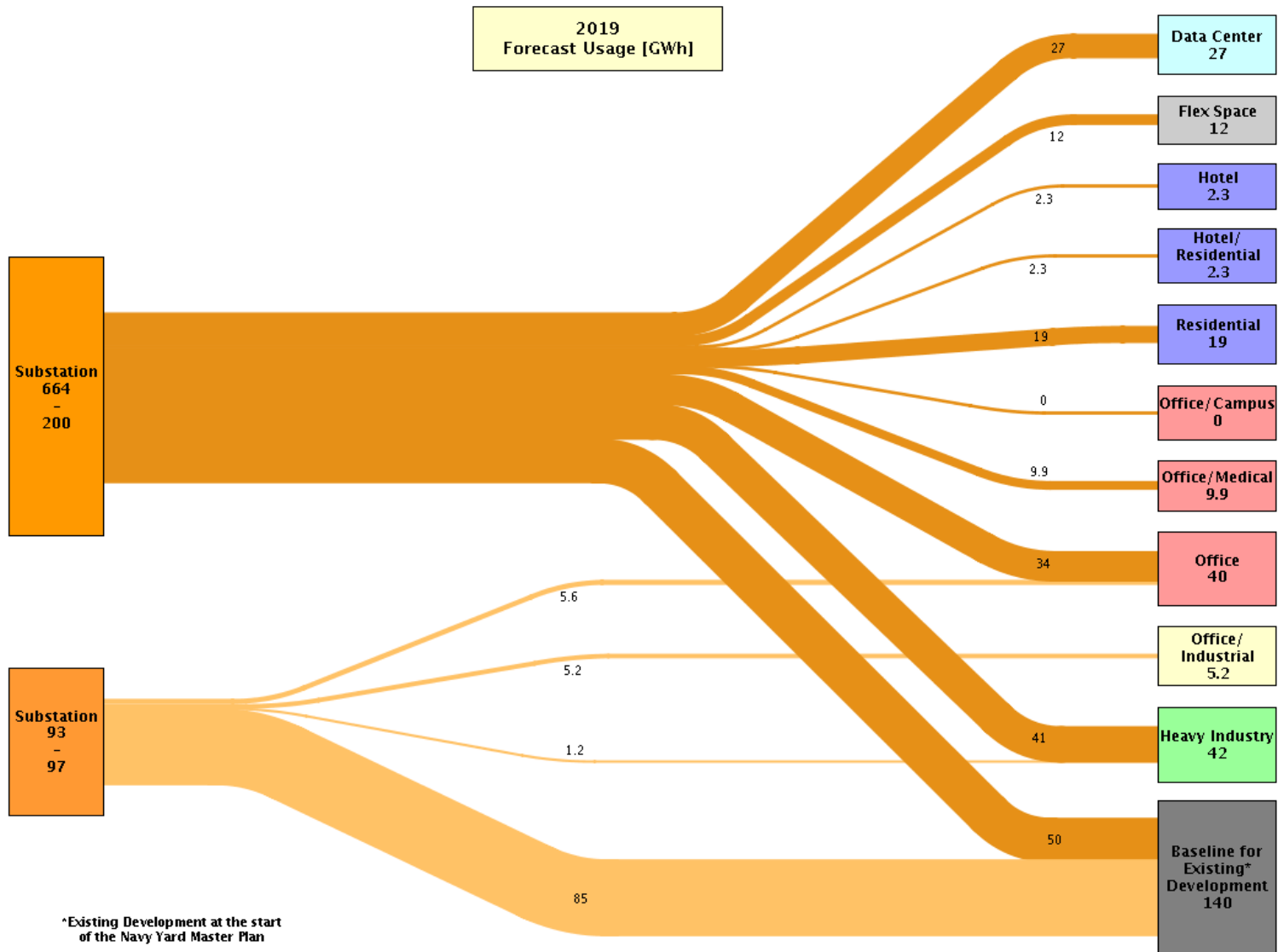


Figure 13. 2019 Energy Usage (GWh) for Navy Yard substations SS93 and SS664. Additions to SS664 usage include 108,000 sq. ft. of hotel/residential space.

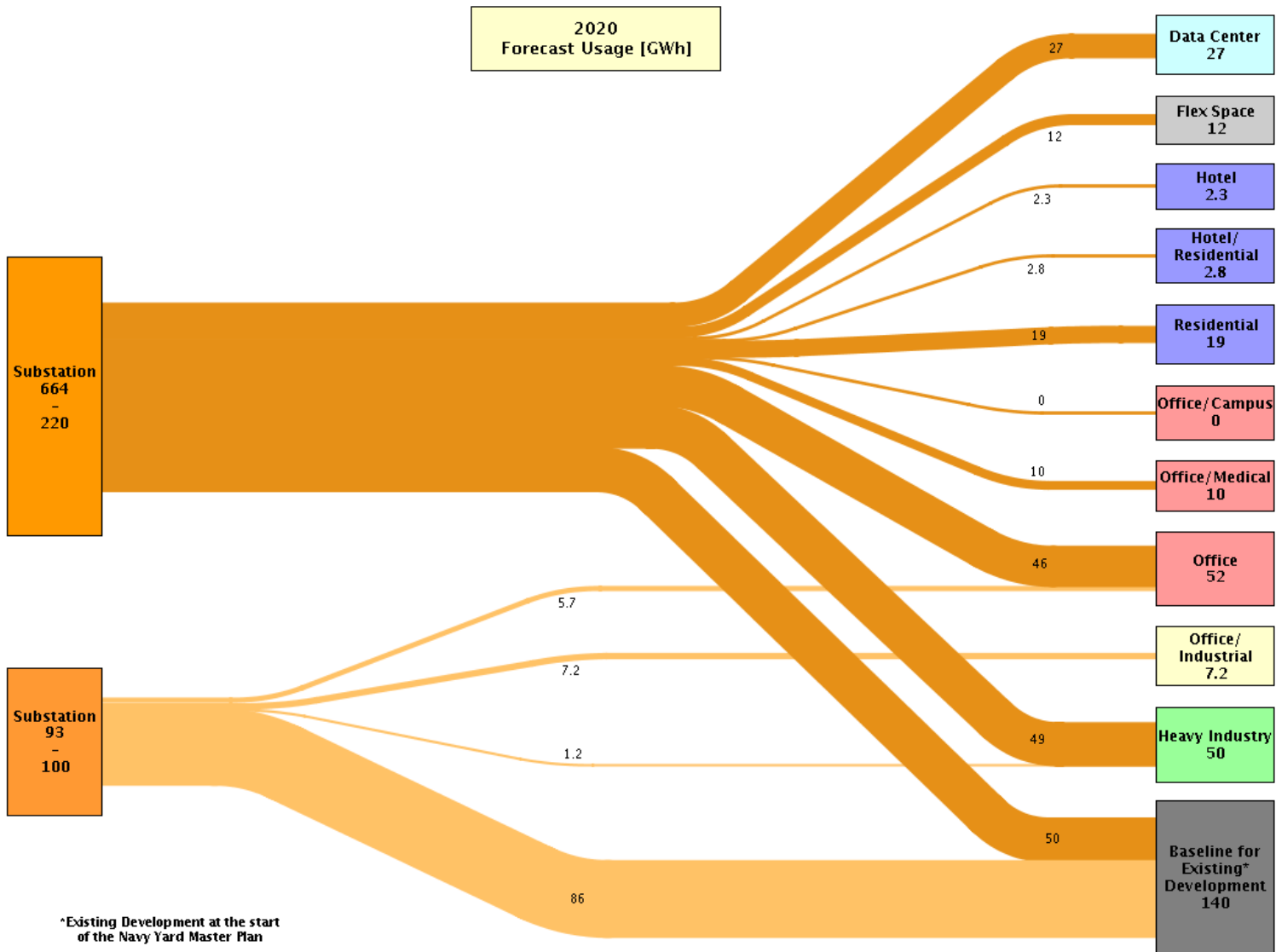


Figure 14. 2020 Energy Usage (GWh) for Navy Yard substations SS93 and SS664.

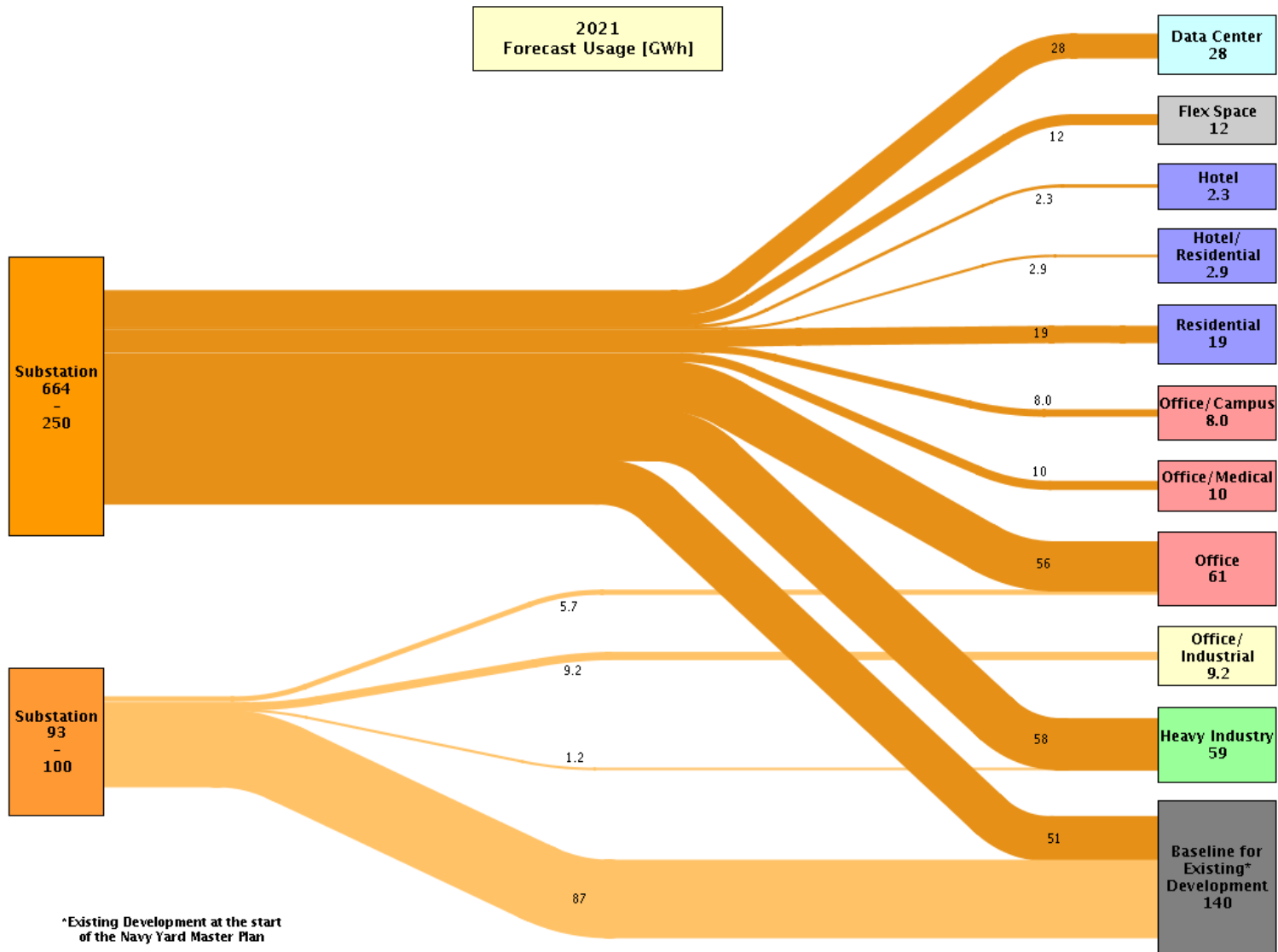


Figure 15. 2021 Energy Usage (GWh) for Navy Yard substations SS93 and SS664. Additions to SS664 usage include 490,000 sq. ft. of office/campus space.

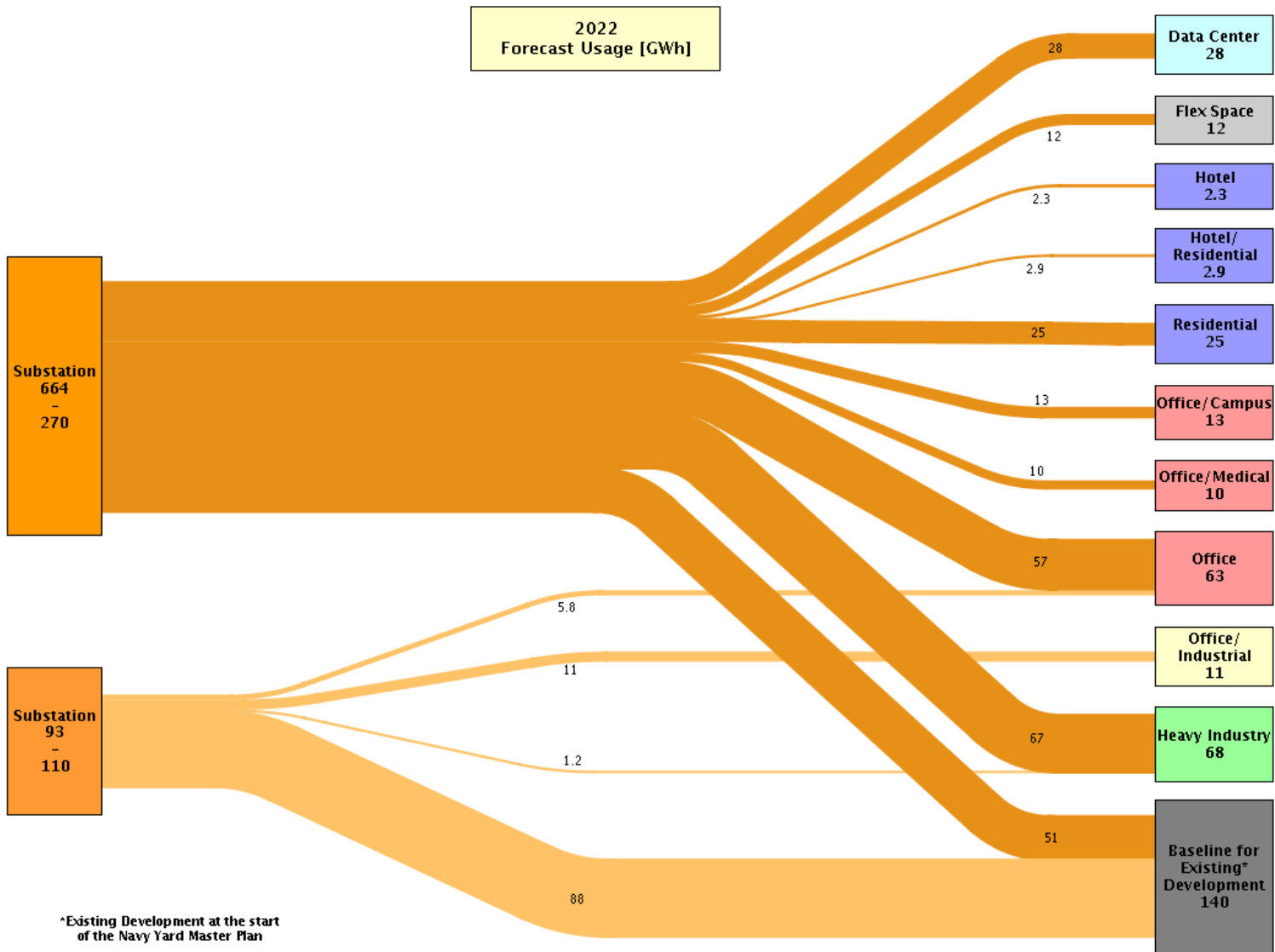


Figure 16. 2022 Energy Usage (GWh) for Navy Yard substations SS93 and SS664.

Conclusions

The Sankey flow diagrams provide a visual compact form of estimated annual energy consumption for reporting and informing stakeholders. The energy flows capture details about the division of energy consumption by building type, property additions, building renovations, and assumed yearly increased in energy use. The regional energy flow details provide the framework to share and discuss electricity distribution, sub-metering needs, and renovation details at the Navy Yard and EEB Hub. It also provides another metrics tools for tracking milestones of the Navy Yard Master Energy Plan with each addition or retrofit and analyzing building or regional performance. While relatively easy to update, it can also be a visualization to explain future plans and help prioritize efforts.

The Sankey diagrams show that with each year and increase in property square footage, substation 664 is expected to manage majority of the load from additions and renovations. There are plans to expand the electrical distribution system of the Navy Yard to provide the capacity and reliability for users [7]. One possibility is the addition of a third substation after 2015 to accommodate the added electrical load.

Ultimately, the prototype annual Sankey diagrams serve as a template for regional energy consumption. The annual time frames are meant to depict transitional effects of major property changes on regional energy usage. The added “transient” details provide a new way to depict energy flows over time as opposed to a single year snapshot Sankey diagram. The visual can be modified and formatted in alternate configurations to capture important details about the Navy Yard energy distribution. This data for this report is from the Energy Master Plan completed in February 2013 and represents projected data at that time. Modifications or updates to Sankey diagrams can be made to reflect changes in the NYMEP plans.

Acknowledgements

Thanks to Rudy Terry and Will Agate at PIDC for their help in developing the Sankey diagrams.

References:

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- [4] Singer, S., Simon, A.J., “EEBHub Navy Yard Sankey Diagram Energy Analysis Final Report,” Lawrence Livermore National Laboratory, Livermore, CA, Tech. Rep. LLNL-TR-613594, 2013.
- [5] Terry, R., “The Navy Yard,” conference talk, *Grid 20/20: Insights on Energy Flow*, Norristown, Pa., April 17, 2013. Retrieved from <http://www.pjm.com/~media/committees-groups/stakeholder-meetings/grid-2020-insights/20130417-distributed-generation-panel-1-terry.ashx>.
- [6] Singer, S., Simon, A.J., “EEBHub Building 101 Sankey Diagram Energy Analysis,” Lawrence Livermore National Laboratory, Livermore, CA, Tech. Rep. LLNL-TR-614312, 2013.
- [7] The Navy Yard – RFP for Energy Master Plan Consultant Services, Retrieved from http://www.pidc-pa.org/uploads/files/rfps/Energy_Master_Plan_RFP_31_June_2011_Final.pdf

Appendix A: Data and Assumptions

Assumptions:

- 2 substations, SS664 has 26 properties while SS93 has 10
- Range of usage: 6-120 W/sf
- LF 60% for baseline, 50% all else
 - LF projection is based on historical, aggregate NY load profile for typical recent year. [R. Terry]
- 1% inc/yr (except East End Development N/A)

Definitions:

Baseline: the load for all existing development at the start of the Master Plan (2008-2009). The current load includes a mix of commercial and industrial uses on two substations.

Feeder: In electric power distribution, a medium-voltage power line transferring power from a distribution substation to the distribution transformers

Flex Space: A term used for lightly zoned buildings. It is mainly used when referring to industrial or office space. Flex space evolved from light industrial warehouses being converted to office space. Includes shared office space among employees and visitors. [Wikipedia]

Load Factor (LF): Corresponds to the ratio between actual energy consumption (kWh) and the maximum power recorded (demand) for that period of time

Table A1 Use Forecast (GWh) for substation SS664 organized by year and Building Use

SS 664 USAGE FORECAST (GWh)	sq. ft. (10 ³)	W/sf	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Baseline			34.3	45.5	47.0	46.4	46.9	47.4	47.8	48.3	48.8	49.3	49.8	50.3	50.8	51.3
Data Center	50	120.0	0	0	0	0	1.6	9.9	18.6	25.7	26.5	26.8	27.1	27.3	27.6	27.9
Flex Space	200	27.0	0	0	0.7	4.2	9.9	11.4	11.5	11.6	11.8	11.9	12.0	12.1	12.2	12.4
Heavy Industry	750	21.3	0	0	0	0	0	0	5.5	14.2	23.0	31.8	40.5	49.3	58.0	66.8
Hotel	100	5.0	0	0	0	0	0.8	2.2	2.2	2.2	2.2	2.2	2.3	2.3	2.3	2.3
Hotel/Residential	108	6.0	0	0	0	0	0	0	0	0	0	0	2.3	2.8	2.9	2.9
Office	2125	62.0	0	0	0	0.1	5.0	8.3	8.7	12.9	23.6	30.7	34.1	46.0	55.7	57.4
Office/Campus	490	6.0	0	0	0	0	0	0	0	0	0	0	0	0	8.0	12.9
Office/Medical	236	27.5	0	0	0	0	0.3	4.2	8.0	9.6	9.7	9.8	9.9	10.0	10.1	10.2
Residential	1070	18.0	0	0	0	0	0	0	0	0	4.8	14.7	19.0	19.2	19.4	25.3
TOTAL			34.3	45.5	47.8	50.7	64.5	83.2	102.3	124.6	150.4	177.1	196.9	219.3	247.0	269.3

Table A2 Use Forecast (GWh) for substation SS93 organized by year and Building Use

SS 93 USAGE FORECAST (GWh)	sq. ft. (10 ³)	W/sf	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Baseline			84.5	87.0	75.3	79.7	80.5	81.3	82.1	83.0	83.8	84.6	85.5	86.3	87.2	88.1
Heavy Industry	0	0	0	0	0	0	0	0	0	0	0	1.2	1.2	1.2	1.2	1.2
Office	207	18	0	0	0	0	0.1	0.6	2.5	5.5	5.5	5.6	5.6	5.7	5.7	5.8
Office/Industrial	300	54	0	0	0	0	0	0	0	0	1.2	3.2	5.2	7.2	9.2	11.3
TOTAL			84.5	87.0	75.3	79.7	80.7	82.0	84.6	88.4	90.5	94.6	97.5	100.4	103.4	106.3

Table A3 Use Forecast (GWh) combined (substation SS93 and SS664) organized by year and Building Use

USE FORECAST (GWh) SS 664 AND SS 93	sq. ft. (10 ³)	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Baseline		118.7	132.5	122.3	126.2	127.4	128.7	130.0	131.3	132.6	133.9	135.3	136.6	138.0	139.4
Flex Space	200	0	0	0.7	4.2	9.9	11.4	11.5	11.6	11.8	11.9	12.0	12.1	12.2	12.4
Office	2332	0	0	0	0.1	5.2	8.9	11.1	18.3	29.1	36.3	39.7	51.6	61.4	63.2
Office/Medical	236	0	0	0	0	0.3	4.2	8.0	9.6	9.7	9.8	9.9	10.0	10.1	10.2
Hotel	100	0	0	0	0	0.8	2.2	2.2	2.2	2.2	2.2	2.3	2.3	2.3	2.3
Data Center	50	0	0	0	0	1.6	9.9	18.6	25.7	26.5	26.8	27.1	27.3	27.6	27.9
Heavy Industry	750	0	0	0	0	0	0	5.5	14.2	23.0	33.0	41.7	50.5	59.2	68.0
Office/Industrial	300	0	0	0	0	0	0	0	0	1.2	3.2	5.2	7.2	9.2	11.3
Residential	1070	0	0	0	0	0	0	0	0	4.8	14.7	19.0	19.2	19.4	25.3
Hotel/Residential	108	0	0	0	0	0	0	0	0	0	0	2.3	2.8	2.9	2.9
Office/Campus	490	0	0	0	0	0	0	0	0	0	0	0	0	8.0	12.9
Total		118.7	132.5	123.1	130.4	145.2	165.2	186.9	213.0	241.0	271.7	294.4	319.7	350.4	375.7
Without Baseline		0	0	0.7	4.2	17.8	36.5	57.0	81.7	108.4	137.8	159.2	183.1	212.4	236.3

Appendix B: Navy Yard Master Plan 2013 Update Details

PROGRAM SUMMARY							
	Central Green	Historic Core	Canal District	Mustin Park District	Port Expansion	Shipyards and Commerce Center	TOTALS
ACRES	72	194	38	81	192	623	1,200
OCCUPIED (SF)	478,796	1,718,402	-	101,344	106,050	3,933,449	6,338,041
FUTURE RENOVATIONS (SF)	-	1,352,380	-	-	-	332,185	1,684,565
NEW CONSTRUCTION (SF)	921,000	1,420,673	948,000	901,000	965,000	235,000	5,390,673
TOTAL (SF)	1,399,796	4,491,455	948,000	1,002,344	1,071,050	4,500,634	13,413,279
RESIDENTIAL UNITS	-	1,018	-	-	-	-	1,018
EMPLOYMENT	5,599	17,392	3,792	4,009	1,071	4,501	36,364

*Square Feet of Residential Units are included in Future Renovations and New Construction Area Totals

**Assumes an average ratio of 250 square feet per employee in Office/R&D and 1,000 square feet per employee in Industrial areas

Figure 8.2 Program summary of The Navy Yard

Figure B1. Table from NYMP showing the occupied, planned renovations, and new construction square footage of each district. [2]

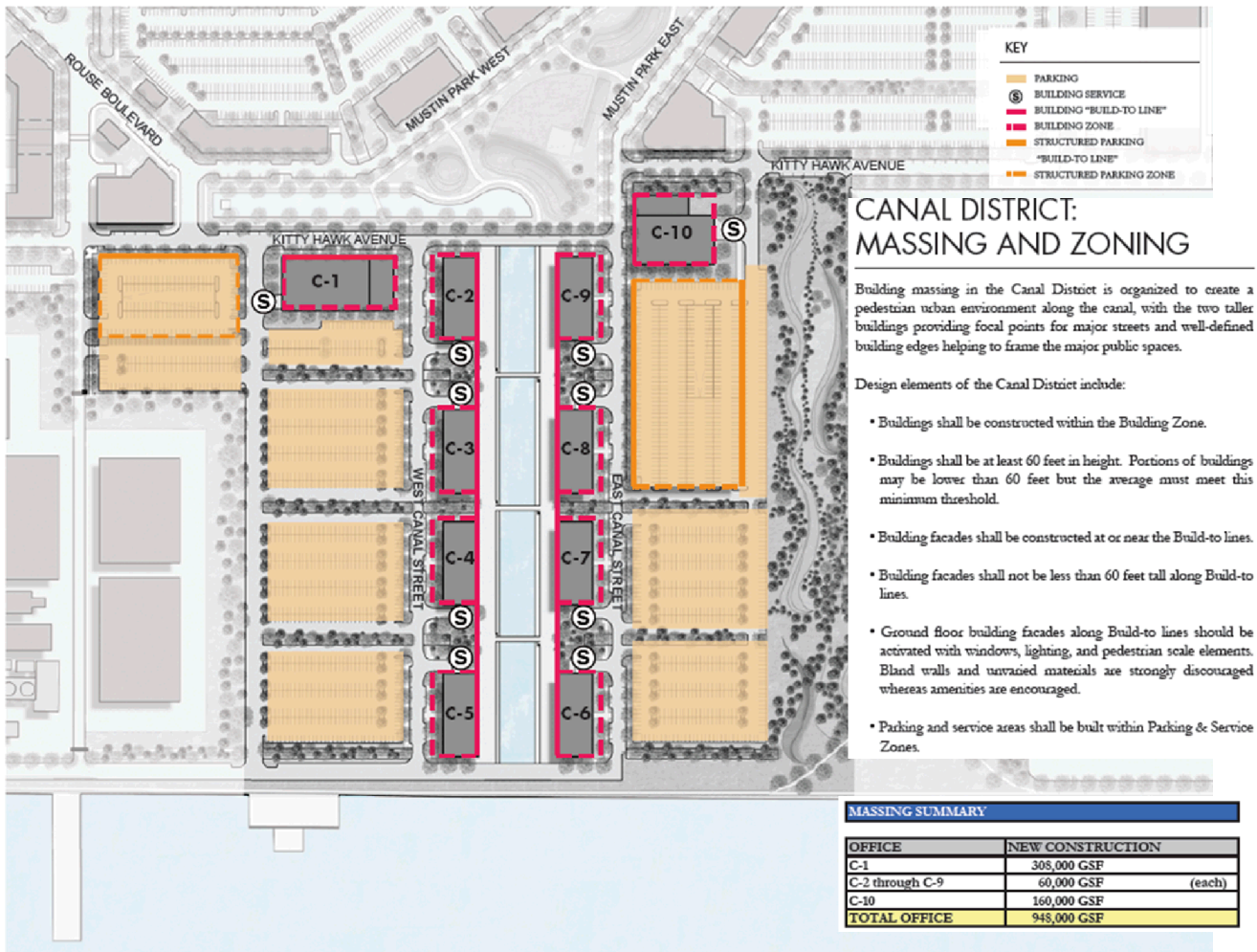


Figure B2. Canal District zoning map from NYMP and table summarizing square footage of new construction. [2]

HISTORIC CORE: MASSING AND ZONING

The building massing in the Historic Core is intended to reinforce the urban grid and the main street axes of Broad Street, 11th Street, and Kitty Hawk Avenue. A high priority is given to enhancing the strong pedestrian character in the Historic Core in order to encourage this district of The Navy Yard as a center for vibrant residential and amenity programs. The combined massing of new construction with preservation of the historic structures helps to define League Island Park, while preserving the open character of the historic Marine Parade Grounds and the Delaware River and Reserve Basin waterfronts by minimizing the impact of new construction in these areas. Important design criteria continue as proposed in the 2004 Master Plan:

- New buildings shall be constructed within the Building Zone.
- New buildings shall be at least 30 feet in height.
- New building facades shall be constructed at or near the Build-to lines.
- Building facades shall not be less than 30 feet tall along Build-to lines.
- Ground floor building facades along Build-to lines should be activated with windows, lighting, and pedestrian scale elements. Bland walls and unvaried materials are strongly discouraged.
- Parking and service areas shall be built within Parking & Service Zones.

MASSING SUMMARY			
CAMPUS		NEW CONSTRUCTION	
H-1		126,000 GSF	
H-2, H-3, H-4		60,000 GSF (each)	
H-5, H-6		52,000 GSF (each)	
H7		40,000 GSF	
TOTAL CAMPUS		450,000 GSF	
RESIDENTIAL	NEW	RENOV.	UNITS
H-8	151,700 GSF		115
H-9	151,700 GSF		115
H-10	124,000 GSF		94
H-11	168,850 GSF		128
H-12	84,425 GSF		64
TOTAL NEW	680,675 GSF		516
624		428,000 GSF	268
83		292,130 GSF	166
608		107,760 GSF	68
TOTAL RENOVATED		827,890 GSF	502
TOTAL RESIDENTIAL	1,508,565 GSF		1018
OFFICE	AREA		
H13		76,000 GSF	
TOTAL OFFICE		76,000 GSF	

Figure B3. Historic Core table from NYMP summarizing square footage of new construction and renovations. [2]

HISTORIC CORE: MASSING AND ZONING

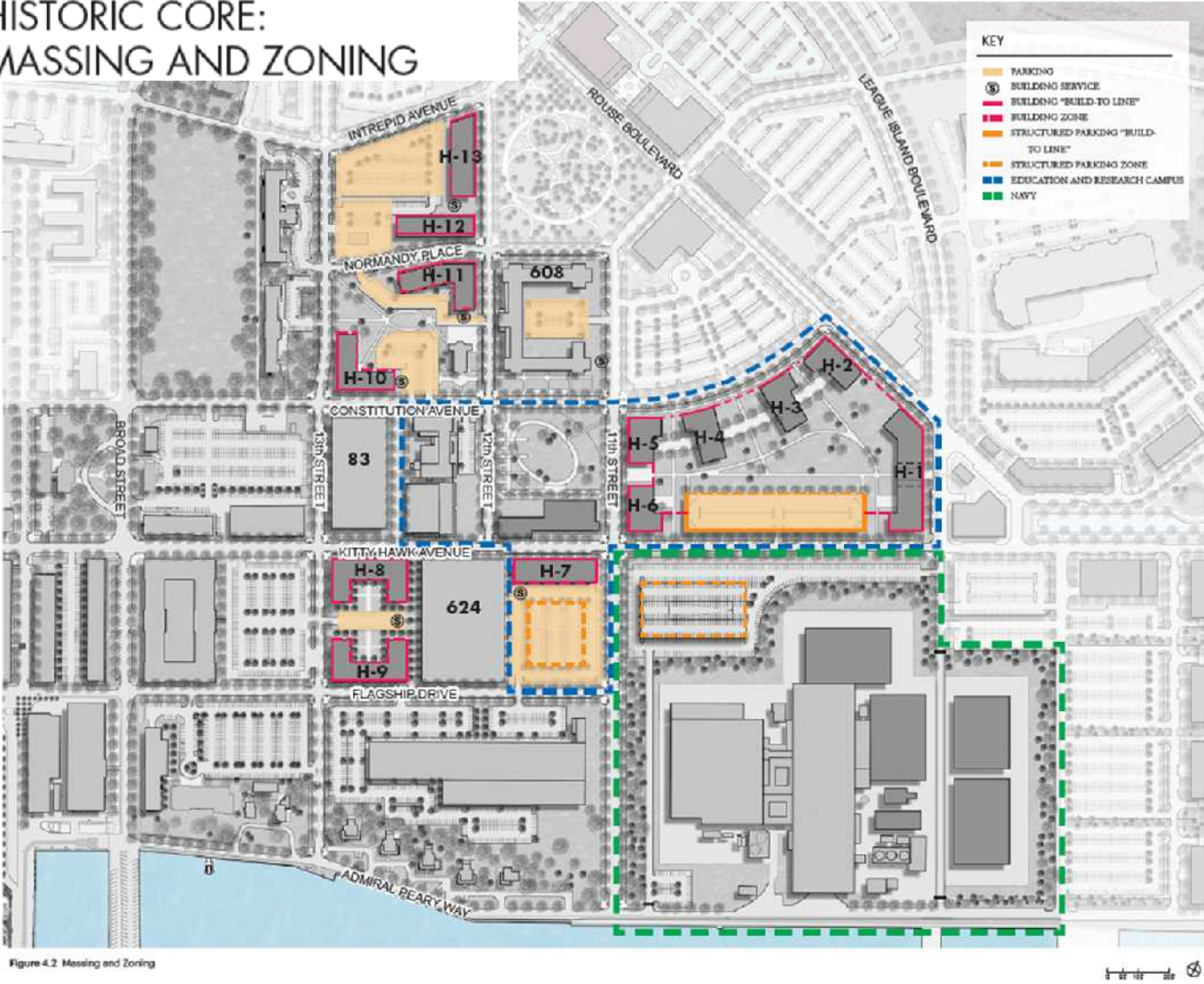


Figure B4. Historic Core zoning map from NYMP. [2]

MUSTIN PARK DISTRICT: MASSING

The building massing in the Mustin Park District is intended to reinforce the major public spaces, giving them strong, well-defined edges around Mustin Park, with the following design guidelines:

- Buildings shall be constructed within the Building Zone.
- Buildings shall be at least 60 feet in height. Portions of buildings may be lower than 60 feet but the average must meet this minimum threshold.
- Building facades shall be constructed at or near the Build-to lines.
- Building facades shall not be less than 60 feet tall along Build-to lines.
- Ground floor building facades along Build-to lines should be activated with windows, lighting, and pedestrian scale elements. Bland walls and unvaried materials are strongly discouraged.
- Parking and service areas shall be built within Parking & Service Zones.

MASSING SUMMARY	
OFFICE	NEW CONSTRUCTION
MP1, MP3, MP4, MP5, MP7	60,000 GSF (each)
MP2, MP8	80,000 GSF (each)
MP6	250,000 GSF
TOTAL OFFICE	710,000 GSF
FLEX SPACE	NEW CONSTRUCTION
MP9	19,000 GSF
MP10	82,000 GSF
MP11, MP12	45,000 GSF (each)
TOTAL NEW FLEX	191,000 GSF

Figure B5. Mustin Park District table from NYMP summarizing square footage of new construction. [2]

MUSTIN PARK DISTRICT: MASSING

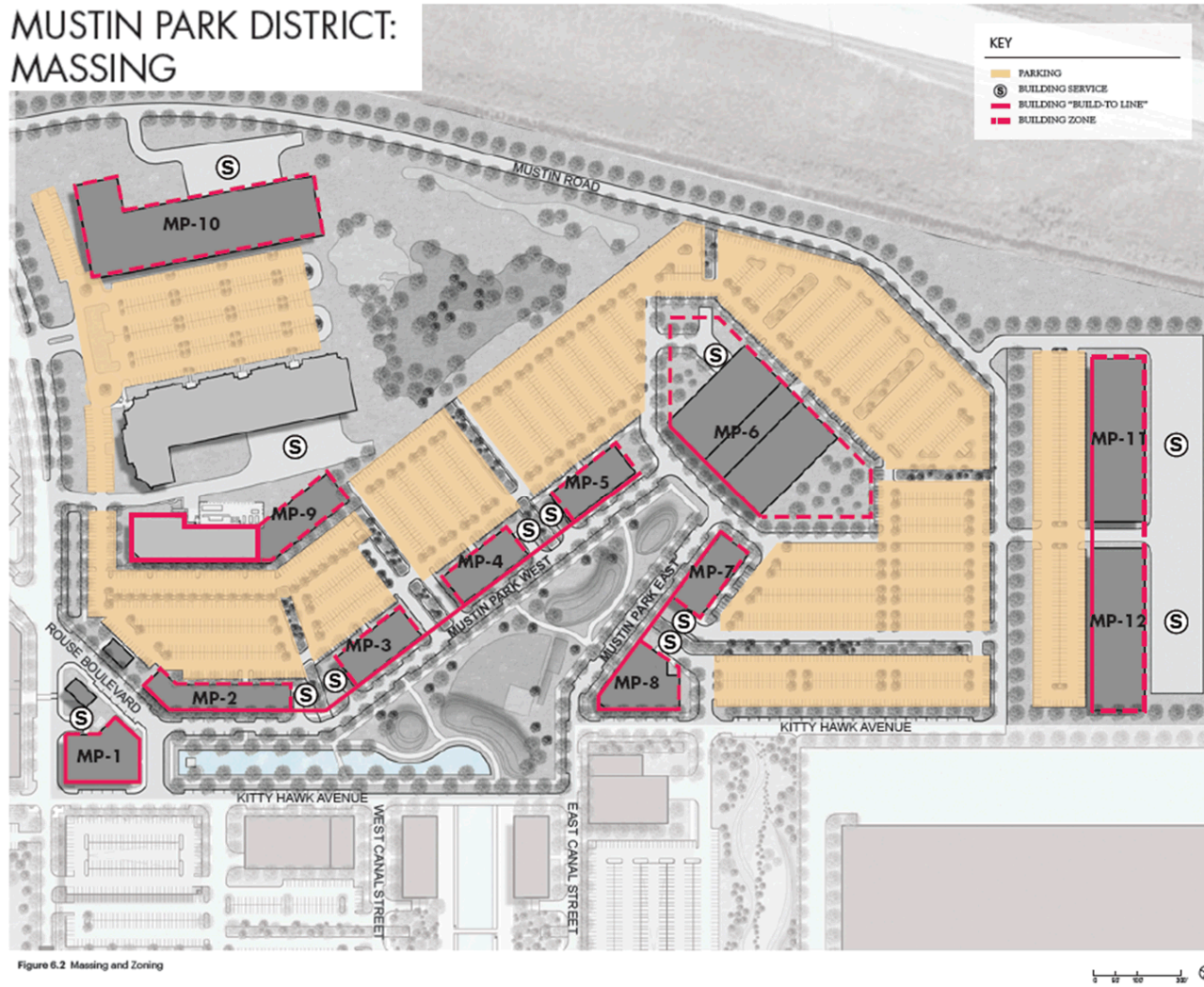


Figure 6.2 Massing and Zoning

Figure B6. Mustin Park District zoning map from NYMP. [2]

Appendix C: Potential for Sankey Diagrams in Building Energy

How Are Sankey Diagrams Useful for Building Energy?

Previously the EEB Hub requested Sankey diagrams depicting energy use in Building 101 (B101) [6]. LLNL developed a template showing building envelope energy exchanges, energy consumption from electricity and natural gas, as well as the end uses. EnergyPlus models and basic approximations about B101 were used to estimate energy flows and generate an annual Sankey diagram, and a representative winter (figure C1) and summer (figure C2) month. The comparison from winter and summer captures the vast differences in natural gas usage for heating and electricity for cooling needs. It is easy to recognize the building's interactions with its environment, and the strain that induces on its energy consumption.

Nowhere else has the engineered and environmental fluxes of energy been consolidated into a single visual reference. These visualizations help stakeholders and building managers identify large sources of energy consumption, gaps in data, and points of needed equipment improvements.

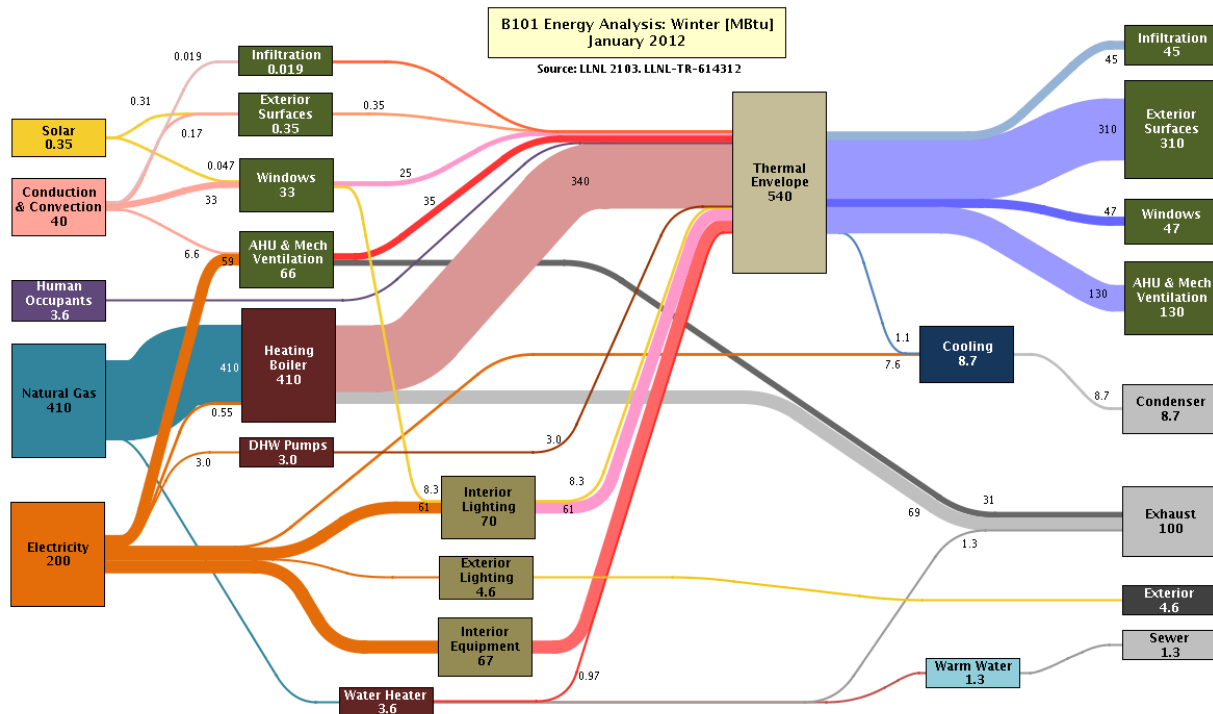


Figure C1. Representative B101 winter Sankey diagram using data from January 2012. Much of the thermal load is lost to the exterior through heat losses to the walls, windows and infiltration. The largest source of energy consumption is natural gas that provides a large amount of heating to the building. [6]

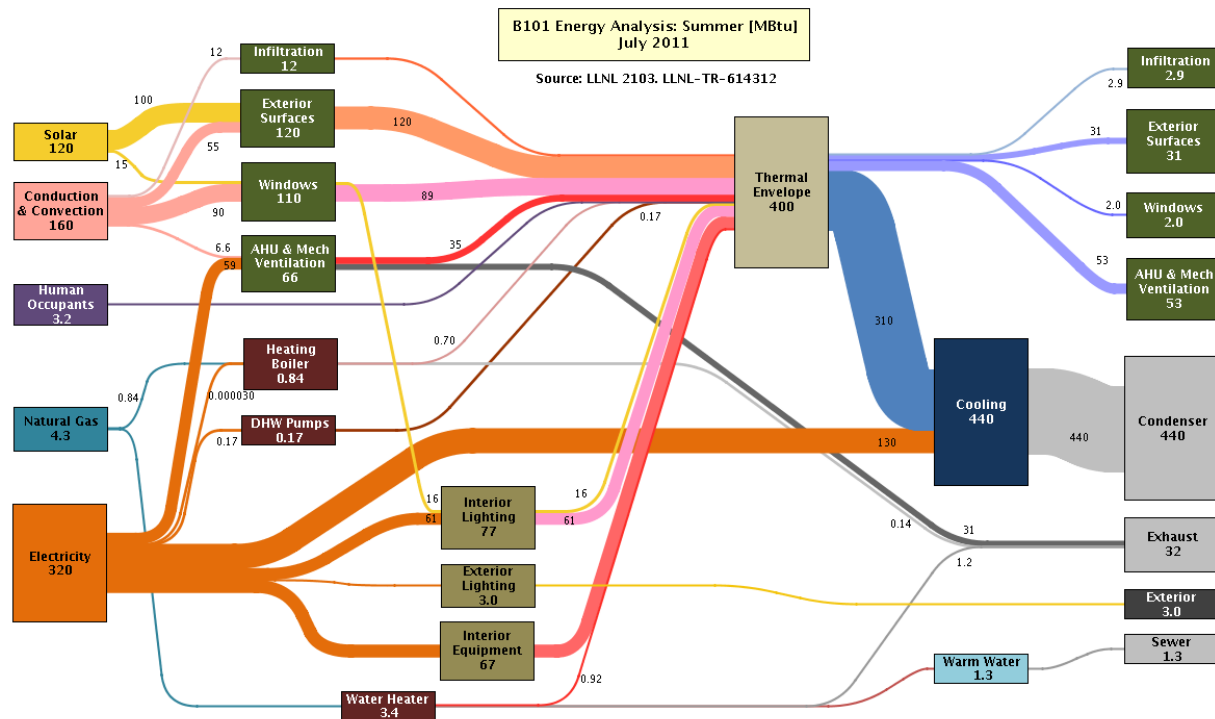


Figure C2. Representative B101 summer Sankey diagram using data from July 2011. In summer, the boilers are turned off as is reflected in the Sankey diagram. Heating to the building is reflected in contributions from several sources: the exterior environment (i.e. solar) provides heat, and interior components give off heat (lights, equipment). The largest energy loss from the building is due to the cooling. [6]

Potential Projects

EnergyPlus models incorporate building parameters, material properties, meteorological data, equipment and their efficiencies, and to some extent, the behavior of its occupants. Sankey diagrams rely on simulated heat gains and some equipment and environmental data to estimate the energy flows within and around the building.

- A. A goal of the building Sankey diagrams is to assist in building retrofits and planning. One approach is to use run comparative EnergyPlus models (i.e. Baseline vs. a case study that incorporates building retrofits). Retrofits could include changing the windows, insulation (R-values and U-values), or equipment (efficiency). Sankey diagrams can be generated for the Baseline and case study. The goal is to visually inform how retrofits change energy usage.
- B. Currently, the process of transferring output from EnergyPlus into a format such that Sankey diagrams can be easily generated is not automated. Developing the platform

necessary to streamline this process can be done with OpenStudio² and support from NREL software development team as part of a multiple lab effort. Currently, conversations with NREL OpenStudio developers have led to an interest to integrate Sankey Diagrams into the OpenStudio platform. Ideas include: using Ruby code in the OpenStudio software development kit (SDK) to retrieve output and write a Sankey generation script. This could be done:

- a. Under the current EEBHub Task 2 project, modeling and simulation. The focus of Task 2 is a “suite of simulation tools for predicting energy use in buildings deployed via a platform for use by architects, designers, engineers, contractors, buildings operators and others. Tools include a Design Advisor intended for the early design stages of a retrofit project, an Energy Auditing Tool to support understanding and investment decisions for advanced energy retrofit (AER) projects, and a Retrofit Manager Tool (RMT) to address needs of facility managers that make critical decisions for building renovation and maintenance.”
 - b. An external (non-Hub) effort. NREL has plans for modular and extensible visualizations within the OpenStudio SDK. A starting point would be to get access to the results reporting framework and work on a prototype to apply Sankey visualizations to whole building simulation results.
- C. Future work may include re-rendering this energy flow diagram as a part of a “live” building energy display based on real-time metered energy data and a reduced-order model of environmental fluxes of energy.

² “OpenStudio is DOE’s platform for rapid, collaborative development of energy analysis applications.” [K. Benne and D. Macumber, *OpenStudio Overview*, Building Energy Informatics Summit, May 15, 2013.] OpenStudio has several applications, including a GUI to edit building parameters; SketchUp plug-in to create building geometry; ParametricAnalysis tool to modify baseline models; ResultsViewer to organize and compare data output; and RunManager to facilitate simulation queues.