Energy Use Intensity and Infrared Thermography as a tool in Building Assessments

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The Importance of Building Efficiency Measurements

Understanding a building's energy usage has become more important over recent years. The building sector uses nearly half of the energy produced in the United States. By identifying ways to reduce a building's energy usage, it can have major impact on reduced carbon emissions.

Energy Use Intensity [EUI]

Building EUIs can provide valuable energy performance metrics for the assessment of a building's energy performance. EUI is defined by the Annual Building Energy Use (kBtu) divided by the building floor area (ft2) and allows for comparisons across similar buildings.
For this study, we defined EUI as the ratio of the total amount of consumed site energy used during the 2013-2014 school year per gross conditioned square foot.

Benchmarking

Benchmarking the data is necessary to compare the Energy Intensity between separate facilities, setting performance goals, monitoring progress, and targeting poor performers (Abouzelof, 2009).
The Commercial Building Energy Consumption Survey [CBECS] was chosen as the most appropriate benchmark. CBECS is a U.S. National Sample Survey that collects data on commercial building types, their building characteristics and their energy consumption (Peterson, 2010). The CBECS data provides a statistical number represents the national median of energy use per building characteristic. The survey is organized into 40 different variables. Of these, building type and climatic zone have the largest impact on the data.

Establishing a Building Set

The EUI data we used in this study was provided to us by the PSU Utilities Manager. New and renovated buildings have EUIs around 40 and science and research facilities have EUIs as high as 220.
We decided on using Residence Halls as a subgroup because they are the only group of PSU buildings that have the same primary building activity. Each Residence hall has its own electricity and natural gas meters, which represent their total energy usage on-site. We chose two buildings, Stratford Hall and Blumel hall, one with a high EUI and one with a lower EUI for comparison.
Stratford Hall was designed in 1927 by Charles W. Ertz. The building has 22,928 sq ft of occupiable space. It is three stories divided into 21 studios and 8 one bedrooms, with 32 occupants for the 2013-2014 school year. The building construction is a wood frame, with brick façade. Heating is provided by one steam boiler located on the SW corner of the first floor. Steam is piped through 2-3 radiators per unit, with condensate flowing back to the boiler room. Water heating is provided by one 100-gallon circulating/storage tank.
Joseph C. Blumel Hall was built in 1986 and renovated in 2012. The building is 9 stories, with 2 levels of parking, and 7 stories of apartments. For the purpose of this project, we excluded the square footage of the two levels of parking and recalculated the buildings EUI using the 136,588 gross square feet for a more direct comparison with Stratford Hall. The building is steel frame, with brick veneer.
Heating is provided by rooftop gas-fired air handling units and electric unit heaters. The gas-fired rooftop units supply the corridors with fresh tempered air. Electric unit heaters are in place in the rooms. There are no return air systems or cooling systems in the building (2008 FCA). Domestic water heating is provided by three boilers supplying hot water to one storage tank.

Benchmark Comparisons

With residence halls, in particular, total energy usage is split between two sources; electricity and natural gas. Each of those energy values (in kBTU) was divided by the total square footage to determine the weight of each energy source. For example, the natural gas usage in Stratford Hall was 1,655,700 kBTU and we divide by Stratford's total floor area of 22,928 ft2, resulting in a natural gas EUI of 72 kBTU/ft2. End-uses from natural gas consumption was estimated based the monthly utility billing data. The only two end-uses in Stratford are space heating and water heating.
Comparing the EUI data to CBECS for the most relevant building characteristics, we discovered that median natural gas energy intensities range from 42-50. The building characteristics we looked at were building type (lodging), year built, and climate. Stratford Hall is currently consuming at least 22 kBTU/ft2 more natural gas energy than typical commercial buildings annually.

Infrared Thermal Imaging

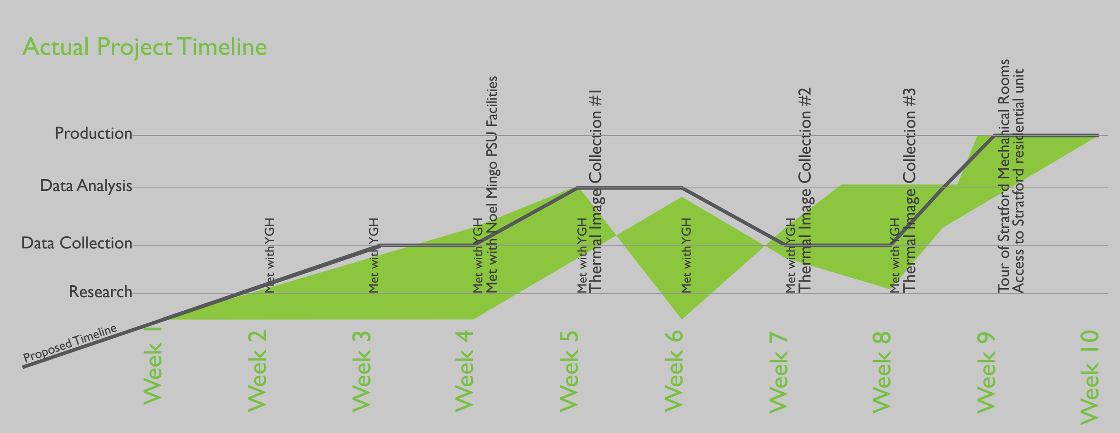
Themal Imaging was used as a non-invasive testing measure to investigate if the high amount of energy was due to the building envelope or the energy systems. Our team collected thermal images on two separate occasions, November 11 at 4:30pm and November 19, 2014 at 7:30am. For the first collection date, the outside air temperature was 39□, Relative Humidity 33% relative humidity, and 30mph wind speed. The conditions on November 19 were 39□, 53% relative humidity, and 7mph wind speed.

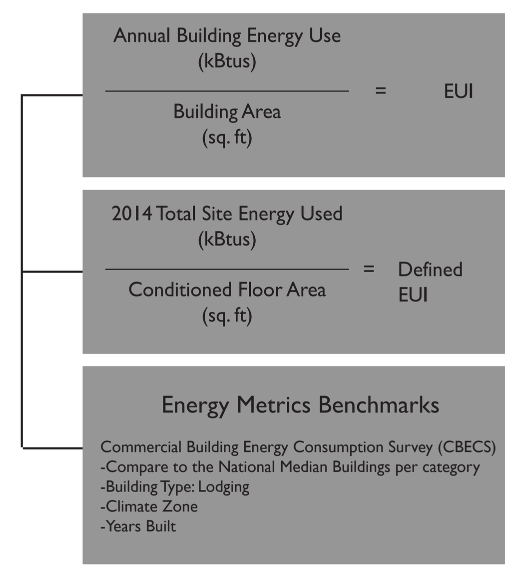
Analysis

The majority of elevated temperature areas on Stratford's building envelope likely showed the location of the steam distribution lines and radiator units located between window bays. One area on the south facade is a vertical line with a higher temperature relative to other areas. Two other areas showed similar high temperatures on the SE and NE corners where brick meets the concrete block exterior. The peak temperatures in these areas were about 55□.
We developed a better understanding of the heating system after viewing the mechanical room and a studio unit. Steam is supplied to the main lines that feed into radiator units in each space. These radiators can be controlled by the occupant. The studio unit included two radiators, in addition to a main supply line running vertically in the corner of the bathroom. The thermal camera revealed two supply lines in the interior walls. The surface temperature on these areas were 95□. The occupant shared that she never turns her radiator on. We recorded an interior temperature of 70F.

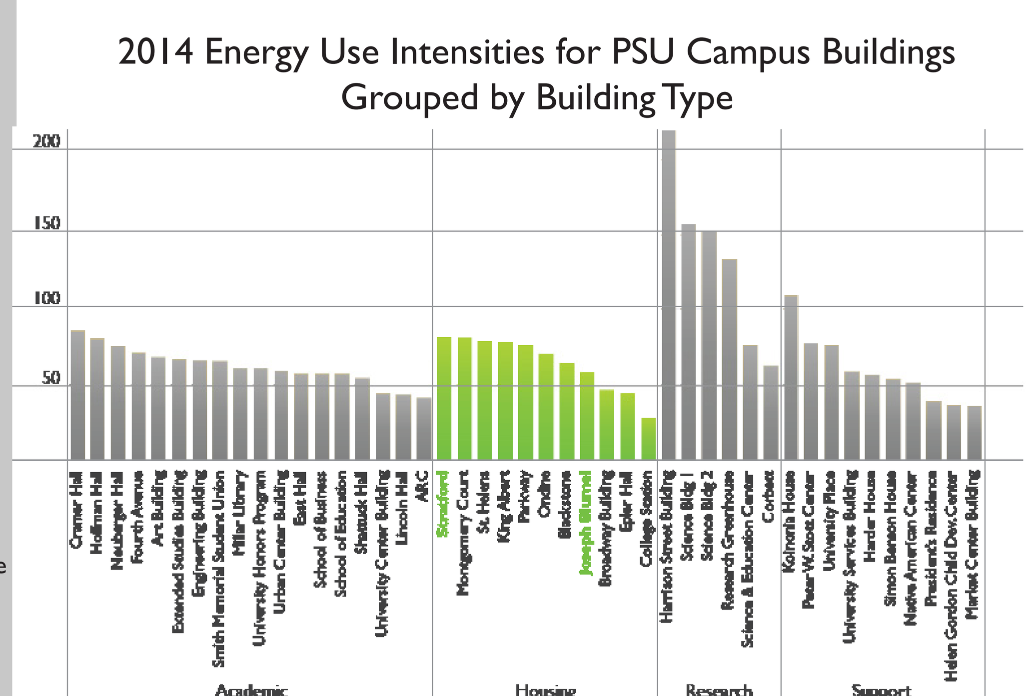
Conclusions

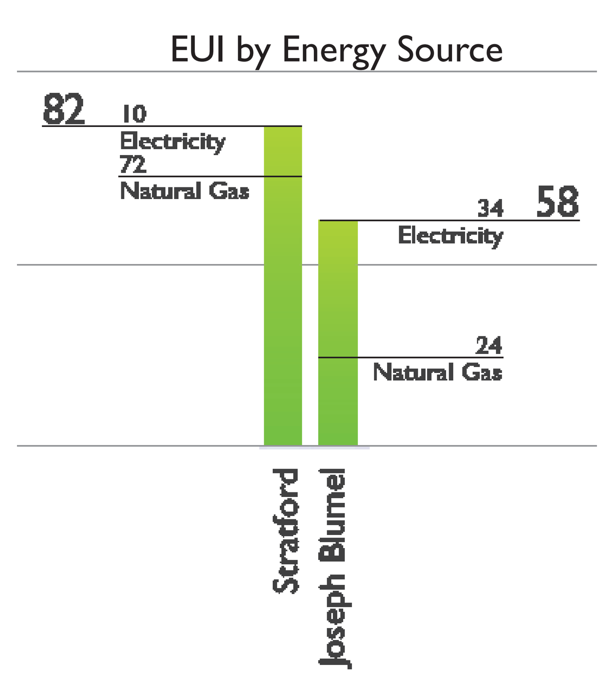
Viewing the thermal images of Stratford Hall alone, one would think that there is significant leakage occurring across the building envelope. In reality, it is true that there are areas of thermal weak points (i.e. single-glazed windows), but for the most part, the images reveal how heat is distributed to each room. When the boiler is operating, it can provide a large amount of heat to the building and in some cases, it can heat a room solely from heat conducting through interior walls from supply lines. In other cases, we viewed occupants releasing excess heat through open windows. The thermal images of Blumel Hall served as model for how thermal separation between the inside and outside spaces would appear on an IR camera.
Although we may have only scratched the surface of a full energy analysis of Stratford, we wanted to propose potential solutions for energy use for space heating, and therefore, reducing the overall energy intensity. The first step is to identify ways to reduce the heating load in the space. Ensuring that occupants understand how to control radiator units may reduce the need for opening windows during the coldest times of the year. The thermostat setpoint was at 73□ and could be lowered to test if the occupants' comfort can be sustained at the reduced point. There may also be ways to optimize where the thermostats are located. The second step is to upgrade to efficient systems. A life cycle cost analysis could be performed on the replacement of the boiler or whether electric in-unit heaters would provide lower energy consumption and higher comfort.

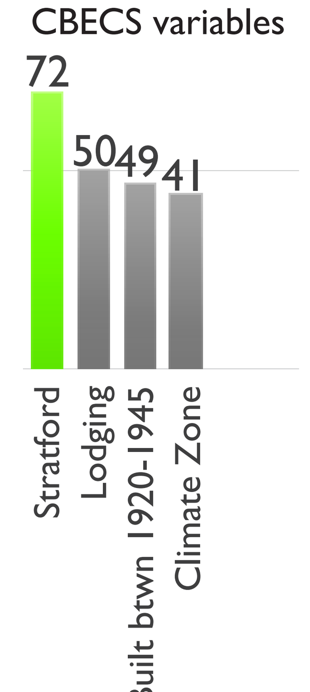


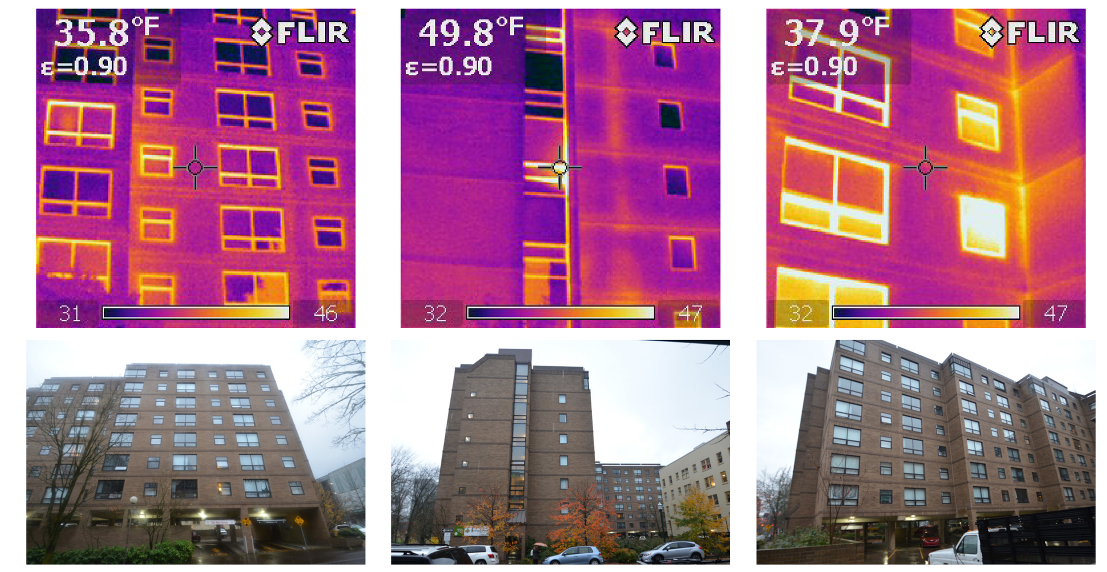


EUI allow for Energy Comparisons between Buildings





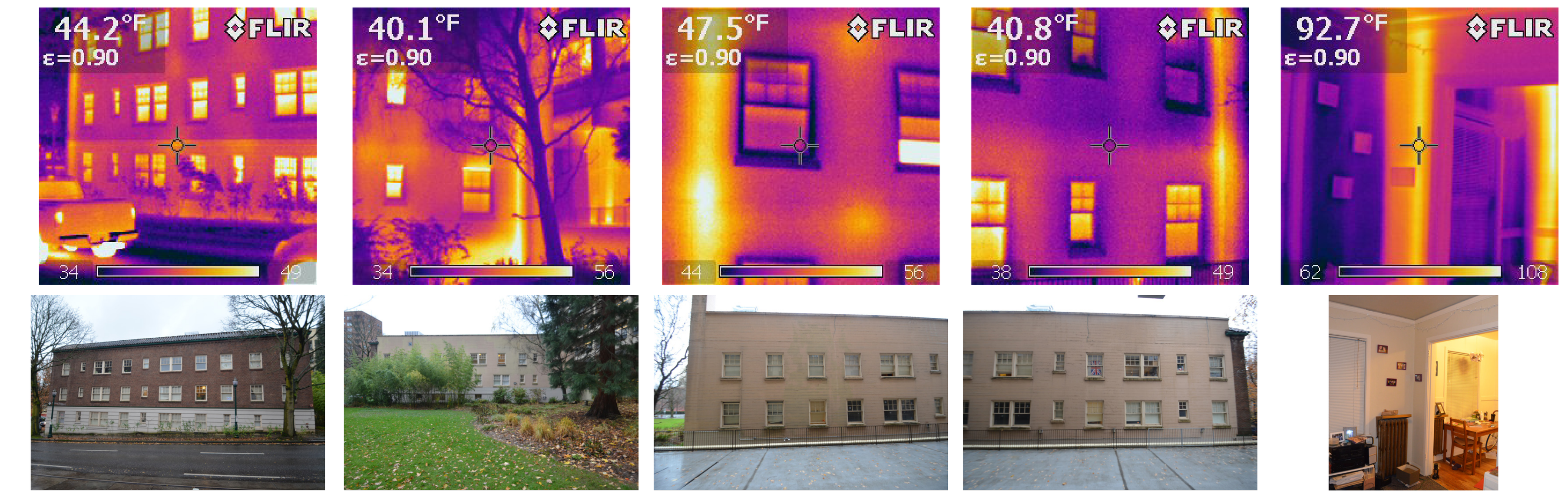




North Facade
-higher temperatures located along structural elements.

West Facade
-Window glazings show better resistance values

South Facade
-Thermal leak through the building envelop at corner
-Heat loss through metal frame windows



North Facade
-higher temperatures shown where
radiators are likely located

West Facade
-South West Corner shows the Boiler room location and main supply line in yellow.
-Warmer patches below the third floor windows show heat transfer through the envelope from interior radiator units.

South Facade 1
-steam supply line behind exterior wall reading around 56 degrees
-Interior windows open to release excess heat

South Facade 2
-South East Corner steam supply line

Interior
-Supply lines can be seen within interior walls, located one foot from the exterior
-Interior room temperature reading at 70F with radiators off.

Joseph Blumel Hall

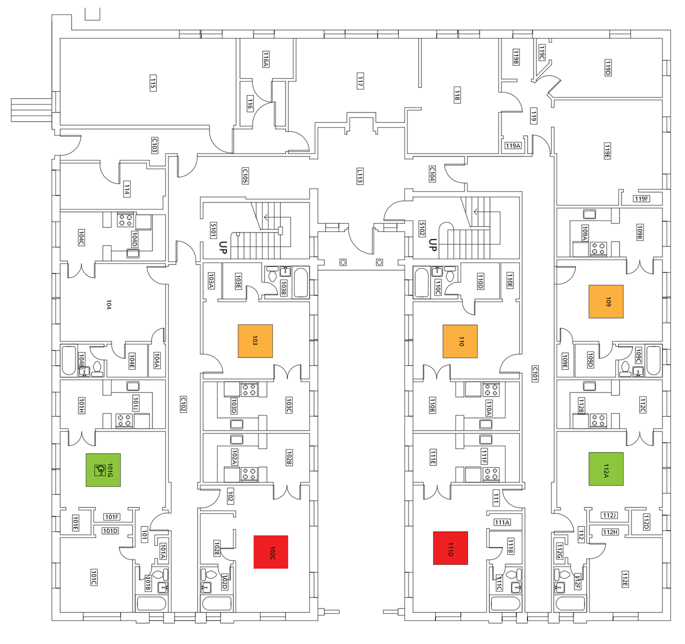
58kBtus/sq. ft

Built: 1986
Architect: Michael & Lakeman
Area: 136,588 ft2
Floors: 9
Annual EUI: 58
Energy Use per occupant: 30,120 kBTU
Construction method: Steel frame with brick masonry cladding
HVAC System: Gas fired air handling units with electric unit heaters

Stratford Hall

82kBtus/sq. ft

Built: 1927
Architect: Charles W. Ertz
Area: 22,950 ft2
Floors: 3
Annual EUI: 82
Energy Use per occupant: 51,741 kBTU
Construction method: Timber envelope with masonry cladding
HVAC System: ~25 year old Steam boiler/in unit radiators set to 73 F



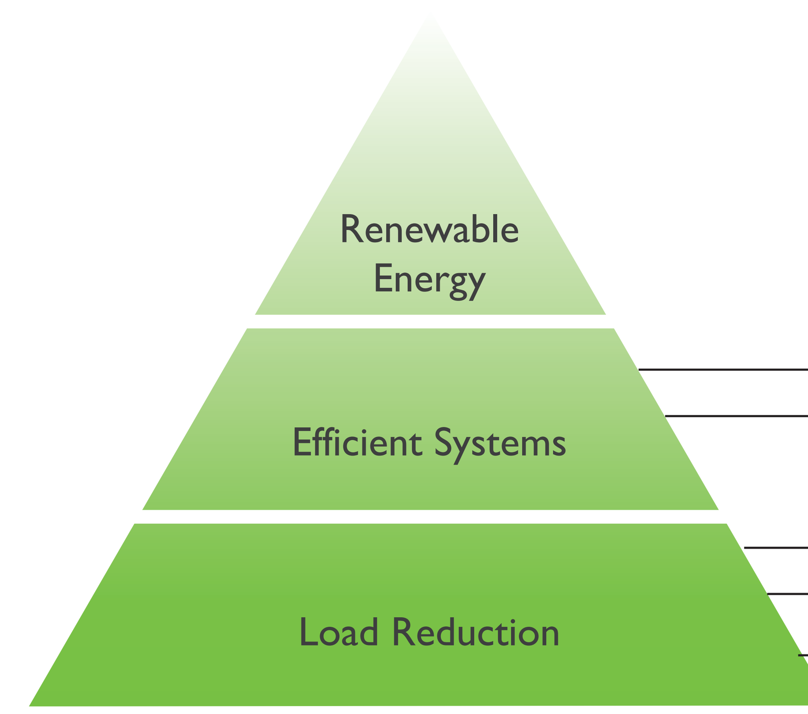
Building	Surface Description	Surface Temp	Δ from OA
Blumel	brick surface	38°F	0
	metal structure elements	41°F	+2
	aluminum window frame	49°F	+10
Stratford	brick surface	40°F	+1
	radiator/steam lines	47°F	+8
	glazing surface	50°F	+11
	steam supply	55°F	+16

Building Material Temperatures with comparison to outdoor air temperature.

The thermal images of Blumel Hall served as model for how thermal separation between the inside and outside spaces would appear on an IR camera. The largest thermal leak is throught the metal window frames.

Elevated temperatures at Stratford show the heating distribution system.

Stratford Hall's Natual Gas Consumption is opperating at least 20 kBTUs/ sq ft over the National Median



Higher Efficiency Boiler
Replace Primary Heating System with in-unit Electric Heat

Ensure occupant knowledge of radiator controls
Lower thermastat set point
Optimize thermastat location