SIMON ENERGY MANAGEMENT

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TECHNICAL APPLICATION DOCUMENT

Date: December 6, 2016

To: Molex, L.L.C. Under NDA Privileged and Confidential

From: Thomas E. Simon

Re: Thermal Bridge Sensor System

Technical detailing including illustrations that describe application use case for the SIMON Energy Management System.

I. CURRENT TECHNOLOGY

Commercial buildings and residences lose 39% of the energy that they consume for heating and cooling[1]. (*Window and Building Envelope Research and Development: Roadmap for Emerging Technologies, U.S. Department of Energy, Building Technologies Office*, February 2014 ("Emerging Technologies Roadmap"), pp. 1,9.) More energy is lost through walls than any other building component. (Id., p. 42.) In 2010, three quadrillion BTU of energy was lost through walls of commercial and residential buildings (id.), more than was consumed by the entire U.S. aviation industry that year. (Id., pp. 1, 42.) However, lack of timely, reliable data on energy loss leads building owners to inaction, "even when retrofits are simple and cost effective." (Id., p. 59.)

Thermographic cameras are currently used to demonstrate energy loss from residential and commercial buildings only on the specific day and time in which a person captures the photo image. While thermal images show where energy is escaping at a specific moment in time, they do not provide on-going specific information that encourages building owners and other stakeholders to make timely informed decisions to invest in energy saving retrofits.

Thermographic cameras produce images of radiation from buildings by converting energy from the infrared wavelength to a visible light display. They can help identify how a wall is constructed by revealing thermal pathways within the wall. These images are an excellent start for an energy loss inquiry. However, they only record the image once on a specific date and time and they deliver inherently incorrect measurements of temperature, because they do not directly account for emissivity, distance, angle of view, ambient temperature, or relative humidity, all of which affect temperature. Also, the images include radiation that originates from surrounding objects and has been reflected onto the surface of the building being imaged. Further, although the thermal image does provide an estimate of the temperature of a building, the camera is using multiple sources of data other than the building to determine value. It does not record actual temperature. The camera is a non-contact temperature measuring device.

[1] In 2010, commercial buildings consumed 22 quadrillion BTU ("quads") of energy, and residential buildings consumed 18 quads of energy, a total of 40 quads. (Emerging Technologies Roadmap, p.1.) Residences lost 7.37 quads in heating and 2.37 quads in cooling. Commercial buildings lost 5.07 quads in heating and .74 quads in cooling. (Id., p. 9.) Total energy lost in heating and cooling residential and commercial buildings in 2010 was 15 quads, 39% of the total energy consumed by those buildings (40 quads). (Id., p.1.)

For example, the emissivity of building materials varies widely and thus must be accounted for to estimate the temperature of the area imaged. The camera operator must address this by correctly identifying the building materials and selecting the correct emissivity factors, which will then be used to estimate the proper temperature readings in the analysis of the camera images. Failure to account correctly for emissivity will cause the subsequent temperature estimates to be inaccurate. The camera employs other algorithms to affect the temperature measurement, including the transmission ability of the transmitting medium (usually air). Finally, the data is never available in real time.

A building owner can use a thermal image to make judgments about how a wall is constructed. However, the thermal image will show where energy is escaping based only on the weather conditions of one specific date and time. This reduces the urgency that real-time information provides. Highlighting real-time energy-loss will encourage decisions to invest in energy saving retrofits. Nor is the development of new retrofitting technology well served by this current technology. The inability to provide specific, timely energy loss data impedes the development of efficient insulating material. Third party verification of the capabilities of insulating material also is currently lacking. (Emerging Technologies Roadmap, p. 44.)

II. SENSOR TECHNOLOGY

The Emerging Technologies Roadmap states, "improved diagnostics and measurement technologies such as improved sensors and new modeling methods, can make a convincing business case for retrofits." (Emerging Technologies Roadmap, p. 59.) The Emerging Technologies Report calls for "more efficient methods to disseminate the critical information to residential and commercial building owners and code officials." (Id.)

Sensors that can collect data in real time and convert the data into a format that integrates with building management software are key, per the Emerging Technologies Roadmap: "[t]he ability of these self-diagnostic building displays to show accurate, real-time data is contingent on the development of low-cost, automated, and non-intrusive sensor technologies." (Id., p. 59.)

> Specifically, sensor technologies that can measure properties such as air leakage, temperature, and moisture within the building envelope should be developed so that energy efficiency, energy consumption, and Indoor Air Quality ("IAQ") can be easily monitored.

(Id., p. 60.)

The sensor technology platform should include software that communicates with decision makers:

> With the development of these sensor technologies, it is important to also develop the appropriate software tools to manage the large amounts of resulting data and give consumers appropriate action recommendations to achieve cost-effective energy savings.

(Id., p. 60.)

III. THE THERMAL BRIDGE SENSOR SYSTEM

SIMON has developed sensor technology that directly measures thermal transmittance between external and internal wall and window surfaces. This thermal bridge sensor technology harvests accurate temperature and other data, organizes the data in a format that can be integrated into building management software, and sends the information through a portal to management software such as ARCHIBUS, Autodesk Revit, and others. The Thermal Bridge system is comprised of Thermal Bridge Sensors, an EMON-Pi communications hub ("CommHub"), and a Web Portal Server. The Thermal Bridge Sensors and CommHub are linked by a Wi-Fi Mesh Network.

The Thermal Bridge Sensors, approximately the size of a credit card, are placed on the interior and exterior of a building wall to measure actual temperature, humidity and barometric pressure. The sensors gather this data and send it via the Wi-Fi Mesh Network to the CommHub. The CommHub organizes the data and uploads it to the Web Portal Server. The Web Portal Server processes the data so it can be shared anytime, with anyone, from anywhere. The Web Portal Server can integrate with building management software, such as Autodesk Revit and ARCHIBUS, to push real-time information into custom reports and financial dashboards.

A. Thermal Bridge Sensors

1. External Surface Thermal Bridge Sensor ("E-Sensor")

E-Sensors read external surface wall temperature via infrared thermopile. Ambient weather conditions for a specific, time-stamped, reading event are synchronized with location GPS NOAA weather data. E-Sensors are powered by photovoltaic cells and thus never need recharging.

2. Internal Surface Thermal Bridge Sensor ("I-Sensor")

I-Sensors measure internal wall surface temperature via an infrared thermopile, and humidity. The I-Sensors are placed on the interior wall so that they are aligned with the location of the E-Sensors on the exterior wall.

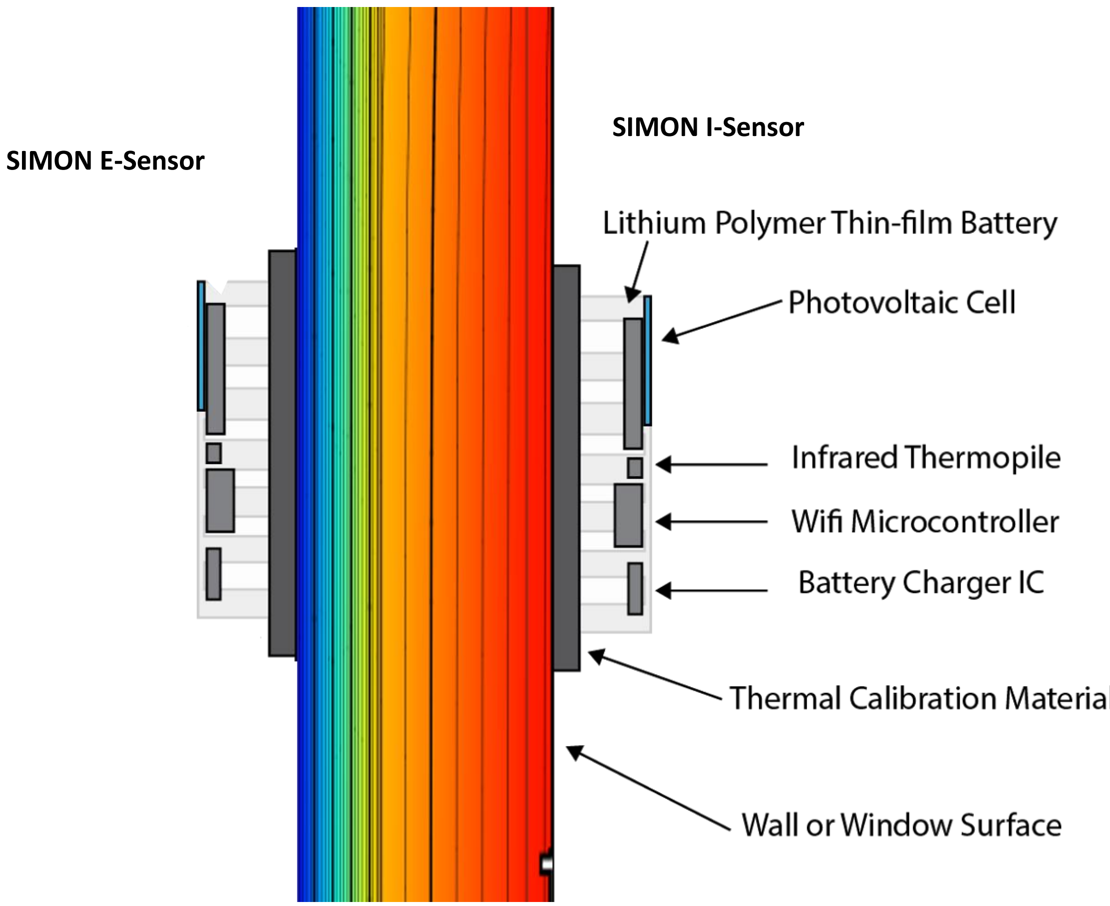
3. Ambient Sensor ("A-Sensor")

A-Sensors measure conditions of a room, including humidity, temperature, and barometric pressure. The A-Sensors can be adapted for specific applications in health care, manufacturing, and security, such as to measure carbon monoxide, radon, natural gas, propane, hydrogen gas, ambient light, UV light, motion, or air currents.

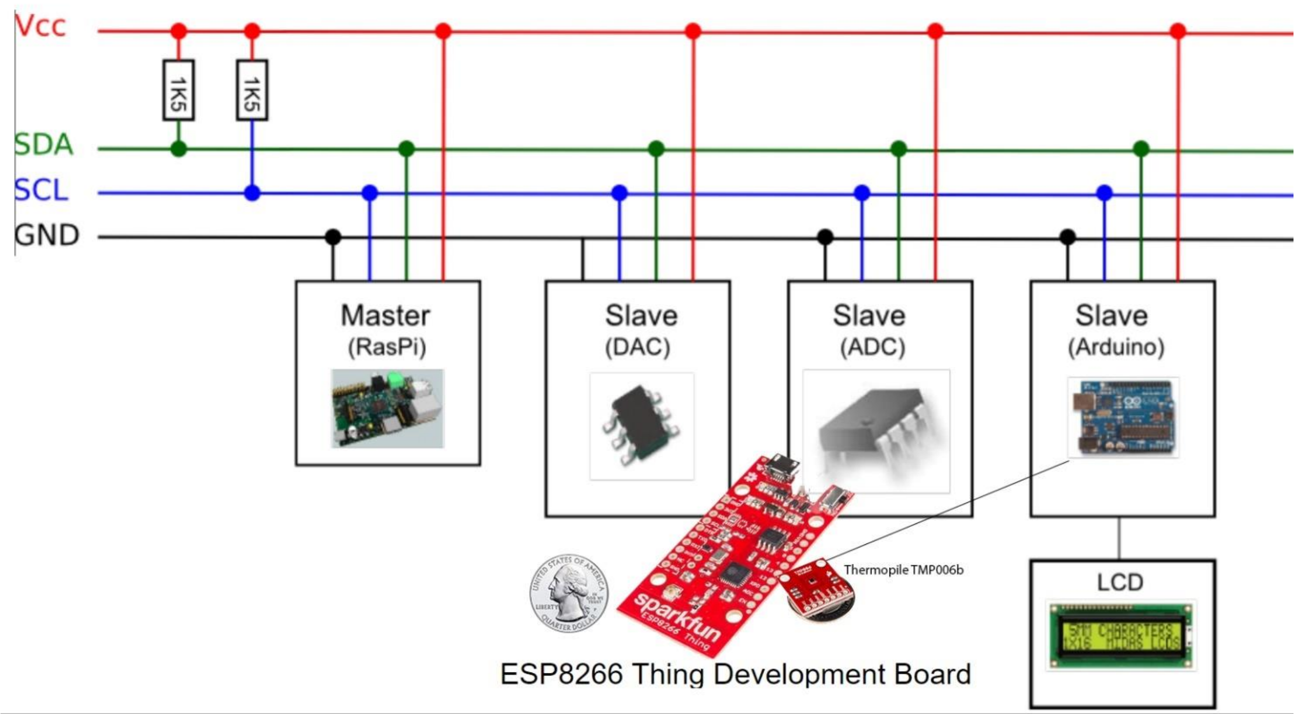
Thermal Bridge Sensors are modular. Each sensor bears a unique identification that is applied during the manufacturing process. The sensors contain the following:

- a Lithium-Polymer thin film battery;
- a photovoltaic cell for wireless recharge of the battery;
- a battery charger integrated circuit;
- a Wi Fi enabled microcontroller (ESP8266) for communicating sensor data and orchestrating other components;
- traces, connectors, resistors, capacitors, and other small electronics to connect all components on the circuit board; and
- a housing to protect the circuit board.

E-Sensors include an infrared thermopile (Texas Instruments TMP006B) for ambient and wall temperature measurement. I-Sensors include an infrared thermopile and a sensor to measure humidity. A-Sensors use a humidity, temperature, and barometric pressure sensor (BME280).



Because different surfaces emit infrared radiation at different amounts, a feature known as the emissivity of the surface, a calibration material ("Thermal Calibration Material") of known emissivity is placed between the sensor body and the surface to be measured. This Thermal Calibration Material permits the uniform temperature measurement of surfaces with emissivity higher and lower than the average, like shiny metals and glass, without additional calibration.

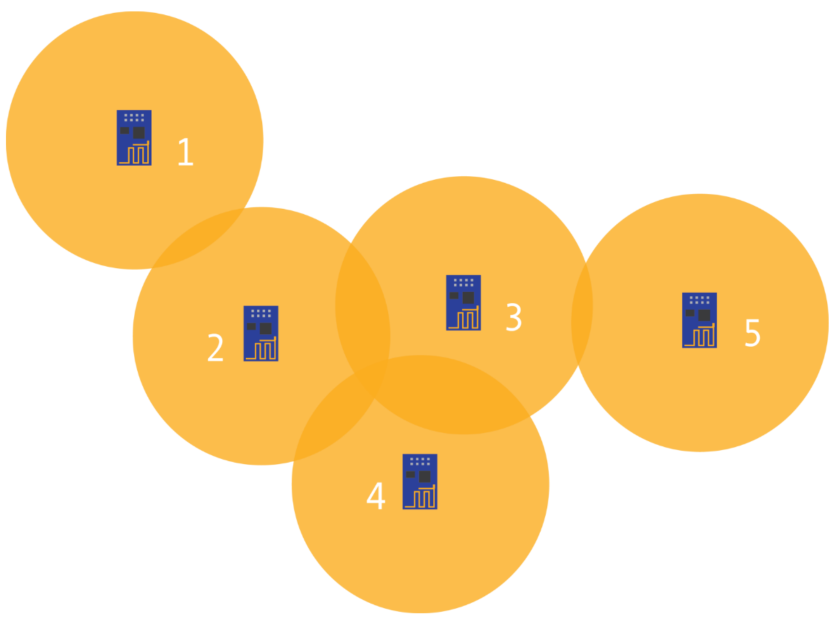


Example Illustration of integrated Thermal Bridge sensor system. Size related to US quarter

B. Wi-Fi Mesh Network

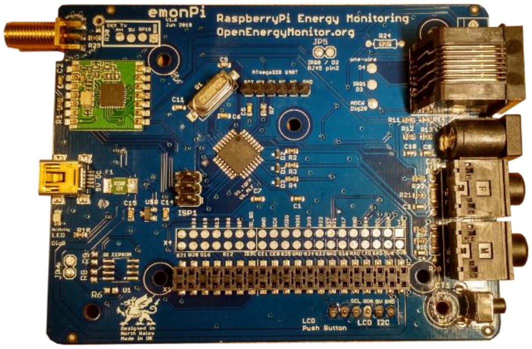
A component of the system is the ability to gather data from multiple sensors for intelligent processing through the EMON CommHub. The sensor data from multiple points feeds into the Wi-Fi Mesh Network and is delivered to the CommHub.

The principle is like the way packets travel around the wired Internet. Data will hop from one device to another until it eventually reaches its destination. Dynamic routing algorithms implemented in each sensor communicates routing information to other sensors in the network. Each sensor then determines, per a protocol, what to do with the data it receives - - pass it on to the next sensor, or keep it. Thus, an operator merely places the sensors on a wall, turns on the EMON CommHub, and the network topology is automatically mapped. The network is power-efficient. The CommHub is the only device that stays on permanently. The sensors have very short duty cycles and are usually in "deep-sleep" mode where they consume very little power.



The above example illustrates the hidden network (1) that the pre-programmed ESP8266 can create and maintain. This allows any ESP to communicate with any other ESP within range of it to communicate with it as well as any other ESP that device is in range of. Here, traffic from ESP #1 can be routed through ESPs #2, #3 (and/or #4) in order to communicate with ESP #5.

C. EMON-PI CommHub



Data from the Thermal Bridge Sensors is transmitted by way of the Wi-Fi Mesh Network to the CommHub. (See OpenEnergyMonitor.org) Sensor information comes to the CommHub with a relative time-stamp. The CommHub converts the data to an absolute synchronized time-stamp. This event data is then uploaded to the Web Portal Server via HTTP JSON. The CommHub includes a default cellular modem (Verizon) to connect with the Web Portal Server if Internet Wi-Fi is unavailable, and a satellite modem is an available option should that be required.

The EMON-PI CommHub components include:

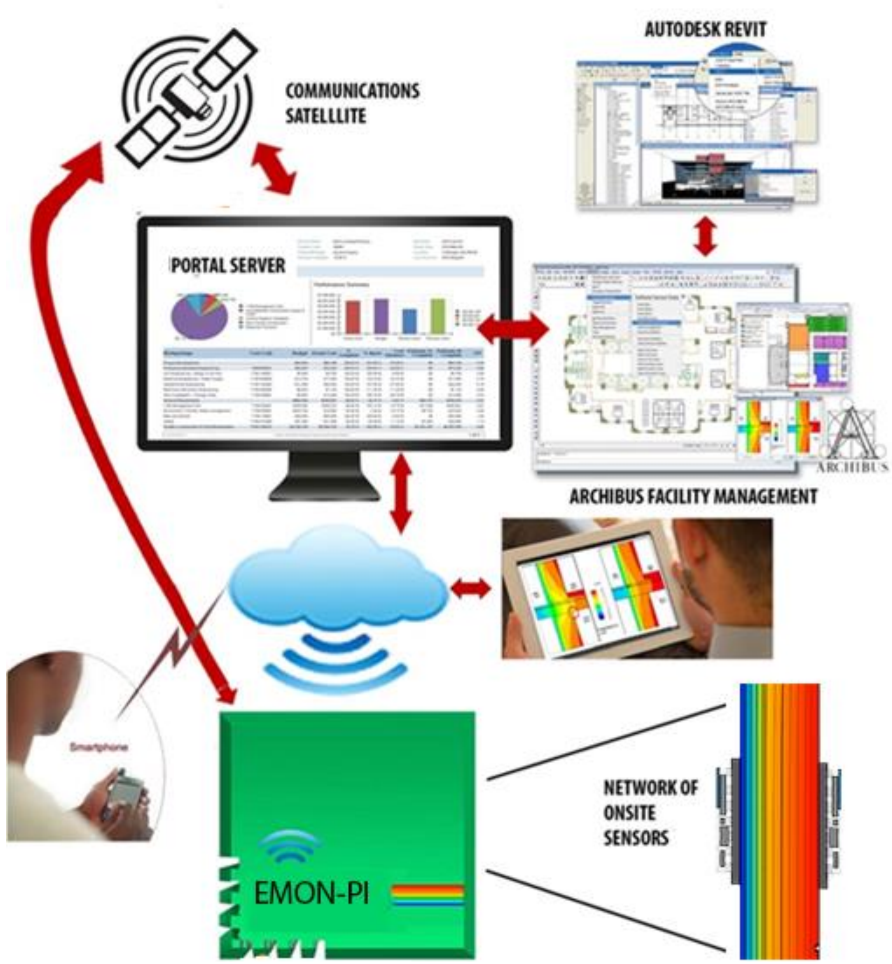
- a Raspberry Pi 3 Model B for Wi-Fi communication with Thermal Bridge Sensors and any existing Wi-Fi network at the installation site;
- an additional USB-Wi-Fi module so the CommHub can serve as a Wi-Fi host and a Wi-Fi client at the same time as needed; and
- a USB-GPS module to access automatic geographic coordinates for use in determining utility rates.

D. Web Portal

Data processing occurs in the Web Portal. The Web Portal stores sensor readings, automates energy loss calculations, and tracks sensor diagnostic data. The Web Portal communicates with building management software through bidirectional Secure File Transfer Protocol transfer of data. The Web Portal will export data to building management software metrics and dashboards. The information from the Web Portal is available securely on the Internet anytime from anywhere by a subscribed user who has authentication access credentials.[2]

[2] See EnOB model we are building from http://enob.pse.de/projects/73/periods3/?page=0&per_page=3

IV. USE CASE FOR THE THERMAL BRIDGE SENSOR SYSTEM



Following are requirements for each building:

- A virtual floor plan CAD image or virtual floor plan (i.e. Autodesk Revit);
- Identification of each category of wall construction used in the building, along with the location on the building where each wall category can be found, and the percentage of the entire building each wall category represents;
- A thermographic image of each wall category;
- Utility bills showing consumed energy; and
- Heating, ventilation, and air conditioning ("HVAC") configuration.

Based on the above requirements, the following pages describe specific operating steps to apply Thermal Bridge Sensor technology using German EnOB and OpenEnergyMoniotor.org as resource guides.

Overview of System Operation

1. For each wall category, a representative ("Sample Wall") is selected, using thermographic images to identify distinct areas where energy is escaping ("Thermal Pathways"). Once Thermal Pathways have been identified, the square foot surface area of each is recorded. See Fig 1.

2. Thermal Bridge Sensors are placed on each Sample Wall Thermal Pathway within a ("Sample Room"). Specific location temperature differentials are recorded. Tablet drawing application tools are used to define and illustrate Sample Room dimensions. See Fig 2.

3. THERMAL BRIDGE Sensor readings are exported to the CommHub via the Wi Fi Mesh Network. Aggregated sensor data is compiled, time-stamped and stored on the CommHub to be shared with the Web Portal. See Fig 3.

4. Energy loss for each Thermal Pathway is calculated on the THERMAL BRIDGE Web Portal by multiplying the U-Factor by the square foot surface area of a specific Thermal Pathway with its interior/exterior time-stamped ambient temperature differential. The sum of individual Thermal Pathway energy loss determines the energy loss for the entire building. See Fig 4.

5. In the THERMAL BRIDGE Web Portal, utility billing information, HVAC configuration, and THERMAL BRIDGE Sensor data are combined to calculate the cost of energy loss. See Fig 5.

6. THERMAL BRIDGE Web Portal applications display near real-time energy cost and humidity data on virtual floor plan in false color, with gradient legend, as a visualization aid. See Fig 6.

7. THERMAL BRIDGE Web Portal formats data to display on financial dashboards and to be shared with facility management and other software applications. See Fig 7.

8. Utility billing information and energy loss are combined through the THERMAL BRIDGE Web Portal to calculate and format GHG emissions data for various management purposes. See Fig 8.

9. Reduction in energy use costs and GHG emissions are projected through the THERMAL BRIDGE Web Portal to substantiate the investment in building performance improvements. See Fig 9.

Fig. 1.
Sample Wall Thermal Pathway Identification

Start

⇩

Using thermographic images, segment building per wall construction types.

⇩

For each wall construction type, select a representative Sample Wall.

⇩

Examine thermographic image of the Sample Wall to identify distinct Thermal Pathways within the wall.

⇩

Calculate square feet of surface area each identified Thermal Pathway covers.

⇩

Finish

Fig. 2.
Sample Room Sensor Data Acquisition

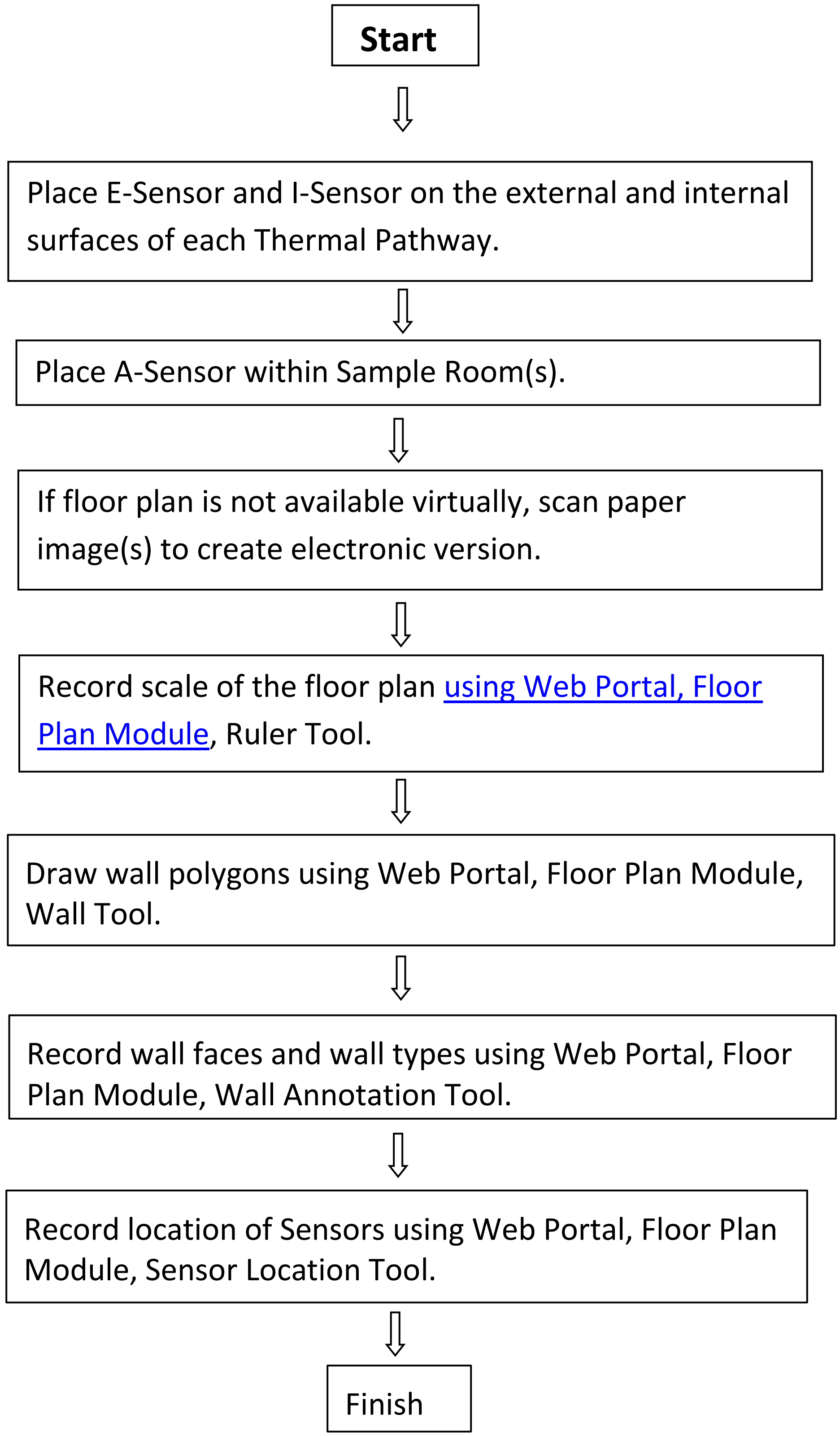


Fig. 3.
Transmit THERMAL BRIDGE Sensor Data

Start

⇩

Record E-Sensor and I-Sensor temperature data on external and internal walls at a specific point in time and transmit data to CommHub via Wi Fi Mesh Network.

⇩

A-Sensor records ambient temperature and humidity inside the Sample Room and transmits data to CommHub via Wi Fi Mesh Network.

⇩

Using GPS locator, transmit concurrent ambient temperature and humidity of the environment outside the building from NOAA or other public sources as time-stamp event associated with sensor data.

⇩

Aggregated sensor data is compiled, time-stamped and stored on the CommHub to be shared with the Web Portal

⇩

Finish

Fig. 4.
Calculate Building Energy Loss

Start

⇩

Web Portal pulls Sensor data from CommHub and uses that data to calculate a U-Factor for the Thermal Pathway.

⇩

The loss of heat or cooling energy ("H/C Loss") is obtained by multiplying the U-Factor of the Thermal Pathway by the square foot surface area of that pathway, and by the differential between the exterior and interior ambient temperatures.

⇩

Calculate average H/C Loss over the entire building by summing the H/C Losses calculated for each Thermal Pathway.

⇩

Use https://www.epa.gov/energy/ghg-equivalencies-calculator-calculations-and-references to identify additional calculations to enhance analytics.

⇩

Finish

Fig. 5.
Energy Cost Calculation

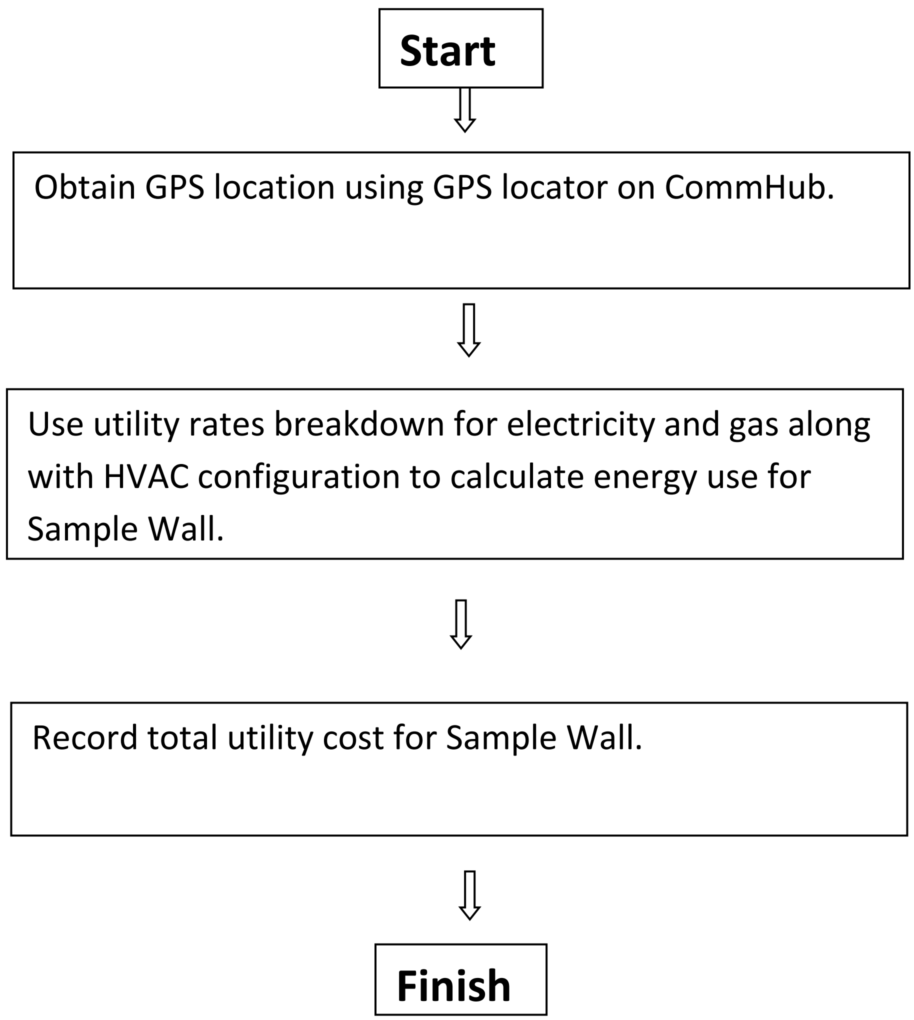
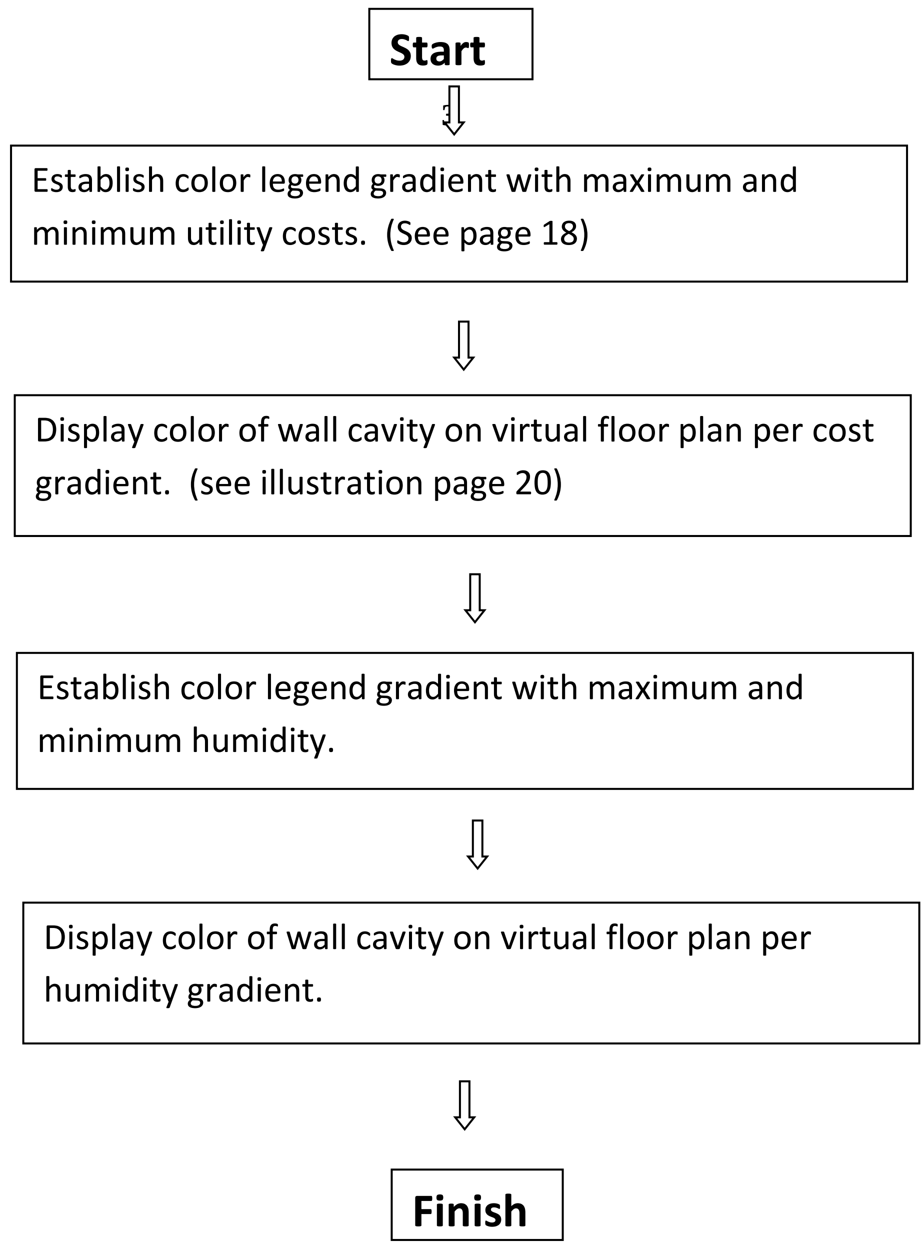
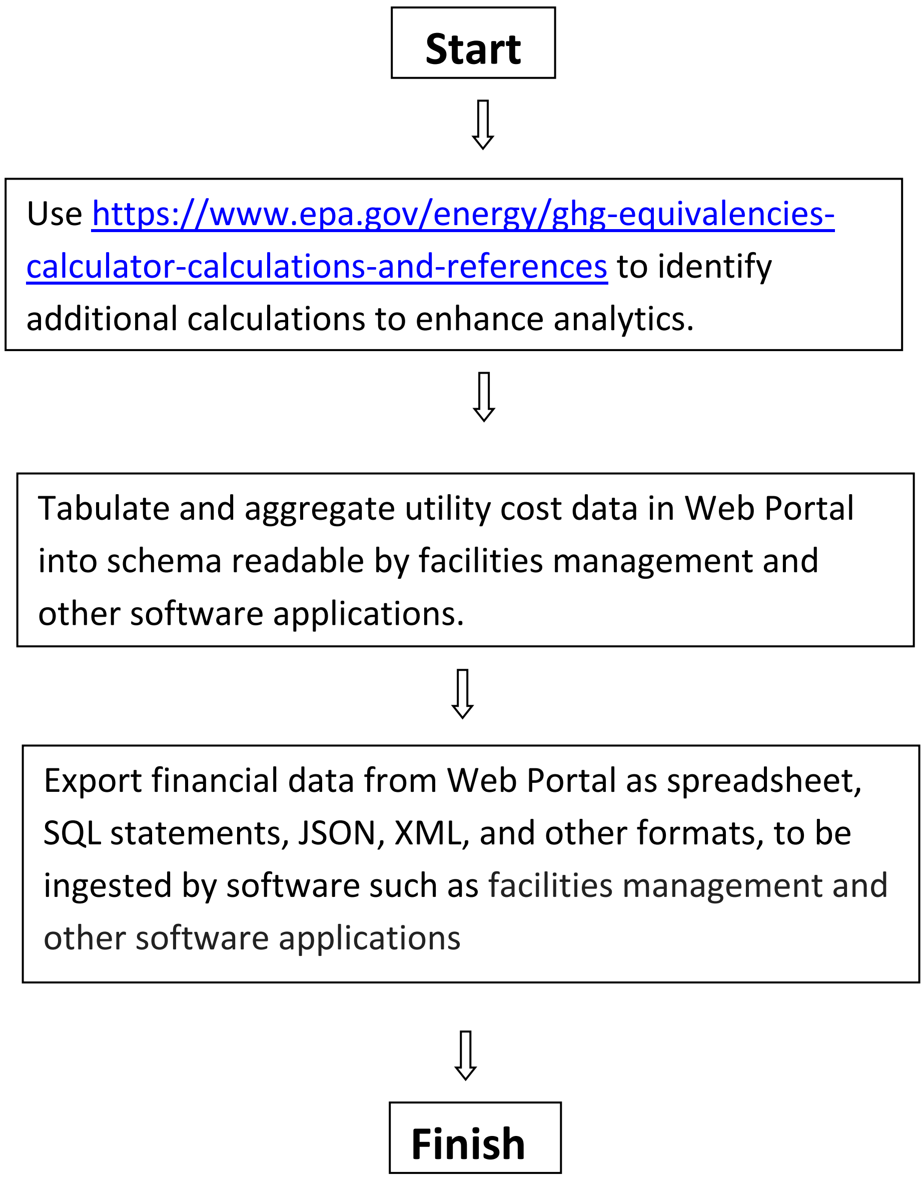


Fig. 6.
Graphic Representation of Utility Cost and Humidity As Wall Colors On Virtual Floor Plan



[3] See gradient tool example illustration

Fig. 7.
Financial Data Dashboard Display of Utility Cost



[4]

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[4] See ARCHIBUS dashboard example in Notes section page 19

Fig. 8.
Use Obtained Data to Calculate GHG Emissions

Start

⇩

Use https://www.epa.gov/energy/ghg-equivalencies-calculator-calculations-and-references to identify additional calculations to enhance analytics.

⇩

Using GPS location from SYNFEM CommHub and known utility GHG Emissions rates, calculate and aggregate total GHG Emissions for compliance analysis.

⇩

Fill compliance forms with GHG Emissions numbers. Or, emit bespoke GHG report.

⇩

Finish

Fig. 9.
Projection of Building Performance Improvements

Start

⇩

Use https://www.epa.gov/energy/ghg-equivalencies-calculator-calculations-and-references to identify additional calculations to enhance analytics.

⇩

Using energy use cost and GHG emissions data, isolate priority investment opportunities for increasing building performance efficiency.

⇩

Create table of building performance efficiency solutions. http://aceee.org/files/proceedings/2012/data/papers/0193-000072.pdf [5]

⇩

Create models to simulate building performance when selected solutions are enacted.

⇩

Rerun energy use cost and GHG emissions calculations to create reports for cost justification analysis.

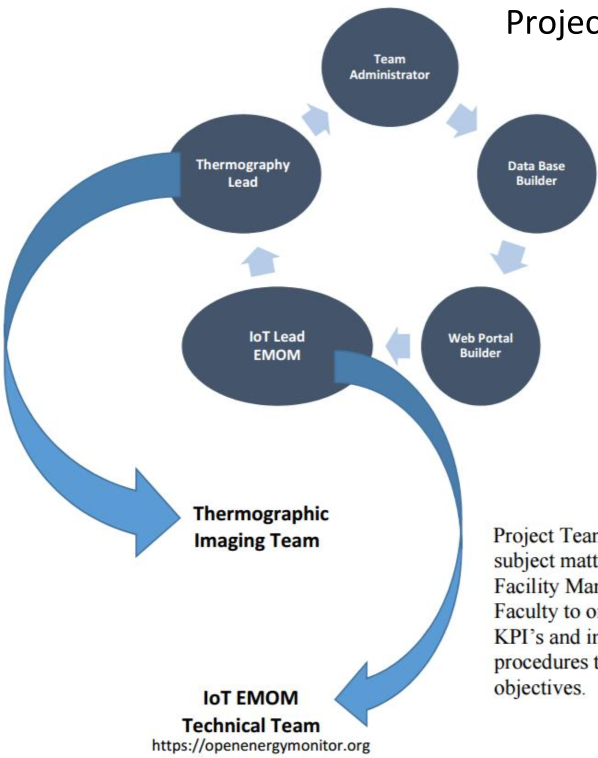
⇩

Finish

[5] See Example simulation model from Autodesk Revit page 20

V. CONCLUSION

Student Interns
Project Team



Project Team works with subject matter experts both Facility Management and Faculty to organize tasks, set KPI's and implement procedures to fulfill project objectives.

Why consider Thermal Bridge Energy Management System as described? In a report by independent consulting group Verdentix for the American Council for an Energy Efficient Economy (ACEEE), "To build a credible business case, it must be based on a complete and robust data set. Organizations should make it a priority to put systems in place that ensure energy data is captured from across all its sites to measure KPIs."

We are proposing a replicable model that includes hardware, software and tools for implementation that can be deployed globally at a fraction of the cost in both time and money of current methods. In addition, the Thermal Bridge Energy Management System provides on-going near real-time monitoring that simplifies facility energy management reporting. Also, we are suggesting cost justification models that integrate energy efficient solutions as described by ACEEE (http://aceee.org/files/proceedings/2012/data/papers/0193-000072.pdf)

We are seeking development, commercialization and investor partners who can build upon the substantial work we have already completed documented herein. Please let us know if you need any further information.

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