Real-Time Monitoring of Envelope Assemblies

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ABSTRACT

This paper will explore how we can move from whole building energy usage data to that which can now include component level energy data (i.e., envelope assemblies). This paper will discuss a recent installation in a new campus building of a distributed low cost data acquisition system that can monitor at the component level. Five different wall/roof orientations were selected to have thermocouple sensors placed through the building envelope assembly. All these sensors will be connected to a programmable logic controller which will be integrated with a campus wide website. This system will not only become the new campus standard but will also have an enormous educational benefit to students who use this website.

INTRODUCTION

In 2010 it was estimated the value of all U.S. commercial real estate was $11.5 trillion, yet the industry knows very little as to how well their buildings are performing from an energy standpoint. ASU has taken a leadership role in understanding whole building energy usage in its campus buildings by developing a campus-wide Energy Information System (EIS) and placing portions of that data on an open website called Campus Metabolism. This work has received considerable acknowledgement from both the energy management as well as from the academic communities. The next step in providing leadership in this area is to provide the industry a component level energy monitoring system to understand how individual building assemblies operate in real-time.

PROJECT BACKGROUND

The origins of this project started with Campus Metabolism which is an ASU public website that displays real-time energy information for select buildings on ASU’s Tempe campus. Campus Metabolism offers a unique inside view into the university's commitment to sustainability initiatives, including its focus on the value of energy efficiency and using alternative energy resources. Campus Metabolism was first commissioned in 2004, in partnership with Ameresco (formerly known in Arizona as Arizona Public Service Energy Services), after the university installed utility-grade instrumentation to accurately monitor energy usage of its buildings on campus. This data was first used by ASU's Energy Information System (EIS) from which it can be passed to other applications.

Building on the performance data being generated by the Energy Information System, Campus Metabolism extends this capability by bringing a wealth of valuable energy information and presenting it graphically for use by students, researchers and the general public. Campus Metabolism is very user-driven by allowing the user to select and graphically present energy performance data in a number of innovative ways. This site allows the user to view either the heating, cooling, electricity or the total energy consumption of the building on a daily, weekly, monthly or yearly basis. These displays also present energy data from the previous time period (day, week, month or year), thus allowing for easy historical comparisons. Figure 1 illustrates a typical screen from the Campus Metabolism website – showing kWh electricity usage in yellow and the previous days kWh electricity usage in grey.

Campus Metabolism has proven to be a very exciting tool with a high level of usage; unfortunately data that is generated is often not disaggregated enough to generate data that will identify how areas that might have small energy loss that can add up to have major energy impacts. We believe we now have the potential to install in a new campus building a low cost distributed acquisition system that can monitor down to the micro (component) level. We hope that this system will become the new standard for ASU and allow ASU to once again provide much needed leadership in the area (like it did with the release of Campus Metabolism).

Having the ability to have this type of instantaneous real-time monitoring of a building’s components, such as walls and roof will have many benefits. For example, procedures for determining the thermal resistance (R-value) of building assemblies have for the most part been a theoretical exercise. R-value testing is usually done in laboratories where the testing is not started until the material reaches “steady state.” Steady state occurs when a material is exposed to a heat source and is allowed to become thermally saturated so that for every single unit of heat entering on one side of the material a single unit of heat exits the opposite side. While very scientific and logical it misses an important issue relevant to predicting in-situ performance – which is the amount of time it takes to reach a steady state. Heat-balance modeling can take this dynamic into consideration; however, for in-situ conditions it has been very difficult to determine given changing temperature and varying solar heat gain during a typical day. Thus, being able to have the ability to take a “snapshot” at any given time of day and then capture the solar gain, ambient temperature, and all surface temperatures at each layer of wall or roof construction we are confident that a more accurate R-value can be determined for each layer of wall or roof assemblies. Such information will also provide an enormous benefit to researchers, building design professionals as well as students and any parties who are interested in understanding how individual building assemblies perform in real-time.

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PROJECT DESIGN

Five different wall/roof orientations within ASU’s new College Avenue Commons (CAC) were selected for monitoring. The CAC is a 137,000 square foot, five-story building for ASU’s new School of Sustainable Engineering and the Built Environment. Each orientation would have the exterior wall/roof monitored by sensors placed in a linear fashion through the envelope assembly, starting on the outside. At each subsequent material layer there will be a thermocouple measuring temperature. The final interior sensors will be heat flux sensors located on the inside surface. All of these sensors will be connected to a standard programmable logic controller (PLC) which will be integrated with other campus wide monitoring systems, as well as connected to the Internet. From there users can access this data via their personal electronic devices (tablet, smart phones or computers).

In addition, to understand the external microclimatic variations, a local weather station will be installed on the roof of the CAC. This station will not only measure the standard weather parameters (like dry bulb, wet bulb, wind speed and direction) but will also include four pyranometers (solar radiation sensors) that will be oriented to measure the exact amount of radiation that each of the building’s four orientations are receiving. This is vital data for determining the correct amount of solar radiation and its direct impact on performance of each of the envelope assemblies’ orientations.

Figure 2 illustrates a wall section and mock-up of how the thermocouples were placed in a typical wall. The first sensor was placed on the outside of the metal cladding, the second in the air cavity of the metal cladding, the third on the outside surface of the insulation board, the forth between the insulation board and the closed cell spray-in insulation, the fifth on the inner surface of the closed cell spray-in insulation, the sixth on the cavity side of the gypsum board and the final sensor (which is a heat flux sensor) was placed on the room side of the gypsum board. The blue strip shown on the wall section drawing between the closed cell spray-in insulation and the gypsum board is the location of the humidity sensor.

The installation of the envelope sensors took place over several months. This was because we decided to wait for each trade to be finished with their work. Thus, we incrementally added sensors as each material layer of wall or roof was completed. While this added time it allowed for more accurate placement of sensors at the boundary of each material layer versus drilling holes after the wall or roof assemblies were completed. Informing each trade about the nature of this project was important so that sensors and wires would not get disturbed or inadvertently cut. As a whole, the CAC contractors as well as each trade were very supportive and interested in its potential outcome of this project.

The classroom spaces that are directly adjacent to each of the envelope monitors will have a large LCD display that will allow students in those spaces to monitor real-time envelope performance. One of these spaces is designated to be ASU’s new HVAC Laboratory, which will be a teaching/research laboratory fitted with dual operating HVAC systems (a Variable Air Volume system and a Chilled Beam with a Dedicated Outdoor Air System) that can be switched between their operations. Here we would expect the classroom instructors to develop a host of learning exercises that would utilize the envelope performance data being generated to explore and test innovative HVAC operations. Thus, with the coupling of envelope monitoring with the HVAC Laboratory, a host of very innovative whole system research questions can also be asked and answered. While not the subject of this paper, we expect that a series of future technical papers will emerge from having such an innovative HVAC Laboratory operating in one of our campus buildings.

RESULTS

As of the time this paper was written, the CAC building is occupied, unfortunately the envelope sensors and data recording capability are only now being commissioned. Thus, rather than showing full operation of the five wall/roof sensor arrays we will show the three proposed Campus Metabolism screen templates that will house the sensor data and allow for display. We will also show measured data from the first wall sensor array that has been commissioned. We expect that at the time of the actual PLEA 2014 Conference (December 2014) to be able to show the real-time functional screen images of the envelope sensor performance from the new Campus Metabolism website.

Figure 3 illustrates the Campus Metabolism screen that would appear after a user selects the College Avenue Commons building. This screen has a brief description of the building along with four areas (Chilled Beam, Lighting, Wall Sensors and Roof) for which real-time data is available. By selecting one of these areas, a more detailed screen will appear. In our case we will select Wall Sensors which will open Figure 4. This screen shows an image of the CAC building on the left with the wall sensor placement highlighted with red dots, and the three rooms located adjacent to the sensor placement appear on the right side. By selecting the “View Snapshot” button, Figure 5 will open. In this screen we will select Room 425, which again shows an image of the CAC building on the left and below is a description of Room 425. Also on the left below the room description is a floor plan highlighting Room 425 in red and the sensor placement with a red dot. On the right side of this screen is a temperature profile through the wall section showing the temperature at each material layer. Below the temperature profile are four options (Last Hour, Last 24 Hours, Yesterday and Custom) which illustrate temperature profiles for those conditions. The Last 24 Hour option is an animation of hourly temperature changes over a 24 hour period. The Custom option allows the user to set-up a temperature profile for any time frame they would like. Finally “Current Conditions” are recorded below the temperature profile, which include data generated from the building’s weather station.

Figure 6 is a plot of a 24-hour temperature profile for each of the eight sensors that were embedded in the south wall of Room 425. This data was gathered on June 30, 2014, while the overall data acquisition system was being commissioned. Thus, it is very preliminary data and we are a little hesitant to interpret too much from this data. We would much rather wait until all the wall, roof and weather station data has been synchronized and operating in real-time. For example, it is not obvious why the temperature profile, which include data generated from the building’s weather station.

CONCLUSION

This project has taken what is usually done in a laboratory and turned the building into the laboratory that can monitor in real-time to show and graphically represent the actual thermal performance of each layer of a typical envelope assembly. This exercise outlines an effective approach for determining real-time temperature performance of envelope assemblies. It is of growing importance to understand how buildings perform down to the component level. Information like this will lead to better...
Figure 3  Screen describing the CAC and showing the four areas for which real-time data is available.

Figure 4  Screen showing the three rooms adjacent to wall sensors and sensor placement (with red dots)

Figure 5  Screen showing Room 425 (highlighted in plan in red) and wall temperature profile

Figure 6  24-hour temperature profile of the eight sensors in the south wall of Room 425
understanding of how building envelopes perform and operate as well as striving for a high level of data transparency. It is hoped that projects like this will give others the information needed to undertake similar installations. By utilizing the Web and presenting data in an interesting and graphically clear manner, it is hoped that it will lead to a host of new and exciting educational outcomes.

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REFERENCES

(2) Campus Metabolism can be viewed at http://cm.asu.edu.