# Eliminating the Design-Operation Energy Gap: A Case Study on Developing a University Level Course

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**Abstract.** The global community has reached a consensus on the need to address global warming through the ratification of the Paris Accord (2015). Achieving the goals set forth in the Paris Accord will necessitate a worldwide initiative to design, construct, operate and maintain Net Zero Energy (NZE) Buildings. Creating a new generation of NZE buildings will require the elimination of the historical "energy gap" between a building's design and its operation. This paper describes the development of a new college-level course at the Milwaukee School of Engineering (MSOE) that applies ASHRAE's Building Energy Quotient certification program to eliminate the energy gap by identifying, quantifying and accounting for the energy gap. The course is a critical step in training the next generation of industry leaders, in a multi-disciplinary environment, if NZE Buildings are to be a viable option for our industry.

## 1 Introduction

### 1.1 The Paris Agreement

In 2015, the parties to the United Nations Framework Convention on Climate Change (UNFCCC) reached a consensus on combatting climate change through the ratification of the Paris Agreement. This landmark agreement specifies a unified approach to climate change by setting a goal to limit the increase in global temperature to 2°C or less above pre-industrial levels to reduce the risk and impact of climate change. Moreover, the Paris Agreement envisions additional efforts to further limit the increase to 1.5°C.

The Paris Agreement is set to start in 2020 and calls for a mobilization of financial resources, a new technology framework and an enhanced capacity-building to be put in place. The agreement also calls for expanded support for developing countries to assist them in meeting the ambitious goals set forth in the agreement.

### 1.2 Complying with the Paris Agreement

Approximately 55% of the world's electric demand is used to light, power, heat, air-condition and ventilate buildings (IEA, 2017). Additionally, approximately 40% of the world's electricity comes from coal-burning plants. Coal, in turn, contributes 70% of the world's Carbon Dioxide ($CO_2$) emissions, a primary Green House Gas (GHG) driving climate change.

Due to the significant GHG contributions made by buildings it stands to reason that the process used to reach the goals of the Paris Agreement will, in large part, flow through the design, construction, operation and maintenance of buildings. The need to produce the most efficient, sustainable and resilient buildings is manifest. Fortunately, a number of organizations worldwide have recognized the need for a new generation of high-performance buildings and have worked steadfastly to produce a design, construction, operation and maintenance protocol to produce buildings with the lowest possible energy use. The ultimate design for such buildings is a Net Zero Energy building.

### 1.3 The Role of Net Zero Energy (NZE) Buildings

The relatively recent emergence of NZE buildings, along with the traditional protection of boundaries, has prevented a consensus on the definition of an NZE building. Two of the more common definitions have been develop by the European Union and the United States. The definition used by European Union (EU) states (EPBD, 2010):

*".... a building that has a very high energy performance, as determined in accordance with Annex I. The nearly zero or very low amount of energy required should be covered to a very significant extent from renewable sources, including sources produced on-site or nearby."*

The United States Department of Energy has a slightly different definition of an NZE building (DOE, 2015).

*"an energy efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy."*

Arising out of these different definitions of an NZE, it is not surprising that there is also a lack of consensus on how to best create an NZE building. In its simplest form, an NZE follows the following steps, in the order listed:

1. An analysis of user demand and behaviour that fully meets user expectations

2. Reducing the energy loads to the lowest possible level
3. Selecting an optimal mechanical and electrical system
4. Harvesting and storing energy from energy streams to and from the building
5. Selecting an optimal renewable energy strategy that covers the difference between the energy required and the energy harvested
6. Eliminate the "energy gap" between design (as designed) and operation (in operation)

Other protocols that have been proposed, but most contain at least the elements found on the list above.

# 2 The Role of ASHRAE's Building Energy Quotient Rating System

In order to produce an NZE, it is necessary to eliminate the "energy gap", the difference between the energy the building is designed to use and the energy that the building actually uses. The three-step process typically used to eliminate the energy gap consists of:

- Identify the gap
- Quantify the gap
- Account for the gap

ASHRAE's Building Energy Quotient (bEQ) is a rating program for buildings based upon energy that was specifically designed to identify and quantify the energy gap. There are two scales to an bEQ rating; In Operation and As Designed. The 'In Operation' rating compares actual building energy use based upon metered energy use. A minimum of 12-months of energy invoices is required. The 'As Designed' rating compares potential energy use based upon the building's physical characteristics (HVAC system, envelope, etc.) with standardized energy use simulation. The use of standardized criteria in the simulation ensures an equitable comparison between buildings that is independent of operational and occupancy variables. Both the 'In Operation' and the 'As Designed' ratings compare similar buildings in similar climate zones thereby producing an equitable comparison.

The bEQ scale is based on calculating the Energy Use Intensity (EUI) based on source energy. The rating is calculated by dividing the EUI of the building by the EUI for a baseline building and multiplying by 100 $(EUI_{Building}/EUI_{Baseline})/100$ The mid-point of the scale (100) then represents the average of all buildings of a similar type in a similar climate zone. The scale improves to a value of zero for excellent buildings, which also constitutes an NZE. Although the label lists an inefficient building as 200, it is possible for a building to receive a rating higher than 200.

The difference between 'In Operation' and 'As Designed' for a specific building identifies and quantifies the energy gap. Accordingly, bEQ is a critically important tool for design and construction professionals in their quest to produce NZEs.

## 2.2 Accounting for the Energy Gap

The first two steps in eliminating the energy gap are straightforward and are outside the scope of this discussion. Accounting for the gap is the critical step in the process and the one step that has caused the most frustration in our industry.

Accounting for the energy gap is a significant conundrum for most design and construction professionals, as it is a widely held believe that designers and constructors cannot control how an owner operates and maintains a building once the construction process has concluded. On the other hand, identification and quantification are comparatively easy steps and use tools that we are familiar with and apply every day. Controlling, or even influencing, owner behaviour is a different matter altogether, particularly on a topic as complex as building operation and maintenance.

The bEQ process does include a reporting process that identifies "low-cost, no-cost" Energy Efficiency Measures (EEM) to help lower the energy gap in a cost-effective manner. The larger issue is ensuring that the owner operates and maintains the building over its service life in a manner consistent with the high-performance design and construction practices that produced the building in the first place. High-performance design and construction techniques have little meaning if the building isn't similarly operated and maintained to those same high-performance standards. This is the source of the frustration felt by design and construction professionals.

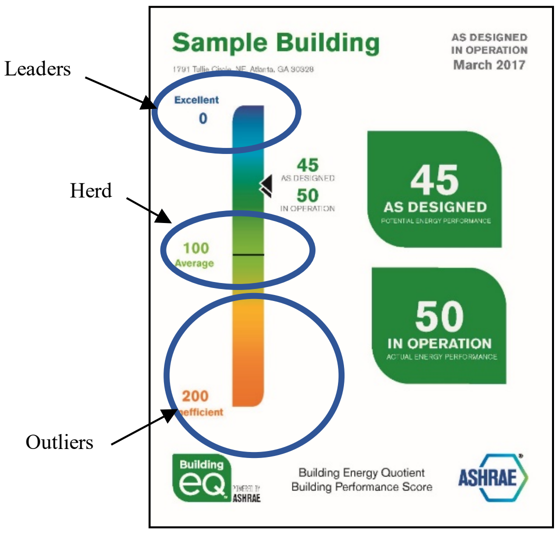
## 2.3 Shaping Human Behaviour through bEQ

Recent research indicates that shaping or influencing human behaviour may provide 10 to 20% energy savings in the operation of a building (Chen, 2016). One of the hidden strengths of the ASHRAE bEQ program is its ability to shape human behaviour.

Human beings have lived in groups or tribes since pre-historic times. We essentially are pre-wired to operate in a "herd", which not only increases our comfort level, it also shapes our behavior. At least in some respect our behavior has been historically shaped to follow the herd.

Evidence of our herding tendency is ubiquitous. Everything from corporate polo shirts to how we buy cars demonstrates our tendency to herd. One example of how our tendency to follow the herd impacts our behavior is found in research done on tip jars. Using a transparent tip jar and then "seeding" the tip jar with coins and paper currency will increase tip revenue (Heath and Heath, 2010). Why? Because of herding, often referred to as behavior herding (Ariely, 2009). People can see the money in the tip jar, and they assume it was inserted by other people (in point of fact, it may be money seeded by the proprietor). There is a natural urge to follow the herd and insert more money of the type that can be seen in the tip jar.

ASHRAE’s bEQ program shapes behaviour through a form of behavioural herding by visually depicting a “herd” at the midpoint representing average performance (Figure 1). Under this strategy ASHRAE’s bEQ program quickly and visually “triggers” or shapes behaviour by letting the viewer know if they are a part of the herd or not. Owners not a part of the herd will be strongly influenced to change their behaviour to at least join the herd. If the client has as its goal creating an NZE or nearly NZE building, this visual process will not only identify the distance the client must cover to get to its stated goal, it will also serve as a motivator to move the client towards taking a leadership role.




*ASHRAE bEQ Label – Courtesy ASHRAE*

## 3 Case Study

The Milwaukee School of Engineering (MSOE) is a private university located in Milwaukee, Wisconsin, USA. The Bachelor of Science degree program in Architectural Engineering (BSAE) focuses on the design of building systems, with specialties in Building Mechanical Systems, Building Electrical Systems, and Building Structural Systems. MSOE also offers a Master of Science degree program in Architectural Engineering, with specialties in Mechanical-Electrical-Plumbing Systems, or in Structural Systems. The course developed for this case study is housed in MSOE’s master program and can be taken as a technical elective in the undergraduate program.

One of the Program Educational Objectives of the BSAE program is that “graduates of the BSAE program are expected to have demonstrated an appreciation for sustainable design by having included aspects of sustainability in their completed projects” (MSOE Undergraduate Catalog, 2019). Conversely in the MSAE program one of the Student Outcomes is that students will be able to “use advanced design techniques to design complex building systems, related to their specialty, made of many components in accordance with building codes, regulations, and/or specifications under realistic constraints such as practice, costs and sustainability” (MSOE Graduate Catalog, 2019). With these outcomes and objectives in mind, the faculty developed a course to address the energy gap in a building using the ASHRAE bEQ rating system.

The course developed for this purpose is titled AE6412 – Building Energy Simulations. The course focuses on the study of building energy assessment principles and protocols for new and existing commercial buildings, as well as a focus on energy modelling to inform and guide the design of a new commercial building. MSOE utilizes a quarter system for course delivery; which means each class consists of ten weeks of instruction followed by a finals week. The AE6412 course is a three-credit course with three lecture hours per week without a separate laboratory for the course. This results in 30-hours of instruction in the course to cover the topics. The students are required to work on a current building project on the campus of MSOE for their semester project and submit the documentation for an ASHRAE bEQ rating.

The course learning outcomes were developed with the ASHRAE standards in mind as well as making a link back to the Program Educational Objectives and Outcomes. The learning outcomes developed are that by the end of the course students should be: 1.) Knowledgeable on building benchmarking and rating systems, 2.) Knowledgeable in the ASHRAE Standards that relate to energy efficiency, 3.) Proficient in utilizing computer energy modelling software to inform design decisions, 4.) Proficient in oral and written communications, and 5.) Knowledgeable of the professional responsibility required of the architectural engineer related to building energy efficiency.

The course begins with an overview of the ASHRAE bEQ rating system and its use. Students then discuss the principles of a Preliminary Energy Use Analysis (PEA) including review of a buildings energy billing data and energy billing rate structures. As part of the PEA the students also review ASHRAE Standard 100 and develop appropriate energy targets for the building. As the final part of the PEA the students conduct the preliminary water and energy use analysis and complete the appropriate ASHRAE bEQ form.

The next component of the course is the ASHRAE Level-1 Walk Thru Analysis. Students were required to develop a questionnaire and perform a Walk-Through Survey on the project as well as review the construction documents for the project. Students were required to document their observations in written form as well as with photographs.

The class then reviews Energy Efficiency Measures (EEM). Students review ASHRAE Standard 100 for EEMs to consider and develop a checklist of likely EEMs for the project. As part of this analysis students review HVAC systems, building automation and controls, lighting systems, and the ventilation/pressurization strategies of the design. Students are then required to conduct an Indoor Air Quality (IAQ) survey. A review of the systems of the building comfort control and indoor air quality are completed using a checklist of likely IAQ issues.

The students then review the requirements for an ASHRAE Level-1 Energy Audit. The financial analysis of the building systems is conducted as well as completing the ASHRAE bEQ in Operation Form 4. As part of the final project students are required to collaborate to submit the ASHRAE bEQ in Operation rating application on behalf of the University.

The final portion of the class is the presentation of the ASHRAE bEQ submission to the administration of the University. Students developed a 45-minute presentation showing the results of their review of the project, comparing the in-operation rating to the as-designed system for the building, identifying the energy gap. Suggested strategies to increase the energy performance of the facility are also presented. This presentation was given to the instructor of record, the Vice-President of Operations, as well as the Owner's Representative for the University.

The University has stated in its strategic plan that sustainability for their campus is a focus for improvement, as stated in Strategy 3 under the Commitment to Being Extraordinary – implement visionary and comprehensive plans for campus buildings, instructional technologies, and information systems (MSOE Strategic Plan, 2018). As part of this strategy the university needs to identify the baseline of their physical plant in terms of energy usage and efficiency, since no such evaluation had been done in the past. In keeping with the experiential-based learning that is the hallmark of MSOE, as well as also being part of the strategic plan as listed in Strategy 3 under the Commitment to Learning and Discovery – ensure that all students use real-world projects and initiatives in their field of study or extracurricular interest to benefit society and the communities where we live and work, it is vital to provide Architectural Engineering with buildings to work on in order to study its energy use. With this in mind, the University asked to have the evaluation of the energy use and energy gap for buildings on campus to be done by students as part of a class, and the AE6412-Building Energy Simulations course was developed specifically to help with this endeavour.

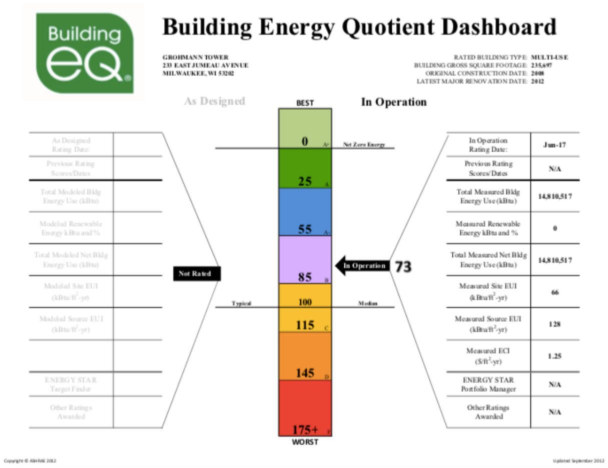
The project used for this course in the last academic year was the Grohmann Tower Apartments building. This is the first building on MSOE's campus to be evaluated for the ASHRAE bEQ rating system, it is also the first building on MSOE's campus to be evaluated for any type of energy or sustainability rating. The building is a 14-story mixed-use high-rise student housing facility located in downtown Milwaukee, Wisconsin. The 2nd and 3rd floor of the building are a parking structure while the 4th thru the 14th floor are the living units. There is also a larger conference room on the 14th floor. The first floor of the building has two separate commercial restaurants as well as a lobby area entrance for the residents of the building. The building has 150 living units in a variety of sizes ranging from 525 square foot (53 square meter) studio units up to 2300 square foot (250 square meter) 2-bedroom units. The project was completed in 2015 and utilizes a water-source heat pump HVAC system and a Johnson Controls Metasys Building Automation System.

*Grohmann Tower Apartments*

The facility has a gross floor area of 235,697 square feet (23,570 square meter) and a gross conditioned floor area of 225,213 square feet (22,521 square meter). Since the building is located in Milwaukee, Wisconsin, it resides in DOE Climate Zone 6A. The energy data used for the evaluation was from January 1st, 2016 thru December 31st, 2017. The data collected showed that the facility used 7,858,917 kBtu of electricity and 6,951,600 kBtu of natural gas for a total building use of 14,810,517 kBtu.

The students entered this data into the ASHRAE bEQ workbook and verified the results. The students then entered the relevant data into the ASHRAE bEQ Dashboard to evaluate their results, showing that the building in operation has a rating score of 85, earning a rating of B for the project.

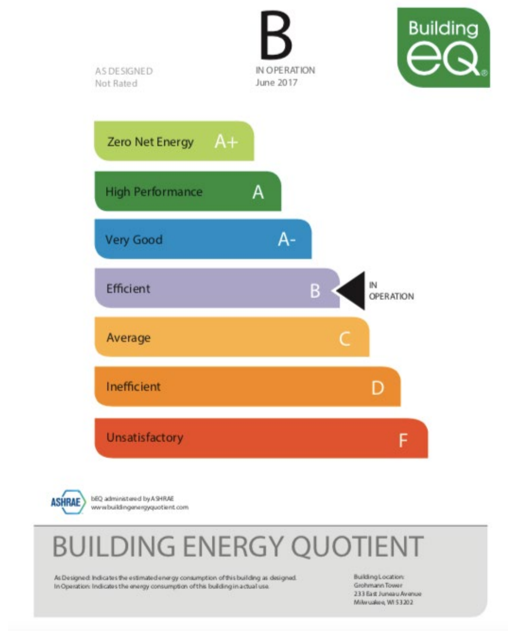
Since the pilot course was run, ASHRAE has completely revamped the bEQ program to include a new bEQ portal where the necessary data is now uploaded online. This eliminates the requirement for downloading and uploading spreadsheets, greatly simplifies the process and increases the response time thus giving the designer timely feedback and enables better design decisions.




*ASHRAE bEQ Dashboard – Grohmann Tower Apartments*

The AE6412 course was offered for the first time in 2017 and consisted of 6 students. All students worked collectively on both the ASHRAE Level-1 Energy Audit as well as the ASHRAE bEQ In-Operation rating application. The submission was accepted and reviewed, and the Grohmann Tower Apartments project was awarded a rating of B, or "Efficient" for 2017.

The students presented their findings to the leadership team of the University, including the Vice President of Operations. The conclusion of the students was in order to improve the energy performance of the building and help close the energy gap, the primary strategy the University should implement is the use of occupancy sensors for the lighting in all of the common areas of the building (e.g. hallways, elevator rooms, $4^{th}$ floor common spaces). The students ran an energy model implementing this technology and it was determined the building would achieve an A rating if this was done. The University is currently researching the possibility of adding these occupancy sensors to the building and will be soliciting bids from contractors in 2019 assuming funding is approved.




*ASHRAE bEQ Label – Grohmann Tower Apartments*

Students were invited to a ceremony to hang the ASHRAE bEQ rating plaque at the Grohmann Tower Apartments. The University will continue to utilize this class to evaluate the energy usage for other facilities on campus. The University is currently constructing a new facility, the Dwight and Dian Diercks Science Hall, a 64,000 square foot (6,400 square meter) facility to house the Computational Science and Software Engineering programs. The building also features a new Nvidia Supercomputer and data centre. The students for the current AE6412 course will be completing an ASHRAE bEQ As-Designed rating, with the following years class doing the In-Operation rating. This provides a unique opportunity for students to do both rating systems and compare the results.

## 4 Conclusion

The need for buildings to become more energy efficient in order to lower the demand for coal is clear. In turn, this will help combat the global warming crisis and help comply with the Paris Agreement. The push for buildings to strive for NZE will continue to grow in the immediate future.

Many building owners are concerned with the energy usage of their facilities, and universities in the United States have significant expenses in this regard for their campuses. Students entering into the Architectural Engineering industry will need to be aware of these concerns in their designs and should be knowledgeable in how to conduct an ASHRAE bEQ rating for a project.

This course showed the tangible benefits of having a college class dedicated to energy analysis and identifying the energy gap thru the ASHRAE bEQ rating system. The University helped make progress towards its strategic goal of obtaining a more energy efficient campus by establishing a baseline of energy usage on the Grohmann Tower Apartments. The University also obtained several strategies from the student presentations on methods to lower energy usage in the building for the future.

The course was successful in instructing students on how to complete an ASHRAE bEQ In Operation rating for a building. The course also met all of its stated learning outcomes as verified thru exam scores as well as by the rubric used to grade the final project submission. Further validating this was the acceptance of the ASHRAE bEQ submission and the project receiving a rating.

The course also helped the students achieve the specific MSAE program outcome to be able to use advanced design techniques to design complex building systems, related to their specialty, made of many components in accordance with building codes, regulations and/or specifications under realistic constraints such as practice, costs and sustainability by evaluating a real-world project thru an ASHRAE Level-1 Energy Audit and then presenting strategies to improve the energy performance of the building. By incorporating these types of projects into the curriculum it is hoped that graduates will then meet the Program Educational Objective to demonstrate an appreciation for sustainable design by having included aspects of sustainability in their completed projects.

It is clear that building owners will continue to seek systems and strategies that lower the energy use of the building. In order to do this, engineers must be trained to perform design analysis of various options to achieve NZE status. It is imperative that college curricula reflect this need and implement courses that address this need. This case study serves as an example that not only will the course help train the future engineering professionals about these strategies, but also that the University can gain tangible benefits from having the students use campus buildings as class projects.

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