

May 2019

Produced by BrainBox AI

# Using Artificial Intelligence to Optimize the Flow of Energy through the Built Environment

Managing the thermal equilibrium of a building using dynamic modulation to achieve improved occupant comfort and greater energy efficiency

# 1.0

---

# Introduction

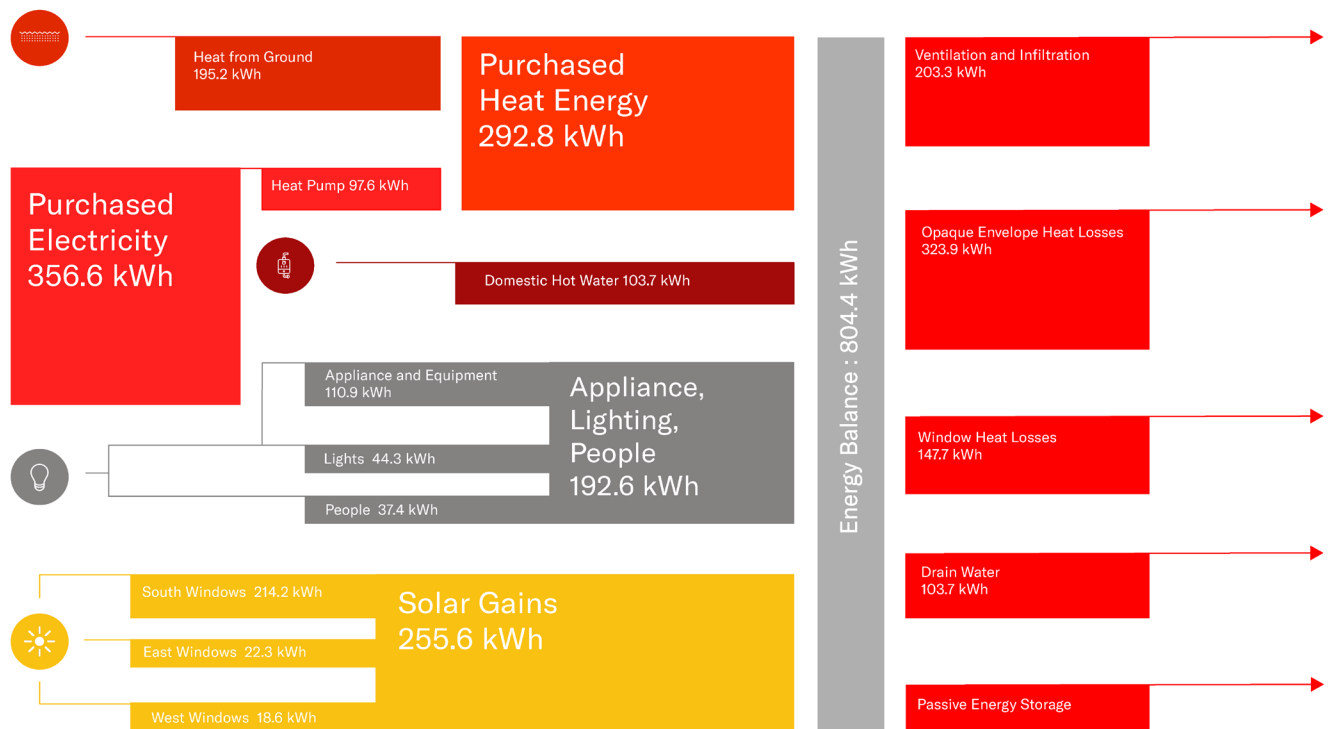
Energy efficiency must be embraced as a dynamic resource in order to achieve real efficiency gains in our built environments. Instead of using a static operating model of building operations and maintenance, we need to think about energy in terms of flow and modulate equipment performance dynamically in response to the ways in which the internal and external environments change over time.

Effectively managing the thermal equilibrium of a building using dynamic modulation is a complex process that requires continuously optimizing energy flow to ensure occupant comfort and maximum energy efficiency. The first steps towards maintaining a building at equilibrium are to calculate its energy leak rate and determine the ideal HVAC system settings to ensure optimal levels for the

power-to-thermal load relationship. However, both the energy leak rate and the power-to-thermal load relationship are themselves dynamic, which means that they change over time as the various factors that impact energy flow change over time, including occupancy, weather conditions, and demand.

The dynamic thermal equilibrium process shown in Figure 1 is based on an understanding of the built environment as an ecosystem of interdependent systems. Maintaining energy balance requires calculating all of the energy flowing into the building, including purchased energy and appliances, lighting, and people, and then balancing those inputs with thermal losses due to such factors as ventilation, infiltration, and drain water. But these factors are dynamic, not static, so the thermal equation for

**Figure 1:** The Dynamic Thermal Equilibrium Process in the Built Environment



a building—and each building has its own unique equation—is constantly changing as conditions change. As a result, effectively maintaining a building at balanced thermal equilibrium also requires finding ways to accurately predict how these inputs and outputs change over time and to ensure that all systems react to these predicted changes in the best possible way. However, because of the complex nature of energy flow, manually determining a building's thermal energy equation and then managing the flow of energy is difficult.

In the built environment, using Artificial Intelligence (AI) is an extremely effective way to maintain a balanced thermal equation. One of the benefits of using AI in the building management space is that it can determine the thermal energy equation for a building in a fraction of the time required by individuals. In fact, the real value of AI arises when its used to predict how the flow of energy will evolve over time and if it anticipates an unwanted thermal event in the future, to make adjustments to the HVAC system to eliminate that event before it happens. In addition to determining which adjustments are best for ensuring occupant comfort, AI can also evaluate the optimal HVAC system configuration required to achieve greater energy efficiency, thereby saving money and making buildings greener by reducing the load on the power grid.

# 2.0

---

## Characterizing the River of Energy

Every built environment has its own unique set of habits and behaviors that affect the river of energy that flows through it. And, these characteristic behaviors are expressed in a collection of thermal energy equations, which, once calculated, will not change over time for a building unless major renovations are carried out.

Characterizing the river of energy by calculating a building's thermal energy equation is the first step towards optimization and requires calculating its energy leak rate and power-to-thermal load relationship.

## 2.1 The Importance of Zones

The best way to characterize the collection of thermal equilibrium equations for a building is to first divide it up into zones or divisions and then derive the collection of equations for each zone. This requires collecting historical data from the zones and then looking for patterns in that data in order to isolate each zone's habits and behaviours. Once the specific energy leak rate and power-to-thermal load relationship has been calculated for each zone, the next step is to aggregate the characterizations of all the zones into a group of zones.

While these tasks can be performed manually, an AI engine can perform them in a fraction of the time, accomplishing in 2 minutes what it would take an engineer 3 weeks to do.

## Deep Learning

Deep learning involves developing a multi-layered brain—referred to as an artificial neural network—that can perform a specific task, like recognize a human face in an image. The process of deep learning works by breaking down this larger task into many smaller tasks, which each layer of the neural network is then trained to perform. Once a layer of the brain has completed its isolated task, for example, establish the outline of the face, it then transforms the image into a new version and sends it to the next layer to be processed. This next layer could be responsible for locating eyes on the outlined face or identifying facial hair. By continually transforming an initial input through the deep layers of the network, the brain successfully completes its assigned task.

## 2.2 Energy Leak Rate

According to the laws of physics, thermal energy will always work to reach an equilibrium, so energy will always flow across a differential to balance the amount of energy on either side. If the energy levels are balanced in a system, then there is no flow. However, if the thermal energy on one side is higher than on the other, energy will start to flow at a certain rate across this differential until equilibrium is achieved.

In the built environment, there are barriers in place, including walls and windows, that work to slow down this rebalancing. The energy leak rate—hereafter referred to simply as the leak rate—is the speed at which energy moves across these barriers and measures the quantity of heat that a built environment loses or gains over a given period of time. It refers to the rate at which energy flows either into or out of a given zone. Each zone has its own unique leak rate that is based on how it was built—including the types of materials used, like insulation and windows—and on its operation and maintenance.

There are two critical factors to consider when calculating leak rate. The first is that every barrier has a unique leak rate that is dependent on its material composition and on how the building itself was built. Therefore, two identical windows installed in two different buildings will have different leak rates. The other factor is that leak rates are dynamic and vary according to changing conditions, including occupancy and weather, which means that the flow of energy in a zone is constantly changing over time. For example, while energy would leak out of a zone on a typical spring morning because it is colder outside than inside, the leak rate in that zone could reverse later in the day if it becomes hotter outside than inside, meaning that energy would start to flow inward through the walls and begin to heat the zone.

One of the keys to effective building management is to maintain the derived temperature of a conditioned space and ensure occupant comfort by continually compensating for the leak rate. This means that, if energy is leaking out of a zone, then maintaining that zone at the derived temperature requires supplying thermal energy to that zone at the same rate at which it is leaving. If

energy is leaking into a zone because the outside temperature is higher, then you have to cool the air and withdraw thermal energy at the same rate at which it is entering.

Calculating the leak rate of a zone based on the materials used and also mapping the dynamic of its leak rate under all possible conditions gives you a clear understanding of what is going to happen in that zone in terms of energy flow. Accurately calculating the leak rate is critical for maintaining a constant and stable temperature in a zone because, if you know how quickly energy is leaking in or out of a zone at any given time, then you can adjust your HVAC system to produce and push the right amount of cold or hot air to compensate for the leak rate in real time and maintain that zone at a constant temperature.

While maintaining a balanced thermal equilibrium in a zone can be done manually, the process of managing the flow of energy through every zone in a building is neither economically nor procedurally viable. Deploying AI in the building management space represents, through dynamic modulation and forecasting, an accurate and cost-effective way to maintain a balanced thermal equilibrium. Initially, AI can be used in combination with linear regression analysis tools to quickly and accurately calculate the leak rates for all zones within a building under all possible conditions. But the real value of this technology becomes clear when AI (1) uses the leak rate behavior for a zone to predict what the temperature will be in that zone at different times in the future and then (2) makes adjustments to the HVAC system in real time based on these predictions to eliminate any unwanted events from the zone's timeline.

## 2.3 Power-to-Thermal Load Relationship

The power-to-thermal load relationship refers to how efficiently the engine in an HVAC system converts power into thermal energy that it then delivers to the various zones in a building. Power is the input into the engine and is measured in kilowatts or cubic metres of gas; thermal load, measured as cubic meters of hot or cold air, is the amount of thermal energy delivered into the zones as output. In building management, it is the conversion relationship between the power that is fed into the engine and the air that is served that is interesting, and the power-to-thermal load relationship measures the level of efficiency of the engine in the HVAC system at maintaining the desired temperature within a building's zones.

While the efficiency of the engine is determined to a large extent by the equipment that was purchased and how that equipment was installed, operators are able to adjust various settings on the engine in order to optimize its performance. For example, in addition to being able to open or close dampers, operators can also adjust the engine to serve more or less air/minute and to slow down the production of heat. Playing with these settings makes it possible to fine tune the engine and find the ideal configuration—or combination of settings—for achieving the most efficient power-to-thermal load relationship for a given zone.

But this relationship is dynamic in nature since the optimal power-to-thermal load relationship for a given zone is dependent on different internal and external conditions, such as occupancy and weather, that change over time. For instance, the ideal configuration for a specific zone with five occupants and with no sunlight during the winter

will be drastically different when there are fifty occupants with full sunlight during the summer.

Therefore, maintaining balanced thermal equilibrium in a zone in the most efficient and effective way possible—which means ensuring occupant comfort, saving money, and reducing carbon footprint—requires calculating the ideal engine configuration under all possible conditions for each zone within a building. And, while this would be costly and time consuming to achieve manually, managing this power-to-thermal load relationship in a building is a task that is perfectly suited for AI.

The process involves giving the AI all of the relevant data concerning both the HVAC system's engine, including performance data, and the zones within the building, including historical data about occupancy levels and weather conditions. From a data perspective, the AI would not be concerned with the kind of HVAC system installed within the building; it would simply look at the available data and calculate the ideal configuration for the engine from an efficiency perspective for all zones under all possible given conditions.

For instance, in order to calculate the most efficient way to keep a zone in winter with five occupants at the desire temperature of 22 degrees, the AI would compare the power-to-thermal load relationship to see if the engine would consume less power by changing the configuration of the system to maintain the desired temperature. The goal in this instance would be to analyze the available data in order to find the right combination of factors that would allow the engine to produce the thermal energy required to maintain occupant comfort in the most cost-effective and environmentally-friendly manner.



# 3.0

---

## Predicting Energy Flow in a Building

Having characterized all zones in a building, the next step is to ensure that each zone is reaching balanced thermal equilibrium at all times and under changing conditions. Accomplishing this requires predicting the future conditions within each zone according to selected variables and then, in response to those predictions, making adjustments in real time to specific pieces of HVAC equipment in order to ensure that each zone is always achieving thermal equilibrium.

In the building management space, AI is the most effective and efficient way to maintain equilibrium. While you could construct a simulation to model a building's behaviour, the process is significantly more time consuming and less accurate than using deep learning for optimization. In comparison to a 40-50% accuracy rate when using simulations to predict building behavior, our research shows that AI is far more accurate.

## 3.1 Deep Learning

The first step is to use deep learning and months of historical data that has been organized in advance to train the engine for each zone in a building. Using deep learning, it is possible to predict what will happen in a zone in the future by first calculating what the leak rate will be and then using that projected leak rate to predict the temperature.

## 3.2 Predicting the Future

Then, the AI engine uses a zone's previously calculated leak rate behavior and power-to-thermal relationship to make predictions about its behavior.

Since these features typically do not change, this characterization can be used to calculate how the zone will react over time to changing conditions, such as occupancy and weather.

Our method of deep learning uses the zone's leak rate behavior and power-to-thermal relationship and what the AI has learned based on the historical data to make predictions about the future value of different parameters. These parameters can include whatever variables building owners want to manage, including temperature levels, humidity levels, and the concentration levels of different gases. From these predictions regarding the future value of key variables, the AI is able to make decisions about how to best manage the thermal equilibrium for every zone in a building.

### Time Series Learning

Time series learning is also a feature of our AI, and this involves instructing the AI to look for patterns in the evolution over time of a given variable at a fixed location. A temperature sensor in a room is an excellent example. This sensor's location does not change, and the AI analyzes how the temperature at that sensor evolves over time as a result of changing conditions to see if it can find any discernible pattern in the data. This type of learning is very important for predicting the future, for understanding how variables change over time based on changing conditions.

# 4.0

---

## Changing the Future

## 4.1 Identifying the Right Course of Action

When the AI engine, based off of its predictions, sees an unwanted event in the future that will disrupt the balanced thermal equilibrium in a zone, the engine begins testing various micro-modifications to the HVAC system to figure out the effects that different combinations of adjustments will have on that zone's future conditions. The AI engine then uses the results of these tests to evaluate which combination of modifications to which pieces of equipment will, over time, most effectively eliminate the unwanted event. Once the right course of action is determined, algorithms then instruct the HVAC control system to make the modifications to the selected components to get the zone to the desired condition.

For example, let us consider a situation in which the engine predicts that the temperature on a particular floor in a building will be too high in three hours. In response to this prediction, the neural network runs models on different micro-modifications to the HVAC system to see the impact that these possible modifications would have on the predicted temperature increase. Using this information, the AI decides on the best course of action—for instance, lowering the blinds and turning on the air conditioning—that will bring the floor to where it needs to be in order to ensure that the rise in temperature in three hours does not occur. It then instructs the HVAC control system in real time to make the desired modifications in order to create the right conditions on the floor.

## 4.2 Re-evaluation of Predictions

In the next phase, the AI engine goes through the entire process again at a later time to check how the zone reacted to the modifications. Using the zone's thermal equation and the new conditions in the zone, it measures the results of the modifications on the specified variables and determines whether or not the instructions actually changed the future in the intended way and if these changes will, in fact, lead to the elimination of the unwanted event. The deep learning engine then tests all the possible combinations of different modifications that could now be applied in order to eliminate the predicted event. Once this is done, the AI again selects those adjustments that will most effectively eliminate the predicted event and instructs the HVAC control system in real time to make the required adjustments.

Continuing with the previous example of a predicted rise in temperature in three hours, the deep learning engine analyses the new conditions on the floor and its learning based on historical data to see what effects, if any, the changes had on that predicted rise in temperature. Based on this information, the deep learning engine again calculates how effective different combinations of possible modifications will now be in eliminating the predicted rise in temperature. Once the AI determines the best course of action based on these calculations, it again instructs the HVAC control system to make the required modifications towards cancelling the predicted event. In this way, the AI, by continuously making adjustments and then reassessing the effectiveness of those adjustments, changes the future in real time and makes what you want to happen a reality.

## 4.3 Multiple Variable and Cost Effectiveness

The above example only dealt with one variable, namely temperature. But, in reality, BrainBox AI can perform the same predictive work and system modifications on as many variables as you want to control in the conditioned space. The example also dealt with only one zone. Our solution performs these evaluations and modifications in real time for all the zones in a building based on the variables selected for each zone. In this way, by controlling the future in each zone, the aggregate result is that it is able to optimize the energy flow in the entire building without any human intervention.

In addition to working on multiple variables for the different zones in a building, our AI engine can also look at energy spending and carbon emissions as part of its decision-making process when trying to figure out the best course of action for eliminating unwanted events in the future. So, in addition to being able to determine the right combination of modifications, BrainBox AI can also determine which modifications would be the most cost effective and which would most significantly reduce a building's carbon footprint.

For example, from a cost analysis perspective, our AI engine can determine when is the right moment during the timeline to make the required modifications to get the desired final result in the most cost-effective way. It does this by evaluating which modifications would cost less to create the desired conditions in the future, those that would need to be done immediately or in twenty minutes. It can also determine which modifications would be the greenest. In this way, BrainBox AI creates the conditions you want in the future at the optimum cost and in a way that protects the environment.

# 5.0

---

## Conclusion

BrainBox AI is the intelligence behind self-operating buildings. Our deep learning engine and proprietary process autonomously optimizes existing HVAC control systems, maintaining a building's thermal equilibrium without human intervention. By (1) accurately predicting future conditions, (2) evaluating the best possible configuration for the existing HVAC system, and then (3) instructing the control system to make the necessary adjustments, BrainBox AI allows you to achieve real energy efficient gains in the built environment. The time has come to use the power of AI to optimize our buildings and save our planet.

## A Look at What's Next

Before taking a more comprehensive look at how our deep learning engine is built, it is important to understand how the data that is fed to our solution is structured. In our next white paper, we will explore how, through data clustering, we organize our data to optimise the learning process of the AI engine, enabling it to make the appropriate adjustments to an HVAC system in response to different thermal situations that it encounters.

Interested in learning more? Visit our website [www.brainboxai.com](http://www.brainboxai.com)

Just as certain words combined in specific ways in sentences and paragraphs have a specific meaning, different variables and values combined together to form different thermal situations also have specific effects when it comes to the flow of energy through the built environment. To support multi-factor environments, we have created the bag of thermal moments concept, with each bag having its own specific associated meaning. When this ability to recognize situations and make decisions about what to do is combined with the capacity to accurately predict the future, it is easy to see how the application of AI to the building energy sector is ushering in a new era in building automation.