ICEBO 2013:

PREDICTIVE ENERGY OPTIMIZATION: THE NEXT GENERATION OF ENERGY MANAGEMENT

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BACKGROUND:

Commercial buildings consume nearly a fifth of all US energy consumption, most of which can be traced to heating and cooling. This creates a huge opportunity to conserve energy through optimizing HVAC operations and connecting a building to the smart grid. The smart grid has great potential but is being restricted by buildings that are using outdated energy management systems.

A quantum leap in building intelligence is required to close the gap between the current state of building operations and the needs of smart grids and smart cities.

Unfortunately for the building HVAC controls industry, there has been little motivation to improve upon the basic control methodologies, which are now over 100 years old. Originally used to control large ships, these methodologies are based on making control actuations – where a valve or damper moves - based on the ‘error’ between current conditions (sensor readings) and the target (set-point).

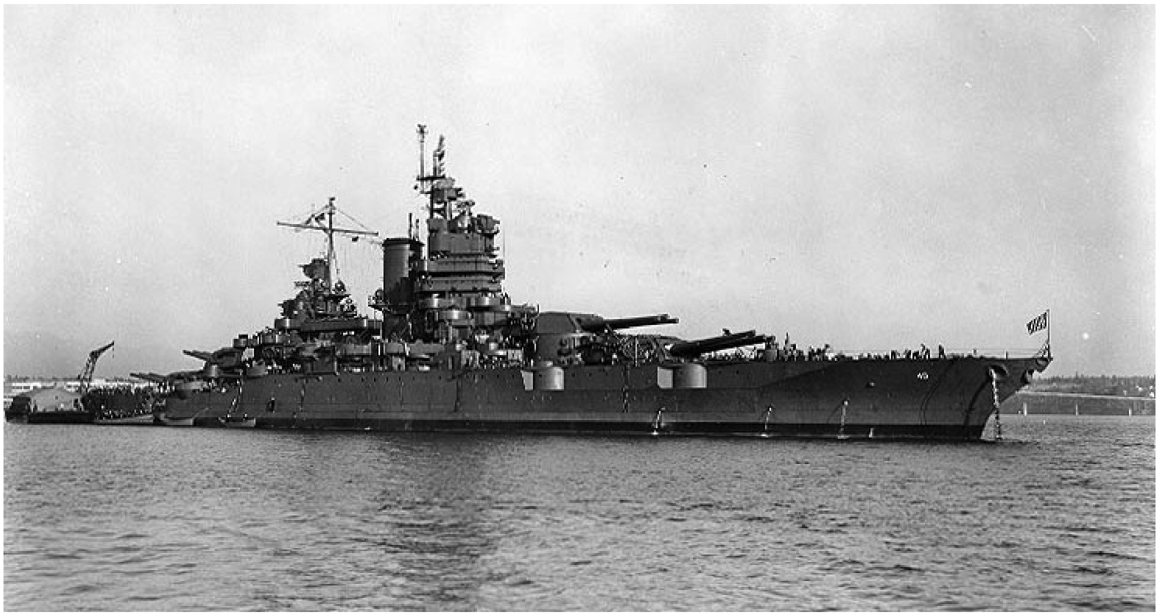

Figure: USS New Mexico trialed early PID control in the early 1900's – but was rejected by personnel. Photo: Wikipedia

Proportional control is used to actuate a device based on applying a 'gain' to this error and is the simplest method of control. Integral control is used by accumulating this error over time and assists with providing 'trim' control. This also provides a smoothing effect to the rapid changes often introduced by proportional only control. Finally, the rate of change (derivative) in the error can also be calculated and used to slow the change in actuation rate – thereby providing further smoothing and a less aggressive approach toward the final target set point.

CURRENT STATE OF CONTROLS TECHNOLOGY:

Combinations of Proportional, Integral and Derivative (PID) control are used throughout almost all digitally controlled buildings in operation today. There are quite literally hundreds and sometimes thousands of devices within a building that actuate their speed or position based on the ubiquitous 'PID Loop'.

Looking at the building controls industry for the last decade or more there has been continued convergence around core control capabilities across the majority of vendors. The fundamental building blocks of control loops and programming remain largely unchanged since the introduction of automated digital control during the 1980's.

Much investment has been made in developing bettering interfaces and engineering tools. Historical data storage and online services have all progressed, as the fundamental building blocks remain unchanged. The control systems run to the set points specified by the engineer.

But what is the best set point? Furthermore, what is the best *combination* of set points?

Precisely navigating to the wrong location does not an effective GPS make.

MOVING FORWARD:

Industries such as petro-chemical have invested in developing advanced control algorithms for processes where small control improvements can deliver significant value. Where industrial feedstock and outputs are often valued in the millions of dollars, the research and development required to create these advanced algorithms provides a significant return on investment.

These algorithms may be used to ensure strict maintenance of process conditions. For example maintaining the temperature at a particular stage in a distillation process. Further advancements in the field of Model Predictive Control allow for accurate transitions between targets during the process. For example, where a process requires a rapid yet controlled transition from one temperature to another in an autoclave.

Model Predictive Control (MPC) builds on the foundation of PID control with the introduction of learning and adaption. By using ‘prior knowledge’ i.e. historical data, MPC based algorithms can learn the basic dynamics of the system, which it intends to control. In the above example of controlling a rapid transition in process temperature, MPC may allow the controller to move directly to an estimate of the most appropriate system output with PID control used to fine-tune the final output.

Although the MPC approach may still not provide the most appropriate final destination, the use of historical data (prior knowledge) to gain insight into the underlying system is a critical piece of the puzzle.

THE GAP:

The field of MPC provides a powerful way to actuate a system with the desired speed and at a high level of accuracy. Unfortunately, however, MPC does not provide insight into what may actually be the best set point. Furthermore, many industrial processes require very specific temperatures, flows, etc. hence the benefit of adding MPC to PID control.

The opposite is true in building systems. HVAC systems in large buildings have a multitude of systems running to set points which have allowable degrees of freedom. A thermostat might be allowed to drift between 72 and 76 degrees (“dead-band”). A chiller plant may be able to supply chilled water anywhere between 35 degrees and 60 degrees. The inter-dependence between systems also introduces unique challenges. Changing the operating point of that chilled water system typically introduces upstream changes to the way the cooling towers operate and, similarly, to the way the downstream cooling coils behave.

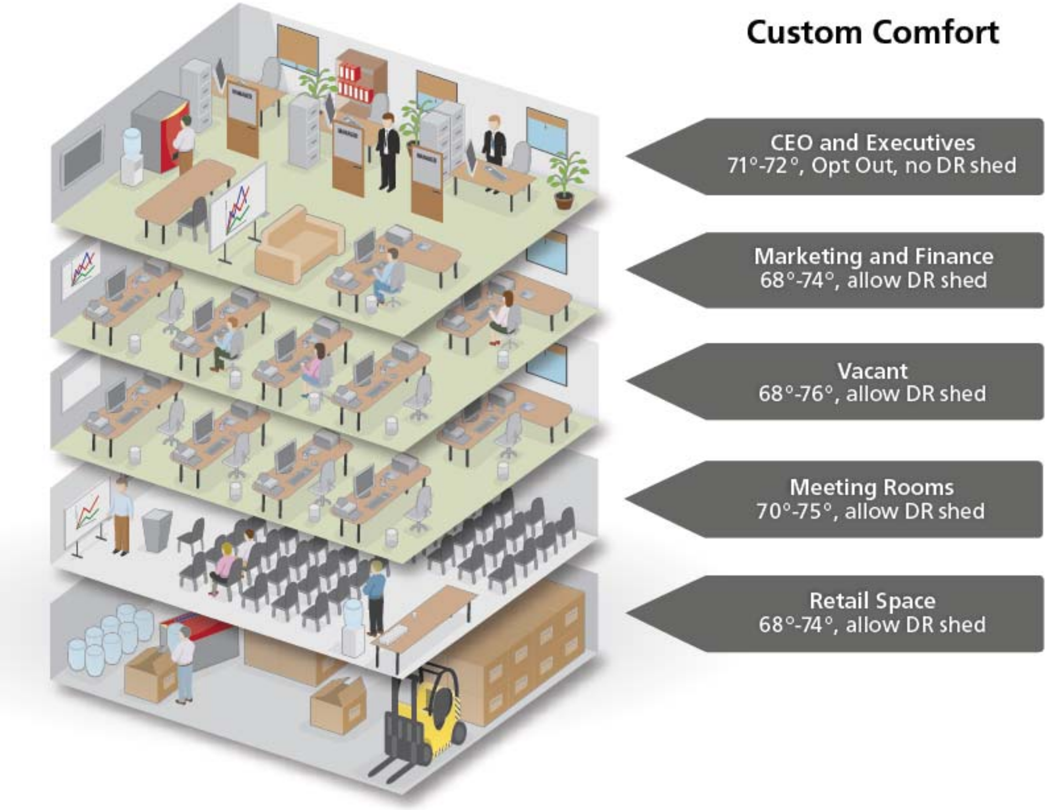

Figure: Example of Occupied Space Degrees of Freedom

Traditionally, the desired set points for all of a building's given control points are specified during design or retro-commissioning. A small portion may be modified day to day by operations staff but the overwhelming majority of the major, energy influencing sub system operating parameters are written out like a script and then implemented by "if, then, else" style programming.

Given the complexity of all possible interactions between the systems within a building, it is no surprise those rules of thumb and other industry standards have developed in an attempt to maximize overall system efficiency. Unfortunately the implementation of fixed, hard programmed logic does not make for a system able to cope with any further increases in complexity.

Multi stage Time of Use (TOU) pricing, real time pricing, demand response, electric vehicle charging, on site renewables, co-generation, energy star targets and a range of other complexities introduce the need to move beyond fixed logic and scripted responses.

THE SOLUTION:

Given the gap between MPC and the need to manage the many degrees of freedom within a building, the answer to the “what set point” question is more likely to be solved by looking at the “production manager’s problem” from the industrial world rather than the MPC solution.

The “production manager’s problem” is a notional, complex problem involving variable cost inputs and production rates with the goal of maximizing some type of metric be it throughput, revenue or profit margin.

A simple widget factory can be used to illustrate the problem: If the labor force, output rate and unit cost are all fixed and known then the throughput/revenue/margin problem is easily solved. However, if a temporary increase in output is needed then the problem begins to get more complex.

If the labor force was previously running at 100% then, to reach the increased output, additional labor is required. How should new labor be introduced? Should additional labor be full time employees as perhaps the cheapest option albeit with the risk of adding long term, committed resources for a temporary surge in output? To avoid the long term head count increase then perhaps the production manager could use expensive overtime or contract labor. With the addition of the simple options the problem rapidly becomes more complex.

Furthermore, there may be a cost reduction for the widget factory feedstock with increased volume. The increased output may also sell for a lower price therefore reducing per-widget revenue. As further impacts on changing production are considered – such as factory space and location – the problem becomes extremely complex very quickly.

The production manager’s problem can be seen in action when considering an airline setting up route schedules. The high capital cost of aircraft acquisition, crews that need to be utilized, locations at varying costs all compound into a very complex problem to optimize.

Clearly, the production manager’s problem is very similar to the building operator’s problem in a world with complex buildings, complex pricing and complex goals.

THE SNOWFLAKE PROBLEM:

For the most part, the production manager’s problem can be written out as a mathematical equation. With today’s computer processing power and mathematical software, a solution to almost any such problem can be found. At the very least a 'feasible region' can be found where a range of possible solutions exist.

This mathematical optimization process is used today in everything from airline route-planning, hydroelectric dam storage/release planning and electrical network planning. Complex problems with complex inputs and without clear answers. Complex problems that are modeled and subsequently solved in software. Complexity that is beyond the limitations of simple rules of thumb or spreadsheets.

Unfortunately, buildings and airlines are like snowflakes – no two are the same.

In the airline route-planning example above, we realize that the complex mathematical formulation developed for one airline's routes will most likely not work for the next airline. This is not such a big problem for a multi billion-dollar airline to address in a custom fashion. A custom solution developed for each building, however, is not really an option.

Following the advice of all good physicists can solve the solution to this small-scale customization problem. *Go back to first principles.*

A PRINCIPLED APPROACH:

All buildings are different. They are all unique.

All buildings also happen to observe the laws of physics. No architect's grand design can overcome the laws of thermodynamics.

Herein lies the solution to the development of a new way of thinking in the operation of buildings. Through the combination of prior knowledge with a physics based mathematical model of the building, customized machine intelligence about that particular building can be created.

With a uniquely developed intelligence, that building can take in weather forecasts, pricing information and other information and make informed decisions. These informed decisions present the quantum leap required to bridge the gap between buildings run on rules of thumb to the smart buildings required by smart grids and smart cities.

Figure: Learning System Architecture

Most importantly, this framework allows for further detail and complexity to be added over time. Scope for improvement that has been lacking in the humble PID loop since it's invention over 100 years ago.

The intelligence of the best building designers and operators must be captured in less structured software capable of a moderate level of self-awareness. When basic self-awareness is coupled to a decision making engine then complex decisions can be made 24 hours a day, 7 days a week.

A building that is aware of both its capabilities as well its demands on a smart grid can work in harmony with its occupants, its operators and its neighbors.

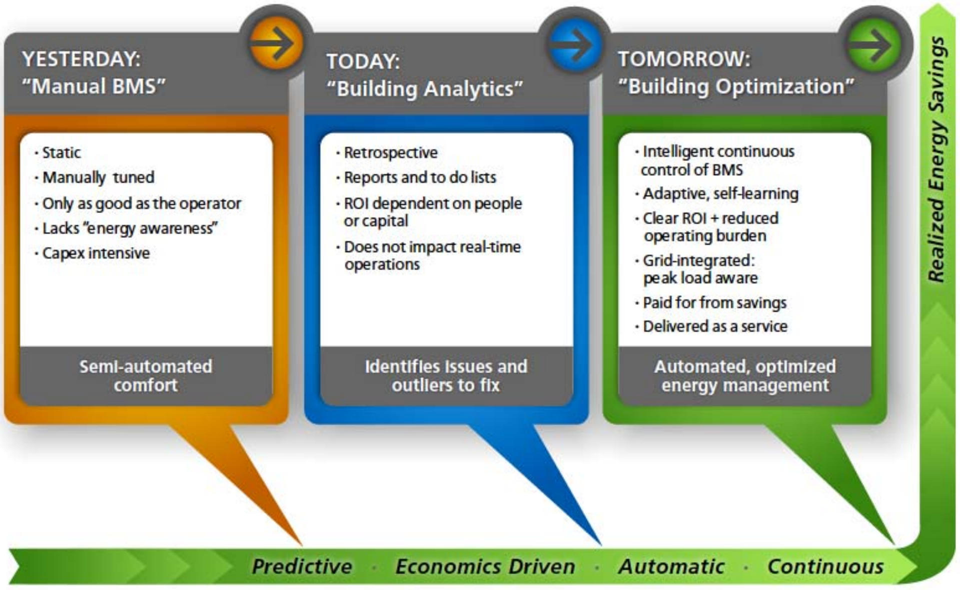

Figure: Industry Progression