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From Hassle to Affordable Comfort: Automating the HVAC of Commercial Buildings

White Paper

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Introduction

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Today's Buildings are equipped with Automation/Management Systems (BAS or BMS) which generate high volumes of data that is mostly used in the drafting of consumption reports. However, this data also contains information about the characteristics of the building and its behavior. Therefore, it could be valuable for tasks such as system reconfiguration and predictive maintenance.

Around 90% of complaints inside buildings are related to heating and cooling issues. This seems to be a paradox since commercial buildings spend at least 40% of their energy bills for their HVAC systems. Furthermore, buildings are the top energy consumers: they were responsible for 30% of worldwide energy consumption in 2016 - a third of the associated CO_2 emissions - according to the International Energy Agency. But what about comfort? How are facility managers able to adjust building settings according to occupants' needs? Can they save energy while meeting those comfort requirements?

In this White Paper we discuss a data driven approach for optimizing the warmup phase of a Building (when to turn it on!) and why it is a better choice than the usual manual and static methods. We present results of its application to a quick service restaurant with a multi-space HVAC system. Our analysis shows that our approach can save 8% on the HVAC energy bill without any real impact on occupant comfort.

Chapter 1

The HVAC Challenge

In the undertaking of improving the energy efficiency and occupant comfort of commercial buildings, the HVAC would naturally be one of the first systems to consider. It is ubiquitous and plays a crucial role in occupants' comfort in many parts of the world. Furthermore, as already mentioned, it is usually responsible for a very large part of a building's total energy costs.

Given its importance, how is the HVAC system of a commercial building configured? Surprisingly, available methods are limited to static rules with predefined parameters. In general, BMS manufacturers define the parameters, e.g. set-point temperatures for rooms and water reservoirs, as well as the schedules of HVACs at the commissioning phase. Scheduling mostly amounts to turning on a few hours before (and off after) working hours. It lacks both knowledge of how the building performs during its operation, and coordination with the project designers. If the building has a Facility Manager, these settings can be readjusted later on (hopefully with a better understanding of the building). Unfortunately, these adjustments are usually made reactively based on the feedback of the occupants (more comfort!) or the management (more savings!). The Facility Manager, receiving conflicting instructions by the stakeholders and handling so many variables that influence energy performance, finds themself in a dead end.

Furthermore, the HVAC configuration and operation represent a dual challenge. Primarily, the goal of an HVAC is achieving certain indoor conditions. This must be done efficiently and without wasting energy. Nevertheless, even if waste is eliminated, there is still a tradeoff relationship between cost and comfort. Consequently, there is an additional requirement to strike an appropriate balance between cost and environmental footprint on one hand, and occupant comfort on the other. The desired balance will differ for different buildings and could even change over time for a specific building.

The "warmup" phase (daily preconditioning of the building) is an important part of an HVAC's operation. As explained, usual BMS schedules simply turn on the HVAC a fixed amount of time before working hours every day. Doing it smarter can be a real headache: warm up too early or too strong and a lot of energy will be wasted; too late or not strong enough will make the occupants' experience very unpleasant. Of course, these choices depend on the specific daily conditions of the building and the weather. On top of that, the preconditioning phase can have effects that last well beyond the first occupied hours, especially in days with harsher weather or if the HVAC is not powerful enough.

Chapter 2

An Automated Approach

Addressing the HVAC challenge to achieve efficiency and eliminate waste while finding the right balance between cost and comfort is far from trivial. HVAC systems of commercial buildings can be very complex with several dozens of sensors, meters and interdependent control parameters. Furthermore, the quality of results depends on ever changing conditions (weather/operational/tariffs) while every action can potentially have lasting effects.

The problem is clearly less suitable for one-fits-all standards or human supervision (which is the status quo discussed earlier) and more appropriate for computational automation. This shift can be facilitated by the widespread adoption of IoT and smart building technologies, the availability of cloud computing, the wealth of external data sources (weather, human behavior, etc.), and the maturity of algorithms in Artificial Intelligence (AI) and building simulation.

Bandora's platform can perform continuous (every few minutes) adjustments to the HVAC based on real time observations. Here we focus on a *warmup controller* that is responsible for the conditions at the beginning of the building's daily occupied hours. The controller aims at applying HVAC settings that have a low cost but result in satisfying indoor conditions. A key feature is the *balance preference*: the user can specify, in an intuitive manner, whether to favor cost reduction or occupant comfort and by how much. Other than that, the controller is truly "hands free".

To accomplish its goal, the controller uses predictive Machine Learning (ML) models in conjunction with multi-objective optimization algorithms, both informed by expert domain knowledge (Figure 1). The ML models are used to forecast various conditions and the impact of potential

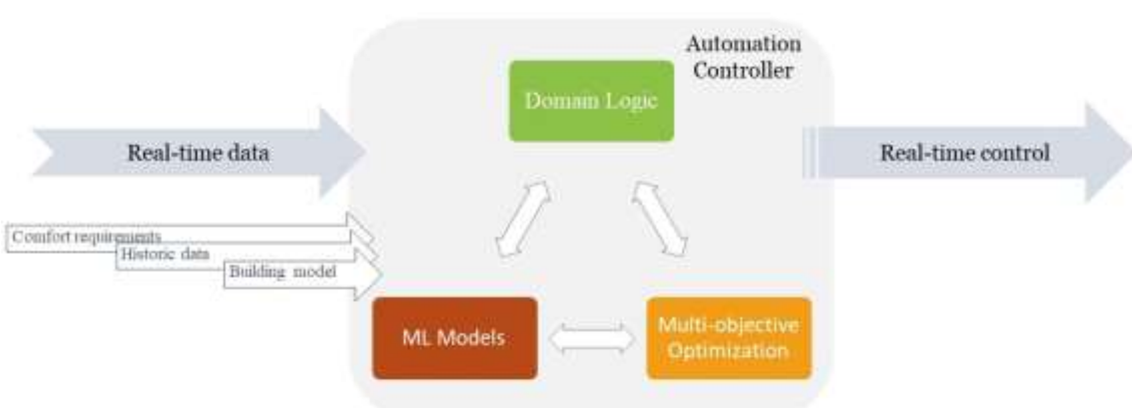

Figure 1: The automation controller design.

actions (temperature, energy consumption, etc.). They act as critics for the optimization algorithm that searches for the best settings to apply. This optimization procedure balances the comfort and cost objectives according to the user's balance preference setting mentioned earlier.

The real-time data input of the HVAC automation controller consists of meter and sensor readings from the building itself, as well as weather conditions and forecasts. Furthermore, some additional (off-line) information is important for achieving best results. A specification of comfort requirements (e.g. temperature ranges per hours, days, etc.) allows tailoring to specific needs and occupation times. Historic data of HVAC operation and building conditions will allow the controller to "hit the ground running", avoiding a learning period. Finally, a rough building model can be valuable to support components that can synthesize data to enhance the controller's ML models or run extensive what-if scenarios to assess different choices.

Chapter 3

Performance Results

We evaluate the controller using the EnergyPlus simulation software. This allows us to compare the outcomes of the controller with that of a baseline in a fair manner (i.e. all other things being equal). The test building is a quick service restaurant with operating hours between 10am and midnight every day. The warmup controller is allowed to change thermostat values and on/off settings between 5am and 10am. At the end of that period, indoor conditions must be acceptable. As a baseline we employ a common preconditioning practice: the HVAC is scheduled to turn on at 5am, with the thermostat set points gradually ramping up (heating) or down (cooling).

Results show that, during a year, the controller can save up to 8% in HVAC energy costs compared to the baseline without significantly impacting comfort (**Table 1**). A graphical summary for one of the building spaces is shown in **Figure 2** where we can clearly see the cost-comfort trade-off curve. The HVAC of the specific

Preference	Cost Savings	Comfort Penalty
Comfort	5.3%	1.6% (<0.7 ºC)
↑	7.1%	1.8% (<0.9 ºC)
Balanced	8.0%	1.8% (<0.9 ºC)
↓	8.6%	1.9% (<1.0 ºC)
Cost	9.2%	2.0% (<1.1 ºC)

Table 1: *Controller performance for the whole building for various balance preferences. Costs are calculated using real tariffs. Savings are relative to the baseline. Comfort penalty is expressed as percentage of occupied time outside comfort range of temperature along with the maximum deviation from the comfort range.*

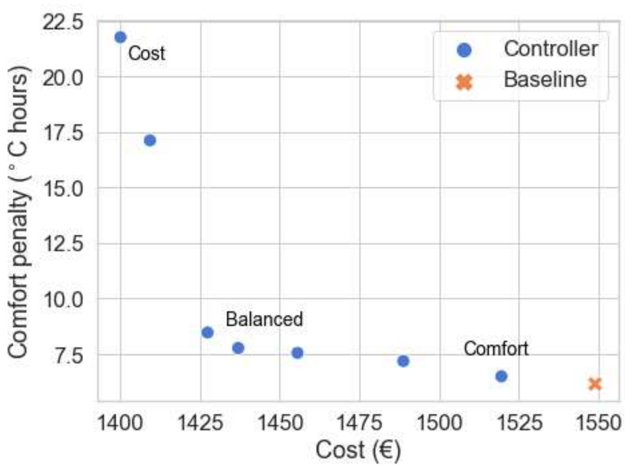

Figure 2: *Cost-comfort tradeoff for various balance settings. Cost is calculated applying real tariffs. The comfort penalty is in "degree hours": the total number of hours outside the comfort range with each hour weighted by the deviation (in ºC) from the comfort range.*

area is well dimensioned; subsequently, the controller is able to reduce consumption without significantly impacting comfort (except for the leftmost settings that heavily favor cost).

A summary of the control actions during the winter months for the same building zone is given in **Figure 3**. We can see an obvious reduction in total heating "effort" compared to the baseline, as well as the just-in-time conditioning approach of the controller. The less frequent/intense control actions in the earlier phases are an average behavior as the controller will generally adjust its actions to the specific conditions of the day, e.g. starting with an already warm building or having a weather forecast for an unusually cold morning. Achieving the same level of adaptability and efficiency with manual schedules would be practically impossible, even if the exact operational and weather conditions of an entire year were known in advance.

Finally, we must note that the energy required for all the computations of the automation controller in the course of a year is estimated at around 30kWh, which amounts to about 3% of the total energy that it saves in the same period and with a balanced cost-comfort setting. Therefore, there is no hidden or externalized impact to the environment.

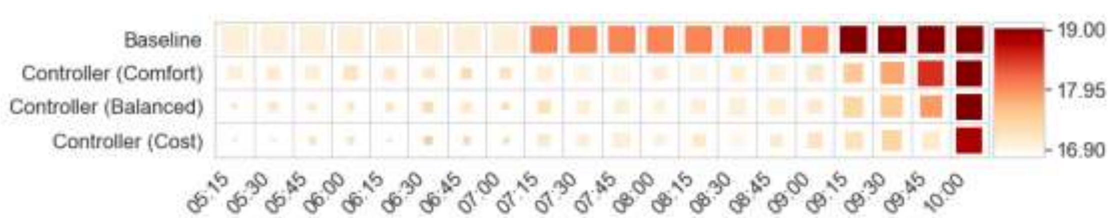

Figure 3: *Summary of controller actions for the winter months, comparing different controller balance settings and the baseline. Each square marker summarizes HVAC settings for a specific time of the day. Sizes denote how often the HVAC was turned on at that time. Color intensity specifies the average set point temperature at that time (considering data where the HVAC was on).*

Conclusion

The shift to true building automation is inevitable. Environmental concerns and energy efficiency goals are unequivocal, while there is no denying the overall automation trend across industries and sectors. All the necessary ingredients and technologies for building automation are already there: IoT and smart building infrastructure, fast networks and clouds, mature AI and building simulation systems.

In this paper, we have demonstrated the benefit of an HVAC automation controller focused on the daily preconditioning phase of the HVAC operation. A desirable feature of automation systems is to give the users sufficient and intuitive control of "what" without burdening them with the "how". To that end, our HVAC automation offers a simple cost-comfort balance setting that allows personalization. In future releases, we will discuss how the system can even provide the user with outcome estimations of various balance settings, as well as additional and complementary control components to automate other aspects of an HVAC and building in general.

Bandora.OM is a non-intrusive cloud platform that gathers information from all systems inside a building to provide dashboards, analytics, anomaly detection and automation. Bandora.OM recognizes the strategic importance of occupant comfort in determining building performance and integrates occupant feedback via a mobile app as part of the ecosystem it creates. The Bandora.OM platform is Building Management System (BMS) and IoT device agnostic, and is designed to complement - not replace - an existing investment in building automation technology. As a cloud-based system, it allows for fast integration and enables one building to benefit from all buildings connected to the system.

Bandora brought together several and unique expertises to delivery Bandora.OM, the only tool that is able to turn any commercial building into an autonomous building. If you want to take a step ahead into innovation, contact us!

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