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| **D3.1** | **Control system architecture proposal for building automation systems** |
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*Open Cyber-Physical System Model-Driven Certified Development*

**Executive summary[4]:**

Poorly functioning and tuned control systems are a frequent source of building underperformance. Simulation can be an excellent method to study building controls, but presently the transfer of simulated control concepts from the design model to actual hardware in the building is often error-prone.

This report proposes a control architecture that will help overcome some of these problems. It attempts to standardize some trivial choices, so that at least these will not lead to unnecessary complications and misunderstandings in this critical issue. The control concepts have been collected from real building controls.

The control architecture is intended to be the same in the simulator as in the actual hardware in the building, enabling a smooth and automated process from design to operation.

[1] Access classification as per definitions in PCA; PU = Public, CO = Confidential. Access classification per deliverable stated in FPP.
[2] Deliverable type according to FPP, note that all non-report deliverables must be accompanied by a deliverable report.
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5 Indicate Main Author(s) with an “X” in this column.
6 Deliverable leader according to FPP, role definition in PCA.
7 Person(s) from contributing partners for the deliverable, expected contributing partners stated in FPP.
8 Typically person(s) with appropriate expertise to assess deliverable structure and quality.
9 Status = “Draft”, “In Review”, “Released”.

**CONTENTS**

# 1 INTRODUCTION

Modern buildings have automation systems of some complexity for the control of heating, cooling, ventilation, lighting, shading and many other key processes for the creation of a comfortable and productive indoor environment. The thereby achieved indoor environment has a profound impact on the productivity of building occupants. For example, studies show that for each degree centigrade of inadequate room temperature, worker productivity will decrease by approximately 2% (Wyon, 2000). This has an impact on the overall economy of a tenants operation that vastly outweighs rental and other facility costs, i.e. the cost of maintaining a high-quality indoor climate is easily justified.

Maintaining a high level of indoor comfort requires energy. Even if the actual cost of energy is often nearly negligible for an individual tenant – in comparison of the increased operation costs of a poor indoor climate – the overall energy expenditure for society for heating and cooling buildings is huge; nearly 40% of global energy is used for this purpose. Consequently, the energy performance of buildings has a major influence on global warming and governments are setting ever increasing building energy efficiency targets. Recent studies have shown that the potential of "active," (i.e. control oriented, energy efficiency) solutions on the building stock might be as high as 50%. This is similar to an estimated potential of "passive solutions," i.e. replacement of physical devices or elements of construction (Cottet, 2012). However, to achieve these savings, control will need to be more integrated and complex, which is a trend that will be pushed even further by the future connection of buildings to so called "smart grids."

In current practice, the control design is merely communicated "on paper" by informal description to control contractors, who manually interpret the control design and intentions and then implement the system in actual hardware. This process is highly inefficient (by reimplementation) and error prone (by misinterpretation of design intent.)

EQUAs focus within the OPENCPS project will be on automatic generation of control code for building automation systems. The structure and content of the building automation system that is present in the simulator will be transferred to actual hardware in the building. This is expected to lead to significant advantages in terms of quality (fewer errors), person time (no reimplementation and misinterpretation of intended functions) and performance of the actual control (more sophisticated and integrated controllers can be applied.)

While traditional building automation technology has a very long history, the practice to build detailed building simulation models in the design phase has still not penetrated into many markets. The Nordic countries (along with the UK) stand apart here, with a model created for almost every new building larger than a single family home. This situation creates an opportunity to take a technology leap in building automation, by joining these two fields. The marriage between detailed building simulation and building automation carries a range of positive effects, in terms of a more efficient work process, and also in control performance, where also modest improvements will lead to significant monetary savings.

Today, standalone equipment controls are the most common. Furthermore, most control strategies are very simple, aiming at keeping constant or scheduled comfort set points. In the near future, control solutions are likely to be more cooperative, sharing information and targets. They will have some learning capacity and apply a predictive strategy (i.e. use available forecasts on price, occupancy and weather to define an optimal strategy over a given time horizon) and/or a reactive strategy (i.e. adapt the predefined strategy to unexpected events) to make the best of building energy storage capacity (Lamoudi, 2012). These advanced control solutions already exist (Dounis, 2009), but their exploitation is prevented by lack of controller interoperability, tools, and expertise of design and implementation teams.

This report proposes development of more realistic control functions in whole-building simulation. A general control architecture is proposed, with different supervision layers at the building and zone levels.

# 2 BUILDING CONTROL ARCHITECTURE

Some typical building control architectures include:

- All equipment controlled separately (a very common approach in old or small buildings).
- Large buildings with some supervision control embedded in their Building Management System (BMS).
- Some level of cooperation between equipment in a zone (blinds, heating, cooling, ventilation, lighting). This zone level control can be purely local, or it can be connected to the building level control.
- Finally, in the context of a smart grid connection, the building control is linked to the outside world, exchanging demand and response signals, energy consumption and price profiles.

The French HOMES research program proposed a generic four layer control architecture that encompasses all of the above:

- The Service layer is responsible for connecting the building energy management with the outside world (energy providers, weather forecast, cooperative district control, etc.).
- The Building layer manages the global building energy balance (i.e. exchange with the energy provider, transformation and distribution through HVAC systems, and storage), planned occupancy schedules and global set points.
- The Zone layer manages the cooperation of zone equipment to achieve the local comfort requirements, taking into account planned as well as actual occupancy.
- The Equipment layer carries out the local control within each piece of equipment applying the strategy defined by higher layers. The Zone equipment layer will receive targets from the Zone layer, while central HVAC systems equipment will communicate directly with the Building layer.

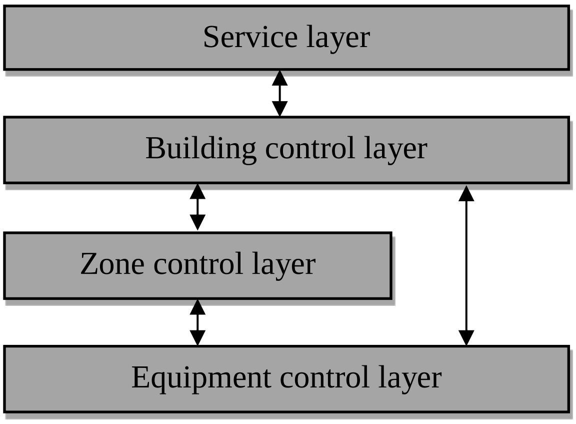


*Figure 1 - HOMES control layer architecture.*

A similar architecture has been proposed in two published German standards on zone control (VDI 3813, 2011) and on building control (VDI 3814, 2008).

Having defined these layers, the next step is to identify which part of the control belongs to which layer and determining the interfaces between the different layers.

Examples of functions that belong to the Building layer are: thermal season management, global comfort set point variation (to adapt to weather), peak load shifting strategies and planned occupancy pattern.

The Zone layer, on the other hand, will manage local planned schedules, occupancy sensors and multi-device optimization (e.g. how the various zone devices work together to achieve the desired comfort level).

The Equipment layer only includes the algorithms needed to apply the strategy and obtain the set points defined by the previous layers.

One of the benefits of this architecture is to separate the supervision layers which reflect a more or less advanced strategy that should, as much as possible, be independent from the choice of equipment. For example, deciding when to apply anti-glare protection can be decided at the Zone layer, independently of the blind type. Then, at the Equipment layer, this functioning mode will be applied in a different way depending on the blind type, e.g. lowering a drape blind based on sun position, darkening electro chromic windows based on façade luminance or positioning the slate of a venetian blind to protect from glare while keeping maximum daylight.

In addition to the proposal of a layered architecture, some of the signals passed between the different layers can also be standardized. Figure 2 shows a selection of such signals, with a proposal for their names. Given the standardized signal names and definitions, a large variation of control properties can be achieved with a minimum number of standard controllers. A user may also define ad hoc controllers and signals. The rule then is that it is an error if a downstream controller requires a signal that the upstream controller does not provide, while a downstream controller may choose to ignore any signal sent to it.

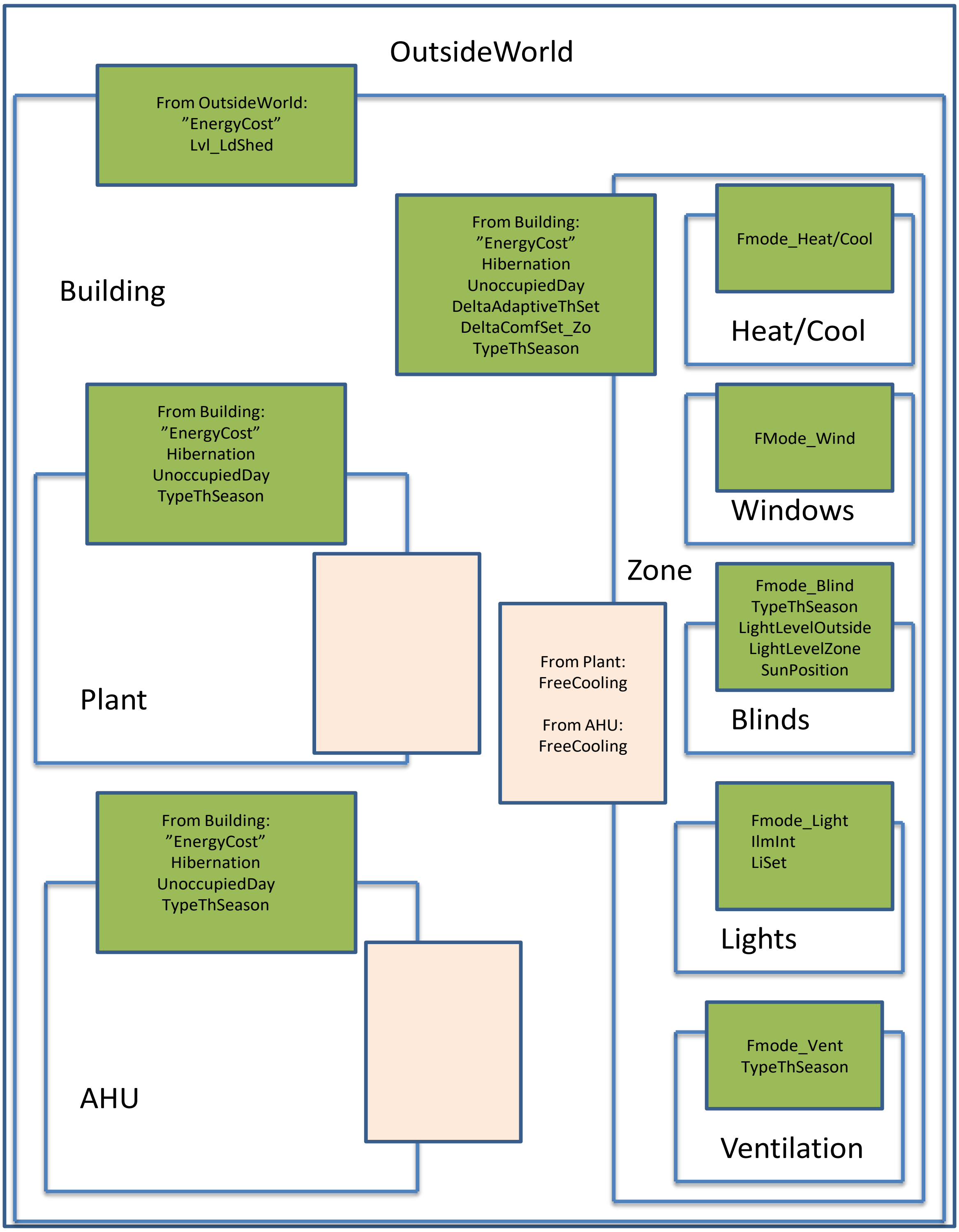


*Figure 2 - Standard controller roles and signals.*

The following example will illustrate the cooperation between the different control layers. Consider a blind controller that has to achieve the following:

- Blinds are closed when the zone is not supposed to be occupied.
- When the zone is supposed to be occupied but no occupant is detected, the blinds are used to optimize heating/cooling needs.
- Blinds are used for anti-glare protection when occupancy is detected.

Figure 3 describes how this strategy is implemented in a typical autonomous blind controller. The planned occupancy schedule and comfort set points are available to the blind control, and every needed sensor (temperature, illumination, occupancy) is directly connected to the function. The blind controller includes all three functioning modes (heat/cool optimization, closed, glare protection).

On the other hand, in the proposed supervisory control architecture, part of the control will be moved to the Building and Zone layers. Figure 4 shows the resulting architecture. The equipment controller is left applying a given functioning mode with specific set points. The Zone layer multi-appliance management relies on the planned occupancy schedule and occupancy sensor signal to define the functioning mode (for all equipment) and adapted comfort set points. The Zone layer receives additional information from the building layer, like the thermal season (is the building generally being heated and/or cooled?), possible offsets in global comfort set points, or information about a specific day during which the building is closed.

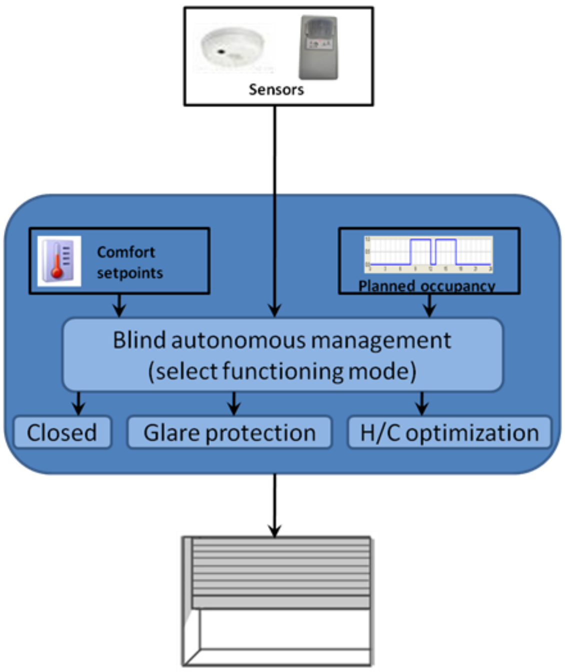


*Figure 3 - Typical autonomous blind control.*

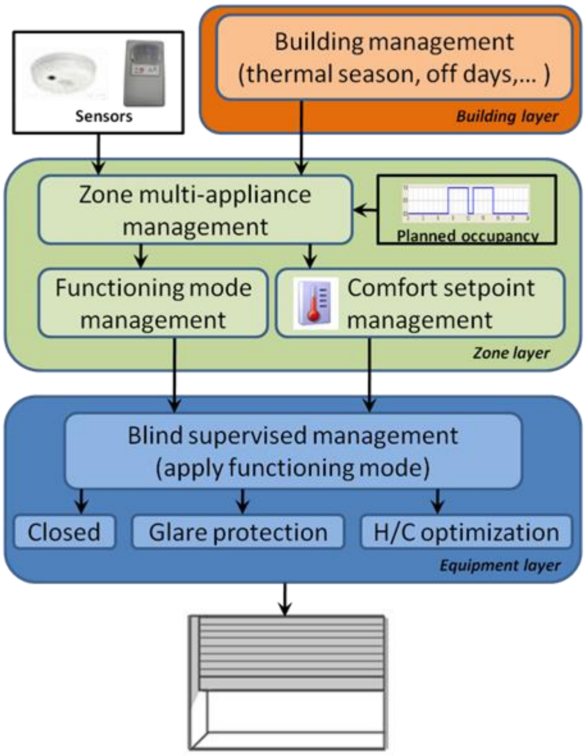


*Figure 4 - Supervised blind control.*

# 3 CONCLUSIONS AND FURTHER WORK

A control architecture that is applicable to simulated as well as physical buildings has been defined. In addition to the fundamental advantage of being able to experiment off-line with various control solutions, the approach opens up some exciting opportunities:

- Automatic controller deployment. With the automatic code generation mechanism that is planned within OPENCPS, the same source code for simulated and actual controllers will be used. This is likely to increase the quality of deployed control solutions and they may better represent the intentions of the HVAC designer.
- Reusable libraries of building, zone and device controllers. Both open-source and commercial controllers could be shared and traded, enabling more proficient controls at lower cost.
- Fewer problems with overly “creative” coding. Today, individual control programmers in the field have perhaps too much freedom to solve typical problems in un-standardized and un-tested ways. An approach that is based on proven components on a higher level of abstraction is likely to result in better quality results and easier debugging.

To meet the climate challenges that inevitably lie ahead, energy conservation measures in existing buildings will be extremely important. Control oriented solutions are often the most attractive, and in many situations they may be the only ones available.

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