Considerations regarding optimization of dynamic facades for improved energy performance and visual comfort

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CONSIDERATIONS REGARDING OPTIMIZATION OF DYNAMIC FACADES FOR IMPROVED ENERGY PERFORMANCE AND VISUAL COMFORT

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ABSTRACT
This contribution discusses requirements, challenges and solutions for simulation-based design optimization of climate adaptive building shells. We compare the different needs of this approach with design optimization of conventional, static facades, and do this with a focus on achieving energy savings while improving indoor environmental quality in terms of thermal comfort and dynamic daylight performance. The solution we propose couples ESP-r with Radiance through the Building Controls Virtual Test Bed, and employs a receding horizon model-based control approach with evolutionary optimization algorithms to ensure high-performance operational façade adaptation.

INTRODUCTION
Climate adaptive building shells (CABS) are seen as a promising design concept for achieving low-energy building operation, while offering potential for improving levels of indoor environmental quality (Davies 1981; Heiselberg 2009). The number of CABS applications in the current building stock is nevertheless limited, with a focus on bespoke projects rather than larger-scale solutions (Loonen et al. 2013). In research and development settings, however, efforts that investigate the potential of innovative adaptable facade components are rapidly increasing. Furthermore, in many technology roadmaps, CABS are recognized as a notable strategy for achieving forthcoming targets for design and operation of nearly zero-energy buildings (IEA 2013; EC 2013).

To facilitate the transition to a more prominent future role for CABS, there is a need to move away from costly, custom-built solutions towards concepts that enable affordable application of adaptable building envelope components at a much wider scale. Computational performance prediction can form an essential resource in supporting, stimulating and accelerating this development process, by functioning as a virtual test-bed for new technologies (Loonen et al. 2014). Optimization methods can, in addition, support design space explorations and help in getting a better understanding of the theoretical performance potential that is achievable with CABS.

In the context of static facades, numerous studies have successfully demonstrated the potential value of combining building performance simulation (BPS) tools with optimization techniques, such as genetic algorithms (GA), to find the set of building envelope design parameters that leads to the best performance with respect to a specified cost function (Evins, 2013). Currently, however, there is no framework available for extending this type of multi-criteria performance optimization to the domain of CABS.

CHALLENGES AND REQUIREMENTS FOR OPTIMIZATION OF CABS
The multi-domain, multi-scale and inherently time-dependent nature of the problem makes that the assessment of CABS’ performance potential by means of optimization is a complex task. Instead of optimizing for a single facade configuration, the goal of the optimization procedure in CABS is to find the sequence (i.e. time series) of dynamic facade properties that best satisfies a set of performance criteria over time. Such information can then be used to identify high-potential CABS design concepts. Compared to design optimization of conventional, static facades, this poses unique requirements for the performance prediction framework:

- **Modelling dynamic facade properties**: Facade properties need to be changeable during simulation run-time to properly account for transient heat transfer and energy storage effects (Loonen, Hoes, and Hensen 2014). In the majority of BPS tools, the options for modelling of adaptable facade actuators are limited (Crawley et al. 2008); ESP-r forms an exception although code modifications are required for more flexibility.

- **Modelling the operation of facade adaptation**: The dynamic interactions in CABS introduce a strong mutual dependence between design and control aspects. Performance of CABS fully depends on the control strategy for facade adaptation during operation. To identify the characteristics of optimal CABS concepts, not only design considerations, but also insights into high-performance operation of the dynamic facade shall be taken into account. Previously developed workflow procedures for optimization of building
envelope design, however, lack capabilities to support performance optimization of the short-term adaptability in CABS, as they are focused on the optimization of properties that remain constant throughout the year (Evins 2013).

PROPOSED OPTIMIZATION APPROACH

Figure 1 introduces the principles of the optimization framework that we developed in response to the points raised above. Various components of the framework can be distinguished:

- Integrated performance prediction with time-varying construction properties by coupling ESP-r with the Radiance three-phase method through the building controls virtual test bed (BCVTB) (Wetter, 2011).
- Model-based building shell control with receding optimization horizons, coordinated by algorithms implemented in Matlab, to optimize façade adaptation in multiple successive steps. Explicit state initialization in ESP-r ensures consistency of thermal history effects between the different models.
- Multi-objective optimization with an evolutionary algorithm, enhanced with seeding of initial populations and soft constraints to aid optimization efficiency.

CONCLUSION

This short paper has introduced the considerations and requirements for simulation-based performance optimization of buildings with adaptable facades. The presentation during the workshop will provide more details on implementation aspects, the implications for optimization algorithms, and will present further points of attention on the basis of results from a case study.

REFERENCES


