Optimal Control of Inflatable Façade Elements to Balance Environmental Disturbances

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ABSTRACT

The high thermal mass of conventional buildings is an important factor for maintaining comfortable indoor conditions. The building itself serves as a heat storage and damps the effects of changing outdoor temperatures or varying solar loads. The lower thermal capacity of light-weight buildings, on the other hand, incorporates faster dynamics and results in a more extreme reaction to outside conditions. This leads to a higher energy demand of the heating, ventilation and air conditioning system to ensure the thermal comfort of the occupants [1]. Moving away from heavy-weight to ultra-light-weight buildings allows to rethink the conventional design of facades as sole thermal or noise insulation. Intelligent façade structures with integrated properties for thermal actuation can be used to control indoor conditions in order to reduce the energy demand. A promising idea is the use of inflatable wall elements that can be adaptively actuated depending on outside conditions and indoor requirements. The change of heat capacity by introducing air and thus increasing the thermal mass of a façade element can be used to control the heat exchange between the building interior and the environment. Furthermore, introducing connections between adjacent wall elements enables the transport of thermal energy from one side of the building to another. This allows for intelligent distribution of solar loads by transferring heated air from the south- to the north-facing side of the building to reduce the heating demand during the winter season [2]. A reverse approach can be used for a diminished cooling demand in summer.

In this work, a thermal network model of a building using inflatable membrane wall elements is developed. The numerous couplings of element-specific mass and temperature dynamics introduce time-variant input constraints which must be taken into account for the derived control approach. Recordings of the temperate climate in Germany are combined with a geometrical solar irradiation model to determine the environmental disturbances.

Optimal control strategies for the intelligent façade elements are developed based on occupancy and temperature set-point profiles for the thermal nodes. The theoretical potential of this type of actuation is determined through perfect-knowledge numerical optimization. Subsequently, an analysis of the achievable thermal peak reduction is performed to quantify the energy saving potential for the identification of rewarding use cases. Moreover, the simulation results are used for the definition of system requirements.

REFERENCES

[1] F. Roberz, R. C. G. M. Loonen, P. Hoes, and J. L. M. Hensen, “Ultra-lightweight concrete: Energy and comfort performance evaluation in relation to buildings with low and high thermal mass,” *Energy and Buildings*, vol. 138, pp. 432–442.

[2] M. Ibrahim, E. Wurtz, P. H. Biwole, and P. Achard, “Transferring the south solar energy to the north facade through embedded water pipes,” *Energy*, vol. 78, pp. 834–845.