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Unlocking flexibility by exploiting the thermal capacity of concrete core activation

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Abstract

Due to its inherent large thermal inertia, concrete core activation (CCA) could assist in active demand response schemes. By shifting the injection or extraction of thermal power in time, demand peaks that normally occur more or less simultaneously in clusters of buildings can be spread out in time. Furthermore, thanks to the low temperature differences allowed with respect to the room temperature, CCA is ideally combined with technologies that have increasing renewable potential, such as heat pumps, low temperature district heating and high temperature district cooling. This paper illustrates the flexibility potential of concrete core activation through the exploitation of its thermal energy storage capacity by dynamic simulations. A validated RC thermal model of a CCA is coupled with a detailed building model, including user occupancy and weather disturbances. The flexibility indicator is calculated based on a method presented in the literature, but using an extended version that allows application to more complex systems, including heat losses. Balancing the building between minimal and maximal temperature, the thermal power needed to heat or cool the building can be modulated up- or downward with respect to the reference energy use. The method is applied to various building types with different insulation levels, in order to map the flexibility potential of CCA heating compared to buildings heated with radiators.

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Keywords: Flexibility, Thermally Activated Building Systems (TABS), Concrete Core Activation (CCA), Optimal control, Active Demand Response (ADR)

1. Introduction

The energy system is currently in a transition towards the use of more renewable energy sources. The variability and unpredictability of these sources pose challenges to the security of supply and to balancing demand and supply of the energy grid. As part of the solution, flexibility can be introduced, using energy storage or active demand response. One technology that combines both is the activation of the thermal inertia of buildings as heat or cold storage, as studied by e.g. Reynders *et al.* [1] and Patteeuw *et al.* [2,3]. Ahcin and Sikic [4] show how demand response can be

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incorporated in the context of the *Energy Hub* [5] model. An interesting take on the load shifting potential based on the minimal and maximal daily load curve of a domestic hot water boiler has been studied by D'Hulst *et al.* [6].

Stinner *et al.* [7] present a comprehensive literature study on flexibility indicators in the built environment, showing that the concept is not unambiguously defined. De Coninck and Helsen [8] the increase in cost with respect to the cost-optimal heating and cooling profile to quantify flexibility and its economic value in houses with heat storage buffers. Nuytten *et al.* [9] calculate the flexibility of a district supplied by a CHP (Combined Heat and Power system) and incorporating central or localized heat storage tanks by means of the maximal time during which consumption can be increased to the nominal power of the supply unit or decreased to zero based on the predetermined heat load curve. The buffer tanks are assumed to be perfectly mixed and insulated, hence heat losses are neglected, which greatly simplifies the calculation of these flexibility curves to interpolating between two piecewise linear load curves. Stinner *et al.* [7] further elaborate this method and apply it to a building with a heat storage tank, looking at flexibility from a temporal, power and energy perspective, always with respect to a reference energy use profile from a dynamic simulation in Modelica. Because of multiple possible objectives, such a reference profile is not straightforwardly defined for the building studied in this paper. Indeed, when the objective is to minimize energy, a different heat load would be found than for a minimal cost objective in a scenario with varying energy prices.

Thermally activated building systems (TABS) are considered particularly beneficial in the context of providing flexibility [10–12]. These papers studied the example of CCA, in which concrete floors are equipped with pipes through which warm or cold water is pumped in order to heat or cool the adjacent rooms. An advantage of this system is that small temperature differences with respect to the room temperature are sufficient for heating and cooling, which opens perspectives for highly efficient, low temperature heat and high temperature cold supply systems, e.g. heat pumps or fourth generation thermal networks.

The flexibility is provided by the increased building thermal mass in heavy concrete floors, but the drawback thereof is the large time constant which hampers the control of the emission system. In addition, only the thermal input is controlled, while the amount and time of heat emission cannot be decided. These drawbacks are handled by advanced control algorithms such as Model Predictive Control (MPC), as studied by for example Sourbron [13] and Sturzenegger *et al.* [14]. Controller models for TABS, and CCA in particular, have been proposed and validated by Koschenz and Lehmann [15], Weber and Jóhannesson [16,17] and Sourbron *et al.* [18]. Work regarding CCA as a storage system providing flexibility has been carried out earlier by van der Heijde *et al.* [19] and Vega [20], by means of defining and quantifying a State-of-Charge (SoC) for this system.

The current paper aims at investigating the maximal flexibility provided by a CCA floor in a residential building for the case of heating only, regardless of the heat production system and of the price of energy, compared to a conventionally heated building. Therefore, the method from Nuytten *et al.* [9] and Stinner *et al.* [7] is adopted and extended. This extension is needed because the complexity of the building structure implies multiple time constants and the heat losses can in this case not be neglected. Therefore, the linear equations are extended to a dynamic calculation.

Nomenclature

CHP	Combined Heat and Power
CCA	Concrete Core Activation
MPC	Model Predictive Control
NZEB	Nearly Zero Energy Building
RC	Resistance-Capacitance
SoC	State of Charge
SD	Semi-Detached building typology
TABS	Thermally Activated Building System