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Integration of Buildings as Energy Storage in a Smart Grid

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***Abstract*— Buildings are a cost-effective alternative to other storage technologies and can support an electricity-driven operation of the electrical grid if their heating and cooling systems are connected to the grid. For the implementation into a real operation the knowledge about the state of charge of the building is essential. Using simulations, the state of charge based on the temperature profile of the construction layers as well as a measureable quantity which represents the state of charge can be determined. The study of the dynamic state of charge is carried out on the basis of a real office building, using the IDA ICE software. The analyses show that the ceiling surface temperature is suitable to represent the state of charge of the building.**

***Keywords*— Energy Storage, Buildings, Energy Simulation, Smart Grid**

I. Core Idea

Currently, various solutions for the harmonization of energy production and demand are being investigated against the background of an increasing influence of fluctuating renewable energies. With their inherent thermal storage potential of the building structure, buildings can substitute other storage technologies as a cost-effective alternative and support an electricity-driven operation. Thus, buildings should primarily be integrated into a smart grid. They don't require additional investments and space for installation and have a long life span. The main requirement for the integration is the connection of the heating and cooling systems to the electrical grid (e.g. cogeneration or power-to-heat/power-to-cool). The existing storage potential can be achieved by permitting a room temperature bandwidth within the comfort range instead of a fixed set point.

II. State of Research

In literature, the usage of buildings as thermal energy storage is adressed, and the flexibility potentials for different types of buildings are analyzed. Hausladen et al. [1] show that with a permitted room temperature bandwith of up to ± 2 Kelvin up to 500 Wh/m² of heat can be stored in residential buildings. In the same scale heating and cooling energy can be stored in office buildings which are equipped with concrete core activation. Investigations based on specific buildings and quarters show an annual load shifting potential of around 10% and 16% of the total heat demand, using room temperature deviations of ± 1 Kelvin [2], [3]. Kensby et al. [4] provide evidence from a pilot test for residential buildings in district heating systems.

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Within the scope of the research project Mobility2Grid the exploitable storage capacity as well as the load shifting potential of buildings for different heat transfer systems are being determined. In previous work, it was demonstrated that buildings can provide a significant load shifting potential of up to 25 kWh/m² per year with a combined heat transfer system of radiators and concrete core activation. During a typical charge/discharge period, up to 230 Wh/m² are stored. Thus, a daily average capacity of electrical balancing energy of 30 Wh/m² can be provided assuming heat and electricity are generated by a cogeneration unit [5].

III. Object of Research and Method

For the implementation of an applicable real operation the knowledge about the state of charge (SOC) of the building storage is essential at any time. For this, an adequate measureable quantity for reliable conclusions regarding the SOC has to be identified, which shall be used as controller input. The dynamic simulation software IDA ICE [6] is suitable to carry out these investigations on the basis of a real modern office building at the EUREF Campus in Berlin (Fig. 1).

Fig. 1. Building 12/13 at the EUREF Campus.

IV. Simulation Model

The simulation model represents a section of the building 12/13 of the EUREF Campus. Two zones are simulated, each with a floor area of approx. 20 m². While the standard zone only has one external wall, the corner zone has two facade orientations and a higher external wall proportion (Fig. 2).

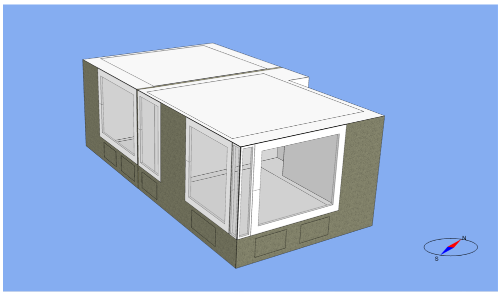

Fig. 2. Two-Zone-Model.

As a new building, the building has a high standard of insulation. The U-values of the external walls are 0.195 W/(m² K), those of the windows 1.23 W/(m² K). The window-to-wall ratio is 52% to 55%. The g-value of the glazing is 0.54. External sun protection is automatically controlled depending on the solar radiation. The small corner windows have U-values of 1.4 W/(m² K) and 1.47 W/(m² K) and have no sun protection device. Mechanical ventilation ensures the minimum outside air volume flow into the zone. The occupancy boundary conditions are mainly based on DIN V 18599-10 [7]. SIA 2024 [8] is used for the occupancy profiles.

The office rooms are heated and cooled by a concrete core activation integrated in a 28 cm reinforced concrete ceiling. Additionally, radiators are installed, which are controlled by the room temperature controller. These are two different heat transfer systems, which have different effects on the absorption of thermal energy into the building structure. Radiators can heat up the room air in a short time, while the surrounding structural elements are heated with delay. The thermally activated ceiling first heats up the ceiling, and secondarily the room air and other structural elements. The set point temperature for room heating during the day is 22 °C. At night and on weekends, the set point is 2 Kelvin lower.

The storable amount of heat in a construction component results from the component's volume, its density, its specific heat and its temperature change. While the physical characteristics are fixed and time-invariant, the temperatures change dynamically. Thus, the actual amount of heat that can be stored in the building varies depending on the dynamic temperature profile of all component layers.

The IDA ICE software models wall constructions using finite differences, which allows the determination of each temperature within the finite differences layers (Fig. 3 and 4).

Using these temperatures, the SOC can be calculated for each time step, according to the following definition: The provisional SOC range is defined for an allowable temperature shift in the building storage of ± 1 Kelvin. An SOC of 50% corresponds to the set point temperature of 22 °C. 100% are reached by definition as soon as the room temperature including all adjacent wall constructions is at 23 °C, while the SOC reaches 0% at 21 °C.

Using the simulation tool, different options of measurable physical quantities are investigated and compared with respect to their suitability as SOC indicator. For this present investigation, the analyses are limited to the heating case.

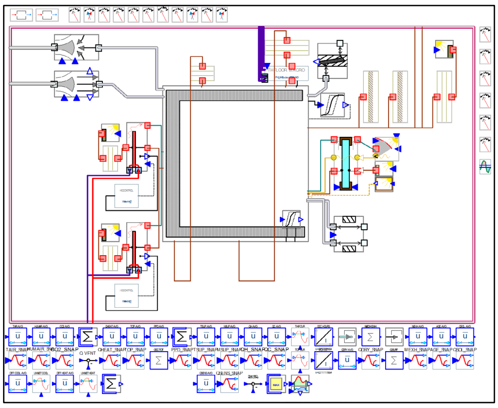

Fig. 3. Zone model in IDA ICE.

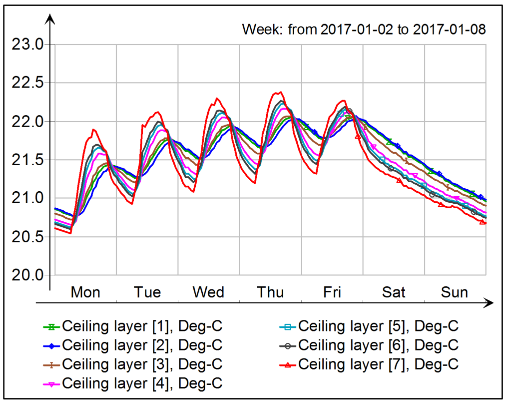

Fig. 4. Temperature profiles resulting for the finite differences wall model (ceiling layers in element depths of 17.5 cm for layer 1 up to 39.7 cm for layer 7), the total ceiling thickness is 40 cm.

V. Results

Results of the current analyses demonstrate the dynamic profile of the thermal SOC of the investigated rooms for standard conditions, initially without systematic load shifting.

SOC, operative and ceiling surface temperature in the standard office room heated by radiators are illustrated for a four week winter period in Fig. 5. During the workdays of the week, the room successively heats up due to internal heat sources, while it cools down during the weekend with no occupation. During a medium workday, the SOC increases by around 25% before it decreases by 18% during the night. Discharging takes also place during the weekend and amounts up to 60%. It can be well observed from the figure that the ceiling surface temperature seems to correlate quite well with the SOC. The operative temperature, however, deviates strongly.

The corner office room shows lower temperatures (Fig. 6) at a similar trend. Due to the larger façade area the transmissions losses are larger. The storage capacity is used to about 50%.

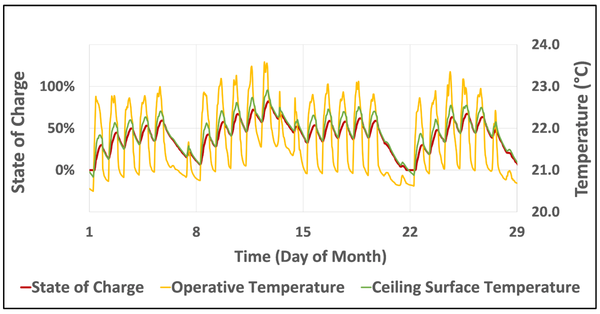

Fig. 5. State of charge and temperatures for a standard office room heated by radiators during four weeks in Winter.

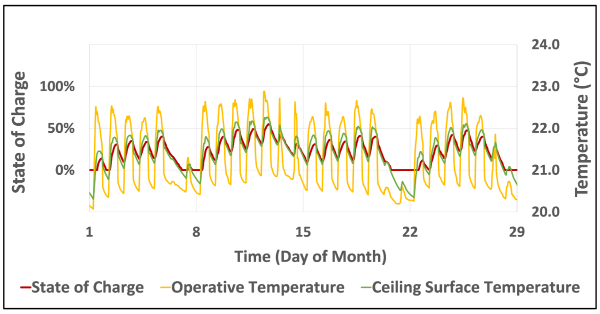

Fig. 6. State of charge and temperatures for a corner office room heated by radiators during four weeks in Winter.

Looking at the case with heating by concrete core activation, the room temperatures oscillate somewhat stronger than for the radiator heating case (Fig. 7). The surface temperature still follow the SOC of the standard room. They show, however, larger deviations. The observed building storage capacity discharge is smaller. In the standard room, about 50% of the capacity is used.

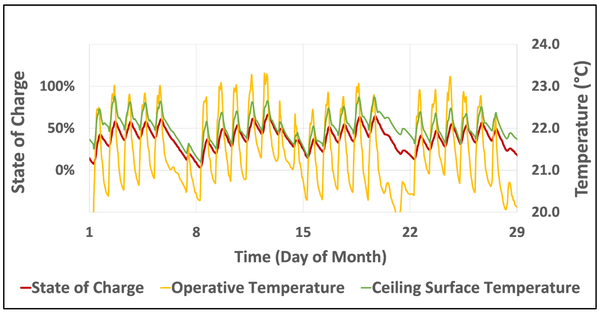

Fig. 7. State of charge and temperatures for a standard office room heated by concrete core activation during four weeks in Winter.

Concrete core activation is not sufficient to heat the corner office room (Fig. 8). The temperature stays frequently below the set points. The storage is barely charged.

Looking at the results, the ceiling surface temperature appears to be a convenient measurable quantity for an indication of the SOC. This is especially well observable for the radiator heating case (Fig. 9) where the correlation coefficient for the standard zone is 0.97.

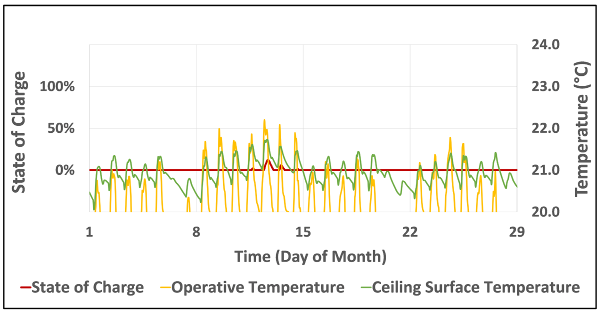

Fig. 8. State of charge and temperatures for a corner office room heated by concrete core activation during four weeks in Winter.

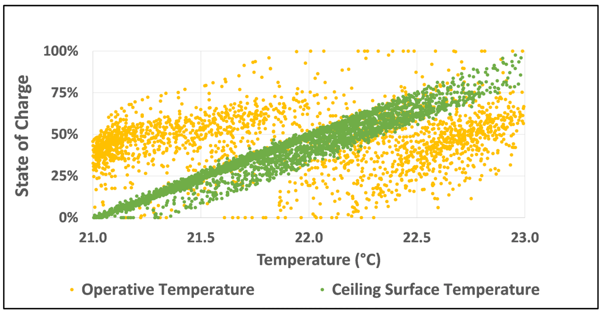

Fig. 9. Correlation between measureable quantities and state of charge of a standard office room heated by radiators.

But also in the concrete core activation case, an adequate correlation can be found (Fig. 10) with a correlation coefficient of 0.92. In comparison to the ceiling surface temperature, the correlation coefficients for the operative temperature show less linear relationship (0.61 for the standard office room heated by radiators and 0.67 in the case of concrete core activation).

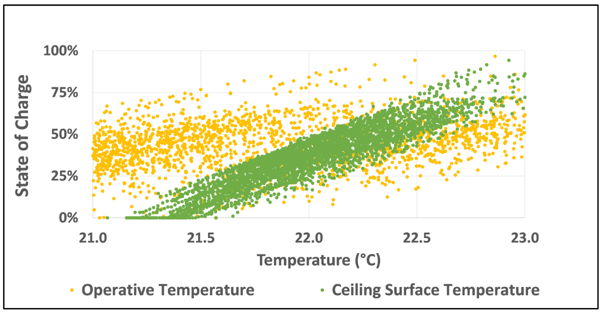

Fig. 10. Correlation between measureable quantities and state of charge of a standard office room heated by concrete core activation.

Implementing a targeted load shifting, different SOC and temperature profiles can be observed in comparison to the base case. As an example, in Fig. 11 one winter week in the corner office room heated by both systems (radiators and concrete core activation in combination) is demonstrated as the base case without any load shifting.

Fig. 12 shows the same section, but with an alternative control, based on the day-ahead price of the electricity market.

In order to do this, a price signal is identified based on the day-ahead price for each time step in dependence on the minimum and maximum day-ahead price for each day. If the price is high the price signal is set to 100% which means that a cogeneration unit would produce more energy by permitting a higher room temperature. At a low electricity price (corresponding 0% in Fig. 12) the cogeneration unit would produce less energy. If the price is neither low nor high the signal is set to 50% like in the base case.

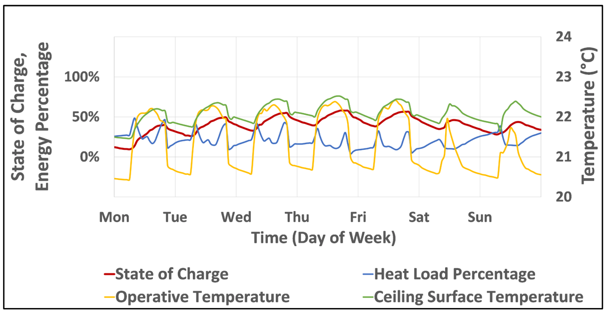

Fig. 11. State of charge, temperatures and heating load for a corner office room during one week in winter (base case).

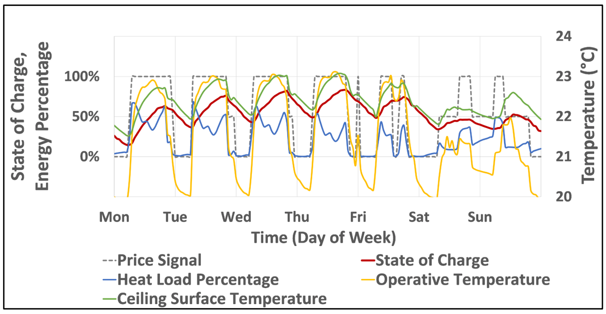

Fig. 12. State of charge, temperatures, price signal and heating load for a corner office room during one week in winter (with load shifting).

From Fig. 12 it can be seen that the temperature profile as well as the heating profile follow the price signal. When the price is high, operative temperatures reach up to 23 °C with higher heating capacity. In the night time when the price is low there is no heat produced and the temperatures fall down to 20 °C. The SOC varies more than in the base case. During the charging and discharging periods on weekdays, an additional 15% of the building storage capacity is utilized on average. For the demonstrated week more heat is stored in the building during charging than it is reused during discharging.

VI. Conclusion and Prospect

The observable variation in the correlation plots suggests simulation analyses using the ceiling surface temperature as control parameter. For the technical realisation one additional measuring point monitoring the ceiling surface temperature has to be installed for each room. Its implementation into control will be subject for further investigations. To ensure the comfort with respect to the room temperature the relationship between the ceiling surface temperature, the operative temperature and the SOC has to be analysed. It is expected that the range of the ceiling surface temperature for actual control and thus the usable storage capacity will be tighter.

References

[1] G. Hausladen, T. Auer, J. Schneegans, K. Klimke, H. Riemer, B. Trojer, L. Qian, and M. de Borja Torrejon, “Lastverhalten von Gebäuden unter Berücksichtigung unterschiedlicher Bauweisen und technischer Systeme. Speicher- und Lastmanagementpotenziale in Gebäuden,“ Stuttgart: Fraunhofer IRB, 2014.

[2] F. Sick, and R. Füger, “Netzdienlichkeit von Gebäuden durch Anlagensteuerung in einem Nahwärmenetz,“ in 27. Symposium Thermische Solarenergie, Regensburg: OTTI, 2017, pp. 1-14.

[3] M. Reinwald, S. Leitschuh, and J. Hochhuber, „Energieinfrastruktur der Zukunft: Energiespeicherung und Stromnetzregelung mit hocheffizienten Gebäuden - Projekt Windheizung 2.0,“ in Sektorenkopplung der Energiesysteme durch Power to Heat: Dialog-plattform des EFZN, Goslar, 14. und 15. Juni 2016, Schriftenreihe des Energie-Forschungszentrums Niedersachsen, H. Wenzl, and F. Kaiser, Eds., Göttingen, 2016.

[4] J. Kensby, A. Trüschel, and J.-O. Dalenbäck, “Potential of residential buildings as thermal energy storage in district heating systems–results from a pilot test,” Applied Energy, vol. 137, 2015, pp. 773–781.

[5] F. Sick, and S. Krutzsch, „Simulationsgestützte Analysen zur stromnetzdienlichen Temperierung von Gebäuden,” in BauSIM2018 - 7. Deutsch-Österreichische IBPSA-Konferenz, 2018, pp. 358–365.

[6] EQUA Simulation AB 2018, “IDA Indoor Climate and Energy,” Version 4.8., Stockholm, 2018.

[7] DIN V 18599-10:2016-10, „Energy efficiency of buildings – Calculation of the net, final and primary energy demand for heating, cooling, ventilation, domestic hot water and lighting – Part 10: Boundary conditions of use, climatic data,“ 2016.

[8] SIA 2024, „Standardisierte Nutzungsbedingungen für die Energie- und Gebäudetechnik. SIA, Swiss Association of Engineers and Architects,“ Zürich, 2006.