Digital Twin for Heat Transition

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The heat transition is a central pillar of the energy transition, aiming to decarbonize and improve the energy efficiency of the heat supply in both the private and industrial sectors. On the one hand, this is achieved by substituting fossil fuels with renewable energy. On the other hand, it involves reducing overall heat consumption and associated transmission and ventilation losses. In addition to refurbishment, digitalization contributes significantly. Despite substantial research on Digital Twins (DTs) for heat transition at different scales, a cross-scale perspective on heat optimization still needs to be developed. DTs can across various scales, from individual buildings to entire urban areas, intending to advance the transition to sustainable heating.

digital twins heat transition data platform

1. Building Scale

On the scale of individual buildings with live sensor data and digitally controllable building system technology, such as heat pumps, thermostatic valves, or ventilation systems, the main objective is to develop control strategies for optimizing energy efficiency while maintaining healthy and acceptable living conditions. Even between buildings of the same size and purpose, many differences exist regarding age and overall quality, room divisions and layout, construction materials, window area, orientation, etc. Also, technical building equipment and automation systems can vary greatly. Therefore, the control strategies to be developed have to be adaptive and must be able to work within different buildings and with different technologies.

In order to develop and test these algorithms, using digital twins of buildings that can simulate the thermal behavior and the effects of HVAC systems and which allow for variations in all of the properties mentioned above. Nevertheless, initially, these DTs will be modeled on three selected representative buildings at the Oldenburg campus of the Jade University of Applied Sciences:

- a new building with wooden walls, cellulose insulation, and triple glazing. Active ventilation and shading, PV-powered heat pump with heat storage tanks;
- a 30-year-old building recently insulated. Bivalent usage of gas heating and heat pump;
- a passively heated additional store to an even older building.

The knowledge about the physical properties of these buildings and the extensive amount of available sensor data on temperature, humidity, air quality, and the actual state of each of the technical systems makes it possible to compare the digital twins with the actual buildings to fine-tune the model.

In the following, the researchers will mainly focus on objectives regarding the new building.

The first objective is to develop and test control strategies for PV-powered heat pumps and heat storage tanks. Different starting conditions, such as indoor and outdoor temperatures and demand profiles, directly and indirectly, influence the optimal operating schedule. The digital twin can be run multiple times with different control strategies for a given set of parameters, and the outcomes can be analyzed and compared.

The second objective is to optimize the operation of ventilation systems based on occupancy and demand, as well as the bivalent operation of natural gas heating and heat pump heating. In this case, the optimum can be defined as minimal energy consumption (which might favor gas heating when outside temperatures are low), minimal fossil resource consumption, or minimal total operational cost.

Since the thermal simulation of a building can be implemented in various levels of detail, a third objective for the digital twin of a given building is to compare these different models. Furthermore, by using actual sensor data as initial conditions and running the simulation for a defined time, the researchers can validate the results against historical data. Thus, future decisions about the necessary level of detail can be supported.

In order to achieve the given objectives, these requirements have to be fulfilled:

- Building properties are modeled (room volumes, wall and window areas, thermal properties of components);
- Active systems such as heat pump and ventilation are modeled and controllable;
- Sensor data are structured and organized for real-time and historical access;
- Training environment is set up and can be connected to data streams.

Furthermore, the resulting digital twins can also be used to simulate specific situations with manually tweaked input conditions for educational purposes. This will allow for what-if scenarios like heating with open doors, replacing walls or window panes with better components, or gathering a crowd of people in a small space. In combination with virtual or artificial reality equipment and a digital 3D model of the building, training units can be devised for students, professionals, or the general public to visualize the effects of the simulated what-if scenarios.

2. Campus Scale

The campus scale DT has three primary objectives: enhance energy system operation and maintenance, and facilitate the proof of concept for new sustainable solutions.

The first objective focuses on improving the system's operation, which entails reducing its CO_2 footprint, enhancing overall efficiency, and minimizing operating costs. The heating, cooling, and electricity networks must be integrated into a unified multi-energy environment to accomplish this objective. Subsequently, DT should be capable of analyzing the flexibility of all network appliances in real-time, enabling optimization of their operation to achieve both efficient device performance and effective load management.

The second objective involves implementing predictive maintenance practices, which help extend the assets' lifespan by proactively identifying maintenance needs and minimizing unexpected failures.

Finally, the DT serves as a foundation for conducting proof of concept for new sustainable solutions. This feature enables testing and validating the viability and functionality of innovative devices within the system in the design phase.

3. Connected Neighborhoods Scale

This urban DT aims to identify energy (esp. heat) supply options for a communal transition strategy to renewable energies. According to the definition, it can be seen as a (long-term) forecast in the sense of the investigation of numerous what-if scenarios. The objective includes several sub-objectives, first quantifying the potential for energetic renovation. This question needs to be combined with possible load balancing between neighborhoods and optimized operational schemes. The latter two points call for information with a sufficiently high time resolution.

The identified supply options, including possible operational strategies, are optimized for multiple objectives, e.g., costs and resilience. For the latter, several scenarios for the boundary conditions are created, allowing to identify the possibility of the energy system to react to possible future changes.

Once identified, the different supply options will serve as a basis for early decisions and a detailed planning process. To allow the application of the method without having to create a hand-tailored digital twin for every possible municipality, the aim is to create a (semi-) automated process based on data that is (typically) easy to obtain or, preferably, publicly available.

4. Urban Scale

Corresponding to the above-mentioned urge for action regarding the heating sector, the federal state parliament of Lower Saxony has passed a law that requires that cities of a certain size develop and publish a heat transition strategy by the end of 2026 [1]. That process includes five specific measures derived from the strategy and the communication with involved stakeholders, such as local energy suppliers and/or grid operators, housing companies, local politicians, and private building owners [2]. The legal obligation and the envisaged challenges make it necessary to bring together the topics of energy/heat planning, digitalization, and urban development in one single tool or application. In public administration, these topics have traditionally been treated separately (or have not yet been implemented). This unification of domains will empower municipalities to derive that one city-wide heat transition strategy. The tool required for this should serve as a planning tool allowing a municipal draft planning and deriving and marking down reasonable energetic quarters/neighborhoods for further investigation. Additionally, the tool should also be usable as an information and communication tool for municipalities to address citizens and stakeholders. Individuals can orient themselves and align their investment decisions from the publicly offered and described city-wide development path toward a fossil-free heating sector. Overall, the tool should lead all stakeholders universe reasonable and coordinated investment decisions in order to avoid climate-harming path dependencies [2].

Developing and implementing an urban DT, is a possible approach to meet the described demands. Since municipalities often lack specialists, they have to rely on products and services from the private sector. Hence another objective associated with urban DT in the context of the WärmewendeNordwest project is to scientifically assess the quality of urban DTs for the purpose of municipal heat planning by building and refining exemplary urban DTs, to derive quality criteria and standards for urban DTs for the purpose of municipal heat planning.

References

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