Abstract

As one of the largest consumers of overall energy, buildings have emerged as attractive targets for using information and communications technologies to advance large-scale sustainability goals. With increasing availability and affordability of sophisticated sensing, control and computational methods, a variety of novel applications have been envisioned in the recent past aiming towards energy savings. However, the centralized building management system with its inflexible and isolated subsystems, currently used to manage the building operations, restrict the widespread development and deployment of novel energy management applications. In this thesis, we hypothesize that decentralized, flexible, and extensible software systems, together with novel applications and analytical techniques, would improve the energy efficiency in buildings.

To support our hypothesis, we present the architecture, design, development, and experimental validation of middleware systems for building energy management, which enable 1) decentralized management of building resources involving different stakeholders, including occupants, to make control-over decisions and energy management policies, by providing appropriate fine-grained access-control mechanisms, 2) flexible interfaces for integrating existing and retrofitted sensing and control systems, and suitable software representations for accessing and managing their operations, e.g. spatio-hierarchical relationship, which are specific to buildings, and 3) an extensible automation framework for developing and deploying energy management applications involving simple and advanced sensor data processing methods for identifying detailed insights about the operational context of the building, and suitable programming abstractions for developers.

We evaluate these systems through multiple real-world deployments in our test-bed buildings consisting of varied categories of functionalities, operations, users, and hundreds of heterogeneous sensor data streams, across the world. On top of this, we also implemented several practical applications ranging from detecting the deviation in the energy usage of building sub-
systems to inferring fine-grained building context using proxy sources. The practical usability of the system was also evaluated through a user study. In summary, this thesis attempts to present a holistic software ecosystem and novel applications by bringing the three major entities – devices, computational methods, and humans, in buildings closer towards optimal energy management.