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Assessing barriers and research challenges for automated fault detection and diagnosis technology for small commercial buildings in the United States

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ABSTRACT

Commercial buildings often experience faults that waste energy, decrease occupant comfort, and increase operating costs. For medium and larger commercial buildings (buildings with more than approximately 1000 m^2 [approximately 10,000 ft^2] of floor area), studies have shown that automated fault detection and diagnosis (AFDD) tools can help building owners and operators identify and correct faults, improving building performance and producing up to 10% energy savings. However, the existing state of the art in AFDD tools and algorithms poorly serves the needs of commercial buildings less than approximately 1000 m^2 (approximately 10,000 ft^2). Using the United States market and building stock as a case study, this article characterizes AFDD needs for small commercial buildings, surveys the types of AFDD tools presently available in the market, identifies gaps and barriers to widespread adoption of AFDD technology in small commercial buildings, and makes recommendations for the future research and development of small buildings AFDD technology.

1. Introduction

Commercial buildings often experience faults that produce undesirable behavior in building systems. Building faults waste energy, decrease occupant comfort, and increase operating costs. In the United States alone, faults in commercial buildings waste an estimated 90–530 TWh (0.3–1.8 quadrillion Btu [quads]) of primary energy—up to 11% of total U.S. commercial building sector energy consumption [1]. Automated fault detection and diagnosis (AFDD) tools help building owners discover and identify the root causes of faults in building systems, equipment, and controls. AFDD has proven an effective way to reduce energy waste and restore buildings to their intended levels of performance [2]. Achievable energy savings from AFDD are on the order of 5–20% of a building's total heating, ventilation, and air conditioning (HVAC); lighting; and refrigeration system energy consumption—or up to 10% of a typical commercial building's total energy consumption [1].

Unfortunately, although AFDD solutions for medium and large commercial buildings are established and commercially available, few effective solutions exist for small commercial buildings. This study examines gaps, barriers, and research challenges for AFDD technology for small commercial buildings in the United States. The study focuses on the U.S. market because it is most familiar to the authors and because data for it are relatively easy to obtain. The U.S. Commercial Building Energy Consumption Survey (CBECS) [3] provides detailed characterization data for the U.S. commercial building stock and is among the most comprehensive data sets of its type available in the world [4]. In addition, there is robust competition among AFDD providers in the U.S [5,6]. Similar analyses could be conducted using buildings data available for other regions [7–9], however, proper alignment of data from various regions is quite difficult [4] and beyond the scope of this study.

Small commercial buildings (buildings with floor area less than approximately 1000 m^2 or 10,000 ft^2) represent roughly 72% of commercial building stock in the United States and account for slightly less than 20% of total U.S. commercial building energy consumption. Despite a proliferation of AFDD products for larger commercial buildings, small buildings lack cost-effective and easily-deployable AFDD tools. Conventional AFDD technology has not achieved a necessary price point—including instrumentation, installation, and configuration costs—to provide adequate return on investment. Alternative AFDD approaches include embedded AFDD, low-cost submetering hardware and software, and low-touch audit algorithms, but these are still largely at an early stage of commercial deployment.

This study characterizes AFDD needs for U.S. small commercial buildings, surveys the types of AFDD tools presently available in the market, and identifies gaps and barriers for widespread adoption of AFDD technology in small commercial buildings. The article examines benefits and challenges associated with conventional and emerging

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AFDD tools, presents a simple analysis framework for estimating the cost-effectiveness of AFDD tools, and provides recommendations for AFDD developers and vendors who seek to enter the small commercial buildings market.

2. Characteristics of small commercial buildings

There is no widely accepted formal size definition for small commercial buildings. Various reports have classified small commercial buildings as commercial buildings up to approximately 460 m^2 (5000 ft^2) [10], 930 m^2 (10,000 ft^2) [11], or 4600 m^2 (50,000 ft^2) [12,13]. In this study, a commercial building is classified as “small” if its floor area is 929 m^2 (10,000 ft^2) or less. This threshold is used in order to better differentiate systems and equipment typically found in very small buildings from those in medium-sized and larger buildings.

The CBECS data indicate that 4.0 million out of 5.6 million commercial buildings in the United States (approximately 72%) meet the small commercial building criteria; among these buildings, 2.8 million are 93–464 m^2 (1001–5000 ft^2) and 1.2 million are 465–929 m^2 (5001–10,000 ft^2) [3]. Each year, these buildings consume 402 TWh (1.37 quads) of site energy—approximately 20% of the U.S. commercial buildings total. For reference, buildings between 930 m^2 and 4645 m^2 (10,001 ft^2 and 50,000 ft^2) make up 22% of commercial building stock and consume 24% of total commercial buildings site energy. The totals for all buildings up to 4645 m^2 (50,000 ft^2) are 94% of building stock and 44% of site energy.

Existing studies do not estimate energy waste due to faults specifically in small commercial buildings (versus the U.S. commercial building sector as a whole), but energy-wasting faults are known to be widespread in small commercial buildings [10] and these buildings are underserved by existing AFDD tools. Their contribution to fault-related energy waste is, conservatively, proportional to their 20% share of U.S. energy consumption, or an estimated 18–106 TWh (60–360 trillion Btu) per year.

Small commercial buildings differ in important ways from larger buildings, and therefore have different analytics needs. This section reviews several key characteristics of small commercial buildings in the U.S. that are relevant to AFDD tool development and deployment. Comprehensive characterization studies of small commercial buildings are available elsewhere [12,14].

2.1. Building types

In CBECS, the commercial building stock is categorized into 14 major building types according to the principal building activity (Fig. 1): education, food sales, food service, health care, lodging, mercantile (retail sales and strip malls), office, public assembly, public order and safety, religious worship, service, warehouse and storage, other, and vacant. Office, service, and warehouse and storage are the three categories with the largest number of buildings and consist of 19%, 14%, and 10% of the total small commercial building stock, respectively.

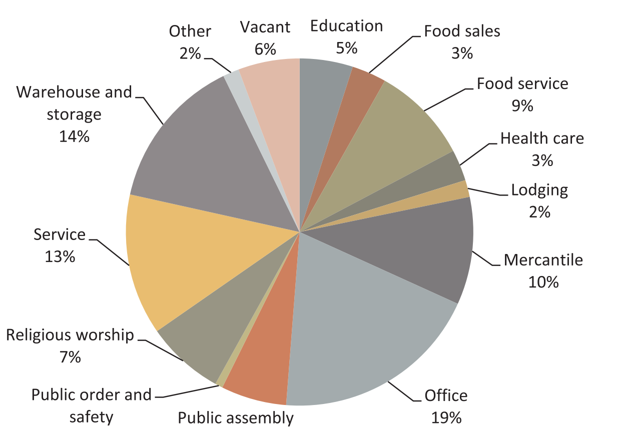

Fig. 1. Types of U.S. small commercial buildings categorized by principal building activity.

A significant fraction of small commercial buildings are part of commercial building portfolios—collections of buildings with a common owner and general purpose [13]. To the authors' knowledge, no comprehensive, publicly available database of small building portfolios exists, although several data points suggest that such portfolios constitute a large fraction of small buildings in the U.S. For instance, of the 94,725 bank branches in the U.S., nearly one-third are operated by only 10 banking chains, according to 2014 data from the U.S. Federal Deposit Insurance Corporation. Wells Fargo alone operated 6314 of these branches in 2014, while JPMorgan Chase and Bank of America each had more than 5000 branches [15]. Similarly, the 2017 *Convenience Store News* Top 100 rankings indicate that the top 10 convenience store chains account for 26.3% (approximately 40,725) of all U.S. convenience stores [16].

Portfolios present better AFDD deployment opportunities than individual buildings because:

- Per-building transaction and initial setup costs may be lower due to economies of scale
- Multiple similar buildings present an opportunity to reuse fault detection and diagnosis rules, reducing per-building engineering labor
- Portfolio owners are better positioned to dedicate staff time and resources to using an AFDD tool.

The ENERGY STAR® 2015 Snapshot, which captures commercial building energy efficiency trends through the U.S. Environmental Projection Agency's ENERGY STAR Portfolio Manager® tool, provides evidence for this hypothesis; the analysis found that companies with large portfolios, primarily retail chains, are “leading the way” with respect to efficiency improvements [17].

2.2. Energy consumption and intensity

Fig. 2 shows energy consumption in U.S. small commercial buildings by end use. Space heating (91 TWh [0.31 quads]), refrigeration (64 TWh [0.22 quads]), and cooking (56 TWh [0.19 quads]) are the three largest end uses and together account for more than 50% of total site energy consumption in small commercial buildings. This differs from larger buildings, in which space heating, miscellaneous loads (“other”), and lighting are the largest end uses. In larger buildings (more than 929 m^2 [10,000 ft^2]), HVAC end uses consume 46% of the total site energy; many existing AFDD tools therefore focus heavily on

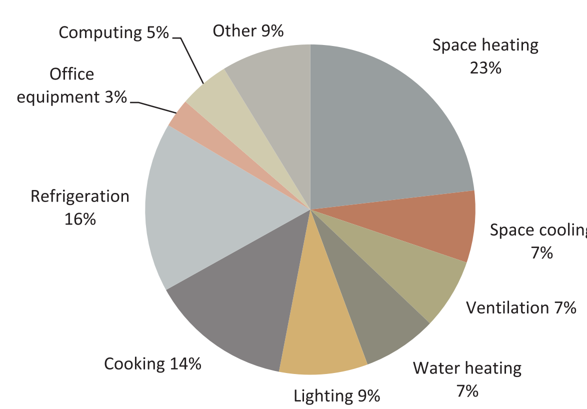

Fig. 2. Energy consumption in U.S. small commercial buildings by end use [3].