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On the application of wireless sensors and actuators network in existing buildings for occupancy detection and occupancy-driven lighting control

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ABSTRACT

Buildings have in recent years been the target of a number of energy efficiency improvement strategies given that they are a major energy end-use sector in most countries. Whilst new buildings due to legislations, increasingly address sustainability and improved energy efficiency considerations, the refurbishment process of older buildings still presents a number of challenges. Advancement in Information and Communication Technology, particularly the application of low-cost Wireless Sensors and Actuators Network does however provide the opportunity to harness yet unrealized energy reduction in existing buildings. This paper presents results from an experimental study evaluating the performance and energy saving potentials of such off-the-shelve, low-cost wireless sensors and actuators network in an existing office building for occupancy detection and occupancy-driven lighting control. The study demonstrates that in addition to improved occupancy information obtainable from Wireless Sensors and Actuators Network, worthwhile savings in the energy consumption of the lighting systems can as well be achieved.

1. Introduction

1.1. Building energy consumption

Buildings, due to the key role they play in the society, represent the largest energy consuming sector in the economy, consuming over one-third of all final energy and half of global electricity [1,2]. In addition, buildings contribute as much as one third of greenhouse gas emissions during their operational phase in both developed and developing countries [3,4]. By 2050, the International Energy Agency(IEA) [2] projects an increase of up to 50% in the energy demand of buildings if steps are not taken to improve energy efficiency. This increase is attributable to rapid growth in the number of households, residential and service floor area, higher ownership rates for existing electricity-consuming devices and increasing demand for new products.

The existing building stock accounts for a significant part of the energy demand in the built environment. In developed economies, at least half of the buildings that will be in use in 2050 have already been built. According to a survey by the U.S. Energy Information Agency, 72 percent of floor stock in the U.S., belongs to buildings over twe nty years old [5]. And in the EU, about 35% of the buildings are over 50 years old [6]. These older buildings most of which are constrained by old equipment, aging infrastructure, and inadequate operational resources, use a great deal of energy. Retrofitting of these older buildings does however represent a great opportunity to achieve worthwhile improvement in energy efficiency and conservation in the built environment [7,8].

Even though renovation represents an opportunity to upgrade the energy efficiency of buildings, the refurbishment rate of existing buildings is still largely low. As noted by the authors in [9,10], the replacement rate of existing buildings with new builds is typically between 1.0–3.0% per annum. This low refurbishment rate is in part largely due to the fact that buildings and its various systems have a rather long-lifespan and retrofitting (i.e., retrofits that include replacing mechanical systems, windows, insulation, lighting systems and other features) requires significant investment [11,12]. This often leads to a situation whereby refurbishments are timed with major renovations or capital-intensive building system replacement.

In recent years, innovation and improvement in information and communication, technology (ICT) as well as in solid-state technology has advanced the application of a number of technologies [13,14], such as wireless sensors and actuators network

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Fig. 1. Test-bed office building.

(WSAN). Wireless sensors and actuators network, which hitherto was considered expensive and underdeveloped for practical large-scale commercial applications is now gaining widespread use in a wide range of applications [15,16]. They have in particular gained widespread use in sectors such as agriculture [16], healthcare [17], smart-grid operation [18] and building operation [19,20]. In building operation in particular, WSAN introduces significant improvement in building operation and management by reducing the complexity of harnessing wired transmission in difficult to reach places [14,21]. In addition, as most building systems are usually in place before occupants' move in, WSAN introduces additional flexibility as it relates to sensor placement [22,23]. This enables obtainability of fine-grained occupancy and indoor environmental parameter information that facilitates improved comfort and energy efficiency.

1.2. Wireless sensors and actuators application in building automation

Buildings today rely on a combination of end-point connections using wired and wireless communication platforms for interconnection of various building systems and processes. Though wired solutions are preferred in majority of cases, wireless devices are becoming more prevalent due to improvement in communication link speed, security, and battery technology [24,25]. Wireless sensors can now boast of batteries having average life spans of up to six years. Wireless sensors as a result nowadays replace, or in some cases augment, traditional hard-wired solutions, resulting in flexible, cost-effective sensing and control solutions in buildings [26,21].

Diverse wireless devices using a variety of communication protocols such as [13,27] Wi-Fi, ZigBee, Z-wave, and Bluetooth as depicted in Table 1, are now commercially available and easily accessible for use in building automation. In addition to modularity and flexibility offered by wireless devices, today's wireless devices are self-organizing, easier to install and maintain [15,28]. Self-organization and modularity of these devices in particular, makes them advantageous in achieving fast, cost effective, less-disruptive and unobtrusive retrofit in existing buildings.

2. Similar studies

2.1. Wireless sensor and actuator application in residential buildings

The residential building sector has in recent years witnessed increased use of WSAN for various applications ranging from occupancy-based control of home appliances and systems [29–31] to more advanced smart home applications [21,32,33]. In [30], the authors demonstrated through experimental data obtained from a seven room, 2100 square foot single-storey ranch-style house built in 1971, that multi-wireless sensor based control strategies for air-conditioning can reduce energy consumption and room-to-room disparities in temperature and humidity compared to a single-sensor temperature threshold thermostat. The authors concluded [30] that the application of comfort based multi-WSN sensors can provide up to 79% normalized energy savings, 32% reduction in room-to-room temperature range, 13% reduction in mean discomfort, and 22% reduction in mean maximum room-to-room difference in discomfort. In a similar study, using wireless sensors for occupancy detection in combination with a smart thermostat, the authors in [29] demonstrated that at very low initial cost per home, energy savings of up to 28% of residential HVAC energy consumption on average can be achieved without sacrificing comfort. In both of these studies however, very little detail relating to the cost effectiveness in relation to the recorded saved energy was provided.

2.2. Wireless sensor and actuator application in commercial office buildings

Whilst the application of WSAN has in recent years being more pronounced in residential buildings [27,34], its application in commercial buildings is beginning to gain momentum. In [35,36], the authors evaluated the competitiveness of wireless sensors in a range of typical building applications and demonstrated that for two different retrofitting applications with WSAN. Though the wireless based systems were reported to be moderately more cost-effective than their wired alternative, the wired sensors did however provide higher data transmission rates.

Modularity and flexibility of wireless devices make it much easier to place sensors at locations in buildings were hitherto sensors could not be placed due to cabling cost or power limitations [37]. This facilitates increased sensing density, as well as increased variety of sensor types that can be applied in a space to make imminent improvements in energy efficiency and building occupants well-being [38]. By using a network of wireless sensors, the authors in [39] showed that the air supply to a large office space can be optimized to improve temperature homogeneity and the operation of the air conditioning system in the space. The authors in [40] on the other hand demonstrated through the use of 27 sensor devices that an accurate analysis of indoor conditions, recognition of inhabitant comfort level, and recommendations on optimal balance between environmental quality and power demands could be achieved in the test-bed building. Wireless sensors also facilitate access to detailed information relating to energy consumption within buildings, as well as the prevailing context under which such consumption occurs. This way, a sophisticated approach to energy control and feedback can be enabled as demonstrated by the authors in [28,40].

The application of WSAN systems has also been shown to enhance the performance of occupancy-driven control applications through the provision of fine-grained occupancy information [41,42]. Building occupancy is a challenging parameter to determine particularly in large commercial buildings where occupants enter and exit buildings, move through spaces and floors in a