Energy and Buildings 128 (2016) 484–490

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Cost-benefit evaluation for building intelligent systems with special consideration on intangible benefits and energy consumption

Zheliang Chen, Fulin Wang*, Qingqing Feng

Beijing Key Laboratory of Indoor Air Quality Evaluation and Control, Department of Building Science, School of Architecture, Tsinghua University, Beijing, China

ARTICLE INFO

Article history:
Received 5 March 2016
Received in revised form 26 June 2016
Accepted 10 July 2016
Available online 11 July 2016

Keywords:
Intelligent building
Cost-benefit evaluation
Net present value
Analytical hierarchy process
Tangible and intangible costs and benefits
Energy consumption

ABSTRACT

Building intelligent system has become one of the standard configurations in a public building even in a residential building. Intelligent buildings are expected to provide high-efficient, convenient, comfortable and energy-saving built environment so as to bring additional benefits. However, problems like sensor faults and control strategy flaws may result in low performance and high energy consumptions and maintenance costs are needed as well. Thus it is needed to synthetically evaluate the costs and benefits of intelligent systems to help building investors to make decisions. This paper proposes a cost-benefit evaluation method for building intelligent systems. Life cycle net present value (NPV) of all the costs and benefits, including tangible and intangible, is used as an index to evaluate the performance of the building intelligent systems. The proposed method puts emphases on the quantitative evaluation of intangible benefits using Analytical Hierarchy Process (AHP) method to determine the weights of each aspects of intangible benefit. The building energy consumptions are taken as an another emphasis as well. The proposed method is applied to evaluate three actual buildings to check its feasibility and effectiveness. Sensitivity analysis of NPV to energy consumption of the case study buildings shows that the energy consumption increase or decrease caused by different performances of intelligent systems can influence the positive or negative of NPV, which implies the building intelligent systems are worth of investment or not.

1. Introduction

Since the concept of intelligent building was put forward in the early 1980s, intelligent system has become one of the standard configurations in a public building even in a residential building. Intelligent buildings are expected to provide high-efficient, convenient, comfortable and energy-saving built environment so as to bring additional benefits, such as improvement of users' work productivity, increment in income of room rent, decrement of human power costs, etc. Intelligent systems play an important role in creating healthy indoor environment and achieving energy conservation. However, problems like sensor faults and control strategy flaws may result in low performance and high energy consumptions of building facilities. Fig. 1 shows the energy consumption of some randomly selected buildings with and without building automation (BA) system in China [1]. From Fig. 1 it can be found that the average annual power consumption intensity of the buildings with BA system installed is 159 kWh/m^{2}a, which is nearly twice of the buildings without BA system, which is only 83 kWh/m^{2}a. Although the sample number is not large enough, the expected tendency of energy saving brought by intelligent systems cannot be seen. The authors' field investigations show that this phenomenon is not special but quit common in China [2].

The reasons for the difference of building energy consumption might include running hours, ventilation mode (i.e. natural or mechanical), air-conditioning method to match the set-point (i.e. temperature-humidity coupled control or decoupled control), building facilities' energy efficiency, human behaviors on using energy, requirement for comfort level, etc. The building intelligent system can benefit energy efficiency by reducing running time (e.g. promptly turning off lights and air-conditioning system when room is unoccupied), energy efficient automatic control strategy (e.g. achieving free-cooling, reducing counteraction of heating and cooling), forming energy-efficient human behaviors, etc. To achieve these energy savings by building intelligent systems, certain costs to maintain the intelligent systems are needed, such as periodical calibration of sensors, replacing faulty actuators, etc. Whether these maintenance and other costs related to building intelligent

* Corresponding author.
E-mail address: flwang@tsinghua.edu.cn (F. Wang).

http://dx.doi.org/10.1016/j.enbuild.2016.07.021
0378-7788/

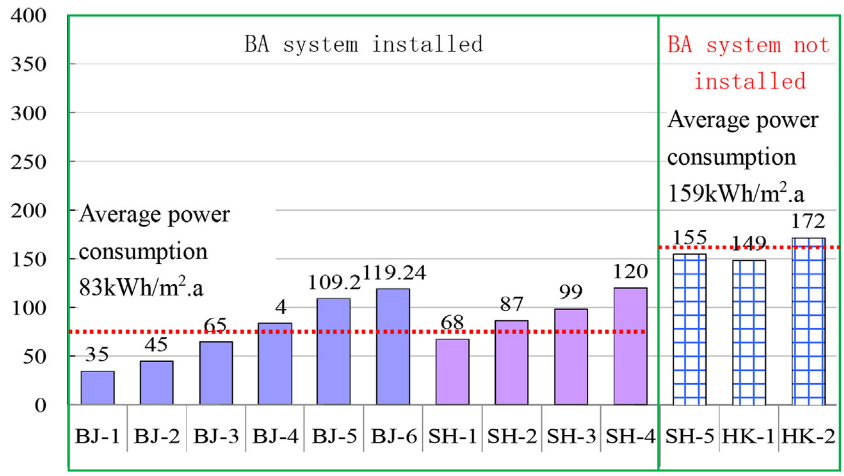

Fig. 1. Annual electricity consumption intencities of some buildings with and without building automation (BA) system in China.

systems can be paid back by the benefits brought by the intelligent systems is a question that cannot be easily answered, especially the quantitative evaluation the intangible benefits brought by the intelligent systems. It needs a scientific and comprehensive method to analyze the costs and benefits of intelligent systems to assess their performances and values.

Current researches on evaluating buildings' intelligent systems usually focus on the analysis of system and function requirements (e.g. air conditioning, building automation, security, fire control, etc.) [2–5], or on the selection of indexes to evaluate intelligent building performance [6–8]. Among these studies, Analytical Hierarchy Process (AHP) method is often used to compare and to rank the required functions or evaluation indexes for intelligent buildings to highlight some aspects in intelligent building design or assessment [3,5–8]. However, these studies evaluate building intelligent systems on a qualitative basis. Therefore this paper proposes a cost-benefit evaluation method for building intelligent systems, especially considers the quantitative evaluation on intangible benefits and the influences of building energy consumption to the cost-benefit evaluation. The proposed cost-benefit evaluation method can be used for building investors to make decision on installing intelligent systems or not. And it can be used for the existing buildings' owners to evaluate the cost-benefit performance of the intelligent systems as well. For the purpose of checking the feasibility and effectiveness of the proposed cost-benefit evaluation method, three buildings case studies were conducted. Finally based on the case study buildings' data, influences of energy consumption and model parameters to cost-benefit evaluation are discussed.

2. Cost-benefit evaluation method for building intelligent systems

Life Cycle Analysis (LCA) is widely used in a project's cost and payback evaluation because of its overall view on both costs and paybacks through the designing phase to the post management phase. Chen et al. used LCA to analyze a building's environmental costs [9]. Gluch and Baumann used LCA to compare the life cycle cost of intelligent buildings with different system integration levels [10]. On the other hand, Net Present Value (NPV) method is usually adopted to quantitatively analyze the cost and payback, which examines cash flows of a project over a given time period and converts them to an equivalent present value. Positive NPV implies the project is worth of investment [11]. Wang used the combination of LCA and NPV to evaluated different design schemes of heating, ventilation and air-conditioning systems [12]. Similarly, this paper proposes a method to analyze the cash flows brought by building intelligent systems during its lifespan using LCA-NPV method for the purpose of giving out a synthetic quantitative value to evaluate whether the intelligent systems are worth of investment or not. The life cycle NPV is calculated using Eq. (1).

$$NPV = \sum_{t=1}^{N} \frac{F_t}{(1+y)^t} - C_0 \tag{1}$$

where F_t is the tth year's net cash flow brought by the intelligent systems, i.e. subtracting cost from benefits (including both tangible and intangible), as shown in Eq. (2); N is the years of lifespan, which is generally 10–15 years for building service systems; C_0 is the capital investment of the intelligent systems; y is the discount rate, which is used to discount the cash future value to present. For building intelligent systems, the bank interest rate can be used as the discount rate [13].

$$F_t = F_{l,t} + F_{e,t} + F_{f,t} + F_{i,t} - F_{m,t} \tag{2}$$

where $F_{l,t}$ is the tth year's labor cost saving; $F_{e,t}$ is the tth year's energy cost saving; $F_{f,t}$ is the tth year's fire insurance cost saving; $F_{i,t}$ is the tth year's intangible benefits; $F_{m,t}$ is the tth year's maintenance costs of intelligent systems.

The following parts explain the method how to determine the values of each item shown in Eqs. (1) and (2).

2.1. Tangible costs and benefits of building's intelligent system

For the purpose of evaluating the cost-benefit of intelligent systems, it is needed to synthetically consider both tangible and intangible costs and benefits. The tangible costs and benefits commonly include the following four aspects:

1) Capital investment C_0: It includes the costs for designing and installing the intelligent systems. In China the capital investment of the intelligent systems for a public building is about 100–300 RMB/m^2 floor area [14]. Table 1 shows the authors' on-site investigated data of three actual buildings, which is similar the data given by reference 14 and can also be used as reference to estimate the capital investment of a building's intelligent systems.
2) System maintenance cost $F_{m,t}$:The maintenance cost of building intelligent systems can be roughly determined according to point number of the intelligent systems. In China the common annual maintenance costs of one intelligent point are shown in Table 2. Accordingly, the total annual maintenance cost of the