Energy and Buildings 70 (2014) 516–522

Contents lists available at ScienceDirect

Energy and Buildings

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

Development and design of a retrofit matrix for office buildings[☆]

G. Hillebrand[a], G. Arends[b], R. Streblow[a], R. Madlener[b,*], D. Müller[a]

[a] RWTH Aachen University, E.ON Energy Research Center, Institute for Energy Efficient Buildings and Indoor Climate (EBC), Mathieustrasse 10, 52074 Aachen, Germany
[b] RWTH Aachen University, School of Business and Economics/E.ON Energy Research Center, Institute for Future Energy Consumer Needs and Behavior (FCN), Mathieustrasse 10, 52074 Aachen, Germany

ARTICLE INFO

Article history:
Received 26 April 2013
Received in revised form 23 August 2013
Accepted 21 October 2013

Keywords:
Energy efficiency
Building refurbishment
Economic evaluation
Simplified data acquisition
Dynamic thermal model

ABSTRACT

This paper describes the methodology developed and the calculation steps used to evaluate the energy efficiency potential of office buildings. The methodology enables a detailed analysis of retrofit options for the building envelope and its energy supply system. Different simplification measures accelerate the data acquisition process for office building stock owners and allow a data handling according to the existing building information, thus enabling office building structures to be prompted to design typical building constructions. We implement solutions enabling both a time-saving accelerated data input for office buildings and the handling of incomplete data. An automated calculation of the most common refurbishment measures allows a comparison of up to 64 combinations of measures, the illustration of energy and CO_2 savings, and an economic evaluation. The latter takes into account the time value of money, the uncertainty of future energy prices, and the possibility of delaying an investment. To this end, a net present value analysis and a real options analysis are implemented, enabling a comparison of retrofit alternatives with different initial and future cash flows both for buildings occupied by the investor (owner-occupier perspective) and for rented buildings (tenant perspective). Energy price scenarios as well as a Monte Carlo simulation account for the uncertainty in energy price trends. For a university building used as a test case, the simplified and time-saving data input methods were successfully tested and an automated evaluation of 64 typical retrofit combinations carried out. The results of the energy, ecological and economic efficiency evaluation shows that a generally preferred retrofit option cannot always be identified. Specifically, for the test case, the best-rated economic refurbishment possibility leads to the largest increase in final energy demand amongst all options considered, which points out the necessity of a multi-criteria evaluation.

1. Introduction

As a consequence of the Kyoto Protocol and the required reduction in CO_2 emissions therein, huge efforts must be made to save high quality or primary energy resources. Besides the discussion about the kind of energy production, a key role comes up to the efficient use of energy in all economic areas [2]. This is also reflected in the climate policy plans of the European Union. By 2020, a reduction of the greenhouse gas emissions of around 20%, a rise in the renewable energies as a share of gross final demand to 20%, as well as an increase in the energy efficiency of up to 20% are planned [3]. Especially in the building stock there is still considerable energy-saving potential. With a portion of 37% in the German CO_2 emissions [4] and a similar portion in the primary and final energy consumption [5], the relevance of energy use in buildings becomes clear. The fact that more than 80% of all buildings are older than 25 years and have not yet been refurbished underlines this hypothesis [6]. This study focuses on office buildings because these buildings consume approximately 10% of the final energy consumption in Germany.

To organize and advise the retrofit process for private and public office building stock holders, this paper describes a tool for a detailed analysis of different retrofit options for the building envelope and its energy supply systems. Different measures, potential energy and CO_2 savings, cost estimates, and additional information, including special user demands and internal building ratings, can be selected and calculated to indicate possible pathways for enhancing the building's energy efficiency. In addition, the tool enables a reliable estimate of the economic impact of each investment alternative. To this end, not only the investment itself, but future cost savings arising from each retrofit measure are also taken into account. The most important of these are (saved) payments for energy or rental income/expenditures (depending on whether the investor is the user or the landlord of the building), financing, and operation and maintenance. Investments with different initial and future payments are made comparable by

---

[☆] Further details on this research can be found in [1].
[*] Corresponding author. Tel.: +49 241 80 49 820; fax: +49 241 80 49 829.
E-mail address: RMadlener@eonerc.rwth-aachen.de (R. Madlener).

0378-7788/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.enbuild.2013.10.029

employing a dynamic evaluation method, i.e. by considering the time value of money, where prior art mostly used static methods. Furthermore, the problem of uncertainty regarding energy price development, which is the most influential parameter, is addressed in two ways: The simultaneous evaluation of different scenarios and Monte Carlo simulation to determine possible outcomes based on historical price developments. Based on the latter, the user may then choose to analyze the value of waiting with the refurbishment.

The remainder of this paper is structured as follows. Section 2 introduces the methodology. Section 3 describes the economic analysis, Section 4 presents a sample application and result visualization, while Section 5 concludes.

2. Development and design of a retrofit matrix

For the energy evaluation of buildings, the European Union has implemented the Energy Performance of Buildings Directive [7]. This EU directive was implemented at the national level in Germany with a set of preliminary standards defined in DIN V 18599 [8]. This standard allows the calculation of the energy efficiency of entire buildings and also considers energy refurbishment potentials. Since the introduction of regulation EnEV 2007 [9], the calculation methodology has been prescribed according to this standard and later been expanded by the coverage of residential buildings with regulation EnEV 2009 [10]. However, the ordinance DIN V 18599 describes a far-reaching and complicated approach to assessing the building envelope and facility technology, which leads to cumbersome procedures and high monetary expenditures. Several studies have examined the time needed for the so-called “requirement certificate”, which evaluates the energy demand of a building and shows alternative retrofit possibilities. It became apparent that the average time needed ranges from 78 [11] to 80 h [12] up to 240 h [13], depending on the building size. Besides the vast amount of time, it was shown that the required data, e.g. concerning construction materials and surfaces, were often either unavailable or inexistent. Based on these outcomes, the future energy evaluation or retrofit tools need to focus on simplification measures in order to accelerate the assessment process and to be more adaptive to the available data stock.

The overall objective of the retrofit tool is the energy analysis of existing non-residential buildings. To implement this, energetic qualities and weaknesses of the building envelope and the system technology need to be assessed and identified. The energy demand of the current building state and refurbished states needs to be calculated. Also, energy losses through ventilation and transmission as well as energy gains through solar irradiation and waste heat of persons or technical equipment need to be balanced. In order to set up an energy balance, detailed information about the building must be available. Data on the size and the characteristic building shell, and details about the functional areas as well as information on the installed technical equipment are needed. Furthermore, a calculation methodology is required that merges the building data and yields an energy balance.

In practice, the parameters for the energy balance need to be extracted from floor plans, views, and detail drawings. As highlighted above, this procedure is very time-consuming and precise information for existing buildings, especially older ones, is typically unavailable. Therefore, it is necessary to enable two possibilities for a fast refurbishment examination: First, simplification measures for a quicker data acquisition have to be adopted. Second, a data stock adaptation due to incomplete building information should be implemented.

The basis of the method developed in this research is not the complete, detailed building data, but instead standardized building types. In a first step, and with a minimal set of data, enveloping surface areas, functional areas, etc. are estimated. Characteristics of the building type can then be shown and typical, common refurbishment possibilities calculated. If more detailed information is available, this can be used to calculate the building performance in a more accurate way. Fig. 1 shows this procedure schematically. On the basis of very limited data, first estimations can be made and a small amount of time is needed for the audit. Depending on the time and available data, a smooth transition according to the depth of detail of the data acquisition is possible. The following analysis exemplarily outlines this approach and explains the implemented calculation core as well as the zoning method.

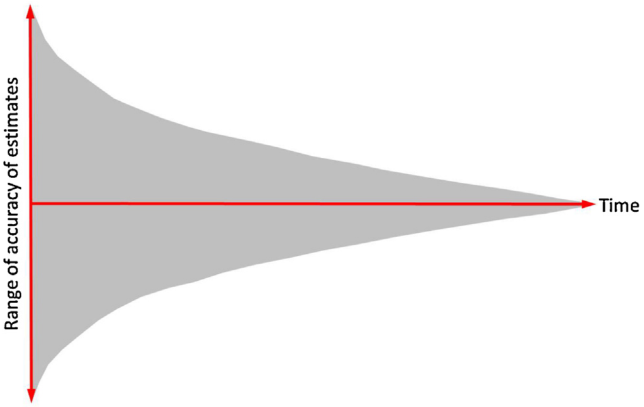

Fig. 1. Concept of the retrofit matrix.

The *computation core* forms the basis for the calculation of the energy demand, with the help of an energy balance. Scrutiniting calculation methods typically used in Germany reveals that monthly or yearly balancing methods are common [8,14]. Besides the calculation of the yearly energy demand, it might also be necessary to compare the energy demand with the real energy consumption. Standard boundary conditions, such as the weather or the behavior of building occupants are used for the calculation of the energy demand, and often deviate considerably from the real weather and the real persons’ behavior. Recalling the energetic evaluation of buildings and refurbishment possibilities, those different boundary conditions may influence the results. For this reason, matching expected demand and actual consumption is necessary. Carrying out such a matching between demand and actual consumption, monthly or yearly values can be imprecise and lead to wrong assumptions. Therefore, higher resolutions in the calculation method for the energy demand and the measurement of energy consumption values may be helpful. For this reason, the calculation method for determining the useful energy needs should enable a more detailed approach. It should allow the computation of yearly and monthly energy needs as well as the computation of daily or hourly values. In practice, a wide variety of different calculation techniques exists within the building industry.

Taking into account the computational speed on the one hand and the accuracy on the other hand, a so-called “two capacity model” (2-c-model) was implemented as the main computation core. This dynamic thermal model is described in detail in the German directive VDI 6007-1 [15] and allows a validation of the calculation method with the aid of 12 test examples. It is also mentioned in the standard for ‘Requirements of methods for calculating thermal and energy simulation of buildings and plants’ [16] and considered there as being sufficiently adequate for building simulations. Since March 2012, it has also become a part of the German standard VDI 2078 [17], which is used for the calculation of the cooling load and room temperatures of rooms and buildings. To verify the implemented algorithms, the calculation methods were validated with the 12 test examples included in the standard VDI 6007-1 [15]. In Fig. 2 the outcomes of a monthly balance