Towards improving energy-efficiency in office buildings

Case study on the affects of technical optimization and augmented user-sophistication

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ABSTRACT

Purpose –The study aimed to determine the effectiveness of various predefined measures and scenario developments in ensuring greater energy-efficiency of existing office buildings. Given the primarily technical nature of these packages, the effects of user-involvement were introduced as an additional theme.

Design/methodology/approach – Measured energy consumption of 19 existing buildings of the Dutch Government Buildings Agency (DGBA) was used for evaluation through application of the PARAP Lifecycle Costing (PARAP LCC) model. In addition the EBOB (Energy Efficient Behavior of Office buildings) simulation model was adapted and used in quantifying the effects of technical measures and user-sophistication on reducing energy consumption in existing office buildings.

Findings – Results from a comparative analysis indicate the extent to which (i) technical measures, (ii) augmented user-sophistication and (iii) the combination of these measures contribute to improved energy-efficiency in existing office buildings.

Research implications/limitations – A limitation of this study is that results are reflective of only a small portion of the property portfolio of the DGBA. Further research is necessary to extend the applicability and conclusiveness of outcomes of the current study to the entire property portfolio.

Practical implications – The combined positive effects of technical measures and user-sophistication on reducing energy consumption in existing buildings provide an evidence-based management approach to the formulation and implementation of measures to improve the energy-efficiency of entire property portfolios.

Originality/value – Most studies on this subject address the question from the singular perspective of optimizing technical installations for building management and control. The current study breaks with this tradition by providing quantified evidence for also considering the positive effects of user-involvement in reducing energy consumption.

Keywords – energy-efficiency, user-sophistication, mathematical models, property portfolios.

Paper type – Case study

INTRODUCTION

Most studies on energy-efficiency in office buildings are case-orientated within the domains of architectural design or building construction. Such studies primarily focus on specific buildings either in the initial phase of building development, buildings recently completed and in the early stages of occupation, or buildings in use. In doing so, the architectural design, in conjunction with the perceived superiority of state-of-the-art technical systems, forms the focus of discussion. End-user involvement is subsequently rarely considered in terms of social and organizational responsibility or the augmentation of the level of sophistication with which end-users interface with state-of-the-art technical building management and control systems. When considering the outcomes of a 2003 study by the European Commission that the built environment is responsible for 40% of the final energy consumption and CO_2 emissions in the European Union (EU), this approach might be validated[1]. However, the current study, in recognition of the relevance of good design and optimally functioning technical systems, investigates the advantages to be gained from augmenting the role of user-sophistication in office buildings. In this respect, the study departs from the notion that augmented levels of user-sophistication in interaction with the built environment can result in significant increases in the energy-efficiency of buildings.

In the government notice entitled "Energy Ambition 2020" of the Dutch Government[2] a reflection was given on the ambitions of the Dutch Government regarding measures for implementation to ensure greater energy-efficiency in office buildings. The measures formulated were predefined as three energy saving packages. However, for implementation it was necessary to first evaluate these energy saving packages in terms of the expected effects thereof on reducing energy consumption in existing office buildings. Given the history of participative research between the DGBA and the Center for People and Buildings (CfPB), a research question focusing on quantifying the effects of the proposed energy saving packages was formulated and presented to the CfPB.

The predefined energy saving packages formulated by the DGBA included thefollowing measures:

- Package 1 – Minimal package:
  To be implemented and realized at any moment. This package includes measures such as heat recovery systems, occupancy detection systems for lighting control, and the improved management and functional control of HVAC systems;
- Package 2 – Replacement package:
  In addition to implementation an success of measures in Package 1, measures in this package are to be implemented according to the lifespan of technical services. As such this package will be realized during the natural replacement of technical services and installations. Additional measures include aquifer thermal energy storage systems, heat pumps and LED lighting;
- Package 3 – Renovation package:
  Following the implementation and success of the previous two packages, measures in this package are to be implemented and realized during natural renovation moments in the lifecycle of buildings. Additional measures included in this package are high-performance glazing (U-factor ≤ 1.6), improved thermal isolation of roofs and walls, and advanced systems for low temperature heating and high temperature cooling.

In addition to the predefined energy saving packages, the following anticipated scenario developments were defined to serve as parameters for assessing the performance of the various measures included the three energy saving packages:

- Scenario 1 – Maintaining current building management and control procedures:
  This scenario was proposed as a control measure for quantifying the departure situation without the implementation of any new measures for improved energy-efficiency. Scenario 1 therefore served as a reference point in benchmarking the effects of the three energy saving packages in subsequent scenarios;

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[1] Research report by European Commission on the energy performance of buildings (http://ec.europa.eu/energy/strategies/2008/doc/2008_11_ser2/buildings_directive_proposal.pdf), project number 2008/0223, viewed on 13 February 2009, p.2.
[2] Dutch Government 2007 coalition agreement Balkenende Cabinet IV (www.regering.nl/Het_kabinet/Regeerakkoord#internelink6), viewed on 13 February 2009.

- Scenario 2 – Application of new ways of working based on functional profiles and work processes specifically formulated to reflect organizational objectives: *In this scenario simulations were done to quantify the effects of 33% less workplaces and the same number of employees (fte) on overall energy consumption;*
- Scenario 3 – Application of server-based computing: *This scenario foresees the placement of server rooms in remote locations and the use of low-energy desktop computers;*
- Scenario 4 – Advanced approach: *This scenario included the combined application of scenarios 2 and 3.*

Initial reviews of the proposed energy saving packages formulated by the DGBA found the measures included in each of the packages of an exclusively technical nature. Given the focus of the CfPB on the relationship between people, work and the workplace environment, the relevance of including measures for studying the effects of user-behavior on the energy-efficiency of office buildings as part of the proposed study was advised. Part of this advice was based on the availability of various tools within the research toolkit of the CfPB. These included the PARAP LCC model (Gerritse *et al.*, 2008) and through knowledge of the EBOB[3] (Energy-Efficient Behavior in Office Buildings) simulation model for quantifying the effects of user-behavior on reducing energy consumption in office buildings. The combined application of these two models was regarded as an appropriate and affective method in addressing the research question.

Given the duality of the resulting research question, various questions pertaining to the effects of the energy saving packages, the anticipated scenario developments and the effects of user-sophistication on energy-efficiency in office buildings were formulated as hypotheses for this research. Five hypotheses were formulated to guide the current study:

- Hypothesis 1: The demand for energy in office buildings are continuously rising due to the increase in the application of information and communication technologies (ICT);
- Hypothesis 2: The proposed technical measures for optimizing building management and control systems as contained in the energy saving packages of the DGBA have a positive effect on reducing energy consumption in office buildings;
- Hypothesis 3: The effects of the various energy saving packages are cumulative. This implies that the effects of measures in subsequent energy packages are highly dependent on the extent to which the technical measures in the previous energy package have been realized;
- Hypothesis 4: The effects of augmented user-sophistication are complimentary to the effects to be obtained from the implementation of the technical measures and anticipated scenario developments;
- Hypothesis 5: The implementation and use of innovative technologies to facilitate user-sophistication will result in further substantial reductions in the energy consumption of office buildings.

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[3] Research report by the European Commission on Energy and Transport on energy efficient behavior in office buildings, project NNE5/2001/263 (http://www.ebob-pro.com/documents/NNE5_2001_263%20EBOB%20PUBLISHABLE%20REPORT.pdf), viewed on 13 February 2009.

METHODOLOGICAL APPROACH

To test the hypotheses a multiple case study approach on the basis of mathematical modeling was proposed to quantify the impact of the predefined energy saving packages, the anticipated scenario developments and aspects of augmented user-sophistication included in the EBOB model. The study was undertaken in 19 existing office buildings of the DGBA, all of which are currently in use by the Dutch Tax and Customs Administration. In the early stages of the study the question arose with regards to the applicability of the expected outcomes of this study, which was based on a relative small and homogenous sample group, on the entire property portfolio of the DGBA. In the concluding reflection this aspect will be discussed in more detail.

In the development of the methodological approach, the various facets of the research question as discussed in the introductory part were considered and duly acknowledged. As such, a multi-method approach using two different mathematical models through which the nature of the research question could be explored was proposed. In this respect, two distinct phases in the development of the methodological approach towards quantifying the combined effects of technical optimization and augmented user-sophistication was identified.

Phase 1: Simulation of the existing buildings

The first step in addressing the research question was to determine the effectiveness of the predefined energy saving packages on improving the energy-efficiency of the selected office buildings. A key characteristic of these predetermined measures was their exclusive focus on technical measures for optimizing building management and control systems. The purpose of this first phase of the research methodology was to validate information obtained on the measured (actual) energy consumption of buildings in the sample group. This was undertaken as a control measure for quantifying the effects of subsequent energy saving measures and scenario developments. This validation process implied the application of a simulation model approach through which the measured energy consumption could be compared against the theoretic energy consumption of the buildings as simulated in the energy simulation model. For this part of the study data on the characteristics of the selected buildings, including energy consumption during the period 1989-1995 and 2005-2007, were provided by the DGBA. This data were used for simulating the existing buildings using the energy simulation model as developed in the international EBOB study and adapted for this purpose of this study

A first step in this phase of the study was the categorization of the physical characteristics and locations of the buildings in a photographic database (see Fig. 1). This step was deemed necessary to provide a visual overview of the selected buildings in which the effects of the proposed energy savings packages and anticipated scenario developments were to be explored. The photographic database also proved relevant in determining aspects such as the number of floors, building width (with respect to single and double corridor variations) and the glass to wall surface ratio of windows on the facades. With the exception of two buildings, all buildings dated from the period 1970-1995, thereby giving an indication of the level of building technology and the properties of building material used. The exceptions were one building from 1941, and one monumental property dating from 1880.

Building	Photo 1	Photo 2	Photo 2
1			

Fig 1. Example of one of the buildings in the photographic database of the 19 buildings considered for the study.

Following the compilation of the photographic database, each of the buildings in the sample group was simulated using the energy simulation model. The simulation process used available data on the physical characteristics of the buildings to match the simulated building model to the existing building – thereby creating a theoretic building model with the resultant theoretic energy profile associated with the specific building in the sample group. Since it was not possible to extract from the data which of the buildings had undergone interim renovations in terms of technical building management and control systems, the simulation of the various buildings in the simulation model provided an opportunity of distilling these observations on a factual basis.

A final step in preparing a research methodology during this first phase of the study was to determine an average office building in terms of gross floor area and the total number of part- and fulltime employees (fte). This step was necessary to provide a reference building for the evaluation of the effects of the various predefined energy saving packages and anticipated scenario developments. The reference building was then used during the second phase of this study as a consistent parameter for comparative analyses of the effects of the various energy saving packages, scenario developments and augmented user-sophistication.

Phase 2: Quantifying user-sophistication

Having established an overview of the energy profiles of buildings in the sample group, the second part of the research question required the application of a different mathematical model to quantify the effects of the proposed energy saving packages and measures for augmented user-sophistication. . In this respect the EBOB simulation model was proposed. EBOB (Energy Efficient Behavior in Office Buildings) is a complex model consisting of various calculation models which link information on the strategy choice for the reduction of energy consumption, building characteristics and information on the organization (Fig. 2). This EBOB model was based on former research of the PARAP study group and used in a international study project. Adapting this model by CfPB for the purpose of this study was a logic choice.

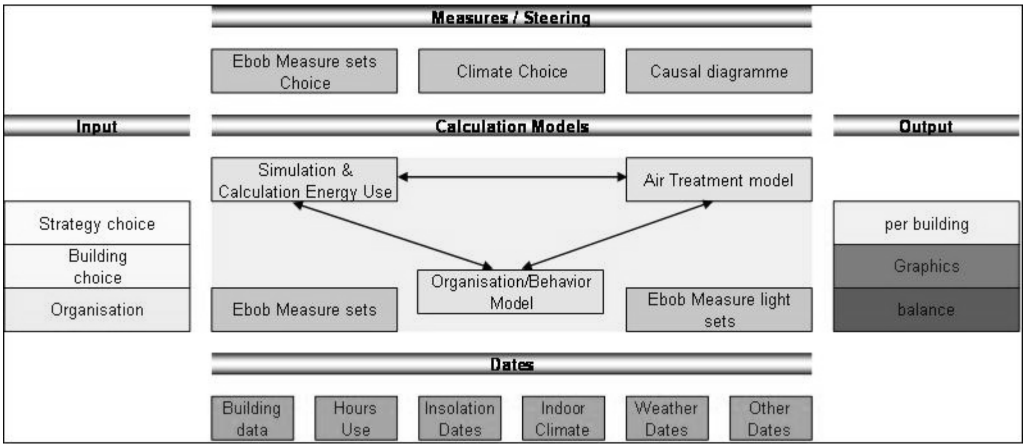

Fig. 2. Front page of the EBOB simulation model showing the various interlinked models and the various input data required for the simulation of the effects of various combinations of strategies for optimized technical measures for building management and control systems and influence on user behavior.

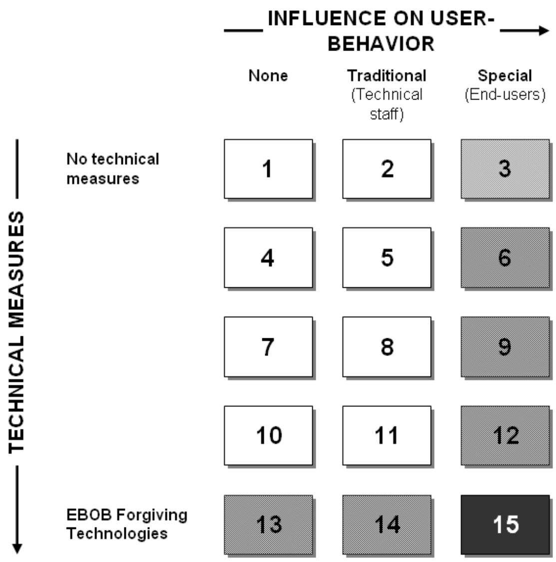

Fig. 3. EBOB input control for the various strategies.

The model consists of 15 different strategies consisting of consistent sets of measures for both technical building management and control systems and predefined measures for influencing the behavior of users. In the model the level of technical measures increases vertically from top to bottom, while measures for influencing user-behavior and ultimately user-sophistication, increases horizontally from left to right (Fig. 3). Characteristics of the EBOB simulation model which were deemed specifically relevant for this study, are the inclusion within the overall strategies of the model of the following:

- 4 strategies focusing specifically on augmenting user-sophistication through influence on user-behavior (strategies 3,6,9,and12);
- 2 strategies focusing specifically on state-of-the-art technologies referred to in EBOB-terms as “forgiving technologies” (strategies 13 and 14);
- 1 strategy which combines the complete augmentation of user-sophistication with the application and effective use of “forgiving technologies (strategy 15).

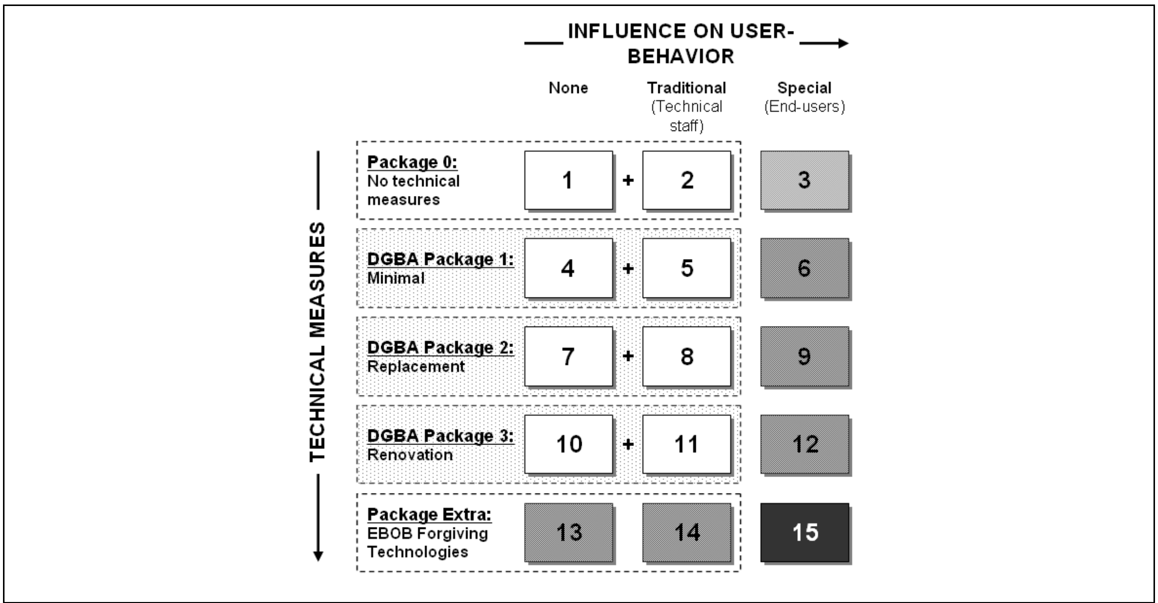

Fig 4. EBOB input control showing the relationship between the 15 EBOB strategies and the three predefined energy saving packages of the DGBA, as well as the two additional packages (Package 0 and Package Extra) added as part of the development of the research methodology.

For the purpose of this study, measures contained in the predefined DGBA energy saving packages were integrated with the strategies of the EBOB model. The measures included in the DGBA energy saving packages are combinations of technical measures for building management and control, as well as traditional guidelines for user-behavior focusing specifically on technical operation and management staff. End-users are not included in these measures. The integration of measures as contained in each of the three energy saving packages of the DGBA with the strategies of the EBOB simulation model is illustrated in figure 4.

In addition to the three DGBA energy saving packages, two additional packages were identified. This was deemed necessary to denote the departure situation where the effects of augmented user-behavior is to be determined without considering any technical measures or training of technical operation and management staff. In the EBOB diagram in figure 4 this package is referred to as Package 0. Package Extra – containing all of the “forgiving technologies” – was identified as the next logical step following the realization of all three of the DGBA energy saving packages. A concise overview of predetermined measures for influencing the behavior of technical staff (strategies 2, 5, 8, 11 and 14) and measures for influencing the behavior of users (strategies 3, 6, 9 and 12) included in simulations with the EBOB model is provided in tables 1.

Input data for the various EBOB-strategies dealing with user-participation can vary between 0% and 100% participation by users. In this study the theoretic approach was based on 100% user-participation. However, in reality user-participation will be less than the assumed 100%. Since the EBOB simulation model is a progressive model, the utopian 100% user-participation is more likely to occur in strategy 15 where user-participation, -involvement and -sophistication is the cumulative effect of all preceding strategies. In order to emphasize the positive effects of augmented user-sophistication on the energy-efficiency of buildings, and their effectiveness in conjunction with optimized measures for technical building management and control, input was consistently done on the premise of 100% user-participation.

A: Measures for influencing the behavior of technical staff (strategies 2, 5, 8, 11 and 14)	• Training in the optimization of building management and control systems; • Training with regards to knowledge of the technical aspects of thermal comfort settings and temperature regulation; • Monitoring of thermal comfort settings in relation to the outside temperature.
B: Measures for influencing the behavior of users (strategies 3, 6, 9 and 12)	• Training en motivation: - Special training and motivation programs for employees with an emphasis on advice energy saving measures. • Heating: - Setting the thermostat 1 degree lower in winter; - Lowering of the temperature regulation after cool nights and warm days. • Cooling: - Increasing the internal temperature setting in summer, but ensuring it never differs more than 8 degrees with the outside temperature; • Lighting: - Turning of lights when not in the workplace, as well as after use of meeting rooms and the in canteens after the lunch period; - Opening sun shades in order to optimize daylight (whereby lights can be turned out); - Ensuring all lights are set out at the end of a working day: • Computers: - Proper application of power management settings for CPU's; - Proper application of power management settings for displays (no screensavers); - Proper application of power management settings for laptops; - Ensuring energy-efficient printers are used. • Lifts: - Use stairs for vertical circulation between 1-3 floors.

Table 1. Concise overview of predetermined measures for influencing the behavior of technical staff (strategies 2, 5, 8, 11 and 14) and measures for influencing the behavior of users (strategies 3, 6, 9 and 12) included in simulations with the EBOB model

RESULTS

Based on the interpretation of the received data a table was compiled showing the combined energy consumption of the selected 19 buildings during the period 1989-1995 and 2005-2007. Results of this initial analysis of the received date resulted in the diagram depicted below (Diagram 1). These results partially confirmed the assumption of Hypothesis 1 that energy consumption is continuously increasing. Whether or not the steady increase during the observed period was due to the increase in the application of information and communication technology (ICT) was not determined. However, based on earlier research by the Central Bureau of Statistics (CBS) in the Netherlands (Meurink *et al.*, 1998), and research by the CfPB into the relation between ICT, management and the workplace environment (Achterberg, 2006) and the integrated workplace (Martens and Pullen, 2007) this relationship between increased energy consumption and an increase in ICT is assumed.

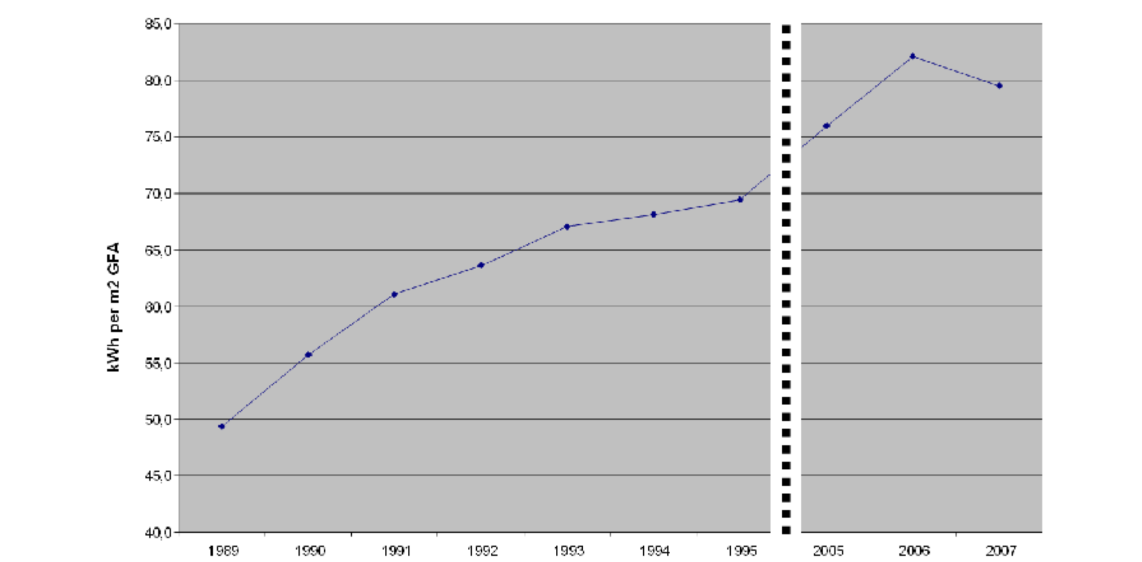

Diagram 1. Results of the analyses of measured energy consumption for the sample group for the period 1989-1995 and 2005 -2007. The broken line indicate the period for which no data was available.

In total the evaluation of the 19 buildings accounted for approximately 169,871 m^2 gross floor area (GFA) with an average GFA of 8940.6 m^2. In Diagram 2 an overview of the various building areas is provided, as well as the deviance from the average GFA as indicated by the horizontal broken line.

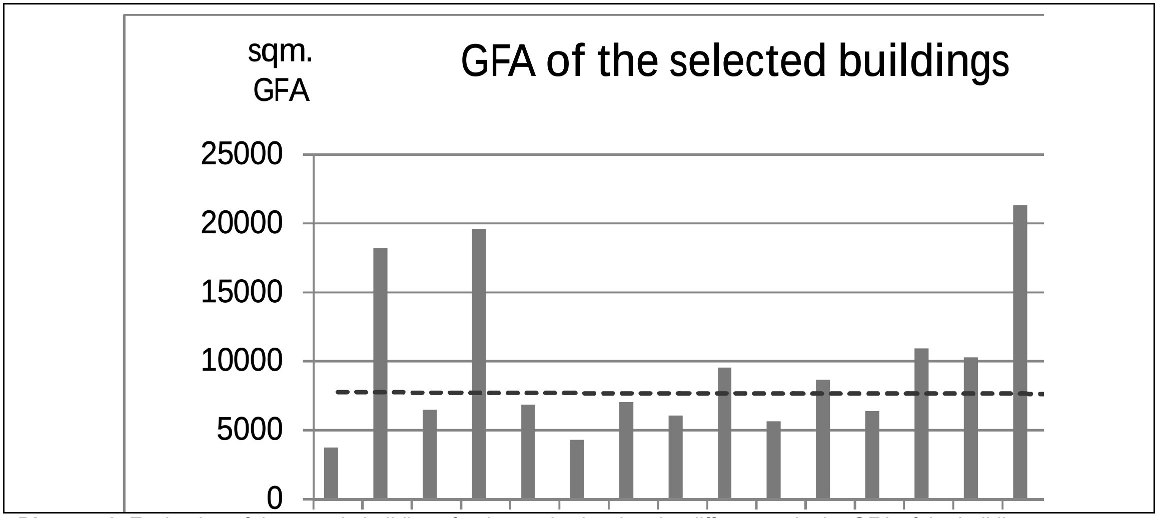

Diagram 2. Evaluation of the sample buildings for the study showing the differences in the GFA of the buildings.

Results pertaining to the effect of user-behavior and – sophistication on the energy efficiency of buildings stem primarily from the application of the EBOB simulation model. To comprehend the extend of these effects, a discussion in comparison with outcomes of simulations with the PARAP LCC model in terms of the application of technical measures for building management and control systems is deemed necessary. Based on this multi-method approach it was possible to determine the effects of firstly, the proposed technical measures (as contained in the three energy saving packages) and anticipated scenario developments and secondly, the comparative effects of augmented user-sophistication through influence on user-behavior based on predefined measures included in the EBOB strategies 3, 6, 9 and 12 . Results presented here will be discussed at the hand of the diagrams and tables depicting the theoretical effects of the proposed measures on overall energy consumption. Given simultaneous display of the effects of the various strategies and anticipated scenario developments in the following diagram, a short explanation of how the diagram and tables are to be interpreted is deemed necessary.

In each of the diagrams information of the Y-axis present the theoretical reduction on energy consumption in kWh per m^2 gross floor area (GFA). Information on the X-axis present the various EBOB strategies as were discussed earlier in this paper (see figs. 3 and 4). as was indicated, strategy combinations 4-5, 7-8 and 10-11 represent the 3 energy saving packages formulated by the DGBA. Since the four anticipated scenario developments form part of the overall question, all strategies pertaining to the effects of technical measures – strategies 1-2, 4-5, 7-8, 10-11 and 13-14 – were simulated four times. This simulation process using the adapted EBOB model was undertaken in order to adequately quantify the effects of applying each of the scenarios on the abovementioned strategies focusing exclusively on technical measures for building management and control. The evaluation and quantification of the EBOB strategies focusing on augmenting user-sophistication through influence on user-behavior were undertaken through application of a similar process using the EBOB simulation model. In diagram 3 the effects of the energy saving packages and the anticipated scenario developments as proposed by the DGBA, as well as the effects of influencing user-behavior are depicted.

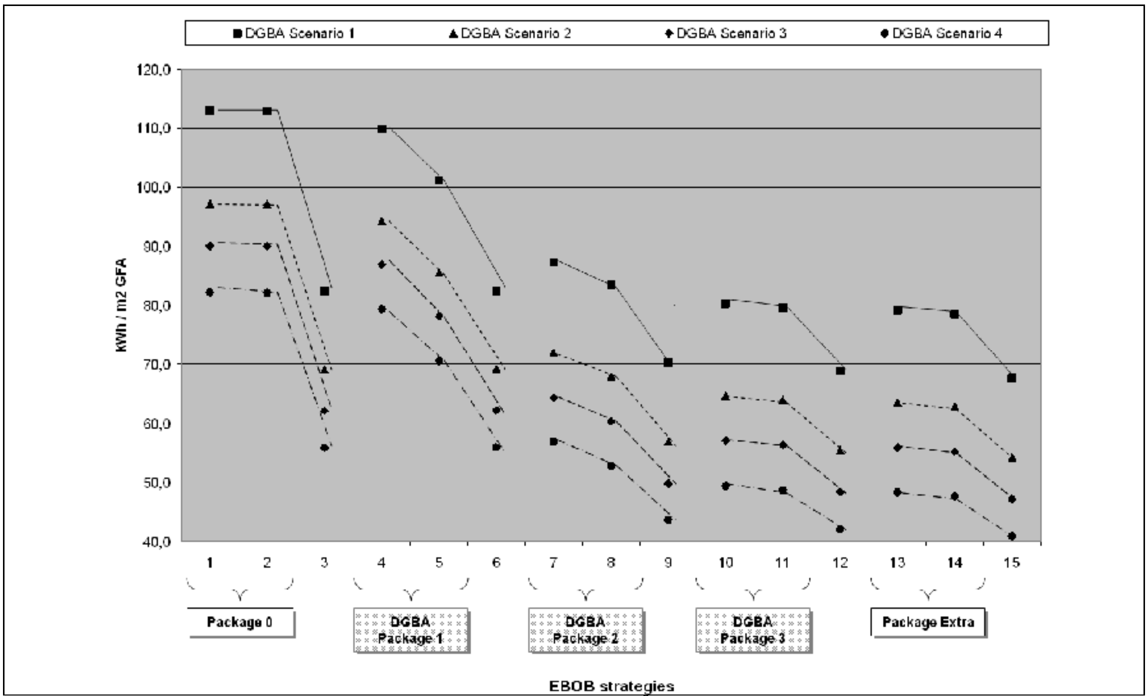

Diagram 3. Summary of the average energy consumption in kWh/m^2 GFA for all buildings on the basis of the 15 EBOB strategies.

Effects of Package 0

Package 0 represents a departure situation with no improvements or optimization of the technical building management and control systems. This situation is indicated by strategies 1 and 2. Since no technical measures are being considered, the effects of these two strategies are the same. However, effects of strategy 3 – influence on user-behavior – indicate that a substantial improvement is possible in terms of reduced energy consumption from 113 kWh/m^2 GFA (strategy 1 and 2) to 82.5 kWh/m^2 GFA. This amounts to a saving of 27% for scenario 1 when compared to the departure situation. Possible gains for the other three scenarios are illustrated in Table 2. In this respect it is important to bear in mind that the simulation was done on the basis of 100% user participation. These differences are also reflected by the effects of scenarios 2, 3 and 4 as applied to each of the strategies in this package (see Table 2).

	Scenario 1 Departure situation	**Scenario 2** New ways of working	**Scenario 3** Server-based computing	**Rgd Scenario 4** Scenario 2 + 3
Package 0: Influence on user-behavior (only):	27%	39%	45%	51%
DGBA Package 1 (EBOB strategies 4+5):	10%	24%	31%	38%
DGBA Package 1 + augmented user-behavior (EBOB strategy 6):	27%	39%	45%	51%
DGBA Package 2 (EBOB strategies 7+8):	26%	40%	47%	53%
DGBA Package 2 + augmented user-behavior (EBOB strategy 9):	38%	50%	56%	61%
DGBA Package 3 (EBOB strategies 10+11):	29%	43%	50%	57%
DGBA Package 3 + augmented user-behavior (EBOB strategy 12):	39%	51%	57%	63%

Table 2. Summary of the effects of augmented user-sophistication through user-behavior.

Effects of Packages 1 to 3

The effects of the three energy saving packages defined by the DGBA indicated similar patterns in terms of the potential reduction in energy consumption as was observed in Package 0. This was found true across all four anticipated scenarios. Strategy 4 represents the implementation of the energy saving measures contained in the Minimal Package (Package 1) of the DGBA. These measures are of an entirely technical nature. Together with measures for training technical staff in the optimal operation of the technical building management and control systems as per Strategy 5, a possible 10% reduction in energy consumption can be realized for DGBA Package 1 in scenario 1. By also including the augmentation of user-sophistication through influence on user-behavior and additional 17% reduction in energy consumption is theoretically possible. Possible gains for the DGBA Packages 1, 2 and 3 across all scenarios are reflected in Table 2.

In each of the Packages and across all scenarios indicated in diagram 3 it was found that augmented user-sophistication through influence on user-behavior consistently contributed to substantial improvements in the energy-efficiency of office buildings. Noticeable is the combined effect of improved technical building management and control systems with augmented user-sophistication. The cumulative impact of this combined approach to reducing the energy consumption of office buildings can be seen in the reduced difference between the purely technical strategies (strategies 4, 7 and 10) and strategies for improving the knowledge of technical management and control staff (strategies 5, 8 and 9) in DGBA Packages 1, 2 and 3. As such, the outcomes of the simulation exercises proved Hypotheses 2, 3 and 4 to be true.

Effects of Package 4

“Forgiving technologies” are seen as technologies that assist users in improving their energy consumption behavior, and to assist in making users more aware of the effects of their actions on energy consumption on a continuous basis. The implementation of the different technological innovations included in this category demands optimum user-sophistication for ensuring that the highest level of energy reduction can be achieved. However, results from the simulation exercises for Package 4 indicated the effects of both forgiving technologies as individual measures and forgiving technologies with influenced user-behavior (strategy 15) to be only substantially lower than the effects of the strategies in Package 3 with the inclusion of Strategy 12 for influencing user-behavior. As such, the outcomes of simulations quantifying the effects of forgiving technologies did not support the hypotheses (Hypothesis 5) that the implementation and use of innovative technologies to facilitate user-sophistication will result in further substantial reductions in the energy consumption of office buildings.

Cost implications of the EBOB strategies

In order to quantify the cost implications of the 15 EBOB strategies relative to one another, all simulations and calculations were done on the basis of a reference building using the PARAP LCC model. In diagram 4 the outcomes of this exercise are presented as the additional cost implications associated with realizing the 15 EBOB strategies in a new building. The additional costs for each of the strategies indicated the expected financial implications of realizing the combinations of technical measures and measures for influencing user-behavior.

In this discussion of the cost implications of the various EBOB strategies two highly relevant points of importance must be emphasized. Firstly, the costs indicated in diagram 4 are direct costs which can be calculated using a lifecycle costing model. These costs do not include organizational costs associated with implementing new workplace strategies, organizational cultures or other costs associated with changes required within the organization to achieve the envisioned reduced energy consumption targets. In this regard it is expected that the higher levels of change will require more effort to create acceptance within the organization, and that this will result in higher cost implications for realizing specific strategies.

The second aspect refers to the cost-effectiveness ratio of the implementation of strategies focusing on forgiving technologies. Here we specifically refer to Package 4 in conjunction with strategy 15 for influencing user-behavior. A comparative analysis of the expected reduction in energy consumption between strategies 13-15 with that of the preceding level of strategies (DGBA Package 3 + strategy 12) indicates only a minimal improvement in energy saving to be achieved. When considered on this basis alone, there seem to be very little reason for not opting for the most innovative and advanced technologies to assist users in realizing energy-efficient office buildings. However, when comparing the additional cost per m^2 / GFA for realizing strategies 13-15 with the anticipated additional costs of the preceding level of strategies (DGBA Package 3 + strategy 12) a completely different picture emerges. Costs associated with the implementation of forgiving technologies were found to be more than double that of DGBA Package 3 with strategy 12 for influencing user-behavior. When considering that this increase in cost is to be associated with very little gain in terms of the energy-efficiency of the building, the impetus for adopting forgiving technologies rapidly diminishes. The apparent minimal increase in effectiveness of the strategies between DGBA Package 3 and Package 4 must be seen in terms of the cumulative effect of the various measures contained in the preceding strategies 1-12 at the moment that Package 4 is considered.

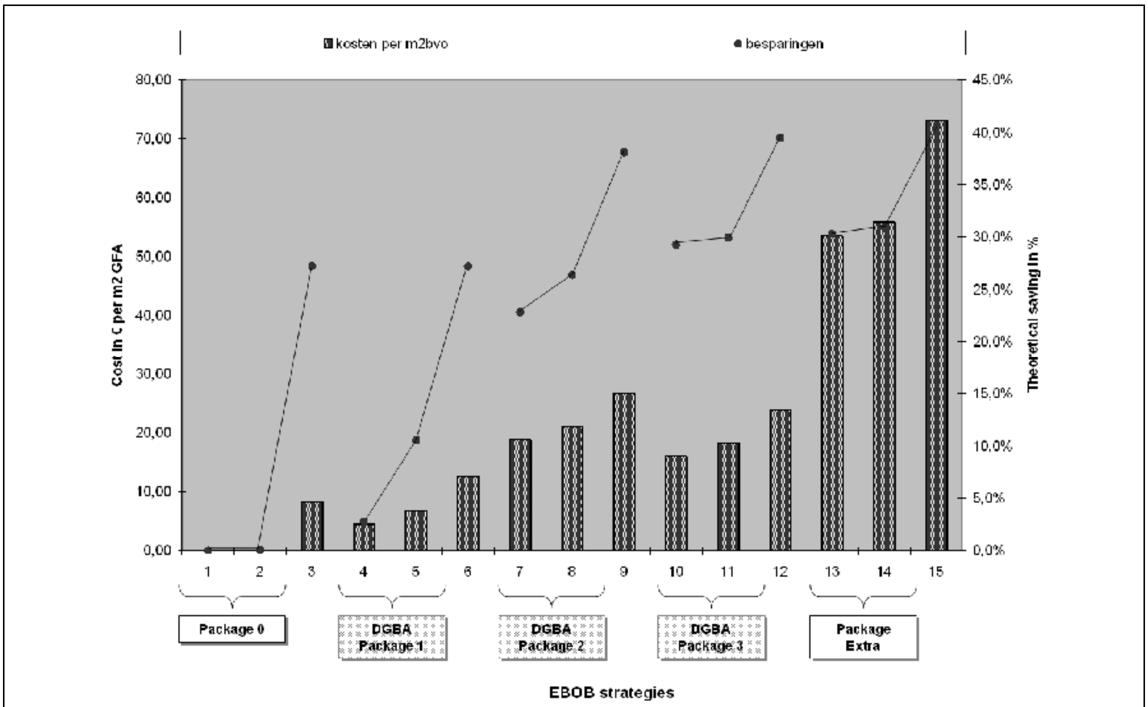

Diagram 4. Summary of the additional cost implications of the various EBOB strategies.

In conclusion of this discussion on the results of the case study the various hypotheses can be reflected on as follows:

Hypothesis	Reflection
Hypothesis 1: The demand for energy in office buildings are continuously rising due to the increase in the application of information and communication technologies (ICT).	This hypothesis was proved true. A continuous increase in energy consumption in the buildings in the sample group was observed for the period 1989-1995 and 1995-2005. The relation with increase in ICT demand was not researched, but assumed on the basis of earlier research.
Hypothesis 2: The proposed technical measures for optimizing building management and control systems as contained in the energy saving packages of the DGBA have a positive effect on reducing energy consumption in office buildings.	This hypothesis was proved true. Outcomes of the simulations for the three energy saving packages of the DGBA indicated in a quantified manner the extent to which the proposed measures have a positive effect on reducing energy consumption in office buildings
Hypothesis 3: The effects of the various energy saving packages are cumulative – meaning that the effects of measures in subsequent energy packages are highly dependent on the extent to which the technical measures in the previous energy package have been realized.	This hypothesis was proved true. Outcomes in quantified terms as indicated in Table 1 illustrated how the effects of the various energy saving packages increase from Package 1 to Package 3.
Hypothesis 4: The effects of augmented user-sophistication are complimentary to the effects to be obtained from implantation of the technical measures and scenario developments;	This hypothesis was proved true. The outcomes of the study as presented in Table 1 consistently found strategies on influence on user-behavior to contribute in a positive manner to the effects of the Packages dealing primarily with technical measures.
Hypothesis 5: The implementation and use of innovative technologies to facilitate user-sophistication will result in further substantial reductions in the energy consumption of office buildings.	This hypothesis was found not true. As was illustrated in diagram 4, when considering the negligible improvements in effectiveness on the basis of energy reduction, the dramatic increase in costs of implementing forgiving technologies is not justified.

Table 3. Summary of the outcomes of the study in terms of the hypotheses.

Conclusion

Conclusions of this study can be drawn on various levels with similar differences in terms of the application and research value thereof.

At first conclusions must be drawn with regards to the methodology that was applied in this case study. The use of a multi-method approach to evaluate the effects of various energy saving packages in combination with the effects of user-sophistication was found to be a successful synergy between two prominent models in the research instrument repertoire of the CfPB. After years of development, the PARAP LCC model was made available at the beginning of 2008. Subsequently the model has been used in various research projects to assist with decision-making in the early stages of the design and construction process. Outcomes of the study again confirm the effectiveness of this instrument in quantifying anticipated changes on the basis of simulation, and the value of these outcomes in assisting strategic decision-making. In combination with the application of the EBOB simulation model this multi-method approach enables evidence-based reasoning and the ability to provide insight in complex management questions pertaining to the implementation of measures to increase the energy-efficiency of buildings. In addition to the mathematical substantiation of the research question, the applied research methodology provides a consistent research approach which brings the philosophical ideals of the CfPB regarding the relationship between people, work and workplace environments in line with evidence-based research methods.

Conclusions can also be drawn with regards to the representativeness of the sample group and the outcomes of this study for the entire property portfolio of the DGBA. Although this aspect was not specifically research in this case study, the fact that all buildings considered in the current case study are currently occupied by the Dutch Tax and Customs Administration, implies that outcomes of the study can be used for strategic decision-making and discussions on implementation within the organizational environment of the Dutch Tax and Customs Administration. Given the positive outcomes of this case study on implementation of technical measures for building management and control systems and measures for augmenting user-sophistication in the 19 buildings occupied by the Dutch Tax and Customs Administration, it is recommended that similar research be undertaken for other functional entities. In this manner it will be possible to develop scientifically substantiated databases on all building types and user groups under the concern of the DGBA.

Thirdly, conclusions can also be drawn in terms of the calculated energy reduction to be achieved through the implementation of the various measures as defined in the three DGBA energy saving packages and the four anticipated scenario developments. Given the outcomes of this case study, it was possible to provide insight in the level of effectiveness to be expected from the various energy saving packages and anticipated scenario developments proposed by the DGBA. In addition to this, the study also emphasizes the need for assuring that advanced energy saving measures such as those included in DGBA Packages 2 and 3 are optimally grouped, and introduced at justifiable moments in the lifecycle of buildings.

Finally, conclusions can also be drawn in terms of the effectiveness of augmented user-sophistication through influence on user-behavior. Outcomes of the simulations for the strategies focusing exclusively on influencing user-behavior (strategies 3, 6, 9, 12 and 15) consistently indicated substantial savings to be achieved in terms of reducing energy consumption though augmented user-sophistication. However, augmenting user-sophistication in energy consumption on the basis of influence on their behavior requires that specific training programs and suggestions for influencing user-behavior be developed, implemented and properly managed. Training programs prior to the commencement of the DGBA Packages 1, 2 and 3 at the level of strategy 3 (Package 0) have the ability (and simultaneous important responsibility) of laying the foundation for acceptance by users of the subsequent implementation of technical measures for building management and control systems and measures for augmenting user-sophistication.

As was earlier mentioned, input data for the various EBOB-strategies dealing with user-participation can vary between 0% and 100% participation by users. In this study the theoretic approach is based on 100% user-participation, but in reality user-participation will be less than the assumed 100%. Conclusions of the simulation exercises therefore need to be interpreted with the acknowledgement of this important matter.

Recommendations

Outcomes of this study also necessitate the acknowledgements of a number of additional aspects which are deemed relevant for not only continued research in this field, but also for consideration as part of the agenda for the future of FM research in general. These can be discussed under two separate headings:

Aspects pertaining to the building / physical environment:

- As was earlier discussed, the need for a structured research approach to include all buildings in the property portfolio of the DGBA should be acknowledged;
- Research into the appropriate moments at which the various energy saving packages can be introduced. This is of specific relevance for DGBA Packages 2 and 3;
- It should also be acknowledged that within the overall property portfolio there are a number of unique buildings that cannot be subjected to a simplification or generalization in terms of GFA alone. These buildings must be identified and researched on a individual basis;
- Renovation of buildings provide the ideal moment for introduction of the advanced energy saving packages. As such, a structured renovation strategy is required;
- New developments in the debate on energy-efficiency in buildings such as the concept of the building as power plant (BAPP) should also be acknowledged.

Aspects pertaining to augmentation of user-sophistication through influence on user behavior:

- Development of focused training programs for technical building management and control staff;
- Development of focused training programs for the augmentation of user-sophistication through influence on user-behavior.

The manner in which the conclusions of this study are generalized should be regarded with care. The effects of energy saving packages, anticipated scenario developments and augmented user sophistication through influence on user-behavior are highly case-specific. Generalization of the simulated effects for a specific combination of building characteristics and user-sophistication may not be applicable to different environments and user-group. The reciprocity between optimized technical building management and control systems and user-behavior has been undeniably proved by this study. The quantified evidence resulting from this study supports the need for considering the role of user-involvement in reducing energy consumption in buildings, while simultaneously emphasizing the need for further research in this field.

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