Band 84

Markus Surmann

Strategic Implications for Commercial Real Estate under Consideration of Energy Efficiency

IRE|BS
International Real Estate Business School
Universität Regensburg

Schriften
zu Immobilienökonomie
und Immobilienrecht

Markus Surmann

Strategic Implications for Commercial Real Estate under Consideration of Energy Efficiency

Die Deutsche Bibliothek – CIP Einheitsaufnahme
Markus Surmann
Strategic Implications for Commercial Real Estate under Consideration of Energy Efficiency
Regensburg: Universitätsbibliothek Regensburg 2017
(Schriften zu Immobilienökonomie und Immobilienrecht; Bd. 84)
Zugl.: Regensburg, Univ. Regensburg, Diss., 2017
ISBN 978-3-88246-378-1

ISBN 978-3-88246-378-1

Verlag: Universitätsbibliothek Regensburg, Regensburg 2017
Zugleich: Dissertation zur Erlangung des Grades eines Doktors der Wirtschaftswissenschaften, eingereicht an der Fakultät für Wirtschaftswissenschaften der Universität Regensburg
Tag der mündlichen Prüfung: 31.Mai 2017
Berichterstatter: Prof. Dr. Sven Bienert
Prof. Dr. Wolfgang Schäfers

Table of Content

1 Introduction

1.1 General Motivation

1.1.1 Commercial real estate and energy efficiency

Recalling some milestones in the history of "Sustainable Development" such as the Brundtland Report from 1987[1], the United Nations Conference on Environment and Development[2] in Rio de Janeiro in 1992 or the Kyoto Protocol[3] from 1997, the issue of sustainability was introduced to the commercial building sector on a global scale primarily years later. This is remarkable, because the building sector accounts for high volumes of carbon emissions on the one hand, and it is affected from the negative impact of climate change on the other hand.

Energy efficiency was identified as a major field of action in the *European Union* (*EU*), when the *Energy Performance of Buildings Directive*[4] (*EPBD*) was implemented in 2002 with introduction of obligatory *Energy Performance Certificate* (*EPC*) ratings by the year 2008. Among other research, the study "Doing well by doing good? Green office buildings" by Eichholtz et al. (2010) provided the first systematic analysis of the impact of energy efficiency certification upon economic outcomes as measured in the market for commercial real estate.

When energy efficiency was applied merely to reduce related energy costs in the past with a focus on engineering in the context of technological progress, its importance was highlighted with the introduction of energy efficiency certificates and "green rating" systems in the real estate industry. Following the global climate protection agenda, commercial real estate was identified as a major driver for increasing energy efficiency and reduction of carbon emissions from the building sector.

The energy consumption of the building sector was found to account for 40% of the total final energy use and 20% to 30% of global *greenhouse gas* (*GHG*) emissions[5]. In regard to the most recent global climate targets from the Paris Agreement[6], research work on the energy efficiency of the commercial building sector is of increasing interest. This becomes even clearer when considering that for an industrialized country, such as Germany, the non-residential building sector accounts for only 15% of the total existing building stock, but for more than 30% of total energy consumption and carbon emissions (Dena, 2015).

In the absence of a sufficient understanding about the relationship between energy efficiency and commercial real estate, this dissertation analyses the potential influence in

---

[1] United Nations World Commission on Environment and Development, 1987.

[2] United Nations Rio Declaration on Environment and Development, 1992.

[3] United Nations Framework Convention on Climate Change, 1998.

[4] European Union Directive on Energy Performance of Buildings, 2002.

[5] World Economic Forum, 2016 (20% share); United Nations Environmental Program, 2009 (30% share).

[6] The *21st Conference of the Parties* (*COP21*) to the United Nations Framework Convention on Climate Change, held in Paris 2015, agreed upon new climate change and sustainability targets by 2030 with stricter reduction of global annual emissions of greenhouse gases, thus implicating increasing pressure on the building sector. United Nations, 2015.

two directions. To conclude some strategic implications for commercial real estate under consideration of energy efficiency, the influence of energy efficiency on commercial real estate is analyzed in a first step. In the second step, the research investigates the factors of influence on energy efficiency of office buildings and corporate real estate assets.

1.1.2 Influence of energy efficiency on commercial real estate

The influence of energy efficiency on commercial real estate is analyzed by means of an effect on the Market Value, assumed as a surrogate for prices from the transaction market. When asking "*How does energy efficiency influence the Market Value of office buildings in Germany and does this effect increase over time*?" the first paper of this dissertation proves for a potential effect of energy efficiency and actual consumption on the Market Value.

In the course of increasing energy efficiency requirements[7] and stricter building codes for new construction, the study hypothesizes a negative effect on the Market Value of office buildings, attributed with lower energy efficiency. As more and more "green" and energy-efficient buildings become market standard, the negative effect on the existing building stock is expected to increase over time with additional economic obsolescence and depreciation, to be anticipated in real estate valuation with declining Market Values.

Based on the dataset of the *Investment Property Database* (*IPD*, now part of *MSCI*) in Germany, the timeframe from 2009 to 2011 is analyzed with declining Market Values in the marketplace after the financial crisis of 2008. The coherently declining Market Values found on average in the tested dataset of *IPD*, raise the question whether the decline is attributed to lower energy efficiency. In this respect, the timeframe from 2009 to 2011 is analyzed when the influence of sustainability issues and energy efficiency were articulated in the market and introduced into real estate valuation in Germany for the first time.

While introducing the valuation-based input parameters of the dataset and applying a novel econometric approach with regard to two small sub-samples for energy efficiency (assessment) and measured actual consumption, the analysis finds no statistically significant relationship between energy efficiency or actual consumption and the Market Value, let alone an increase in this effect over time. The negative effect of building age on Market Values was found almost constant – on the contrary to the expectation of an increase with additional economic obsolescence and depreciation for the less efficient existing building stock. Besides the two small sub-samples for energy efficiency and actual consumption and other deficiencies of the dataset, the study concludes that in the German valuation practice the influence of energy efficiency has not been priced into Market Values of office buildings in the observed period. Furthermore, *EPC*s may not be the appropriate measure to capture the economic influence of energy efficiency or consumption on Market Values. In real estate valuation, also a lack of market parameters might rule out an increasing effect of energy efficiency or consumption – even if observable in the marketplace for the relevant time frame.

---

[7] The *EU Energy Performance of Buildings Directive* (*EPBD*) and, in particular, the *German Energy Saving Ordinance* (*EnEV*).

As the study results suggest no significant influence of energy efficiency or consumption on the Market Value of office buildings, the question follows if energy efficiency is priced in commercial real estate in alternative ways.

1.1.3 Factors of influence on energy efficiency of office buildings

For the investigation of alternative ways in the pricing of energy efficiency for commercial real estate, the factors of influence on energy efficiency and differences in the energy consumption on asset level are of major research interest. The building age and refurbishment or revitalization cycles, as well as the behavior of occupants might be relevant for pricing-in energy efficiency.

To identify the factors of influence on energy efficiency, the second paper of this dissertation "*Energy efficiency: behavioural effects of occupants and the role of refurbishment for European office buildings*" analyses the relationship between metered energy consumption, physical building characteristics and occupant attributes. The latter determine the actual energy consumption in interaction with the physical building, thereby implying the effect of a behavioral response to the physical building characteristics.

As noted above, it stands to reason that the physical building characteristics became subject to more stringent energy efficiency regulation and stricter building codes for new construction and revitalization or major refurbishment. But with regard to the implemented regulation, it is in question if these measures are followed also by higher energy efficiency and – in fact – reduced energy consumption in more recent office buildings, confronted with the behavior of occupants and in comparison to their assumed less efficient older peers.

The role of refurbishment for office buildings is examined in a way whether it contributes to a reduction of the energy consumption when the overall quality and energy efficiency of office buildings is improved. Major refurbishment is expected to consider higher energy efficiency standards, thus allowing for higher energy conservation. Notwithstanding, refurbishment is executed to improve the building quality with additional services and the installed technical equipment. For this reason, refurbished buildings with additional services and technical equipment in use might be attributed to higher actual energy consumption, compared to office buildings without refurbishment. In regard to the extent of refurbishment, the analyzed dataset of the *Green Rating Alliance* (*GRA*) possesses detailed information to differentiate among the intensity of refurbishment measures.

Observations attributed with refurbishment, in particular when the overall quality of office buildings is improved, seem to have a significantly higher energy consumption than buildings without refurbishment measures. Even more surprising, more recently constructed buildings are not associated with lower energy consumption, compared to older office buildings. The results prove for the existence of the so-called principle of additionality inherent in buildings of lower age with additional services and technical equipment applied. But in addition, this points also to a possible lack in the regulatory framework to reduce actual energy consumption. However, when particularly investigating the interaction effect between building age and refurbishment, the observations of most recent refurbishment turn out to be of lowest additional energy consumption, in linear relationship to refurbishment measures carried out several years ago.

For the physical building characteristics, the highest energy consumption is achieved in very large office buildings of the tested dataset. This suggests that additional technical equipment and higher energy loads for heating and cooling are required to bridge large vertical distances in office towers – rejecting the assumption of economies of scale for the used dataset. With more than 200 observations in the dataset located in France, the electric production of heating is estimated with significant lower consumption of up to more than 20%, in reference to other heating production types.

In regard to the behavioral effects of occupants, potentially undermining or offsetting beneficial energy savings from increased energy efficiency of the physical building, the results estimate that multi-tenant office buildings are associated with lower energy consumption compared to buildings occupied by a single tenant, ceteris paribus. Confronted with the assumption that multi-tenant office buildings are exposed to more – and potentially contradicting – decisions of the tenants, how to operate their occupied part of the building, compared to a more centrally operated single-tenant building, this result is counterintuitive to the initial assumption. In contrast, the obtained results for the energy consumption per square meter office space is found intuitive to the expectation of an increase in energy consumed with a higher occupancy rate, e.g. more office space allocated per occupant is attributed with lower energy consumption, in particular with increasing vacancy.

In conclusion, more stringent energy efficiency standards in the *EU* are likely to increase the thermal quality of new or refurbished buildings, but these attempts do not seem to emerge with significant influence for energy conservation due to the principle of additionality. Only recent refurbishments turn out to be more dedicated to energy efficiency and *EU*-regulation.

In the absence of an extensive research framework for actual energy consumption of commercial buildings, based on empirical evidence from Europe[8], the paper aims to contribute to a better understanding of energy consumption in office buildings. However, the results need to be considered with precaution against deriving firm conclusions due to the small sample size and some drawbacks in the analyzed dataset.

1.1.4 Factors of influence on energy efficiency of corporate real estate assets

Besides the physical building characteristics and the behavior of occupants, commercial real estate is also subject to other dimensions of influence on the energy efficiency. With regard to corporate real estate assets in the retail and wholesale business, the operational sales performance is a major factor on the energy consumption. Furthermore, certain management decisions are directly affecting the energy consumption, and thus the environmental performance of corporations. In addition to more stringent energy efficiency standards and besides the physical building attributes, the corporate management decisions regarding energy efficiency measures and conservation of energy with the aim of cost savings are potential drivers to reduce carbon emission from corporate real estate

---

[8] Guerra Santin et al., 2009; Kahn et al., 2014.

assets. Presuming a potential carbon pricing in the future[9], energy consumption of real estate is of major interest in the sustainability strategy of corporations, especially in the highly visible business of food wholesale and hypermarket retail.

The third paper of this dissertation "*The energy efficiency of corporate real estate assets: The role of energy management for corporate environmental performance*" investigates the influence of physical building characteristics, operational sales performance and corporate energy management on energy consumption. The research analyzes the role of energy management for achieving energy conservation and contributing to a more efficient corporate environmental performance. A unique multi-national and extensive dataset containing big-box wholesale and hypermarket stores of the *METRO GROUP* is applied to a sophisticated panel regression, to explain the electricity and total energy consumption of the corporate real estate assets. In regard to the available consumption data of the stores, the electricity consumption is analyzed on a monthly and the total energy consumption on an annual basis.

With reference to the proposed reduction target of *METRO GROUP*, to reduce corporate CO_2 emission by 20% until the year 2020 (based on emissions in 2011), the results of the study point to significant reductions realized already by the end of 2014.

Confronted with the physical building characteristics of age and revitalization, the results indicate only an ancillary influence on the electricity and total energy consumption, whereas the technical equipment applied for refrigeration in combination with heating, ventilation and air-conditioning is critical for the consumption. Nonetheless, the stores of lowest building age indicate the highest per square meter consumption, when different technical systems applied need a few years for optimization to realize lower consumption, thus providing a practical implication for the roll-out of further energy reduction measures to *METRO GROUP*.

The results of the analysis suggest a significant utilization of economies of scale to leverage on the reduction of energy consumed and the prevention of CO_2 emissions, for instance when allocating human capital in terms of energy managers to certain counties with sufficient energy-savings potential. Furthermore, the strategy of corporate energy management to focus on "Problem-Stores" identified with significantly higher consumption seems to provide prospects for immediate reduction of energy consumed. Corporate owned vs leased assets show no systematic difference in the energy consumption due to the centralized energy management and the customized building formats as "build to suit", which allow only limited store-to-store variation in energy consumption within the same building format category.

Due to the design of the econometric approach, the relationship between the operational sales business and the electricity consumption in the stores was modelled over the average calendar year. The result underlines the highest electricity consumption over the summer months when refrigeration and cooling loads are at peak level in the stores. In addition, seasonal effects of the sales business, such as the period prior to Christmas,

---

[9] The introduction of a global taxation on carbon emissions was postulated by the World Monetary Fund, the World Bank Group and several heads of national governments over the course of the *COP21* in Paris 2015. Frankfurter Allgemeine Zeitung, 2015; CleanEnergy Project, 2016.

were identified with higher electricity consumption in proportion to higher sales productivity.

The operational sales performance proves to be *the* key driver for energy consumption in the stores. In a linear model, an increase in the turnover per square meter of 1% is associated with higher electricity consumption of 3.2%, when electricity and total energy consumption are found to increase from a certain level of turnover with an exponential function. Considering the specific cost structures of the single stores, derived via *EBIT* figures in the data, the significant effect explains that a slight rise in the cost structure is coherent with higher electricity and total energy consumption by trend. In conclusion, a key challenge for corporate (energy) management is to further realize energy savings toward a more efficient corporate environmental performance, while increasing the sales productivity with high volumes of customers.

1.2 Research Questions

The main research question of this dissertation can be summarized as follows:

What is the impact of energy efficiency on commercial real estate and which strategic implications are resulting from differences in the energy efficiency of commercial buildings?

In regard to the three papers of this dissertation, the following section provides an overview of the research questions for the analyses in the single papers.

How does energy efficiency influence the Market Value of office buildings in Germany and does this effect increase over time?

- Are less energy-efficient office buildings exposed to additional economic obsolescence and depreciation, anticipated in the German real estate valuation practice with declining Market Values?
- Is this negative influence on the Market Value of the existing building stock increasing over time parallel to accelerated energy efficiency regulation for new construction?
- When sustainability and energy efficiency was articulated as relevant for real estate valuation and a significant decline in Market Values for the tested portfolio is observed in the relevant timeframe, has this decline been attributed to lower energy efficiency or higher energy consumption?
- Are *EPC*s an appropriate measure to indicate the energy efficiency for the pricing in real estate valuation; do they indicate differences between energy efficiency (assessment) and actual metered consumption?
- Is the econometric prediction obtained from a large dataset capable to leverage on the stability of the target variables, which are only available within two small sub-samples of the large dataset?

Energy efficiency: behavioural effects of occupants and the role of refurbishment for European office buildings

- Is the regulatory framework in the *EU* with increased energy efficiency requirements for new construction and major refurbishment affecting commercial real estate in such a way that energy consumption is in fact reduced in more recent office buildings or those with recent refurbishment?

- Are refurbishment measures an appropriate approach to increase the energy efficiency with lower actual consumption, or – on the contrary – is refurbishment following the principle of additionality with higher actual consumption once refurbishment is effected in office buildings?
- How is the influence of building age on energy consumption and are differences in consumption "priced" in relation to the building age?
- How do building age and refurbishment interact in terms of energy consumption?
- Do large office buildings consume less energy per square meter when utilizing economies of scale in heating, cooling and ventilation?
- How does occupant behavior potentially influence the energy consumption in office buildings and is the so-called "rebound effect" inherent in the tested European dataset?
- Are single- or multi-tenant office buildings consuming lower energy and why?

The energy efficiency of corporate real estate assets: The role of energy management for corporate environmental performance

- Do more recent constructed stores show significantly lower energy consumption than their less recently constructed peers and is revitalization of wholesale and hypermarkets offering substantial energy-savings potential?
- Is the intensity of energy consumption within the same wholesale and hypermarket format categories comparatively similar, due to the customized corporate building formats as "build to suit", and do large observations show lower per square meter consumption (economies of scale)?
- Is a variation of energy consumption in the stores over the calendar year correlated to the influence of the outdoor weather conditions, but also to the operational sales business (with seasonal peaks in consumption)?
- Is the ownership status of the assets (owned vs leased), with reference to centralized energy management, proving for differences in energy consumption?
- How much energy-savings potential can be realized when certain measures are introduced to stores with a significantly higher energy consumption, to leverage on the total portfolio energy efficiency?
- How much energy-savings potential do countries possess, in which an own energy manager (human capital) is allocated to economize on energy consumption when utilizing economies of scale and increasing store profitability through energy cost savings?
- To what extent will energy cost savings be offset if presuming a pricing for the internalization of *GHG* externalities to be in place by the year 2020?
- What is the ratio between the monetized energy costs from store operations in relation to the annualized profit margin from the operational sales business?
- How strong are energy consumption and sales productivity or store performance (*EBIT*) correlated and is an increase in the sales productivity or performance always followed by higher energy consumption in the stores?
- What are the practical implications for *METRO GROUP* toward a more efficient corporate environmental performance?

1.3 Course of Analysis

This section documents the status of the three papers contained in this dissertation.

How does energy efficiency influence the Market Value of office buildings in Germany and does this effect increase over time?

- Authors: Markus Surmann, Wolfgang Brunauer, Sven Bienert
- Submission to: *Journal of European Real Estate Research* (*JERER*)
- First Submission: 26 April 2015
- Revised Submission: 25 August 2015, 11 September 2015
- Accepted for publication: 13 September 2015 by Stanley McGreal (Editor)
- Paper presented at: 21st European Real Estate Society Annual Conference, 27 June 2014, Bucharest, Romania

Energy efficiency: behavioural effects of occupants and the role of refurbishment for European office buildings

- Authors: Markus Surmann, Jens Hirsch
- Submission to: *Pacific Rim Property Research Journal* (*PRPRJ*)
- First Submission: 21 September 2015
- Revised Submission: 9 December 2015, 3 March 2016
- Accepted for publication: 17 March 2016 by David Parker (Editor)
- Paper presented at: 21st Pacific Rim Real Estate Society Annual Conference, 21 January 2015, Kuala Lumpur, Malaysia

The energy efficiency of corporate real estate assets: The role of energy management for corporate environmental performance

- Authors: Markus Surmann, Wolfgang Brunauer, Sven Bienert
- Submission to: *Journal of Corporate Real Estate* (*JCRE*)
- First Submission: 6 December 2015
- Revised Submission: 29 January 2016
- Accepted for publication: 4 February 2016 by Howard Cooke (Guest-Editor)
- Paper presented at: 23rd European Real Estate Society Annual Conference, 10 June 2016, Regensburg, Germany

1.4 References

CleanEnergy Project (2016), *Nach Paris: IWF fordert weltweite CO_2-Steuer*, Website CleanEnergy Project, available at: http://www.cleanenergy-project.de/politik/7053-nach-paris-iwf-fordert-weltweite-co2-steuer (accessed 31 October 2016).

Eichholtz, P., Kok, N. and Quigley J.M. (2010), "Doing well by doing good? Green office buildings." *American Economic Review*, Vol. 100 No. 5, pp. 2492-2509.

European Union Directive on Energy Performance of Buildings (2002), Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on Energy Performance of Buildings, available at: http://eur-lex.europa.eu/legal-content/DE/
TXT/PDF/?uri=CELEX:32002L0091&from=EN (accessed 31 October 2016).

Frankfurter Allgemeine Zeitung (2015), "Merkel will einen Preis für das Kohlendioxid", 1 December 2015, available at: http://www.faz.net/aktuell/wirtschaft/klimagipfel/merkel-lobt-in-paris-den-emissionshandel-13942878.html (accessed 31 October 2016).

Guerra Santin, O., Itard, L. and Visscher, H. (2009), "The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock", *Energy and Buildings*, Vol. 41 No. 11, pp. 1223-1232.

Kahn, M.E., Kok, N. and Quigley, J.M. (2014), "Carbon emissions from the commercial building sector: the role of climate, quality, and incentives", *Journal of Public Economics*, Vol. 113 No. C, pp. 1-12.

United Nations World Commission on Environment and Development (1987), Our Common Future, ("Brundtland Report"), Oxford.

United Nations Conference on Environment and Development (1992), Rio Declaration on Environment and Development, available at: http://www.unep.org/documents.multilingual/default.asp?documentid=78&articleid=1163 (accessed 31 October 2016).

United Nations Framework Convention on Climate Change (1998), Kyoto Protocol on the United Nations Framework Convention on Climate Change, available at: http://unfccc.int/resource/docs/convkp/kpeng.pdf (accessed 31 October 2016).

United Nations Environment Program (2009), UNEP Sustainable Buildings and Climate Initiative, Paris, available at: http://www.unep.org/sbci/pdfs/SBCI-BCCSummary.pdf (accessed 31 October 2016).

United Nations (2015), *Paris Agreement*, Paris.

World Economic Forum (2016), *Environmental Sustainability Principles for the Real Estate Industry*, Geneva.

2 How does energy efficiency influence the Market Value of office buildings in Germany and does this effect increase over time?

Markus Surmann, Wolfgang Brunauer, Sven Bienert

Structured abstract

Purpose: The paper aims to estimate the effect of energy efficiency on the Market Value of office buildings and considers whether this effect increases over time.

Design/methodology/approach: The authors analyze a dataset of office building valuations from 2009 to 2011, provided by the *German Investment Property Database*. The authors use hedonic regression models to determine the effect of energy efficiency and energy consumption on Market Values. Using *generalized additive models* for modelling nonlinear covariate effects, the authors control for further building characteristics and location. Due to the small sample size, the authors introduce an innovative econometric approach that mitigates this problem.

Findings: Mainly due to the small sample size, and in spite of the newly developed econometric methodology, the authors do not find clear evidence of the relationship between energy efficiency and the Market Value. However, the study nonetheless provides interesting insights into the composition of office building Market Values in Germany.

Originality/value: In addition to the empirical results for the German office market, the main contribution of this paper lies in the econometric methodology. Beside the application of cutting-edge statistical techniques, the authors develop a method for handling datasets, for which the variable of interest is rarely observed, leveraging on the total available data. Thus, the methodology offers promising prospects for future research in similar settings.

Keywords: Office buildings, Energy efficiency, Energy consumption, Energy performance certificates, Hedonic pricing, Valuation, Sustainable real estate

Paper type: Research paper

Acknowledgment: The authors are thankful to *Investment Property Datenbank (IDP)*, Germany, for provision of the dataset used in this study.

2.1 Introduction

Increasingly more "Green Buildings" with sustainable building features and superior energy efficiency are entering the commercial property markets. Properties with outstanding "green" features, and their potential influence on increasing rents and values in the marketplace associated with higher economic performance, have been investigated on a global scale in the past.

However, due to increasing energy efficiency requirements for new construction, less efficient buildings are expected to be subject to greater economic depreciation, i.e. declining Market Values. This negative effect on the existing building stock with a lack of energy efficiency is generally assumed to increase over time. The accelerated energy efficiency regulation for new construction will lead to a situation in which energy-efficient buildings are market standard and older properties experience physical deterioration and obsolescence, with an emerging "sustainability impairment".

Therefore, our study empirically measures the difference in Market Values due to energy efficiency and determines whether this difference really increases over time, controlling for all available building characteristics and spatial heterogeneity.

The remainder of this paper is structured as follows: Section 2.2 reviews the background and related research. In Section 2.3, we explain the characteristics of the underlying dataset and discuss the methodological approach. The results are summarized in Section 2.4, before Section 2.5 highlights some major conclusions and implications.

2.2 Background and related research

2.2.1 Background

Since the introduction of *Energy Performance Certificates* (*EPC*)[10] in the European Union and voluntary green building certification labels, the benefits associated with outstanding "green features" and superior energy efficiency on Market Values and rents have been investigated on a global scale (Eichholtz et al., 2010; Pivo and Fisher, 2010; Fuerst and McAllister, 2011a, 2011b; Leopoldsberger et al., 2011; Chegut et al., 2014; Shimizu, 2012; Fuerst et al., 2013; Cajias and Piazolo, 2013). There has been a focus on this "innovation" introduced to the market mainly through new construction or major refurbishment, achieving potentially higher Market Values and rents, experiencing less investment risk with higher occupancy rates and possibly reduced obsolescence. By contrast, the consequences for the existing building stock, experiencing a potentially higher economic depreciation[11] has not attracted similar attention.

The introduction of the "*Energy Saving Ordinance EnEV*" in 2002 and adoption of its further amendments in 2009 and 2014, set the regulatory framework for continuously increasing energy efficiency requirements for new construction in Germany. When *EnEV* 2009 led to an increased energy efficiency of 30%, compared to its first version from 2002, the update of 2014 requires an additional efficiency enhancement compared to the

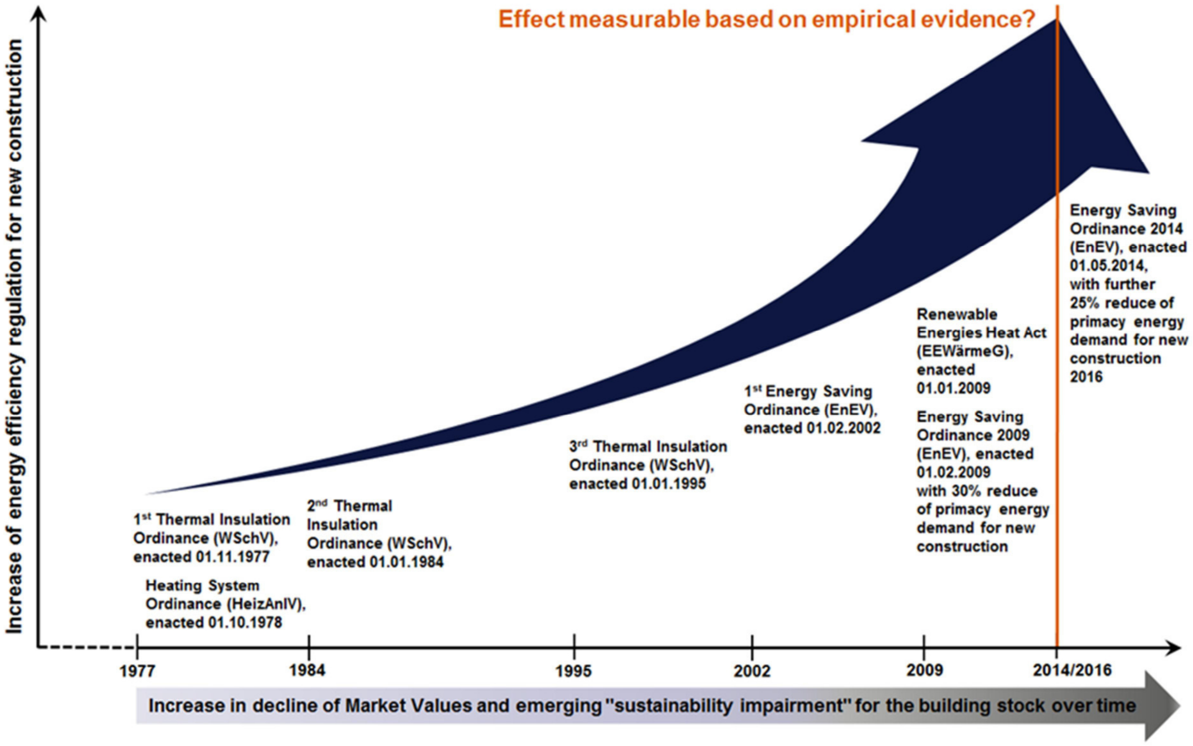
---

[10] Over the course of the *European Energy Performance of Buildings Directive*, the *EPC* ratings were introduced in 2002 and became mandatory by the year 2008.

[11] Depreciation defined as real loss in the existing use value in capital terms (property investment performance).

former standard of 2009, of 25% after 2015. A synopsis of the increasing energy efficiency requirements for new construction through regulation in Germany over the past decades is given in Figure 1.

Figure 1: Escalating energy efficiency requirements for new construction through regulation in Germany



These remarkable advancements are expected to reduce the market potential for the less energy-efficient building stock. In tandem with the competitive advantage of energy-efficient buildings, a decline in Market Values has been described in the context of property valuation practice, quantified in "grey discounts" for the inefficient existing building stock (Bienert et al., 2010; Lorenz and Luetzkendorf, 2011).

Moreover, due to the acceleration of more restrictive requirements for new construction and the enhanced intrinsic energy efficiency from the physical building features, the price differences in the property market are expected to reveal further increasing differentiation potential, in the form of an emerging "sustainability impairment". Therefore, postulated premiums for higher energy efficiency on the Market Value might be observable only as a temporal phenomenon of new buildings, as office property life cycles become shorter, especially in prime city locations. If the downward tendencies accelerate through competitive disadvantages in the transmission mechanism of the marketplace, a higher economic depreciation for the existing building stock with a decline in Market Values is the theoretical result – depending on the age and quality of buildings, as well as on location and the property market cycle.

In property valuation, the decrease of values and rents with an increase in building age is a determinant – anticipating physical deterioration and economic obsolescence over time. For office buildings in London, a lower depreciation rate for older, as approved to new properties, was investigated by Baum (1991), Baum and McElhinney (1997) and recently for the *UK* by Crosby et al. (2015). Different depreciation rates within European office markets have been investigated by Baum and Turner (2004) and Crosby et al. (2011).

In the *German income approach*[12], the building age is usually derived by subtracting the estimated remaining economic lifetime from the expected economic lifetime of use. However, this economic lifetime view does not refer to the technical lifetime of buildings and may need to be adjusted, due to major renovation or building refurbishment. As a response to more and more restrictive requirements for new construction and enhanced intrinsic energy efficiency, physical deterioration and obsolescence of the building stock might be observable, together with higher economic depreciation through an increasing effect of energy efficiency, with a negative impact on Market Values of the existing building stock over time.

In the context of our hypotheses, energy efficiency (assessment) and actual consumption are attributes, for which the effects on the Market Value, as a surrogate for prices, can be estimated and isolated.

2.2.2 Related research

Recent research work has focused on the competitive advantages of green and energy-efficient buildings. Accordingly, it has also provided some evidence of a potential negative impact, as a framework for further investigation of increasing energy efficiency requirements and more and more efficient buildings[13], confronting the existing and less efficient building stock. As the results regarding potential premiums for higher energy efficiency or higher depreciation with a decline in Market Values and rents, discussed below, have been analyzed by means of hedonic regression models using different databases, the results should be interpreted with caution. Statistical analysis may provide results for the covered dataset as a model, but not fully explain the actual (real-world) situation and mechanisms in the marketplace.

Leopoldsberger et al. (2011) found evidence of a discount in net rents of -1% if energy cost increases by approximately 10% in a linear relationship. Applying a semi-parametric regression model to the dataset, they showed that within the range of energy expenses from €0.20 up to €2.00 per square meter and month, there is a "zone of indifference" for tenants. An increase in energy costs does not affect the net rental level within this zone, but exceeding energy costs of more than €2.00 per square meter account for a mean decline in the net rent of -5.8%.

Fuerst and McAllister (2011b) provided empirical evidence regarding the impact of *EPC* ratings on the rental and capital values of commercial property assets, based on observations from the *Investment Property Database* (*IPD*) *UK*. Introducing *EPC*s as a proxy for the intrinsic energy efficiency of commercial buildings in log-linear hedonic regression models, the results yielded – surprisingly – no significant effect on Market Rent or Market Values. The study concludes that *EPC*s are not yet considered in the decision-making processes of prospective tenants or buyers, nor associated with substantial cost

---

[12] For the *German income approach*, see §§ 17-20 of the *German Real Estate Valuation Ordinance* (Immobilienwertermittlungsverordnung – *ImmoWertV*, 2010).

[13] The expanding supply of (certified) green buildings is regularly monitored and published for the German and European markets by the *RICS* (RICS, 2013; RICS, 2015).

savings anticipated in valuation results. Furthermore, the explanatory power of *EPC*s based on intrinsic energy efficiency might be limited, compared to actual energy consumption. Potential cost savings proposed by greater intrinsic energy efficiency are expected to be neglected by users in terms of actual energy consumption, due to behavioral aspects (Kahn et al., 2014). Additionally, it is argued that compared to the residential property sector, commercial property tenants pay less attention to potential energy costs savings, as they use but do not own these properties. Given the lack of evidence of higher rents and values for energy-efficient commercial buildings, on the contrary, the results also provide no evidence of a negative impact on less efficient observations in the investigated portfolio.

Based on a dataset with actual realized rental transactions from *CoStar UK*, a study investigated the potential impact of energy efficiency on the rental value of *UK* office buildings (Fuerst et al., 2013). The results indicate a significant rental premium for energy-efficient office space in a cohort with aggregated most efficient *EPC*s and lowest building age, tested via binary variables. This interaction between *EPC* category and building age reveals a very interesting implication for our supposition of a negative impact for the less efficient (older) building stock. Fuerst et al. (2013) point out that the premium appears to be driven mainly by the youngest cohort of energy-efficient buildings, whereas the estimated coefficients for the binaries of *EPC* rating and building age indicate increasing negative values in most higher building age cohorts. Beside the rental depreciation with increasing building age, the results show that this depreciation affects less energy-efficient office buildings stronger than those of the same age cohort, but with comparably higher *EPC* ratings. Fuerst et al. (2013) conclude that information displayed in *EPC*s in not completely considered in the commercial property market. Furthermore, building age or physical inspection is potentially considered by market participants for rental decisions as a proxy for inferring energy efficiency or, even more so, the actual consumption when running the building.

From the Dutch office property market, evidence of a potentially increasing effect of energy efficiency has been provided by Kok and Jennen (2012). The negative impact of *EPC* ratings reflecting non-energy-efficient office properties was estimated at a discount of -6% on realized rents. However, these results also underlie the intrinsic energy efficiency as assessed for the *EPC* indication – not the actual energy consumption. The study analyzes the development of premiums for more energy-efficient observations and of discounts for a portfolio containing lower energy-rating observations over time from 2005 to 2010. If the premium is observable in the market, is strongly dependent on the real estate market situation (in particular, the financial crisis of 2008 and 2009), while the expected discounts became apparent in 2010 for the first time. Empirical evidence of dynamic price premiums dependent on the particular phase in the property market cycle has been observed for the condominium market of the Tokyo metropolitan area (Shimizu, 2012). Based on these observations, a cyclical dimension of the economic depreciation for the less efficient building stock also has to be considered.

Cajias and Piazolo (2013) provide evidence of discounts on Market Values for higher energy consumption of residential buildings within the German market, based on the *IPD* database including observations from 2008 to 2010. Following their results, a higher energy consumption of 10% per square meter is associated with a significantly lower

Market Value of -4.5% for the tested residential portfolio, all else remaining equal. Confronted with the assumption of an emerging "sustainability impairment" and accelerating economic depreciation for the existing building stock over time, the cross-sectional analysis of Cajias and Piazolo (2013) provides no evidence.

Comparing the energy efficiency of the residential to the commercial sector, some interesting results emerge from the *USA*. When regressing the energy consumption of commercial buildings, it turned out that relatively newer buildings and those of higher quality consume more electricity, contrasting with evidence from the residential sector, where newer buildings prove more to be energy-efficient than the older building stock (Kahn et al., 2014).

2.3 Data sample and econometric methodology

2.3.1 Data sample

The data used for this study was provided by institutional property investors to the *Investment Property Database* (*IPD*) with office building observations, located mainly in the so-called "Big-7-Locations" of Germany (Berlin, Cologne, Dusseldorf, Frankfurt, Hamburg, Munich and Stuttgart). The data include Market Values, rents, building characteristics, measures of energy efficiency and location indicators of German office buildings and cover the time period 2009 to 2011. These years represent the timeframe when sustainability issues and energy efficiency were controversial in the marketplace and introduced into property valuation in Germany for the first time, based on a body of literature for valuation practitioners (RICS, 2009; HypZert, 2010a, 2010b; Meins et al., 2011) and international research, postulating evidence of premiums for "green" and energy-efficient buildings. The data was gathered for Market Valuation, using the *German income approach* (ImmoWertV 2010; Meins et al., 2011). The *German income approach* is based on normed mathematical calculations with market estimations and specific valuation input parameters for ascertaining the Market Value. Thus, the national German methodology does not necessarily confirm to the *RICS* Red Book standards, which are applied in the international context of Market Valuation (Crosby et al., 2011).

In contrast to transaction prices, which can only be observed irregularly, the Market Value is derived in annual property valuations. To avoid confounding effects, due to intertemporal sample variation, we only use a "balanced" sample of office observations for our study, meaning that observations for each unit are available for each of the years 2009 until 2011.

There are two main variables of interest in our regression models:

1. Energy efficiency based on the physical building characteristics assessed for *EPC*s; and
2. Actual energy consumption measured for *EPC*s.

The reason for the second specification is that occupant energy-consumption behavior also plays an important role in the carbon footprint of the building stock. Unfortunately, only a small sub-sample includes measures of energy efficiency or actual consumption figures, based on *EPC* ratings (Table 1).

Table 1: Market Value of total office observations and sub-samples for energy efficiency and consumption

Market Value in bn€	2009	2010	2011
Total office observations "large sample" (n = 366)	9.647	9.469	9.406
Sub-sample energy efficiency (n = 44)	1.111	1.088	1.090
in % of "large sample"	11.52%	11.49%	11.59%
Sub-sample energy consumption (n = 57)	2.099	2.057	2.061
in % of "large sample"	21.76%	21.73%	21.91%

With 44 observations, the Market Value share of the sub-sample for energy efficiency accounts only for approximately 11.5% of the total Market Value of the portfolio, which comprises 366 office observations. The sub-sample for energy consumption (57 observations with a Market Value of almost €2.1 billion) has a share of 22% of the total Market Value, based on 366 observations obtained from the *IPD* database, which we further on call "large sample". The observations in the sub-samples for energy efficiency and energy consumption are both included in this large sample.

Instead of the annual recurring input parameters from property valuations for the large sample during the timeframe from 2009 to 2011, the figures from *EPC* ratings with energy efficiency or consumption have only been reported once (in 2008 or 2009) and added to the *IPD* database at this time. Thus, there is a temporal mismatch between the dependent variable (Market Value) and the explanatory variables of interest.

As the two sub-samples including energy efficiency or consumption are very small, the results of analysis based solely on these sub-samples would be very volatile. One way to deal with this problem is to "borrow" strength from the variable effects determined from the large sample, to analyze the variable effects of interest in the small sub-samples, which will be explained in detail in the following subsection.

However, this approach may be problematic if the two distinct sub-samples, namely the sample *without* measured energy efficiency and the sample *including* energy efficiency or consumption, differ to a large extent in relevant characteristics, particularly if the variable domains do not intersect, which might indicate a selection bias. The approach is justifiable if the variable domains intersect, and the regression models are specified appropriately (i.e. including the relevant variables in the correct functional form).

Turning to the Market Value, it is evident that the mean values within the large sample, and the both sub-samples reflect a significant decline from 2009 to 2010, which is followed by a smaller decline from 2010, compared to 2011 (Table 2).

Table 2: Descriptive statistics for "large sample" and sub-samples for energy efficiency and consumption

Office observations "large sample" 2009 / 2010 / 2011 (n = 366)

2009	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
Market Value (€/sqm)	606	1,717	2,293	2,546	2,969	9,325
Expected economic lifetime (years)	50.00	70.00	70.00	69.54	70.00	80.00
Building age (years)	1.00	8.00	16.00	17.23	24.00	50.00
Usable building area (sqm)	714	4,364	7,672	9,798	12,730	48,160
Maintenance (€/sqm p.a.)	3.08	7.27	8.08	8.17	9.00	13.93
Vacancy rate (%)	0.00	0.00	1.70	11.08	14.51	100.00
2010	**Min.**	**1st Qu.**	**Median**	**Mean**	**3rd Qu.**	**Max.**
Market Value (€/sqm)	606	1,651	2,224	2,485	2,943	9,106
Expected economic lifetime (years)	50.00	70.00	70.00	69.51	70.00	80.00
Building age (years)	2.00	9.00	17.00	18.16	24.75	51.00
Usable building area (sqm)	714	4,364	7,672	9,798	12,730	48,160
Maintenance (€/sqm p.a.)	3.31	7.43	8.13	8.28	9.01	20.44
Vacancy rate (%)	0.00	0.00	2.03	12.43	15.48	100.00
2011	**Min.**	**1st Qu.**	**Median**	**Mean**	**3rd Qu.**	**Max.**
Market Value (€/sqm)	558	1,640	2,198	2,480	2,941	9,893
Expected economic lifetime (years)	50.00	66.25	70.00	69.40	70.00	80.00
Building age (years)	3.00	10.00	18.00	19.10	25.75	52.00
Usable building area (sqm)	714	4,364	7,672	9,798	12,730	48,160
Maintenance (€/sqm p.a.)	3.31	7.50	8.16	8.31	9.14	14.21
Vacancy rate (%)	0.00	0.00	2.38	11.76	14.35	100.00

Sub-sample energy efficiency 2009 / 2010 / 2011 (n = 44)

2009	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
Market Value (€/sqm)	1,043	1,800	2,416	2,604	3,113	6,453
Expected economic lifetime (years)	50.00	60.00	70.00	67.50	70.00	80.00
Building age (years)	3.00	7.00	13.00	15.48	21.25	42.00
Energy efficiency (demand in kWh/m²a)	133.20	208.30	246.80	286.50	302.10	824.20
Usable building area (sqm)	1,538	5,086	7,562	10,530	16,230	34,930
Maintenance (€/sqm p.a.)	5.00	6.03	7.38	7.58	8.49	12.00
Vacancy rate (%)	0.00	0.34	7.70	17.90	24.99	82.63
2010	**Min.**	**1st Qu.**	**Median**	**Mean**	**3rd Qu.**	**Max.**
Market Value (€/sqm)	915	1,733	2,284	2,479	3,025	5,592
Expected economic lifetime (years)	50.00	60.00	70.00	66.59	70.00	80.00
Building age (years)	4.00	8.00	14.00	15.68	22.00	40.00
Energy efficiency (demand in kWh/m²a)	133.20	208.30	246.80	286.50	302.10	824.20
Usable building area (sqm)	1,538	5,086	7,562	10,530	16,230	34,930
Maintenance (€/sqm p.a.)	5.00	6.12	7.40	7.45	8.47	12.08
Vacancy rate (%)	0.00	0.89	8.48	22.04	31.91	100.00
2011	**Min.**	**1st Qu.**	**Median**	**Mean**	**3rd Qu.**	**Max.**
Market Value (€/sqm)	897	1,643	2,322	2,463	3,039	5,315
Expected economic lifetime (years)	50.00	60.00	70.00	66.02	70.00	80.00
Building age (years)	5.00	9.00	15.00	17.25	23.00	50.00
Energy efficiency (demand in kWh/m²a)	133.20	208.30	246.80	286.50	302.10	824.20
Usable building area (sqm)	1,538	5,086	7,562	10,530	16,230	34,930
Maintenance (€/sqm p.a.)	5.00	6.14	7.41	7.57	8.25	12.68
Vacancy rate (%)	0.00	1.12	8.57	20.60	33.42	100.00

Sub-sample energy consumption 2009 / 2010 / 2011 (n = 57)

2009	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
Market Value (€/sqm)	1,043	1,843	2,434	2,956	3,513	8,167
Expected economic lifetime (years)	50.00	60.00	70.00	68.10	70.00	80.00
Building age (years)	3.00	6.25	11.00	14.07	18.00	42.00
Energy consumption (kWh/m²a)	9.00	197.50	242.60	270.30	316.50	878.30
Usable building area (sqm)	1,538	5,491	9,210	11,780	17,410	34,930
Maintenance (€/sqm p.a.)	5.00	6.08	7.37	7.50	8.29	12.00
Vacancy rate (%)	0.00	0.47	8.17	17.12	25.52	82.63
2010	**Min.**	**1st Qu.**	**Median**	**Mean**	**3rd Qu.**	**Max.**
Market Value (€/sqm)	915	1,785	2,388	2,857	3,413	8,100
Expected economic lifetime (years)	50.00	60.00	70.00	67.41	70.00	80.00
Building age (years)	4.00	7.25	12.00	14.47	19.00	40.00
Energy consumption (kWh/m²a)	9.00	197.50	242.60	270.30	316.50	878.30
Usable building area (sqm)	1,538	5,491	9,210	11,780	17,410	34,930
Maintenance (€/sqm p.a.)	5.00	6.40	7.57	7.48	8.09	12.08
Vacancy rate (%)	0.00	0.87	10.12	21.46	31.62	100.00
2011	**Min.**	**1st Qu.**	**Median**	**Mean**	**3rd Qu.**	**Max.**
Market Value (€/sqm)	897	1,719	2,398	2,850	3,416	8,700
Expected economic lifetime (years)	50.00	60.00	70.00	66.98	70.00	80.00
Building age (years)	5.00	8.25	14.00	15.90	20.00	50.00
Energy consumption (kWh/m²a)	84.70	198.00	242.60	274.60	320.00	878.30
Usable building area (sqm)	1,538	5,491	9,210	11,780	17,410	34,930
Maintenance (€/sqm p.a.)	5.00	6.41	7.59	7.60	8.11	12.68
Vacancy rate (%)	0.00	1.26	11.51	20.79	32.85	100.00

Comparing the large sample with the two sub-samples in 2011, the Market Value with an average of €2,480 per square meter for the large sample indicates more or less the same Market Value as the sub-sample for energy efficiency. However, the consumption sample reaches a higher level with €2,850 per square meter on average. With approximately 16 years of building age, the consumption sample turns out to have the youngest observations on average. Interestingly, the costs for maintenance show a remarkably lower level for the younger average efficiency and consumption samples. When looking at the average vacancy rate in the timeframe from 2009 to 2011, both sub-samples including energy attributes, show a higher vacancy rate compared to the average vacancy rate of the large sample. However, we estimate the mean values of the valuation input parameters from the large sample and both sub-samples as more rather similar than with too much deviation for the approach described above.

The assessed energy demand of the efficiency sample ranges from 133 kWh to 824 kWh with an average of 287 kWh/(sqm*a). For annual consumption, the span is from 85 kWh to 878 kWh and 270 kWh/(sqm*a) on average. Despite the valuation-based input parameters of the dataset, energy efficiency or consumption have only been measured once, at the beginning of the observation period. First, the energy demand displayed in *EPC*s is a measure based on the physical, mainly thermal, building features, which do not undergo current or even annual re-assessments, due to an unchanged status. Second, the metered energy consumption is a dynamic parameter with potential oscillation from time to time, based on behavioral aspects of building use, but furthermore, also of externalities such as the climatic amplitude over time.

Our approach is based on the assumption that a response to the energy efficiency and consumption of office buildings is observable in property valuation. With regard to the dynamics of an increasing effect, the valuation input parameters are expected to anticipate the potentially stronger influence of energy efficiency and consumption on Market Values within the timeframe. The significant decline in average Market Values for the large sample and both sub-samples from 2009 to 2010 is expected to be higher for the few observations associated with a lack of energy efficiency or higher consumption in the sub-samples, due to higher economic depreciation.

2.3.2 Econometric methodology

To determine the effect of energy efficiency or consumption on the dependent variable, we have to control for all other factors affecting the Market Value. One way to achieve this is a hedonic model, where the dependent variable is decomposed into implicit prices of the building characteristics (Rosen, 1974). This can be achieved by a multiple regression model accounting for all available building characteristics and locational effects. As is common in hedonic price models (Malpezzi, 2003), we transform the response variable of Market Value logarithmically, as we expect building characteristics to have multiplicative effects on the dependent variable. The estimated effects can then be interpreted as elasticities if both sides are logarithmically transformed or semi-elasticities if the explanatory variable enters the equation in absolute values.

In a first step, we follow the usual approach of regressing the dependent variable on all available explanatory covariates, including the variable of interest. The resulting linear *ordinary least squares* (*OLS*) model for each of the data sub-samples with observed energy efficiency or consumption is displayed in equation (1). We transform all strictly positive metric variables logarithmically when estimating a log-linear function with the following equation:

$$\text{(LN)Market Value}_\text{i} = \alpha + \beta_1\,\text{(LN)GND}_\text{i} + \beta_2\,\text{Age}_\text{i} + \beta_3 \begin{bmatrix} \text{(LN)Energy Efficiency}_\text{i} \\ \text{(LN)Energy Consumption}_\text{i} \end{bmatrix} +$$

$$\beta_4\,\text{(LN)Size}_\text{i} + \beta_5\text{(LN)Maintenance}_\text{i} + \beta_6\,\text{Vacancy Rate}_\text{i} + \beta_7\,\text{Vacancy Binary}_\text{i} +$$

$$[\mathbf{Location_i}'\boldsymbol{\gamma}] + \begin{bmatrix} \varepsilon_\text{i} \\ \delta_\text{i} \end{bmatrix} \tag{1}$$

For the explanatory variables, *(LN)GND* controls for the natural logarithm of the expected economic lifetime of the building, applied in the *German income approach* ("Gesamtnutzungsdauer"). *Age* is derived by subtracting the estimated remaining economic lifetime from the expected economic lifetime, as the residual parameter. It usually reflects major renovation or refurbishment with improved physical characteristics of buildings, thus expressing depreciation over time. *(LN)Energy Efficiency* is the logarithm of the estimated energy demand in kWh/(sqm*a) from *EPC* ratings. In the model for energy consumption, as explanatory, *(LN)Energy Consumption* is the metered annual consumption in kWh/(sqm*a). *(LN)Size* controls for the building floor area in square meters. *(LN)Maintenance*, reflecting the valuation-based approximation for ongoing maintenance costs, is contained along with the *Vacancy Rate* and a *Vacancy Binary variable*, controlling for a 0% Vacancy Rate[14]. Furthermore, a matrix of *Location dummies* enters the equation to control for spatial heterogeneity[15]. α is the regression intercept, $\beta 1$, $\beta 2$, […] $\beta 7$ are the regression coefficients for object characteristics, γ is a vector of regression coefficients for the location dummy effects, while ε and δ denote *iid* error terms for the respective equation, expected to follow a normal distribution of mean zero and constant variance.

The approach outlined in equation (1) has the serious drawback that the small sample size in our sub-samples may lead to rather unstable results. Yet, we have the large sample available with all relevant variables, except energy efficiency or consumption observed. This leads us to the question of how we could benefit from the large sample. Our approach is to use the prediction gained from this sample, including all building characteristics necessary, except energy efficiency or consumption, to predict the effects of dependent variables of the small sub-samples. For this purpose, we estimate the coefficients of the large sample, without observations for energy efficiency and consumption with equation (2a).

$$\text{(LN)Market Value}_\text{i} = \alpha + \beta_1\,\text{(LN)GND}_\text{i} + \beta_2\,\text{Age}_\text{i} + \beta_3\,\text{(LN)Size}_\text{i} +$$

$$\beta_4\,\text{(LN)Maintenance}_\text{i} + \beta_5\,\text{Vacancy Rate}_\text{i} + \beta_6\,\text{Vacancy Binary}_\text{i} +$$

$$[\mathbf{Location_i}'\boldsymbol{\gamma}] + \varepsilon_\text{i} \tag{2a}$$

---

[14] The latter is introduced to handle the occurrence of zeros instead of missing inputs for the vacancy rate.

[15] Location dummies differentiate between the *CBD*s of Berlin, Cologne, Dusseldorf, Frankfurt, Hamburg, Munich and Stuttgart, two other categories in "*Big 7*" cities, suburban locations near "*Big 7*" cities, "*B-Cities*" and Rest of Germany.

Although this kind of linear specification is usually applied for hedonic price models, it has been shown in several studies of real estate (Mason and Quigley, 1996; Pace, 1998; Parmeter et al., 2007; Brunauer et al., 2012; 2010) that the assumption of linearity in parameters often seems to be too restrictive. This demands the use of more flexible non- and semi-parametric regression models. A very popular framework of semi-parametric models is provided by *generalized additive regression models* (*GAM*), as described for instance in Wood (2006). In *GAM*, the effects of continuous covariates are estimated using regression splines, which allow for nonlinearity in a regularized statistical framework. This framework reveals nonlinear relationships between response and explanatory variables[16]. Thus, we replace the linear effects $\beta_j x_{ij}$ of all continuous covariates[17] with possibly nonlinear functions $f_j(x_{ij})$, see equation (2b):

$$\begin{aligned}\text{(LN)Market Value}_i = {} & \alpha + \beta_1\,\text{(LN)GND}_i + f_1\,(\text{Age}_i) + f_2\left(\text{(LN)Size}_i\right) + \\ & f_3\left(\text{(LN)Maintenance}_i\right) + f_4\,(\text{Vacancy Rate}_i) + \beta_2\,\text{Vacancy Binary}_i + \\ & [\mathbf{Location}_i{}'\boldsymbol{\gamma}] + \varepsilon_i \end{aligned} \tag{2b}$$

The introduction of *GAM* is aimed at obtaining higher model quality and predictive power displayed in a lower *Akaike Information Criterion* (*AIC*), compared to the linear model type. When choosing between models, Wood (2006) recommends using whichever model has the lowest value of *iid*, because estimated models with lower *AIC* are generally expected to be closer to the true model. For an overview and discussion of additive models, see Fahrmeir et al. (2007) and Wood (2006).

In a next step, the partial prediction of the variable effects is extracted from model (2b) and applied to the sub-samples (which include the two variables of interest, energy efficiency and consumption). This means that the regression function is evaluated for the covariate values observed in the two sub-samples.

The crucial point here is that the *difference* between the prediction and the observed Market Values can be used to infer the variables of interest. Calculating this difference corresponds to a model in which the Market Values of the sub-samples are regressed on the variables of interest and the prediction from the large sample, with the parameter of the latter artificially set to one. We choose a more general approach, where the parameter (or nonlinear function) of the prediction from the large sample is determined directly in the model.

Our approach of stabilizing the regression results through prediction from the large sample, is reasonable if there is no strong correlation between the energy measures and other building characteristics or the location. Therefore, we regress energy efficiency and consumption on the explanatory variables, contained in the partial prediction extracted from model (2b), in a supplementary model in equation (3).

$$\begin{bmatrix}\text{(LN)Energy Efficiency}_i \\ \text{(LN)Energy Consumption}_i\end{bmatrix} = \alpha + f_1\,(\text{Prediction (LN)Market Value}_i) + \begin{bmatrix}\eta_i \\ \kappa_i\end{bmatrix} \tag{3}$$

---

[16] We use the standard specification of *thin plate regression splines*, which are *low-rank smoothers* based on truncated *Eigen-decomposition*. The smoothing parameters are selected automatically, using the *generalized cross validation criterion* (Wood, 2003).

[17] Except (LN)GND, for technical reasons.

The residual output estimated in this "helper regression" contains all the information not explained through the systematic part of the model and can be considered as independent ("orthogonalized") from the prediction.

Including this residual output as an explanatory variable in the final model makes the resulting effects directly attributable to energy efficiency or consumption, without any confounding effects from other covariates.

Finally, in equation (4a), we integrate the prediction for *(LN)Market Value* from the large office sample and the residual η_i (for energy efficiency) and κ_i (for energy consumption) taken from equation (3) as explanatory variables:

$$\text{(LN)Market Value}_i = \alpha + \beta_1 \begin{bmatrix} \eta_i \\ \kappa_i \end{bmatrix} + \beta_2\,(\text{Prediction (LN)Market Value}_i) + \begin{bmatrix} \sigma_i \\ \varphi_i \end{bmatrix} \tag{4a}$$

To provide evidence of the hypothesized relationship, we apply the model in a specification with a linear coefficient of the effect in equation (4a) and with nonlinear regression splines for the residuals in equation (4b):

$$\text{(LN)Market Value}_i = \alpha + f_1 \begin{bmatrix} \eta_i \\ \kappa_i \end{bmatrix} + f_2\,(\text{Prediction (LN)Market Value}_i) + \begin{bmatrix} \sigma_i \\ \varphi_i \end{bmatrix} \tag{4b}$$

With the notation above, we apply the regression model on the energy efficiency, as well as to the consumption sub-sample.

To sum up, our approach can be written algorithmically as follows:

1. Estimate a regression model using the large sample dataset without energy efficiency or consumption. This sample provides relatively precise estimates for the effects of building characteristics (floor size, age etc.) and location.
2. Use the model results of 1. and predict the effects of building and locational characteristics for the two sub-samples. In this step, the regression function is simply evaluated for the building characteristics and locations of the two sub-samples. We obtain an estimated Market Value as if no energy efficiency or consumption had been observed.
3. From a further regression step of the respective energy variable on building and locational characteristics, the unexplained residual output is used to "clean" the energy variables from correlation with other building attributes (orthogonalization).
4. The final equation regresses the target variable on the "cleaned" energy variable and the partial prediction of Market Value from the large sample containing building and locational characteristics.

2.4 Empirical results

2.4.1 Linear regression model

The results of our log-linear hedonic model following equation (1) applied for estimating the effects of energy efficiency and consumption within the sub-samples are summarized in Table 3. The effects for energy efficiency on Market Values are shown at first and for consumption, underneath on the table.

Table 3: Log-linear hedonic regression results for the effects of energy efficiency and consumption on the Market Value from equation (1)

Sub-sample energy efficiency: Cross sections 2009-2011 (n = 44)

	(LN) Market Value in €/sqm		
Explanatory variables Coefficient [p-values]	**2009**	**2010**	**2011**
Intercept	5.079	3.759	4.394
	[0.014]*	[0.056]	[0.016]*
(LN) Expected economic	0.857	1.162	0.978
building lifetime (years)	[0.034]*	[0.003]**	[0.012]*
Building age (years)	-0.018	-0.018	-0.019
	[0.003]**	[0.003]**	[0.001]***
(LN) Energy efficiency (kWh/m^{2}a)	-0.069	-0.129	-0.140
	[0.577]	[0.259]	[0.235]
(LN) Usable building area (sqm)	0.030	0.065	0.078
	[0.706]	[0.377]	[0.281]
(LN) Maintenance costs (€/sqm)	-0.215	-0.199	-0.106
	[0.371]	[0.423]	[0.626]
Dummy vacancy (if vacancy 0% = 1)	-0.092	-0.082	-0.282
	[0.459]	[0.531]	[0.052]
Vacancy rate (%)	-0.001	0.000	-0.004
	[0.641]	[0.886]	[0.073]
Fixed effects			
Dummy variables location (n)	10	10	10
[p-values]	[0.002]**	[0.001]**	[0.001]**
R^2	0.793	0.822	0.857
Adjusted R^2	0.658	0.705	0.764
AIC-Criterion	12.28	5.28	2.48
F-Statistic [p-values]	[0.000]	[0.000]	[0.000]

Significance: *** 0.001; ** 0.01; * 0.05

Sub-sample energy consumption: Cross sections 2009-2011 (n = 57)

	(LN) Market Value in €/sqm		
Explanatory variables Coefficient [p-values]	**2009**	**2010**	**2011**
Intercept	3.952	1.886	2.030
	[0.017]*	[0.259]	[0.201]
(LN) Expected economic	0.784	1.242	1.202
building lifetime (years)	[0.021]*	[0.001]***	[0.001]**
Building age (years)	-0.022	-0.021	-0.023
	[0.000]***	[0.000]***	[0.000]***
(LN) Energy consumption (kWh/m^{2}a)	0.056	0.017	0.006
	[0.330]	[0.771]	[0.915]
(LN) Usable building area (sqm)	0.071	0.110	0.088
	[0.187]	[0.047]*	[0.131]
(LN) Maintenance costs (€/sqm)	-0.016	-0.029	0.161
	[0.933]	[0.889]	[0.440]
Dummy vacancy (if vacancy 0% = 1)	-0.053	0.005	0.015
	[0.629]	[0.963]	[0.889]
Vacancy rate (%)	-0.002	-0.001	-0.004
	[0.341]	[0.422]	[0.032]*
Fixed effects			
Dummy variables location (n)	10	10	10
[p-values]	[0.000]***	[0.000]***	[0.000]***
R^2	0.850	0.848	0.848
Adjusted R^2	0.786	0.783	0.783
AIC-Criterion	6.17	8.56	14.59
F-Statistic [p-values]	[0.000]	[0.000]	[0.000]

Significance: *** 0.001; ** 0.01; * 0.05

For both sub-samples, a higher economic lifetime has a significantly positive effect on the Market Value, while an increase in building age of one year lowers the Market Value by approximately -2%. Over the whole observation period, these negative effects for building age remain almost constant. For building age, we do not detect any increase or acceleration in the economic depreciation rate, due to a potential higher physical deterioration or obsolescence.

The effect of the vacancy rate on Market Values is weak and only significant for the energy consumption sub-sample in 2011. This provides some indication that vacancy rates for the tested small sub-samples might not be reflected in the valuation methodology of the *German income approach* as a significant factor, affecting the Market Value negatively, due to estimated short-term re-letting expectations for vacant office space.

The effects of usable area and maintenance costs are generally not significant either. Of course location matters and the location variable effects are highly significant in both equations.

Turning to the variables of interest, we find no significant coefficients for energy efficiency or consumption effects on Market Values within the timeframe. While the coefficients for energy efficiency are negative (if insignificant) and increase over time, those for energy consumption even have the wrong sign. To sum up, although achieving a high share of explained variance (R^2 > 79%), overall, the covariate effects are relatively unstable and insignificant, most likely due to the small size of both samples.

2.4.2 Regression results for the large sample

Table 4 provides the results for equation (2a), a log-linear hedonic regression model based on the large sample. A comparison with the previous results provides some interesting insights.

Table 4: Log-linear hedonic regression results (OLS) for office observations of the large sample from equation (2a)

Office observations "large sample" in cross sections 2009-2011 (n = 366)

	(LN) Market Value in €/sqm		
Explanatory variables Parametric coefficients [p-values]	**2009**	**2010**	**2011**
Intercept	7.509 [0.000]***	7.310 [0.000]***	6.035 [0.000]***
(LN) Expected economic building lifetime (years)	0.028 [0.856]	0.103 [0.095]	0.326 [0.043]*
Building age (years)	-0.016 [0.000]***	-0.016 [0.000]***	-0.018 [0.000]***
(LN) Usable building area (sqm)	0.042 [0.034]*	0.045 [0.026]*	0.044 [0.029]*
(LN) Maintenace costs (€/sqm)	0.034 [0.619]	-0.039 [0.586]	0.140 [0.062]
Dummy vacancy (if vacancy 0% = 1)	0.034 [0.311]	-0.005 [0.878]	0.060 [0.080]
Vacancy rate (%)	-0.005 [0.000]***	-0.003 [0.000]***	-0.003 [0.000]***
Dummy variables location (n)	10	10	10
Loc. dummies: F-Statistic [p-values]	[0.000]***	[0.000]***	[0.000]***
R^2	0.666	0.650	0.669
Adjusted R^2	0.650	0.633	0.653
AIC-Criterion	91.48	108.98	94.20
Total Model: F-Statistic [p-values]	[0.000]***	[0.000]***	[0.000]***

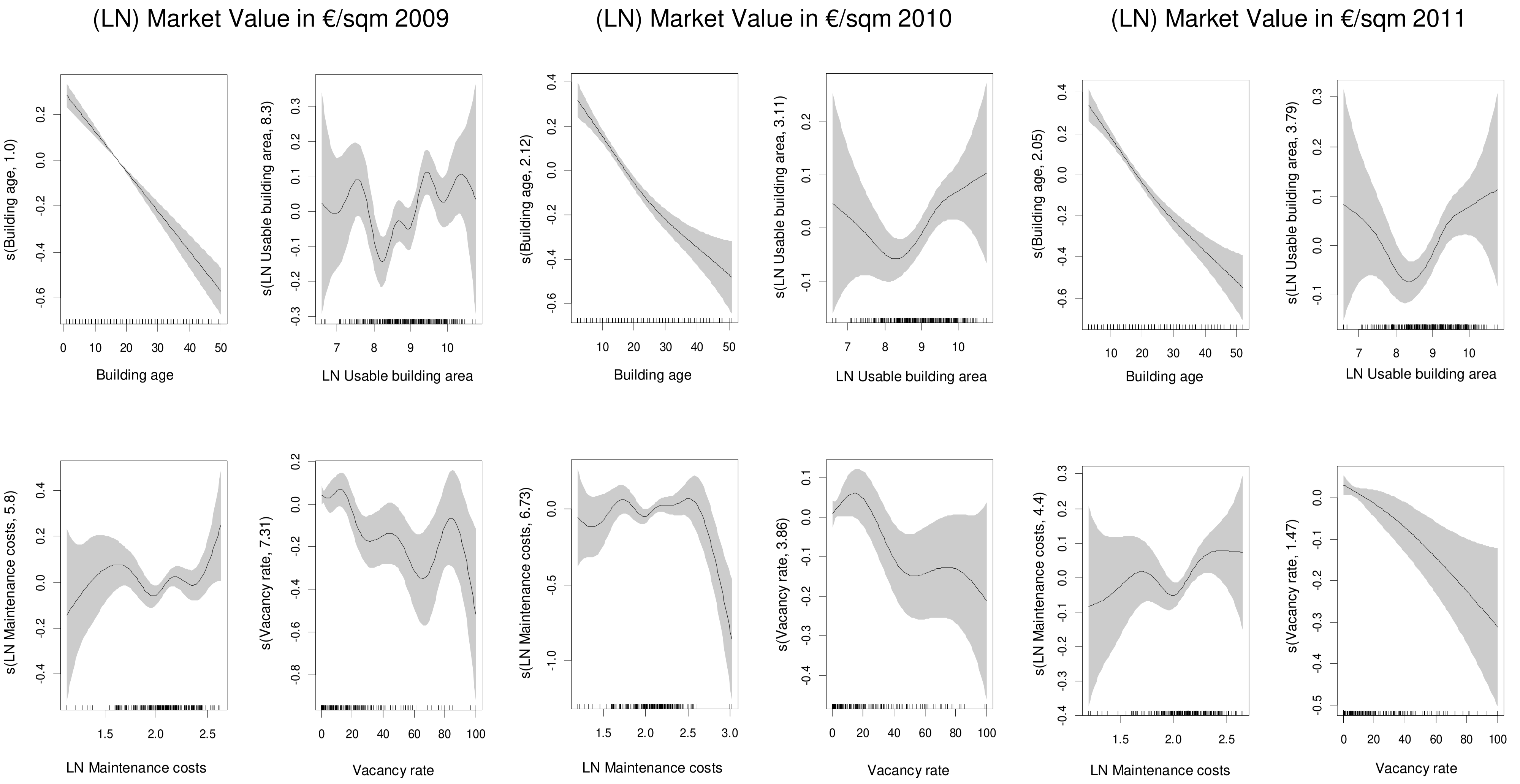
Significance: *** 0.001; ** 0.01; * 0.05

The effect of building age is highly significant with a constant negative effect on Market Values over the timeframe. Consistent with the results in Table 3, an increase in building age of one year is followed by age-related depreciation of approximately -2%. In contrast, the effect of economic building lifetime is much lower and mostly insignificant in the large sample. This may be due to collinearity between building lifetime and building age.

The coefficients for building area are positive and significant, although rather low; doubling the building area leads to an increase in Market Values of 4% to 5%. The effect of the vacancy rate is significantly negative and of low variability over time. An increase in the vacancy rate of 10 percentage points is associated with slightly lower Market Values (-3% to -5%). Maintenance costs do not have a significant effect on Market Values, while location is again extremely relevant.

Figure 2 shows the regression splines for the estimated covariate effects in equation (2b), where the continuous black lines are the expected effects and the grey areas are point-wise 95% confidence intervals. The y-axes can be approximately interpreted as the percentage effect on Market Values. When the *effective degrees of freedom* (*edf*) are estimated at 1.0, a linear relationship between explanatory and response is explained. With an estimated *edf* of more than 1.0, the analyzed relationship follows a nonlinear function.

Figure 2: Regression splines of the large sample for explanatory variables from equation (2b)



The effect of building age is strong and indicates a linear relationship in 2009 (*edf* estimated at 1.0), followed by a slightly nonlinear course in 2010 and 2011, which depicts an almost linear decrease in Market Values with increasing building age up to approximately 25 years. For older office buildings the depreciation of the Market Value is lower than for observations with an age less than approximately 25 years. This corresponds to some extent to the results of Baum and McElhinney (1997) and Crosby et al. (2015) for the *UK*. However, it is somewhat surprising for Germany, because the formal logic of the *German income approach* implies a stronger age-related depreciation for higher than of lower building age.

The effect of usable building area has a U-shape, although this is somewhat volatile in 2009. The regression splines for usable building area in 2010 and 2011 indicate a decline in Market Values up to an area of approximately 4,500 square meters. For larger buildings, a positive relationship between Market Values and size can be observed, when there might be some form of positive scale effect or other unmeasured characteristics associated with larger buildings. The effect of maintenance cost is unstable, although we retain it in the model as a control variable. The effect of the vacancy rate is strong and becomes even more pronounced and nearly linear over time.

To sum up, the results for the large sample are mostly intuitive and much more stable than those for the sub-samples. This supports our strategy outlined before, namely to borrow strength from these results for the sub-samples.

Therefore, we apply the regression function resulting from equation (2b) to predict (LN)Market Value for the sub-samples. This predicted Market Value is to be integrated into the final regression model as outlined in equation (4b). However, to remove dependencies between the Market Value prediction and the energy measures, we estimate the supplementary regression described in equation (3) and use the residuals from this equation instead of the variables of interest. The results of this model are presented in Table 5. The effects of the predicted Market Value on energy measures are insignificant (shown by the *F*-Statistic) and weak, meaning that omitting this step would lead to similar results. However, we decide to use the "cleaned" version of the variable to consistently demonstrate our econometric approach.

Table 5: Supplementary regression results for energy efficiency or consumption as the response variable from equation (3)

Response Variable:	**Energy efficiency (n = 44)**			**Energy consumption (n = 57)**		
Parametric coefficients [p-values]	**2009**	**2010**	**2011**	**2009**	**2010**	**2011**
Intercept	5.579 [0.000]***	5.579 [0.000]***	5.579 [0.000]***	5.475 [0.000]***	5.475 [0.000]***	5.475 [0.000]***
s(Prediction Market Value)	1.000 [0.556]	2.622 [0.723]	1.000 [0.487]	1.000 [0.861]	3.377 [0.236]	7.406 [0.118]
R^2	0.008	0.070	0.012	0.001	0.133	0.273
Adjusted R^2	-0.015	0.010	-0.012	-0.017	0.079	0.164
F-Statistic [p-values]	[0.556]	[0.787]	[0.487]	[0.514]	[0.392]	[0.408]

Significance: *** 0.001; ** 0.01; * 0.05

2.4.3 Final regression model including residuals and prediction

Our final model regresses the Market Value on the unexplained residual output of either energy efficiency or consumption from equation (3) and the prediction of (LN)Market Value from equation (2b).

As expected, the effect of the predicted Market Value is close to 1 and highly significant. This means that the basic relationship between Market Values and explanatory variables derived from the large sample is also applicable to the sub-samples. However, the results of the linear specification described in equation (4a) show no significant effects of energy efficiency. For 2009, even a positive coefficient is estimated, while, as expected, the effect is negative in 2010 and 2011. Thus, the results provide neither evidence of an increasing effect of energy efficiency on Market Values nor of a significant effect at all.

There are no significant parametric coefficients for energy consumption either. However, in this case, the coefficients for energy consumption display a negative impact in 2009 and 2010, but a positive one in 2011 (Table 6).

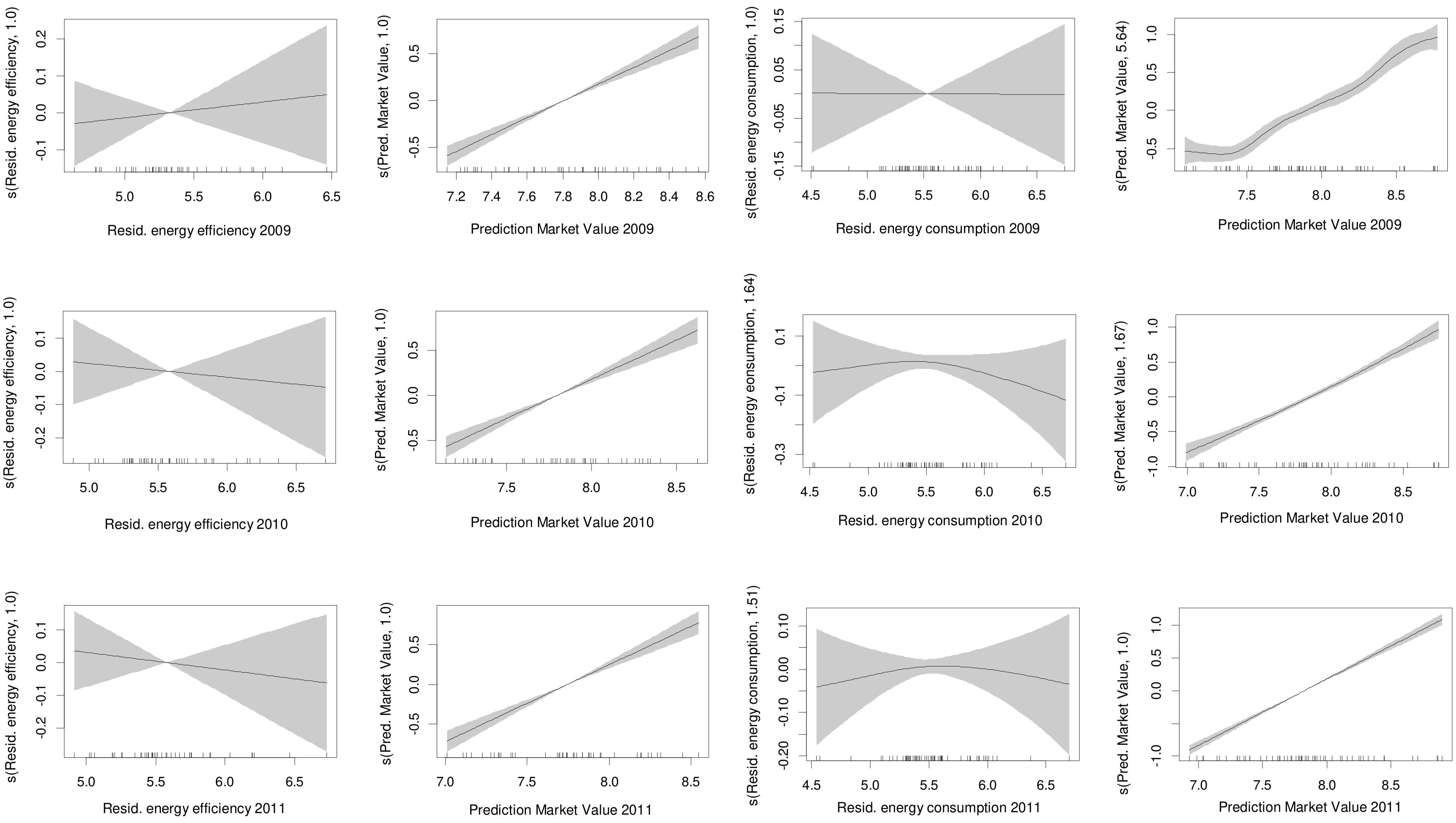
Table 6: Regression results incl. residuals of energy efficiency or consumption and partial prediction (large sample) from equation (4a)

	Energy efficiency (n = 44)			**Energy consumption (n = 57)**		
Parametric Coefficients [p-values]	**2009**	**2010**	**2011**	**2009**	**2010**	**2011**
Intercept	0.547	1.127	0.549	0.006	0.187	-0.126
	[0.494]	[0.206]	[0.528]	[0.991]	[0.744]	[0.771]
Residuals of energy efficiency or consumption as response	0.043	-0.042	-0.054	-0.003	-0.038	0.007
	[0.610]	[0.657]	[0.558]	[0.964]	[0.558]	[0.898]
Prediction Market Value	0.896	0.878	0.964	1.001	1.003	1.011
	[0.000]***	[0.000]***	[0.000]***	[0.000]***	[0.000]***	[0.000]***
R^2	0.744	0.697	0.738	0.850	0.855	0.919
Adjusted R^2	0.732	0.682	0.725	0.844	0.850	0.916
AIC-Criterion	-8.42	-1.36	-0.74	-22.85	-23.37	-50.30
F-Statistic [p-values]	[0.000]***	[0.000]***	[0.000]***	[0.000]***	[0.000]***	[0.000]***

Significance: *** 0.001; ** 0.01; * 0.05

Proceeding to the specification with regression splines of the final regression *GAM*, following equation (4b), we obtain linear functions for the residuals of energy efficiency as explanatory variables in all three years of the timeframe under examination (Figure 3).

Figure 3: Regression splines for residuals of energy efficiency or consumption and partial prediction (large sample) from equation (4b)



(LN) Regression splines for energy efficiency 2009-2011

Regression splines for energy consumption 2009-2011

The regression splines for energy efficiency reveal a positive relationship in 2009 and a slightly increasing negative influence from 2010 to 2011, although this cannot be considered as significant (significance tables not shown here). The effect of energy consumption does not show any significant relationship to Market Values.

In summary, we use a novel econometric approach, containing all available observations, to derive stable results for our variables of interest. However, we find no statistically significant relationship between energy efficiency or actual energy consumption and the Market Value, let alone an increase in this effect. The reasons for this are on the one hand, obviously the small sample size and other deficiencies of the sample (energy efficiency and consumption are only measured once). On the other hand, one might argue that in German valuation practice, this issue has not been priced into Market Values at all in the observed period.

2.5 Conclusion and outlook

This study is an attempt to provide evidence of an effect of energy efficiency on the Market Value for office buildings in Germany and whether this effect increases over time. The assumption is derived from the continuously increasing energy efficiency requirements for new construction in Germany and the growing number of "green" office buildings in the marketplace. Through a further acceleration of these effects in pricing and valuation, an emerging "sustainability impairment" is expected, resulting in increasing economic depreciation associated with a decline in Market Values for the existing building stock. As we do not observe actual transaction prices, but Market Values for a sample of office buildings, there may be some inertia in the transmission of this effect in actual valuation practice.

Overall, the results from the semi-parametric model approach (*GAM*) for the large sample are of interest for market participants. However, the main weakness in the dataset is that only for the small sub-samples measures of energy efficiency and consumption are available. We address this issue by designing a novel econometric approach, for which we use all available observations without energy measures to draw conclusions about the small sub-samples. Furthermore, we control for possible dependence of energy measures on predicted Market Values. Thus, we leverage the prediction gained from a large sample of office buildings to stabilize the results for the variables of interest in each small sub-sample.

However, although the proposed method works well, as indicated by the intuitive and consistent results in the various steps of this approach, we find no significant evidence of the hypothesized relationship between Market Values and energy measures. Even with regard to the significant decline in Market Values for the tested portfolio from 2009 to 2010, it turns out that a lack of energy efficiency or higher consumption was not attributed as relevant for the Market Value. Yet, this is in line with the results of Fuerst and McAlliser (2011b) for the *IPD* database *UK*.

The assumption of increased physical deterioration and obsolescence for the building stock with faster economic depreciation (exceeding the approximately constant age-related rate), observable through an increasing negative impact of energy efficiency or consumption on Market Values, does not prove valid for the tested data sample.

Some explanations are at hand:

- Although the small number of observations in the two sub-samples is stabilized by the partial prediction, the number of observations is still too small to provide reliable evidence of the expected relationship.
- Both sub-samples are based on *EPC*s for the available observations, which may not be the appropriate measure to capture the effect of energy efficiency or actual consumption in Market Values over time – especially as this was measured only once in 2008 or 2009. In particular, the variables of interest are only measured once and not in each of the years in the observation period so that there might be additional confounding effects.
- Another interpretation might be that an actually increasing effect of energy efficiency or consumption with higher economic depreciation for existing building stock has not been observed in the marketplace from valuation practice, which observes the market, but does not determine it. This would follow the argumentation that decision makers (tenants) of office buildings use these buildings, but do not own them (Kahn et al., 2014). For this reason, energy costs and potential cost savings of office buildings may not have a strong influence on the decisions of tenants/occupants – contradicting experience from the residential sector in the relevant timeframe in Germany (Cajias and Piazolo, 2013). However, it seems more reasonable that valuation practice does not completely reflect the effect of energy efficiency or consumption on transaction prices, potentially due to missing information in the course of valuations for the existing building stock. For valuation practice, it has been argued that German valuers stick to their values – even when undertaking valuations for performance measurement (such as *IPD*) on a Market Value basis (Crosby et al., 2011). As marking to market is expected to consider average prices rather than best (or lower) prices, a lack of market parameters might rule out an increasing effect of energy efficiency or consumption – even if observable in the marketplace for the relevant timeframe. Furthermore, institutional property investors providing the data to *IPD* might stick to their book values, striving to keep high Market Values in actual valuations.
- The observation of Fuerst et al. (2013) from *UK* office rents, in which building age is a possible factor also considered in terms of energy efficiency and related costs by market participants, might be of some explanatory impact to our results, considering that valuation practice might act the same way. Ascertaining the potential energy performance from the physical, especially thermal characteristics and the building year (age), might be reasonable – but also perhaps misleading.

The effect of energy might be reflected in higher economic depreciation for inefficient buildings or those with actually higher consumption in the future. Therefore, a database containing observations over a longer period of time may be needed to find evidence of the effect. While the potential "sustainability impairment" of the building stock in the rental and transactional market might not be anticipated in valuation practice so far, transactional datasets with a large number of observations are needed to further explore the theoretical considerations outlined in this study.

Finally, and rather surprisingly, our study results contradict observations provided by Cajias and Piazolo (2013) for the residential building stock in Germany, based on valuation input parameters of the *IPD* database as well. This means that a more differentiated view between the commercial and residential building stock is also necessary.

Responding to the increasing energy efficiency requirements for new construction, and as energy-efficient commercial buildings prevail more and more, we expect the enhancement of energy performance for the building stock to be of increasing interest within the real estate economy over time. As the practice of property valuation is crucial for this process, the European Union is providing funding for a new project within its "Intelligent Energy Europe Program". With emphasis on energy efficiency and renewable energy issues, "RenoValue" is intended to enhance the role of property valuation by providing training for valuation professionals, coordinated by the *RICS*.

Finally, to provide clear evidence of the theoretical issues outlined in this study, more and more recent data are needed, based on realized transactional and valuation input evidence. Therefore, evidence of the increasing effect of energy efficiency on the Market Value over time, with higher depreciation of inefficient office buildings or those of higher energy consumption in Germany, remains to be obtained.

2.6 References

Baum, A. (1991), *Property Depreciation and Obsolescence*, Routledge, London.

Baum, A. and McElhinney, A. (1997), "The Causes and Effects of Depreciation in Office Buildings: A Ten Year Update", Report for working paper of the Department of Land Management and Development, University of Reading, Reading.

Baum, A. and Turner, N. (2004), "Retention Rates, Reinvestment and Depreciation in European Office Markets", *Journal of Property Investment and Finance*, Vol. 22 No. 3, pp. 214-235.

Bienert, S., Schuetzenhofer, C., Leopoldsberger, G., Bobsin, K., Leutgeob, K., Huettler, W., Popescu, D., Mladin, E.-C., Boazu, R., Koch, D., and Edvardsen, D.-F.(2010), "Integration of Energy Performance and Life-Cycle Costing into Property Valuation Practice", available at: www.immovalue.org (accessed 9 March 2014).

Brunauer, W.A., Lang, S., Wechselberger, P. and Bienert, S. (2010), "Additive Hedonic Regression Models with Spatial Scaling Factors: An Application for Rents in Vienna", *Journal of Real Estate Finance and Economics*, Vol. 41 No. 4, pp. 390-411.

Brunauer, W., Feilmayr, W. and Wagner, K. (2012), "A new residential property price index for Austria", *Statistiken – Daten und Analysen Q3/2012*, Austrian National Bank, Vienna, pp. 90-102.

Cajias, M. and Piazolo, D. (2013), "Green performs better: energy efficiency and financial return on buildings", *Journal of Corporate Real Estate*, Vol. 15 No. 1, pp. 53-72.

Chegut, A., Eichholtz, P. and Kok, N. (2014), "Supply, demand, and value of green buildings", *Urban Studies Journal*, Vol. 51 No. 1, pp. 22-43.

Crosby, N., Devaney, S. and Law, V. (2011), "Benchmarking and valuation issues in measuring depreciation for European office markets", *Journal of European Real Estate Research*, Vol. 4 No. 1, pp.7-28.

Crosby, N., Devaney, S. and Nanda, A. (2015), "Which factors drive rental depreciation rates for office and industrial properties?", *Journal of Real Estate Research*, available at: http://pages.jh.edu/jrer/papers/abstract/forth/accepted/jrer_250(f140902R2).html (assessed 14 September 2015).

Eichholtz, P., Kok, N. and Quigley J.M. (2010), "Doing well by doing good? Green office buildings." *American Economic Review*, Vol. 100 No. 5, pp. 2492-2509.

Fahrmeir, L., Kneib, T. and Lang, S. (2007), *Regression. Modelle, Methoden und Anwendungen*, Springer, Berlin.

Fuerst, F. and McAllister, P. (2011a), "Green noise or green value? – Measuring the effects of environmental certification on office values", *Real Estate Economics*, Vol. 39 No. 1, pp. 45-69.

Fuerst, F. and McAllister, P. (2011b), "The impact of energy performance certificates on the rental and capital values of commercial property assets", *Energy Policy*, Vol. 39 No. 10, pp. 6608-6614.

Fuerst, F., van de Wetering, J. and Wyatt, P. (2013), "Is intrinsic energy efficiency reflected in the pricing of office leases?", *Building Research and Information*, Vol. 41 No. 4, pp. 373-383.

HypZert (2010a), "Nachhaltigkeit von Immobilien unter Berücksichtigung der Wertermittlung", Fachgruppe Energie und Umwelt des HypZert e.V., Berlin.

HypZert (2010b), "Energieeffizienz der Gebäude – ein Hauptaspekt der Nachhaltigkeit", Fachgruppe Energie und Umwelt des HypZert e.V., Berlin.

ImmoWertV (2010), *Immobilienwertermittlungsverordnung*, as of 19 May 2010, Bundesanzeiger Verlag, Bonn.

Kahn, M.E., Kok, N. and Quigley, J.M. (2014), "Carbon emissions from the commercial building sector: the role of climate, quality, and incentives", *Journal of Public Economics*, Vol. 113 No. C, pp. 1-12.

Kok, N. and Jennen, M. (2012), "The impact of energy labels and accessibility on office rents", *Energy Policy*, Vol. 46 No. C, pp. 489-497.

Leopoldsberger, G., Bienert, S., Brunauer, W., Bobsin, K. and Schuetzenhofer, C. (2011), "Energising property valuation: putting a value on energy-efficient buildings", *The Appraisal Journal*, Vol. 79 No. 2, pp. 115-125.

Lorenz, D. and Luetzkendorf, T. (2011), "Sustainability and property valuation: systematisation of existing approaches and recommendations for future action", *Journal of Property Investment & Finance*, Vol. 29 No. 6, pp.644-676.

Malpezzi, S. (2003), "Hedonic pricing models: a selective and applied review", in O'Sullivan, T. and Gibb, K. (Ed.), *Housing Economics and Public Policy, Essays in Honor of Duncan Maclennan*, Blackwell, Oxford, pp. 67-89.

Mason, C. and Quigley, J.M. (1996), "Non-parametric hedonic housing prices", *Housing Studies*, Vol. 11 No. 3, pp. 373-385.

Meins, E., Luetzkendorf, T., Lorenz, D., Leopoldsberger, G., Ok Kyu Frank, S., Burkhard, H.-P., Stoy, C. and Bienert, S. (2011), *Nachhaltigkeit und Wertermittlung von Immobilien, Leitfaden für Deutschland, Österreich und die Schweiz (NUWEL)*, CCRS Center for Corporate Responsibility and Sustainability, University Zurich, Zurich, available at: www.nuwel.ch/ (accessed 12 February 2014).

Pace, R.K. (1998), "Appraisal using generalized additive models", *Journal of Real Estate Research*, Vol. 15 No.1, pp. 77-99.

Parmeter, C.F., Henderson, D.J. and Kumbhakar, S.C. (2007), "Nonparametric estimation of a hedonic price function", *Journal of Applied Econometrics*, Vol. 22 No. 3, pp. 695-699.

Pivo, G. and Fischer, J.D. (2010), "Income, value and returns in socially responsible office properties", *Journal of Real Estate Research*, Vol. 32 No. 3, pp. 243-270.

RICS (2009), "Sustainability and commercial property valuation", Valuation Information Paper No. 13, Royal Institution of Chartered Surveyors, Coventry.

RICS (2013), *Going for Green: Sustainable Building Certification Statistics Europe*, Royal Institution of Chartered Surveyors, Frankfurt, Brussels.

RICS (2015), *Going for Green: Sustainable Building Certification Statistics Europe*, Royal Institution of Chartered Surveyors, Frankfurt, Brussels.

Rosen, S. (1974), "Hedonic prices and implicit markets: product differentiation in pure competition", *The Journal of Political Economy*, Vol. 82 No. 1, pp.35-55.

Shimizu, C. (2012), "The investment value of green buildings – the sustainability of property value", Working Paper No. 10, Business Ethics & Compliance Research Center, Reitaku University, Kashiwa City.

Wood, S. (2003), "Thin plate regression splines", *Journal of the Royal Statistical Society*, B-Series, Vol. 65 No. 1, pp. 95-114.

Wood, S. (2006), *An Introduction to Generalized Additive Models with R*, Taylor & Francis Group, Boca Raton, FL.

Further reading

Eilers, P. and Marx, B. (1996), "Flexible smoothing with B-splines and penalties", *Statistical Science*, Vol. 11 No. 2, pp. 89-121.

Halvorsen, R. and Palmquist, R. (1980), "The interpretation of dummy variables in semilogarithmic equations", *The American Economic Review*, Vol. 70 No. 3, pp. 474-475.

Hardy, M.A. (1993), *Regression with Dummy Variables*, Sage University Paper Series on Quantitative Applications in the Social Sciences, No. 07-093, Sage, Newbury Park, CA.

Lorenz, D. and Lützkendorf, T. (2008), "Sustainability in property valuation – theory and practice", *Journal of Property, Investment and Finance*, Vol. 26 No. 6, pp. 482-521.

Piazolo, D. and Wilke, E. (2012), "Out-Performance energieeffizienter Gebäude". *Immobilien und Finanzierung*, Vol. 63 No. 3, pp. 84-86.

Porter, M. and Kramer, M. (2006), "Strategy & society: the link between competitive advantage and corporate social responsibility", *Harvard Business Reviews*, Vol. 84 No. 12, pp. 78-92.

Wilke, E. (2011), *An Analysis of the Impact of Property Efficiency on Investor's and Occupier's Performance*, Verlag Dr Kovac, Hamburg.

3 Energy efficiency: behavioural effects of occupants and the role of refurbishment for European office buildings

Markus Surmann, Jens Hirsch

Abstract

Energy consumption in office buildings is determined partly by fixed building characteristics, but also by the behaviour of occupants. Within the European Union, office buildings have become subject to more stringent energy efficiency regulation for new construction or extensive refurbishment, with the aim to reduce energy consumption and carbon emissions. The study determines the influence of physical building characteristics and occupant behaviour on energy consumption, and in particular, the role of refurbishment in different intensities on energy consumption is investigated. The dataset of the *Green Rating Alliance* is tested to provide evidence, by applying multiple regression models for energy consumption. The results highlight considerably increased energy consumption of single-tenant compared to multi-tenant office buildings. Very large office buildings consume significantly more energy per square meter that their smaller peers. A building's modelled water consumption turns out to be a good indicator for the actual energy consumption, emphasizing the importance of assessing further sustainability measures. Overall, buildings of higher age turn out to be of lower energy consumption, pointing to additional appliances and equipment in more recent buildings, to provide better services and more comfort. In general, extensive refurbishment measures account for significantly higher energy use, since the overall quality of the buildings is improved with additional appliances and equipment. Testing for the interaction effect between building age and refurbishment, the results demonstrate significantly lower additional energy consumption for buildings with more recent extensive refurbishment, compared to those with refurbishment several years ago. However, the results need to be considered with precaution against deriving firm conclusions due to the small sample size and some drawbacks in the applied dataset.

Keywords: Sustainable real estate, energy efficiency, carbon emissions, behavioural real estate, office buildings.

Acknowledgments: The authors are thankful to *Green Rating Alliance* (*GRA*) for provision of the dataset used in the study.

3.1 Introduction

In the *European Union* (*EU*), energy consumption by the building sector accounts for 40% of the total final energy use. Over the past decade, *EU* policy has required all member states to implement increased energy efficiency regulation for new construction. As a consequence, office buildings became subject to more stringent energy efficiency regulation for new construction or extensive refurbishment. The term "refurbishment" is used within this study referring to other terms used in the real estate industry, such as retrofit, redevelopment or revitalisation, usually defining major construction works affecting the thermal, technical and further energy consuming characteristics within the existing building structure. In a theoretical framework, these measures are expected to save energy, provided the technical facilities and their operability, as well as the behaviour of occupants, do not undermine the potential positive effects, or additional services with further equipment and additional energy consumption is applied.

The energy consumption of office buildings is determined mainly by core operations, which refer to physical building characteristics (heating, cooling, lighting, ventilation and elevators) and consumption from applied technical equipment, depending on occupant behaviour in the buildings. That is, besides the fixed building characteristics such as location, size, building fabric and age, energy consumption in office buildings also depends substantially on the behaviour of their occupants.

While more stringent energy efficiency regulation is intended to reduce carbon emissions from the existing building stock, the question arises as to whether this can be achieved essentially by focusing on the physical building characteristics in the context of technological progress. The controversial debate about the existence of a latent "rebound effect", implying a negative behavioural response of occupants when confronted with a more energy-efficient building quality, pertains to the role of the occupants with their behaviour towards energy consumption. Since the rebound effect is attributed to occupant behaviour with additional use of the same services due to increased efficiency, it is rather difficult to identify this effect. For the existing building stock refurbishments are in many cases not realized in order to only increase the energy efficiency, but to increase or to provide further services, such as technical equipment that might be installed, in order to satisfy increased user requirements.

In this context, the study tries to investigate the relationship between actual energy consumption, physical building characteristics and behavioural attributes of occupants, subject to attempts to control for outdoor weather conditions and spatial heterogeneity.

The results provide evidence that refurbishments are associated with higher consumption in the tested office building portfolio, due to additional appliances and equipment. Testing a small sub-sample with refurbishment dedicated to energy efficiency and thermal building characteristics, no indication of a potential rebound effect or significant energy savings from these refurbishment measures are found. Although newer buildings are subject to more stringent energy efficiency regulation, this study reveals that newer office buildings do not necessarily consume less energy. This is found to be true only for most recently refurbished observations in the tested portfolio.

The remainder of this study is as organised as follows. Section 3.2 provides the background to this study and considers some related research. In Section 3.3, the characteristics of the used dataset are explained and the econometric methodology is discussed. Section 3.4 presents the results of the regression model, while Section 3.5 highlights some major conclusions and recommendations for further research.

3.2 Background and empirical framework

3.2.1 Background

Due to a significant greenhouse gas externality associated with energy consumption, the building sector has considerable potential in reducing global carbon emissions from the existing building stock. In the absence of any carbon pricing, an increment in energy consumption of commercial buildings has a negative impact on climate change.

Within the *EU*, the *European Performance of Buildings Directive* (*EPBD*) obliged all member states to implement increased energy efficiency regulation for new construction. In the course of the *EPBD*, *Energy Performance Certificates* (*EPC*) were introduced in 2002 and became mandatory by the year 2008. The regulation was implemented, based on a theoretical framework requiring the application of stricter building codes for new construction, and for existing structures undergoing complete or major refurbishment. This applies also for office buildings. The targeted reduction in energy consumption is based mostly on the potential offered by the physical building. However, little attention has been paid to the success factors of refurbishment in the context of energy savings.

Over the past decade, research insights into energy consumption and potential carbon emission savings in the commercial building sector of Europe have remained limited. This corresponds to experiences in the *US*, where Kahn et al. (2014) found that research on commercial building energy consumption is still limited and most of it has been provided by engineers rather than economists. Research on the engineering dimension of energy efficiency of office buildings exhibits an extensive body of literature from the past decades, for example in the related research projects of the *Association of European Renewable Energy Research Centres* (2016), *Fraunhofer ISE* (2015), *Fraunhofer IBP* (2009) or Post-occupancy Review of Buildings and their Engineering (1997). However, a study by Guerra Santin et al. (2009) argues that empirical results, especially on occupants' influence in the commercial or office building sector of Europe, remain unsatisfactory.

The energy consumption of office buildings is determined by the combination and interaction of multiple factors. The physical building characteristics include location, building envelope (referring to building size, fabric and age) and technical equipment, such as heating, cooling, ventilation, lighting, elevators and *IT* equipment. The most relevant factors influencing energy consumption for heating and cooling are the thermal characteristics and related technical systems, the building type with regard to the surface to cubic volume ratio, occupant behaviour and the outdoor weather conditions. Since the largest energy consumption in office buildings is determined by heating, ventilation and air-conditions (*HVAC*), a significant intensification in the energy consumption, due to the expansion of *HVAC* systems in new buildings, was observed over the past decades. With the further expansion of new office space build, a growing trend of energy consumption is expected for the future (Lombard et al., 2008).

Based on *UK* office buildings Jenkins et al. (2008) investigate that the energy consumption is primarily dominated by heating energy consumption. Their study assumes a more efficient office equipment and lighting in the future with lower levels of surplus heat production, but an increasing demand in heating energy for substitution. This will be mitigated to some extent by the temperature increase coming along with climate change.

Due to economies of scale in heating and cooling of office buildings, very large structures might behave differently to their smaller peers. Kahn et al. (2014) prove for significantly higher energy consumption with increase in building size. They assume that heating and cooling of large buildings requires additional equipment and energy loads to bridge large vertical distances in office towers, offsetting otherwise beneficial economies of scale.

The difference between actual energy consumption and engineering-predicted intrinsic energy consumption depends on the final construction with its installed technical systems and also on the utilisation of such systems, for example, in response to the indoor temperature set by occupants. However, the predicted intrinsic energy consumption is estimated on the basis of several determinants included in a modelled code baseline building, to indicate potential cost savings. Thus, the intrinsic assessment does not necessarily predict the future actual consumption since the prediction is applied as an engineering benchmark for relative energy performance, to allow for comparisons between buildings or implement stricter energy efficiency regulation in building codes (New Buildings Institute, 2008). Torcellini et al. (2004) suggest that the deviation between actual consumption and predicted savings from intrinsic assessment is caused by higher than expected loads form occupants' behaviour and systems which do not perform together as designed.

The comparison between intrinsic predictions and actual consumption is even more difficult, since the intrinsic energy assessment might not predict all issues and variation in operational factors of energy consumption, such as "plug loads". These plug loads represent not the "regulated loads" for basic building comfort, such as *HVAC* and lighting, but the "unregulated" or process-related energy consumption, which is primarily driven by building equipment (elevators, computers, video-screens) and activity of building occupants. In the modelling of intrinsic energy for certification of *Leadership in Energy and Environmental Design* (*LEED*) a default of 25% of total "baseline energy" was included. More importantly, previously completed *LEED* projects were not able to attempt any energy savings in the unregulated plug load category with a widely varying percentage of plug loads (New Buildings Institute, 2008) and Scofield (2009) argues that evidence for lower energy from *LEED*-certification of office buildings has not been provided in a previous study.

Further key factors account for differences between the predicted intrinsic and actual energy consumption, such as differing occupancy hours and intensities, experimental – especially energy saving – technology does not perform as expected or a lack of knowledge, how to run the building most energy-efficiently by facility managers and/or occupants (Newsham et al., 2009). To sum it up, it remains reasonable that actual energy consumption is affected by multiple factors, whereas intrinsic energy assessment has limits in the applied determinants to predict actual energy consumption.

3.2.2 Behavioural effect of office occupants

Among the research of occupant behaviour and related effects on energy consumption exists only a small body of literature and the most of it is dedicated to modelling tools to simulate the influence of occupant behaviour and how occupants interact with building equipment and plug loads.

Besides the fixed influence of applied technical equipment in buildings, occupant behaviour concerning *HVAC* is highly dynamic and depends not only on the outdoor weather conditions, but also on the type of *HVAC* equipment and occupant experiences with them. Individual heating or cooling systems, instead of a centralised control system, allow for a varying usage between different (parts in) office buildings.

Technical equipment and plug loads in office buildings are prone to be significantly influenced by the behaviour of occupants in different appliances and intensities. Another influence factor is whether the building is rented out to a single tenant or to several. The allocated office space per occupant implies an important effect as well as the overall occupancy rate, indicating business cycle effects. Kahn et al. (2014) found that a 1% higher occupancy rate increases electricity consumption by 2.6% in office buildings. Depending on the specific industry and the related technical equipment, such as *IT*, occupants' activities and behavioural patterns result in a different intensity of energy consumption.

Moreover, the individual awareness and behavioural attitude of occupants towards energy consumption and potential energy (cost) savings is assumed, to play an overall important role in the dynamic dimension of energy consumption (Bloom et al., 2011). Experience from the *USA* demonstrates that the presence of a building engineer significantly lowers consumption, compared to buildings without an engineer (Kahn et al., 2014). For Australian office properties, Gabe (2014) found that a frequent site energy consumption auditing is a potential strategy to reduce energy consumption and mitigate greenhouse gas emissions. As part of a so-called green management strategy, the repetitive auditing experiences to be a successful approach for motivating owners to invest in energy efficiency technologies. For a European portfolio of corporate real estate assets from the wholesale and hypermarket sector, Surmann et al. (2016) found evidence that a centralised corporate energy management contributes to recurring energy consumption reductions and thus energy measures for corporate assets provide leverage toward a more efficient corporate environmental performance.

Research work of Kavulya and Becerik-Gerber (2012) analysed occupant behaviour in an office environment and interaction of occupants with energy consuming equipment in visual observations with tracking of daily activities on commonly used office appliances. The results estimate an energy saving potential of up to 38%, if occupants switch of appliances not in use, due to higher awareness between consumption and occupant usage data. The study argues that energy awareness plays a key role to modify the behaviour of occupants towards reduced energy consumption.

3.2.3 Refurbishment and rebound effect

The term rebound effect refers to a situation in which the actual energy savings from an innovation are lower than those expected from improved efficiency, due to more extensive – rebound – consumption by users, either in the form of more hours of use or a higher quality of energy service (Herring and Roy, 2007). Experience from the automobile industry shows that a reduction in fuel consumption was achieved, while the safety and comfort attributes of cars had been enhanced remarkably (Knittel, 2012). With regard to cars, the term rebound effect means that a more fuel efficient car will lead to more kilometres travelled (Gillingham et al., 2013).

Similar observations were expected from the commercial building sector in the past, offsetting increased energy efficiency to some extent. The effect has been investigated and described in an early study for commercial buildings by Greening et al. (2000). They conclude that the range of estimates for the size of the rebound effect is very low to moderate. Based on a review of studies for gasoline and electricity consumption, Gillingham et al. (2013; 2015) argue that the behavioural response of users offsets between 5% and up to 30% of intended energy savings. They conclude that the rebound effect is rather small and therefore no excuse for inaction in the economy.

For commercial real estate it is difficult to distinguish between the rebound effect and the "principle of additionality", in which higher energy efficiency is realised with the provision of increased or additional services and comfort, provided with less energy consumption than they would otherwise have. This principle of additionality usually comes along in the course of refurbishments or in the development of new buildings, when additional or new technical equipment is installed, in order to satisfy increased user requirements. The principle is observed for commercial buildings of lower age or recent refurbishment with higher energy consumption compared to their older peers. Recent research results from the *USA* reveal that both younger office buildings and those of higher quality are in fact responsible for higher electricity consumption (Kahn et al., 2014).

Kahn et al. (2014) state that energy consumption and building quality are complements – not substitutes. Even when technological progress reduces the theoretical energy demand from *HVAC* and lighting, the increase in quality attributes, such as a more attractive lobby and office space, more elevators and individual adaption of comfort temperature by occupants, may actually increase energy consumption. Hence, the replacement of older structures by new buildings or at least extensive refurbishment is likely to increase the energy consumption of the durable building stock.

Results for a refurbishment variable included in the work of Kahn et al. (2014) have documented that refurbished buildings feature a higher energy consumption of 19%, compared to similar-sized buildings without refurbishment. Besides a potential, but expected to be small, rebound effect when improved building quality provides better *HVAC* and lighting systems which may induce greater energy use, the additional services employed in the course of refurbishment account for the increase in consumption for the most part.

Furthermore, refurbishment is not associated only with energy-saving measures of the technical equipment in a building, but often involves a replacement or enlargement of the technical infrastructure, especially lighting, *HVAC* and *IT*, which might be associated with additional energy consumption. A survey by Kok et al. (2012) found only 14% of refurbishments with improvements solely dedicated to sustainability, whereas refurbishment was carried out to improve the overall quality of the buildings. In the context of the necessity to update otherwise obsolete buildings (Baum and McElhinney, 1997; Baum and Turner, 2004) also energy efficiency improvements were considered for the technical equipment replaced, but moreover the building quality standard as a whole is enhanced. This corresponds to the observation of Chegut et al. (2015) that although sustainable construction is gaining market share, new construction and building refurbishments are still mostly conventional.

With regard to the discussed empirical findings, this study is intended to investigate the relationship between actual energy consumption, physical building characteristics and occupant attributes. With increasing building size up to a certain point, we expect lower energy consumption by trend for office buildings, due to economies of scale in heating and cooling. For very large office buildings (office towers), we expect higher energy consumption while economies of scale are offset by higher energy loads to bridge large vertical distances in office towers. Since energy efficiency regulation within the *EU* has become more rigorous for new construction or extensive refurbishment, we test whether higher energy efficiency is achieved for younger office buildings. The effect of refurbishment is of special interest in this study. On the one hand, major refurbishment is expected to consider higher energy efficiency standards, thus allowing for improvements of the thermo-physical quality of the buildings and potential energy savings. On the other hand, research results prove for additional energy consumption in the course of refurbishment, due to the provision of additional services and new technical equipment employed.

3.3 Dataset

In order to answer our research questions, we use the dataset of the *Green Rating Alliance* (*GRA*), which provides physical office building characteristics and occupant attributes in detail at the building level. The dataset includes two main sources of energy consumption; first, the actual metered energy consumption and second, the intrinsic energy consumption as result of the Green Rating auditing. However, the dataset of *GRA* contains actual energy consumption and intrinsic assessment metered only once at a certain point of time in the years from 2008 to 2012 for issuing the Green Rating audit. Therefore, the dataset is not covering a panel of observations over time, which is a drawback for the analysis.

The intrinsic energy measure of *GRA* is based on an individual assessment of the physical building characteristics, with an estimation of the thermal qualities of different construction and fit-out elements, inherent in each single building. The calculation of intrinsic consumption is modelled under standard – optimised – conditions of the building use with assumptions of occupant behaviour concerning schedules and temperature set points. While this fixed standard model is equal for each building in the assessment, the intrinsic energy should be seen as a measure of potential energy consumption, without taking into account the impact of occupant behaviour differing among buildings. Since *GRA*'s intrinsic benchmark is modelling under optimised conditions of the building use and does not account for plug loads from the occupants, we expect much lower intrinsic figures than actual metered consumption.

The dataset also contains actual and intrinsic measures concerning the buildings' annual water consumption. Parallel as for energy consumption, actual measures are derived from metered consumption and intrinsic measures from modelling based on standard assumptions. In regard to the relationship between energy and water consumption, office buildings designed with higher energy efficiency standards or stricter building codes might also have higher standards in water efficiency for lower actual consumption. Investors committed for investment in sustainable real estate consider metered water consumption besides energy consumption. Among other institutional investors, *Bouwfonds Investment Management* (2013) states commitment, to contribute to a reduction in water intensity of the real estate they manage. We hypothesize a correlation between energy and water consumption, due to a more efficient building design and higher efficiency requirements from increased regulation, as well as from the social responsible investment strategies of institutional investors (Cajias and Bienert, 2011; Cajias et al., 2011; Kerscher and Schaefers, 2015).

Therefore, we use intrinsic water consumption measures from *GRA* to estimate actual energy consumption, because the intrinsic consumption is based directly on building characteristics and not influenced by occupant behaviour, thereby avoiding potential bias.

To control for the attributes of outdoor weather conditions and temperature, the *heating degree days* (*HDD*) and *cooling degree days* (*CDD*) of the respective auditing year were used. The *HDD* and *CDD* were calculated on a basis of 65°F (18.3°C), obtained from the database of *Weather Underground* (2015). While the auditing process of *GRA* with actual measurement is assessed over a time period of at least 8 months (normally 12), we applied the *HDD* and *CDD* with respect to the year in which more than 4 months of the auditing period were carried out. Our total sample comprises 288 observations, combining the *GRA* sample with the *HDD* and *CDD* in a period from 2008 to 2012.

In the context of our theoretical considerations on the role of physical building characteristics, building age and size, as well as ceiling height and heating production type and the intensity of refurbishment are of a major research interest. To investigate the influence of occupants, we focus on the attributes of building area per office occupant, and differentiate between single and multi-tenant-occupied buildings. We expect a significant difference between buildings rented on single-tenant basis, compared to those on a multi-tenant basis. Our supposition is that multi-tenant buildings face more decisions regarding the heating, cooling and lighting of the office space in question, thus resulting to higher consumption.

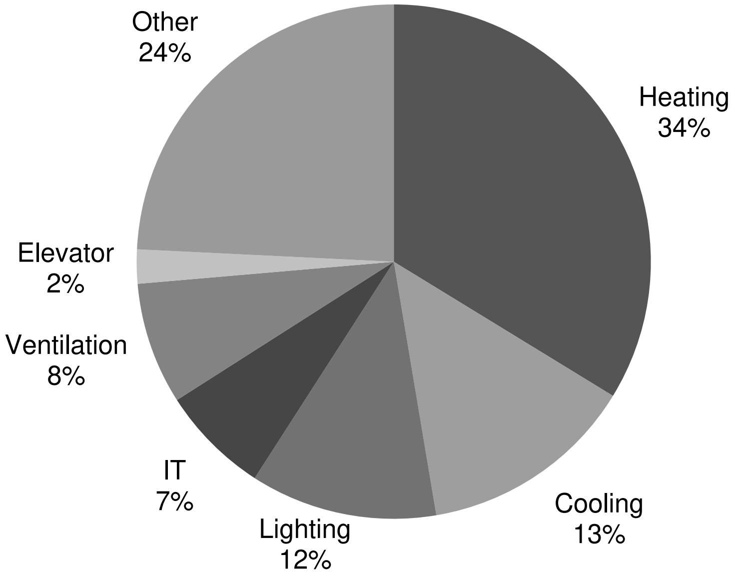
The sub-categories of the total actual energy consumption applicable from the dataset, enable distinguishing between each energy-consuming sub-category. Table 1 includes some descriptive statistics of the applied metric response and explanatory variables:

Table 1: Descriptive statistics of applied metric attributes

Descriptive Statistics	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
Actual energy consumption in kWh/sqm/a	73.5	175.7	235.2	254.8	317.2	696.5
Intrinsic energy consumption in kWh/sqm/a	46.2	104.3	129.0	138.2	162.1	368.7
No. of heating degree days in year of Green Rating audit	1,317	2,429	2,652	2,757	3,009	3,941
No. of cooling degree days in year of Green Rating audit	0	123	163	179	183	734
Intrinsic water consumption in cbm/sqm/a	0.094	0.266	0.333	0.352	0.432	1.060
Actual energy consumption heating in kWh/sqm/a	6.1	49.1	75.5	83.5	101.6	365.7
Actual energy consumption cooling in kWh/sqm/a	0.0	12.1	24.5	34.6	41.6	205.0
Actual energy consumption lighting in kWh/sqm/a	1.0	17.5	24.2	27.5	35.3	115.6
Actual energy consumption IT in kWh/sqm/a	1.1	8.3	12.8	15.9	20.7	77.1
Actual energy consumption ventilation in kWh/sqm/a	0.0	8.4	14.6	19.8	25.1	144.7
Actual energy consumption elevator in kWh/sqm/a	0.0	2.3	3.9	5.3	6.3	61.1
Actual energy consumption other in kWh/sqm/a	0.0	24.5	50.2	68.7	93.1	503.0
Building age (economic)	0.0	3.0	9.0	11.7	19.0	50.0
Building area in sqm	1,340	5,596	10,040	13,960	17,979	108,070
Building area in sqm per occupant	5.2	17.0	21.8	26.2	30.7	147.1
Ceiling height in meters	2.3	2.6	2.7	2.8	2.9	4.3

Comparing the actual with the intrinsic energy consumption, a large gap is obvious at first glance. Since the intrinsic consumption is a measure in relation to the physical building characteristics and a standard factor for occupant influence, modelled under optimised conditions of the building use, the large gap meets our expectations.

Figure 1: Sub-categories' share of total actual energy consumption



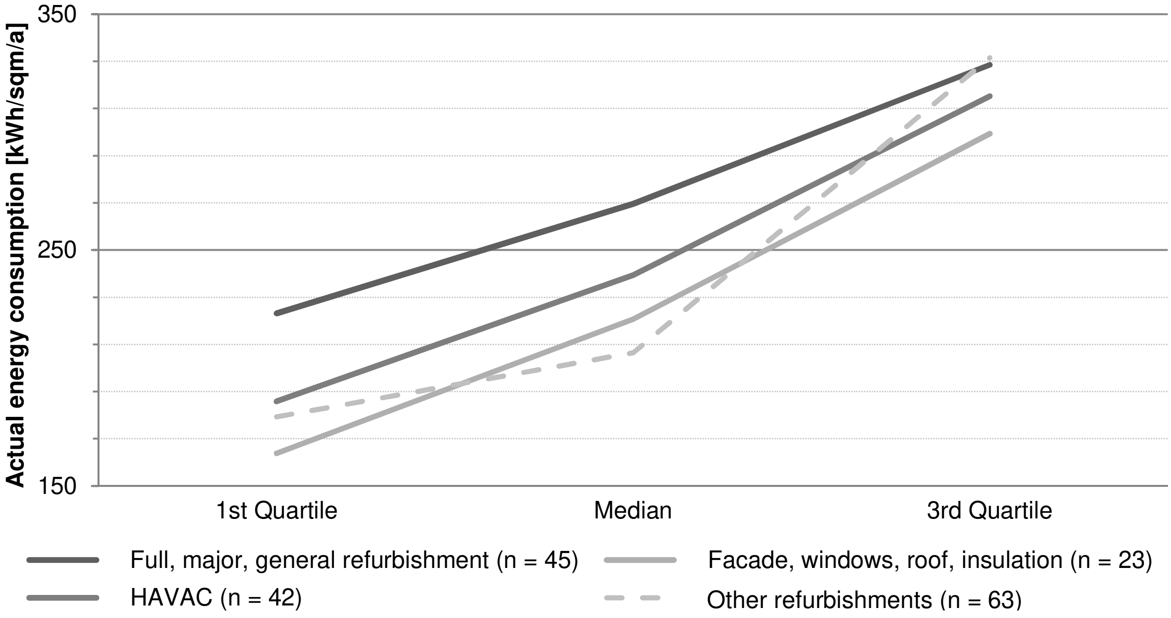
When looking at the share of sub-categories to the total energy consumption in Figure 1, it is evident that heating, cooling and ventilation account for more than 55% of the total actual consumption. The sub-category "other" accounts for a share of 24% of the total consumption, including consumption e.g. from (underground) car park, canteen and outside lighting. However, the share of these categories summarised under "other" was not applicable from the *GRA* dataset, what points to a limitation when explaining actual energy consumption.

The economic building age was derived from the (historical) construction year under consideration of complete or extensive (full/major/general) refurbishment in the past and yields an average of 12 years. This result demonstrates the importance of the information from the dataset regarding refurbishment.

Table 2: Actual energy consumption and refurbishment sub-samples

Refurbishment and Actual energy consumption [kWh/sqm/a]	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
Total Sample (n = 288)	73.4	175.7	235.2	254.8	317.2	696.5
Refurbishment = no (n = 115)	86.3	169.6	223.2	240.4	296.1	696.5
Refurbishment = yes (n = 173)	73.4	181.6	243.1	264.4	328.5	685.5
Refurbishment <= 5 years (n = 109)	73.5	175.9	238.4	262.4	328.5	685.5
Refurbishment > 5 years & <= 15 years (n = 50)	111.6	188.7	240.4	256.1	294.3	615.2
Refurbishment > 15 years (n = 14)	134.4	190.2	251.2	310.2	444.8	503.3
Full, major, general refurbishment (n = 45)	104.0	223.2	269.6	276.1	328.5	478.6
Façade, windows, roof, insulation (n = 23)	91.8	163.8	220.7	243.9	299.4	538.8
HVAC (n = 42)	108.6	185.8	239.3	261.6	315.2	609.7
Other refurbishments (n = 63)	104.0	179.3	206.4	263.7	331.5	685.5

Figure 2: Actual energy consumption and type of refurbishment



At first glance, we find no verification that refurbishment has a positive impact on energy efficiency in such a way, as to decrease actual energy consumption of the tested office buildings (see Table 2). Mean and median values of actual consumption of refurbished buildings are slightly above the levels of non-refurbished buildings. In comparison to the total sample, the observations attributed to having undergone a refurbishment in the past (n = 173) suggest a 3.6% higher energy consumption on average which points to the principle of additionality. The sub-sample for buildings refurbished more than 15 years ago indicates significantly higher actual energy consumption, especially concerning the mean and 75%-percentile, when compared with more recently refurbished buildings (see Table 2). It can be concluded that refurbishments in the last 15 years came with a stronger focus on energy efficiency. Actually, the share of refurbishments with a focus on façade, windows, roof, insulation or *HVAC* is much higher for recently refurbished buildings (≤15 years: 23.2%) than for other buildings (> 15 years: 4.5%).

A small sub-sample of 23 observations attributed with energy efficiency refurbishment concerning façade/windows/roof/insulation, which is expected to reduce energy consumption, shows the lowest actual energy consumption, as regards first, second and third quartile and the mean value as well as compared to the total sample. The result indicates a conservation potential of around 4.5% on average and approximately 6.6% for the median value, due to the refurbishment of thermal building characteristics. In contrast to the slight decrease in actual consumption in relation to the refurbishment of only thermal building characteristics, we found the actual consumption of 45 observations attributed with full/major/general refurbishment with a 13.2% higher consumption on average. This sub-sample even exceeds the average per square meter consumption of the total sample by 7.7%. Buildings with extensive (full/major/general) refurbishment also show higher energy consumption than buildings with refurbishments concerning *HVAC* equipment (Figure 2). We assume that for extensive refurbishments the potential positive effects of renewing thermal building characteristics or *HVAC* equipment might be counteracted by other changes in the building resulting into higher energy consumption. At first glance, the result proves for the principle of additionality as effect of extensive refurbishment measures.

To verify these preliminary results while accounting for other effects, we include refurbishment details as explanatory variables in our regression analysis.

Table 3: Correlation matrix of metric attributes

Correlation Matrix		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
LN(actual energy consumption in kWh/sqm/a)	(1)	1								
LN(intrinsic energy consumption in kWh/sqm/a)	(2)	0.544	1							
No. of heating degree days in year of Green Rating audit (HDD)	(3)	0.084	0.225	1						
No. of cooling degree days in year of Green Rating audit (CDD)	(4)	-0.200	-0.254	-0.556	1					
Intrinsic water consumption in cbm/sqm/a	(5)	0.233	0.306	0.004	-0.072	1				
Building age (economic)	(6)	-0.056	0.020	-0.089	0.089	0.057	1			
LN(building area in sqm)	(7)	0.126	-0.043	0.073	-0.044	-0.118	-0.054	1		
LN(building area in sqm per occupant)	(8)	-0.143	-0.019	0.039	-0.061	0.127	-0.029	0.023	1	
Ceiling height in meters	(9)	0.076	0.125	0.112	-0.047	-0.012	-0.174	0.033	0.082	1

The correlation matrix for metric attributes in Table 3 shows an orthogonal linear relationship between the response and explanatory variables. Corresponding to our expectations, a positive bivariate relationship between intrinsic and actual energy consumption is observable. *HDD* (*CDD*) demonstrate a positive (negative) bidirectional relationship with actual and intrinsic consumption. Somewhat surprisingly, the energy consumption decreases with an increase in *CDD*. Anyway, this result is only based on correlation and needs to be further examined by a regression analysis, taking into account all other possible explanatory factors. The intrinsic water consumption shows a positive bivariate correlation with actual energy consumption.

The negative relationship between building age and actual consumption is at first glance interesting, when observations of older buildings turn out to be less energy consuming.

The building size is expected to be inversely related to energy consumption (per square meter), due to economies of scale in larger buildings. However, this does not appear to be true for actual consumption. The building area allocated per occupant has been calculated from the building area and the total number of occupants, both obtained from *GRA* data. The negative bivariate correlation between the building area allocated per occupant might be the result of missing information about vacancy as more space per occupant can mean: a) a higher vacancy rate and b) larger offices or common spaces. The two possible explanations cannot be distinguished from one another with the given *GRA* data.

3.4 Econometric approach

The energy consumption of office buildings can be explained with a function of the consumption from core operations (*HVAC*) in relation to the physical building and additional consumption from appliances with installed equipment and plug loads both used by the occupants. In order to determine these effects on the response variable, we have to control for all other factors affecting energy consumption. To address this issue within a multiple regression model, the dependent variable is decomposed into the implicit contribution of the available building characteristics and occupant attributes, while controlling for the outdoor weather conditions and effects from spatial heterogeneity.

The general regression model via ordinary least squares is described in equation 1, with Y as the response variable, X as a vector containing the explanatory variables, β as unknown parameters and ε as error term.

$$\mathrm{Y}_i = \alpha_i + \beta \mathrm{X}_i + \varepsilon_i \tag{1}$$

In our approach, the regression model is used for actual energy consumption metered in kWh/sqm/a. The vector containing the explanatory variables includes the physical building and occupant attributes, as well as the *HDD* and *CDD* controlling for the local outdoor climate weather conditions and effects from spatial heterogeneity.

For the regression of actual energy consumption, the response variable is transformed logarithmically (Malpezzi, 2003). This procedure allows for the interpretation of the estimated effects as elasticities if both sides are logarithmically transformed, or semi-elasticities if the explanatory variable enters the equation in absolute values. Furthermore, strictly positive metric variables are transformed logarithmically when estimating a log-linear function in equation (2):

$$[\mathrm{LN}(\text{actual E cons.})_i] = \alpha + \beta_1\,\mathrm{HDD}_i + \beta_2\,\mathrm{CDD}_i + \beta_3 \begin{bmatrix} \text{building age class}_i \\ \text{building area class}_i \\ \mathrm{LN}(\text{area/occupant})_i \\ \text{intrinsic water cons.}_i \end{bmatrix} +$$

$$\beta_4\,\text{single tenant binary}_i + \beta_5\,\text{electric heating binary}_i + \beta_6\,\text{refurb. binary}_i +$$

$$[\text{country}_i'\kappa] + \varepsilon_i \tag{2}$$

where (*actual E cons.*)$_i$: represents the actual energy consumption of building *i*, *(area/ occupant)*$_i$: represents the allocated area per occupant, *intrinsic water cons.*$_i$: represents the intrinsic water consumption, *single tenant binary*$_i$: represents single- or multi-tenant use, *electric heating binary*$_i$: represents electric heat production, *refurb. binary*$_i$: represents full/major/general refurbishment, *country*$_i$: represents location (country) and ε_i: represents an *iid* error term.

The explanatory variables *HDD* and *CDD* control for the local outdoor weather conditions in the relevant year of the Green Rating audit of the observations (building *i*).

The *building age* is included to test for differences between newer and older buildings. This was considered under economic considerations, reflecting total or major refurbishment with improved physical characteristics of the buildings, thus expressing a proxy for depreciation. This economic building age was classified in three groups (0-10, 11-20, >20). The *building area* is introduced to the regression model in terms of dummy variables representing the building's belonging to one of five quantiles. The building area allocated per occupant in square meters is entered logarithmically into the model with *LN(area/occupant)*.

The Green Rating audit data also contain information about the buildings' sustainability characteristics besides energy consumption, e.g. *Water consumption*, waste and carbon emissions, metrically scaled in units per square meter and year. Carbon emissions are highly correlated with energy consumption and therefore omitted for the regression. If one of the non-energetic sustainability ratings has significant explanatory power for a building's energy consumption, sustainability characteristics might become more relevant for investors, because they can help to identify energy-efficient buildings. In this regard, we use the intrinsic values for water consumption, to assess the influence on energy consumption. The actual values are not considered, due to expected bias by the specific occupant behaviour. Furthermore, a dummy variable for *electric heating* enters the equation to control for energy consumption related to different technical systems in the buildings.

With regard to the occupant attributes, the *single tenant binary* distinguishes between a single or multi-tenant use of the building premises.

In order to provide evidence for the effect of refurbishment on energy consumption, another dummy variable is introduced, to estimate the effect of a *full, major or general refurbishment*. Since we have few observations in the dataset with refurbishment dedicated to energy efficiency and thermal building characteristics, we use the attributes *façade/windows/ roof/insulation* instead of the binary for extensive refurbishment in a second specification of the regression model. For the small sub-sample of 23 observations, a positive effect in the regression of energy consumption might point to a potential rebound effect with no energy savings resulting from the refurbishment. A negative coefficient could indicate energy savings due to the refurbishment measures.

A matrix of *country* dummies was considered to control for spatial heterogeneity, e.g. energy efficiency regulation with regard to local building codes and different pricing of energy between the 14 European countries. Due to the introduced *HDD* and *CDD* with reference to the location-based outdoor weather conditions, we do not append additional location dummies, to control for spatial heterogeneity, so as to avoid any selection bias.

Since the assumption of linearity in the effects of regression models often seems to be too restrictive in a real estate context (see e.g. Brunauer et al., 2012; 2010; Mason and Quigley, 1996; Pace, 1998; Parmeter et al., 2007), it seems appropriate to use more flexible non- and semi-parametric regression models. For example, the effect of building age is known to be nonlinear (for instance, Fahrmeir and Tutz, 2001). We consider *generalized additive models* (*GAM*), as described in Wood (2006), to discover nonlinear effects for the continuous covariates. Applying *GAM* provides the advantage, to express the nonlinear effects in the relationship between response and explanatory variables in visualized nonlinear regression splines.

To control for nonlinearity in the effects of our regression model, we replace the linear effects $\beta_j x_{ij}$ of the continuous covariates with possibly nonlinear functions $f_j(x_{ij})$ in equation (3):

$$[\mathrm{LN}(\text{actual E cons.})_i] = \alpha + \beta_1\,\mathrm{HDD}_i + f_1(\mathrm{CDD}_i) + f_2(\text{building age}_i) + f_3(\text{building area}_i) + f_4(\mathrm{LN}(\text{area/occupant})_i) + f_5(\text{intrinsic water cons.}_i) + f_6(\text{refurb. binary}_i * \text{building age}_i) + \beta_2\,\text{single tenant binary}_i + \beta_3\,\text{electric heating binary}_i + \beta_4\,\text{refurb. binary}_i + [\text{country}_i'\kappa] + \varepsilon_i \tag{3}$$

The linear effect for *HDD* is not replaced with a nonlinear function for technical reasons. It is common practice in regression modelling to introduce combined variables for important effects to estimate the interaction between the both variables. To further investigate the effect of refurbishment on energy consumption, the *building age* of those observations attributed *with refurbishment* from the past is introduced with a nonlinear function. Besides the separate main effect of full/major/general refurbishment, the interaction effect of building age for observations with a refurbishment in the past is included in the regression. This procedure allows to estimate and display the effect, to be interpreted as the additional energy consumption of observations undergone a refurbishment by trend.

3.5 Research results

3.5.1 Results for actual energy consumption from equation (2)

The results of our log-linear regression model for actual energy consumption are summarised in Table 4. The results for the regression with extensive refurbishment attributes full/major/ general as explanatory variable are shown in column 1. The model specification in column 2 adds the observations for refurbishment dedicated to energy efficiency and thermal characteristics with façade/windows/roof/insulation instead of the extensive regression observations. In regard to the dataset employed, the adjusted R^2-value of both models appears to be low. Therefore, the results are to be considered with precaution.

Table 4: Regression results of log-linear model on actual energy consumption as response variable from equation (2)

Response variable: LN(actual energy consumption in kWh/sqm/a)

Explanatory Variables Coefficient (t-Values)	1	2
Intercept	5.700 (17.069)***	5.702 (17.141)***
Number of HDD in audit year/100	-0.011 (-1.534)	-0.008 (-1.202)
Number of CDD in audit year/100	-0.055 (-1.674)	-0.060 (-1.761)
Economic building age 11-20 years	0.063 (1.273)	0.053 (1.077)
Economic building age > 20 years	-0.101 (-1.654)	-0.128 (-2.141)*
Building area second quantile	0.010 (0.189)	0.008 (0.143)
Building area third quantile	-0.015 (-0.206)	-0.030 (-0.435)
Building area fourth quantile	0.060 (0.887)	0.035 (0.530)
Building area fifth quantile	0.154 (2.365)*	0.141 (2.165)*
Single tenant	0.142 (2.909)**	0.147 (2.959)**
LN(sqm building area/occupant)	-0.127 (-2.409)*	-0.122 (-2.307)*
Intrinsic water consumption (cbm/sqm/a)	0.482 (2.882)**	0.483 (2.789)**
Electric heating	-0.192 (-3.665)***	-0.200 (-3.791)***
Full/major/general refurbishment	0.139 (2.344)*	
Façade/windows/roof/insulation refurbishment		-0.014 (-0.228)
Countries (n)	14	14
R^2	32.47	31.78
Adjusted R^2	25.64	24.88

Significance: *** 1%, ** 5%, * 10%

For the tested portfolio, the influence of outdoor weather conditions on actual energy consumptions seems to be very low, while the coefficients of *HDD* and *CDD* are not of any significance.

Turning to further explanatory variables measuring the influence of physical building characteristics, we found the classified economic building age to have virtually no explanatory power and lacking greater significance. Only the model specification including refurbishment with regard to energy efficiency and thermal characteristics in column 2 displays a low significant effect of those buildings with the highest economic building age (21-50 years). The actual energy consumption per square meter is 12% lower than in the group of youngest buildings (0-10 years). For the interpretation of the coefficients for binary variables in a semi-logarithmic regression, the percentage effect is calculated as anti-logarithm of the estimated coefficients with (($exp(\beta x) - 1) * 100$) with regard to the omitted reference variable (Halvorsen and Palmquist, 1980; Hardy, 1993).

While the economic building age was derived under consideration of the (historic) construction year and the applicable refurbishment year, as well as the intensity of refurbishment, we also run the regression model with the (historic) construction year and found no significant effect, again. This is a remarkable finding, due to the overall expectation of an impact from the increased energy efficiency regulation in *EU*-member states over the past decade. Subject to potential limitations in the dataset with only 288 observations, this result would suggest that stricter building codes and construction standards seem to emerge without exerting a significant impact on the conservation of actual energy consumption.

Regarding the building area, the expectation of less consumption in heating and cooling does not appear for the tested portfolio. On the contrary, the quantile with the largest buildings even shows a significant increase in energy consumption between 15% and 16%, compared to the quantile with the smallest buildings. The dataset might include some high-rise office towers, contained in the quantile with the largest buildings and attributed with much higher consumption per square meter.

The building area allocated per office occupant has a significant effect on energy consumption, indicating a decreased consumption for an increasing area per occupant. At first, this points to the relationship of higher vacancy in office buildings being associated with lower per square meter consumption. Furthermore, the evidence suggests that occupants with more space allocated, but constant equipment and plug loads (ceteris paribus) consume less per square meter. In other words: More occupants on the same office area will increase energy use per square meter, which is in line with the literature review in Section 3.2. Further explanatory power is expected from the regression with nonlinear effects and illustration in regression splines following equation (3).

The single tenant binary provides significant results. The coefficients demonstrate that single-tenant office buildings have significantly higher energy consumption than multi-tenant-occupied ones. With regard to the omitted multi-tenant reference category, the dummy variable explains a higher actual consumption of 15% (both column 1 and 2). Our expectation was that multi-tenant buildings would have higher energy consumption, because of somewhat contradictory decisions when running the building. A conclusion might be that a single tenant intends more to heat, cool, ventilate and light a building centrally as a whole, not differentiating (even when possible) between single building parts or floors, e.g. cooling of upper floors only. According to this interpretation, within a multi-tenant building, each tenant might behave in a more decentralised manner specifically for the smaller occupied part of the building. The more, a large single tenant might potentially consider energy prices with minor importance when referred to business turnover and allocated headcount cost.

The variable for intrinsic water consumption per square meter and year shows significance as explanatory variable for energy consumption. An increase in water consumption of 100 litres per square meter and year comes along with an approximately 6% increase in actual energy consumption. A water-efficient building infrastructure seems to be an indicator for a better energy performance by trend.

The electric production for heating has a highly significant negative effect on energy consumption. Under control of all other factors, energy consumption per square meter is more than 20% lower for electric heating in comparison to district heating network or boilers, thus indicating higher energy efficiency.

Turning to the refurbishment details introduced in our econometric approach, we obtain a significant coefficient for the aggregated dummy, containing full/major/general refurbishment, with reference to omitted observations without any refurbishment. The result reveals a positive impact on actual energy consumption for observations attributed with an extensive refurbishment. Compared to buildings without refurbishment, extensive refurbishment is attributed to have a higher energy consumption of 15%. The result proves for the principle of additionality being associated with refurbishment for the tested portfolio. This suggests that refurbishment was carried out to provide increased or additional services and comfort from appliances with additional or new equipment to satisfy user requirements.

Turning to the model specification with the small sub-sample for refurbishment dedicated to energy efficiency and thermal building characteristics, we find no significant impact of refurbishment associated with thermal qualities, contained in façade/windows/roof/ insulation. The coefficient is estimated with a negative value, which is intuitive to our expectation, but insignificant.

3.5.2 Results for actual energy consumption from equation (3)

The introduction of *GAM* and visualization with smoothed curves in regression splines is considered to control for nonlinearity in the effects of the regression. Table 5 provides the parametric coefficients for the linear effects following equation (3).

Table 5: Parametric coefficients of log-linear model on actual energy consumption as response variable from equation (3)

Response variable: LN(actual energy consumption in kWh/sqm/a)	
Explanatory Variables Coefficient (t-Values)	
Intercept	5.120 (15.881)***
Number of HDD in audit year/100	-0.006 (-0.828)
Single tenant	0.100 (2.050)*
Electric heating	-0.219 (-4.009)***
Full/major/general refurbishment	0.091 (1.443)
Countries (n)	14
R^2	44.50
Adjusted R^2	36.01

Significance: *** 1%, ** 5%, * 10%

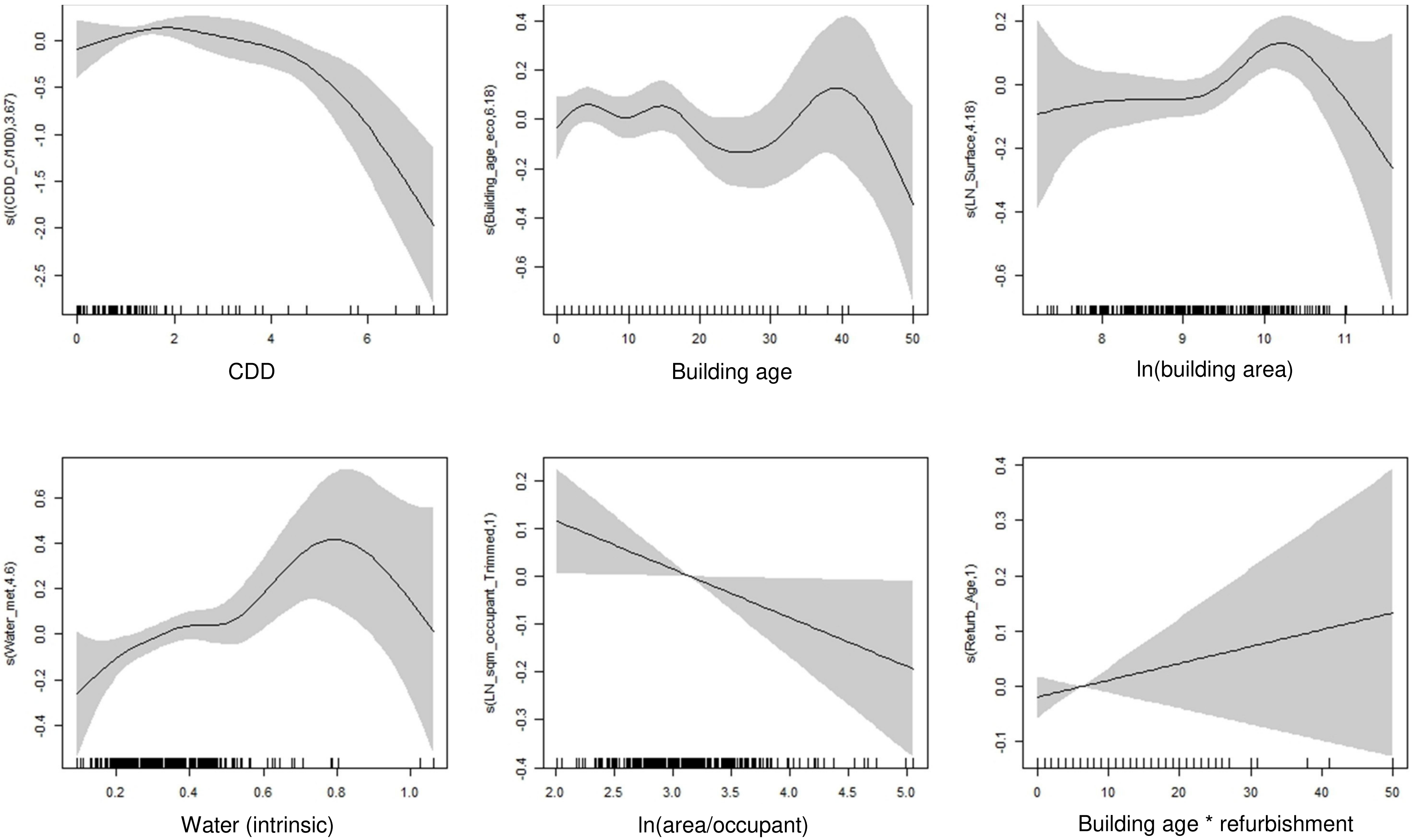
While lacking any significance, the continuous covariate for *HDD* was not visualized with a regression spline for technical reasons. For the single tenant binary, the results show again significantly higher energy consumption for single-tenant-occupied buildings. The coefficient for electric heating proves for significantly higher energy efficiency, again.

Interestingly, the introduced dummy variable for full/major/general refurbishment shows a positive coefficient, but is lacking significance. When this separate main effect is remaining without significance, we expect the interaction effect of building age for observations with a refurbishment in the past to explain the additional energy consumption of buildings with refurbishment in relation to their age.

The model with application of *GAM* in equation (3) reveals a higher explanatory power with adjusted R^2 above 36%, compared to the linear model specification from equation (2). However, the unexplained variation in the models remains of a considerable level.

The further covariate effects from equation (3) are illustrated in the regression splines of Figure 3. In each graph, the y-axes can be approximately analysed as the percentage effect on energy consumption. The value for the *estimated degrees of freedom* (*edf*) higher than 1.0 displays a nonlinear function in the relationship. Within the splines the continuous black lines are the expected effects and the grey areas are point-wise 95 percent confidence intervals.

Figure 3: Regression Splines of log-linear model on actual energy consumption as response variable from equation (3)



The regression spline for *CDD* indicates only limited observations for the small dataset and only few observations with a higher annual number of *CDD*, thus indicating instability in the effect. However, the effect is significant for very low number of *CDD* (between values 0 and 2 on the x-axes), indicating slightly higher energy consumption when *CDD* are increasing due to higher air-condition loads.

The regression spline for building age shows high volatility in the effect. The highest energy consumption is estimated for office buildings around 15 years of age, whereas the most recent buildings consume slightly less energy, potentially with reference to higher energy efficiency. Older buildings with more than 20 years of age are attributed with significant lower energy consumption. The effect is significant up to the age of 30 years, followed by instability with limited number of observations. At first glance, this suggests that observations of building age lower than 15 years indicate higher consumption in regard to additional appliances and equipment. Older buildings are assumed to provide less services and comfort, therefore associated with lower consumption, since we cannot distinguish between refurbished and non-refurbished observations in this spline.

The regression spline for the building size is supportive to our interpretation of the linear effect. Up to a building size of approximately 12,000 square meters the effect is almost indifferent for smaller observations. For buildings of more than 12,000 square meters, a strong and significant increase in energy consumption is observable with further increase in the building area. The effect might result from high-rise office towers in the dataset with higher levels of energy consumption, due to large vertical distances. The result proves not for any potential economies of scale in energy consumption in reference to the building size.

Higher intrinsic water consumption assessment corresponds to significantly higher actual energy consumption up to a certain level, indicated in the spline. Energy and water efficiency are correlated to each other. This could reflect the stricter efficiency regulation and building codes, indeed affecting the physical building. Further explanation could be that for most recent constructed buildings, rated in the Green Rating audit, the modelled intrinsic water consumption is set low when new buildings in fact consume lower energy.

The regression spline for office area allocated per occupant proves for a linear relationship (*edf* = 1.0) in the effect, corresponding to the significant effect found before in the linear specification of the regression model. More space per occupant allocated is attributed with lower energy consumption per square meter. We found this corresponding to the results of Kahn et al. (2014), who observed that an increase in the occupancy rate increases the electricity consumption of office buildings.

The regression spline for the interaction effect between building age and refurbishment illustrates also a linear relationship with highest energy efficiency for the most recent refurbished buildings. Since this effect is to be interpreted as the additional energy consumption of refurbished observations in relation to the building age and besides the main effect of refurbishment, introduced with a dummy for full/major/general refurbishment, it turns out that with higher age (as a proxy for the time when full/major/general refurbishment was carried out), the additional energy consumption of the buildings is significantly increasing. In general, younger observations have significantly lower energy consumption than older buildings. For the younger peers, although assumed with additional services and equipment introduced upon refurbishment, it seems that they are more energy-efficient than their older peers. This indicates a less energy-efficient refurbishment for older buildings carried out in the past, but with limited observations for a building age of more than 25 years and a rather board confidence cone. The regression spline suggests that refurbishment from the past (more than 10 years ago) was less dedicated to energy-efficient appliances and equipment, compared to most recent refurbishment efforts, all else equal. This result for lower additional energy consumption in relation to refurbishment and lower building age might reflect the influence of stricter building codes and more efficient design of office buildings, implemented over the last years.

To sum it up, the introduced *GAM* visualised with regression splines provides a more precise understanding of the effects for the tested portfolio from *GRA*.

3.6 Conclusion

The objective of this study was to determine the influence of physical building characteristics and of occupant attributes on the actual energy consumption of European office buildings contained in the database of the *GRA* with 288 observations. Furthermore, we analysed the role of refurbishment on energy consumption with the effects of an extensive refurbishment and refurbishment solely dedicated to energy efficiency and thermal building characteristics.

Besides the application of a regression model to estimate linear effects on actual energy consumption, the study introduces *GAM* and visualization with smoothed curves in regression splines to control for expected nonlinearity in the effects of the regression.

The assumed impact of occupant attributes on energy savings was shown to apply for the distinction between single and multi-tenant buildings. Single-tenant buildings have a higher actual energy consumption between 12% and 15% compared to multi-tenant buildings (depending on the applied model specification). The result indicates a less energy-efficient behaviour of single tenants responsible for one building as a whole.

The electric production of heating is estimated with significantly lower energy consumption per square meter of up to more than 20%. It could be the case that highly efficient technology for heating production is employed in office buildings which are overall attributed with a relatively high energy efficiency standard in the tested portfolio. Given the fact that the dataset has almost 200 observations located in France, of which more than 50% are equipped with electric heating production, this result might point to higher energy efficiency employed with electric production of heating, compared to the omitted reference production types gas, fuel or a district heating network.

In the regression model with linear effects, significantly lower energy consumption is found for observations with more than 20 years of building age. The introduced specification with *GAM* allows a more detailed interpretation of the effect with highest energy consumption for office buildings around 15 years of age. For more recent buildings, slightly lower energy consumption is observed, potentially indicating higher energy efficiency in regard to increased energy efficiency regulation in *EU*-member states over the past decade. However, these attempts do not seem to reveal a significant impact on the conservation of actual energy consumption, based on the observations of the *GRA* portfolio.

Corresponding to the principle of additionality with more and new appliances and equipment in more recent office buildings, we found older buildings of more than 20 years up to 30 years of age associated with significant lower energy consumption. These buildings are assumed to provide less services and comfort, which seems to correspond to observations for *US* office buildings.

Besides the linear coefficients introduced to control for the classified building size, the regression spline is of much higher explanatory quality for the nonlinear effect. The energy consumption of office buildings up to size of approximately 12,000 square meters is identified with a zone of almost indifference, followed by significantly higher energy consumption with increasing building area. For observations around 30,000 square meters, the highest consumption is observable. We find this in line with results of Kahn et al. (2014) when arguing that higher consumption is achieved in office towers, to bridge large vertical distances than in more compact building structures – rejecting the assumption of economies of scale.

Regarding actual energy consumption, the high explanatory power of the intrinsic water consumption is an interesting result of the study. Since this intrinsic measure is modelled according to the technical building characteristics and is independent of actual building use, it provides a potential indicator for high energy efficiency. This could reflect stricter efficiency regulation and building codes, indeed affecting the physical building. From an investor's point of view, this underlines the importance of measuring further sustainable characteristics besides energy, when high water efficiency is identified to be an indicator of high energy efficiency from the *GRA* dataset.

The linear coefficient but even more the regression spline for the allocated office space per occupant proves for a significant relationship with lower energy consumption per square meter when more office space is allocated per occupant. The regression spline indicates a linear effect in the relationship. Besides the effect of higher vacancy in office buildings associated with lower consumption, this also suggests that more occupants on the same office area will increase energy use per square meter from applied equipment and plug loads (especially if the building is heated or cooled centrally).

Since the role of refurbishment is of major research interest in this study, the attributes for extensive refurbishment (full/major/general) proved for significantly higher energy consumption of 15% as a linear covariate effect, compared to buildings without any refurbishment measures. For the tested portfolio, we find the principle of additionality being associated with refurbishment that provides increased or additional services and comfort from appliances with additional or new equipment. Since the extensive refurbishment was dedicated to improve the overall quality of the buildings, the measures might include those of higher energy efficiency, but from the additional appliances and equipment, the overall energy consumption is higher compared to peers without refurbishment.

Refurbishment dedicated solely to energy efficiency and thermo-physical building characteristics remains insignificant in the second specification of the regression model. The coefficient is estimated with a negative value, corresponding to potential energy savings, but insignificant, most probably because of only 23 observations. Since the effect is not estimated with a positive coefficient, there is no indication of a potential rebound effect inherent in the portfolio at all.

Finally, the regression spline for the interaction effect between building age and refurbishment, to be interpreted as additional energy consumption of refurbished buildings, shows the highest energy efficiency for the most recent refurbished buildings, although assumed with additional services and equipment introduced upon refurbishment. While the regression spline indicates a less energy-efficient refurbishment for older buildings carried out in the past, this suggests that refurbishment from the past was less dedicated to energy-efficient appliances and equipment, compared to most recent refurbishment efforts, all else equal. This result for lower additional energy consumption in relation to refurbishment with lower building age might reflect stricter building codes and more efficient design of office buildings, implemented over the last years.

In the discussion and conclusion of our study results, we repeatedly referred to the small database from *GRA* of only 288 office buildings in 14 European countries as a major drawback.

As of now, there is no extensive research framework for energy consumption of commercial, especially office buildings, based on empirical evidence from Europe. This study aims to contribute to a better understanding of energy consumption in office buildings, in particular when it comes to the role of refurbishment with differing intensity. However, there are limitations remaining from the small dataset, which lacks higher explanatory power. A reason for the very moderate fit of the regression models, indicated in the relatively low R^2-values and rather weak significance of the attributes, might be due to omitted variables in our models or defaults in the used data.

Since the used dataset contains the actual metered energy consumption and the intrinsic assessment only assessed once for issuing the Green Rating audit, the results of the study should be interpreted with precaution. According to the limited nature of the dataset, we cannot exclude the possibility that any potential bias due to omitted variables is included in the outcomes. Besides the rather small number of observations from different years between 2008 and 2012, we do not have further information in regard to the building quality and maintenance or the equipment and appliances, differing among the observations. Furthermore, the missing information in regard to the sub-category "other" in the dataset is a limiting factor that could reduce explanatory power and introduce omitted variable bias. Moreover, we do not know the vacancy rate in the buildings or unemployment rates for the relevant timeframe. Also, the business industries of the office occupants might be associated with potential differences in energy consumption, compared to each other. Another limitation is that we do not know and control for the relevant energy cost in the buildings. However, as an advantage, the used dataset contains detailed information to differentiate among the intensity of refurbishment measures, which is a precondition to investigate the role of refurbishment on energy consumption.

We tried to mitigate the problem of nonlinearity in the effects of the estimated regression coefficients with the introduction of *GAM*. The obtained regression splines provide a more precise understanding of the effects for the observed portfolio. However, a dynamic analysis of a panel with more observations over time – controlling the effects before and after refurbishment – is recommended.

Beyond the recommendation to consolidate our research results on a more extensive database, we believe that fostering the awareness of actual energy consumption in the direction of potential savings by occupants is furthermore an issue. Apart from technological progress and a more extensive and stricter energy efficiency regulation, the design of an effective (incentive) mechanism to shift office occupant behaviour towards energy conservation might achieve higher energy savings in practice. How this mechanism could be designed is a subject for further research, especially in the field of behavioural real estate research.

3.7 References

Association of European Renewable Energy Research Centres (2016), available at: www.eurec.be/en/ (accessed 28 February 2016).

Baum, A. and McElhinney, A. (1997), "The causes and effects of depreciation in office buildings: a ten year update", Report for working paper of the Department of Land Management and Development, University of Reading, Reading.

Baum, A. and Turner, N. (2004), "Retention rates, reinvestment and depreciation in European office markets", *Journal of Property Investment & Finance*, Vol. 22 No. 3, pp. 214-235.

Bloom, N., Genakos, C., Martin, R. and Sadun, R. (2011), "Modern management: good for the environment, or just hot air?", *Economic Journal*, Vol. 120 No. 544, pp. 551-572.

Bouwfonds Investment Management (2013), Corporate social responsibility policy, available at: www.bouwfondsim.com/wp-content/uploads/2014/10/BIM_CSR-Policy_14112013.pdf (accessed 15 November 2015).

Brunauer, W.A., Lang, S., Wechselberger, P. and Bienert, S. (2010), "Additive hedonic regression models with spatial scaling factors: an application for rents in Vienna", *The Journal of Real Estate Finance and Economics*, Vol. 41 No. 4, pp. 390-411.

Brunauer, W., Feilmayr, W. and Wagner, K. (2012), "A new residential property price index for Austria", *Statistiken – Daten und Analysen Q3/2012*, Austrian National Bank, Vienna, pp. 90-102.

Cajias, M. and Bienert, S. (2011), "Does sustainability pay off for European listed real estate companies? The dynamics between risk and provision of responsible information", *Journal of Sustainable Real Estate*, Vol. 3 No. 1, pp. 211-231.

Cajias, M., Fuerst, F., McAllister, P. and Nanda, A., (2011), "Is ESG commitment linked to investment performance in the real estate sector?", Working Papers in Real Estate and Planning. 08/11, Working Paper, University of Reading, Reading.

Chegut, A., Eichholtz, P. and Kok, N. (2015), "The price of innovation: an analysis of the marginal cost of green buildings", working paper, as of 23 October 2015, available at: www.corporate-engagement.com/files/publication/CEK_Cost_102315.pdf (accessed 22 November 2015).

Fahrmeir, L. and Tutz, G. (2001), *Multivariate Statistical Modelling Based on Generalized Linear Models*, Springer, New York, NY.

Fraunhofer IBP (2009), *Studie zur Energieeffizienz innovativer Gebäude-, Beleuchtungs- und Raumkonzepte (EnEff-Studie)*, Fraunhofer-Institut für Bauphysik (IBP), Holzkirchen.

Fraunhofer ISE (2015), Fraunhofer-Institut für Solare Energiesysteme ISE, available at: www.ise.fraunhofer.de/en/about-us (accessed 28 February 2016).

Gabe, J. (2014), "Successful greenhouse gas mitigation in existing Australian office buildings", *Building Research & Information*, Vol. 44 No. 2, pp. 160-174.

Gillingham, K.M., Kotchen, M.J., Rapson, D.S. and Wagner, G. (2013), "The rebound effect is overplayed", *Nature*, Vol. 493 No. 7433, pp. 475-476.

Gillingham, K.M., Rapson, D.S. and Wagner, G. (2015), "The rebound effect and energy efficiency policy", *Review of Environmental Economics and Policy*, Vol. 10 No. 1, pp. 68-88.

Greening, L.A., Greene, D.L. and Difiglio, C. (2000), "Energy efficiency and consumption – the rebound effect – a survey", *Energy Policy*, Vol. 28 No. 6-7, pp. 389-401.

Guerra Santin, O., Itard, L. and Visscher, H. (2009), "The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock", *Energy and Buildings*, Vol. 41 No. 11, pp. 1223-1232.

Halvorsen, R. and Palmquist, R. (1980), "The interpretation of dummy variables in semilogarithmic equations", *The American Economic Review*, *Vol. 70* No. 3, pp. 474-475.

Hardy, M.A. (1993), *Regression with dummy variables*, Sage University Paper series on Quantitative Applications in the Social Sciences, No. 07-093, Sage, Newbury Park, CA.

Herring, H. and Roy, R. (2007), "Technological innovation, energy efficient design and the rebound effect", *Technovation*, Vol. 27 No. 4, pp. 194-203.

Jenkins, D., Liu, Y. and Peacock, A.D. (2008), "Climatic and internal factors affecting future UK office heating and cooling energy consumptions", *Energy and Buildings*, Vol. 40 No. 5, pp. 874-881.

Kahn, M.E., Kok, N. and Quigley, J.M. (2014), "Carbon emissions from the commercial building sector: the role of climate, quality, and incentives", *Journal of Public Economics*, Vol. 113 No. C, pp. 1-12.

Kavulya, G. and Becerik-Gerber, B. (2012), *Understanding the influence of occupant behavior on energy consumption patterns in commercial buildings*, International Conference on Computing in Civil Engineering, June 2012, (Proceedings), pp. 569-576.

Kerscher, A.N. and Schaefers, W. (2015), "Corporate social responsibility and the market valuation of listed real estate investment companies", *German Journal of Real Estate Research*, Vol. 1 No. 2, pp. 117-143.

Knittel, C.R. (2012), "Automobiles on steroids: product attribute trade-offs and technological progress in the automobile sector", *American Economic Review*, Vol. 101 No. 7, pp. 3368-3399.

Kok, N., Miller, N.G. and Morris, P. (2012), "The economics of green retrofits", *Journal of Sustainable Real Estate*, Vol. 4 No. 1, pp. 4-22.

Lombard, L.P., Ortiz, J. and Pout, C. (2008), "A review on buildings energy consumption information", *Energy and Buildings*, Vol. 40 No. 3, pp. 394-398.

Malpezzi, S. (2003), "Hedonic pricing models: a selective and applied review", in O'Sullivan, T. and Gibb, K. (Eds), *Housing Economics and Public Policy, Essays in Honor of Duncan Maclennan*, Blackwell, Oxford, pp. 67-89.

Mason, C. and Quigley, J.M. (1996), "Non-parametric hedonic housing prices", *Housing Studies*, Vol. 11 No. 3, pp. 373-385.

New Buildings Institute (2008), "*Energy performance of LEED for new construction buildings*", prepared for: U.S. Green Building Council, New Buildings Institute, Vancouver, WA.

Newsham, G.R., Mancini, S. and Birt, B.J. (2009), "Do LEED-certified buildings save energy? Yes, but…", *Energy and Buildings*, Vol. 41 No. 8, pp. 897-905.

Pace, R.K. (1998), "Appraisal using generalized additive models", *Journal of Real Estate Research*, Vol. 15 No. 1, pp. 77-99.

Parmeter, C.F., Henderson, D.J. and Kumbhakar, S.C. (2007), "Nonparametric estimation of a hedonic price function", *Journal of Applied Econometrics*, Vol. 22 No. 3, pp. 695-699.

Post-occupancy Review of Buildings and their Engineering (1997), *PROBE 9: Energy and engineering PROBE technical review*, available at: www.cibse.org/Knowledge/Building-Services-Case-Studies/PROBE-Post-Occupancy-Studies (accessed 28 February 2016).

Scofield, J.H. (2009), "Do LEED-certified buildings save energy? Not really…", *Energy and Buildings*, Vol. 41 No. 12, pp. 1386-1390.

Surmann, M., Brunauer, W.A. and Bienert, S. (2016), "The energy efficiency of corporate real estate assets: the role of energy management for corporate environmental performance", *Journal of Corporate Real Estate*, Vol. 18 No. 2, pp. 68-101.

Torcellini, P.A., Deru, M.,B. Griffith, B., Long, N., Pless, S. and Judkoff, R. (2004), *Lessons learned from the field evaluation of six high-performance buildings*, ACEEE summer study on energy efficiency of buildings, Conference Paper, National Renewable Energy Laboratory, Golden, CO.

Weather underground (2015), available at: www.wunderground.com (accessed 22 July 2015).

Wood, S. (2006), *An introduction to generalized additive models with R*, Taylor & Francis Group, Boca Raton, FL.

Further reading

Allcott, H. (2011), "Social norms and energy conservation", *Journal of Public Economics*, Vol. 95 No. 5, pp. 1982-1995.

Eichholtz, P., Kok, N. and Quigley J.M. (2010), "Doing well by doing good? Green office buildings", *American Economic Review*, Vol. 100 No. 5, pp. 2492-2509.

ENTRANZE Project (2014), *Policies to ENforce the TRAnsition to Nearly Zero-Energy buildings in Europe, ENTRANZE*, available at: www.entranze.eu (accessed 25 September 2014).

Fahrmeir, L., Kneib, T. and Lang, S. (2007), *Regression: Modelle, Methoden und Anwendungen*, Springer, Berlin.

Fuerst, F. and McAllister, P. (2011a), "Green noise or green value? – Measuring the effects of environmental certification on office values", *Real Estate Economics*, Vol. 39 No. 1, pp. 45-69.

Fuerst, F. and McAllister, P. (2011b), "The impact of energy performance certificates on the rental and capital values of commercial property assets", *Energy Policy*, Vol. 39 No. 10, pp. 6608-6614.

Fuerst, F., van de Wetering, J. and Wyatt, P. (2013), "Is intrinsic energy efficiency reflected in the pricing of office leases?", *Building Research and Information*, Vol. 41 No. 4, pp. 373-383.

Haas, R., Auer, H. and Biermayr, P. (1998), "The impact of consumer behaviour on residential energy demand for space heating", *Energy and Buildings*, Vol. 27 No. 2, pp. 195-205.

Konrad, K. and Thun, M. (2012), *The role of economic policy in climate change adaption*, Working Paper of the Max Planck Institute for Tax Law and Public Finance, No. 2012-08.

Lam, J.C., Wan, K.K.W., Liu, D. and Tsang, C.L. (2010), "Multiple regression models for energy use in air-conditioned office buildings in different climates", *Energy Conservation and Management*, Vol. 51 No. 12, pp. 2692-2697.

Leopoldsberger, G., Bienert, S., Brunauer, W., Bobsin, K. and Schuetzenhofer, C. (2011), "Energising property valuation: putting a value on energy-efficient buildings", *The Appraisal Journal*, Vol. 79 No. 2, pp. 115-125.

Leth-Peterson, S. and Togeby, M. (2001), "Demand for space heating in apartment blocks: measuring effect of policy measures aiming at reducing energy consumption", *Energy Economics*, Vol. 23 No. 4, pp. 387-403.

Rosen, S. (1974), "Hedonic prices and implicit markets: product differentiation in pure competition", *The Journal of Political Economy*, Vol. 82 No. 1, pp. 35-55.

The New York Times (2011), When energy efficiency sullies the environment, March 8, 2011, p. D1, New York edition, New York, NY, available at: www.nytimes.com/2011/03/08/science/08tier.html (accessed 15 November 2015).

Wood, S. (2003), "Thin plate regression splines", *Journal of the Royal Statistical Society*, B-Series, Vol. 65 No. 1, pp. 95-114.

Wooldridge, J. (2002), *Econometric analysis of cross-section and panel data*, The MIT Press, Cambridge, MA.

4 The energy efficiency of corporate real estate assets: The role of energy management for corporate environmental performance

Markus Surmann, Wolfgang Brunauer, Sven Bienert

Structured abstract

Purpose: On the basis of corporate wholesale and hypermarket stores, this study investigates the relationship between energy consumption, physical building characteristics, operational sales performance and the impact of energy management on the corporate environmental performance.

Design/methodology/approach: A very unique dataset of *METRO GROUP* over 19 European countries is analyzed in a sophisticated econometric approach for the timeframe from January 2011 until December 2014. Multiple regression models are applied for the panel, to explain the electricity consumption of the corporate assets on a monthly basis and the total energy consumption on an annual basis. Using *generalized additive models*, to model nonlinear covariate effects, the authors decompose the response variables into the implicit contribution of building characteristics, operational sales performance and energy management attributes, under control of the outdoor weather conditions and spatial-temporal effects.

Findings: *METRO GROUP*'s wholesale and hypermarket stores prove significant reductions in electricity and total energy consumption over the analyzed timeframe. Due to the implemented energy consumption and carbon emission reduction targets, the influence of the energy management measures, such as the identification of stores associated with lowest energy performance, was found to contribute toward a more efficient corporate environmental performance.

Originality/value: In the context of corporate responsibility/sustainability of wholesale, hypermarket and retail corporations, the energy efficiency and reduction of carbon emissions from corporates' real estate assets is of emerging interest. Besides the insights about the energy efficiency of corporate real estate assets, the role of the energy management, contributing to a more efficient corporate environmental performance, is not yet investigated for a large European wholesale and hypermarket portfolio.

Keywords: Energy efficiency, Carbon emissions, Corporate energy management, Corporate real estate management (CREM), Multiple regression, Wholesale and retail stores

Paper type: Research paper

Acknowledgments: The authors thank *METRO AG* and *METRO PROPERTIES Holding GmbH* for providing the data used in this research study. The views expressed herein are those of the authors and do not necessarily reflect those of *METRO AG*, *METRO PROPERTIES Holding GmbH* and *DataScience Service GmbH*.

4.1 Introduction

Given that the generation of energy is still highly reliant on fossil energy sources, the carbon emissions associated with consumption of electricity remain at a substantial high level. For instance, in Germany, the electricity production in 2014 was based on coal sources at 43.2% and on natural gas and petrol fuel at 10.9% (BDEW, 2015). With approximately three million buildings, the non-residential building sector accounts for only 15% of the existing building stock in Germany, but for more than 30% of total energy consumption and carbon emissions (Dena, 2015).

Commercial real estate and especially corporate real estate assets in the wholesale and hypermarket sector have significant *greenhouse gas* (*GHG*) externalities, due to the high carbon emissions associated with energy consumption for store operations in big-boxes.

Because wholesale and hypermarket buildings account for a large portion of energy consumption and carbon emissions for the operating corporations, the related costs of operations are subject to certain key business considerations. Thus, corporations have started to implement energy and carbon emission reduction strategies. On the one hand, the aim is to achieve savings from energy conservation and thereby increase the operational profitability from the sales business – even more when profit margins are lowering. On the other hand, investing in energy efficiency is intended to show customers and society an appropriate environmental practice for leveraging on corporate sustainability for the corporate brand.

Reducing the energy consumed in corporate real estate assets is of emerging interest with respect to the sustainability strategy of wholesale, hypermarket and retail corporations. For them, it is important to engage in sustainability, due to their reputation and high customer visibility. However, in the absence of significant pricing allocation, industry pressure to account for and disclose carbon emissions has increased over the past years (World Bank Group, 2015; CDP, 2014).

In this context, industry leaders have set up corporate energy management organizations, to operationalize ambitious energy- and emission-reduction targets, which affect store profitability positively through reducing operational expenses.

Using the example of *METRO GROUP*, this study explores the energy efficiency measures of corporate real estate assets within a specific asset class. The research investigates the level of energy consumption and carbon emission reduction, together with realized cost savings, and relation to the operational performance. With regard to the role of corporate energy management, the study analyzes the contribution to a more efficient corporate environmental performance. Finally, the study concludes with a scenario, of how corporate real estate assets might be affected in the event of having carbon emission pricing in place.

The remainder of the study is as follows: Section 4.2 provides the empirical framework and insights from related research, while Section 4.3 introduces the case study for corporate real estate assets of *METRO GROUP*. This is followed by the underlying working hypotheses of this research (Section 4.4). The characteristics of the dataset are explained in Section 4.5, followed by a sophisticated econometric methodology in Section

4.6. Section 4.7 presents the results and Section 4.8 provides a reflection on the hypotheses and concludes with recommendations for further research.

4.2 Empirical framework

4.2.1 Energy and electricity consumption

Retail buildings are associated with the highest energy consumption in the commercial building sector. In the *UK* and Spain, they are attributed with 22% and in the *US*, even with 32% of total commercial building energy consumption (Lombard et al., 2008). For the food retail sector in Germany, a total energy consumption of 14.1 TWh was estimated for 2009 (IFEU et al., 2011).

Energy consumption and emissions from wholesale, hypermarket and retail stores depend on building size and age, store format, the operational business with product mix, customer frequency and technical equipment, applied to refrigeration, heating, ventilation and air conditioning (*HVAC*), artificial lighting, *IT* and sales systems, restaurants and further equipment for the preparation and display of products.

For supermarkets and hypermarkets in the *UK*, a study by Spyrou et al. (2014) showed that, with increasing store size, the energy consumption per square meter decreases. Also, Tassou et al. (2011) explain a decline in the energy consumption per square meter with increasing building (sales floor) area, up to a certain level.

For the thermo-physical, but even more so, the technical status of the premises, the building envelope and equipment, referring to newly constructed buildings compared to older buildings and retro-fitted stores might be different between the stores and sales formats, but also within a particular sales line. For *Walmart*, Kahn and Kok (2014b) found evidence that more recently constructed stores have lower electricity consumption than older buildings. They argue that the quality of the stores is held constant, whereas the energy efficiency of equipment in the store is improved with decreased energy use intensity in newly constructed stores.

Store formats exhibit major differences in size, and in the proportion of particular functions in the buildings, e.g. the share between food and non-food sales and storage areas, the proportion of cooled and refrigerated areas or heated and non-heated storage areas. In wholesale and hypermarket stores, a portion of the non-food sales area can also be associated with higher levels of energy consumption, e.g. electronic products such as high electricity consuming *TV* walls.

Retail food stores in the *UK*, with formats ranging from convenience stores to hypermarkets, display a wide variability of energy intensity, even within stores of the same retail chain (Tassou et al., 2011). Referring to Spyrou et al. (2014), the intensity in energy consumption *between* different wholesale, hypermarket and retail building formats is expected to be different, but comparatively similar *within* the same format categories. For a sample of *Walmart* stores across California, Kahn and Kok (2014a) found only little store-to-store variation in energy consumption and suggest that *Walmart* standardizes the construction and operation of the energy performance of its stores, with high importance being accorded to centralized management practices.

The impact of store operations on energy consumption is correlated with the opening hours of the store, and with the number of customers passing entrance doors, affecting the indoor temperature with heat gains or cooling losses and the refrigeration load, when selecting cooled or frozen food. The intensity of energy consumption is therefore highly dependent on the sales productivity, measured by the stores turnover figures. The *TESCO*-funded research of Spyrou et al. (2014) designed a regression model to predict the annual electricity demand, which proved that the sales productivity has the second highest explanatory and predictive power, after the *sales floor area* (*SFA*).

The proportion of total energy consumption was found to have a split of approximately 80% for electricity and 20% for heating energy consumption in *UK* hypermarkets, and more than 70% for electricity consumption in supermarkets (Spyrou et al., 2014; Tassou et al., 2011). Actual energy consumption in the German food retailing business accounts to 36% for refrigeration, 30% for heating, 20% for lighting, 8% for cooling and 6% for other uses (IFEU et al., 2011). The difference between wholesale or hypermarket stores, selling fresh and frozen food, and other retail buildings is almost completely attributable to the refrigeration technology used for food retailing (Braun et al., 2014; IFEU et al., 2011).

Refrigeration was found to have the largest share of 29% of total electricity consumption in the *UK* hypermarkets (Tassou et al., 2011). For smaller-sized supermarkets, the electricity consumed for food refrigeration was observed even to have a share of over 50% (Ge and Tassou, 2011). Beside the local outdoor weather and indoor temperature and humidity conditions, the intensity of electricity consumption for the refrigeration load depends on customers when removing products and refilling by staff (Tassou et al., 2011).

HVAC systems in stores, which provide thermal comfort to customers and staff, account for 5% to 9% and lighting for 17% to 23% of total electricity consumption (Spyrou et al., 2014; Tassou et al., 2011). Other services and equipment in stores, such as bakery and preparation, customer restaurants, elevators or escalators and offices, also account for a reasonable percentage of the total electricity consumption.

Interaction between the *HVAC* system and the refrigeration units in the building is crucial for energy savings. Depending on the outdoor weather conditions, both systems could support each other when cooling is needed in the summer months with high loads of energy, but also operate antagonistically to each other through heating the sales floor while simultaneously refrigerating parts of the sales floor and cold storage rooms.

For a multi-national store portfolio, differences between the individual countries also need to be considered. On the one hand, customer behavior is changing, on the other hand, different regulatory regimes, such as in the pricing of energy between countries, will have an impact on energy consumption. For instance, *Walmart*'s electricity consumption was found to be lower with respect to the higher-priced utilities in California (Kahn and Kok, 2014a).

4.2.2 Carbon emissions

Due to significant *GHG* externalities associated with energy consumption, the building sector is regarded as having a large potential for reducing global carbon emissions from the durable building stock (WBCSD, 2015). In the *USA*, the retail sector accounts for the second largest amount of CO_2 emissions in the entire commercial sector of the *US* economy (Sullivan and Gouldson, 2014; RILA, 2012), when emissions from buildings, and also for the total supply chain, with distribution to the stores and delivery to the customers, are considered.

A recent calculation for the retail sector in Germany estimated an annual energy consumption of 46 TWh associated with CO_2 emissions of 18 million tons (HDE, 2013). Anticipating a potential mid-term efficiency realization of 8.8 TWh/a, future energy savings in the German retail sector have been predicted with a margin of 19% compared to 2011 (IFEU et al., 2011).

Gouldson and Sullivan (2014) argue that among retail supermarket chains, a competitive environment not only exists in terms of customers and sales turnover, but also in the reduction of consumed energy and carbon emissions set by industry peer pressure. They report from *TESCO* that the strategy to reduce carbon emissions in cooperation with suppliers puts pressure on other retailers to follow this strategy (Gouldson and Sullivan, 2014). Furthermore, the real estate investment market also puts pressure on these assets, with regard to the socially responsible investment strategies of institutional investors (Cajias and Bienert, 2011; Cajias et al., 2011; Kerscher and Schaefers, 2015).

Over the past years, many large corporations started voluntarily to disclose information about their carbon emissions. In 2012, over 80% of the largest 500 corporations in the world reported this information to the *Carbon Disclosure Project* (CDP, 2012). In 2014, at least 150 companies used an internal carbon price, ranging from US$ 6 to US$ 89 per ton of CO_2 emissions (CDP, 2014).

4.2.3 Corporate energy management

Spyrou et al. (2014) explain that managing and minimizing energy consumption is an important opportunity for both business competitiveness and national CO_2 emission targets. When analyzing *Walmart*, Kahn and Kok (2014a) argue that corporation size and centralization of management play key roles in determining an indicator of a corporate's environmental performance. Because costs associated with energy consumption directly affect the operational profitability of wholesale and hypermarket stores, corporates set up energy management organizations, to establish and operationalize ambitious energy- and emission-reduction targets.

From the mid-2000s, the *UK* retailers started to focus on specific reduction targets for carbon emissions per unit of store floor area, or to build new and more efficient buildings, compared to older peers. Based on observations by Sullivan and Gouldson (2014), the *UK* retailers have achieved reductions in their energy and carbon emission intensity by between 2.5% and 5.5% per year over the period from 2007 to 2011.

In the *USA*, *Walmart* set the target to reduce its carbon emissions from existing facilities by 20% in 2011, compared to 2005. In 2010, they announced their intention to reduce 20 million tons of carbon emissions from the global supply chain by the end of 2015

(Walmart, 2015a), which they exceeded by eliminating 28.2 million tons. However, *Walmart* does not disclose its total energy consumption (GreenBiz, 2015). In contrast, some operators do not set emission reduction targets at all, for example *US*-based *Costco Wholesale*, or do not publish them, such as *US*-based *Safeway* and German-based *Aldi* and *Lidl* discount stores.

In their research results, Kahn and Kok (2014a) found no difference in consumption among leased vs owned *Walmart* stores, suggesting that central energy management acts to negate any initial conditions, such that leased assets are inherently inefficient.

Spyrou et al. (2014) argue that from an organizational management point of view, the identification of stores that have undergone significant changes in the performance for no apparent reason, is the starting point for ensuring an efficient performance of the building stock.

4.2.4 Profitability of energy savings

Energy efficiency measures in the wholesale and hypermarket sector may pay off, once they are introduced in the operational business. Investments in more efficient sales areas might be reasonable to obtain bottom-line savings. An additive investment in energy-efficient equipment for permanent future capital savings might turn out to have higher economic impact on profitability than entail an increase in sales turnover in the short-run.

The role of energy management in wholesale and retail corporations has been highlighted, due to smaller profit margins and energy cost savings leveraging on the profit margins of corporations. Reporting on *Walmart*'s success with its energy efficiency initiative, The Guardian (2011) comments that energy efficiency helps retailers to compensate for lower profit margins. As the retail sector becomes even more competitive, lower profit margins induce companies to invest in strategies that can both reduce energy consumption costs and maximize profits (The Guardian, 2011). For the *UK*, energy consumption costs in the food retail sector are significantly affecting profitability, as the operating margins have been observed at a generally low average of 4.2% in 2005 (Spyrou et al., 2014). A recent study of the major 250 sales lines in Germany revealed actual energy costs with a margin between 1.3% and 1.7% of total annual net sales turnover. Considering that the average profit margin of those retailers is 1.5%, the annual energy costs turn out to be equivalent to approximately 100% of the profit (Dena, 2015).

The example of French-based *Carrefour* makes clear that the annual investment of €30 million on its energy efficiency programs is small, compared to the worldwide revenues of €90 billion (only 0.03%), but accounts for 3% of its net profit. However, compared to the money invested, retailers may be able to gain reasonable dividends from the investment by installing energy-efficient lighting systems, attaching freezer doors and automated information and communication systems (The Guardian, 2011). With regard to the investment budget of top *USA* and *UK* retailers in low-carbon technologies and financial support for renewable energy, Sullivan and Gouldson (2014) conclude that there are relatively narrow cost-benefit ratios, if retailers expect paybacks of less than three years for most investments. The energy management of *Walmart* aims for a three-year payback on its investments in energy efficiency (The New York Times, 2012).

The profitability of energy-saving measures becomes particularly obvious when looking at the extensive research and existing body of literature on the relationship between daylighting and increased retail sales. For *Walmart* stores equipped with natural lighting, in only half of the store, the day-lighted area was found to have significantly higher sales per square foot than the artificially lighted area, also when compared to the equivalent departments in other non-day lighted stores (Fedrizzi and Rogers, 2002).

For large corporations, it was observed that it is relatively possible to allocate their investments to improving the efficiency of their durable building stock, compared to owners who operate only one or a few stores. Therefore, industrial concentration can enable higher levels of energy efficiency through economies of scale. In the case of *Walmart*, the size, capital market access without liquidity constraints and management expertise enable professional cost minimization (Kahn and Kok, 2014a).

Considering the investment allocation in energy efficiency, human capital plays a key role for success in corporate energy management. An on-site manager, as well as staff training, may influence the use-intensity of equipment, which depends on store performance (Kahn and Kok, 2014a; Bloom et al., 2011). Sullivan and Gouldson (2014) argue that, in the course of corporate action, retail companies have engaged with their employees on energy and carbon management, by establishing awareness and education campaigns, creating store-specific energy-reduction plans and providing rewards and incentives for good performance.

4.3 Energy consumption and carbon emissions of METRO GROUP

For a wholesale and hypermarket corporate such as *METRO GROUP*, store operations with energy consumption for refrigeration, *HVAC*, lighting, *IT* and others are a major driver of carbon emissions. Beside the strategy of mere costs savings from reduced consumption of electricity and fossil fuels, the corporation set up a corporate responsibility and sustainability agenda, so as to introduce voluntary commitments with regard to the limits and future saving targets of energy consumption and carbon emissions.

This strategy follows the argumentation according to which corporations in the retail sector have a high public profile, thus facing pressure to promote sustainable consumption in general. Accordingly, they act as "translators" of the sustainability disclosure to customers (Lehner, 2015). Jones et al. (2014) observed that major retail corporations increasingly recognize the importance of publicly reporting on the impact of their activities via annual *corporate social responsibility* or *sustainability reports* (*CSR*). *METRO GROUP* introduced a corporate reporting system, taking carbon accounting and further activities into account, based on standards from the following:

- *Global Reporting Initiative* (*GRI*);
- *UN Global Compact* (*UNGC*);
- *Dow Jones Sustainability Index* (*DJSI*);
- *Carbon Disclosure Project* (*CDP*) / *CDP* Water Disclosure; and
- Forest Footprint Disclosure.

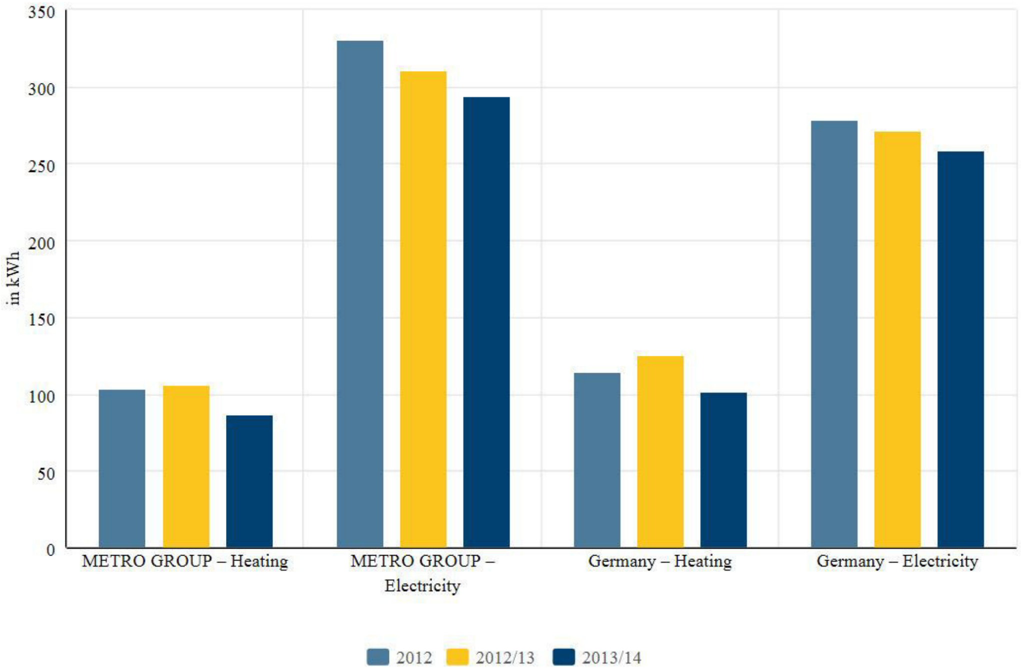
Furthermore, when rating agencies evaluate the business model of a corporate in the wholesale and retail industry, they anticipate the view of the business "through the eye of the customer". For this reason, the attitude toward sustainability, operationalized in a sustainability agenda, yields a direct impact in financial dimensions on the corporate's overall investment grade.

METRO GROUP implemented a centralized energy management division in the course of corporate responsibility activities, with the mission of contributing to energy conservation and the reduction of carbon emissions. The main target for the corporation is set at an overall reduction of CO_2 emissions per square meter *sales floor area* (*SFA*) of 20% until 2020, based on emissions in 2011. To achieve its 2020 targets, the corporation set several objectives on the baseline of 2011, for example:

- Reduction of CO_2 emissions from electricity consumption by 21%;
- Reduction of CO_2 emissions from heating energy consumption by 10%; and
- Reduction of CO_2 emissions from refrigeration agents by 29%.

For the corporate's total electricity consumption, a decrease of 37 kWh/m²/a (-11%) was reported between the end of the financial year in December 2012 and September 2014 (end of the financial year from October 2013 until end of September 2014, after a change in the financial year basis). Within the same timeframe, the total heating energy consumption was metered at a decline of -15% (Figure 1).

Figure 1: Electricity and heating energy consumption per square meter of METRO GROUP (Source: METRO GROUP Corporate Responsibility Report 2013/14)



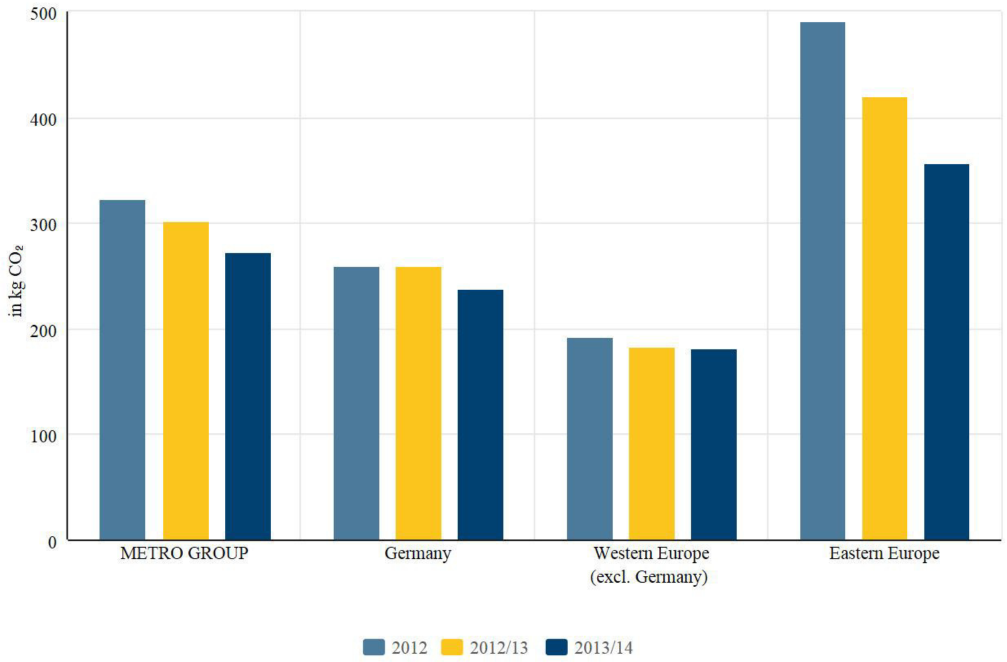
In progressing towards the emission targets for 2020, *METRO GROUP*'s accounting and reporting standard is based on the *Greenhouse Gas Protocol* (2004) with three different scopes (Table 1).

Table 1: Carbon emissions in tons CO_2 (CO_2 equivalents) of METRO GROUP (Source: METRO GROUP Corporate Responsibility Report 2013/14)

Reference year	2011	2012	2012/13	2013/14	Reduction (2011 baseline)
Scope 1 – direct greenhouse gas emissions	1,084,509	1,132,693	1,068,706	1,015,157	**-6.4%**
Scope 2 – indirect greenhouse gas emissions	2,432,102	2,379,478	2,068,787	1,803,799	**-25.8%**
Scope 3 – other indirect greenhouse gas emissions	7,064,278	7,001,010	6,309,475	6,278,003	**-11.1%**
Total greenhouse gas emissions	10,580,889	10,513,181	9,446,967	9,096,959	**-14.0%**

The annual emission status is recorded by *METRO GROUP*'s Carbon Intelligence System, which captures the consumption data for the wholesale and hypermarkets. The reduction achievements over the past years result mainly from reduced electricity consumption in the stores. However, *METRO GROUP* no longer considers effects from changes in the portfolio and total store space over the course of the emission reporting (Figure 2).

Figure 2: Greenhouse gas emissions per square meter of METRO GROUP (Source: METRO GROUP Corporate Responsibility Report 2013/14)



At first glance, the comparison of overall CO_2 emission volumes per square meter of *METRO GROUP* shows significant differences between the portfolios in Western and Eastern Europe. On the one hand, further reduction in Western Europe seems difficult, due to the relatively low emission level already achieved. On the other hand, Eastern Europe seems to provide enormous saving potential, since emissions declined by more than 25% between 2012 and September 2014.

4.4 Working hypotheses

With reference to the outlined empirical framework of related research referring to various studies and the specific energy consumption and carbon emissions of *METRO GROUP*, the following working hypotheses provide the framework for the empirical analysis of the corporate real estate assets of *METRO GROUP*:

H1. Due to the regulatory framework with continuously increasing energy efficiency requirements for new construction in the European Union and technological innovations (*LED* etc.), newer buildings show significantly lower energy consumption than their less recently constructed peers, all else equal.

H2. Revitalization of wholesale and hypermarket stores provides substantial energy-savings potential.

H3. The intensity of energy consumption of different wholesale and hypermarket formats is expected to differ *between* format categories, but to be comparatively similar *within* the same format categories. The customized corporate building formats as "build to suit" allow only limited store-to-store variation in energy consumption. Large observations show lower per square meter consumption (economies of scale).

H4. Annual variation in energy consumption in the stores over time is highly correlated with the influence of outdoor weather conditions, and also the operational sales business (with seasonal peaks in consumption).

H5. With regard to the centralized energy management, the ownership status of the assets (owned vs leased), in combination with the rental contract basis ("triple net"), does not prove differences in energy consumption.

H6. With regard to the physical building characteristics and technical operations, the identification of stores that have a significantly lower performance provides leverage on the total portfolio efficiency for achieving the corporate environmental performance targets ("low hanging fruits").

H7. Energy consumption "on-site" might be influenced more intensively in country organizations, provided with an responsible energy manager (human capital) at the country level, than in countries without an own energy manager. Therefore, energy managers are allocated to counties with sufficient energy-savings potential. Thus, economies of scale provide an incentive to economize on energy consumption, when human capital yields higher profitability from energy savings.

H8. In the absence of any direct carbon pricing today, energy conservation with cost savings directly affecting the operational profitability of stores, turns out to be a promising driver. For *METRO GROUP*, the operating energy costs of the stores monetize to an amount within the range of the annualized profit margin from the operational sales business. For corporate energy management, the corporate real estate assets prove to be a key driver for leveraging on profitability and lowering carbon emissions.

H9. Energy consumption, especially electricity consumption, is highly correlated with sales productivity and store performance (*EBIT*). Therefore, it is a key challenge for corporate management to decouple high and increasing sales productivity from related energy consumption, toward a more efficient corporate environmental performance.

4.5 Dataset

The very unique dataset, applied in this study, relies on several sources provided by *METRO AG* and *METRO PROPERTIES Holding GmbH*. It allows for the novel approach, to introduce energy in terms of electricity and heating consumption, physical building characteristics and key performance figures from the sales business. In particular, the sales productivity with turnover per square meter is expected to indirectly represent usage intensity or footfall on store level. For the timeframe from January 2011 until December 2014, the dataset from *METRO GROUP* covers electricity consumption on a monthly basis and heating energy with the annual consumption. The dataset provides the possibility to analyze the electricity and heating energy consumption – with potential reductions – in a panel over the observation period. Due to the structure of the dataset, the contained variables have differences in the time-related occurrence:

1) Time-constant variables:
    - store *ID*;
    - country;
    - sales line company;
    - sales line building format;
    - construction year;
    - revitalization year;
    - gross floor area (*GFA*);
    - sales floor area (*SFA*);
    - ownership status (leased vs owned); and
    - heating production type (gas, oil, district heating).
2) Time-varying variables on annual basis (variation between years):
    - building age;
    - electricity consumption in kWh/m²/a;
    - heating energy consumption in in kWh/m²/a;
    - total energy consumption in in kWh/m²/a (electricity and heating consumption);
    - total heating degree days (*HDD*) p.a.;
    - total cooling degree days (*CDD*) p.a.;
    - electricity price in €/m²/a;
    - sales productivity (turnover in €/m²/a); and
    - store-*EBIT* in €/m²/a.
3) Time-varying variables on monthly basis (variation between months):
    - electricity consumption in kWh/m² per month; and
    - *HDD* and *CDD* per month.

The dataset contains 781 wholesale and hypermarket buildings of *METRO GROUP* in 19 European countries. The hypermarket portfolio of the sales line "Real" is located only throughout Germany with a total of 300 stores. The total number of stores located in Germany amounts to 407 stores, of which 56 account for the sales line "METRO Cash & Carry" and 51 for "Cash & Carry Schaper".

The European portfolio, except the German stores, contains only wholesale stores of the sales lines *METRO* or *makro Cash & Carry* (*MCC*). It covers 374 wholesale stores with different building formats, of which the most are located in France (92), Italy (47), Spain/Portugal (45), Poland (30), Romania (26) and Turkey (24).

The different store formats of *MCC* wholesale and Real hypermarkets in terms of *SFA* are shown in Table 2.

Table 2: Store formats of MCC and Real hypermarkets

Sales floor area (SFA) in m²	**Min.**	**Mean**	**Max.**	**n**
METRO Cash & Carry formats (wholesale)				
Classic	8,959	14,213	34,295	110
Junior	5,128	8,263	13,835	193
Eco	2,071	3,696	11,305	127
Schaper (METRO Gastro)	1,980	3,389	6,680	51
Real hypermarket formats (retail)				
Hypermarket (stand-alone)	2,691	6,750	14,322	257
Center (retailpark)	3,543	7,069	13,910	43

While heating energy consumption is only available on an annual basis, the total energy consumption (electricity plus heating energy consumption) was aggregated on an annual basis for the full timeframe. To control for the local outdoor weather conditions and temperature-elasticity of energy consumption and in reference to the structure of the database, the number of *HDD* and *CDD* are introduced on a monthly and an annual basis. Both *HDD* and *CDD* are calculated on the computation basis of 65°F (equal to 18.3°C), obtained from the database of *Weather Underground* (*wunderground.com*). The monthly figures for electricity consumption were combined with the monthly total of *HDD* and *CDD* to a sample with 37,488 observations (i.e. 781 Stores over 4 years, observed on 12 months within each year).

Table 3 provides the descriptive statistics of the applied metric variables for energy consumption, physical building characteristics and sales business performance. With regard to confidentiality, the absolute figures of key performance indicators from the operational sales business remain undisclosed in this study.

Table 3: Descriptive statistics for corporate real estate sample of METRO GROUP

Descriptive Statistics	**Min.**	**1st Qu.**	**Median**	**Mean**	**3rd Qu.**	**Max.**
Electricity consumption in kWh/m²/month	1.2	15.7	19.4	20.0	23.6	49.3
Electricity consumption in kWh/m²/a	21.2	191.5	234.4	240.2	282.6	904.2
Heating consumption in kWh/m²/a	1.4	41.3	67.5	77.1	97.8	984.8
Total energy consumption in kWh/m²/a	73.8	254.0	304.0	317.3	366.3	1,006.0
No. of heating degree days (HDD)/month	0	117	352	414	681	1,465
No. of cooling degree days (CDD)/month	0	0	0	37	32	700
No. of heating degree days (HDD)/a	46	4,380	5,288	4,970	5,893	10,490
No. of cooling degree days (CDD)/a	0	173	246	440	474	2,874
Construction year building	1960	1984	1996	1993	2002	2011
Building age	0.0	10.0	16.0	19.5	28.0	54.0
Gross floor area (GFA) in m²	2,700	5,951	10,180	11,030	14,420	42,240
Sales floor area (SFA) in m²	1,980	4,780	6,947	7,477	9,269	34,295
SFA to GFA ratio	0.25	0.63	0.69	0.71	0.79	1.00
No. of floors	1.00	1.00	1.00	1.47	2.00	5.00
Sales productivity in €/m²/a			not disclosed			
Store-EBIT in €/m²/a			not disclosed			
Store-EBIT profit margin			not disclosed			
Electricity price €/m²/a			not disclosed			
Total energy price €/m²/a			not disclosed			

Considering the mean values of annual electricity and heating consumption, a share of 75.7% for electricity and 24.3% for heating energy turns out in relation to the total energy consumption p.a. The buildings are, on average, almost 20 years old, with a range of 0 until even more than 50 years. The *SFA*-to-*GFA* ratio with an average of 71% is in line with the expectation, as well as the number of floors of the big-box premises, ranging between 1 and 2 on average.

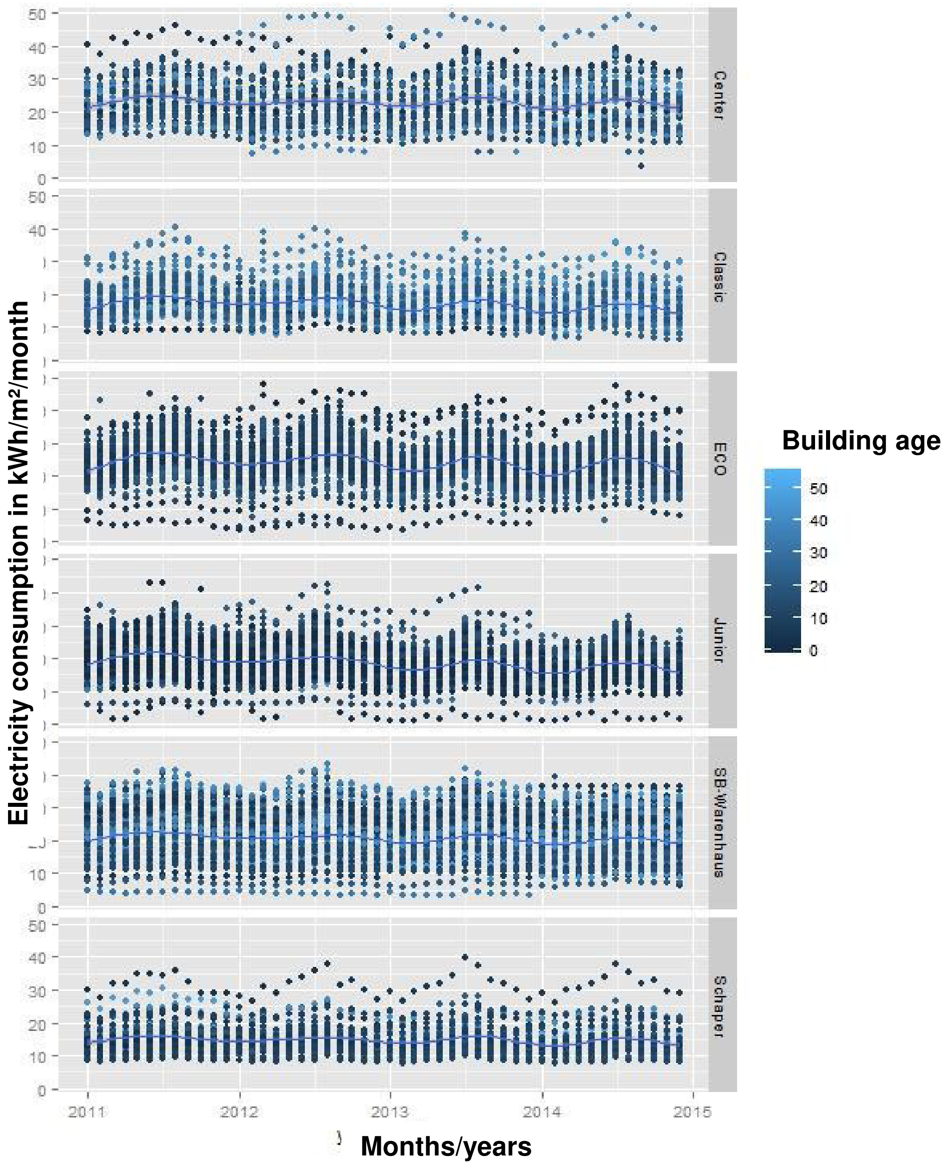
An analysis of the energy consumption of the wholesale and hypermarkets in each year of the timeframe indicates significant reductions in the electricity, as well as in the total consumption per square meter from 2011 to 2014 on average (Table 4). When comparing the total sample (n = 781) to a sub-sample, containing only those observations, attributed with a revitalization in the past (n = 195), a difference in the average age of the buildings of more than 10 years is observable. These results are corresponding to the construction year. Because revitalization is related to higher building age, the results for electricity and total consumption show significantly lower mean and median values in comparison to those of the total sample in each single year. The difference in electricity consumption seems to be most responsible for the decline in the total consumption of both samples, whereas the realized savings in heating energy consumption seem to be marginal. At first glance, this corresponds to *H2*, suggesting that the energy efficiency of equipment is improved in stores with revitalization, whereas the (thermo-physical) quality of the building remains unchanged.

Table 4: Energy consumption in total sample and revitalization sub-sample

Descriptive Statistics			**Total Sample (n = 781)**						**Revitalization Sample (n = 195)**			
	Min.	**1st Qu.**	**Median**	**Mean**	**3rd Qu.**	**Max.**	**Min.**	**1st Qu.**	**Median**	**Mean**	**3rd Qu.**	**Max.**
Construction year building	1960	1984	1996	1993	2002	2011	1960	1972	1979	1982	1993	2010
Building age 2011	0	9	15	**18**	27	51	1	18	32	**29**	39	51
Building age 2012	1	10	16	**19**	28	52	2	19	33	**30**	40	52
Building age 2013	2	11	17	**20**	29	53	3	20	34	**31**	41	53
Building age 2014	3	12	18	**21**	30	54	4	21	35	**32**	42	54
Electricity consumption in kWh/m^2 2011	46,0	205,1	250,5	**253,4**	300,8	508,0	46,0	196,7	233,7	**240,5**	277,2	422,7
Electricity consumption in kWh/m^2 2012	48,6	198,9	240,6	**245,2**	287,6	528,2	48,6	189,7	224,9	**231,1**	266,8	436,3
Electricity consumption in kWh/m^2 2013	23,1	188,3	228,4	**234,3**	274,5	519,6	23,1	179,3	208,6	**218,8**	255,3	423,7
Electricity consumption in kWh/m^2 2014	21,2	179,2	220,2	**227,9**	266,4	904,2	21,2	166,4	196,3	**209,5**	249,2	400,5
Relative reduction from 2011 to 2014				**-10,1%**						**-12,9%**		
Total energy consumption in kWh/m^2 2011	80,5	267,4	318,2	**332,5**	388,3	912,2	123,8	260,3	298,4	**315,7**	358,7	912,2
Total energy consumption in kWh/m^2 2012	73,8	262,0	314,2	**325,1**	372,0	919,1	115,1	253,5	291,3	**304,1**	337,8	919,1
Total energy consumption in kWh/m^2 2013	79,8	252,7	300,4	**315,9**	361,6	837,1	116,0	240,8	274,8	**291,1**	326,3	837,1
Total energy consumption in kWh/m^2 2014	114,0	235,5	280,9	**295,5**	342,3	1006,0	116,1	221,8	256,8	**272,8**	307,5	1006,0
Relative reduction from 2011 to 2014				**-11,1%**						**-13,6%**		

A look at the panel on monthly basis (Figure 3) shows the amplitude and variation in the electricity consumption in annual cycles over the timeframe for the different store formats. Culmination of seasonal peaks in consumption is significant each year in months July and August. While analyzing the electricity without consideration of the heating energy consumption, the peaks in the summer months are not surprising with higher electricity consumption for refrigerating and cooling loads than in months with lower outside temperature, as assumed in *H4*.

Figure 3: Electricity consumption of different store formats

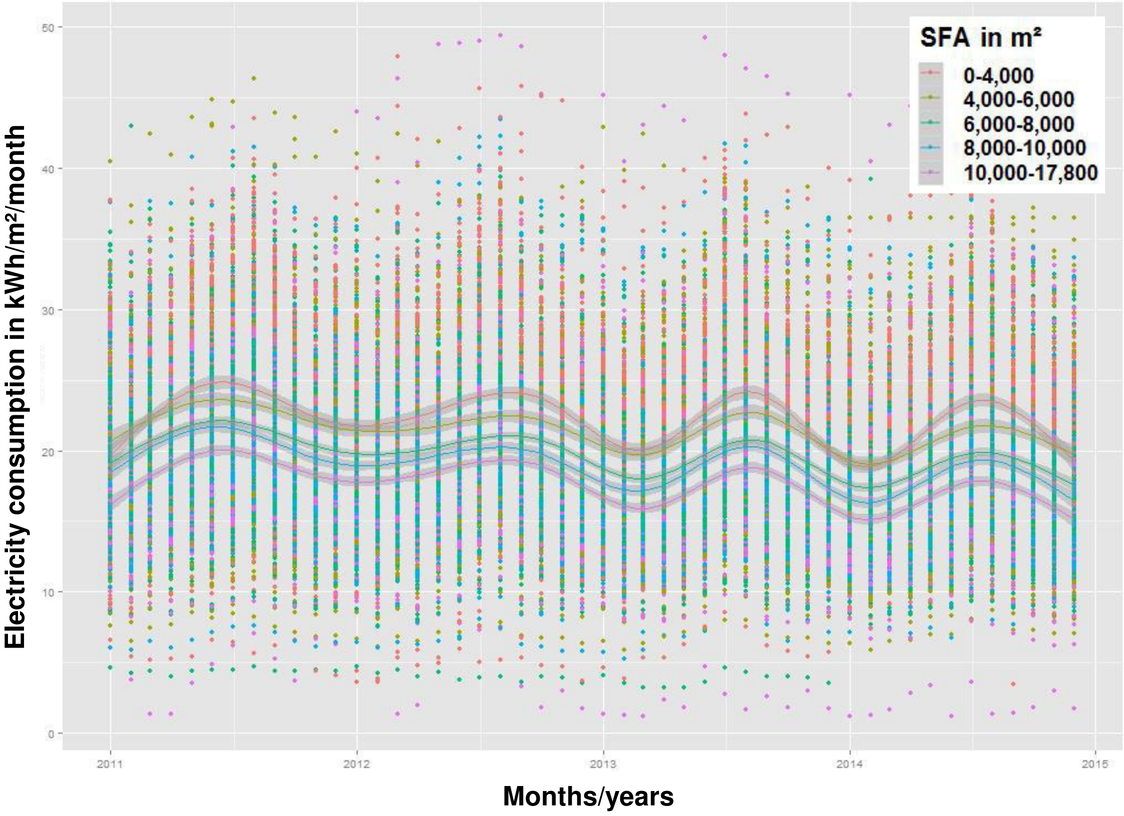


While the smoothing curves (splines) indicate the monthly consumption per square meter on average (blue line), the hypermarket format as stand-alone (named "SB-Warenhaus") offers the largest range in the monthly electricity consumption with an average oscillating around 20 kWh/m²/month. However, the Center format indicates slightly lower variation but higher consumption above 20 kWh/m²/month on average. For wholesale, the Eco format shows the highest variation between the stores and the highest consumption on average, which is significant above the oscillating levels of the other wholesale formats. Surprisingly, the Classic format appears with relatively low consumption on average but old buildings – compared to the Junior and Eco formats with higher consumption but much newer buildings. The Schaper format remains with the lowest consumption on an average over the timeframe.

By trend, these results are in line with the expectation of different electricity consumption intensities *between* the formats, but comparative similarity *within* the same format categories according to *H3*. This indicates evidence that customized corporate building formats as "build to suit" and energy management measures with reduction targets allow only limited store-to-store variation.

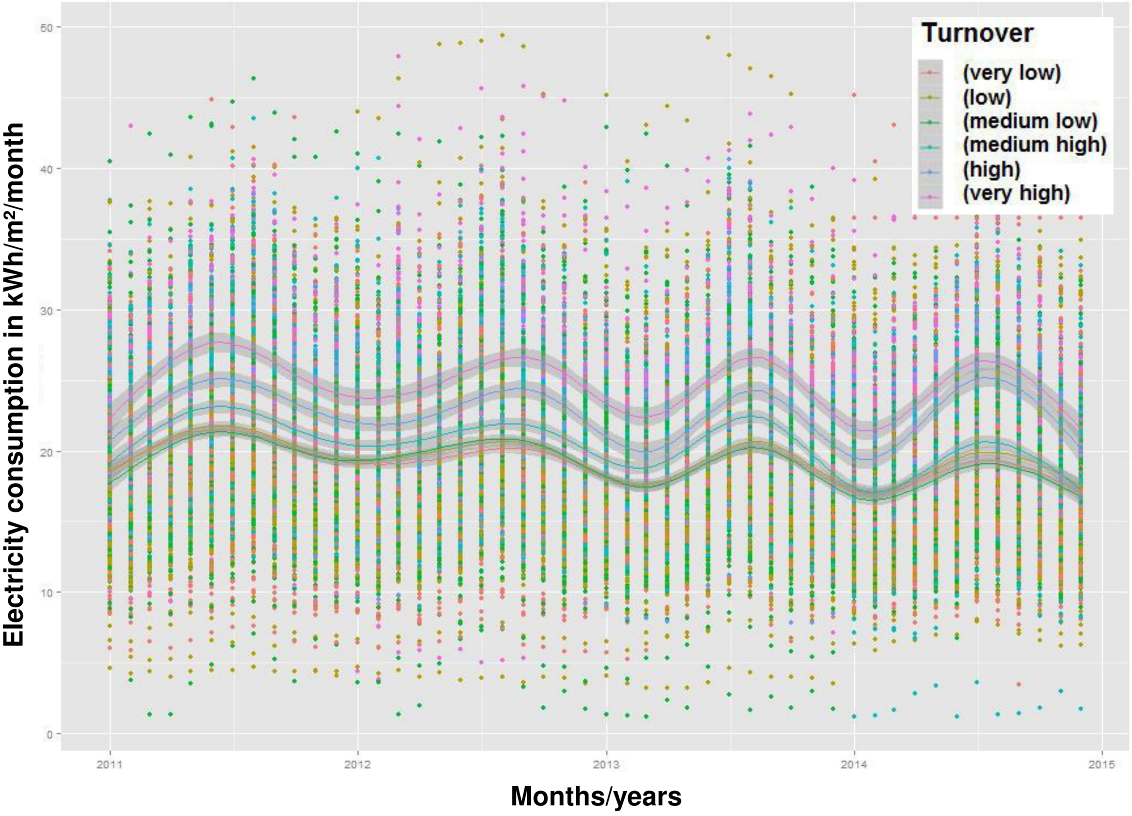
Over the timeframe, the splines for five categories of the *SFA* denote a decline in the consumption by trend when assuming a linear development. The splines illustrate correlation between the electricity consumption and the *SFA*. Higher *SFA* is, by trend, attributed to relatively lower electricity consumption per square meter, which proves for the existence of economies of scale described also in *H3* (Figure 4).

Figure 4: Electricity consumption in SFA-categories



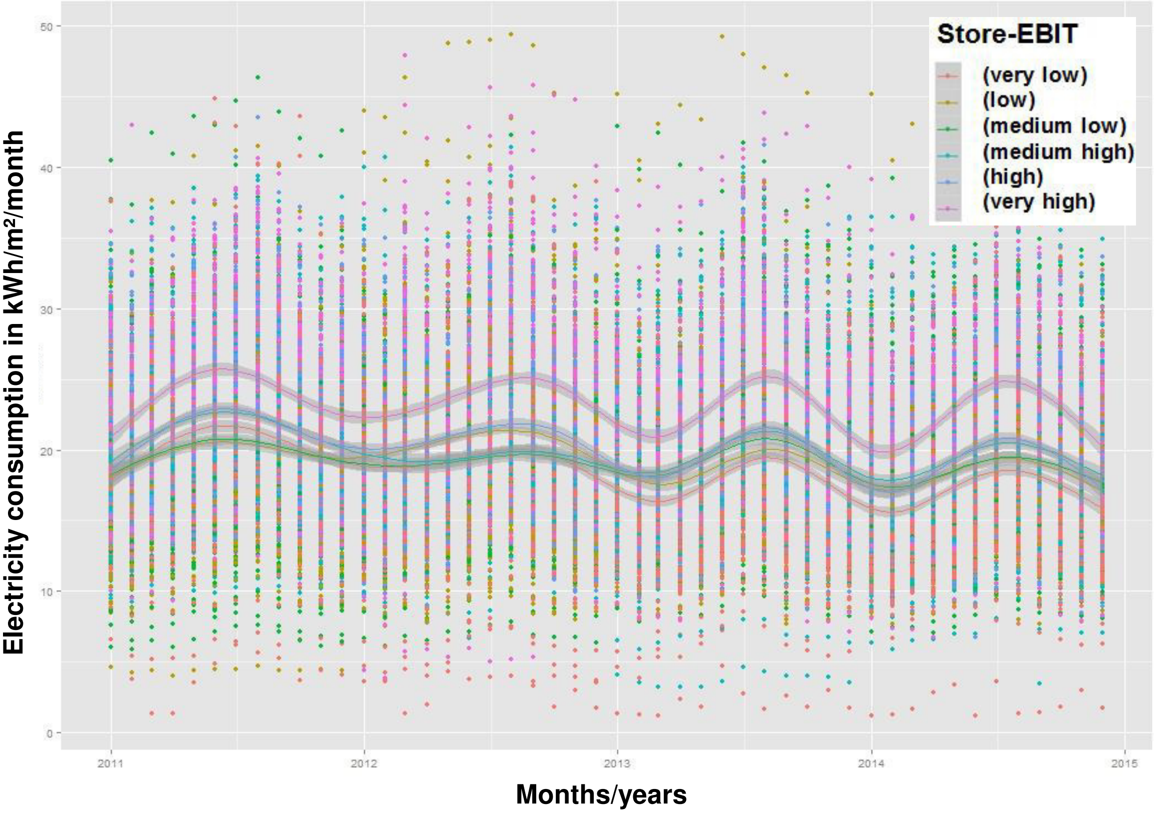
Introducing turnover figures (€/m²/a) with six categories of intensity as splines to the panel, the expected correlation between higher sales productivity and increased electricity consumption turns out significantly among the three categories representing higher turnover figures. This meets the expectation when hypothesizing high correlation between electricity consumption and sales productivity in *H9* (Figure 5).

Figure 5: Electricity consumption in turnover-categories



Despite a high range in the scatter zone for the monthly observations, the splines of the three lower turnover categories remain almost close to each other within the same range.

Figure 6: Electricity consumption in EBIT-categories



A preliminary indication for the relationship between the Store-*EBIT*, illustrated again in six spline categories for the classification of the *EBIT*-intensity (Figure 6), turns out with the supposed correlation between high *EBIT* and increased consumption in the stores (*H9*). This appears most significantly for the spline-category with highest *EBIT* (in €/m²/a) and also in the scatter zone. The differentiation for the categories ranging below is less significant to almost indifferent related to the intensity of electricity consumption, as seen before for certain turnover categories.

4.6 Econometric approach

With regard to the structure of the dataset in terms of different time-constant and time-varying variables, a sophisticated econometric approach is designed. Considering the data available in a different time-related structure, two panel regression models were designed to explain: electricity consumption with observations available on a monthly basis and total electricity consumption on an annual basis. In the applied multiple regression models, the response variables are decomposed into the implicit contribution of the available building characteristics and the attributes related to operational sales performance, while controlling for outdoor weather conditions and locational effects from spatial heterogeneity.

In a basic model specification for the panel regression, with 37,488 observations on a monthly basis over the timeframe from January 2011 until December 2014, equation (1) is applied with electricity consumption as response y (dependent variable). The cross-sectional component can be represented by the store identifier i, with constant effects attributed to the stores, and the time-related component t, which is the month of observation of electricity consumption.

$$\mathbf{y} = \alpha + \zeta' \mathbf{X} + f(\mathbf{t}) + f(\mathbf{i}) + \varepsilon \tag{1}$$

For total energy consumption, as response y (dependent variable) in the panel regression, equation (1) is applied the same way, but the time component t represents the year of observation of total consumption from 3,124 observations.

As the assumption of linearity in the effects of regression models often seems to be too restrictive in a real estate context (see e.g. Brunauer et al., 2010; 2012; Mason and Quigley, 1996; Pace, 1998; Parmeter et al., 2007), it seems appropriate to use more flexible non- and semi-parametric regression models. In this context, *generalized additive models* (*GAM*) are considered, as described in Wood (2006), to identify nonlinear effects for the continuous covariates. Applying *GAM* has the advantage, of expressing the nonlinear effects in the relationship between response (dependent variable) and explanatory (independent) variables in visualized nonlinear regression splines.

In this approach, the store-specific effect is modeled by means of a random effect. For example, the effect of building age is known to be nonlinear (Farhrmeir and Tutz, 2001) and, therefore, it can be modeled by splines in an approach that penalizes over-fitting (Oelker and Tutz, 2013). Furthermore, the design of the approach allows to decompose the time effect in the regression of electricity consumption into a fixed-year effect and a nonlinear cyclical monthly effect. For total energy consumption, the time effect is only decomposed into a fixed-year effect. Additionally, and besides the store characteristics, the variation in electricity and total consumption is explained by spatial-temporal covariates (*HDD*, *CDD*), which are also modeled in a nonlinear manner.

Bearing in mind common practice in hedonic price models (Malpezzi, 2003), a logarithmical transformation of the response variables (natural logarithm of electricity consumption and total energy consumption) was applied, while expecting multiplicative effects of the building characteristics on the dependent variables. This procedure enables for the interpretation of the estimated effects as elasticities, if both sides are logarithmically transformed or semi-elasticities if the explanatory variable enters the equation in absolute values. Furthermore, this approach mitigates the problem of heteroscedasticity. The response variables a) electricity and b) total energy consumption, as well as the other strictly positive metric explanatory variables, are transformed logarithmically, when estimating a log-linear function with the following equation:

$$\begin{gathered}
\ln(\text{Electricity Consumption}_{\text{i,t}}) = \\
\alpha + \boldsymbol{\beta'}\text{Year} + \boldsymbol{\gamma'}\text{No. Floors}_{\text{i}} + \delta\,\text{Revitalization Binary}_{\text{i}} + \theta\,\text{Ownership Binary}_{\text{i}} + \\
\boldsymbol{\kappa'}\text{Store Format}_{\text{i}} + \lambda\,\text{Problem-Store Binary}_{\text{i}} + \rho\,\text{F8-Country Binary}_{\text{i}} + \\
\boldsymbol{\sigma'}\text{Country}_{\text{i}} + f(\text{i}) + f(\text{Month}) + f(\text{Building Age}_{\text{i,t}}) + f(\ln(\text{GFA}_{\text{i}})) + \\
f(\text{SFA Ratio}_{\text{i}}) + f(\ln(\text{Sales Productivity}_{\text{i,t}})) + f(\widetilde{\text{Store-EBIT}}_{\text{i,t}}) + \\
f(\text{HDD}_{\text{i,t}}) + f(\text{CDD}_{\text{i,t}}) + \varepsilon_{\text{i,t}} \qquad (2)
\end{gathered}$$

In the regression of electricity consumption on the explanatory variables, a vector of coefficients is applied, containing the annual values applicable to the four years from the dataset. This *year* effect is introduced to the model with parametric coefficients, so as to quantify the expected electricity savings from 2011 to 2014. For the physical characteristics, the *number of floors* of the buildings is estimated with a vector of linear coefficients. The dichotomous variable, *revitalization binary*, distinguishes between observations that underwent a revitalization in the past (or not), to predict potential electricity savings associated with store revitalizations. With regard to the hypothesis, the *ownership binary* controls for differences between leased and owned stores. The *store formats* are included in a vector with the specifications mentioned in Table 2, so as to control for differences between the wholesale and hypermarket formats in electricity consumption.

Over the past years, the energy management of *METRO GROUP* selected those stores with the weakest energy performance of the wholesale portfolio, called "Problem-Stores". In a benchmark for an average calculation, the stores with the worst 20% in energy consumption per square meter *SFA*, were identified in 2013. Because immediate intervention measures are needed to reduce energy consumption and improve efficiency, these stores were targeted with individual reductions. In the course of the regression, a binary variable is attributed to *Problem-Stores*, to estimate the surplus consumption compared to the portfolio average.

METRO GROUP differentiates in terms of number of stores and sales activity, between eight Focus-Countries and the other – less important – countries in the portfolio. Within the *F8-Countries* with higher organizational overheads, energy management is represented with a specific country manager, dedicated explicitly to energy management. Because these F8-Countries might be associated with higher consumption, but also with higher saving potential, a binary is included. To control for spatial heterogeneity, binary variables for each *country* in the portfolio are contained in a vector of coefficients for the location dummy effects.

Furthermore, the regression equation contains the store identifier *i*, with constant effects attributed to the stores, which provides a quality-adjusted identification of higher- and lower-performing stores in terms of energy efficiency. When a dataset with observations on a monthly basis is used, the electricity consumption in each month of the four years can be expressed with a *function of months* and displayed with a spline, which combines the observations into one representative spline for a "modelled year".

Building age is introduced as a function, to explain the effect on electricity consumption in a regression spline, as well as the two other physical characteristics, *ln(GFA)* and *SFA-Ratio*. Although the *GFA* accounts for the total size of a building and the intensity of energy consumption, not every part in the building necessarily has the same energy-consumption intensity. Therefore, it is common practice to account for *SFA*, which is introduced here with the percentage ratio of *SFA* to *GFA*, to avoid collinearity in the effects.

The performance attributes are expected to yield significant effects on the electricity consumption. The turnover figures of the stores are introduced with *ln(sales productivity)* per square meter, to consider the local impact of a store in terms of population size and catchment area, determining the number of customers, differences in purchasing power and the intensity of competition in the local market environment.

However, it stands to reason that sales productivity and *EBIT* are highly correlated with each other. Because it is expected that the *EBIT* is a suitable indicator of the cost structure (including electricity costs) at the individual store level, the *EBIT* is reconsidered for integration in a "cleaned" mode, from which the explanatory power of the sales productivity has been eliminated. For this reason, a "helper regression" is designed in equation (3), which contains a residual output, as the unexplained part of the regression that is used to eliminate the correlation with sales productivity (orthogonalization).

$$\mathrm{StoreEBIT}_{\mathrm{i,t}} = f(\ln(\mathrm{Sales\ Productivity}_{\mathrm{i,t}})) + \widetilde{\mathrm{Store\text{-}EBIT}}_{\mathrm{i,t}} \tag{3}$$

The *residual output of the Store-EBIT* contains the information not explained through the systematic part of the model from equation (3). This information, reflecting the specific cost structures in the operational sales business as an explanatory variable in the final model, ensures that the resulting effects are directly attributable to electricity consumption.

The model includes the specific *HDD* and *CDD* of the individual store locations on a monthly basis, to control for spatial heterogeneity in the outside temperature variation over the timeframe as spatial-temporal covariates. Although heating energy consumption is not considered in the regression for electricity consumption, the impact of outdoor weather conditions via *HDD* might be reasonable, due to additional heating-production loads (e.g. for storage premises) – based on electricity – associated with very low temperatures. *CDD* are included, while higher electricity consumption for refrigeration and cooling is expected with an increasing outside temperature.

For the regression of total energy consumption on an annual basis in b), this model is applied with some differences in notation, when the spline for a nonlinear cyclical monthly effect "f(Month)" is excluded from the model. To explain the contained heating-energy consumption, a binary for the *heating production type* in the stores is introduced, controlling for different heating energy efficiency between the fuels of gas, oil and district heating systems. *HDD* and *CDD* are introduced with the annual total degree days as explanatory variables.

4.7 Results

First, the results of the regression for electricity consumption as response are presented here, followed by the results of the regression for total energy consumption in the next subsection.

4.7.1 Results for electricity consumption

The results of the log-linear regression model applied for estimating the effect of electricity consumption are summarized in Table 5 with parametric coefficients following equation (2), and nonlinear regression splines depicted as smoothed curves in Figure 7.

Table 5: Parametric coefficients from regression of electricity consumption from equation (2)

Response Variable: ln(Electricity consum. in kWh/m^2/month)	
Parametric Coefficients [t-values]	
Intercept	2.947 [66.841]***
Year 2012 (2011 = omitted)	-0.031 [-15.763]***
Year 2013 (2011 = omitted)	-0.075 [-26.914]***
Year 2014 (2011 = omitted)	-0.102 [-27.376]***
No. floors 2 (No. floors 1 = omitted)	0.020 [0.904]
No. floors 3 (No. floors 1 = omitted)	0.040 [0.798]
No. floors 4 (No. floors 1 = omitted)	0.294 [1.607]
No. floors 5 (No. floors 1 = omitted)	0.328 [1.272]
Revitalization Binary (Revitalization = 1)	-0.006 [-0.214]
Ownership Binary (owned = 1)	-0.012 [-0.408]
Classic (Hypermarket, stand-alone = omitted)	-0.111 [-1.964]*
Junior (Hypermarket, stand-alone = omitted)	-0.229 [-3.688]***
Schaper (Hypermarket, stand-alone = omitted)	-0.502 [-10.343]***
Eco (Hypermarket, stand-alone = omitted)	-0.122 [-1.820]
Center (Hypermarket, stand-alone = omitted)	-0.006 [-0.135]
"Problem-Store" Binary ("Problem-Store" = 1)	0.148 [4.854]***
F8-Countries Binary (F8-Countries = 1)	0.112 [2.260]*
AT (Germany = omitted)	0.083 [1.133]
BE (Germany = omitted)	0.000 [-0.001]
DK (Germany = omitted)	0.182 [1.672]
FR (Germany = omitted)	-0.029 [-0.452]
IT (Germany = omitted)	0.097 [1.662]
NL (Germany = omitted)	0.084 [1.303]
PT (Germany = omitted)	0.271 [2.924]**
ES (Germany = omitted)	0.120 [1.681]
TR (Germany = omitted)	0.060 [0.773]
BG (Germany = omitted)	0.378 [4.886]***
HR (Germany = omitted)	0.320 [3.190]**
CZ (Germany = omitted)	0.318 [4.428]***
GR (Germany = omitted)	0.270 [3.130]**
HU (Germany = omitted)	0.306 [4.163]***
PL (Germany = omitted)	0.345 [4.559]***
RO (Germany = omitted)	0.307 [5.620]***
RS (Germany = omitted)	0.300 [3.173]**
SK (Germany = omitted)	0.285 [2.773]**
R^2	**0.885**
Adjusted R^2	**0.883**
AIC-Criterion	**-62339.78**
No. of observations (n)	**37488**

Significance: * 0.001; ** 0.01; * 0.05**

The significant coefficients indicating the intensity of electricity consumption for the calendar years quantify substantial electricity savings from 2011 to 2014. In 2012, the consumption was 3.1% lower, with a further decline of 7.2% in 2013, and electricity savings of almost 10% in 2014, compared to electricity consumed in 2011 as a reference. With regard to Table 5, in semi-logarithmic regressions the percentage effect of the coefficients for binary variables is calculated as anti-logarithm of the estimated coefficients with ((*exp*(βx) – 1) * 100) in relation to the omitted reference variable (Halvorsen and Palmquist, 1980; Hardy, 1993).

These results point to significant reductions, achieved in the course of implemented reduction targets and efficiency measures of corporate energy management. Pertaining to *METRO GROUP*'s 20% reduction target of CO$_2$ emissions, this is an initial indicator of success (corresponding to *H8*) – considering that a reduction of almost 10% was realized in the four years after the target-setting baseline. Assuming significant electricity costs savings, a "conservation pay-off" from cost structures related to the operational sales business might be possible.

The introduced differentiation for the number of floors in the buildings remains insignificant. A significant effect of floor numbers is assumed when considering installation of elevators or escalators in the wholesale and hypermarket stores. However, these attributes may not be significant in relation to the size and compactness of the building structure – and also with respect to the introduced dummies for the different store formats. It appears that the wholesale formats do consume much less energy per square meter than the omitted stand-alone hypermarkets as reference. For the small-sized format of Schaper, the electricity consumption is almost 40%, for the Junior-Format approximately 20% and even for the *MCC*-Format Classic, almost 11% lower than in stand-alone hypermarkets. This is remarkable, given that the Classic-Format is very often attributed with escalators and elevators to a so-called "Mezzanine-Floor", whereas most of the stand-alone hypermarkets feature only one flat floor. Furthermore, the difference between hypermarkets in retail parks (Center) and those which are stand-alone, is marginal and insignificant (as proposed in *H3*).

Surprisingly, with regard to *H2* and the results of Table 4, the revitalization binary turns out to be insignificant. However, it might be the case that the revitalization attribute contained in the dataset is dedicated rather to construction measures affecting the outside and inside appearance of the stores and sales floor, but less significant for the technical status of electricity-related building and sales floor facilities and equipment.

In line with *H5* for the ownership status of the assets, no significant effect on electricity consumption is found, according to whether a store is owned by *METRO GROUP* or leased. The result points to the fact that *METRO GROUP*'s reduction targets cover both owned and leased assets, so that corporate energy management is responsible for reduction measures, independent of the ownership status. Furthermore, many stores were constructed according to the customized corporate building formats as "build to suit". In the case of a later sale and lease-back of corporate assets, based on a "triple-net" contract, the insignificance appears reasonable.

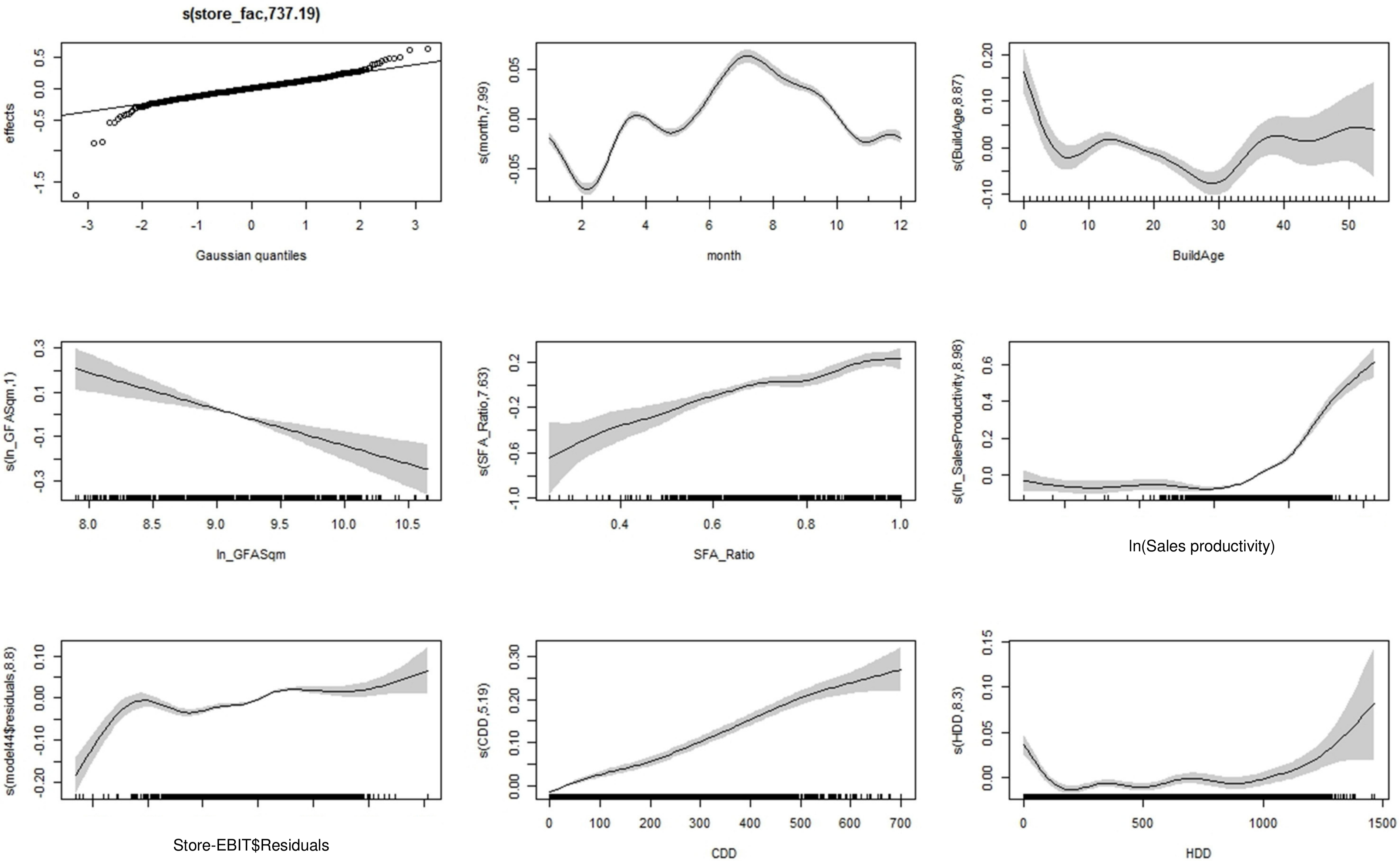
For the Problem-Stores, identified by corporate energy management, the results yield a higher consumption estimate of 16%, compared to the portfolio average, all else equal. This confirms the obvious potential of the stores for higher costs savings and thus higher profitability and lower carbon emissions, following *H6*. Although each Problem-Store is targeted with individual energy reductions, this nevertheless provides a reference point for the reduction targets from a management perspective. Confronting the higher electricity consumption of the Problem-Stores with a reduction of 16% to the average, might result to cost savings of €4.39/m²/a and an assumed reduction of CO_2 emissions by 2.42 kg/m²/a.

The binary variable for the Focus-Countries reveals higher consumption of approximately 12% in reference to the non-Focus-Countries. This meets the expectation of higher energy savings potential that can be realized through country-wide managers (with regard to *H7*), dedicated explicitly to energy management. The single-country binaries exhibit significantly increased electricity consumption in several – mostly Eastern European –

countries. This is in line with Figure 2 of this study and shows disproportionately high savings potential – but *a fortiori* higher pressure for reduction measures.

Figure 7 illustrates the regression splines for the covariate effects from equation (2). The y-axes can be analyzed approximately as the percentage effect on electricity consumption. A linear relationship between explanatory and response is explained, if the *effective degrees of freedom* (*edf*) are estimated at 1.0. An estimated *edf* higher than 1.0 displays a nonlinear function in the relationship. Within the splines, the continuous black lines are the expected effects, and the grey areas are point-wise 95% confidence intervals.

Figure 7: Regression splines from regression for electricity consumption from equation (2)



In the results, the store identifier allows for the quality-adjusted identification of higher and lower performing stores, and indicates only few outliners. The function of months displayed in a combined regression spline over the "average calendar year" explains that lowest electricity consumption is observable in January, February and the beginning of March. Culmination of a seasonal peak is significant in July and August when refrigeration loads are at maximum level (*H4*). Furthermore, seasonal effects seem evident in the spline. In December, the consumption intensity is relatively high, compared to January and February, which reflects higher sales productivity prior to Christmas – usually the timeframe with the highest turnover in the business year and an increased volume of illumination. For March and April, a significant increase occurs followed by a decrease in May. First, the increase might be due to increasing outside temperatures, with higher refrigeration and cooling consumption. Second, the decrease in May seems surprising and could be interpreted as the result of a large number of public holidays and closed stores at this time of the year.

The spline for building age proves, surprisingly, to have the highest consumption in the newest stores, which is counterintuitive to *H1*. Because the consumption decreases immediately in the following, up to an age of 6 years, a cautious interpretation might be that new stores need a few years of operation, to achieve a relatively low consumption level. With increasing age, a slightly higher consumption follows up to an age of 12 years, after which a continuous decrease until the age of 28 years is observable. The lowest consumption, around the age of 30 years might account for older stores with less complex technical standards and equipment. However, it seems to be more likely that these stores were given to an electricity or energy-related retro-fit, compared to their older peers. If this appears to be the case, the retro-fit has obviously not been attributed to a revitalization of the stores – corresponding to the result for the revitalization binary (*H2*).

In line with other research, a linear decline in electricity consumption per square meter with increasing *GFA* is observed. The *SFA*-to-*GFA* ratio confirms to the expectation that a higher share of *SFA* to *GFA* relates to higher consumption by trend. Hence, it is reaffirmed that *SFA* is the relevant parameter in terms of electricity consumption.

The spline for sales productivity indicates at first a zone of indifference associated with low levels of turnover, which is followed by an almost exponential function. From a certain point, the slight increase turns into a progressively stronger increase. This proves higher electricity consumption with increasing turnover, as hypothesized in *H9*. In a linear function, a turnover increase of 1% is associated with an increase of 3.2% in electricity consumption. This result suggests a key challenge for the energy management, which is to realize energy savings permanently, while simultaneously increasing sales productivity with high volumes of customers.

The residual output of equation (3) was estimated as an indicator of the cost structure in the operational sales business, with overhead costs such as for personnel, energy and utilities etc. After a phase, associated with the cost structure of a very low Store-*EBIT*, the significant effect explains that a slight rise in the cost structure is coherent by trend with higher electricity consumption up to a certain crest, confirming *H9*. From this point onwards, some indifference in the effect, followed even by a very slight decrease in consumption, can be observed. Interpreted with care, this might suggest that at stores with very high costs, certain electricity-saving measures (such as the Problem-Store reduction targets) in fact reduce operational costs as a contribution to Store-*EBIT*. However, for the most part, the results prove clearly, that higher operational cost structures are linked to slightly higher electricity consumption.

The regression spline for *CDD* corresponds to the supposition in *H4* that with higher outdoor temperatures, more electricity is used for refrigeration and cooling in the stores. An increase in *HDD* verifies only a marginal effect on electricity consumption as expected. From 200 up to 1,000 *HDD*, an almost indifferent zone of the effect is followed by slightly higher consumption in stores facing more than 1,000 *HDD*. This suggests additional heating-production loads, based on electricity, at very low outside temperatures, e.g. for usually unheated storage premises and the use of additional equipment. The higher consumption at lower than 200 *HDD* is intuitively surprising, but may account for a still relatively high refrigeration load and electricity consumed in regard to relatively high outdoor temperatures. The immediate descent with increasing *HDD* supports to this interpretation.

4.7.2 Results for total energy consumption

The results obtained in the regression model for total energy consumption following equation (2), with the explained model-specification, correspond in many ways to the results discussed before, for electricity consumption. Thus, the major differences and additional results with regard to thermo-physical and heating-related attributes are explained below.

For total energy consumption, an annual reduction of almost 3% in 2012, 5% in 2013 and even 11% in 2014 has been realized, with reference to the energy consumed in 2011. Again, Schaper turns out as the format of lowest energy consumption, with a 20% lower consumption than in stand-alone hypermarkets. Surprisingly, the Eco format is found to have 16% higher consumption than in those hypermarkets. For the heating production type, oil was found to have 7% higher consumption than natural gas. The Problem-Stores account for 11% higher consumption than the portfolio average. With regard to the results obtained for electricity consumption, this might indicate higher thermo-physical and heating efficiency in the Problem-Stores, whereas electricity consumption remains the major issue.

The binary for the Focus-Countries reveals a significantly higher consumption of up to 60% in the Focus-Countries. Few country binaries yield lower energy consumption with reference to Germany (omitted), for France by -30%, Italy by -15% and Turkey by -23%. The countries in Eastern Europe reconfirm the results for electricity, but some even yield higher total energy consumption than for electricity only. This suggests that beside electricity, heating energy efficiency is weak as well. For the omitted reference binary of Germany, the results might point to the more restrictive building codes over the past decades, with effectively lower levels of consumption. The results are in line with the overall *GHG* emissions of *METRO GROUP*, as illustrated in Figure 2.

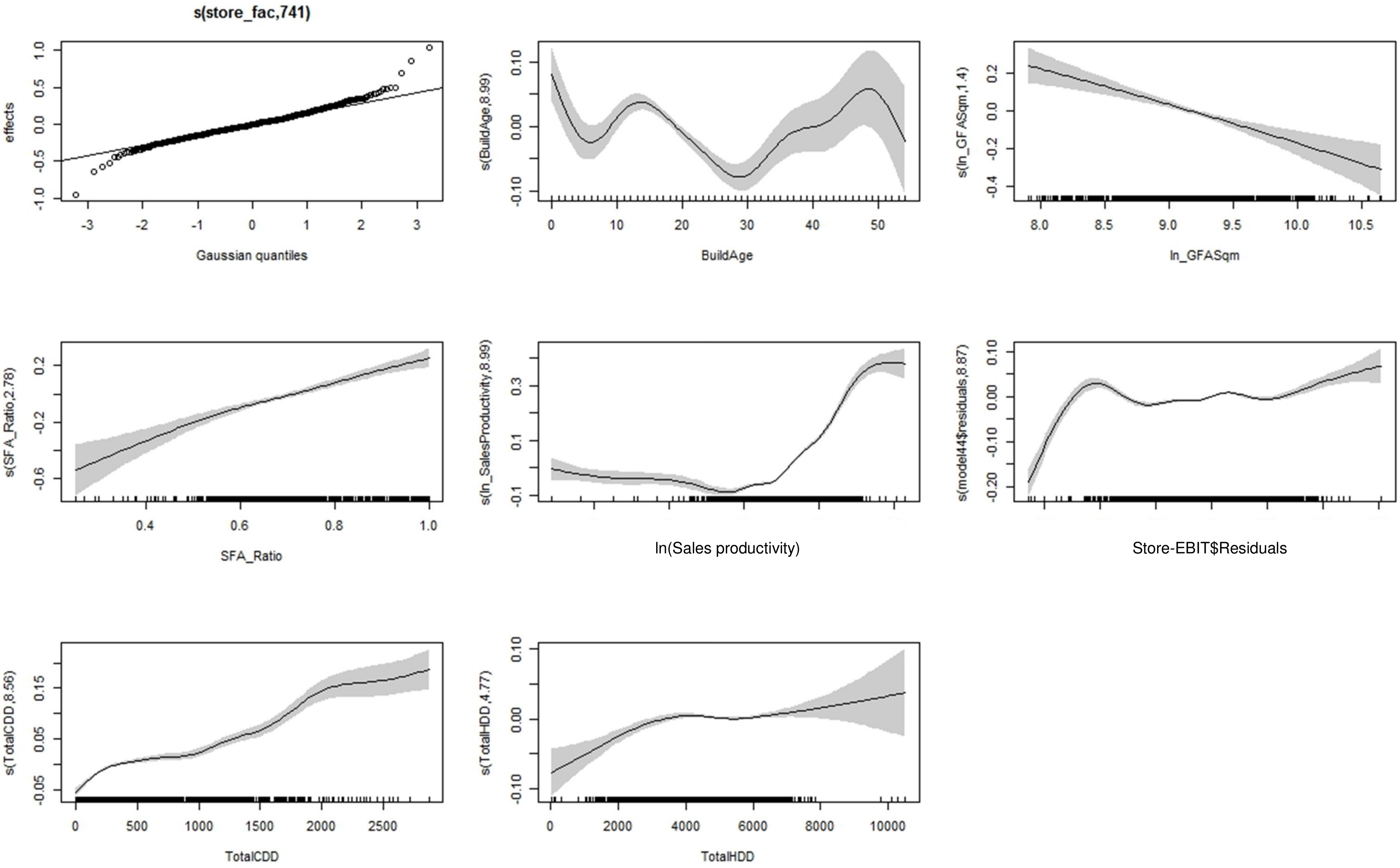
Table 6: Parametric coefficients from regression of total energy consumption from equation (2)

Response Variable: ln(Total energy consum. in kWh/m^2/month)	
Parametric Coefficients [t-values]	
Intercept	5.295 [101.129]***
Year 2012 (2011 = omitted)	-0.026 [-15.853]***
Year 2013 (2011 = omitted)	-0.055 [-21.904]***
Year 2014 (2011 = omitted)	-0.115 [-35.660]***
No. floors 2 (No. floors 1 = omitted)	0.011 [0.401]
No. floors 3 (No. floors 1 = omitted)	-0.007 [-0.121]
No. floors 4 (No. floors 1 = omitted)	0.190 [1.118]
No. floors 5 (No. floors 1 = omitted)	0.245 [1.017]
Revitalization Binary (Revitalization = 1)	0.032 [1.167]
Ownership Binary (owned = 1)	0.039 [1.392]
Classic (Hypermarket, stand-alone = omitted)	0.034 [0.622]
Junior (Hypermarket, stand-alone = omitted)	-0.005 [-0.080]
Schaper (Hypermarket, stand-alone = omitted)	-0.229 [-5.178]***
Eco (Hypermarket, stand-alone = omitted)	0.147 [2.351]*
Center (Hypermarket, stand-alone = omitted)	-0.077 [-1.794]
Oil heating (gas = omitted)	0.069 [2.172]*
District heating (gas = omitted)	0.041 [1.234]
"Problem-Store" Binary ("Problem-Store" = 1)	0.108 [3.805]***
F8-Countries Binary (F8-Countries = 1)	0.481 [10.449]***
AT (Germany = omitted)	0.371 [5.478]***
BE (Germany = omitted)	0.263 [3.438]***
DK (Germany = omitted)	0.240 [2.335]*
FR (Germany = omitted)	-0.354 [-5.994]***
IT (Germany = omitted)	-0.167 [-3.102]**
NL (Germany = omitted)	0.287 [4.889]***
PT (Germany = omitted)	0.084 [0.976]
ES (Germany = omitted)	-0.042 [-0.648]
TR (Germany = omitted)	-0.267 [-3.681]***
BG (Germany = omitted)	0.450 [6.210]***
HR (Germany = omitted)	0.444 [4.754]***
CZ (Germany = omitted)	0.488 [7.264]***
GR (Germany = omitted)	0.473 [5.894]***
HU (Germany = omitted)	0.441 [6.535]***
PL (Germany = omitted)	0.090 [1.258]
RO (Germany = omitted)	0.449 [7.854]***
RS (Germany = omitted)	0.415 [4.727]***
SK (Germany = omitted)	0.488 [5.154]***
R^2	**0.937**
Adjusted R^2	**0.936**
AIC-Criterion	**-90885.02**
No. of observations (n)	**3124**

Significance: * 0.001; ** 0.01; * 0.05**

Overall, there is little variation in the covariate effects explained in the splines (Figure 8). Once again, the stores with a building age of around 30 years prove to have the lowest consumption. The youngest and the oldest observations are associated with significantly higher levels of energy consumed. This ambiguous result is comparable to those of Spyrou et al. (2014), that the construction year proved not to exert a significant influence on energy consumption. It seems that the influence of building age and related thermo-physical characteristics is only marginal compared to other factors.

Figure 8: Regression splines from regression for total energy consumption from equation (2)



The spline for *HDD* is intuitive to the assumption of higher energy consumption due to increased *HDD*. A comparison of the spline to the result for electricity consumption shows the significant effect when explaining total energy consumption. The spline illustrates that from a crest point onwards, no higher consumption arises, if *HDD* are increasing from that point onwards. This indifference in the effect might be because, despite a further increase in *HDD*, the heating systems do not exceed their energy use, while they have already reached the peak load.

4.8 Reflection, conclusion and outlook

This study investigates the relationship between energy consumption, physical building characteristics, operational sales performance and the potential impact of corporate energy management. A very unique multi-national dataset, containing big-box wholesale and hypermarket stores of *METRO GROUP*, is applied to a sophisticated panel regression, explaining the electricity and total energy consumption of corporate real estate assets. In this context, the research analyzes the role of corporate energy management for achieving energy conservation and contributing toward a more efficient corporate environmental performance.

The dataset with 781 stores is used twofold, in a regression for electricity consumption on a monthly basis with 37,488 observations, and for total energy consumption on an annual basis with 3,124 observations, in the timeframe from 2011 until 2014. The econometric approach is designed to explore nonlinear covariate effects between response and explanatory variables, which are depicted in regression splines.

The results prove significant electricity and total energy savings in the wholesale and hypermarkets of *METRO GROUP*. An exemplified pay-off calculation from lower electricity consumption achieved by 2014, is estimated with more than €3.00/m^2/a and forecasted to almost €9.00/m^2/a by 2020. In an indicative scenario, assuming pricing for the internalization of *GHG* externalities, the potential electricity cost saving by 2020 would be offset by almost 10% due to CO_2 pricing. The applied cost of €30.00/ton CO_2 is derived from assumed "social cost" of US$32/ton of carbon dioxide calculated in Kahn and Kok (2014b) for the case of *Walmart* in California (with reference day 30 November 2015).

With regard to the hypothesis from the empirical framework of this study, the results prove no evidence for higher energy efficiency of more recent wholesale and hypermarket stores (*H1*). In particular, the relatively new stores in Eastern Europe, show higher consumption, on average. It is concluded that the influence of building age is only marginal, compared to other factors, such as the technical facilities and equipment used. This corresponds to the results obtained for revitalization (*H2*). Whereas the sub-portfolio with stores which have undergone revitalization yields lower consumption on average, the insignificant effect obtained in the regression might suggest that revitalization is attributed more to construction measures for the appearance of the stores, but less to energy-consuming technical equipment.

A comparison of the electricity consumption between the different sales line and store formats (*H3*) revealed annual consumption cycles, with relatively similar store-to-store variation for the same formats, and higher variation among different formats. Hypermarkets are identified as having significantly higher consumption on average, as well as with greater variation between single stores. This implies the impact of the customized corporate building formats as "build to suit", and the influence of centralized energy management.

The summer months were found to be associated with the highest electricity, as well as total energy consumption, due to the highest refrigeration and cooling loads. January and February are observed as being the months of lowest consumption. Beside the outdoor and indoor temperature impact, seasonal effects of the operational sales business are also displayed in the regression outcome (*H4*).

Due to the customized building formats and centralized energy management, which apply both to owned and leased stores, in combination with the "triple-net" rental contract basis, no significant difference in the energy consumption of owned and leased stores is investigated (*H5*).

The identification of "Problem-Stores", in terms of energy efficiency from energy management, provides a reference point with regard to achieving individual reduction targets for the stores (*H6*). The reduction of electricity consumption by 16% in the Problem-Stores, compared to the average of the *MCC* wholesale portfolio, is followed by cost savings of €4.39/m²/a and an assumed reduction of CO_2 emissions of 2.42 kg/m²/a.

The six *METRO GROUP* Focus-Countries, included in the study dataset, are identified as associated with significantly higher electricity and total energy consumption, thus having the highest energy saving potential (*H7*). Considering the number of stores in the countries and the size of the local organizations – with their own energy manager at the country level – these countries are advised, to take advantage of existing economies of scale for economizing on energy consumption, so that human capital gains higher profitability from savings.

This suggests that – besides the reduction of carbon emissions – continuous energy conservation with cost savings is also a promising driver for operational store profitability. From the dataset, electricity costs are revealed of 0.55% and total energy costs with 0.73% of the annual turnover per square meter. *H8*, proposing annual operating energy costs approximately in the range of the annualized profit margin from the operational sales business (Dena, 2014) is not confirmed, as the total energy costs amount to a margin of not even 50% of the annual profit margin. Notwithstanding, the corporate real estate assets of *METRO GROUP* will provide leverage on store profitability, if further cost savings can be realized from lower consumption in the course of attempting to achieve the energy reduction targets.

For the most part, the results prove clearly that higher operational cost structures are linked to slightly higher energy consumption. Energy consumption and related costs are highly correlated with sales productivity and store performance (*EBIT*). This constitutes a key challenge, namely, to realize energy savings permanently toward a more efficient corporate environmental performance, while retaining or increasing sales productivity with high volumes of customers (*H9*).

The research outlined in this study explores the energy efficiency of corporate real estate assets and the key role of corporate energy management. However, for the tested wholesale and hypermarket store portfolio of *METRO GROUP*, the cost structure of corporate energy management is not part of this study. In this regard, a current cost-benefit analysis provides an opportunity for future research in related studies.

Furthermore, besides the energy manager in Focus-Countries, the extent of human capital engaged in energy savings and corporate environmental performance is not analyzed in this study and is thus another avenue for further research, especially in the field of behavioral real estate. In this regard, the study recommends raising the awareness of (real estate asset) management and staff, with regard to energy efficiency and environmental issues for higher corporate environmental performance. Highlighting the role of wholesale and hypermarkets as a transmission mechanism for sustainability issues, as anticipated by customers, might support to this objective.

4.9 References

BDEW (2015), Bundesverband der Energie- und Wasserwirtschaft e.V., Berlin, available at: www.bdew.de (accessed 24 April 2015).

Bienert, S., Schuetzenhofer, C., Leopoldsberger, G., Bobsin, K., Leutgeob, K., Huettler, W., Popescu, D., Mladin, E.-C., Boazu, R., Koch, D., and Edvardsen, D.-F. (2010), "Integration of energy performance and life-cycle costing into property valuation practice", available at: www.immovalue.org (accessed 9 March 2014).

Bloom, N., Genakos, C., Martin, R. and Sadun, R. (2011), "Modern management: good for the environment, or just hot air?", *Economic Journal*, Vol. 120 No. 544, pp. 551-572.

Braun, M.R., Altan, H. and Beck, S.B.M. (2014), "Using regression analysis to predict the future energy consumption of a supermarket in the UK", *Applied Energy*, Vol. 130 No. 30, pp. 305-313.

Brunauer, W.A., Lang, S., Wechselberger, P. and Bienert, S. (2010), "Additive hedonic regression models with spatial scaling factors: an application for rents in Vienna", *The Journal of Real Estate Finance and Economics*, Vol. 41 No. 4, pp. 390-411.

Brunauer, W., Feilmayr, W. and Wagner, K. (2012), "A new residential property price index for Austria", *Statistiken – Daten und Analysen Q3/2012*, Austrian National Bank, Vienna, pp. 90-102.

Cajias, M. and Bienert, S. (2011), "Does sustainability pay off for European listed real estate companies? The dynamics between risk and provision of responsible information", *Journal of Sustainable Real Estate*, Vol. 3 No. 1, pp. 211-231.

Cajias, M., Fuerst, F., McAllister, P. and Nanda, A., (2011), "Is ESG commitment linked to investment performance in the real estate sector?", Working Papers in Real Estate and Planning Nos 08/11, University of Reading, Reading.

CDP (2012), *Business Resilience in an Uncertain, Resource Constrained World: CDP Global 500 Climate Change Report*, Carbon Disclosure Project (CDP), London.

CDP (2014), *Global Corporate Use of Carbon Pricing: Disclosures to Investors*, Carbon Disclosure Project (CDP), London.

Christina, S., Dainty, A., Daniels, K. and Waterson, P. (2014a), "How organizational behavior and attitudes can impact building energy use in the UK retail environment: a theoretical framework", *Architectural Engineering and Design Management*, Vol. 10 No. 1/2, pp. 164-179.

Christina, S., Waterson, P., Dainty, A. and Daniels, K. (2014b), "Improving energy efficiency in the retail sector through job redesign: a sociotechnical systems approach", paper presented for the 11th International Symposium on Human Factors in Organizational Design and Management, and 46th Annual Nordic Ergonomics Society Conference (NES), Copenhagen, 17-20 August.

Dena (2015), *Energieeffizienz im Einzelhandel. Analyse des Gebäudebestands und seiner energetischen Situation*, Deutsche Energie-Agentur GmbH (Dena), Berlin.

Eilers, P.and Marx, B. (1996), "Flexible smoothing with B-splines and penalties", *Statistical Science*, Vol. 11 No. 2, pp. 89-121.

Fahrmeir, L., Kneib, T. and Lang, S. (2007), *Regression. Modelle, Methoden und Anwendungen*, Springer, Berlin.

Fahrmeir, L. and G. Tutz (2001), *Multivariate Statistical Modelling Based on Generalized Linear Models*, Springer, New York, NY.

Fedrizzi, R. and Rogers, J. (2002), *Energy Efficiency Opportunities: Big Box Retail and Supermarkets*, The Center for Energy and Climate Solutions, Arlington, VA.

Ge, Y.T. and Tassou, S.A., (2011), "Thermodynamic analysis of transcritical CO_2 booster refrigeration systems in supermarket", *Energy Conversation and Management*, Vol. 52 No. 4, pp. 1868-1875.

Gouldson, A.P. and Sullivan, R. (2012), "Ecological modernisation and the space or feasible action on climate change", in: *Climate Change and the Crisis of Capitalism: A Chance to Reclaim, Self, Society and Nature*. Routledge, London, pp. 114-126.

Gouldson, A.P. and Sullivan, R. (2014), "Understanding the governance of corporations: an examination of the factors shaping UK supermarket strategies on climate change", *Environment and Planning A*, Vol. 46 No. 12, pp. 2972-2990.

GreenBiz (2015), *Walmart Sustainability at 10: An Assessment*, Website GreenBiz, available at: www.greenbiz.com/article/walmart-sustainability-10-assessment (accessed 17 November 2015).

Greening, L.A., Greene, D.L. and Difiglio, C. (2000), "Energy efficiency and consumption – the rebound effect – a survey", *Energy Policy*, Vol. 28 No. 6, pp. 389-401.

Guerra Santin, O., Itard, L. and Visscher, H. (2009), "The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock", *Energy and Buildings*, Vol. 41 No. 11, pp. 1223-1232.

Halvorsen, R. and Palmquist, R. (1980), "The interpretation of dummy variables in semilogarithmic equations", *The American Economic Review*, Vol. 70 No. 3, pp. 474-475.

Hardy, M.A. (1993), *Regression with Dummy Variables*, Sage University Paper series on Quantitative Applications in the Social Sciences, No. 07-093, Sage, Newbury Park, CA.

HDE (2013), *Der Einzelhandel als Vorreiter eines modernen Energieeffizienzmanagements*, Handelsverband Deutschland (HDE), Berlin.

Herring, H. and Roy, R. (2007), "Technological innovation, energy efficient design and the rebound effect", *Technovation*, Vol. 27 No. 4, pp. 194-203.

Heschong Mahone Group (1999), *Skylighting and Retail Sales. An Investigation into the Relationship Between Daylighting and Human Performance*, Pacific Gas and Electric Company on behalf of the California Board for Energy Efficiency, Fair Oaks, CA.

IFEU, Fraunhofer ISI, Prognos, Gws, IREES, Orange, IfnE, ZEE (2011), "Energieeffizienz: Potenziale, volkswirtschaftliche Effekte und innovative Handlungs- und Förderfelder für die Nationale Klimaschutzinitiative", Final Report, IFEU, Fraunhofer ISI, Heidelberg, Karlsruhe, Berlin, Osnabrück, Freiburg.

Jones, P., Hillier, D. and Comfort, D. (2014), "Assurance of the leading UK retailors' corporate social responsibility/sustainability reports", *Corporate Governance*, Vol. 14 No. 1, pp. 130-138.

Kahn, M.E. and Kok, N. (2014a), "Big-box retailers and urban carbon emissions: the case of Wal-Mart", Working Paper #5, New York University, Marron Institute of Urban Management, New York City, NY.

Kahn, M.E. and Kok, N. (2014b), "Big-box retailers and urban carbon emissions: the case of Wal-Mart" NBER Working Paper Series, Working Paper 19912, National Bureau of Economic Research, Cambridge, MA.

Kahn, M.E., Kok, N. and Quigley, J.M. (2014), "Carbon emissions from the commercial building sector: the role of climate, quality, and incentives", *Journal of Public Economics*, Vol. 113 No. C, pp. 1-12.

Kerscher, A.N. and Schaefers, W. (2015). "Corporate social responsibility and the market valuation of listed real estate investment companies", *German Journal of Real Estate Research*, Vol. 1 No. 2, pp. 117-143.

Lehner, M. (2015), "Translating sustainability: the role of the retail store", *International Journal of Retail & Distribution Management*, Vol. 43 Nos 4/5, pp. 386-402.

Lombard, L.P., Ortiz, J. and Pout, C. (2008), "A review on buildings energy consumption information", *Energy and Buildings*, Vol. 40 No. 3, pp. 394-398.

Malpezzi, S. (2003), "Hedonic pricing models: a selective and applied review", in O'Sullivan, T. and Gibb, K. (Ed.), *Housing Economics and Public Policy, Essays in Honor of Duncan Maclennan*, Blackwell, Oxford, pp. 67-89.

Mason, C. and Quigley, J.M. (1996), "Non-parametric hedonic housing prices", *Housing Studies*, Vol. 11 No. 3, pp. 373-385.

METRO GROUP (2014), *Corporate Responsibility Report 2013/14*, METRO AG, Dusseldorf.

Oelker, M.-R. and Tutz, G. (2013), *A General Family of Penalties for Combining Differing Types of Penalties in Generalized Structured Models*, Department of Statistics University of Munich, Technical Report Number 139, Munich.

Pace, R.K. (1998), "Appraisal using generalized additive models", *Journal of Real Estate Research*, Vol. 15 No.1, pp. 77-99.

Parmeter, C.F., Henderson, D.J. and Kumbhakar, S.C. (2007), "Nonparametric estimation of a hedonic price function", *Journal of Applied Econometrics*, Vol. 22 No. 3, pp. 695-699.

RILA (2012), *2012 Retail Sustainability Report*, Retail Industry Leaders Association (RILA), Arlington, VA.

Spyrou, M.S., Shanks, K., Cooka, M.J., Pitcher, J. and Lee, R. (2014), "An empirical study of electricity and gas demand drivers in large food retail buildings of a national organization", *Energy and Buildings*, Vol. 68 No. 19, pp. 172-182.

Sullivan, R. and Gouldson, A. (2014), "Comparing the climate change actions, targets and performance of UK and US retailers", *Corporate Social Responsibility and Environmental Management*, available at: onlinelibrary.wiley.com/doi/10.1002/csr.1364/abstract (accessed 31 October 2015).

Tassou, S.A., Ge, Y., Hadaway, A. and Marriott, D. (2011), "Energy consumption and conservation in food retailing", *Applied Thermal Engineering*, Vol. 31 No. 2, pp. 147-156.

The Guardian (2011), "Retailers need to save money to make money", 26 April, available at: www.theguardian.com/sustainable-business/retailers-efficiency-thinner-profit-margins (accessed 7 November 2015).

The New York Times (2012), "Meccas of shopping try hand at being misers of energy", 11 April, p. F2, available at: www.nytimes.com/2012/04/11/business/energy-environment/retailers-seek-to-conserve-energy-to-cut-costs.html?_r=0 (accessed 7 November 2015).

The Wall Street Journal (2008), "Big (green) box: retailers get the energy-efficiency gospel", 23 June, available at: blogs.wsj.com/environmentalcapital/2008/06/23/big-green-box-retailers-get-the-energy-efficiency-gospel/ (accessed 7 November 2015).

Walmart (2015a), *Greenhouse Gas Emissions*, Corporate Website Walmart Stores, Bentonville, AR, available at: corporate.walmart.com/global-responsibility/environment-sustainability/greenhouse-gas-emissions (accessed 15 November 2015)

WBCSD (2015), *World Business Council for Sustainable Development*, available at: www.wbcsd.org/changing-pace/current-context/buildings.aspx (assessed 14 November 2015).

Weather Underground (2015), available at: www.wunderground.com (accessed 22 August 2015)

Wood, S. (2006), *An Introduction to Generalized Additive Models with R*. Taylor & Francis Group, Boca Raton, FL.

World Bank Group (2015), "Carbon pricing watch 2015: an advance brief from the state and trends of carbon pricing 2015 report, to be released late 2015", Working Paper, World Bank Group, Washington, DC.

Further reading

Allcott, H. and Greenstone, M. (2012), "Is there an energy efficiency gap?" *Journal of Economic Perspectives*, Vol. 26 No. 1, pp. 3-28.

Cajias, M. and Piazolo, D. (2013), "Green performs better: energy efficiency and financial return on buildings", *Journal of Corporate Real Estate*, Vol. 15 No. 1, pp. 53-72.

Chegut, A., Eichholtz, P. and Kok, N. (2014), "Supply, demand, and value of green buildings", *Urban Studies Journal*, Vol. 51 No. 1, pp. 22-43.

Costco Wholesale (2009), *Corporate Sustainability Report, January 2009*, Corporate Sustainability and Energy Group, Costco Wholesale, Issaquah, WA.

Costco Wholesale (2015), *Costco Wholesale Sustainability Report 2015*, Costco Wholesale, Issaquah, WA.

Crosby, N., Devaney, S. and Law, V. (2011), "Benchmarking and valuation issues in measuring depreciation for European office markets", *Journal of European Real Estate Research*, Vol. 4 No. 1, pp.7-28.

Crosby, N., Devaney, S. and Nanda, A. (2015), "Which factors drive rental depreciation rates for office and industrial properties?", *Journal of Real Estate Research*, available at: http://pages.jh.edu/jrer/papers/abstract/forth/accepted/jrer_250(f140902R2).html (assessed 14 September 2015).

Doda, B., Gennaioli, C., Gouldson, A., Grover, D. and Sullivan, R. (2015), Are corporate carbon management practices reducing corporate carbon emissions? *Corporate*

Social Responsibility and Environmental Management, Vol. 23 No. 2, available at: http://onlinelibrary.wiley.com/doi/10.1002/csr.1369/full (assessed 1 November 2015).

Eichholtz, P., Kok, N. and Quigley J.M. (2010), "Doing well by doing good? Green office buildings." *American Economic Review*, Vol. 100 No. 5, pp. 2492-2509.

Ellison, L. and Sayce, S. (2007), "Assessing sustainability in the existing commercial property stock, establishing sustainability criteria relevant for the commercial property investment sector", *Property Management*, Vol. 25 No. 3, pp. 287-204.

Gillingham, K.M., Kotchen, M.J., Rapson, D.S. and Wagner, G. (2013), "The rebound effect is overplayed", *Nature*, Vol. 493 No. 7433, pp. 475-476.

Gillingham, K.M., Rapson, D.S. and Wagner, G. (2015), "The rebound effect and energy efficiency policy", *Review of Environmental Economics and Policy*, Vol. 10 No. 1, pp. 68-88.

GreenMoney Jounal (2010), "Whole Foods Market commits to reduce energy consumption by 25 percent per square foot by 2015", Website GreenMoney Journal, available at: http:// archives.greenmoneyjournal.com/article.mpl?newsletterid=52&articleid=765 (accessed 11 November 2015).

Holmes, T.J. (2011), "The diffusion of Wal-Mart and economies of density", *Journal of the Econometric Society*, Vol. 79 No. 1, pp. 253-302.

Jenkins, D., Liu, Y. and Peacock, A.D. (2008), "Climatic and internal factors affecting future UK office heating and cooling energy consumptions", *Energy and Buildings*, Vol. 40 No. 5, pp. 874-881.

Kok, N., Miller, N. G. and Morris, P. (2012), "The economics of green retrofits", *Journal of Sustainable Real Estate*, Vol. 4 No. 1, pp. 4-22.

Konrad, K. and Thun, M. (2012), *The role of Economic Policy in Climate Change Adaption*, Max Planck Institute for Tax Law and Public Finance, Munich.

Leopoldsberger, G., Bienert, S., Brunauer, W., Bobsin, K. and Schuetzenhofer, C. (2011), "Energising property valuation: putting a value on energy-efficient buildings", *The Appraisal Journal*, Vol. 79 No. 2, pp. 115-125.

METRO GROUP (2015), *Corporate Website*, METRO AG, www.metrogroup.de (accessed 15 November 2015).

Pope, D. and Pope, C. (2012), "When Walmart comes to town. Always low housing prices? Always?", Working Paper 18111, National Bureau of Economic Research, Cambridge, MA.

Porter, M. and Kramer, M. (2006), "Strategy and society: the link between competitive advantage and corporate social responsibility", *Harvard Business Reviews*, Vol. 84 No. 12, pp. 78-92.

RILA (2013), *2013 Retail Sustainability Report*, Retail Industry Leaders Association (RILA), Arlington, VA.

Rosen, S. (1974), "Hedonic prices and implicit markets: product differentiation in pure competition", *The Journal of Political Economy*, Vol. 82 No. 1, pp.35-55.

Shimizu, C. (2012), "The investment value of green buildings – the sustainability of property value", Working Paper No. 10, Business Ethics & Compliance Research Center, Reitaku University, Kashiwa City.

Solomon, D.M., Winter, R.L., Boulanger, A.G.; Anderson, R.N. and Wu, L.L. (2011), "Forecasting energy demand in large commercial buildings using support vektor machine regression", Columbia University Computer Science Technical Reports, Columbia University Academic Commons, New York City, NY, pp. 1-9.

Thomson, B. (2007), "Green retail: retailer strategies for surviving the sustainability storm", *Journal of Retail & Leisure Property*, Vol. 6 No. 4, pp. 281-286.

Wackernagel, M. and Reese, W. (1995), *Our Ecological Footprint: Reducing Human Impact on the Earth*, New Society Publishers, Gabriola Island, B.C.

Walmart (2015b), *Global Responsibility Report*, Walmart Stores, Bentonville, AR.

Whole Foods (2010), *Whole Foods Market Commits to Reduce Energy Consumption by 25 Percent per Square Foot by 2015*, 20 April, Whole Foods, Austin, TX, available at: http://media.wholefoodsmarket.com/news/whole-foods-market-commits-to-reduce-energy-consumption-by-25-percent-per-s (accessed 12 October 2015)

Wood, S. (2003), "Thin plate regression splines", *Journal of the Royal Statistical Society*, B-Series, Vol. 65 No. 1, pp. 95-114.

Wooldridge, J. (2002), *Econometric Analysis of Cross-Section and Panel Data*. The MIT Press, Cambridge, MA.

5 Conclusion

5.1 Executive Summary

How does energy efficiency influence the Market Value of office buildings in Germany and does this effect increase over time?

The study aims to provide evidence for the influence of energy efficiency on the Market Value for office buildings and whether this effect increases over time. Parallel to the continuously increasing energy efficiency requirements for new construction and the growing number of "green" office buildings in the marketplace, a negative effect on the existing building stock is expected to increase over time with additional economic obsolescence and depreciation, to be anticipated with declining Market Values in valuation practice.

A novel econometric approach is designed to address the issue that energy efficiency and consumption measures are only available in two small sub-samples of the dataset. Therefore, the econometric approach is leveraging the prediction gained from the total sample of office buildings to stabilize the results for the variables of interest in both of the small sub-samples.

The intuitive and consistent results in the various steps of the approach show that the designed method works well. However, the results indicate no statistically significant evidence for the hypothesized relationship between energy efficiency or actual consumption and the Market Value, let alone an increase in this effect. A significant decline in Market Values for the tested portfolio was observed for the timeframe from 2009 to 2011, but not attributed to lower energy efficiency or higher actual consumption. The assumption of additional economic obsolescence and higher depreciation (exceeding the almost constant age-related rate) for the building stock, observable through an increasing negative effect of energy efficiency or consumption on Market Values, does not prove valid for the tested dataset.

Besides the drawback from the dataset with only two small sub-samples for the variables of interest and the basis of *EPC*s, which may not be the appropriate measure to capture the effect on Market Values over time, the valuation practice in Germany might not completely reflect the effect of energy efficiency or consumption on transaction prices, potentially due to missing information in the course of valuations for the existing building stock. Furthermore, institutional property investors providing the data to *IPD* (now part of *MSCI*) might stick to their book values, striving to keep high Market Values in actual valuations.

In conclusion, the study recommends to further explore the outlined theoretical considerations on the basis of transactional datasets with a large number of observations. With regard to further increasing energy efficiency requirements and more energy-efficient commercial buildings in the marketplace, an enhancement of energy performance for the building stock is of increasing interest for the real estate industry. Thus, the investigation of higher obsolescence or economic depreciation of inefficient office buildings or those of higher consumption provides a framework for further research. To foster the understanding of energy efficiency on commercial real estate, also the existence of a cyclical component for the effect on Market Values with regard to real estate market cycles, as indicated by Kok and Jennen (2012), is recommended for further research. As a strategic implication and in reference to the results of Cajias and Piazolo (2013), a more differentiated view between the commercial and residential building stock is suggested, since decision makers (tenants) of office buildings use these buildings, but do not own them – instead of residential real estate.

Energy efficiency: behavioural effects of occupants and the role of refurbishment for European office buildings

The study is an attempt to determine the influence of physical building characteristics and of occupant attributes on the actual energy consumption of office buildings. In reference to increased energy efficiency regulation for new construction and major refurbishment measures, lower actual consumption is expected in more recent buildings or those undergone extensive refurbishment measures with improved thermal quality and energy efficiency.

On the contrary to this expectation, the attempts of higher energy efficiency standards do not generally seem to emerge with a conservation of energy due to the principle of additionality in more recent constructed or refurbished buildings. Based on a static approach, major refurbishment was found to contribute to a significant increase in actual consumption by 15%, compared to assets without any refurbishment. For refurbishment dedicated solely to energy efficiency and thermo-physical characteristics, the coefficient was estimated with a negative value, corresponding to potential energy savings, but insignificant. This suggests no indication of a potential rebound effect inherent in the tested dataset.

The introduced specification with *GAM* mitigated some deficits from the applied dataset and found office buildings around 15 years of age with the highest energy consumption. For younger buildings the slightly lower consumption points to potentially higher energy efficiency in the course of the implemented regulation in *EU*-member states over the past decade, but also to the principle of additionality with more and new appliances and equipment in more recent office buildings, while older buildings of more than 20 years of age show significantly lower energy consumption. The interaction effect between building age and refurbishment, indicating additional energy consumption of refurbished buildings, showed the lowest energy consumption for the most recent refurbished buildings. Even though assumed with additional services and equipment introduced upon refurbishment, the result suggests that most recent refurbishment might reflect stricter building codes and more efficient design of office buildings, while refurbishment years ago was less dedicated to energy efficiency.

For the portfolio of *GRA* with almost 200 observations located in France, the electric production of heating was found with lower energy consumption per square meter of up to more than 20%, compared to omitted reference production types gas, fuel or a district heating network. In particular, the regression spline for building size proved for nonlinearity in the effect and rejecting the assumption of economies of scale. Up to a building size of approximately 12,000 square meters a zone of almost indifference was observed, followed by significantly higher energy consumption with increasing building size. That points to office towers in the dataset with energy losses from large vertical distances to be bridged, in comparison to more compact buildings.

Concerning the corporate social responsible investment strategies of institutional investors the intrinsic water consumption modelled for the observations in the dataset was analysed as a further sustainability criterion for the indication of an energy-efficient building design with lower consumption. An effect of stricter efficiency regulation and building codes, indeed affecting the physical building, might be suggested if high water efficiency is identified to be an indicator of high energy efficiency.

Besides the influence of refurbishment measures and missing economies of scale in energy consumption of large office structures, the higher consumption in single-tenant office buildings (between 12% and 15%) exhibits strategic implications for developers and investors. In conclusion, this result might point to a less energy-efficient behavior of single tenants responsible for the entire building operations, in comparison to multi-tenant offices with presumed more decentralized operations for the occupied office space. Furthermore, the linear relationship between increased occupancy rates (e.g. less vacancy) and higher volumes of energy consumption was found in line with the supposition that more workplaces for occupants on the same office area will increase the energy use per square meter from applied equipment and plug loads of occupants. On the one hand, this underlines the role of occupants and their behavior in relation to the total energy consumption in office buildings when applied equipment and plug loads act as drivers for higher consumption. On the other hand, this provides evidence that occupant behavior is of large potential for energy conservation.

While the study is intended to contribute to a better understanding of energy consumption in office buildings, the addressed limited nature of the dataset implies some restrictions in the explanatory power of the obtained results. The problem of nonlinearity in the effects of the estimated regression coefficients was mitigated to some extent with the introduction of *GAM*, to gain a more precise understanding of the effects for the observed portfolio. As a major advantage, the used dataset contains detailed information to investigate the role of refurbishment on energy consumption. Although the result of higher energy consumption in office buildings attributed with refurbishment is in line with other research for the *USA* (Kahn et al., 2014), a dynamic analysis with more observations over time – controlling the effects before and after refurbishment – is recommended.

The energy efficiency of corporate real estate assets: The role of energy management for corporate environmental performance

The study investigates the influence of energy efficiency of commercial real estate beyond the physical building characteristics and the behavior of occupants. For the applied dataset of *METRO GROUP*, containing big-box wholesale and retail hypermarket stores, the operational sales performance is analyzed with regard to the effect on energy consumption. To further investigate the impact of management decisions on energy consumption, the role of corporate energy management for achieving energy conservation and contributing toward a more efficient corporate environmental performance is of particular interest in the research. This becomes even clearer in consideration that the corporate environmental performance in the food wholesale and retail industry is a significant criterion in financial dimensions for the evaluation of the business model from rating agencies, when issuing an overall investment grade for the corporation.

In the econometric methodology, applied to the extensive dataset of 781 stores in total, a sophisticated panel regression was designed to explain the electricity and total energy consumption of the corporate real estate assets. For electricity consumption the database provided the opportunity to explore the effects in a panel on a monthly basis over four years from January 2011 until December 2014 with 37,488 observations. For the same period of time on annual basis, the total energy consumption was available with 3,124 observations. Again, the approach was designed to explore nonlinear effects which were illustrated in regression splines with smoothed curves.

The results showed significant reductions in electricity and total energy consumption of the wholesale and hypermarkets, realized within the four-year timeframe and in reference to the proposed reduction target, which is to reduce CO_2 emissions by 20% until 2020, based on emissions in 2011. In an indicative pay-off calculation the lower electricity consumption in 2014 was associated with saved energy costs of more than €3.00/m²/a with expected savings of around €9.00/m²/a by 2020. Presuming a pricing for the internalization of *GHG* externalities, the calculation also assessed that potential electricity cost saving by 2020 would be offset by almost 10% due to the presumed CO_2 pricing in place.

With regard to the location of the stores, the relatively new stores in Eastern Europe were identified to be associated with significantly higher energy consumption on average. For the physical building characteristics, the study founds no systematic evidence of higher efficiency with lower consumption for more recently constructed stores or for stores attributed with revitalization. The results point to a limited influence of building age and revitalization, in comparison to other factors, such as the technical facilities and equipment used in the stores. This is found in line with observations from supermarkets in the *UK*, analyzed in a study of Spyrou et al. (2014).

In comparing the electricity consumption between the different sales lines and store formats of *METRO*, the smoothed curves of the regression splines illustrated annual consumption cycles with relatively limited store-to-store variation *within* the same formats, but higher variation *between* different formats. The reason lays in the customized corporate building formats, as well as in the influence of the energy management, which identifies "Problem-Stores" with significantly higher consumption. Certain reduction measures are introduced to these stores with a higher electricity consumption of 16% on portfolio average. The reduction to the portfolio average was calculated with potential cost savings of €4.39/m²/a and an assumed reduction of CO_2 emissions of 2.42 kg/m²/a.

The annual consumption cycles clearly proved for the highest electricity and total energy consumption in the summer months because of the highest refrigeration and cooling loads. The winter months were associated with much lower energy consumption, except the seasonal effect prior to Christmas with highest volume of customers and additional illumination.

Again, the customized building formats and the centralized energy management, responsible for owned and leased stores (on a "triple-net" rental contract basis), yield no significant difference in the energy consumption among the ownership status of the assets.

From the management perspective, the allocation of human capital into country organizations, associated with significantly higher electricity and total energy consumption – and thus savings potential – is a promising strategy to economize on energy consumption with utilization of existing economies of scale. With an own energy manager at the country level, these countries prove for higher savings potential as a driver to reduce carbon emissions and to increase the operational store profitability as well.

A recent study on the energy efficiency of the German retail industry proposed the annual operating energy costs approximately in the range of the annualized profit margin from the operational sales business (Dena, 2014). However, for the applied data of *METRO* the electricity costs account for 0.55% and total energy costs for 0.73% of the annual turnover per square meter. Hereby, the annual total energy costs amount to a margin of not even 50% of the annual profit margin from the operational sales business. Nonetheless, the realization of lower consumption in the corporate real estate assets, associated with cost savings, provides further leverage on the operational store profitability.

The operational sales performance in the stores was identified as *the* key driver for energy consumption. An increase in the turnover per square meter of 1% was found to be associated with higher electricity consumption per square meter of 3.2% in a linear relationship. The results also revealed the link between higher operational cost structures, derived from the *EBIT* of the stores, and slightly higher energy consumption. This correlation implies a key challenge for the wholesale and retail industry, which is to realize energy savings, while increasing the sales productivity with high volumes of customers.

With regard to the cost structure of a corporate energy management, the study concludes to assess the profitability of human capital employed in cost-benefit analysis. As a practical implication the study recommends raising awareness of (real estate asset) management and staff, with regard to energy efficiency and highlighting the role of food wholesale and hypermarket stores as a transmission mechanism for sustainability issues, as anticipated by customers.

5.2 Final Remarks

The three studies of this dissertation aspire to contribute to a better understanding of the relationship between energy efficiency and commercial real estate. To gain strategic implications for practical implementation in the real estate industry, the influence of energy efficiency on commercial real estate was analyzed, followed by the investigation of influencing factors on the energy efficiency of commercial real estate.

The effect of lower energy efficiency or higher energy consumption determining declining Market Values in valuation practice from the marketplace was not found to be true. This is astonishing due to the chosen timeframe of the analysis from 2009 to 2011 with decreasing Market Values in the marketplace after the financial crisis of 2008, as well as decreasing Market Values proven in the tested dataset of *IPD*. When lower energy efficiency was not attributed to a decrease on the Market Value for this timeframe, the current real estate market environment, with transaction prices at peak in connection with low interest rates from the capital markets, might – even more – abolish the argumentation of a potential negative influence from lower energy efficiency on commercial real estate.

The analysis on the behavioral effects of occupants and the role of refurbishment for European office buildings provides some practical implications for real estate developers and investors. In particular, the effect of refurbishment associated with higher energy consumption due to the principle of additionality was found with contrary result to the assumed expectance of lower energy consumption from real estate practice. While the applied equipment and plug loads were identified as a major driver on energy consumption, the issue, to shift office occupant behavior toward the conservation of energy, needs to be addressed in practice. Office towers were identified to be of higher energy consumption in bridging large vertical distances – but in spite of this proved result, this building type is constructed more than ever around the globe. This may provide an implication to real estate developers and investors, focusing on low energy consumption and reduced *GHG* externalities, associated with their projects or portfolio target assets. For these investors it might be reasonable to assess further sustainability measures, such as the water consumption of buildings as a proxy for energy efficiency, to reduce their investment risk in terms of corporate social responsibility.

The unique dataset of *METRO GROUP* provided the profound opportunity to analyze the relationship between energy consumption, the operational sales business and the role of a corporate energy management. The provision of operational sales figures on store level was supportive to the exclusive quality of this research. The study conclusions deliver certain practical implications for wholesale and retail hypermarket stores, as well as for the corporate real estate and energy management. For *METRO GROUP*, the identified result of highest electricity and total energy consumption in most recently constructed buildings is currently considered with a practical implication for the energy efficiency of the corporate real estate assets. Because the relationship between newest stores and higher energy consumption was not fully recognized in the past, the corporate energy management set up activities to closer align the different technical systems in new stores with each other, to leverage on the further reduction potential in the stores. In addition to the set reduction target for CO_2 emissions in 2020, the corporation announced a new target, which is to curb carbon emissions by 50% in 2030 as compared to 2011 by means of company-wide energy efficiency measures.

Among other German-based corporations, *METRO GROUP* was recently signing the corporate declaration on the draft of the Climate Action Plan 2050 for Germany. This declaration postulates to enact the targets from the Paris Agreement and to transform the German economy toward the use of 100% renewable energy in the long-term up to the year 2050 (Frankfurter Allgemeine Zeitung, 2016; Sueddeutsche Zeitung, 2016).

Finally, the three papers of this dissertation may make their way into the relevant areas of research. Moreover and among the sophisticated econometric approaches, the strategic implications may provide instructive conclusions to the real estate industry. Apart from the global targets for climate change mitigation and the political agenda on "Sustainable Development", the commitment and best practice from the economy and relevant industries is – more than ever – of essential necessity to aspire a more sustainable future.

5.3 References

Cajias, M. and Piazolo, D. (2013), "Green performs better: energy efficiency and financial return on buildings", *Journal of Corporate Real Estate*, Vol. 15 No. 1, pp. 53-72.

Dena (2015), *Energieeffizienz im Einzelhandel. Analyse des Gebäudebestands und seiner energetischen Situation*, Deutsche Energie-Agentur GmbH (Dena), Berlin.

Frankfurter Allgemeine Zeitung (2016), "Konzerne für mehr Klimaschutz", 7 November 2016, available at: http://www.faz.net/aktuell/wirtschaft/energiepolitik/adidas-commerzbank-co-fordern-einhaltung-des-pariser-klima-abkommens-14516283.html#GEPC;s5 (accessed 7 November 2016).

Kahn, M.E., Kok, N. and Quigley, J.M. (2014), "Carbon emissions from the commercial building sector: the role of climate, quality, and incentives", *Journal of Public Economics*, Vol. 113 No. C, pp. 1-12.

Kok, N. and Jennen, M. (2012), "The impact of energy labels and accessibility on office rents", *Energy Policy*, Vol. 46 No. C, pp. 489-497.

Spyrou, M.S., Shanks, K., Cooka, M.J., Pitcher, J. and Lee, R. (2014), "An empirical study of electricity and gas demand drivers in large food retail buildings of a national organization", *Energy and Buildings*, Vol. 68 No. 19, pp. 172-182.

Sueddeutsche Zeitung (2016), "Unternehmen fordern mehr Klimaschutz", 7 November 2016, available at: http://www.sueddeutsche.de/wirtschaft/klimaschutzplan-unternehmen-fordern-mehr-klimaschutz-1.3236712 (accessed 7 November 2016).

Universität Regensburg
IRE|BS Institut für Immobilienwirtschaft
Fakultät für Wirtschaftswissenschaften