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INFLUENCE OF REBOUND EFFECTS ON THE ACHIEVEMENT OF ENERGY SAVING TARGETS AFTER AN INCREASE IN ENERGY EFFICIENCY ON NON-RESIDENTAL BUILDINGS

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Abstract. ***Purpose.*** This article draws attention to rebound effects, which are responsible for missing the planned energy savings after an increase in efficiency. For residential buildings already exist wide scientific studies to rebound effects after a thermal retrofit. This article present first findings to rebound effects in non-residential buildings. ***Methodology***. It is presents a methodology for the determination of rebound effects and their causes in non-residential buildings. In addition to the mathematical calculation of the rebound effects semi-structured-interviews to identify the causes were describe. Conclusion***s.*** This article focuses on four office and administrative buildings with regard to their actual and calculated building heat pre- and post-thermal-retrofit and comes to the conclusion that even in non-residential buildings rebound effects are to be expected. However, the causes differ significantly compared to residential buildings. ***Originality.*** For the first time a methodology for the determination of rebound effects and its causes has been developed for non-residential buildings and tested on case study objects. In addition, the obtained results compared with literature review for non-residential buildings and residential buildings. ***Practical value.*** These article gives information on whether rebound-effects exists after a thermal retrofit and in the case these effect exist it renames possible reasons of this effect.

Keywords*: rebound effect, direct rebound effect, non-residential buildings, thermal retrofits*

ВПЛИВ ЗВОРОТНИХ ЕФЕКТІВ НА ДОСЯГНЕННЯ ЦІЛЕЙ ЕНЕРГОЗБЕРЕЖЕННЯ ПІСЛЯ ЗБІЛЬШЕННЯ ЕНЕРГОЕНЕРГОЕФЕКТИВНОСТІ НЕЖИТЛОВИХ БУДІВЕЛЬ

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Анотація. *Мета.* Ця стаття звертає увагу на зворотні ефекти, які пов’язані з відсутністю запланованих дій щодо економії енергії, але впливають на досягнення енергозберігаючих цілей. Для житлових будинків вже існують широкі наукові дослідження щодо зворотних ефектів після теплової модернізації. Ця стаття представить перші висновки щодо зворотних ефектів у нежитлових будинках. ***Методика.*** Стаття представляє методологію для визначення зворотних ефектів і їх причин в нежитлових будинках. У доповнення до математичних розрахунків щодо зворотних наслідків для виявлення причин було використано полуструктуроване інтерв’ю. ***Результати.*** Ця стаття зосереджена на чотирьох офісних та адміністративних будівлях, демонструє фактичні і розрахункові показники споживання будівлею тепла до і після теплової модернізації, приходить до висновку, що навіть у нежитлових будівлях можна очікувати зворотні ефекти. Тим не менш, їх причини істотно відрізняються у порівнянні з житловими будинками. ***Наукова новизна.*** Вперше була розроблена методика для визначення зворотних ефектів для нежитлових будівель, з’ясовано їх причини, застосоване соціологічне дослідження. Крім того, отримані результати порівнюються з наведеними у літературі матеріалами для нежитлових будівель та житлових будинків. ***Практична значимість.*** У статті наводяться відомості про те, чи існує зворотний ефект після термічної модифікації та з’ясовані можливі причини цього ефекту.

Ключові слова: *зворотний ефект, пряма дія зворотного ефекту, нежитлові будівлі, теплове переобладнання*

ВЛИЯНИЕ ОБРАТНЫХ ЭФФЕКТОВ НА ДОСТИЖЕНИЕ ЦЕЛЕЙ ЭНЕРГОСБЕРЕЖЕНИЯ ПОСЛЕ УВЕЛИЧЕНИЯ ЭНЕРГОЭФФЕКТИВНОСТИ НЕЖИЛЫХ ЗДАНИЙ

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Аннотация. ***Цель.*** Данная статья обращает внимание на обратные эффекты, которые связаны с отсутствием запланированных действий относительно экономии энергии, однако влияют на достижение энергосберегающих целей. Для жилых зданий уже существуют широкие научные исследования по обратным эффектам после тепловой модернизации. Эта статья представит первые выводы по обратным эффектам в нежилых зданиях. ***Методика.*** Статья представляет методологию для определения обратных эффектов и их причин в нежилых зданиях. В дополнение к математическим расчетам по обратным следствиям для выявления причин было применено полуструктурированные интервью. ***Результаты.*** Эта статья сосредоточена на четырех офисных и административных зданиях, демонстрирует фактические и расчетные показатели потребления зданиями тепла до и после тепловой модернизации, приходит к выводу, что даже в нежилых зданиях можно ожидать обратные эффекты. Тем не менее, их причины существенно отличаются по сравнению с жилых домов. ***Научная новизна.*** Впервые была разработана методика для определения обратных эффектов для нежилых зданий, выяснены их причины, использованы социологические исследования. Кроме того, полученные результаты сравниваются с приведенными в литературе материалами для нежилых зданий и жилых домов. ***Практическая значимость.*** В статье приводятся сведения о том, существуют ли обратные эффекты после термической модификации и выяснены возможные причины этого эффекта.

Ключевые слова: *обратный эффект, прямое действие обратного эффекта, нежилые здания, тепловое переоборудование*

Introduction. The production of thermal energy accounted 58% of total final energy consumption in the year 2013 in Germany [1]. The largest proportion (approximately 35% of total final energy consumption) accounted for the production of heat in buildings for space heating and hot water (building heat) [1]. This leads to a high proportion of the building heat on the carbon dioxide emissions (CO_2). Around 24% of carbon dioxide emissions of Germany caused by the building heat, approximately 17% accounted for residential buildings and 7% for non-residential buildings [2].

The German housing stock consists of more than 18 million residential and 2.5 million non-residential buildings [3, 4]. About 70% of the residential buildings were erected before the first legal regulations for the thermal quality of buildings were adopted in 1979 [4]. Starting with that year, minimum requirements for energy efficiency of buildings became obligatory. Among the majority of these older buildings only for a small amount a thermal retrofit on the building envelope has been carried out. This majority of existing buildings do not fulfill any minimum energy standards and, therefore, they have very high energy consumption.

The German government has decided reduction of primary energy demand in existing buildings by 80% until the year 2050 (based on 2008) by the Energy Concept in the year 2010 [5]. Already by 2020 reduction target for building heat says 20% based on 2008 [5]. To achieve these goals a significant reduction of energy consumption for space heating in residential and non-residential buildings is necessary. A reduction of building heat be achieved by retrofit to improve the thermal quality of the building envelope (e.g. insulation of the façade and/ or the upper and lower building closure or a replacement of windows and doors) or replacement the heat generator or the heat source.

For residential buildings was observed that the amount of the calculated consumption and the actual consumption are different in several scientific studies. The calculated consumption is determined by approach of standard condition of use (e.g. temperature of rooms, the consumption of warm water, the ventilation durations). In Germany, the standard conditions of use are specified in the "Energieeinparverordnung" [5]. In contrast of the calculated consumption the actual consumption reflects the real consumption of energy (e.g. listed on the invoice of companies for energy supply). After a thermal retrofit the amount of the actual consumption is higher than the amount of the calculated consumption. Before the thermal retrofit it was the other way around, the calculated consumption is higher. One explanation can be offered by the rebound effect. Rebound effects occur after there was an increase in the energy efficiency of products or services and the costs for these products or services are reduced, and, as the result, they are consumed more than previously [8]. The consumers change their behavior and consume more energy than previously. Thus, the expected energy savings and energy reduction goals will not be achieved. A direct rebound effect is present when an increase in energy efficiency leads to increased consumption of this product or service. For example, as a result of purchasing a new car with lower fuel consumption per kilometer driven, the cost per kilometer declines and, as a consequence of the lower costs, more total kilometers are driven with the new car, compared to the older one. The planned energy savings were reduced by additional trips. An indirect rebound effect occurs when an increase in energy efficiency leads to increased consumption of other product or service. For example, as a result of buying a new car with lower fuel consumption per kilometer driven, the cost per kilometer declines and, as a consequence of lower costs, money will be accumulated. With this money an additional electrical device (e.g. a TV) is bought. This article considers only the direct rebound effect, therefore in the following just called rebound effect.

Identification of an unsolved problem. Residential buildings are already well studied for the presence of the rebound effect after a thermal retrofit. But for non-residential buildings only a few results are available. However, the known results of residential buildings cannot be transferred to non-residential buildings really, because on the one hand the buildings are used differently and on the other hand the occupants of the non-residential buildings aren´t pay for the cost of building heat usually [6]. In residential buildings, the residents pay the costs for the building heat itself usually. However, it seems the level of costs for energy consumption is an important motivation for the user behavior. Therefore, it is interesting to determine if there is a change in user behaviors by occupants of non-residential buildings after a thermal retrofit.

Analysis of the recent research. The mathematical derivation of the rebound effect has been described several times in detail, compare [6, 7, 8]. At this point, the adopted definition is reproduced [6]:

$$R(S) = \frac{\ln\left(\frac{E_2 * C_1}{C_2 * E_1}\right)}{\ln\left(\frac{C_1}{C_2}\right)}$$

R(S) elasticity rebound-effect of energy services consumption (S);

E_1 / E_2 actual consumption pre / post-retrofit;

C_1 / C_2 calculated consumption pre / post-retrofit.

The mathematical model is based on the actual and the calculated consumption pre / post-retrofit. This makes it possible to analyze if the user behavior has changed as a result of the thermal retrofit.

The rebound effect is understood as elasticity rebound effect. The elasticity is a term from the economics that expresses the development of demand to prices changes. In the context of rebound effects was found that the elasticity approach fits very well [6, 8, 12].

Only if the rebound effect is zero, there are no change in user behavior. For residential buildings the rebound effect lies between 16% (study in Belgium with 964 buildings [9]), 48% (studies in UK with 52 buildings [8]) and 50% (study in France with 913 buildings [10]).

Identification of unsolved part of the general problem. The attention of rebound effects has been established in science for wide range of applications. However for the general public, rebound effects and their causes and consequences are mostly unknown. But this can result in overestimation of energy saving, compare Fig. 1. For residential buildings in Germany it had been founded that residents, which are living in old and inefficient buildings, limit their user comfort. Thus, the actual energy consumption for space heating is lower than the calculated consumption.

After the thermal retrofit the user behavior has change, the residents know that the building is now more efficiency and consume more energy for space heating mostly unconsciously. For example the room temperature raised, more rooms heated or room are heated for a longer time.

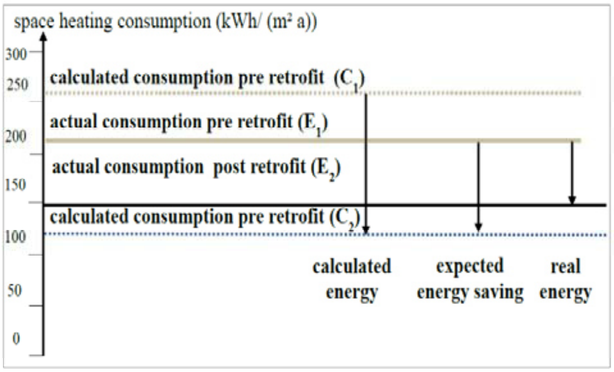

Fig. 1. Schematic diagram for residential buildings (Source: compiled by the authors)

Thereby the actual energy consumption is above the calculated energy consumption after thermal retrofit. As a consequence of Rebound-Effects the real energy saving is less than the expected and calculated saving. This can lead to failure: a) the climate protection goals and b) the individual expectations of the economics for the thermal retrofit of homeowners.

Purpose. The purpose of the research is the development and testing a method to estimate if Rebound-Effects exist by non-residential-buildings. And should this be the case, the causes and the amount have been determined.

Methodology. After a definition of terms and mathematical definition of evaluation parameters, a methodology was developed [6]. The methodology was tested on four selected case study objects. Selection criteria for the case study objects were [6]: a) building should be office or administration buildings, which were used as constant as possible throughout the year and for several years; b) comprehensive thermal retrofit was carried out; c) thermal retrofit completed already three years ago; d) the amounts of the actual and calculated consumption pre- and post-retrofit are available; e) buildings should have undergone no extensive floor space change the last years.

The calculated consumption was removed from energy-concept of each building. These energy concepts were developed based on the requirements of the German "Energieeinsparverordnung" by engineering offices. The state pre- and post-retrofit were calculated separately. The actual consumption pre and post-retrofit were removed from invoice values of energy supply companies and divided by the heated area. For the actual consumption different numbers of observed periods are available (2-5 years). Each observed period was corrected of the weather by the correction factors of the German Weather Service for the respective postcode area. The available values were averaged arithmetically.

By the case study objects semi-structured interviews have been carried out with technical staff like caretaker, technicians, facility and property managers. Content of the interviews were [6]: a) a comparison between the structural condition of the building, the thermal retrofit with the adoptions of the energy concept of the buildings and b) checked the reactions of the occupants with regard to the condition of the building pre- and post-retrofit. In addition in each case study object have been carried out semi-structured interviews with the occupants (approximately five persons in each object). Content of the interviews were [6]: a) the ventilation and heating behavior of a typical office day, b) type of ventilation (opening the whole window, shock-ventilation in German „Stoßlüften" or tilting the window in German „Kipplüftung"), c) type of use the space heating, d) expectations for the retrofit; e) changes caused by the retrofit; f) private ventilation and heating behaviors. The digitally recorded interviews were transcribed and the transcript analyzed.

Another point was the calculation of rebound effects for case study objects and interpretation of the results with literature data and the findings from the interviews.

Findings. As case studies objects four buildings in Germany were selected: two customs building, one police office and a College building for Music. Semi-structured-interviews were conducted with 32 persons (21 occupants and 12 persons of the technical staff) [6].

First, the results of the analysis of user behavior will be presented. Over 90% of occupants had an office in an old and inefficient building before the thermal retrofit, either in the case study object or in another building. Therefore, it can be assumed, that the occupants could reflect the expectations and impact of the thermal retrofit very well. More than a half of the occupants can use their office most of the time alone. Some of the users (10 of the interviewed people), which are housed in shared offices, reported that they have a different temperature sensitivity as the colleague/s in the office. They said that they adapted to each other via the clothing style, individual operation of the "own" radiator or ventilation of the overheated office when the colleague is not in the office. Nearly all occupants ventilated their office in the beginning of a working day. The type of ventilation varied: the half of the interviewed persons opening the whole window, a quarter of them tilting the window and a quarter combined both types. Reasons for tilting instead of whole opening are the fear against flying paper on the desk and flowers that stand in the way, or temperature-sensitive technology. The duration and the type of ventilation are greatly influenced by subjective user behavior but also by external factors. It was observed that the occupations, which have an office near a multi-lane road, said that they quickly close the window because the traffic noise had a negative impact on the working environment.

In analyzing the type of use the space heating the occupants indicated that they turned up the heating much higher before retrofit and the rooms cooled down more quickly. In addition, the heating control before the retrofit was bad, so they turned on the heating to the maximum level and then ventilated the warm air away.

During the ventilation only a small part of the user turns the heating off or down. For many respondents it is only important that the office would be warm. After the retrofit, many users find it pleasant that the heating can be controlled better and the rooms remained warm longer.

The occupants said that the common areas become problematic after the retrofit in terms of ventilation and heating. These rooms must be ventilated after retrofit and nobody felt responsible for it. The heating position has been changed in the common areas often and remaining after the use at this level. Thus, the common areas for the next users were either overheated or cooled too much.

More than half of the respondents said that they pay more attention to efficient behavior in the private sector for themselves and other persons in the household. The heating turned off while ventilation and when leaving the house / apartment significantly more. Also during ventilation in the private sector there is more attention to energy efficiency, thus two thirds of the persons which tilt and tilt / shock ventilation in the office said that they ventilate only shock. Also seeming barriers, like flowers in front of the window are removed willingly.

The calculation of rebound effects for non-residential buildings showed negative or very small positive rebound effects in three of the four case study objects, see Table 1.

Table 1

Calculated and actual space heating consumption and the rebound effects of the case study objects (non-residential buildings) [7]

	Calculated consumption C (kWh/ (m² a))		Actual consumption E (kWh/ (m² a))		Rebound-Effect (%)
	Pre-retrofit	Post-retrofit	Pre-retrofit	Post-retrofit	
Police office	123	61	106	52	-1,6
Customs office 1	244	136	204	117	4,9
Customs office 2	215	96	206	88	-5,5
College building for Music	140	83	143	47	-113

A negative rebound effect suggests a positive change in user behaviors after retrofit. These findings are in contrast with the results of rebound effects in residential buildings. Therefore, the results of case studies objects must be interpreted: a) on the one hand the number of examined objects with four buildings is very low. From literature studies a rebound effect in non-residential buildings be detected, but this is also a wide spread of 17% - 73% (in 30-93 buildings [8]). b) Another reason for a small rebound effect of the case study objects lies in the fact that in contrast to residential buildings the actual and calculated consumption pre-retrofit demand closer together. That means, users of non-residential buildings consume careless energy as in residential buildings before retrofit, it also indicate the results of the users interviews. c) It would also be conceivable that the calculation rule (Energieeinsparverordnung) for the amount of the calculated consumption is too high for non-residential buildings.

The case studies object for the College building for Music is a special case, because inside installed sound insulation of the practice rooms works like an additional interior insulation. This additional interior insulation was not considered in the energy concept and so the amount for the calculated consumption is probably too high.

Originality and Practical value. For the first time a methodology for the determination of rebound effects and its causes has been developed for non-residential buildings and tested on case study objects. In addition, the obtained results compared with literature review for non-residential buildings and residential buildings.

These article gives information on whether rebound-effects exists after a thermal retrofit and in the case these effect exist it renames possible reasons of this effect.

Conclusions. Although the case studies objects have negative or very low rebound effects, but it can be concluded from the analysis of the literature that rebound effects exist for non-residential buildings too. However, the number of examined buildings is still relatively low, comparisons [8]. The aim should therefore be that comparison data sets for actual and calculated consumption for non-residential building pre- and post-retrofit will create. It is important to know the basis of the amounts. It is notable that occupants in non-residential buildings use carefree energy markedly as in private homes. Here it seems to missing incentive to save energy through energy efficiency behavior. Rebound effects should be given more attention not only in residential buildings but also in non-residential buildings. It is important to know Rebound-Effects and their causes, because they have an impact on the achievement of savings goals for the government and private house-owners.

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