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Interaction between building design, management, household and individual factors in relation to energy use for space heating in apartment buildings

Karin Engvall[a,*], Erik Lampa[a], Per Levin[b], Per Wickman[c], Egil Öfverholm[d]

[a] Department of Medical Science, Uppsala University, SE-75185 Uppsala, Sweden
[b] Projektengagemang Energi & Klimatanalys AB, Box 24, SE-182 11 Danderyd, Sweden
[c] ATON Teknikkonsult AB, St Göransgatan 84, 112 38 Stockholm, Sweden
[d] The Swedish Energy Agency, Box 310, SE-63104 Eskilstuna, Sweden

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ABSTRACT

In Stockholm, 472 multi-family buildings with 7554 dwellings has been selected by stratified random sampling. Information about building characteristics and property management was gathered from each property owners. Energy use for space heating was collected from the utility company. Perceived thermal comfort, household and personal factors were assessed by a standardized self-administered questionnaire, answered by one adult person in each dwelling, and a proportion of each factor was calculated for each building. Statistical analysis was performed by multiple linear regression models with control for relevant factors all at the same time in the model. Energy use for heating was significantly related to the building age, type of building and ventilation, length of time since the last heating adjustment, ownership form, proportion of females, and proportion of occupants expressing thermal discomfort. How beneficial energy efficiency measures will be may depend on the relationship between energy use and factors related to the building and the property maintenance together with household and personal factors, as all these factors interact with each other. The results show that greater focus should be on real estate management and maintenance and also a need for research with a gender perspective on energy use for space heating.

1. Introduction

The Swedish law on energy declaration of buildings [1] recommends energy efficiency together with a good indoor environment. The EU Directive on Energy Performance of Buildings (EPBD) [2] will have consequences for policy tools for energy efficiency in the building production and actions for energy efficiency measures in older buildings. In residential buildings it may also have an impact on household budget and habits, and on perceived indoor environment.

In the ambition to get energy efficient new and refurbished buildings the Swedish organizations of building contractors and property-owners have developed a new program and method to define standardized occupancy for residential buildings called the SVEBY standard [3]. This program quantifies qualitative criteria, more or less statistically based, for the impact of inhabitants' use of buildings to evaluate the predicted energy use. To evaluate the sustainability of an individual building several multi-criteria methods have been developed and established in different countries, e.g. BREEAM (Building Research Establishment Environmental Assessment Method) in UK [4] and LEED (Leadership in Energy and Environmental Design) in USA [5].

The Swedish Green Building Council [6] has developed a certification system called "Environment Building", based on a holistic perspective on the building, through the building process to the users of the building. The tool classifies sustainable green buildings and assesses the performance of energy use, potential health and well-being, pollutants in building materials etc. The City of Stockholm demands in its environmental program for new buildings prospective building contractors to show the predicted energy use initially and the measured energy use after the second heating season, together with perception of the indoor environment. If the building doesn't fulfill the expectations, a discussion between the authority and the building owner will start about the reason why, but also about who is responsible. Is it the building

* Corresponding author. Tel.: +46 70 4933321; fax: +46 18 519978.
E-mail addresses: karin.engvall@medsci.uu.se, karin.engvall@beteendeperspektiv.se (K. Engvall).

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design, technical consultants, the contractors, the organization of the property management and especially how much may depend on the residents' behavior in the building? This is a rather general discussion in Sweden, not only in the City of Stockholm.

The residential environment is a complex issue in the building society. The indoor environment is influenced by interaction between building characteristics, building service maintenance systems and occupants [7]. Even researchers have found a greater need for a holistic perspective and multidisciplinary studies to be able to understand all different factors that may affect energy use and energy efficiency in the built environment. Today, some researchers primarily do technical measurements for how different solutions for the construction and installation techniques may affect energy use for heating, as the design of the building envelope and materials or selected heating and ventilation systems [8,9]. Other researchers are studying how different energy efficiency measures in existing buildings affects energy use in homes [10]. There are also researchers who have studied the link between perceived thermal comfort and measured indoor temperature [11–13], and some have even studied how various energy efficiency measures in apartment buildings affect the perception of indoor environment and health [14].

The conclusion of several studies is that energy use for heating depends not only on the dwelling features, but also on household composition and lifestyle [10,15,16]. Most of these studies take demographic characteristics, particularly residents' age and household size into account. Another study proved that occupants' characteristics and behavior significantly affect energy use for space heating (4.2%), when controlling for building characteristics, but building characteristics determines a larger part of the energy use in a dwelling (42%). Further analysis showed that occupants' behavior is determined by type of dwelling and HVAC systems, meaning that the effect of occupants characteristic might be larger since these determine the type of dwelling [17]. Noted is that today there are more studies on energy use in detached houses than in apartment buildings and, there are few studies on how energy use for heating is related to the management and the level of property maintenance of the building. Today there is a broad consensus that social energy consumption and greenhouse gas emissions not only are influenced by technical efficiency but also lifestyle and socio-cultural factors. This leads to that in the development of policy instruments there will be an increasing need for models to study how all these issues work together [17–19].

The aim of our study was to identify the most relevant factors for space heating related to the building design, management, occupant's use and behavior in the dwelling and perceived thermal comfort as well as household and individual factors among those living in the building. The challenge is to understand how individual needs and requirements affect the household behavior in each apartment, and how this in turn affects the function of the building's design and technical systems. This is important for both the indoor environment and energy use for heating. This paper presents findings from a multi-factorial analysis about energy use for space heating in apartment buildings in Stockholm, Sweden.

2. Material and methods

2.1. Number of houses, apartments and housing surveys in the database

Initial survey data was collected from February to April 2005. A stratified random sample of 501 houses of a total of 14,465 (3.5%) apartment buildings in Stockholm was the basis for data collection. The sample was stratified by the age of the buildings to get a sufficient large random sample of houses from different building age categories. In order to be able to analyze answers from the occupants for each individual building it demanded buildings with ≥15 apartments. Data on the buildings' age and type of ownership was taken from the National Building Register, Real Property Register, and Municipal Cadastral Agencies.

After having excluded buildings with special accommodation, such as special houses for elderly or students, a randomly selected adult (≥18 y) from each apartment was asked to answer a standardized self-administered questionnaire [20]. If two adults were on the contract of the apartment, alternately men and women were chosen to participate in the study. The questionnaire gave information about perceived indoor climate, and health, about household and individual factors among the residents as well as behavior in the apartment. In total 7640 of 10,506 residents (73%) in 481 buildings answered the questionnaire. A questionnaire about building characteristics and management was sent to the property owners. In total 98% of the property owners answered the questionnaire. Thus there are 472 houses with 7554 answers from the occupants including real estate data from the property owner. Finally, the study encompasses 374 houses with 6156 households, that includes questionnaire data, real estate data provided by the property owners and quality assured energy data about energy use for space heating in each individual building.

2.2. Energy use in the database

Information about energy use for heating for each individual building in the study was gathered from the national database with energy declaration handled by the National Board of Housing, Building and Planning [21]. Measured data on electricity and heating for the building for the period evaluated in the questionnaire study (March 2004–March 2005) was also gathered from the utility company Fortum Corporation.

Information on conditioned space area in the database was selected from different registers and surveys, and a special quality control was done of the data for square meters in each individual building and register, being the basis of kilowatt-hour per square meters and year (kW h/m^2 and year) used in the analysis. Special attention was also given to secure that energy measurements really were for the individual building and not for the whole property. Property in Sweden can consist of several buildings. Data on energy use for heating (kW h/m^2 A_{Temp} year) was controlled by certified energy consultants in the project group, and recalculated for exclusively heating excluding domestic hot water (data calculated) and culvert heat losses (data calculated), when all data was added together into a new database. A_{Temp} is the floor area of rooms that are heated to ≥+10 °C in the building, and is the value used as a standard for energy declarations in Sweden. It roughly correspond the conditioned area inside the outer walls. In the quality control process of the data for energy use, there also was a classification of its reliability for how data was collected and calculated. These two different energy quality groups will later be used as subsamples to test our results. The methods for quality assurance of energy data in the residential buildings included in the study has been reported in Swedish [22].

2.3. Perceived indoor environment, and household and personal factors

Information on perceived indoor environment, household and personal factors was gathered from the Stockholm Indoor Environment Questionnaire (SIEQ), a sociological validated, standardized, self-administrated questionnaire to evaluate the indoor environment with questions about perceived indoor air quality, thermal comfort, sound and light. It also has questions about residents' health related to the indoor environment. The questionnaire also