Aalborg Universitet

CLIMA 2016 - proceedings of the 12th REHVA World Congress

Heiselberg, Per Kvols

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Heiselberg, P. K. (Ed.) (2016). CLIMA 2016 - proceedings of the 12th REHVA World Congress: volume 1. Aalborg: Aalborg University, Department of Civil Engineering.

Indoor climate quality after renovation for improved energy efficiency

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Abstract
The building sector is responsible for approximately 40 % of the Danish energy consumption. As every year less than 1 % of the building stock is rebuild after demolition of old buildings, improved energy efficiency of existing buildings are in focus. In the late seventies to mid-eighties unwise energy efficiency retrofitting caused several cases of indoor climate degradation. This project describes possibilities, barriers and methods of combining energy performance and indoor climate enhancements in today's retrofitting of rental dwellings. The project followed three energy retrofitting projects through both planning and construction. Advanced tools for design of retrofitting measures to increase energy performance and quality of the thermal indoor climate were used during the planning processes. Energy performance and indoor climate quality were assessed using simple classification tools before and after the retrofitting. The results showed significant energy savings in all projects. There was a marked difference between expected and measured energy consumption in one building and good agreement in the two others indicating a strong impact of good maintenance and operations on energy performance. The indoor quality classifications show minor improvements. By using design tools beyond the simple legal requirements, the rental dwelling marked is a far step ahead of most retrofitting of owner-occupied dwellings and houses. The fear of indoor climate degradation from retrofitted energy saving measures may be countered by the use of modern design tools and attention to inner moisture membranes and needs for renovation of ventilation systems.

Energy-efficient retrofit, indoor climate certification, residential, energy performance certification

1. Introduction

Approximately two thirds of the Danish building stock were constructed before 1979, when Danish building codes were revised in order to include energy efficiency requirements for the first time. The revisions were made as a result of the first energy crisis. The requirements have since then several times been strengthened. But annually less than 1 % of the building stock is demolished and rebuild according to the present codes. If the path towards more sustainable and energy efficient buildings is by demolition and rebuilding the much wanted reduced energy demand will advance at a very slow pace. The existing Danish residential building stock represents a much larger potential for energy savings. Retrofitting measures to increase energy efficiency is a much faster route to reductions of energy consumption.

Achieving a good quality of the indoor climate for building occupants is the main purpose of most construction activities. Prerequisites for good indoor climate are satisfactory air change and comfortable temperatures. The conditioning of the indoors require energy for air transport and heatingconditioning and compensation for energy loss though building envelope caused by temperature differences between indoor and outdoor. It would be easy to reduce the energy demand of a building by reducing temperature differences and air changes. But obviously this would happen at the expense of the quality of the indoor climate and the main purpose of the building would be compromised.

Many reports concerning bad quality of the indoor climate as a result of unqualified efforts to save energy in existing buildings have been written. Annoyances include cold drafts from windows and cold bridges caused by reduced water temperature and circulation in heating systems and in particular radiators below windows. More serious with impact on occupant health and durability of structures are the numerous reports concerning dampness and mold problems [1]. Investigations in rented apartments have revealed visible mould growth in 1 out of 8 dwellings in the existing building stock [2]. Similar prevalence has been found in a more recent analysis [3]. The reasons for this are among others occupant behavior in relation to moisture sources and airing out by window openings, low indoor temperatures, faults causing leaky building envelope or installations and moisture build up in structures. These unintended results of bad behavior, poor design or construction quality are often linked to faulty retrofitted energy efficiency measures. New more energy efficient windows are often far more airtight than the old ones and the old warning signal for moisture problems, namely condensation on the windows may not be pronounced on modern double glazing with U-values around 1,1 W/m^2 K.

Quality measures of the indoor climate are numerous. Human requirements include several aspects of perceivable exposures including temperatures, air quality, sounds and light and also more subtle impact from exposures causing symptoms like fatigue and headache or even serious morbidity. Increased morbidity caused by poor indoor climate quality is often associated with the quality of the indoor air. The many parameters, differences in individual sensitivity and preferences and large variations in obvious exposures in different buildings have caused some confusion in relation to naming and measuring indoor climate quality. In order to overcome such problems Danish Standards have issued a national standard "DS 3033, Voluntary classification of the quality of the indoor climate in residential houses, schools, children's day-care centers and offices" [4]. Further justification of the standard may be found in [5].

The standard contains requirements for classification profiles for dwellings including the following seven parameters:

- Ventilation rate measured by tracer gas
- Thermal conditions, registration of details of construction and installations
- Radon measured by passive sampling during 2 months
- Formaldehyde measured by active sampling during 30 min
- Particles, registration of distances to roads with heavy traffic and ventilation principles
- Moisture and mould growth by measurements
- Daylight assessed by geometrical proportions between window and floor sizes and the light transmittance of window panes

Quality of each parameter is expressed on a 5 point scale from A++ through A+, A and B to C where A++ represents the best quality. Furthermore the standard contains the calculus for merging the profile into one single letter on the quality scale. In the merging calculations particular weight is given to ventilation rate, radon, formaldehyde and moisture as parameters with direct impact on the health of occupants.

Energy labels are given in relation to insulation standards as they may be assessed by non-destructive inspection [8]. The calculated and degree day adjusted annual heat consumption with some additional use allowances for the smaller buildings give the energy labels for large buildings shown in Table 1.

Table 1. Maximum annual heat consumption in the Danish energy labelling scheme for buildings.

Label	Heat kWh/m^2	Label	Heat kWh/m^2	Label	Heat kWh/m^2
A2020	20.0	B	70	E	190
A2015	30.0	C	110	F	240
A2010	52.5	D	150	G	-

When retrofitting energy saving measures in poorly insulated houses there may be a tendency among occupants to change behavior towards achieving a more comfortable indoor climate. One primary reason for this may be that the energy saving measures makes improved indoor climate affordable [6]. This shift in behavior is often difficult to predict but in general the shift reduces the achieved energy savings compared to more simple and traditional calculations of savings potential [7].

Bad experiences with poor indoor climate quality after renovation works aiming at energy savings underline the need for a broader assessment of the impact of retrofitted energy savings measures on the quality of the indoor climate. Several owners of buildings with rental dwelling have expressed a need for better documentation of both energy savings and indoor climate quality after renovation works.

The purpose of the present paper is to demonstrate and discuss the impact on energy use and indoor climate quality in three case buildings where retrofitting of energy saving measures had been decided by the building owners.

2. Method

The project followed three renovation projects in buildings with rental dwellings to elucidate impacts on indoor climate quality and energy use after the renovation. The assessments were made using standardized tools as described in DS 3033 [4] and Danish legislation [8].

To investigate the motivation for renovation and the perceived quality of the renovated apartments among tenants, qualitative interviews with both tenants and operation staff were performed. To get data for consumption of heating energy, the project bought access to the data warehouse of the district heating company HOFOR. Metered data for water supply volume, cooling of water and energy delivery were sampled every hour. In the project the data were agglomerated into diurnal consumption during the years 2013-2015. The data are considered valid since they also form the basis for energy payments. To normalize heat consumption among tenants, average consumption was used. In one case, Albertslund Syd this was not possible before the renovation. The only alternative was to use data from manual annual readings of heat meters in each dwelling. During the renovation, meters for automated remote reading was also installed here and diurnal consumption data are after the renovation available.

The three cases included:

Albertslund Syd. Attached houses with two floors erected in 1963-65 including 94 buildings. Typically one building includes 6-7 dwellings of 98 m^2. The case includes a total of 550 dwellings. The renovation works were very comprehensive. Buildings were torn down with only concrete walls on first floor and foundations remaining and then rebuild according to present standards.

Figure 1. Facade picture of Albetslund Syd before renovation.

Gl. Jernbanevej. One block of flats with 5 floors erected in 1899 with brick walls. First floor accommodates shops. Other 4 floors have a total of 16 flats on 1139 m^2 floor area. Flats have an average floor area of 71 m^2. It is the intention to add one more habitable floor on the roof level and use the generated revenue to finance an extension of the building envelope with added floor area, window area and insulation on the back side of the building. The renovation works was delayed and not initiated while the project was ongoing.

Figure 2. Facade picture of Gl. Jernbanevej before renovation and as of today.

AB Bustrup. One block of flats with 5 floors erected in 1918 with brick walls and a total floor area of 5585 m^2. The block has 87 flats and the average floor area of one flat is 64 m^2. The renovation only included exchange of windows and some mounting of new balconies.

Figure 3. Facade picture of AB Bustrup.

Heating in all three cases was based on radiators with thermostatic valves under most façade windows. Supply temperature of the water based heat distribution system was adjusted by local operation staff at each building. Heat supply was water borne district heating. Hot tap water was also heated by the supply of district heating and metered together with consumption for room heating.

3. Results

As seen in Table 2 the energy labels show significant improvements in particular in Albertslund Syd. Here it is obvious that operation of the heating systems have been more energy efficient than normally assumed, in particular before renovation but also to some degree after. Operation staff has caused significant savings compared to standardized calculations based on the insulation standards of the buildings.

Table 2. Energy labels before and after renovation based on assessment of insulation of building envelopes and on metered energy consumption. Apartments at the end of buildings in Albertslund Syd were labeled E while the others with smaller area of outer walls were labeled D.

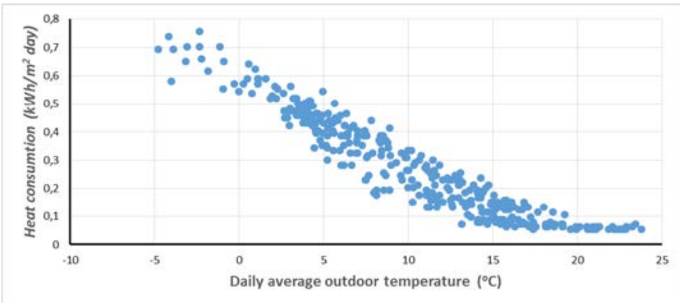
	Before		After	
	Calculated	Metered	Calculated	Metered
Albertslund Syd	D-E	C	A-2010	A-2015
Gl. Jernbanevej	D	D	-	-
AB Bustrup	D	C	C	C

In Table 3 the same story of efficient operation of heating systems is shown based on the standardized calculation of annual energy consumption based on insulation standard and on actual metered consumption. Before renovation the actual consumption was 58 % of standardized and expected consumption in Albertslund Syd while it was 104 % in Gl. Jernbanevej and

71 % in AB Bustrup. These significant differences may be caused both by modest indoor temperatures and low air change in Albertslund Syd and AB Bustrup and by efficient adjustment of flow and supply temperatures in heating system by good building automation and responsive operation staff.

Table 3. Energy consumption before and after renovation based on legally required standardized calculations based on insulation of building envelope and on metered data after adjustment for degree days (base 17 °C). (*) Some uncertainty about calculated consumption before renovation in Gl. Jernbanevej

kWh/m² year	Before		After	
	Calculated	Metered	Calculated	Metered
Albertslund Syd	192	112	48	24
Gl. Jernbanevej	* 120	125	-	-
AB Bustrup	147	105	78	93



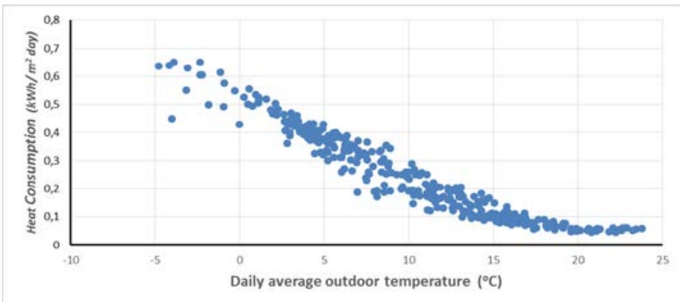


Figure 4. Energy signature or relation between daily average outdoor temperature and heat consumtion in first Gl Jerbanevej and then AB Bustrup in the year 2014.

To analyze the reasons further for the differences between calculated and actual heat consumption the energy signatures for the year 2014 in the two cases with detailed information about heat consumption are shown in Figure 4. The two buildings are comparable in insulation standard. It may be seen that there is a bigger spread of observations and a somewhat steeper increase in heat consumption at lower temperatures in Gl. Jernbanevej than in AB Bustrup. This could indicate less systematic control of supply temperature and possibly increased heat losses from installations at low outdoor temperatures.

For the year 2014 a more detailed analysis of heat consumption was performed at the two cases. The consumption independent of outdoor temperatures (GUF) for distribution losses and heating of hot tap water were quantified as the heat consumption at the best fitted horizontal line to the tail end at outdoor temperatures above 17 ^oC in Figures 4 and 5. Subtracting this consumption from consumption of all days and finding the average of the remaining consumption gives the heat consumption dependent of outdoor temperatures (GAF). Average outdoor temperature for both locations in 2014 was 9.0 ^oC. The key energy signature figures may be sees in Table 4.

Table 4. Key energy signature numbers for the two comparable cases before renovation.

	Gl. Jernbanevej	AB Bustrup
Heat consumption dependent on outdoor temperature (GAF_{17}), kWh/^oC day m^2	0.031	0.028
Heat consumption independent of outdoor temperature (GUF), kWh/day m^2	0.066	0.060
Ratio of independent to dependent consumption	24 %	25 %
Average cooling of district heating water (^oC)	21	33

The most apparent difference in Table 4 is the much bigger cooling of the district heating supply water in AB Bustrup. This indicates better balancing and continuous adjustment of the heat distribution system and possibly somewhat bigger radiators.

Table 5 shows the results of the indoor climate classification. The reduction to C for daylight at the new windows in AB Bustrup and maintained low grading for moisture in Albertslund Syd are notable.

During design of the comprehensive renovations in Albertslund Syd and Gl. Jernbanevej, advanced computer based systems were utilized for predictions.

In Albetslund Syd the operation staff was professional with relevant competences. The heat consumption was below the calculated but some problems complying with cooling requirements from district heating were apparent. Tenants had opposed the initial plans to increase window areas in top floor of renovated dwellings because they thought privacy would be compromised. In general tenants were happy with the results of the renovation.

In Gl. Jernbanevej one volunteer tenant operated the heating system. It was apparent that both supply temperature of heating and hot tap water were set too high. The volunteer janitor reported that the automated supply temperature adjustment did not function and he had to make frequent manual adjustments. The heat consumption was in agreement with the calculated but some surcharges to the district heat supply company had to be paid due to obvious problems complying with cooling requirements.

Table 5. Indoor climate labels in the 3 cases.

	Albertslund Syd		Gl. Jernbanevej		AB Bustrup	
	Before	After	Before	After	Before	After
Ventilation	B-A+	A++	A++	-	B-A++	B-A+
Temperatures	A++	A+-++	A+	-	A+-++	A+-++
Radon	-	-	A++	-	A++	A++
Formaldehyde	A++	A++	A++	-	A++	A++
Particles	A++	A++	A	-	A	A
Moisture	C-B	C-B	C-A+	-	C-B	C
Daylight	B	B	C-B	-	B	C
Altogether	B	B	A-B	-	B	B

In AB Bustrup a dedicated janitor had a thorough understanding of the heating system. The heat consumption was below the calculated while complying with cooling requirements for district heating. Tenants reported reduced annoyance by cold draft from windows and were satisfied with the results of the exchange of windows.

4. Discussion

The occupant density and behavior were not included in the analysis. Nevertheless significant observed differences could be explained by qualifications and dedication among operation staff.

Decisions concerning initiation of renovation works could among others be justified by improved indoor climate quality, savings on energy expenditure and catching up with maintenance deficits by bundled comprehensive renovation. Exchange of windows in AB Bustrup seems simply justified by need for renovation of old windows. The very comprehensive renovation in Albertslund Syd is obviously a bundled renovation to maintain the value of the worn down buildings. The planned but not yet executed renovation in Gl. Jernbanevej has aspects of improving the size and quality of renovated dwellings, but also the increased revenue by adding a new level with apartments contributes to the motivation.

It may be noted that the exchange of windows in AB Bustrup to coated energy efficient windows resulted in lowered indoor climate grading for daylight in the renovated dwellings. It may cause some concerns in

Albertslund Syd that the rating for moisture and mould in the renovated dwellings did not improve significantly after renovation. It is possible that this was caused by insufficient water protection during construction.

5. Conclusions

Quality of the indoor climate was apparently not jeopardized by the renovations but only small improvements could be observed.

Both labeling schemes for energy efficiency and indoor climate quality are rough and robust systems but relevant and detailed information are not assessed and visualized. Improvements apparent to occupants may not result in improved labeling.

Most important justification of renovation was the maintenance deficit and need to assure the value of the buildings. The energy savings were a much less important issue. Quality of the indoor climate was an issue during planning and execution of renovation works.

Well qualified and attentive operation staff may improve the energy efficiency of a building significantly. Many smaller buildings may have reduced efficiency by lack of qualifications or attention by operation staff.

Acknowledgment

The project behind this paper is part of the skimmel.dk project supported by The National Building Fund and The Property Owners Investment Fund.

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