Indoor climate in renovated and energy retrofitted social housing

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SUMMARY
The objective of the present survey was to evaluate tenants' experiences and satisfaction with renovated and energy retrofitted social housing erected in the 1960s. Tenants filled in a questionnaire about perceived indoor climate, overall satisfaction, the renovation process and changed behaviour related to indoor climate. There was overall satisfaction with the renovation, despite inconvenience during the renovation process. The indoor climate was generally improved. The factors most improved were temperature conditions during winter where problems with low temperature, draught and cold areas in the flat were reduced. In addition, improvements were experienced by most of the tenants regarding air quality, daylight, noise from the outside as well as neighbours, and problems with mould growth were reduced. However, the evaluation also showed that the installation of ventilation systems introduced noise that annoyed a minor group of tenants. The building renovation only to a limited extent resulted in changes in tenants' behaviour, probably because the retrofitting measures were of a "passive" nature.

PRACTICAL IMPLICATIONS
The evaluation demonstrated that investing in renovation and energy retrofitting of older social housing, including better wall and roof insulation, low-energy windows and ventilation systems with heat recovery beside reducing the energy consumption and energy bills, provides tenants with other benefits like better perceived indoor climate and comfort, lower risk of mould growth and a nicer building appearance.

KEYWORDS
Building renovation, co-benefits, energy savings, indoor environment, tenant's satisfaction.

1 INTRODUCTION
The need for renovation and energy savings in Danish residential buildings is massive, especially in the large number of buildings built in the 1960s and 1970s (Thomsen et al., 2012). An estimate of the Danish building stock has revealed a total energy-saving potential of 30%, given a payback time of 20 years (Wittchen, 2009). Only relatively few homes are renovated with a strong focus on the reduction of energy consumption. Nonetheless, a relatively large number of such renovation projects were initiated in social housing, which is the subject of this study.

The main reason for most renovation projects is a worn-down building envelope, such as: leaking roof, eroded facades and leaky windows. In addition, the indoor climate in older dwellings are often challenged, e.g. by damp surfaces and mould due to thermal bridges, draught from old cold windows and cold surfaces and poor air quality due to little ventilation. These disadvantages can be remedied by retrofitting the building envelope with better up-to-date facade insulation, roof insulation, low-energy windows and ventilation systems with heat recovery. These improvements may, besides saving energy, lead to potential benefits for the

occupants such as improved perceived indoor climate and comfort, more healthy buildings and reduced sensitivity to energy price fluctuations (Almeida, M. et al., 2015). These benefits, often referred to as co-benefits, are not yet thoroughly studied and verified for the Danish building stock.

The advantage for the occupants of living in new nearly zero-energy buildings was demonstrated in a Danish survey carried out among house owners living in low-energy single-family houses. The survey revealed a high general satisfaction and that more than 90% perceived the indoor environment as satisfactory both in summer and winter (Knudsen et al., 2015). The majority of the house owners perceived the various indoor climate parameters to be better in their new low-energy house compared with conditions in their former older house. Only a minority of the house owners were annoyed e.g. by too high temperature in summer and too low temperature in winter, technical problems and some were bothered by noise from technical installations.

Often renovation projects focusing on energy savings are solely aimed at technical measures in order to reach specific energy performance targets, low energy consumption and/or specific carbon (CO_2) reduction (direct benefits). Benchmarking on these direct benefits may not be optimal, taking into consideration that a significant part of the energy consumption depends on occupant behaviour and that the indoor climate cannot be separated either from the energy saving measures or from the occupants' operating the heating and ventilation systems.

It should therefore be considered, how to implement a more systematic accumulation of knowledge and experiences with building renovation projects with a focus on energy savings in the future. Figure 1 is an attempt to illustrate possible interactions.

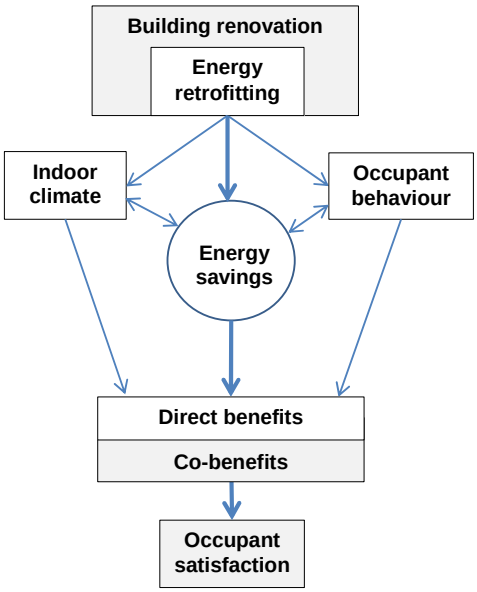

Figure 1. A simplified model with possible interactions between energy retrofitting, energy savings, indoor climate and occupant behaviour and the direct benefits and (indirect) co-benefits for the occupants.

The objective of the present survey was to evaluate tenants' experiences and satisfaction with renovated and energy-retrofitted social housing erected in the 1960s. This paper focuses on the evaluation of potential benefits for the perceived indoor climate and comfort, but also touches on other benefits, the overall satisfaction, the satisfaction with the renovation process, and whether the tenants have changed indoor climate behaviour as a result of the renovation.

2 METHOD

The questionnaire survey was carried out in two large Danish settlements belonging to the social housing sector; in terraced houses in Albertslund Syd located west of Copenhagen and in blocks of flats in Vapnagaard located in Elsinore North of Copenhagen, for details see Knudsen and Jensen (2015). Both settlements are representative of the first large wave of prefabricated constructions built in the 1960s. The terraced houses in Albertslund Syd consist of 550 dwellings, and Vapnagaard 1450 dwellings.

The renovation and energy retrofitting

Recently, both settlements have been through renovation and energy retrofitting, see Table 1.

Table 1. Overview of energy-saving measures and other improvements in the two settlements. (X) indicates that the measure was voluntary for the tenants.

Energy-saving measures etc.	Vapnagaard in Elsinore	Albertslund Syd in Albertslund
New entrance facade with additional insulation	X	X
New living-room facade with additional insulation	X	X
New end-wall facade with additional insulation	X	X
Additional insulation of the roof	X	X
Additional insulation of the floor against the basement	X	X
Balanced ventilation system with energy recovery		X
Exhaust ventilation system (renovated)	X	
New low-energy windows (all)		X
New low-energy windows (north facade)	X	
New bathroom	(X)	X
New kitchen	(X)	X
Renovation of green areas	X	X

The energy retrofitting was most ambitious and comprehensive in Albertslund Syd. This was due to two reasons: 1) Conditions of the terraced houses in Albertslund Syd were very poor and the worst to start with. Generally worn-down buildings with no insulation under the floors, windows in poor condition, much building damage and pronounced mould-growth problems and 2) Albertslund Syd is located in the municipality of Albertslund with great ambitions to be a low-carbon municipality and a leading climate laboratory among climate friendly municipalities in Denmark. As a consequence, the Climate Plan 2009-2015 for future development in Albertslund had a strict focus on energy savings and carbon reduction in the building sector (Albertslund, 2006). The energy retrofit in Albertslund Syd resulted in a reduced heat consumption of 61%, which was substantial compared with Vapnagaard, see Figure 2.

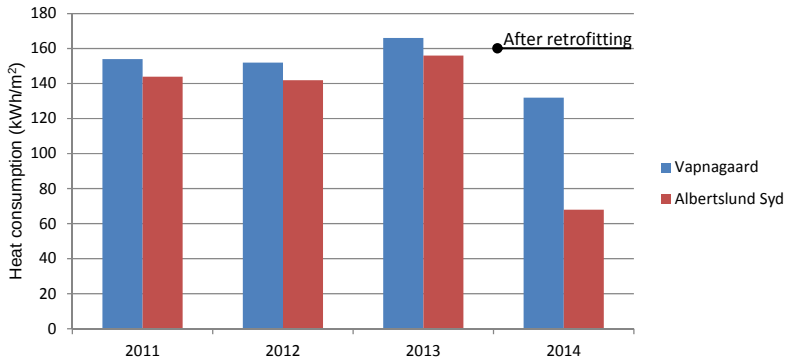

Figure 2. Overview of the heat consumption before and after the energy retrofitting of the two settlements, Vapnagaard and Albertslund Syd. Dwellings still under renovation are omitted.

The questionnaire
A first version of a questionnaire was developed and tested in a small-scale project (Knudsen et al., 2015), then modified and finally applied in the two settlements.

The questionnaire focused on the tenants' overall satisfaction with how the renovation was carried out and more specifically their experiences and satisfaction, after the renovation. The latter included the perceived indoor climate (temperature, draught, air quality, noise and daylight) before and after the renovation, including an evaluation of whether it has become worse or better. Tenants were also asked about changed behaviour after the renovation related to indoor climate. Moreover, the tenants were asked whether they found the rent increase after the renovation reasonable in relation to savings on heating and/or other benefits achieved, e.g. on the indoor climate. Open questions, where tenants could provide input in their own words, were included in all sections of the questionnaire.

The tenants were briefly informed about the coming questionnaire survey at residents' meetings and as news on the housing association's homepage. In February 2015, the questionnaire survey was conducted among 1426 tenants living in the two settlements, 240 tenants in terraced houses in Albertslund Syd and 1186 tenants in blocks of flats in Vapnagaard. The survey was carried out by distributing a letter to each dwelling with a brief description of the project and an invitation to participate in the survey. The tenants accepted the invitation by filling in a questionnaire using an online survey system. To encourage tenants to complete the questionnaire, they were offered the opportunity to participate in a draw for three gift certificates worth € 93 (DKK 700). One week after distributing the letter, a poster was hung up in the stairwells with a friendly reminder to those who had not yet responded. By the final deadline, a total of 259 tenants (56 in Albertslund Syd and 203 in Vapnagaard) out of 1426 had answered, corresponding to a response rate of 18% (23% in Albertslund Syd and 17% in Vapnagaard).

3. RESULTS
Since the most significant results were found for the Albertslund Syd settlement, mainly results from that settlement are presented in the following. For more details about the whole survey, see Knudsen and Jensen (2015).

Overall satisfaction
Over half (63%) of the tenants found that the result of the renovation lives up to their expectations. Questioned about whether they can recommend other housing associations to renovate their properties with focus on reducing energy consumption, 74% of the tenants supported this recommendation. This relatively high satisfaction should be seen in relation to the fact that more than 70% of the tenants experienced some kind of inconvenience during the renovation process, including noise, dust and the presence of craftsmen. In spite of this, only 20% were overall dissatisfied with how the renovation was carried out whereas 58% were satisfied. This relatively high satisfaction may reflect that the communication about the renovation process had ensured an alignment of expectations among the tenants.

The rent increase was limited, 5 to 9%, due to subsidies from "Landsbyggefonden" (National Building Fund), a self-governing institution founded by the social housing associations. Therefore, probably most of the tenants did not find the rent increase unreasonable compared with the energy savings and benefits like improvements of their flat and a better indoor climate.

Perceived indoor climate and other benefits

A majority of the tenants perceived a clear improvement of the indoor climate after the building renovation, but they also experienced other benefits.

In different ways, the questionnaire investigated whether the tenants perceived the indoor temperature conditions to be worse or better after the retrofitting, see Figure 3. As the green colour indicates, the majority of the tenants experienced improvements on all parameters. The most significant finding was that around 85% of the tenants perceived improvements of the temperature all year round and during the winter. In general, it is notable how small the number of tenants is who experienced problems with low temperatures, periods when it was too cold and cold areas in the dwelling. The exception is the indoor summer temperature and periods when it is too hot indoors. Here 15% found that it had become worse after the renovation.

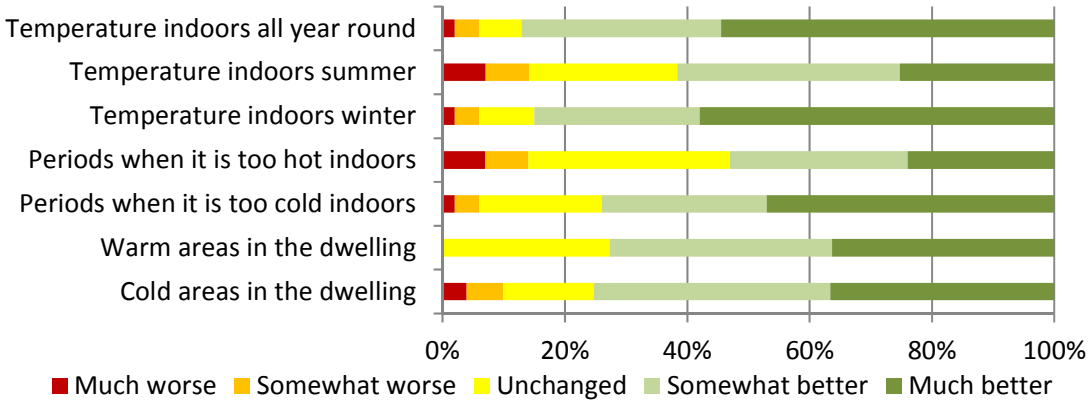

Figure 3. The frequency of tenants' responses in Albertslund Syd about whether the perceived indoor temperature conditions have become better or worse after the retrofitting.

The tenants were also asked whether they perceived that various other indoor climate aspects, like air quality, draught, noise and daylight, had become worse or better after the retrofitting, see Figure 4. Concerning these aspects of the indoor climate, the tenants also perceived significant improvements, except for one factor: Sound and noise from installations. Whereas better insulation and low-energy windows reduced sound and noise from the outside and from neighbours, the building retrofit has introduced sound and noise from new installations, which mainly stem from the new ventilation system according to comments.

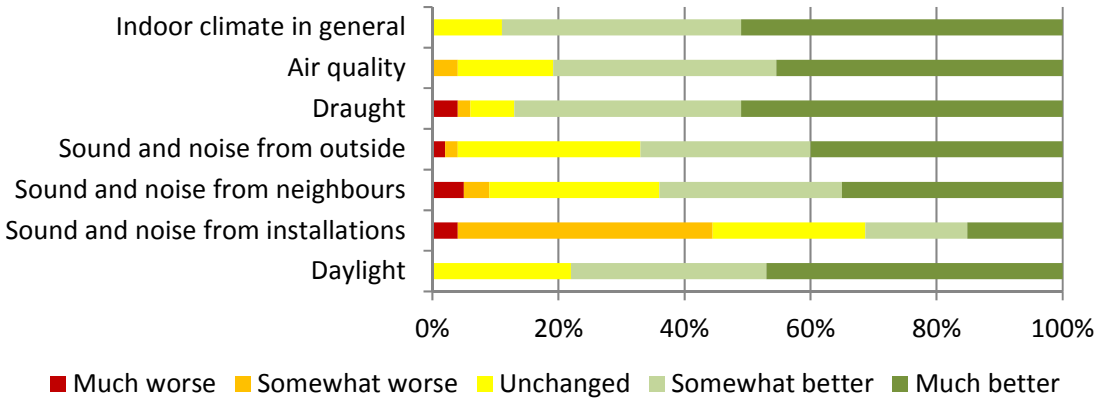

Figure 4. The frequency of tenants' responses in Albertslund Syd about whether various perceived indoor climate aspects have become better or worse after the retrofitting.

The questionnaire also addressed whether the tenants perceived if other potential benefits had become worse or better after the retrofitting, see Figure 5. A majority of the tenants found that the possibility of ventilation and airing the dwelling was improved. A reason for this can be the lack of such possibilities in the dwellings before the renovation. In contrast, it can be noticed that almost one third of the tenants find that condensation on the outside of windows has become worse, and possibly a surprise for them. The view from the dwelling is the factor most unchanged, whereas the building appearance has improved the most. As expected, most of the tenants find fewer problems with mould growth.

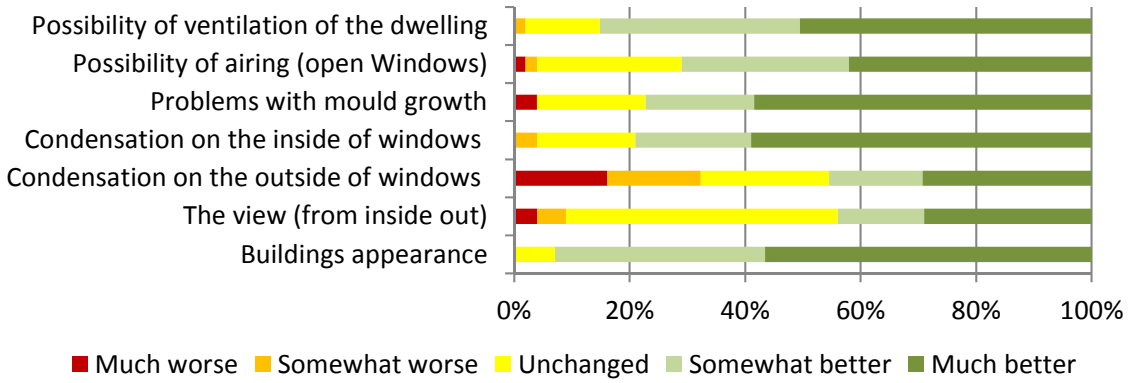

Figure 5. The frequency of tenants' responses in Albertslund Syd about whether various other perceived benefits have become better or worse after the retrofitting.

The tendencies of the improvements after renovation are rather equal in the two settlements, but the improvements were markedly greater in Albertslund Syd where the renovation was the more comprehensive. The only exception is the increased noise from a new ventilation system. In both settlements, the tenants found that the appearance of the buildings had markedly improved.

Changed behaviour after renovation

The tenants were asked whether they have changed behaviour after the renovation with regard to setting the temperature, airing of their dwelling in winter by opening windows and use of cooker hood.

In Albertslund Syd, the greatest change in behaviour was found for the indoor temperature, where 72% of the tenants changed their behaviour concerning how they set the temperature during winter. 52% set the temperature lower and 22% set it higher. The reason for setting the temperature lower (on the thermostat) was the reduced demand for heat after the renovation, rather than an actual wish for a lower temperature. This is supported by the fact that only 5% of the tenants had a problem with the temperature being too low after the renovation compared with 58% having problems with a too low temperature before the renovation. The satisfaction with the temperature conditions in the dwellings rose from 15% before to 68% after the renovation. Likewise, the number of tenants who were satisfied with the draught conditions rose from 13% before to 83% after the renovation.

Regarding airing of the dwelling in the winter by opening windows, the majority did as before (74%), just as the majority used the cooker hood as before (89%).

All in all, since the setting of the temperature on the thermostat at another level than before does not represent a real change in behaviour, the building renovation only to a limited extent resulted in changes in the tenants' indoor climate behaviour. This may not be a surprise

because the retrofitting measures were all “passive” in nature, i.e. they do not invite the tenants to change behaviour.

4 DISCUSSION

Since the 2000s, the agenda of global climate change has once again put focus on the energy retrofitting of existing buildings due to the large potential for reducing energy consumption and for reducing greenhouse gas emissions at the same time.

Energy retrofitting in connection with renovation of existing buildings is a complex business, which can have adverse and unexpected effects if done incorrectly. This was experienced after the energy crises in the 1970s. At that time, it was easy to achieve energy savings, and in the 1980s and 1990s a lot of energy-saving measures were carried out, mostly through new windows and tightening the buildings leading to reduced ventilation rates (Janssen, 1999) rather than by extra insulation. However, the tightening of buildings without establishing sufficient ventilation rates resulted in a negative impact on the indoor air quality. Directly by an increased concentration of air pollutants. Indirectly by an increased numbers of house dust mites due to a more humid dwelling and mould growth due to condensation on badly insulated wall surfaces (Batty et al, 1984). These negative experiences may have fostered a fear of energy retrofitting not least among tenants in social housing, where large blocks of flats were negatively affected.

A recent survey demonstrated benefits for house owners living in new nearly-zero energy single-family houses (Knudsen et al., 2015). The survey revealed a high general satisfaction and that more than 90% perceived the indoor environment as satisfactory both in summer and winter. The majority of the house owners perceived the various indoor climate parameters to be better in their new low-energy house compared with conditions in their former older house.

Similarly, this survey demonstrates that focusing on energy retrofit and carbon reduction by investing in better wall and roof insulation, low-energy windows and ventilation systems with heat recovery are not only an investment in energy savings and carbon reduction. It is at the same time an investment in benefits like better indoor climate and greater satisfaction among the tenants. However, as the study also shows, care must be taken not to introduce new problems, like e.g. noise from a new ventilation system.

The positive results are a good indication of having avoided the potential pitfalls seen in previous rounds of energy retrofitting of older dwellings, e.g. not establishing adequate ventilation rates. But the renovation was only recently completed; so long-term experience is still lacking. Nonetheless, the positive responses given by the tenants indicate that the housing administration, the municipality, the architects and building constructers have learned the lesson. Not least the focus on the necessity of sufficient ventilation and the installation of mechanical ventilation systems in the dwellings are promising for the future indoor climate.

5 CONCLUSIONS

It is possible to renovate and retrofit with focus on energy savings in an older building stock and at the same time to add value for tenants in the form of improved perceived indoor climate as well as a number of other benefits.

The most improved indoor climate factors were temperature conditions during winter, where problems with low temperature, draught and cold areas in the flat were reduced. In addition,

improvements were experienced by most of the tenants regarding air quality, daylight and noise from outside and from neighbours and problems with mould growth was reduced.

A particularly important point to remember when energy retrofitting is to avoid technical installations with annoying sound and noise, like e.g. a ventilation system.

The positive effects on indoor climate and other benefits in addition to energy savings may, if communicated in the right way, reduce barriers and motivate tenants and thereby help building organisations to initiate major renovation of their old building stock.

The studied building renovations only to a limited extent resulted in changes in the tenants' indoor climate behaviour, probably because the retrofitting measures were all "passive" in nature.

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