Combined Retrofitting with Low Temperature Heating and Ventilation Energy Savings

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Abstract

This paper presents the modeling results of combining low temperature heating (ventilation radiator) with ventilation energy-demand savings. Investigations on operational energy and thermal comfort are in focus. IDA ICE is employed to investigate the thermal performance and energy usage. The results show that low temperature heating can reduce mean air temperature fluctuations in the selected archetype. When combining low temperature heating with ventilation and air-tightness renovations, the thermal performance of the heating system can be largely improved to an acceptable level. The retrofitting strategy can save 41 % of heating energy demand and 27 % of total primary energy.

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Keywords: Retrofitting, Low temperature heating, Simulation, Ventilation, Energy savings

1. Introduction

In response to tightening EU energy and climate directives, Sweden is actively engaged toward sustainable transition of national building stock, targeting at least 50 % of the total energy use, 49 % share of renewable energy sources, 40 % reduction of greenhouse gas emissions compared with 1990 level by the year 2020 (1). Specifically to the existing residential buildings, Swedish government has established an ambitious energy efficiency target in housing stock by 50 % (per heated floor area) by 2050 compared with 1995 level (2). As regards energy retrofitting accomplished so far in Sweden, a 17 % of final energy savings were achieved by energy-renovations in the past decades. However, total energy utilization in Sweden has not been largely reduced (3). The by far greatest portion of
Retrofitting measures is still envelope and ventilation renovation-based, which commonly need multiple visits, large impacts to the occupants and have relatively long operating process. As an energy-efficiency alternative, low temperature heating (LTH) technology has shown promising advantages and shortcuts to improve the efficiency of heat supply. These are contributed by easily installed solution, thermal comfort contributions and improved radiator emission efficiency (4). Previous studies show that low temperature ventilation radiator based space heating methods/ the combination of different LTH with conventional pre-heated ventilation convectors are among the highest category to comply indoor environment quality and energy efficiency (5)(6)(7)(8). Moreover, theoretical analysis and computational fluid dynamic simulation have shown evidences that advanced design and selection of LTH components can efficiently avoid cold draught and reduce the supply temperature curve to 40 - 45 °C without compensating thermal outputs (9)(10).

However, most of the studies carried out were based on the new constructed archetypes such as single-family house and ideal zone environment, or net-zero buildings designed with existing relatively low energy demand (5) (11). It was found that in existing leaky multi-family building stock with high energy demand, there is a risk that LTH may not be able to provide enough temperature to maintain the required thermal comfort level (11). Pilot retrofitting projects from industry and existing studies reported that for low-raise Swedish multifamily houses, renovating the existing exhaust/natural ventilation to mechanical balanced ventilation with heat recovery (FTX) can contribute 30-40 % energy-demand savings (12)(13). Air-tightness retrofitting also shows high sensitivity. However, investigations about combining LTH with ventilation energy savings in retrofitting practice are far less reported in literatures.

In this study, combined measures consisting of LTH and ventilation retrofitting are simulated and analyzed for one typical low-raise Swedish multi-family housing stock built among 1965-1975. Investigations on operational energy savings and thermal comfort improvements when combining LTH with FTX ventilation are in focus. The findings aim to provide technical decision supports for both occupants and stakeholders for future large-scale implementation of LTH in existing Swedish residential buildings.

### Nomenclature

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tr>
<td>ACH</td>
<td>Air changes rate, h⁻¹</td>
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<td>AHU</td>
<td>Air handing unit</td>
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<tr>
<td>BBR</td>
<td>Swedish building regulation</td>
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<tr>
<td>FTX</td>
<td>Mechanical balanced ventilation with heat recovery</td>
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<td>IDA ICE</td>
<td>Indoor climate and energy performance simulation program</td>
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<td>LTH</td>
<td>Low temperature heating</td>
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### 2. Methodology

IDA ICE 4.6 is applied for the simulation of thermal performance and operational energy use. Validation of IDA ICE program was evaluated by IEA solar heating and cooling program, Task 22, Subtask C in 2003 [14]. The applications of IDA ICE for LTH and ventilation modeling were further validated in several studies, including both single family houses and multi-family residential buildings. It was found that good agreements with measurement was achieved for air temperatures and temperature gradients in multi-family houses (11) (15). For houses installed with low temperature ventilation radiators, it is revealed that the maximum errors of annual energy modelling are below 7 % compared with on-site field measurements (16).

In this study, a 2-storey district-heated Swedish multifamily house from Million Program (1965 – 1975) is selected to represent our analysis. The selected building has a total heated floor area of 1580 m² and is located in the northern suburbs of Stockholm. The appearance of the archetype (northern façade) is shown in Fig.1a. Constructed building model (southern façade) is depicted in Fig.1b. Each flat consists of one balcony oriented to the south, and one storage room (without window and openings). On basis of the different occupancies, the building is modelled by 85 zones, including three types of occupant schedule:
• Living room and bedroom
• Bathroom and kitchen, domestic hot water (DHW) usage schedule
• Window and opening based on the set temperature controls schedule (open when operative temperatures exceeds 25 °C)

Wind profile is based on the suburban inventory, Ashrae-1993. District heating supply/return temperature is set to 75/50 °C before retrofitting, based on the averaged statistics of Swedish district heating (17). Annual ambient temperature is based on the climate data of Stockholm/Bromma, shown in Fig.2a, in which the lowest design temperature is marked in red box as -18 °C. Supply temperature to the hydraulic circuits and radiator is design temperature compensated, which is shown in Fig.2b. LTH supply temperature is further designed as a function of decreased energy demand as two retrofitting scenarios, Fig.2b shows:
• LTH (ventilation radiator) + FTX system with 85 % heat recovery
• LTH (ventilation radiator) + FTX system with 85 % heat recovery + air-tightness (60% improvements)

The selection and sizing of low temperature heating radiator is based on the principle of increasing emission efficiency of radiators. Ventilation radiator is designed with the width of conventional radiators, but with one more ventilation vent connecting radiator with outdoor air. Increased air temperature differences in the ventilation channel beneath the radiator will improve heat convection. Outdoor air is then preheated and filter by the radiator. Pilot testing and modelling results show that the supply/return temperature can be reduced to 35/28 °C without compensating the heat outputs (18), no extra energy is needed to operate the radiator. The working principle of ventilation radiator can be found in (4) (16).

Fig. 1. (a) The appearance of the selected archetype; (b) Constructed model in IDA ICE simulation

Fig.2. Ambient temperature for annual building performance simulation

3. Results and discussion

Annual dynamic simulations are performed to find the indoor air/operative temperature variations and energy use before and after retrofitting. Due to differences in living schedule and internal heat gains from occupancies, bathroom and kitchen were considered separately from living room and bedroom. The total annual simulation duration is approximately 6 hours. Fig.3a shows the hourly simulation results of operative and air temperature before retrofitting. The zone that has the worst thermal performance in a year is found. It is observed that the worst apartment locates at the most northwest position of the building, shown by frame in Fig.3b. The kitchen in this
apartment has the lowest mean air temperature and highest operative temperature fluctuations (shown in Fig.3a),
during 960-1120 simulation hours, first week in February (marked in Fig.3a). This is explained by the orientation
(solar radiation) and as-built ventilation system. Exhaust ventilation only installed in kitchen and bathroom. This
simulation period is further investigated as a representative periodic reference to evaluate the retrofitting profits
when implemented with low temperature heating and ventilation renovations. Fig.4 shows the mean air temperature
fluctuations before retrofitting and when the existing radiator is replaced with ventilation radiator (without
ventilation system renovation).

![Image](a) ![Image](b)

Fig.3. Annual mean air temperature in the room with worst performance before retrofitting and location (b) in the constructed building model (framed area)

It is observed that LTH can contribute reduced mean air temperature fluctuations from 16.6-21.0 °C (before retrofitting) to 17.3-20.6 °C (after LTH). However, the averaged main air temperature (18.9 °C ) is not improved before retrofitting (19.2 °C). This result confirms that low temperature ventilation radiator will not significantly improve the mean air temperature if no extra energy-demand renovation is implemented in the presented archetype.

Fig.5a shows the mean air temperature and operative temperature when combining LTH with FTX system. Additional air-tightness renovation by 60 % air leakage upgrading (1.0 ACH under 50 Pa difference after retrofitting) is shown in Fig.5b. It is observed that when combining LTH with FTX, the thermal performance can be largely for both relatively stable mean air temperature and operative temperature. The results are further improved by air-tightness improvements to 1.0 ACH, which is not difficult to achieve and also easy to operate from empirical retrofitting reports. No additional renovation on building envelope is required to achieve this thermal performance. Generic results of PMV-based mean PPD level before and after each LTH-based retrofitting is also performed. The mean PPD is 22 % before retrofitting (44.8 – 5.4 %). Among the five LTH-based retrofitting, ventilation retrofitting has a contribution of 12.3 % (average), with a deviation of 26.2 – 5 %. This means this retrofitting can provide sufficient thermal comfort level by the joint effect, according to the lowest PPD limitation set by EN ISO 7730. No any further renovations are needed.

Tab.1 shows the energy usage before and after retrofitting (combining LTH + FTX+ air tightness). Primary heating source is district heating with an average initial primary energy factor of 0.98 and 0.79 for high and low temperature district heating in Stockholm, respectively. Primary electricity energy mix is selected as Swedish mix with a primary energy factor of 2.15. The energy performance results show that combining LTH with FTX system and air-tightness renovation may save up to 41.3 % of heating energy demand, shown in Tab.1. The contribution of total delivered energy is limited due to the fact that replacing exhaust ventilation and high temperature radiator by LTH+ FTX system needs an extra 5.3 kWh/m² year electricity to operate the AHU and circulation pump in the district heating substations. Total delivered energy is 96.2 kWh/m² year, this is still higher than the limited value of BBR (90 kWh/m² year). However, it can be further compensated by reducing building electricity usage, such as more efficient circulation pumps in district heating substations and DHW energy savings. The largest contribution is obtained for total primary energy: a saving potential of 26 %, shown in Tab.1. This can explained by the reduced
distribution heat loss in LTH system, which leads to a relatively lower primary energy factor and distribution efficiency in district heating grids.

![Fig.4. Air temperature under design temperature before and after retrofitting without ventilation renovation (selected zone)](image)

![Fig.5. Operative and air temperature under design temperature after renovating ventilation with heat recovery and air tightness](image)

**Table 1.** Energy usage before and after retrofitting combining LTH with FTX and air-tightness renovation

<table>
<thead>
<tr>
<th></th>
<th>Before retrofitting (kWh/m² year)</th>
<th>After LTH+FTX + air tightness retrofitting (kWh/m² year)</th>
<th>Savings (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>87.1</td>
<td>51.1</td>
<td>41.3</td>
</tr>
<tr>
<td>Electricity</td>
<td>18.0</td>
<td>23.3</td>
<td>No savings</td>
</tr>
<tr>
<td>DHW</td>
<td>21.8</td>
<td>21.8</td>
<td>No savings</td>
</tr>
<tr>
<td>Total delivered energy</td>
<td>126.9</td>
<td>96.2</td>
<td>24.1</td>
</tr>
<tr>
<td>Total primary energy</td>
<td>145.4</td>
<td>107.6</td>
<td>26.0</td>
</tr>
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**4. Conclusion**

This study shows that the proposed retrofitting strategy with LTH + ventilation+ air-tightness renovation leads to higher and more stable thermal performance of heating system. The ventilation system is renovated from exhaust
ventilation to balanced ventilation with 85% heat recovery. Air tightness is improved by 60% before retrofitting. The proposed system can contribute 41% and 27% savings of heating and total primary energy, respectively.

Acknowledgements

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