Energy and Buildings 126 (2016) 535–544

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

# Case study of low-temperature heating in an existing single-family house—A test of methods for simulation of heating system temperatures

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ARTICLE INFO

*Article history:*
Received 24 April 2015
Received in revised form 7 March 2016
Accepted 14 May 2016
Available online 17 May 2016

*Keywords:*
Low-temperature heating
Radiator system
IDA ICE
Radiator exponent
Design heating power
Return temperature

ABSTRACT

Low-temperature heating provides an efficient way of heating our buildings. To obtain a high efficiency it is important that the heating systems in the buildings are operated with both low supply and return temperatures. This study set out to investigate how typical assumptions in the modelling of heat emissions from existing hydraulic radiators affects the heating system return temperatures calculated in a building simulation model. An existing single family house with hydraulic radiators was modelled in the simulation program IDA-ICE. Simulations were performed with various levels of detail and the calculated indoor temperatures and radiator return temperatures were compared to temperatures measured in the case house. The results showed that the detail of the simulation model has a large influence on the results obtained. The estimated return temperatures from the radiators varied by up to 16 °C depending on the assumptions made in the simulation model. The results indicated that a detailed building simulation model can provide a good estimate of the actual heating system operation, provided that actual radiators and realistic indoor temperatures are taken into account in the model.



## 1. Introduction

More than 25% of the final energy consumption in the EU is attributed to households [1]. The households are thereby the sector with the second largest final energy consumption in the EU, which makes the sector a central focus area for energy consumption reductions. One way of reducing the energy consumption of households in cold climates is to improve the efficiency of the heating systems. Low-temperature heating provides one promising solution to how this may be done. By reducing the heating system temperatures it is possible to increase the efficiency of heat production from solar collectors, heat pumps, and condensing boilers. Furthermore the heat loss from the distribution systems inside both new and existing buildings is reduced [2,3]. The highest heating system efficiencies are obtained when both supply and return temperatures are as low as possible. Recent research has therefore described the benefits of using heating system supply and return temperatures as low as 50 °C/20 °C [4]. However while the supply temperature is often controlled according to a weather compensation curve, the return temperature is highly dependent on the design and operation of the heating system. This study therefore set out to test methods for evaluation of the possibility to obtain a low return temperature in heating systems with supply temperatures of 55 °C or lower.

Recent studies have shown how new houses can be designed with a low-temperature heating system supplied by either low-temperature district heating [5], a heat pump [6], or a boiler [2]. Less focus has been put on the heating systems in existing houses. This is despite the fact that the existing buildings form the larger part of the building mass. In Denmark most existing houses are heated by hydraulic radiator systems that were dimensioned according to design temperatures such as 90 °C/70 °C or 70 °C/40 °C. If these houses are to be heated by supply and return temperatures of 55 °C/25 °C or lower, it may be necessary to evaluate whether the heating system is suited for this type of low-temperature operation. A reduction of the heating system supply temperature might lead to poor thermal comfort and high heating system return temperatures in case the existing radiators in the houses are too small. This could in turn lead to poor heating system efficiency.

Recent studies that have investigated the use of radiator systems for low-temperature heating in existing buildings include [7–11]. These studies investigated the heat supply and heat demand in certain case study buildings by applying numerical analysis [9,10] or by using building simulation programs [7–9,11]. These types of anal-

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http://dx.doi.org/10.1016/j.enbuild.2016.05.042
0378-7788/

**Nomenclature**

| | |
|---|---|
| $T_s$ | Supply temperature |
| $T_r$ | Return temperature |
| $T_i$ | Indoor temperature |
| $P$ | Heat flux emitted from the water [W] |
| $q_m$ | Water mass flow rate [kg/s] |
| $C_{water}$ | Specific heat of water [J/kg °C] |
| K | Power law coefficient depending on radiator height and width [W/m °C] |
| $l$ | Length of the radiator [m] |
| $n$ | Radiator exponent [–] |
| $\Phi_0$ | Design heating power at the standard test conditions [W] |
| $\Phi$ | Heating power at the operating temperatures [W] |
| $\Delta T_0$ | Mean temperature difference between radiator and surroundings in the standard test conditions [°C] |
| $\Delta T$ | Mean temperature difference between radiator and surroundings at the operating temperatures [°C] |
| $\Delta T_{arit}$ | Arithmetic mean temperature difference |
| $\Delta T_{log}$ | Logarithmic mean temperature difference |

ysis require that assumptions are made about the design heating power of current radiators and about the applicability of parameters and equations describing heat emissions from the radiators. For example, the estimation of the design heating power of the current radiators in the building investigated might be based on calculations of the design heat loss of the building and the design heating system temperatures [7,8,10,11]. Heat emissions from the radiators might be calculated using either arithmetic or logarithmic mean temperature differences, and by applying specified or standard radiator exponents. Another major assumption is that indoor temperatures can be based on standard set-points of 20 °C or 22 °C [7,8,10].

Very little is known about the consequences of applying these assumptions. Therefore it is difficult to make reasonable assumptions and take into account any inaccuracies that might derive from such assumptions. This is important because the existing radiator sizes, may not correspond to the radiator sizes expected from the estimated design heat loss of the buildings [12]. Nor is it fully accurate to calculate the heat emission from the existing radiators using standard parameters and equations that have not been adjusted to the properties of low-temperature heating [13]. Lastly, indoor temperatures have a large effect on the heat emissions of a low-temperature heating system. Therefore accurate indoor temperatures may play a significant role for the validity of the results.

### 1.1. Objective

This paper set out to investigate the significance of the assumptions applied in simulations dealing with low-temperature radiator heating. The results from the study provide new knowledge on how dynamic simulations and measurements can be performed in order to obtain realistic results from evaluations of low-temperature heating systems – knowledge which may increase the accuracy of future studies in this area of research.

## 2. Method

The investigations presented in this paper were based on a case study of a Danish single-family house. The house was modelled in the commercial simulation tool IDA ICE and a number of simulations were performed to test how different assumptions affected the simulation results. The simulation results were evaluated with regard to indoor temperatures and heating system supply and return temperatures, and the calculated values were compared to temperatures measured in the house. The pros and cons of the investigated methods for simulation of low-temperature heating in existing buildings were discussed, and a suggestion was given for how to perform future studies on this topic.

## 3. Case study & simulation model

The case study was based on a typical Danish red-brick house from the 1950s. The original part of the house consists of approximately 100 $m^2$ of living area and a 70 $m^2$ basement (of which 18 $m^2$ is currently heated). In 1992, a two-storey extension was added to the house with 43 $m^2$ on the ground floor and 27 $m^2$ on the first floor. The house was modelled in the building simulation tool IDA ICE. The building construction was studied during a visit to the house and otherwise determined on the basis of drawing material and standard constructions at the time the house was built [14]. A picture of the case study house and the simulation model are shown in Fig. 1.

Three occupants live in the house and they were considered to be at home most of the time, because two are retired and the third often studies at home. Electrical equipment was identified during the visit to the house, and all internal heat gains were modelled using specified schedules. The average internal heat gains from equipment, light and occupants in the schedules were 5.2 W per $m^2$ heated floor area. This corresponds well with the average of 5 W/$m^2$ that is usually applied for Danish energy calculations [15]. The occupants were assumed to have a standard hot water consumption of 41 L hot water per person per day [16], and the house was assumed to be naturally ventilated by a fixed air flow of 0.3 l/s per $m^2$ heated floor area. Real weather data from northern Zealand, Denmark, was obtained from the Danish Metrological Institute and

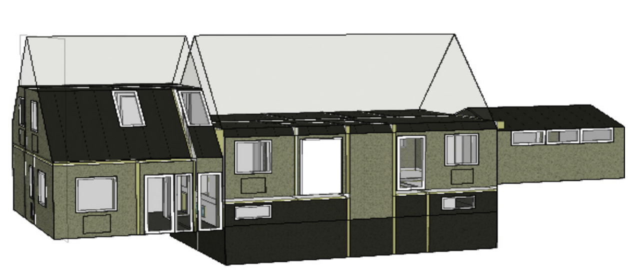

**Fig. 1.** Picture of the case study house (left) and model of the case study house in IDA-ICE (right).