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Low temperature radiator heating distribution and emission efficiency in residential buildings

Mikk Maivel*, Jarek Kurnitski

Faculty of Civil Engineering, Department of Structural Design, Tallinn University of Technology Ehitajate tee 5, 19086, Tallinn, Estonia

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ABSTRACT

Low and nearly zero energy buildings with decreased heating need can utilize low temperature heating systems for energy efficient heating. Distribution and emission losses for low temperature radiator heating cannot be found from European standards or scientific literature. The use of the losses of conventional systems can result in significant overestimation of heating energy use. In this paper, distribution and emission losses of low temperature and conventional radiator heating system were determined in North and Central Europe climates for low energy detached houses and apartment buildings. Detailed dynamic components of heating system in the whole building energy simulation model allowed to quantify these losses. Main findings of the study show that distribution losses can be controlled with low temperature heating curves and emission losses with PI type thermostats. For conventional systems the losses higher than 50% of heating need were calculated in the apartment building. With low temperature heating curve, PI thermostats and limited heating period distribution and emission losses were possible to keep below 1% in detached houses in both climates. In apartment buildings the minimal achievable losses were significantly higher, between 6 and 12% in North and Central European climates, respectively. Proportional thermostats add 2 to 6% to these losses. Based on results, heating curve of 45/35 °C can be recommended for detached houses and even 40/30 °C for apartment buildings. Insulating distribution and connection pipes in heated spaces proved to have no practical effect on heat losses. Compared to EN 15316-2-1:2007, the losses were significantly lower especially for low temperature heating curves. A new set of tabulated values is proposed for the revision of the standard. It was possible to explain the mechanism of losses, but still it was not possible to calculate losses from hourly energy need data with the correlation equation leading to overestimation by factor of about 10 compared to dynamic simulation.

1. Introduction

Widely used space heating systems in European buildings are radiator and floor heating or their combinations. These systems have shown performance complying with the highest indoor climate category thermal comfort specification [1] according to EN 15251:2007 [2]. In the EU, buildings account for 40% of the total primary energy use and residential buildings accounted in 2000 25.9% of final energy use [3]. Within buildings themselves, the proportion of energy allocated to space heating is 57% when averaged through [3]; 60% in UK [4] and even 62% in Estonia apartment buildings and 70% in dwellings [5,6]. Compared to existing housing stock the share of space heating energy use from total delivered energy (space heating; supply air heating; domestic hot water; cooling; fans and pumps; lighting and appliances) is 25% in nZEB detached houses and 12% in apartment buildings in northern climate [1].

General movement towards low-energy and nZEB, required by EPBD recast 2010/31/EU [7] has created new challenge for heating systems. Heating need obviously decrease, the control and system losses are stressed compared to existing buildings with higher heating energy need. According to EN 15316-1:2007 [8] heating system can be divided into four main parts: generation, storage, distribution and emission, and all these parts have losses. In this paper we focus on distribution and emission losses, generation and storage losses are not studied. A heat generation loss (i.e. boiler efficiency) has been previously extensively studied in the product development as well as in scientific studies. Some examples of these studies have found that it is possible to save energy up to 20% by improving boiler control [9] or up to 15% by changing conventional boiler to condensing boiler [10]. Generation losses are described with calculation equations and tabulated values in standards 15316-4-1:2007 [11]; 15316-4-2:2007 [12]; 15316-4-3:2007 [13]; 15316-4-4:2007 [14]; 15316-4-5:2007 [15]; 15316-4-6:2007 [16] and 15316-4-7:2007 [17].

Distribution and emission losses have not been widely studied. The reference study of 15316 [18] reports tabulated values for

* Corresponding author. Tel.: +37256461251.
E-mail addresses: mikk.maivel@ttu.ee, mikkmaivel@gmail.com (M. Maivel).

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List of nomenclature

nZEB	nearly zero energy building
EU	European Union
UK	United Kingdom
EPBD	Energy Performance of Buildings Directive
IDA ICE	IDA Indoor Climate and Energy
TRY	Test Reference Year
PI	proportional integral
P	proportional
Ideal	simulation case without heating system losses
Det45	detailed heating system with heating curve 45/35 °C
Det70	detailed heating system with heating curve 70/55 °C
D	distribution pipe
DC	distribution and connection pipe

distribution and emission losses of 15% for heating curves 55/45 °C and 19% for 70/55 °C in residential dwelling radiator heating system in Brussels. For low temperature heating systems we were not able to find any reference. A very old study [19] reports additional emission loss up to 5% of the heat emission of radiator in old buildings with poor insulation and less than 1% in new buildings with good insulation. The reason of very limited studies might be the complicated dynamic phenomena of distribution and emission losses. Distribution losses contribute as internal heat gains and may not be estimated by theoretical hand calculation, because of dynamic heat gain utilization process and not constant flow rates in the pipes. Emission losses depend on flow temperatures and heat output of radiator in addition to wall insulation and need also dynamic treatment. Until now, building energy simulation tools do not typically support the detailed modeling of the heating system with pipework, thermostats and radiators all with continuously changing flow rates and temperatures.

In this study we modeled the building and full heating system with special pump, pipe, valve, controller and radiator models in order to be able to run dynamic simulation of distribution and emission losses including all flow and heat transfer effects. This is arguably the most detailed radiator heating system modeling attempt ever been done in a building energy simulation tool. Conventional and low temperature radiator heating system was modeled in Estonian reference detached house and apartment building which were run with Estonian and German climate. Constant speed and constant pressure pump control was used to have realistic flow control. Most of simulations were done with PI controlled thermostatic valves, which provide de-facto ideal control and help to distinguish distribution losses. To show the effect of control losses of typical radiator thermostats, some cases were run with P controllers. As a result, we were able to quantify distribution, emission and control losses in two climates (North and Central European) for low energy houses and apartment buildings with conventional and low temperature heating curves. One objective of the study, in addition to scientific ones, was to provide input for the revision of 15316 standards, which is one task of the preparation of second generation EPBD standards, to be completed due 2015. With the data provided, the revised standard can cover low temperature heating systems, which are especially suitable for low energy and nearly zero energy buildings.

2. Methods

2.1. Classification of thermal losses of heating system

The main parts of a heating system, generation, storage, distribution and emission, all have some losses. According to 15316-2-3:2007 [20], distribution losses consist of system thermal losses and auxiliary losses (pumping energy etc.). Emission losses consist of heat loss due to non-uniform temperature distribution, heat loss due to heat emitter position and heat loss due to control indoor temperature are studied. Emission losses are described and tabulated values can be found in 15316-2-1:2007 [21].

All thermal losses are divided to recoverable and non-recoverable losses according to 15316:2007. The distribution losses caused by pipes in unheated area are calculated as non-recoverable losses and losses in heated rooms contribute as recoverable losses until the temperature set-point is not exceeded. Since the set-point is exceeded, the part of the loss becomes non-recoverable; this part can be quantified based on the comparative calculation with ideal heating and control. Emission loss caused by the heat emitter (radiator) position is the additional back-wall loss through the external wall behind the radiator (compared to the heat loss through the same external wall without radiator) and the control loss is caused by thermostatic valve type controller.

The losses are defined as additional loss to space heating energy need in %. The efficiency η is the reciprocal value, i.e. the energy use with losses can be calculated as $1/\eta$. All losses in series or parallel can be calculated as additional loss for the system in % or as the total system efficiency. If losses are in the series, the subsystem efficiencies may be calculated and the total systems efficiency is calculated by Eq. (1):

$$\eta_{tot} = \eta_{emission} \times \eta_{distribution} \times \eta_{storage} \times \eta_{generation} \tag{1}$$

where $\eta_{emission}$ is emission efficiency; $\eta_{distribution}$ is distribution efficiency; $\eta_{storage}$ is storage efficiency and $\eta_{generation}$ is heat generation efficiency, calculation rules can be found in 15316:2007 standard or sub-standards.

For example, if the heating energy need in a room is 100 kW h, emission losses 10 kW h and distribution losses 15 kW h, the $\eta_{emission} = 100/110 = 0.909$ and $\eta_{distribution} = 110/125 = 0.88$. The total efficiency is $0.909 \cdot 0.88 = 0.8$, which can be calculated also as $100/125 = 0.8$. Emission efficiency, depending on parallel components, can be calculated with 15316-2-1:2007 by Eq. (2):

$$\eta_{emission} = \frac{1}{4 - (\eta_{stratification} + \eta_{control} + \eta_{embedded})} \tag{2}$$

where $\eta_{control}$ is the part efficiency level for room temperature control; $\eta_{embedded}$ is the part efficiency level for specific losses of the external components (embedded systems) and $\eta_{stratification}$ is stratification efficiency it is the part efficiency level for a vertical air temperature profile (non-uniform temperature), it is calculated by Eq. (3):

$$\eta_{stratification} = \frac{\eta_{str1} + \eta_{str2}}{2} \tag{3}$$

Stratification is influenced by:

- over-temperature (η_{str1}) that is neglected in this study, but analyzed in the discussion
- Specific heat loss via external components (η_{str2}), (e.g. additional heat loss from back-wall of radiator), simulation model consider it.

2.2. Simulation model

Analyzed detached house represents a typical recently built detached house; the building has been used as a reference building in Estonian cost optimal calculations [1]. By small changes the same house was modified to describe a multi-story apartment building. External wall in one end of the building were made adiabatic, which means that the model unit represents one apartment of a long building, Figs. 1 and 2. Similarly, the external roof was change