Energy and Buildings 125 (2016) 55–65

Contents lists available at ScienceDirect

Energy and Buildings

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

“Review of thermostatic control valves in the European standardization system of the EN 15316-2/EN 215”

J. Seifert [a,*], M. Knorr [a], A. Meinzenbach [a], F. Bitter [b], N. Gregersen [c], T. Krogh [c]

[a] TU Dresden, Institute of power engineering, chair of building energy systems and heat supply, Germany
[b] WSPLab, Institute of power engineering, chair of building energy systems and heat supply, Germany
[c] Danfoss, Institute of power engineering, chair of building energy systems and heat supply, Germany

ARTICLE INFO

Article history:
Received 6 May 2015
Received in revised form 16 March 2016
Accepted 23 April 2016
Available online 30 April 2016

Keywords:
Heat emission in rooms
Thermostatic valves
EN 15316-2
Room temperature control loop

ABSTRACT

The control quality of thermostatic valves is influenced by design parameters of the valves as well as by design parameters of the overall system. Both of these influences should also be taken into account by the energetic evaluation of thermostatic control valves.

The following article presents a closed analytical approach for calculating the room temperature control loop and the comparison of this model to measurements in a well-known test room. In a second chapter sensitivity analysis are carried out with the numerical model under steady state conditions for relevant parameters. The results of these investigations were compared to current normative specifications.

1. Introduction

Thermostatic control valves are widely used in Europe. They are the most often installed local control devices for free heating surfaces (eg. radiators). The energy rating of the mentioned system for example is described in DIN V 4701-10 [1] and DIN V 18599 [2], however in different ways. In DIN V 4701-10 expenditure factors for proportional controllers are defined, as given in Table 1. The standard DIN V 18599 defines efficiency factors. The corresponding characteristic values are given in Table 2.

It is common for both standards, that no design-specific data influence the energy assessment. The proportional range $\Delta\vartheta_{P,des} = 1K$ and respectively $\Delta\vartheta_{P,des} = 2K$, as it is used for differentiation in DIN V 4701-10, does not constitute a constructive characteristic of the sensor. Rather the design conditions of the heating system are taken into account by means of this parameter. The method described in prEN15316-2 is on the other hand based on specific construction data of the sensors (see Table 3, eg. water-temperature influence, hysteresis). The hysteresis and the water temperature are singled out as significant parameters and one has to refer to DIN EN 215 [4].

Since the calculation procedures are very different in the said standards, an investigation is necessary to detect the most important factors influencing the energetic evaluation of thermostatic room controllers. A large numbers of papers have been published on this topic in the last years (for example Xu et al. [5,6], Peeters et al. [7], Fraisse et al. [8] and Adolph et al. [9]), with the focus on dynamic numerical simulations. But dynamic numerical simulations are very complex and require a large number of input parameters. For this reason the focus of the present paper is on an analytical solution of the room temperature control loop, which needs only small number of input parameters. For this purpose a closed, analytical, stationary model is developed and used. In a second chapter a large number of parameters were investigated and based on these new equations for the normative parameter control accuracy were presented.

2. Analytical, stationary model

The numerical model consists of the model of the control circuit and the model of the controlled system, which can be found in [10] ore [11] (see Fig. 1).

The mathematical formulation for the controlled system depends on the room behavior, the radiator and the valve. Accord-

Abbreviations: CA, control accuracy; EW, external wall; IW, internal wall; P, proportional; WTI, water temperature influence.

* Corresponding autor at: Technical University of Dresden, Helmholtzstraße 14, 01062 Dresden, Germany.

E-mail addresses: joachim.seifert@tu-dresden.de (J. Seifert), martin.knorr@tu-dresden.de (M. Knorr), andrea.meinzenbach@tu-dresden.de (A. Meinzenbach), frank.bitter@wsplab.de (F. Bitter), nhg@danfoss.com (N. Gregersen), tvk@danfoss.com (T. Krogh).

http://dx.doi.org/10.1016/j.enbuild.2016.04.066
0378-7788/

List of Symbols

A	Not insulated area (m^2)
A_{ins}	Insulated area (m^2)
A_{Rad}	Heat transfer area of the radiator (m^2)
$A_{Rad,N}$	Heat transfer area of the radiator (at the design conditions) (m^2)
A_{Room}	Heat transfer area of the room (m^2)
A_{tot}	Total area of the room (m^2)
A_{TRV}	Heat transfer area of the thermostatic controller (m^2)
c_p	Specific heat capacity (kJ/(kg K))
h	Heat transfer coefficient (W/(m^2 K))
h_{tot}	Total heat transfer coefficient (W/(m^2 K))
H	Valve lift (mm)
H_{100}	Maximum valve lift (mm)
k_C	Transfer coefficient of the controller (mm/K)
k_S	Transfer coefficient of the controlled system (K/mm)
$k_{V,b}$	Flow coefficient (design conditions) (m^3/h)
k_V	Flow coefficient (m^3/h)
m	Radiator exponent
$\dot{m}$	Mass flow (heating) (kg/s)
$\dot{m}_V$	Mass flow (ventilation) (kg/s)
$\dot{m}_N$	Mass flow at design conditions (heating system) (kg/s)
$\bar{\dot{m}}$	Mass flow ratio
n	Exponent for mass flow dependence of internal heat transfer coefficient
Δp_{tot}	Pressure loss overall system (Pa)
Δp_{Valve}	Pressure drop at the valve (Pa)
q_h	Specific heat demand (kWh/m^2)
$\dot{Q}$	Heat output (W)
$\dot{Q}_i$	Internal gains (W)
R_i	Room-side thermal resistance of the sensor (K/W)
R_W	Water-side thermal resistance of the sensor (K/W)
u	Heat transmission coefficient (W/(m2 K))
V_0	Closed-loop gain
λ	Air exchange rate (h^{-1})
ϑ_e	External temperature (°C)
ϑ_i	Internal temperature (°C)
ϑ_R	Return temperature (°C)
$\vartheta_{R,des}$	Return temperature at design conditions (°C)
$\vartheta_{des,R}$	Set point temperature in the room (°C)
ϑ_{TRV}	Temperature of the sensor (°C)
ϑ_S	Supply temperature, surface temperature (°C)
$\vartheta_{S,des}$	Supply temperature at design conditions (°C)
ϑ_W	Water temperature (°C)
$\Delta\vartheta_{Hys}$	Hysteresis (K)
$\Delta\vartheta_{m,des}$	Over-temperature at design conditions (K)
$\Delta\vartheta_{des}$	Temperature difference at design conditions (K)
$\Delta\vartheta_P$	Proportional band (K)
$\Delta\vartheta_{P,des}$	Proportional band at the design conditions (K)
$\Delta\vartheta_{TRV}$	Change in sensor temperature caused by change in water temperature of 30 k (K)
Ψ_V	Valve authority

ing to the derivation in [10] ore [11] the following relationship can be written for the actuator:

$$\bar{\dot{m}} = \frac{\dot{m}}{\dot{m}_{des}} = \frac{1}{\sqrt{1 + \Psi_{V,des} \times \left[\left(\frac{k_{V,des}}{k_V} \right)^2 - 1 \right]}} \tag{1}$$

Table 1
Expenditure factors for heat emission in the room according to DIN V 4701-10 [1].[6]

	q_h in kWh/m^2					
	40	50	60	70	80	90
P-controller-2 K (EW)	1.08	1.07	1.06	1.05	1.04	1.04
P-controller-1 K (EW)	1.03	1.02	1.02	1.02	1.01	1.01
P–controller-2 K (IW)	1.11	1.09	1.08	1.07	1.05	1.05
P–controller-1 K (IW)	1.06	1.04	1.04	1.04	1.02	1.02

Table 2
Efficiency factors for heat emission with free heating surfaces (radiator) ceiling height ≤ 4 m according to DIN V 18599 [2].

	efficiency factors
unregulated, with central supply temperature regulation	0.80
Master room space or one-pipe heating	0.88
P-controller (before 1988)	0.88
P-controller	0.95

Table 3
Temperature fluctuation caused by control for thermostatic controllers according to EN 15316-2 [3].

Off	Nominal load
0.45 × hysteresis	0.45 × (hysteresis + water temperature influence)

The derivation of the behavior of the radiator is also given in [10]. For the relative heating load ϕ, the following expression can be written:

$$\phi = \frac{\dot{Q}}{\dot{Q}_{des}} = \bar{\dot{m}} \times \frac{(\vartheta_S - \vartheta_i)}{(\vartheta_S - \vartheta_i)_{des}} \times \frac{1 - e^{-\frac{\phi^{\frac{m}{1+m}} \times \Delta\vartheta_{des}}{\bar{\dot{m}}^{\frac{1+m-n}{1+m}} \times \left(\frac{A_{Rad,des}}{A_{Rad}}\right)^{\frac{1}{1+m}} \times \Delta\vartheta_{m,des}}}}{1 - e^{-\frac{\Delta\vartheta_{des}}{\Delta\vartheta_{m,des}}}} \tag{2}$$

For the stationary transmission behavior of the room a thermal balance gives the following Eq. (3).

$$\phi = \frac{\dot{Q}}{\dot{Q}_{des}} = \frac{u_{Room} \times A_{Room} \times (\vartheta_i - \vartheta_e) + \dot{m}_V \times c_p \times (\vartheta_i - \vartheta_e) - \dot{Q}_i}{u_{Room} \times A_{Room} \times (\vartheta_i - \vartheta_e)_{des} + \dot{m}_V \times c_p \times (\vartheta_i - \vartheta_e)_{des}}$$
$$= \frac{(\vartheta_i - \vartheta_e) - \frac{\dot{Q}_i}{u_{Room} \times A_{Room} + \dot{m}_V \times c_p}}{(\vartheta_i - \vartheta_e)_{des}} \tag{3}$$

Using Eq. (3) in Eq. (2) and solving for ϑ_i Eq. (4) can by written.

$$\frac{(\vartheta_i - \vartheta_e) - \frac{\dot{Q}_i}{u_{Room} \times A_{Room} + \dot{m}_V \times c_p}}{(\vartheta_i - \vartheta_e)_{des}} = \bar{\dot{m}} \times \frac{(\vartheta_S - \vartheta_i)}{(\vartheta_S - \vartheta_i)_{des}}$$
$$\times \frac{1 - e^{-\frac{\Delta\vartheta_{des}}{\bar{\dot{m}}^{\frac{1+m-n}{1+m}} \times \left(\frac{A_{Rad,des}}{A_{Rad}}\right)^{\frac{1}{1+m}} \times \Delta\vartheta_{m,des}} \times \left(\frac{(\vartheta_i - \vartheta_e) - \frac{\dot{Q}_i}{u_{Room} \times A_{Room} + \dot{m}_V \times c_p}}{(\vartheta_S - \vartheta_i)_{des}} \right)^{\frac{m}{1+m}}}}{1 - e^{-\frac{\Delta\vartheta_{des}}{\Delta\vartheta_{m,des}}}} \tag{4}$$

Rearranging by ϑ_i one obtains:

$$\vartheta_i = \vartheta_e + \frac{\dot{Q}_i}{u_{Room} \times A_{Room} + \dot{m}_V \times c_p} + \bar{\dot{m}} \times \frac{(\vartheta_S - \vartheta_i) \times (\vartheta_i - \vartheta_e)_{des}}{(\vartheta_S - \vartheta_i)_{des}}$$

[6] Tables 1 and 2 show efficiency factors. These factors can be transferred in temperature differences. 1 K temperature difference result in 6% ... 10% energy difference depending on the insulation of the buidling.