DIRECT ACTING ELECTRIC HEATING – TESTING OF CONTROL SYSTEMS
PART 3: EVALUATION USING REAL-TIME SIMULATION

Key words: Electric heating, control system, real-time simulation, test method

The general background and terminology are described in NT Method NT VVS 123, Part 1: “Direct-acting electric heating – Testing of control systems – Terminology and evaluation in a test chamber”. Real-time simulation is necessary for the evaluation of multi-zone systems. It can, however, also be used as an alternative or complement to the climate chamber tests described in Part 1. The full Nordtest method comprises a combination of laboratory tests and computer simulation,


NT Method NT VVS 125, Part 3: “Direct-acting electric heating – Testing of control systems – Evaluation using real-time simulation” (i.e. this part).

1 SCOPE AND FIELD OF APPLICATION

The test method is designed for evaluation of electric-heat controllers (see Part 1) by means of real-time simulation. Real-time simulation, also known as emulation, can be used for single-zone or multi-zone controllers. For single-zone evaluation it is an alternative or complement to the test chamber evaluation described in Part 1. The present part, i.e. Part 3, deals with real-time simulation and comprises:

– control accuracy at constant load,
– performance during a change in the outdoor temperature,
– performance during a step change in the set value for the room temperature,
– performance during a step change in an internal load,
– airing function (operation with an opened window),
– performance during opening/closing of interior doors (multi-zone systems),
– water heating,
– load control.
The purpose is to evaluate not only the input/output characteristics of the controller but the total function of the combination sensor-controller-heater-building. The method includes evaluation of efficiency, comfort and various supplementary control functions. The single-zone building is a model of the test chamber in Part 1 and the multi-zone building is a combination of single-zone models. The method is, however, not intended for evaluation of systems using room sensors integrated in the heaters.

2 REFERENCES
NT Method NT VVS 123 contains a comprehensive list of references. The list below only provides references actually used in this part of the test method.


3 DEFINITIONS
NT Method NT VVS 123 (Ref. 2.1) contains a list of definitions within the field of electric heating and associated controllers and NT Method NT VVS 124 (Ref. 2.2) includes some sensor-specific definitions not given in Part 1. This part provides definitions unique to evaluation by real-time simulation.

3.1 Real-time simulation (emulation)
Method of evaluating technical systems or components where a computer models the operating environment of the real test object and the test object operates in this modelled environment in response to modelled events.

4 DESIGNATIONS
NT Method NT VVS 123 contains a list of symbols within the field of electric heating and the associated controllers and NT Method NT VVS 124 adds some symbols pertaining to evaluation of sensors. Additions specific to this part are:

4.1 Symbols for physical quantities

<table>
<thead>
<tr>
<th>Latin letters</th>
<th>Greek letters</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>coefficient of heat transfer; convection (W/K/m²)</td>
</tr>
<tr>
<td>c</td>
<td>specific thermal capacity of model element (J/K/m²)</td>
</tr>
<tr>
<td>C</td>
<td>specific thermal capacity of total component (J/K/m²)</td>
</tr>
<tr>
<td>r</td>
<td>specific thermal resistance of model element (K/W/m²)</td>
</tr>
<tr>
<td>R</td>
<td>specific thermal resistance of total component (K/W/m²)</td>
</tr>
</tbody>
</table>

4.2 Subscripts

<table>
<thead>
<tr>
<th>Latin</th>
<th>Greek</th>
</tr>
</thead>
<tbody>
<tr>
<td>AE</td>
<td>α</td>
</tr>
<tr>
<td>door</td>
<td>γ</td>
</tr>
<tr>
<td>g</td>
<td></td>
</tr>
<tr>
<td>l</td>
<td></td>
</tr>
</tbody>
</table>

5 GENERICS
NT Method NT VVS 123 and NT Method NT VVS 124 provide generic information on sampling and documentation of test objects.

6 PRINCIPLES OF TEST METHOD
A comprehensive laboratory test of an electric-heat controller comprises control characteristics, comfort, energy efficiency, noise and electrical characteristics. The principle of method of test by means of real-time simulation resembles the test chamber method of NT VVS 123 with a virtual test chamber modelled in a computer. For the purpose of this method, control sensors must first be evaluated according to NT VVS 124.

6.1 Control characteristics
Control characteristics are tested according to 6.1.1–6.1.6.

6.1.1 Settings
According to NT VVS 123, 6.1.1.

6.1.2 Room temperature control
According to NT VVS 123, 6.1.2. Multi-zone testing also includes opening and closing of doors between rooms.

6.1.3 Supplementary control functions
According to NT VVS 123, 6.1.3.

6.1.4 Interruption of power supply
According to NT VVS 123, 6.1.4.
6.1.5 Comfort
According to NT VVS 123, 6.1.5.

6.1.6 Power and efficiency
According to NT VVS 123, 6.1.6.

6.2 Sound emission
According to NT VVS 123, 6.2.

6.3 Electrical characteristics
According to NT VVS 123, 6.3.

7 TEST EQUIPMENT
Test equipment shall be designed so that all requirements in this method can be fulfilled, e.g. concerning set values, stability and uncertainty of measurement. Section 10 provides requirements concerning measuring uncertainties. Measuring equipment shall be calibrated with traceability to national or international standards.

Figure 7.1 illustrates the principle of the test equipment for evaluation of control characteristics by means of real-time simulation. The test equipment consists of:

- A computer (e.g. a Personal Computer) to control the test procedure and store relevant data, and to model the building and its activities,
- An interface for communication between the test object, the computer and the sensor climate boxes, including measurement of the controller output,
- Cooling and air handling equipment to provide cold air to the sensor boxes,
- Controllers for implementing computed sensor temperatures in the sensor boxes.

The personal computer (PC) contains a model of the test chamber/building, its ambient outdoor climate and the activities inside (internal loads, airing etc.). The effective temperature at the room thermostat position is calculated in the model and this temperature, with a time delay corresponding to the tested time constant of the sensor, is realized in a small climatic box where the real sensor is installed. The tested controller acts in response to the sensed temperature and controls the power input to the electric room heaters. For systems with outdoor temperature control, the modelled outdoor temperature is also realized in a small climatic box.

7.1 Single-zone testing
Single-zone testing corresponds to the test chamber method of NT VVS 123. The simulation program models a room according to Figure 7.2 (Appendices 1–5 provide design data). The room model shall incorporate heat exchange by means of:

- Controlled ventilation (1.0 ACH),
- Airing (opening of windows),
- Conduction through interior walls, ceiling and floor (t\text{room} to t\text{amb} = +20 °C),
- Conduction through the exterior wall and window (t\text{room} to t\text{out}),
- Radiation between all interior surfaces,
- Heat input through the heater and internal loads,
- Heat storage in interior decoration, walls, ceiling, floor, window and room heater.

The room model shall include an electric convector heater which can be operated by the electric-heat controller. With a rated power of 1250 W, the electric convector heater gives an energy ratio of around 0.8 at the design temperature conditions of the room (t\text{out} = –20 °C, t\text{room} = +20 °C). The room model shall also include an internal heat load. Further details may be found in Appendix 1–7.

The test setup shall have access to a stabilized voltage of 230/400 V for the supply of the electric-heat controller.

![Figure 7.1. Principle of method of evaluation by means of real-time simulation.](image1)

![Figure 7.2. Modelled room for single-zone evaluation of control functions (side view).](image2)
The heating requirement of the room is characterized by three loss factors:
- heat loss, room ⇒ outdoor,
  \[ P_{1\text{room}} = L_1 \cdot (t_{\text{room}} - t_{\text{out}}) \]
- heat loss, room ⇒ other surroundings,
  \[ P_{2\text{room}} = L_2 \cdot (t_{\text{room}} - t_{\text{amb}}) \]
- heat loss, due to ventilation,
  \[ P_{\text{vent}} = L_{\text{vent}} \cdot (t_{\text{room}} - t_{\text{out}}) \]

The loss factors \( L_1 \), \( L_2 \) and \( L_{\text{vent}} \) are derived in the respective appendices and then the design power input at steady state will be:
\[ P_{e,\text{des}} = (L_1 + L_{\text{vent}}) \cdot (t_{\text{room}} - t_{\text{out}}) + L_2 \cdot (t_{\text{room}} - t_{\text{amb}}) \]
\[ P_{e,\text{des}} = (1 + 0.5) \cdot (20 - (–20)) + 1 \cdot (20 - 20) = 1.0 \text{ kW}. \]

7.2 Multi-zone testing

Multi-zone testing cannot normally be carried out in full-scale test chambers since it would involve a number of expensive climate chambers. In this test method, multi-zone testing is accomplished by creating a model building as a combination of single-zone models connected by a hall according to Figure 7.3.

The room model shall include in each room an electric convector heater which can be operated by the electric-heat controller. With an energy ratio of approximately 0.7 to 0.8 at the design temperature conditions of the room (\( t_{\text{out}} = –20 ^\circ\text{C}, t_{\text{room}} = +20 ^\circ\text{C} \)), the rated power inputs can be set to 1250 W for heaters 1 and 2, 1000 W for heaters 3 and 4 and 200 W for heater 5. This gives an overall design energy ratio of 0.74. The room model shall also include internal heat loads. Further details may be found in Appendix 1–7.

The test setup shall have access to a stabilized voltage of 230/400 V for the supply of the electric-heat controller. Ventilation rates in the respective rooms are:
- Room 1 and 2: \( q_{\text{vent}} = 1.0 \text{ ACH} \),
- Room 3 and 4: \( q_{\text{vent}} = 0.5 \text{ ACH} \),
- Room 5: \( q_{\text{vent}} = 0 \text{ ACH} \).

In addition to the single-zone heat exchanges, the multi-zone model must incorporate heat exchange by:
- Ventilation and heat storage of the hall,
- Air flows through open interior doors,
- Conduction through interior partition walls (\( t_{\text{room},i} \) to \( t_{\text{room},j} \)).

The heating requirement of the room is characterized by loss factors:
- heat loss, room ⇒ outdoor,
  \[ P_{1\text{room},i} = L_{1i} \cdot (t_{\text{room},i} - t_{\text{out},k}) \]
- heat loss, room ⇒ other surroundings,
  \[ P_{2\text{room},i} = L_{2i} \cdot (t_{\text{room},i} - t_{\text{amb}}) \]
- heat loss, due to ventilation,
  \[ P_{\text{vent},i} = L_{\text{vent},i} \cdot (t_{\text{room},i} - t_{\text{out},k}) \]

The loss factors are derived in the respective appendices and then the design power input at steady state will be:
\[ P_{e,\text{des}} = \sum_{i=1}^{5} ((L_{1i} + L_{\text{vent},i}) \cdot (t_{\text{room},i} - t_{\text{out},k}) + L_{2i} \cdot (t_{\text{room},i} - t_{\text{amb}})) \]
\[ P_{e,\text{des}} = 3.5 \text{ kW}. \]

8 PREPARATION OF TEST SAMPLES

According to NT VVS 123 and 124 (Chapter 8). Connect the outputs from the electric-heat controller to the computer interface. Install the control sensors in their respective climate boxes, connect them to the electric-heat controller and connect the controller to the electric mains.

Synchronize the clocks of the tested controller and the computer model and program the temperature set-back according to the test sequence of Chapter 9 into the electric-heat controller. Enter data for the control sensors, obtained from testing according to NT VVS 124, into the computer model. Make a functional check of the test object.

Controllers with self-tuning or adaptive functions shall run through the full test procedure of section 9.1 or section 9.2 at least once before the actual test is carried out. This provides a learning period of at least 72 h which should be adequate for systems not using seasonal learning periods.

9 TEST PROCEDURE AND EXPRESSION OF RESULTS

The general test procedure resembles that of NT VVS 123 in a test chamber. However, tests according to this part can be performed for both single-zone and multi-zone systems. Furthermore, test chamber results may be used to verify the single-zone test made by real-time simulation according to this part of the Nordtest method.

9.1 Single-zone testing

The single-zone test sequence corresponds to that of NT VVS 123 in a test chamber (see Table 9.1 and Figure 9.1).
9.1.1 Settings
According to NT VVS 123, 9.1.

9.1.2 Room temperature control
According to NT VVS 123, 9.2.

<table>
<thead>
<tr>
<th>Designation</th>
<th>Time (h)</th>
<th>Event</th>
<th>Time-interval (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>–</td>
<td>Stabilization period 24</td>
</tr>
<tr>
<td>t_0</td>
<td>0</td>
<td>Constant conditions ((t_{\text{ref}} = +20 , ^\circ\text{C}, \ t_{\text{out}} = -5 , ^\circ\text{C}, \ P_{\text{int}} = 0 , \text{W})) 8</td>
<td></td>
</tr>
<tr>
<td>t_1</td>
<td>8</td>
<td>Ramp increase in the outdoor temperature (5 K/h) 2</td>
<td></td>
</tr>
<tr>
<td>t_2</td>
<td>10</td>
<td>New constant outdoor temperature ((t_{\text{out}} = +5 , ^\circ\text{C})) 5</td>
<td></td>
</tr>
<tr>
<td>t_3</td>
<td>15</td>
<td>Ramp decrease in the outdoor temperature (–5 K/h) 2</td>
<td></td>
</tr>
<tr>
<td>t_4</td>
<td>17</td>
<td>Original constant outdoor temperature ((t_{\text{out}} = -5 , ^\circ\text{C})) 9</td>
<td></td>
</tr>
<tr>
<td>t_5</td>
<td>26</td>
<td>New reference value for the room temperature ((t_{\text{ref}} = +18 , ^\circ\text{C})) 8</td>
<td></td>
</tr>
<tr>
<td>t_6</td>
<td>34</td>
<td>Original reference value for the room temperature ((t_{\text{ref}} = +20 , ^\circ\text{C})) 16</td>
<td></td>
</tr>
<tr>
<td>t_7</td>
<td>50</td>
<td>Internal heat load ((P_{\text{int}} = 0.9P_{\text{room}} = 560 , \text{W})) 5</td>
<td></td>
</tr>
<tr>
<td>t_8</td>
<td>55</td>
<td>Original internal heat load ((P_{\text{int}} = 0 , \text{W})) 17</td>
<td></td>
</tr>
<tr>
<td>t_9</td>
<td>72</td>
<td>Airing (opening of the window) 0.25</td>
<td></td>
</tr>
<tr>
<td>t_{10}</td>
<td>72.25</td>
<td>Original conditions (closed window) 1.75</td>
<td></td>
</tr>
<tr>
<td>t_{11}</td>
<td>74</td>
<td>Interruption of the power supply ((t_{\text{out}} = -5 , ^\circ\text{C})) 0.25</td>
<td></td>
</tr>
<tr>
<td>t_{12}</td>
<td>74.25</td>
<td>Original conditions (connected power supply) 2.75</td>
<td></td>
</tr>
<tr>
<td>t_{13}</td>
<td>77</td>
<td>Termination of the test</td>
<td></td>
</tr>
</tbody>
</table>

**Measurements**

The following quantities shall be measured and reported (also see Chapter 11):

**Temperature**: – air temperatures in the climatic boxes,
**Power/energy**: – electric-heat controller: internal use,

– relative on-time for each zone (outputs from the controller),

**Time**: – test duration and clock times for events.

**Computations**

The following quantities shall be computed and reported (also see Chapter 11):

**Test object**: – reference/set value for the room temperature, \(t_{\text{room,ref}} / t_{\text{room,set}}\)

Air flow: – exhaust air flow rate in the ventilation duct, \(q_{\text{EA}}\),

– air flow to room, \(q_{\text{SA}}\),

– air flow through window, \(q_{\text{win}}\)

Temperature: – incoming supply air, \(t_{\text{SA}} = t_{\text{out}}\),

– outgoing exhaust air, \(t_{\text{EA}}\),

– radiation shielded air temperature at the room sensor, \(t_{\text{roomA}}\),

– radiation shielded air temperatures in the room, \(t_{\text{A1room}} - t_{\text{A3room}}\),

– operative temperature in the middle of the room, \(t_{\text{op}}\),

– temperatures on the inside of walls, ceiling, floor, \(t_{\text{surf}} - t_{\text{surf}}\),

– temperatures on the outside of walls, roof, floor, \(t_{\text{sur}} - t_{\text{sur}}\),

– temperatures on the window and convector/radiator,
Power/energy: – room heater (convector/ radiator heater), \( P_{\text{erad}} \)
  – internal load, \( P_{\text{int}} \)
  – thermal transmission (walls, ceilings, floors, windows),
  – ventilation, \( P_{\text{vent}} \) \( P_{\text{venttot}} \)
  – air change through window,

Time: – test duration and clock times for events.

Reporting:
Reporting is to be in a descriptive form as well as by means of diagrams of the temporal variations during the period 0 h to 74 h of:

– temperatures on window (\( t_{\text{win}} \)), heater (\( t_{\text{erad}} \)), in room (\( t_{\text{room}} \)) and outdoors (\( t_{\text{out}} \)),
– other surface temperatures (\( t_{\text{surf}} \)),
– air temperatures (\( t_{\text{A1}}, t_{\text{A2}}, t_{\text{A3}} \)), operative temperature (\( t_{\text{op}} \)) and temperature at the control sensor (\( t_{\text{s}} \)),
– system (control) deviation (\( q_{\text{cdev}} = t_{\text{set}} - t_{\text{room}} \)) and deviation between the temperature at the control sensor and the temperature in the room (\( q_{\text{scdev}} = t_{\text{s}} - t_{\text{room}} \)),
– electric power input to the heater/radiator (\( P_{\text{erad}} \)) and the internal heat load (\( P_{\text{int}} \)).

Furthermore, a number of quantities are derived according to NT VVS 123 9.2.1–9.2.5.

9.1.3 Supplementary control functions
According to NT VVS 123, 9.3.

9.1.4 Interruption of power supply
According to NT VVS 123, 9.4.

9.1.5 Comfort
According to NT VVS 123, 9.5.

9.1.6 Power input and efficiency
According to NT VVS 123, 9.6.

9.2 Multi-zone testing
The multi-zone test sequence resembles that of the single-zone one in 9.1 but is modified to include 5 rooms (i.e. up to 5 zones) according to Figure 7.3. Table 9.2 and Figure 9.2 illustrate the test sequence.

9.2.1 Settings
According to NT VVS 123, 9.1.

9.2.2 Room temperature control
According to NT VVS 123, 9.2.

In this test procedure, the outdoor temperature will at times be different (\( t_{\text{out1}} \) and \( t_{\text{out2}} \)) on the different sides of the building to simulate the effect of insolation.

Table 9.2. Sequence of events during evaluation of the control function (multi-zone).

<table>
<thead>
<tr>
<th>Designation</th>
<th>Time (h)</th>
<th>Event</th>
<th>Time-interval (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>–</td>
<td>–</td>
<td>Stabilization period, all doors and windows closed</td>
<td>24</td>
</tr>
<tr>
<td>( t_0 )</td>
<td>0</td>
<td>Constant conditions (( t_{\text{ref1}} = +20 ^\circ \text{C} ), ( t_{\text{out1}} = -5 ^\circ \text{C} ), ( P_{\text{int}} = 0 \text{ W} ))</td>
<td>8</td>
</tr>
<tr>
<td>( t_{11} )</td>
<td>3</td>
<td>Ramp increase in the outdoor temperature (( t_{\text{out1}} = 5 ^\circ \text{C} ))</td>
<td>2</td>
</tr>
<tr>
<td>( t_{21} )</td>
<td>5</td>
<td>New constant outdoor temperature (( t_{\text{out1}} = +5 ^\circ \text{C} ))</td>
<td>5</td>
</tr>
<tr>
<td>( t_{31} )</td>
<td>10</td>
<td>Ramp decrease in the outdoor temperature (( t_{\text{out1}} = -5 ^\circ \text{C} ))</td>
<td>2</td>
</tr>
<tr>
<td>( t_{41} )</td>
<td>12</td>
<td>Original constant outdoor temperature (( t_{\text{out1}} = t_{\text{out2}} = -5 ^\circ \text{C} ))</td>
<td>9</td>
</tr>
<tr>
<td>( t_{12} )</td>
<td>13</td>
<td>Ramp increase in the outdoor temperature (( t_{\text{out2}} = -5 ^\circ \text{C} ))</td>
<td>2</td>
</tr>
<tr>
<td>( t_{22} )</td>
<td>15</td>
<td>New constant outdoor temperature (( t_{\text{out2}} = +5 ^\circ \text{C} ))</td>
<td>5</td>
</tr>
<tr>
<td>( t_{32} )</td>
<td>20</td>
<td>Ramp decrease in the outdoor temperature (( -5 ^\circ \text{K/h} ))</td>
<td>2</td>
</tr>
<tr>
<td>( t_{42} )</td>
<td>22</td>
<td>Original constant outdoor temperature (( t_{\text{out2}} = t_{\text{out1}} = -5 ^\circ \text{C} ))</td>
<td>9</td>
</tr>
<tr>
<td>( t_{51} )</td>
<td>25</td>
<td>New temperature reference value for room 1 (( t_{\text{ref1}} = +18 ^\circ \text{C} ))</td>
<td>8</td>
</tr>
<tr>
<td>( t_{52} )</td>
<td>27</td>
<td>New temperature reference value for room 2 (( t_{\text{ref2}} = +18 ^\circ \text{C} ))</td>
<td>7</td>
</tr>
<tr>
<td>( t_{53} )</td>
<td>28</td>
<td>New temperature reference value for room 3 (( t_{\text{ref3}} = +18 ^\circ \text{C} ))</td>
<td>6</td>
</tr>
<tr>
<td>( t_{54} )</td>
<td>29</td>
<td>New temperature reference value for room 4 (( t_{\text{ref4}} = +18 ^\circ \text{C} ))</td>
<td>5</td>
</tr>
<tr>
<td>( t_{55} )</td>
<td>30</td>
<td>New temperature reference value for room 5 (( t_{\text{ref5}} = +18 ^\circ \text{C} ))</td>
<td>4</td>
</tr>
<tr>
<td>( t_{6} )</td>
<td>34</td>
<td>Original reference value for the room temperature (( t_{\text{ref}} = +20 ^\circ \text{C} ))</td>
<td>16</td>
</tr>
<tr>
<td>( t_{7} )</td>
<td>50</td>
<td>Opening of all doors</td>
<td>5</td>
</tr>
<tr>
<td>( t_{71} )</td>
<td>50</td>
<td>Internal heat load in room 1 (( P_{\text{int}} = 0.9P_{\text{room}} = 560 \text{ W} ))</td>
<td>5</td>
</tr>
<tr>
<td>( t_{72} )</td>
<td>51</td>
<td>Internal heat load in room 2 (( P_{\text{int}} = 0.9P_{\text{room}} = 560 \text{ W} ))</td>
<td>4</td>
</tr>
<tr>
<td>( t_{73} )</td>
<td>52</td>
<td>Internal heat load in room 3 (( P_{\text{int}} = 0.9P_{\text{room}} = 430 \text{ W} ))</td>
<td>3</td>
</tr>
<tr>
<td>( t_{74} )</td>
<td>53</td>
<td>Internal heat load in room 4 (( P_{\text{int}} = 0.9P_{\text{room}} = 430 \text{ W} ))</td>
<td>2</td>
</tr>
<tr>
<td>( t_{8} )</td>
<td>55</td>
<td>Original internal heat load (( P_{\text{int}} = 0 \text{ W} ))</td>
<td>17</td>
</tr>
<tr>
<td>( t_{9} )</td>
<td>72</td>
<td>Airing: Closing of door 1 and opening of window 1</td>
<td>0.25</td>
</tr>
<tr>
<td>( t_{10} )</td>
<td>72.25</td>
<td>Original conditions (closed window and open door)</td>
<td>1.75</td>
</tr>
<tr>
<td>( t_{11} )</td>
<td>74</td>
<td>Interruption of the power supply (( t_{\text{out1}} = -5 ^\circ \text{C} ))</td>
<td>0.25</td>
</tr>
<tr>
<td>( t_{12} )</td>
<td>74.25</td>
<td>Original conditions (connected power supply)</td>
<td>2.75</td>
</tr>
<tr>
<td>( t_{13} )</td>
<td>77</td>
<td>Termination of the test</td>
<td></td>
</tr>
</tbody>
</table>
Measurements

The following quantities shall be measured and reported (also see Chapter 11):

Temperature: – air temperatures in the climatic boxes, $t_{\text{room}}$

Power/energy: – electric-heat controller: internal use, $P_{\text{int}}$

Time: – test duration and clock times for events

Computations

The following quantities shall be computed and reported (also see Chapter 11):

Test object: – reference/set values for room temperatures, $t_{\text{room,ref}} / t_{\text{room,set}}$

Air flow: – exhaust air flow rate in the ventilation duct, $q_{\text{EA}}$

Temperature: – incoming supply air, $t_{\text{SAj}} = t_{\text{out,i}}$

– outgoing exhaust air, $t_{\text{EA}}$

– radiation shielded air temperature at room sensor $i$, $t_{\text{roomA,i}}$

– radiation shielded air temperatures in room $i$, $t_{\text{A1room,i}} - t_{\text{A3room,i}}$

– operative temperature in the middle of room $i$, $t_{\text{op,i}}$

– temperatures on the inside of walls, ceiling, floor, $t_{\text{sur,i}} = t_{\text{sur,i}}$

– temperatures on the outside of walls, roof, floor, $t_{\text{amb,j}} = t_{\text{amb,j}}$

– temperatures on the windows and heaters,

Power/energy: – room heater (convector/radiator heater), $P_{\text{erad}}$

– internal loads, $P_{\text{int}}$

– thermal transmission (walls, ceilings, floors, windows),

– ventilation, $P_{\text{vent}}$

– air change through windows and doors, $P_{\text{AEwin,i}}$ and $P_{\text{AEEd,i}}$

Time:

Reporting:

Reporting is to be in a descriptive form as well as by means of diagrams of the temporal variations during the period 0 h to 74 h of:

– temperatures on windows ($t_{\text{win,i}}$), convectors/radiators ($t_{\text{rad,i}}$), in rooms ($t_{\text{room,i}}$) and outdoors ($t_{\text{out1}}$ and $t_{\text{out2}}$) in all rooms $i$,

– other surface temperatures ($t_{\text{sur,i}}$) in all rooms $i$,

– air temperatures ($t_{\text{A1,i}}, t_{\text{A2,i}}, t_{\text{A3,i}}$), operative temperatures ($t_{\text{op,i}}$) and temperatures at the control sensors ($t_{s,i}$) in all rooms $i$,

– system (control) deviations ($q_{\text{cdev,i}} = t_{\text{set,i}} - t_{\text{room,i}}$) and deviation between the temperature at the control sensor and the temperature in the room ($q_{\text{scdev,i}} = t_{s,i} - t_{\text{room,i}}$) in all rooms $i$,

– electric power input to convectors/radiators ($P_{\text{erad,i}}$) and the internal heat loads ($P_{\text{int,i}}$) in all rooms $i$.

Furthermore, a number of quantities are derived according to NT VVS 123 9.2.1–9.2.5.

9.2.3 Supplementary control functions

According to NT VVS 123, 9.3.

9.2.4 Interruption of power supply

According to NT VVS 123, 9.4.
9.2.5 Comfort
According to NT VVS 123, 9.5.

9.2.6 Power input and efficiency
According to NT VVS 123, 9.6.

10 MEASURING UNCERTAINTIES AND STABILITY

In the real-time simulation, the only measurands are the emulated temperatures in the climate boxes for indoor and outdoor control sensors, the elapsed times and the clock times.

10.1 Measuring uncertainties

Measuring uncertainties shall be derived in accordance with EAL-R2 (Ref. 2.3). Uncertainties shall not exceed the values of Table 10.1.

Table 10.1. Maximum permissible measuring uncertainties.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Instrumental uncertainty</th>
<th>Measuring uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>– air temperature (at the room sensor)</td>
<td>±0.05 K</td>
<td>±0.2 K</td>
</tr>
<tr>
<td>– air temperature (at the outdoor sensor)</td>
<td>±0.3 K</td>
<td>±0.5 K</td>
</tr>
<tr>
<td>Time:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Clock time</td>
<td>±10 s</td>
<td>±1 min</td>
</tr>
<tr>
<td>– Elapsed time, time interval</td>
<td>±1 s</td>
<td>±3 s</td>
</tr>
</tbody>
</table>

In Table 10.1 the instrumental uncertainty comprises uncertainties due to calibration, resolution of the indicator etc. Measuring uncertainty, in addition to instrumental uncertainties, also covers methodical uncertainties such as conditions of installation, stability etc. Values refer to the expanded (global) uncertainty, $U_j = k \cdot u_j$ with the coverage factor $k = 2$.

The global uncertainty is the quantified uncertainty that shall be stated in the report for each relevant measured or calculated variable.

10.2 Stability and control deviation

Table 10.2 provides the criteria for stability and the permissible deviations between set values and measured values during testing. In Table 10.2, the right-hand column gives the permissible deviation from set values instead of the deviation from mean values which is used in Parts 1 and 2. The reason is that in the emulation of computed sensor temperatures, it is quite important to be close to the set values.

Table 10.2. Stability and permissible maximum deviations.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Set value $^*$</th>
<th>Deviation between mean value and set value $^**$</th>
<th>Deviation of single values from the set value $^***$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– air temperature (at the room sensor)</td>
<td>*</td>
<td>±0.1 (±0.3) K</td>
<td>±0.5 K</td>
</tr>
<tr>
<td>– air temperature (at the outdoor sensor)</td>
<td>**</td>
<td>±0.1 (±0.3) K</td>
<td>±1.0 K</td>
</tr>
<tr>
<td>Time:</td>
<td>****</td>
<td>–</td>
<td>±1 min</td>
</tr>
</tbody>
</table>

$^*$ The set value is the computed value from the model.

$^**$ Refers to the mean value of the test period. The value within parentheses refers to 5 minute intervals.

$^***$ Not applicable during airing (opening of windows).

$^****$ This includes synchronization of the clocks in the computer and the tested controller.

11 TEST REPORT

The test report shall include the following information whenever it is relevant for a specific test:

a) Name and address of the testing organization
b) Identification number of the test report
c) Name and address of the organization or person who ordered the test
d) Purpose of the test
e) Reference to the test method and any deviations from this method
f) Method of sampling and other circumstances (e.g. date and person responsible for the sampling)
g) Date of arrival of the test object and its condition on arrival
h) Date of the test
i) Name of manufacturer, type designation and serial number of the test object
j) Conformity with accompanying documents (Section 8)
k) Description of the test object stating specific functions
l) Description and explanation of the specific functions
m) Installation of the test object
n) Conditioning of the test object (e.g. settings, adjustments, test runs)
o) Test results (tables and diagrams) from:

– determinations of air flow (Sections 9.1 and 9.2)
– determinations of temperature (Sections 9.1 and 9.2)
– determinations of power and energy (Sections 9.1 and 9.2),
p) Measuring uncertainties, stability and control deviation (Section 10)
q) Identification of testing equipment and measuring instruments
r) Date and signature of the test report.
APPENDIX 1. ROOM MODELS

The room layout derives from a test chamber according to IEC 675 (described in Ref. 2.1). For details regarding component models, see Appendix 2 and 3.

A1.1 SINGLE-ZONE MODEL

Figure A1.1 gives the layout of the single-zone model. All walls are considered as exterior walls.

Figure A1.1. Layout of single-zone model (side view and top view respectively).

Table A1.1 provides design data for the single-zone model.
Table A1.1. Design data for the single-zone model (power: heating at –20 °C).

<table>
<thead>
<tr>
<th>Building Element</th>
<th>H (m)</th>
<th>W (m)</th>
<th>A (m²)</th>
<th>U (W/m²K)</th>
<th>L (W/K)</th>
<th>R (K/m²W)</th>
<th>C (kJ/m²)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall 1.1 (window)</td>
<td>1.5</td>
<td>3.0</td>
<td>4.5</td>
<td>2.5</td>
<td>11.3</td>
<td>0.4</td>
<td>9.0</td>
<td>450</td>
</tr>
<tr>
<td>Wall 1.2 (under the window)</td>
<td>0.8</td>
<td>3.5</td>
<td>2.8</td>
<td>0.4</td>
<td>1.1</td>
<td>2.5</td>
<td>23.5</td>
<td>45</td>
</tr>
<tr>
<td>Wall 1.3 (top-window)</td>
<td>1.7</td>
<td>3.5</td>
<td>1.5</td>
<td>0.4</td>
<td>0.8</td>
<td>2.5</td>
<td>23.5</td>
<td>23</td>
</tr>
<tr>
<td>Wall 1 (wall incl. window)</td>
<td>2.5</td>
<td>3.5</td>
<td>8.8</td>
<td>1.5</td>
<td>13.0</td>
<td>-</td>
<td>-</td>
<td>518</td>
</tr>
<tr>
<td>Wall 2 (Floor)</td>
<td>4.0</td>
<td>3.5</td>
<td>14.0</td>
<td>0.4</td>
<td>2.5</td>
<td>23.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Wall 3 (Ceiling)</td>
<td>4.0</td>
<td>3.5</td>
<td>14.0</td>
<td>0.4</td>
<td>2.5</td>
<td>23.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Wall 4 (Rear wall)</td>
<td>2.5</td>
<td>4.0</td>
<td>10.0</td>
<td>0.5</td>
<td>2.0</td>
<td>20.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Wall 5 (Front wall)</td>
<td>2.5</td>
<td>4.0</td>
<td>10.0</td>
<td>0.5</td>
<td>2.0</td>
<td>20.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Wall 6 (Gable)</td>
<td>2.5</td>
<td>3.5</td>
<td>8.8</td>
<td>0.5</td>
<td>2.0</td>
<td>20.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Transmission (in/outdoor)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13.0</td>
<td></td>
<td></td>
<td>518</td>
</tr>
<tr>
<td>Ventilation (in/outdoor)</td>
<td>Vol. = 35.0 m³</td>
<td>ACH = 1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>465</td>
</tr>
</tbody>
</table>

Heater position: Symmetrically positioned under the window.

Window position: > 0.8 m above floor, symmetrically positioned on the wall.

Ventilation: \( q_{EA} \approx 1.0 \text{ACH/h} (~0.70 \text{dm}^3/\text{s/m}^2) \).

Thermal insulation: See table.

A1.2 MULTI-ZONE MODEL

Figure A1.2 gives the layout of the multi-zone model. Walls towards the outdoors and surroundings as well as ceilings and floors are considered as exterior walls and the rest as interior walls. Simulation can be made with temperatures above ceiling and below floor at \( t_{amb} = +20 \degree C \) (equivalent to a flat) or at \( t_{amb} = t_{out} \degree C \) (equivalent to a semidetached house with a crawl space).
Total power for all five zones at an outdoor temperature of 
−20 °C is 3466 W (flat) or 5542 W (semidetached house).
Tables A1.2–A1.6 provide design data for the multi-zone model. The loss factors within parentheses will be included in the case of the semidetached house and hence increase the heating demand.

Table A1.2. Design data for the multi-zone model: Zones 1 and 2 (power refers to heating of the flat at −20 °C).

<table>
<thead>
<tr>
<th>Multi-zone model, Zones 1 and 2 Building Element</th>
<th>H (m)</th>
<th>W (m)</th>
<th>A (m²)</th>
<th>U (W/m²/K)</th>
<th>L (W/K)</th>
<th>R (K/m²/W)</th>
<th>C (kJ/m²)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall1.1 (window)</td>
<td>1.5</td>
<td>3.0</td>
<td>4.5</td>
<td>2.5</td>
<td>11.3</td>
<td>0.4</td>
<td>9.0</td>
<td>450</td>
</tr>
<tr>
<td>Wall1.2 (under the window)</td>
<td>0.8</td>
<td>3.5</td>
<td>2.8</td>
<td>0.4</td>
<td>1.1</td>
<td>2.5</td>
<td>23.5</td>
<td>45</td>
</tr>
<tr>
<td>Wall1.3 (top-window)</td>
<td>1.7</td>
<td>3.5</td>
<td>1.5</td>
<td>0.4</td>
<td>0.6</td>
<td>2.5</td>
<td>23.5</td>
<td>23</td>
</tr>
<tr>
<td>Wall1.6.1 (door)</td>
<td>2.0</td>
<td>0.7</td>
<td>1.4</td>
<td>0.5</td>
<td>2.5</td>
<td>23.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Wall1.6.2 (wall-door)</td>
<td>2.5</td>
<td>3.5</td>
<td>7.4</td>
<td>0.5</td>
<td>2.5</td>
<td>23.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Wall 1 (wall incl. window)</td>
<td>2.5</td>
<td>3.5</td>
<td>8.8</td>
<td>1.5</td>
<td>13.0</td>
<td>–</td>
<td>–</td>
<td>518</td>
</tr>
<tr>
<td>Wall 2 (floor)</td>
<td>4.0</td>
<td>3.5</td>
<td>14.0</td>
<td>0.4</td>
<td>(5.6)</td>
<td>2.5</td>
<td>23.5</td>
<td>0</td>
</tr>
<tr>
<td>Wall 3 (ceiling)</td>
<td>4.0</td>
<td>3.5</td>
<td>14.0</td>
<td>0.4</td>
<td>(5.6)</td>
<td>2.5</td>
<td>23.5</td>
<td>0</td>
</tr>
<tr>
<td>Wall 4 (rear wall)</td>
<td>2.5</td>
<td>4.0</td>
<td>10.0</td>
<td>0.5</td>
<td>2.0</td>
<td>20.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Wall 5 (front wall)</td>
<td>2.5</td>
<td>4.0</td>
<td>10.0</td>
<td>0.5</td>
<td>2.0</td>
<td>20.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Wall 6 (wall incl. door)</td>
<td>2.5</td>
<td>3.5</td>
<td>8.8</td>
<td>0.5</td>
<td>2.0</td>
<td>20.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Transmission (in/outdoor)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13.0</td>
<td></td>
<td></td>
<td>518</td>
</tr>
<tr>
<td>Ventilation (in/outdoor)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.0</td>
<td></td>
<td></td>
<td>465</td>
</tr>
</tbody>
</table>

Table A1.3. Design data for the multi-zone model: Zones 3 and 4 (power refers to heating of the flat at −20 °C).

<table>
<thead>
<tr>
<th>Multi-zone model, Zones 3 and 4 Building Element</th>
<th>H (m)</th>
<th>W (m)</th>
<th>A (m²)</th>
<th>U (W/m²/K)</th>
<th>L (W/K)</th>
<th>R (K/m²/W)</th>
<th>C (kJ/m²)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall1.1 (window)</td>
<td>1.5</td>
<td>3.0</td>
<td>4.5</td>
<td>2.5</td>
<td>11.3</td>
<td>0.4</td>
<td>9.0</td>
<td>450</td>
</tr>
<tr>
<td>Wall1.2 (under the window)</td>
<td>0.8</td>
<td>3.5</td>
<td>2.8</td>
<td>0.4</td>
<td>1.1</td>
<td>2.5</td>
<td>23.5</td>
<td>45</td>
</tr>
<tr>
<td>Wall1.3 (top-window)</td>
<td>1.7</td>
<td>3.5</td>
<td>1.5</td>
<td>0.4</td>
<td>0.6</td>
<td>2.5</td>
<td>23.5</td>
<td>23</td>
</tr>
<tr>
<td>Wall1.6.1 (door)</td>
<td>2.0</td>
<td>0.7</td>
<td>1.4</td>
<td>0.5</td>
<td>2.5</td>
<td>23.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Wall1.6.2 (wall-door)</td>
<td>2.5</td>
<td>3.5</td>
<td>7.4</td>
<td>0.5</td>
<td>2.5</td>
<td>23.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Wall 1 (wall incl. window)</td>
<td>2.5</td>
<td>3.5</td>
<td>8.8</td>
<td>1.5</td>
<td>13.0</td>
<td>–</td>
<td>–</td>
<td>518</td>
</tr>
<tr>
<td>Wall 2 (floor)</td>
<td>4.0</td>
<td>3.5</td>
<td>14.0</td>
<td>0.4</td>
<td>(5.6)</td>
<td>2.5</td>
<td>23.5</td>
<td>0</td>
</tr>
<tr>
<td>Wall 3 (ceiling)</td>
<td>4.0</td>
<td>3.5</td>
<td>14.0</td>
<td>0.4</td>
<td>(5.6)</td>
<td>2.5</td>
<td>23.5</td>
<td>0</td>
</tr>
<tr>
<td>Wall 4 (rear wall)</td>
<td>2.5</td>
<td>4.0</td>
<td>10.0</td>
<td>0.5</td>
<td>2.0</td>
<td>20.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Wall 5 (front wall)</td>
<td>2.5</td>
<td>4.0</td>
<td>10.0</td>
<td>0.5</td>
<td>2.0</td>
<td>20.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Wall 6 (wall incl. door)</td>
<td>2.5</td>
<td>3.5</td>
<td>8.8</td>
<td>0.5</td>
<td>2.0</td>
<td>20.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Transmission (in/outdoor)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13.0</td>
<td></td>
<td></td>
<td>518</td>
</tr>
<tr>
<td>Ventilation (in/outdoor)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.5</td>
<td></td>
<td></td>
<td>232</td>
</tr>
</tbody>
</table>

Total power for all five zones at an outdoor temperature of 
−20 °C is 3466 W (flat) or 5542 W (semidetached house).
Table A1.4. Design data for the multi-zone model: Zone 5 (power refers to heating of the flat at –20 °C).

<table>
<thead>
<tr>
<th>Building Element</th>
<th>H (m)</th>
<th>W (m)</th>
<th>A (m²)</th>
<th>U (W/m²/°K)</th>
<th>L (W/K)</th>
<th>R (K/m²/W)</th>
<th>C (kJ/m²°C)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall1.1 (window)</td>
<td>0.0</td>
<td>2.5</td>
<td>0.4</td>
<td>9.0</td>
<td>0.4</td>
<td>2.0</td>
<td>20.5</td>
<td>0</td>
</tr>
<tr>
<td>Wall1.2 (under the window)</td>
<td>0.0</td>
<td>0.5</td>
<td>2.0</td>
<td>23.5</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wall1.3 (top-window)</td>
<td>2.5</td>
<td>3.5</td>
<td>8.8</td>
<td>0.5</td>
<td>2.0</td>
<td>23.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Wall1.6.1 (door)</td>
<td>2.0</td>
<td>0.7</td>
<td>1.4</td>
<td>0.5</td>
<td>2.0</td>
<td>20.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Wall1.6.2 (wall-door)</td>
<td>2.5</td>
<td>3.5</td>
<td>7.4</td>
<td>0.5</td>
<td>2.0</td>
<td>20.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Wall 1 (wall with heater)</td>
<td>2.5</td>
<td>1.0</td>
<td>2.5</td>
<td>0.5</td>
<td>2.0</td>
<td>20.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Wall 2 (floor)</td>
<td>7.1</td>
<td>1.0</td>
<td>7.1</td>
<td>0.5</td>
<td>(3.6)</td>
<td>2.0</td>
<td>20.5</td>
<td>0</td>
</tr>
<tr>
<td>Wall 3 (ceiling)</td>
<td>7.1</td>
<td>1.0</td>
<td>7.1</td>
<td>0.5</td>
<td>(3.6)</td>
<td>2.0</td>
<td>20.5</td>
<td>0</td>
</tr>
<tr>
<td>Wall 4 (rear wall)</td>
<td>2.5</td>
<td>7.1</td>
<td>17.8</td>
<td>0.5</td>
<td>2.0</td>
<td>20.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Wall 5 (front wall)</td>
<td>2.5</td>
<td>7.1</td>
<td>17.8</td>
<td>0.5</td>
<td>2.0</td>
<td>20.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Wall 6 (wall facing heater)</td>
<td>2.5</td>
<td>1.0</td>
<td>2.5</td>
<td>0.5</td>
<td>2.0</td>
<td>20.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Transmission (in/outdoor)</td>
<td>Loss factor for transmission = --</td>
<td>--</td>
<td>966</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ventilation (in/outdoor)</td>
<td>Vol. = 17.8 m³</td>
<td>ACH = 0</td>
<td>465</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loss factor for ventilation =</td>
<td>0</td>
<td>Total power</td>
<td>1431</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table A1.5. Design data for the multi-zone model: Zones 1–5 (power refers to heating of the semidetached house at –20 °C).

<table>
<thead>
<tr>
<th>Semi-detached house: Zones 1–2</th>
<th>Transmission (in/outdoor)</th>
<th>Loss factor for transmission = 24.2</th>
<th>966</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventilation (in/outdoor)</td>
<td>Vol. = 17.8 m³</td>
<td>ACH = 0</td>
<td>465</td>
</tr>
<tr>
<td>Loss-factor for ventilation =</td>
<td>0</td>
<td>Total power</td>
<td>1431</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Semi-detached house: Zones 3–4</th>
<th>Transmission (in/outdoor)</th>
<th>Loss factor for transmission = 24.2</th>
<th>966</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventilation (in/outdoor)</td>
<td>Vol. = 17.8 m³</td>
<td>ACH = 0</td>
<td>232</td>
</tr>
<tr>
<td>Loss-factor for ventilation =</td>
<td>0</td>
<td>Total power</td>
<td>1198</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Semi-detached house: Zone 5</th>
<th>Transmission (in/outdoor)</th>
<th>Loss factor for transmission = 7.1</th>
<th>284</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventilation (in/outdoor)</td>
<td>Vol. = 17.8 m³</td>
<td>ACH = 0</td>
<td>0</td>
</tr>
<tr>
<td>Loss factor for ventilation =</td>
<td>0</td>
<td>Total power</td>
<td>284</td>
</tr>
</tbody>
</table>
APPENDIX 2. ROOM ELEMENT MODELS

Heat flows are assumed to be one dimensional and the heat resistance (R) and thermal capacity (C) are assumed to be equally divided between nodes. Thermal resistance (R) values are the inverse of the U values in Appendix 1.

A2.1 WINDOWS

Figure A2.1 illustrates the model of a two-pane window. To model the heat exchange by radiation, the view factors between the inside pane and the walls, floor and ceiling of the room must be calculated. The thermal resistance of glass is neglected compared with the resistance of air and vice versa for thermal capacitance. Hence resistance and capacitance elements are given by:

**Surface, inside**

- **Convection:** \( \alpha_1 = 3.0 \, \text{W/(m}^2\cdot\text{K)} \)
- **Radiation:** \( \gamma_1 = 5.0 \, \text{W/(m}^2\cdot\text{K)} \)
- **Resistance:** \( r_{\alpha1} = 0.125^* \, (\text{m}^2\cdot\text{K})/\text{W} \)
- **Capacitance:** \( c_g = 4500 \, \text{J/(m}^2\cdot\text{K)} \)

**Surface, outside**

- **Convection:** \( \alpha_2 = 20.0 \, \text{W/(m}^2\cdot\text{K)} \)
- **Radiation:** \( \gamma_2 = 5.0 \, \text{W/(m}^2\cdot\text{K)} \)
- **Resistance:** \( r_{\alpha2} = 0.04^* \, (\text{m}^2\cdot\text{K})/\text{W} \)
- **Capacitance:** \( c_g = 4500 \, \text{J/(m}^2\cdot\text{K)} \)

**Internal**

- **Conduction:** \( r_A = 0.235 \, (\text{m}^2\cdot\text{K})/\text{W} \)
- **Capacitance:** –

**Total**

- **Resistance:** \( R_{\text{win}} = U^{-1} = (r_{\alpha1} + r_A + r_{\alpha2}) = 0.4^* \, (\text{m}^2\cdot\text{K})/\text{W} \)
- **Capacitance:** \( C_{\text{win}} = 2 \cdot c_g = 9000 \, \text{J/(m}^2\cdot\text{K)} \)

* Only approximate values; the radiation part will depend on temperature.

---

A2.2 DOORS

Doors are treated in the same way as interior walls (see A2.4).

---

A2.3 INTERIOR DECORATION

Figure A2.2 illustrates the model of interior decoration (one unit in each room). To model the heat exchange by radiation, the weighted mean surface temperature of the room is used. Resistance and capacitance elements are given by:

**Surface**

- **Area:** \( A_{\text{int,dec}} = 10 \, \text{m}^2 \)
- **Convection:** \( \alpha_1 = 2.0 \, \text{W/(m}^2\cdot\text{K)} \)
- **Radiation:** \( \gamma_1 = 5.0 \, \text{W/(m}^2\cdot\text{K)} \)
- **Resistance:** \( r_{\alpha1} = 0.14^* \, (\text{m}^2\cdot\text{K})/\text{W} \)
- **Capacitance:** –

**Internal**

- **Resistance:** \( r_{\text{int,dec}} = 0 \, (\text{m}^2\cdot\text{K})/\text{W} \)
- **Capacitance:** \( c_{\text{int,dec}} = 8000 \, \text{J/(m}^2\cdot\text{K)} \)

**Total**

- **Resistance:** \( R_{\text{int,dec}} = (\alpha_1 + \gamma_1) A_{\text{int,dec}}^{-1} = 0.014^* \, \text{K/W} \)
- **Capacitance:** \( C_{\text{int,dec}} = c_{\text{int,dec}} \cdot A_{\text{int}} = 80000 \, \text{J/K} \)

* Only approximate values; the radiation part will depend on temperature.

---

A2.4 INTERIOR WALLS

Figure A2.3 illustrates the model of interior walls. Ceilings and floors are treated as external walls. To model the heat exchange by radiation, the view factors between each wall and the other walls, floor and ceiling of the room must be calculated. Resistance and capacitance elements are given by:

**Surface, inside 1**

- **Convection:** \( \alpha_1 = 2.0 \, \text{W/(m}^2\cdot\text{K)} \)
- **Radiation:** \( \gamma_1 = 5.0 \, \text{W/(m}^2\cdot\text{K)} \)
- **Resistance:** \( r_{\alpha1} = 0.143^* \, (\text{m}^2\cdot\text{K})/\text{W} \)
- **Capacitance:** \( c_1 = 9000 \, \text{J/(m}^2\cdot\text{K)} \)

**Surface, inside 2**

- **Convection:** \( \alpha_2 = 2.0 \, \text{W/(m}^2\cdot\text{K)} \)
- **Radiation:** \( \gamma_2 = 5.0 \, \text{W/(m}^2\cdot\text{K)} \)
- **Resistance:** \( r_{\alpha2} = 0.143^* \, (\text{m}^2\cdot\text{K})/\text{W} \)
- **Capacitance:** \( c_5 = 9000 \, \text{J/(m}^2\cdot\text{K)} \)

**Internal**

- **Conduction:** \( r = 0.4 \, (\text{m}^2\cdot\text{K})/\text{W} \)
- **Capacitance:** \( c_2 = \ldots = c_4 = 700 \, \text{J/(m}^2\cdot\text{K)} \)

**Total**

- **Resistance:** \( R_{\text{int,w}} = U^{-1} = (r_{\alpha1} + 4r + r_{\alpha2}) = 1.89^* \, (\text{m}^2\cdot\text{K})/\text{W} \)
- **Capacitance:** \( C_{\text{int,w}} = \sum_{j=1}^{5} c_j = 20100 \, \text{J/(m}^2\cdot\text{K)} \)

* Only approximate values; the radiation part will depend on temperature.
A2.5 EXTERNAL WALLS

Figure A2.4 illustrates the model of external walls. The same values apply for ceilings and floors. To model the heat exchange by radiation, the view factors between the inside of the external wall and the other inside walls, floor and ceiling of the room must be calculated. Resistance and capacitance elements are given by:

**Surface, inside 1**
Convection: $\alpha_1 = 2.0 \text{ W/(m}^2\text{K})$
Radiation: $\gamma_1 = 5.0 \text{ W/(m}^2\text{K})$
Resistance: $r_{\alpha_1} = 0.143^\ast (\text{m}^2\text{K})/\text{W}$
Capacitance: $c_1 = 10,000 \text{ J/(m}^2\text{K})$

**Surface, outside 2**
Convection: $\alpha_2 = 20.0 \text{ W/(m}^2\text{K})$
Radiation: $\gamma_2 = 5.0 \text{ W/(m}^2\text{K})$
Resistance: $r_{\alpha_2} = 0.04^\ast (\text{m}^2\text{K})/\text{W}$
Capacitance: $c_5 = 10,000 \text{ J/(m}^2\text{K})$

**Internal**
Conduction: $r = 0.333 (\text{m}^2\text{K})/\text{W}$
Capacitance: $c_2 = \ldots = c_6 = 700 \text{ J/(m}^2\text{K})$

**Total**
Resistance: $R_{\text{int,w}} = U^{-1} = (r_{\alpha_1} + 6r + r_{\alpha_2}) = 2.18 (\text{m}^2\text{K})/\text{W}$
Capacitance: $C_{\text{ext,w}} = \sum_{j=1}^{7} c_j = 23500 \text{ J/(m}^2\text{K})$.

* Only approximate values; the radiation part will depend on temperature.

---

**Figure A2.4. Heat transfer model of external walls.**

---

A2.6 ROOM AIR

For dynamic considerations the room air is modelled as a lump of homogeneous temperature with a thermal capacity of:

$C_A = 1200 \text{ J/(m}^3\text{K})$.

This capacity determines the rate of temperature change during transient conditions.
APPENDIX 3. ROOM HEATER MODELS

A3.1 HEATER

According to Part 1 of this method (test in a climatic chamber, Ref. 2.1), the heater should be a convector heater with the following characteristics:

Height: 0.3 < H < 0.6 m, design energy ratio: 0.7 < ε_{des} < 0.8.

Tables A1.1–A1.4 provide heating requirements at the design conditions of tin = +20 °C and tout = –20 °C. Tables A3.1 and A3.2 below provide corresponding convector/radiator sizes based on ε_{des} ≈ 0.75 and a rated heating capacity in the range 3000–4000 W/m² frontal area.

Table A3.1. Design data for individual convector/radiator heaters for model flats.

<table>
<thead>
<tr>
<th>Zone</th>
<th>H_r (m)</th>
<th>W_r (m)</th>
<th>A_r (m²)</th>
<th>P_e,nom (W)</th>
<th>P_e,rated (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single zone model:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zone 1</td>
<td>0.125</td>
<td>3.0</td>
<td>0.375</td>
<td>983</td>
<td>1300</td>
</tr>
<tr>
<td>Multi zone model:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zone 1 and 2</td>
<td>0.125</td>
<td>3.0</td>
<td>0.375</td>
<td>983</td>
<td>1300</td>
</tr>
<tr>
<td>Zone 3 and 4</td>
<td>0.100</td>
<td>3.0</td>
<td>0.300</td>
<td>750</td>
<td>1000</td>
</tr>
<tr>
<td>Zone 5</td>
<td>0.150</td>
<td>0.5</td>
<td>0.075</td>
<td>0</td>
<td>300</td>
</tr>
</tbody>
</table>

Table A3.2. Design data for individual convector/radiator heaters for model semidetached house.

<table>
<thead>
<tr>
<th>Zone</th>
<th>H_r (m)</th>
<th>W_r (m)</th>
<th>A_r (m²)</th>
<th>P_e,nom (W)</th>
<th>P_e,rated (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single zone model:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zone 1</td>
<td>0.200</td>
<td>3.0</td>
<td>0.600</td>
<td>1431</td>
<td>1900</td>
</tr>
<tr>
<td>Multi zone model:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zone 1 and 2</td>
<td>0.200</td>
<td>3.0</td>
<td>0.600</td>
<td>1431</td>
<td>1900</td>
</tr>
<tr>
<td>Zone 3 and 4</td>
<td>0.150</td>
<td>3.0</td>
<td>0.450</td>
<td>1198</td>
<td>1600</td>
</tr>
<tr>
<td>Zone 5</td>
<td>0.200</td>
<td>0.5</td>
<td>0.100</td>
<td>284</td>
<td>400</td>
</tr>
</tbody>
</table>

A3.2 HEATER MODEL

Figure A3.1 illustrates the model of heaters. To model the heat exchange by radiation, the view factors between the front of the radiator and the inside walls, floor and ceiling of the room must be calculated (the view factor between the rear wall and the mounting wall is taken to be one). Resistance and capacitance elements are given by:

**Surface, front**

Convection: \( \alpha_{rf} = 4 \cdot \frac{|T_{rf} - T_{room}|}{0.25} \)

Radiation: \( \gamma_f = 5.0 \text{ W/(m}^2\text{K)} \)

Resistance: \( f_{ref} \approx 0.05–0.1 \text{ (m}^2\text{K)/W} \)

Capacitance: \( c_{rf} = 800 \text{ J/(m}^2\text{K)} \)

**Surface, back**

Convection: \( \alpha_{rb} = 4 \cdot \frac{|T_{rb} - T_{room}|}{0.25} \)

Radiation: \( \gamma_r = 5.0 \text{ W/(m}^2\text{K)} \)

Resistance: \( f_{ref} \approx 0.05–0.1 \text{ (m}^2\text{K)/W} \)

Capacitance: \( c_{rb} = 800 \text{ J/(m}^2\text{K)} \)

**Internal**

Convection: \( \alpha_{ri} = 8 \cdot \frac{|T_{ri} - T_{room}|}{0.25} \)

(radiation is included in conduction) \( W/(m}^2\text{K})

Conduction: \( r_{rf} = 0.03–0.04 \text{ (m}^2\text{K)/W} \)

\( r_{rb} = 0.03–0.04 \text{ (m}^2\text{K)/W} \)

Capacitance: \( c_{ri} = 4400 \text{ J/(m}^2\text{K)} \)

**Total**

Resistance: \( R_{rf} = (r_{ref} + r_{rf}) = 1^* \)

\( R_{rb} = (r_{ref} + r_{rb}) = 1^* \text{ (m}^2\text{K)/W.} \)

Capacitance: \( C_{rad} = 6000 \text{ J/(m}^2\text{K)} \)

* Only approximate values; the radiation part will depend on temperature

To calculate the absolute values of heat transfer and storage for each individual heater, specific values are multiplied by the frontal area \( A_{rf} \) of the heater (see Table A3.1).
APPENDIX 4. AIR FLOWS

Air flows through windows and doors are modelled as being dependent on the opening area, the height of the opening, and the temperature difference between the two sides of the opening.

A4.1 AIR FLOW THROUGH WINDOWS

The air flow through a window, e.g. during airing, is modelled as:

\[ q_{\text{win}} = 50 \cdot 10^{-3} \cdot A_{\text{win}} \cdot f(t) \cdot H_{\text{win}} \cdot |T_{\text{room}} - T_{\text{out}}|^{0.5} \text{ m}^3/\text{s} \]

\( f(t) \) is the time related opening factor; a closed window corresponds to \( f(t) = 0 \) and a fully open window to \( f(t) = 1 \).

A4.2 AIR FLOW THROUGH DOORS

The air flow through a window, e.g. during airing, is modelled as:

\[ q_{\text{door}} = 50 \cdot 10^{-3} \cdot A_{\text{door}} \cdot f(t) \cdot H_{\text{door}} \cdot (T_{\text{room}} - T_{\text{room}})^{0.5} \text{ m}^3/\text{s} \]

\( f(t) \) is the time related opening factor; a closed window corresponds to \( f(t) = 0 \) and a fully open window to \( f(t) = 1 \).

A4.3 VENTILATION

Ventilation is assumed to be fully mixed and independent of the outdoor temperature. It is also assumed that there are sufficient openings to permit an uninterrupted ventilation flow even when interior doors are closed. The inlet air mixes with the room air to a uniform bulk temperature in each room. The mass of the room air in relation to the thermal inputs to the air from ventilation, the room heater and internal loads decides how quickly the temperature changes.
APPENDIX 5. POSITIONING AND MODELLING OF SENSORS

A5.1 STATIC OPERATIVE SENSOR TEMPERATURE

The operative sensor temperature derives from contributions by convection, radiation and conduction:

\[ t_s = k_A \cdot t_A + k_r \cdot t_r + k_w \cdot t_w \]

where \( t_s \) is the operative temperature of the sensor for given conditions (which is derived from the temperatures of the air and surrounding surfaces), \( t_A = t_{As} \) is the air temperature and \( k_A \) the corresponding weighting coefficient, \( t_r \) is the equivalent radiating temperature of the surrounding surfaces with the overall weighting coefficient \( k_r \), and finally \( t_w = \) temperature of the wall where the sensor is mounted and \( k_w \) its weighting coefficient. Values of the weighting coefficients are determined according to ref. 2.2. If tests have not been carried out, the following default values may be used:

\[ k_A = 0.7, \quad k_r = 0.15, \quad k_w = 0.15 \]

(different types of sensors, however, may differ considerably).

The air temperature \( t_{As} \), as experienced by the sensor, is determined from the room temperature, \( t_{room} \), the temperature influence from the heater, \( \Delta t_L \) (see A5.3 below), and the temperature influence at sensor height \( H_s \) from the vertical gradient \( g_t \) in the room. The gradient is estimated from the room and outdoor temperatures, \( t_{room} \) and \( t_{out} \).

\[ t_{As} = t_{As0} + \Delta t_L + \Delta t_{Hs} \]

with

\[ t_{As0} (\tau + \Delta \tau) = t_{As} (\tau) + t_{room} (\tau) \cdot \Delta t \]

with the integration time \( \tau_I = 3600 \) s and

\[ \Delta t_{Hs} = (k_{Hs} \cdot H_s - k_{H0}) \cdot (t_{As0} - t_{out}) \]

with \( k_{Hs} = 0.02 \) \([\text{m}^{-1}]\) and \( k_{H0} = 0.03 \) \([-\text{ }]\).

The equivalent radiating temperature is calculated according to

\[ t_r = \sum_{j=1}^{j=6} F_{s,j} \cdot t_j \]

where \( t_j = \) temperature of surface \( j \) and \( F_{s,j} = \) view factor between the sensor and surface \( j \) (the size of the sensor is considered to be negligible compared with the radiating surfaces). View factors must be calculated for individual sensor positions.

A5.2 DYNAMIC SENSOR MODEL

The dynamics of the sensor are approximately characterized by a single pole with the time constant \( \tau_s \) (see Ref. 2.1, 3.6.24, and ref. 2.2, 9.2). Then the sensor temperature can be expressed approximately as

\[ t_s (\tau + \Delta \tau) = t_s (\tau) + \Delta t_s (1 - e^{-\Delta \tau / \tau_s}) \]

where \( \Delta t_s \) represents the indicated change of the sensor temperature at an infinite time after a step change in the ambient temperature of the sensor.

A5.3 DYNAMICS OF ROOM/HEATER/SENSOR COMBINATION

In addition to the dynamic model of the heater (A3.2) and the dynamics of the room (A2.1–A2.6), there is a time lag, \( \tau_L \), due to the transport time of warm air from the radiator to the sensor. There is also an attenuation, \( \alpha_t \), of the outlet temperature from the heater due to mixing with room air before it reaches the sensor. The transport time and attenuation may be determined for individual combinations of sensor position, type of heater and operating conditions in a test chamber according to Ref. 2.1. The attenuated air temperature is the value to be included as \( t_{As} \) in the expression for the operative temperature of the sensor in A5.1.

If no measured data are available, the following relations for lag time and attenuation may be used:

\[ \tau_L = \frac{3 \cdot L^2}{u_{ro} \cdot \ln(3 \cdot L + 1)} \] \([\text{s}]\) and \[ \alpha_t = \frac{1}{(10 \cdot L + 1)} \] \([-\text{ }]\)

with

\[ \Delta t_L (\tau) = \alpha_t \cdot \Delta t_{ro} (\tau - \tau_L) \] \([\text{K}]\)

with \( \Delta t_L = t_{As} - t_{room} \) at the sensor location and \( \Delta t_{ro} = t_{Ac,out} - t_{room} \) at the heater outlet.

The above relations are based on a characteristic heater temperature, \( t_{rad} \), a characteristic outlet air velocity, \( u_{ro} \), from the heater, and a characteristic length, \( L \). The characteristic heater temperature is estimated as:

\[ t_{rad} = \frac{\alpha_{ef} \cdot t_d + k_s \cdot t_d + \alpha_{g} \cdot t_g}{\alpha_{ef} + \alpha_{g} + \alpha_{ro}} \] \([\text{K}]\)

with \( k_f = 0.5 \).

The outlet temperature difference, \( \Delta t_{ro} \), is estimated from the mean heater temperature:
\[ \Delta t_{ro} = (t_{rad} - t_{room}). \]

The outlet air velocity is given by:

\[ u_{ro} = k_{rad} \cdot H_{rad}^{0.2} \cdot (t_{rad} - t_{room}) \text{ [m/s]} \text{ with } k_{rad} = 0.03. \]

\( L \) is the length of the convection path between heater and sensor according to Figure A5.1:

\[ L = L_1 + L_2 + \left( \frac{L_{rad2}}{L_{rad1}} \left( \frac{L_1 + L_3}{L_1 + L_2} + 1 \right) \right) L_3 + L_4 \text{ [m]} \]

Figure A5.1. Length of convection path between heater and control sensor.
APPENDIX 6. CLIMATIC BOXES FOR SENSORS

Climatic boxes are used to emulate the computed operative temperatures of the indoor control sensors. If the controller uses an outdoor sensor, the outdoor temperature according to the outdoor temperature profile in Figures 9.1 and 9.2 should also be emulated in a climatic box. The climatic boxes should be equipped with fans to provide forced convection and hence high coefficients of heat transfer and short time constants (the real sensitivity and time constant of a sensor are included in the model by means of tested values of sensitivity coefficients and time constants according to Ref. 2). The emulated temperature must be measured in close proximity to the control sensor. To facilitate rapid changes of temperature, e.g. during tests with opening of windows, it is recommended to supply all indoor climatic boxes with cold air and to balance the temperature at the correct value by means of electric heaters.