Potential of ventilative cooling in German residential buildings

QUALICHeCK-Webinar, 2016-12-01

Auf Wissen bauen
Introduction

- **Background**
  - Highly insulated buildings with almost completely airtight building envelopes can increase the cooling demand in residential buildings
  - Active cooling implies additional investment costs and increased energy consumption
  - Increased night ventilation is cost-effective option to influence indoor climate, however, it is not widely considered by building planners

- **Scope of the study**
  - Parameter study on the influence of construction types, planning designs, heat protection levels, ventilation strategies and user behavior on the summer indoor climate
  - Determination of the impact of increased night ventilation on the indoor climate and the theoretical cooling demand
Approach of Study

- Development of building models for typical newly built single and multi-family houses in Germany
  - Well known building (used in other scientific studies)
  - Representative for new buildings in Germany
- Analysis of different energy concepts according to DIN V 18599
- Proof of summer heat protection using the simplified method according to DIN 4108-2
- Thermal building simulation for assessing the summer indoor climate in critical rooms
- Development of a calculation model for implementing night ventilation and analysis of the impact of ventilative cooling
Building model – Single-family house

- **Key figures**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross floor area [m²]</td>
<td>271</td>
</tr>
<tr>
<td>Net floor area [m²]</td>
<td>226</td>
</tr>
<tr>
<td>Living space [m²]</td>
<td>152</td>
</tr>
<tr>
<td>Useable floor area [m²]</td>
<td>250</td>
</tr>
<tr>
<td>Gross volume [m³]</td>
<td>781</td>
</tr>
<tr>
<td>Net volume [m³]</td>
<td>594</td>
</tr>
<tr>
<td>S-V-Ratio [m²/m³]</td>
<td>0.64</td>
</tr>
</tbody>
</table>

- **Building elements**

<table>
<thead>
<tr>
<th>Element</th>
<th>Area [m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>External wall</td>
<td>153.0</td>
</tr>
<tr>
<td>Window</td>
<td>28.2</td>
</tr>
<tr>
<td>Doors</td>
<td>2.4</td>
</tr>
<tr>
<td>Roof</td>
<td>120.5</td>
</tr>
<tr>
<td>Roof window</td>
<td>7.0</td>
</tr>
<tr>
<td>Ground slab</td>
<td>90.2</td>
</tr>
<tr>
<td>Wall against soil</td>
<td>100.8</td>
</tr>
<tr>
<td>Total</td>
<td>502.1</td>
</tr>
</tbody>
</table>

- **Elevation (North / West)**

- **Floor plan**
Building model – Multi-family building

- **Key figures**

<table>
<thead>
<tr>
<th>Element</th>
<th>Area [m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross floor area [m²]</td>
<td>1.544</td>
</tr>
<tr>
<td>Net floor area [m²]</td>
<td>1.146</td>
</tr>
<tr>
<td>Living space [m²]</td>
<td>1.042</td>
</tr>
<tr>
<td>Useable floor area [m²]</td>
<td>1.168</td>
</tr>
<tr>
<td>Gross volume [m³]</td>
<td>3.650</td>
</tr>
<tr>
<td>Net volume [m³]</td>
<td>2.920</td>
</tr>
<tr>
<td>S-V-Ratio [m²/m³]</td>
<td>0.43</td>
</tr>
</tbody>
</table>

- **Elevation (South)**

- **Building elements**

<table>
<thead>
<tr>
<th>Element</th>
<th>Area [m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>External wall</td>
<td>830.9</td>
</tr>
<tr>
<td>Window</td>
<td>175.6</td>
</tr>
<tr>
<td>Doors</td>
<td>32.2</td>
</tr>
<tr>
<td>Roof</td>
<td>257.4</td>
</tr>
<tr>
<td>Cellar ceiling</td>
<td>257.4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1533.6</strong></td>
</tr>
</tbody>
</table>
## Energy concept – Building physics

<table>
<thead>
<tr>
<th>Building element</th>
<th>EnEV 2016</th>
<th>KfW 55</th>
<th>KfW 40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside wall</td>
<td>0,28</td>
<td>0,16</td>
<td>0,14</td>
</tr>
<tr>
<td>Flat roof</td>
<td>0,20</td>
<td>0,12</td>
<td>0,10</td>
</tr>
<tr>
<td>Cellar ceiling</td>
<td>0,35</td>
<td>0,25</td>
<td>0,15</td>
</tr>
<tr>
<td>Entrance doors</td>
<td>1,80</td>
<td>1,30</td>
<td>1,10</td>
</tr>
<tr>
<td>Window</td>
<td>U [W/m²K]</td>
<td>1,3</td>
<td>0,95</td>
</tr>
<tr>
<td></td>
<td>SHGC [-]</td>
<td>0.6</td>
<td>0.55</td>
</tr>
<tr>
<td>Thermal bridges</td>
<td>ΔU [W/m²K]</td>
<td>0,05</td>
<td>0,05</td>
</tr>
<tr>
<td>Air tightness</td>
<td>n₅₀ [1/h]</td>
<td>1,00</td>
<td>1,00</td>
</tr>
</tbody>
</table>
Energy concept – Building services

- **Heating**
  - Electrical air-to-water heat pump for heating and domestic hot water
  - Heat emission via underfloor heating with buffer storage
  - Centralized DHW storage, DHW distribution with circulation

- **Ventilation**
  - Mechanical ventilation system
    - EnEV-Standard: Exhaust air system
    - KfW-Efficiency House: Balanced mechanical ventilation system with heat recovery 80%
  - Year-round operation of the ventilation system, user controlled
Proof of summer heat protection - Approach

- Minimum requirements for hygienic structural winter and summer heat protection (DIN 4108-2)
  - Temperature-related requirements (Hygienic, indoor climate and prevention of structural damage)
- Verification procedure
  - Simplified verification based on room characteristic:
    \[ f(A_{\text{win}}, \text{SHGC}, F_c, A_{NFA}) \]
  - Thermal building simulation:
    - Defined climate conditions and calculation models
    - Defined user behavior: Internal heat loads (100 Wh/m²d), air change rates, control of solar shading system
## Proof of summer heat protection - Results

<table>
<thead>
<tr>
<th>Flat</th>
<th>Room</th>
<th>Dir.</th>
<th>$f_{WG}$ [m²/m²]</th>
<th>$C_{wirk} / A_g$ [Wh/K]</th>
<th>Night ventilation</th>
<th>$S_{vorh}$</th>
<th>$S_{zul}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Living</td>
<td>South / West</td>
<td>0.25</td>
<td>167</td>
<td>-</td>
<td>0.045</td>
<td>0.076</td>
</tr>
<tr>
<td></td>
<td>Sleeping</td>
<td>South</td>
<td>0.19</td>
<td>167</td>
<td>-</td>
<td>0.035</td>
<td>0.090</td>
</tr>
<tr>
<td>2</td>
<td>Kitchen</td>
<td>South</td>
<td>0.36</td>
<td>182</td>
<td>2 h⁻¹</td>
<td>0.065</td>
<td>0.090</td>
</tr>
<tr>
<td></td>
<td>Living</td>
<td>South</td>
<td>0.20</td>
<td>142</td>
<td>-</td>
<td>0.036</td>
<td>0.088</td>
</tr>
<tr>
<td>3</td>
<td>Child 2</td>
<td>South</td>
<td>0.25</td>
<td>159</td>
<td>-</td>
<td>0.046</td>
<td>0.075</td>
</tr>
<tr>
<td></td>
<td>Sleeping</td>
<td>East</td>
<td>0.21</td>
<td>156</td>
<td>-</td>
<td>0.038</td>
<td>0.085</td>
</tr>
</tbody>
</table>

Kitchen in flat 2 needs an increased night ventilation; all other rooms fulfill the requirements of summer overheating protection without ventilative cooling.
Thermal building simulation - Approach

- Software TRNSYS 17
- Whole building simulation (SFH), top floor simulation (MFB)
- Simulation time step: 1 hour
- Parametrization of simulation model in accordance with DIN V 18599
- Calibration of the simulation models with results of energy demand calculation in accordance with DIN V 18599
- Air exchange between rooms is only considered for the case of night ventilation

➢ The chosen calculation models and parameters are not in compliance with the verification procedure of summer heat protection according to DIN 4108-2
Thermal building simulation - Parameters

- Parameters chosen in conformity to DIN V 18599 default values
  - Internal heat loads: SFH = 45 Wh/m²d; MFH = 90 Wh/m²d
  - DHW demand: SFH = 11 kWh/m²a; MFH = 15 kWh/m²a
  - Set point temperature for heating (20°C) and cooling (26°C)
  - Climatic conditions (reference climate: TRY Potsdam)
  - Calculation model for infiltration and window ventilation
- Ambient conditions
  - No shading of neighboring buildings
  - Medium wind shielding
  - Reflectance of ambient surfaces: 20% (grass)
Thermal building simulation – User profiles internal loads

- **Kitchen**: Heat load \( [W/m^2] \) over hours of the day.
- **Living**: Heat load \( [W/m^2] \) over hours of the day.
- **Sleeping**: Heat load \( [W/m^2] \) over hours of the day.
- **Bath**: Heat load \( [W/m^2] \) over hours of the day.
Thermal building simulation – Variation of building concept

1. Insulation level: EnEV 2016 / KfW55 / KfW40

2. Building construction: heavyweight building / lightweight building

3. Window size: standard / increased window area (+ 15%)

4. Solar shading control: automatic / time control / user control / no shading
Thermal building simulation – Control of solar shading system

1. Automatic control using solar sensors
   - Closing: Total solar radiation on façade > 300 W/m²
   - Opening: Total solar radiation on façade < 200 W/m²

2. Manual control during absence (time control with weather forecast)
   - Closing: 7 a.m., if mean $T_{amb}$ will exceed 30°C
   - Opening: 7 p.m.

3. Manual control during presence based on internal temperature and solar radiation
   - Closing: $T_{i,air} > 26°C$ and total solar radiation on façade > 300 W/m²
   - Opening: Total solar radiation on façade < 200 W/m²
Simulation results – Thermal insulation

Excess temperature degree hours [Kh]

- EnEV-Standard
- KfW-Efficiency House 55
- KfW-Efficiency House 40
- Threshold value

Bedroom Flat #1
Living room Flat #1
Kitchen Flat #2
Living room Flat #2
Childroom 2 Flat #3
Bedroom Flat #3
Simulation results – Solar shading

Excess temperature degree hours [Kh]

- Bedroom Flat #1
- Living room Flat #1
- Kitchen Flat #2
- Living room Flat #2
- Childroom 2 Flat #3
- Bedroom Flat #3

- Auto control
- User control
- Time control
- No shading
- Threshold value
Simulation results – Building design

Excess temperature degree hours [Kh]

- Bedroom Flat #1
- Living room Flat #1
- Kitchen Flat #2
- Living room Flat #2
- Childroom Flat #3
- Bedroom Flat #3

Reference case
Light weight building
Increased window area
Threshold value
Ventilative cooling – Calculation method

- Calculation method based on air mass flow balance

- Air mass flows are determined according to DIN EN ISO 13791 – App. I
  - Considering of thermal buoyancy and wind:

  - \[ m_a = m_{a,T}; \text{ if } \frac{v_f}{(\Delta \theta)^{0.5}} < \left[ 0.26 \ast \left( \frac{A_T}{A_W} \right)^{0.5} \ast \left( \frac{\Delta H}{\Delta C_W} \right)^{0.5} \right] \]
  - \[ m_a = m_{a,W}; \text{ if } \frac{v_f}{(\Delta \theta)^{0.5}} > \left[ 0.26 \ast \left( \frac{A_T}{A_W} \right)^{0.5} \ast \left( \frac{\Delta H}{\Delta C_W} \right)^{0.5} \right] \]
Ventilative cooling – Effective window openings

- Window openings:
  - Sleeping room: Tilted window, shutter closed
  - Ground floor / Accessible windows from outside: Tilted windows
  - Other windows: Windows half open
  - Room doors: open

- Effective ventilation cross section:
  - $H = H_{win} - 0.15m$; $B = B_{win} - 0.15m$
  - Window fixed parapet: $H = (H_{win} - 0.15m) \* 2 / 3$
  - Half open window: $A_{eff,i} = (H \* B) \* 0.5$
  - Tilted window: $A_{eff,i} = (H + B) \* a$
    - $a = 0.11m$
  - Closed shutter: $A_{eff,s,i} = A_{eff,i} \* 0.3$

Source: ASR A3.6
Ventilative cooling – Control strategy

User control based on time schedule and outdoor temperature

- Opening: 11 p.m., if mean $T_{i,\text{air}} > 24^\circ C$ and $T_{\text{amb}} < 22^\circ C$

- Closing: 7 a.m., $T_{i,\text{air}} < 18^\circ C$ or if it is rainy
Ventilative cooling – Ventilation zones
Simulation results – Air volume flow of ventilative cooling in living room at 20/07

Heat gains from walls

\[ T_e > 22 \, ^\circ C \]

Opening time

Closing

Air volume flow [m³/h]

Temperature [°C], wind velocity [m/s]

0 400 800 1200 1600 2000

21 22 23 24 1 2 3 4 5 6 7 8 9

Hour of day

Thermal buoyancy  Wind_East  Wind_South  T_amb  v_wind  T_Int
Simulation results – Surface temperature in living room at 20/07

- Temperature [°C]
- Hour of day

Lines in the graph represent:
- T_Ceiling
- T_Floor
- T_Wall_South
- T_Air_Living
- T_ambient
Simulation results - Influence of ventilative cooling in living room of flat 1
Simulation results – Influence of ventilative cooling on excess temperature degree hours

Excess temperature degree hours [K\text{h}]

- Bedroom Flat #1
- Living room Flat #1
- Kitchen Flat #2
- Living room Flat #2
- Childroom 2 Flat #3
- Bedroom Flat #3

- No solar shading
- Light weight building
Summary and Outlook

- Summer overheating problems in typical newly built residential buildings in Germany can be controlled under today's climatic conditions by an adapted building design and the use of sun protection under today's climatic conditions.
- Intelligent use of solar shading system, heat storage capacity of building components, thermal insulation and building design have proved to be the most important parameters.
- Night ventilation has been proved to be an efficient and effective measure to minimize the risk of overheating and make the use of an active cooling system dispensable.