On the impact of typical model simplifications

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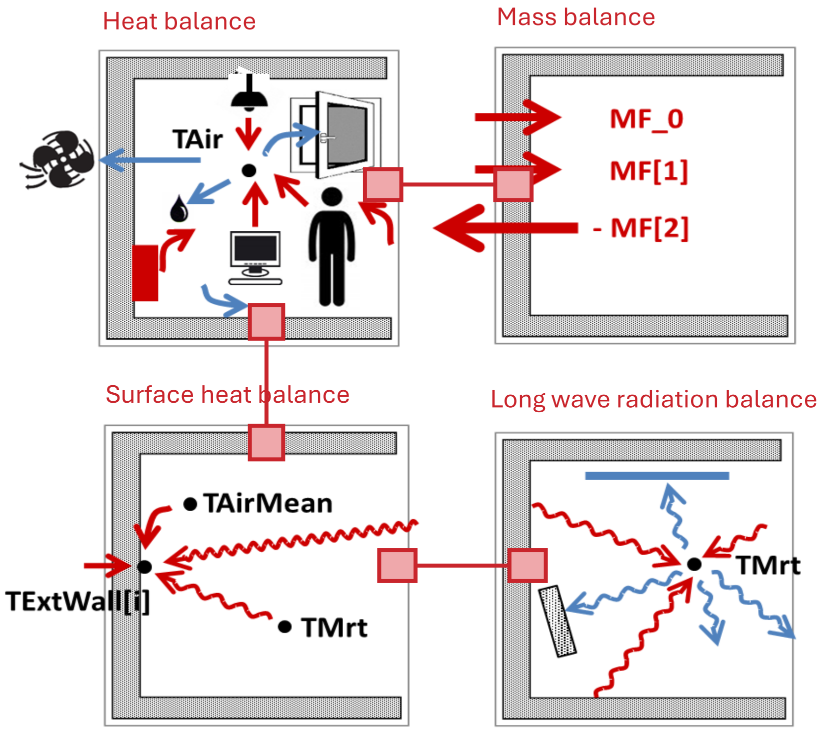
Widely used model simplifications may alter simulation results

Motivation of this study: What are the consequences of typical model simplifications?

- Simplified models remain widely used due to regulatory standards (e.g., VDI 2078)
- Typical assumptions:
  - constant heat transfer coefficients
  - linearized radiation
  - lumped thermal mass
- Additional simplifications:
  - no view factors
  - simplified occupant loads
  - fixed window properties
- Detailed models (e.g., IDA ICE) resolve dynamic heat transfer and non-linear effects

Detailed model approach of IDA ICE



Study objective:

Examine factors influencing the results in the VDI validation test cases

Image source: https://equa.cloud.xwiki.com/xwiki/bin/view/IDA_ICE/ICE_Descriptions/ICE_models/SimZone/

The VDI 6020 model

A network of lumped thermal resistances and heat capacities

- Heat conduction modeled via analogy to electrical transmission lines (RC networks)
- n-capacitance (n-C) model represents distributed thermal mass across building components
- 2-capacity model simplifies to internal vs. external thermal masses for VDI validation use and basis for VDI 2078 cooling load calculation
- Further simplifications: reduced wall capacities, linearized radiation, constant convection, uniform radiation distribution

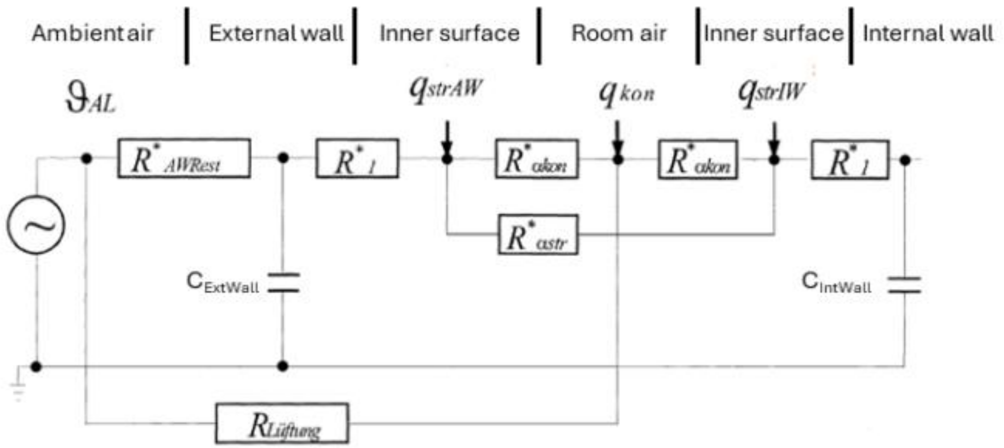
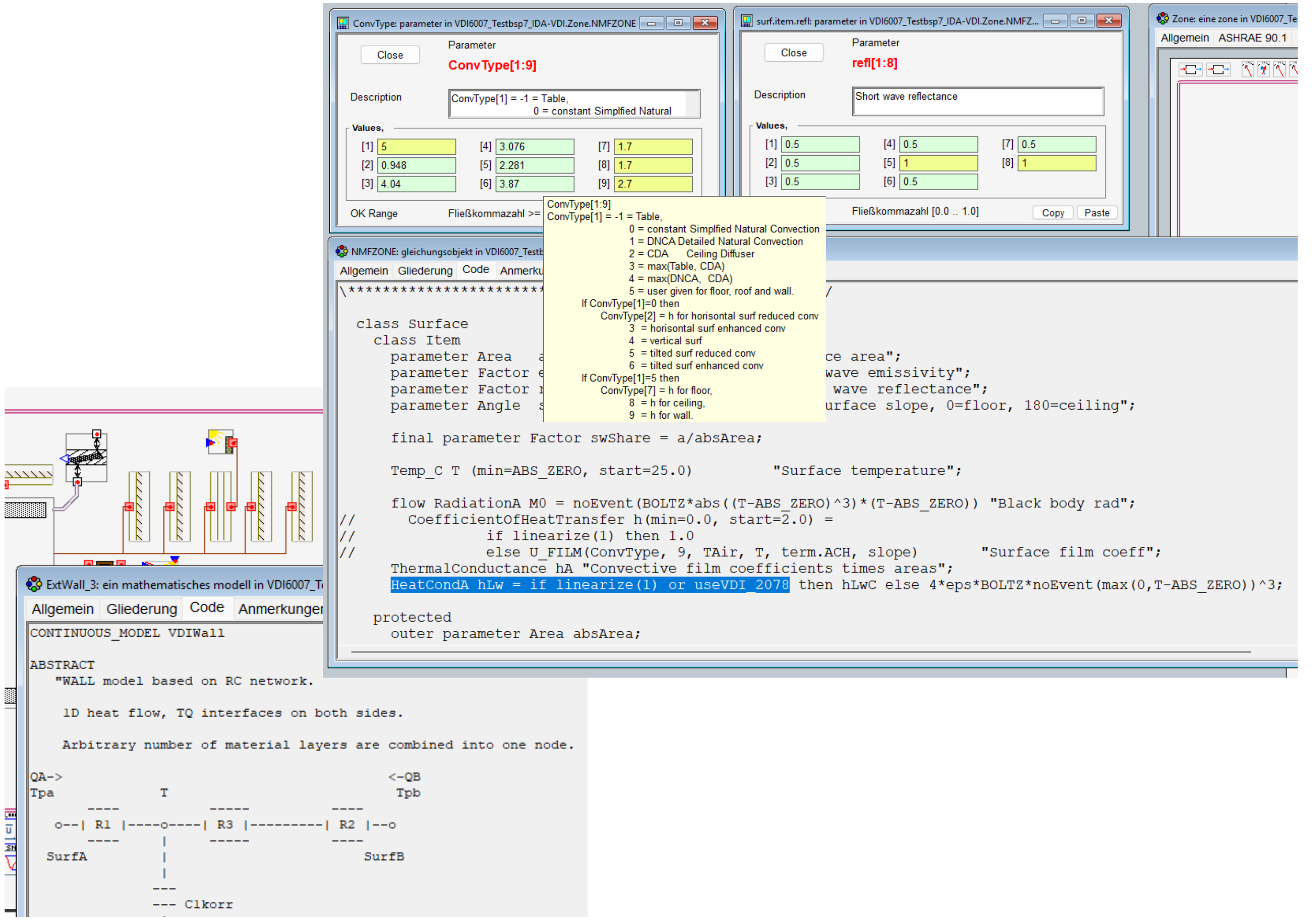


Figure 1: Illustration of a room as a 2-capacity model where the internal loads are convective and radiating (Verein Deutscher Ingenieure e.V. 2001, 28)

Reconciling physics-based IDA ICE models with VDI-compliant simplifications

"IDA VDI" – A simplification of IDA ICE models based on VDI requirements

- VDI 2078 requires software validation per VDI 6020
- IDA ICE uses advanced physics-based, non-linear models
- VDI calculation engines are limited to simplified linear flow problems
- Significant result deviations prevent direct validation of IDA ICE
- Model simplifications enable VDI-compliant version ("IDA VDI")



Model simplifications in focus

VDI 6007 Test Case 7

- Lumped capacity wall models ("**VDIWalls**") with
  - 1 instead of 5 capacities in each external wall model
  - 1 instead of 5 capacities in the internal slab (floor-ceiling) model
- Simplified zone model ("**VDIZone+ConvType**") with
  - linearized radiation coefficients
  - constant convection coefficients instead of depending on temperature difference
  - long-wave and short-wave radiation distributed evenly across all surfaces instead of taking view factors into account

Note: The modeling of radiation through windows is completly absent in the selected test case. Instead solar heat gains are specified as boundary conditions on room surfaces.

The validation case

VDI 6007 Test Case 7

- Test Case 7: rectangular room, heavy construction controlled thermal conditions (VDI 6007)
- IDA ICE baseline model vs. VDI-compliant mathematical zone model
- Replacement of detailed physical models with standardized VDI simplifications
- Two isolated simplifications: **VDIWalls** and **VDIZone+ConvType**
- Comparison metrics: air temperature, operative temperature, heating/cooling power

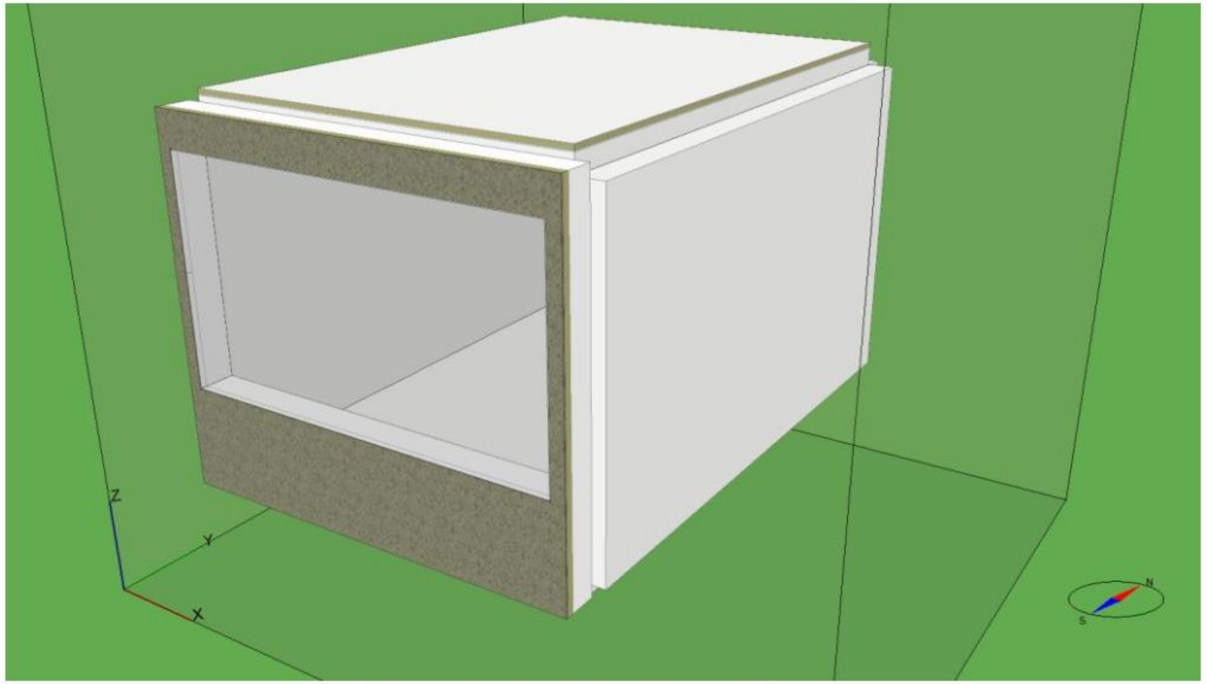


Figure 2: VDI 6007, Test Case 7

Standardized VDI simplifications enable formal validation but introduce measurable deviations from detailed equation-based building simulation models

Validation of the IDA VDI Model Against VDI 6007 (Test Case 7)

Accuracy of the IDA VDI model in reproducing reference results

- Near-identical agreement in heating/cooling power vs. VDI 6007 reference
- Accurate prediction of timing and magnitude of peak heating output
- High fidelity in reproducing dynamic effects (heat storage and release)
- Operative temperature evolution closely matches reference trajectory
- Deviations are minimal and attributable to numerical effects only

Figure 4: Comparison of operative temperature:
IDA VDI model versus reference op. temperature according to VDI 6007, Test Case 7

The IDA VDI model reliably reproduces VDI 6007 reference results, confirming correct implementation of the simplified, guideline-compliant zone model.

Comparison between VDI and IDA ICE

How VDI-based model simplifications affect transient heating/cooling power and operative temperature

- Identical initial conditions yield divergent transient responses (IDA VDI vs. detailed IDA ICE)
- VDI model constrained to strict hourly time steps; detailed model responds continuously
- Heating/cooling power: linear decline (VDI) vs. faster, nonlinear decay (IDA ICE)
- Operative temperature: moderate rise (~26.5 °C) vs. steeper increase (>28 °C)
- Deviations emerge early and amplify over the daily cycle

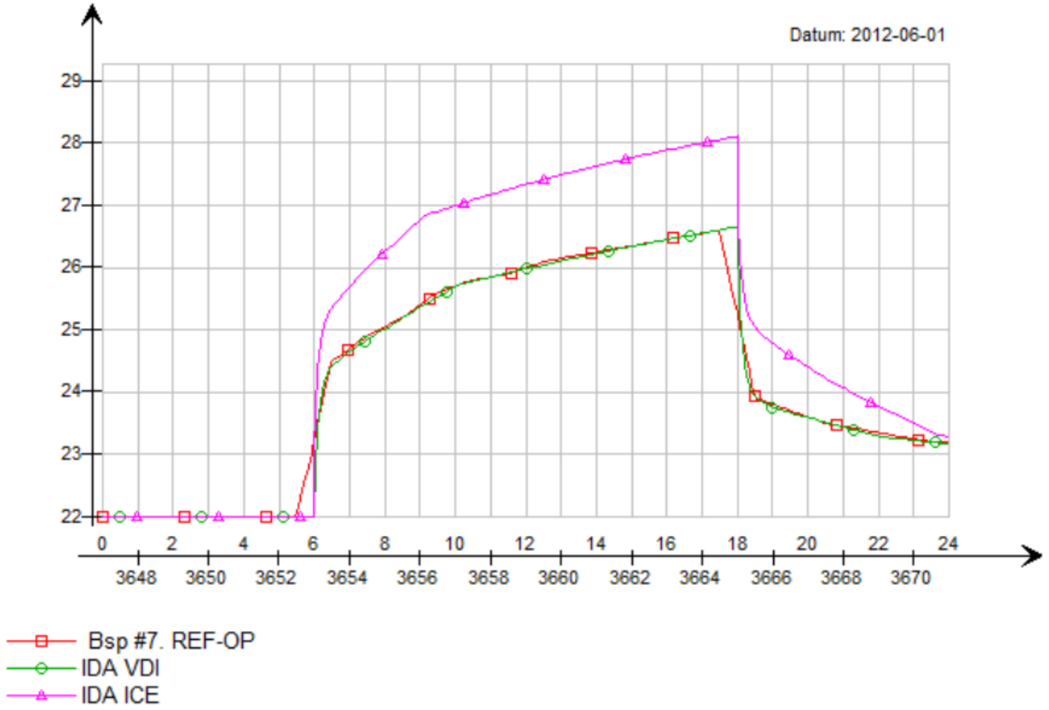


Figure 6: Comparison of operative temperature:
IDA ICE model versus IDA VDI model according to VDI 6007, Test Case 7

VDI 6007 simplifications significantly dampen and delay dynamic thermal responses compared to detailed simulation, leading to systematic differences in power and temperature evolution.

Analysis of individual VDI model simplifications

VDI Wall model

- Lumped capacity wall models (“**VDIWalls**”) with
  - 1 instead of 5 capacities in each external wall model
  - 1 instead of 5 capacities in the internal slab (floor-ceiling) model

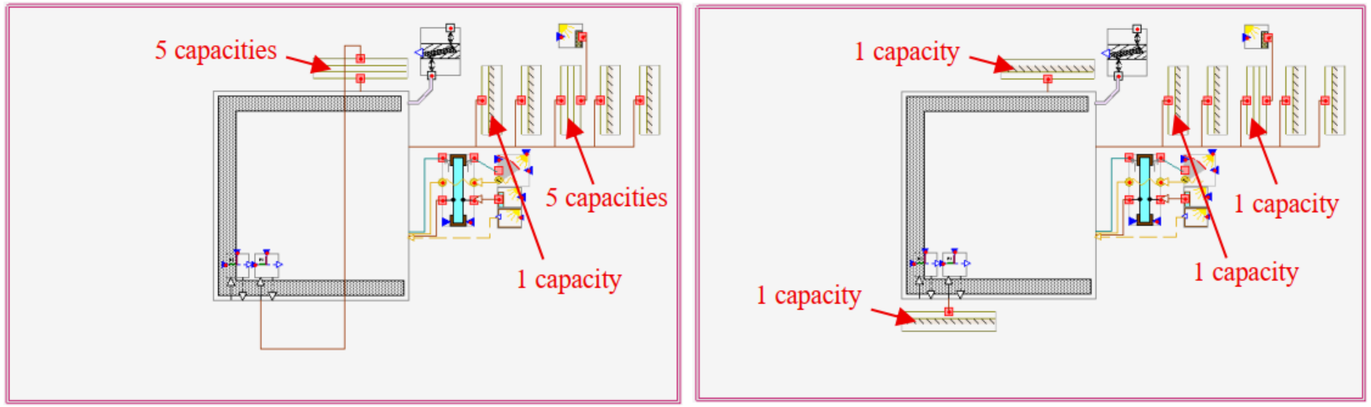


Figure 7: Schematic IDA ICE model view:
On the left with original IDA ICE models and on the right with VDI Wall models

VDI-driven simplification from multi-capacity to single-capacity wall models does not significantly degrade validation outcomes, despite reduced structural detail.

Analysis of individual VDI model simplifications

VDI Zone model and convective coefficients

- Simplified zone model (“**VDIZone+ConvType**”) with
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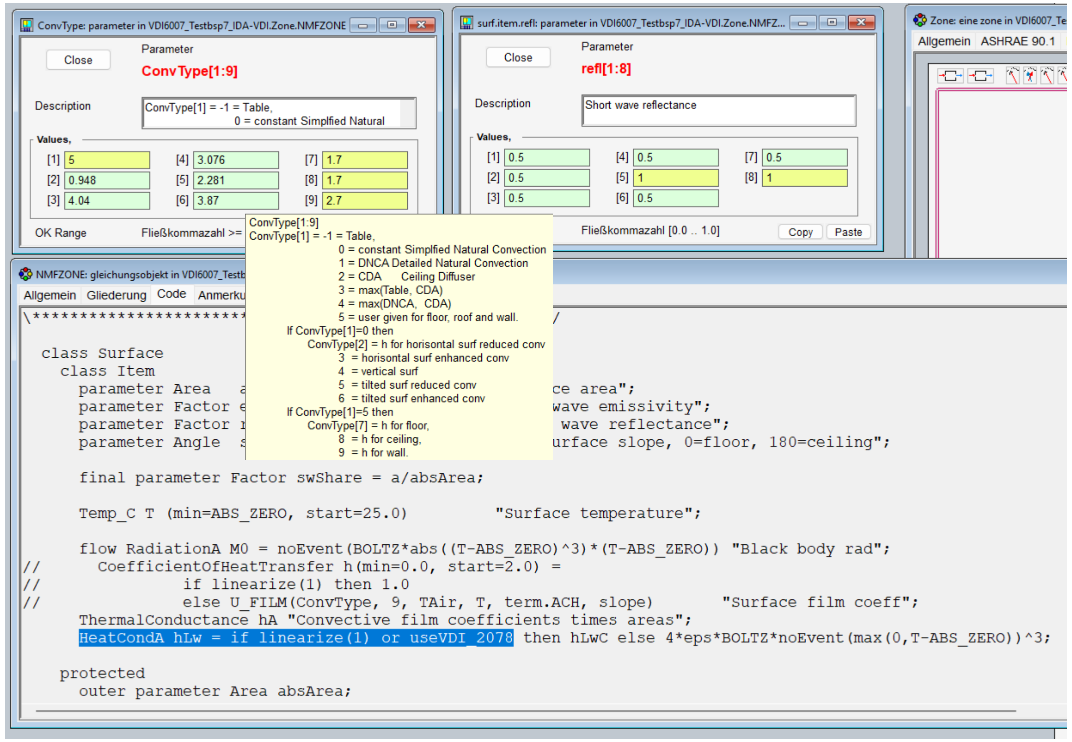
  - long-wave and short-wave radiation distributed evenly across all surfaces instead of taking view factors into account



Analysis of individual VDI model simplifications

VDI Zone model and convective coefficients

- VDI zone model enforces constant convective coefficients and linearized longwave radiation
- Radiative exchange simplified: no view factors; uniform distribution across surfaces
- Room air temperature: minor differences between zone models, but strong dependence on wall model formulation
- Simplified wall models increase damping of thermal dynamics and alter transient response
- Operative temperature deviates significantly only after zone model simplifications (radiation + convection)

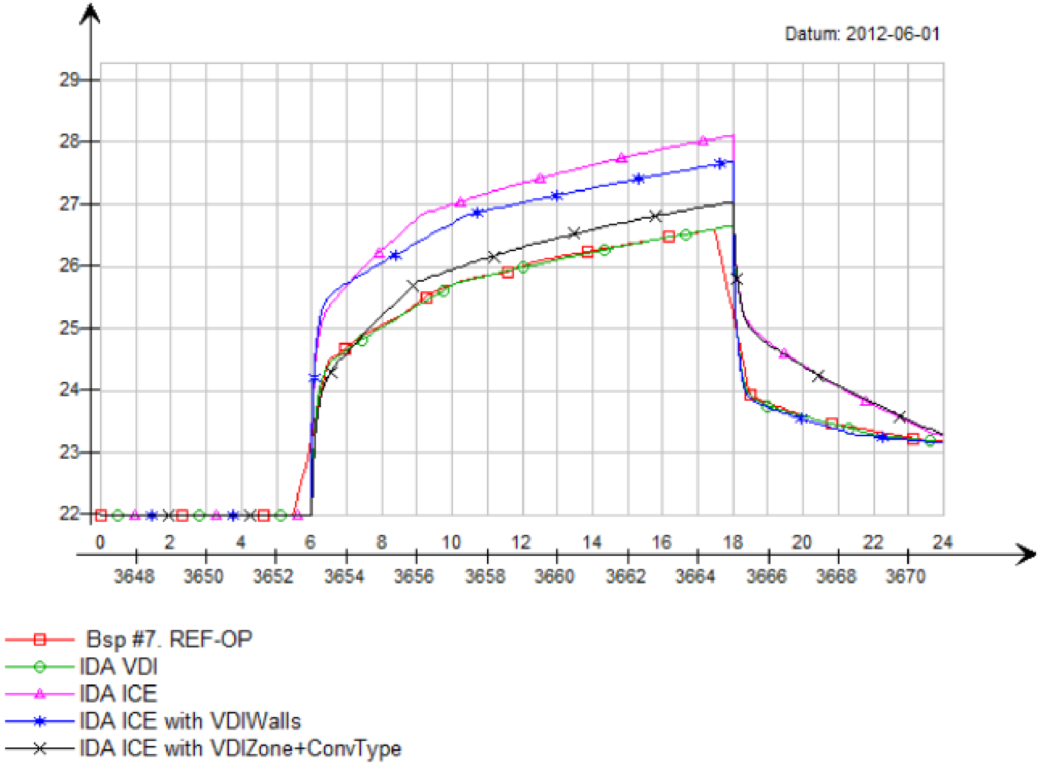


Figure 10: Comparison of operative temperature according to VDI 6007, Test Case 7: IDA ICE model versus various individual adjustments to VDI

VDI simplifications, particularly those affecting radiative and convective heat transfer, substantially distort thermal dynamics.

Impact on HVAC sizing and thermal comfort assessment

Effects of simplified vs. dynamic modeling approaches

- VDI-compliant simplified models ensure reproducibility but introduce systematic deviations
- Simplifications distort heating/cooling power estimation → frequent system oversizing
- Steady-state and simplified models systematically overestimate energy demand
- Operative temperature deviations (~1.5 °C) reveal major comfort prediction inaccuracies
- Equation-based dynamic models capture nonlinear radiation and coupled processes → higher fidelity results

Only sufficiently detailed, equation-based dynamic simulations enable accurate HVAC sizing and reliable thermal comfort assessment.

Impact on Building design

VDI validation requirements constrain the use of advanced simulation methods

- VDI validation forces simplification of even highly accurate models
- Simplifications may disregard essential physical principles
- Dynamic simulation tools (e.g., IDA ICE) are technically mature but underutilized
- Standards-based simplified methods dominate practice and hinder innovation
- Equation-based dynamic simulations are essential for accurate comfort and heat transfer modeling

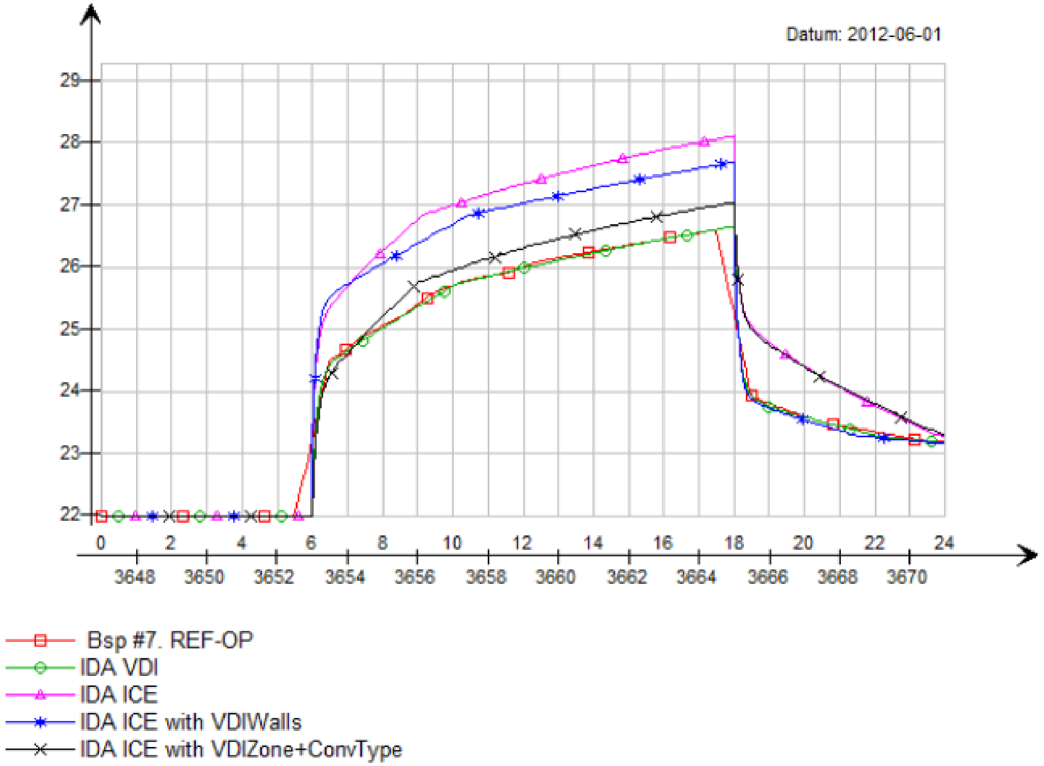


Figure 10: Comparison of operative temperature according to VDI 6007, Test Case 7: IDA ICE model versus various individual adjustments to VDI

VDI-based validation frameworks inhibit physically accurate, equation-based simulations, limiting innovation and optimization in building design.