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Experience-based user guide for IDA-ICE

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Publication date:
2023

Document Version
Publisher's PDF, also known as Version of record

[Link to publication from Aalborg University](#)

Citation for published version (APA):

Schaffer, M., Bugenings, L. A., Andersen, K. H., & Melgaard, S. P. (2023). *Experience-based user guide for IDA-ICE*. Department of the Built Environment, Aalborg University. DCE Lecture notes No. 83

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DEPARTMENT OF THE BUILT ENVIRONMENT
AALBORG UNIVERSITY

Experience-based user guide for IDA-ICE

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DCE Lecture Notes No. 83

Experience-based user guide for IDA ICE

by

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April 2023

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Published 2023 by
Aalborg University
Department of the Built Environment
Thomas Manns Vej 23
DK-9220 Aalborg Ø, Denmark

Printed in Aalborg at Aalborg University

DCE Lecture Notes No. 83

Introduction

The number of nowadays available BPS software outnumbers 100 by far (Best Directory, n.d.; Crawley et al., 2008), and each has different capabilities, foci, and requires different user knowledge to deploy different functions.

Developed in the framework of the IDA project, IDA ICE was released in 1998 with a focus on indoor climate and energy (ICE). The program is based on equation-based modelling and uses a variable timestep differential-algebraic (DAE) solver. To use the power of DAEs-based (differential-algebraic system of equations) modelling, the neutral model format (NMF) language was developed and applied to the first public domain library of IDA ICE (Sahlin et al., 2004).

Based on the nodal method, IDA ICE treats each zone as a homogeneous volume where quantities such as temperature, pressure, and concentration represent the whole zone. The zones (also nodes) represent, for example, a room, a building component, or a heat and contamination load. For each of these nodes, the physical phenomena are solved individually (Fouquier et al., 2013; Hilliaho, 2017).

IDA ICE provides different user interfaces: the wizard for less experienced users, the standard where users use the graphical interface, and the advanced for the users who want to interact with the mathematical model (Sahlin et al., 2004)

This lecture note aims to give insight into some of the not so straightforward to find functionalities of IDA ICE, to summarise the theoretical background of important components and give examples for good practice. The IDA ICE version used throughout this lecture notes is 4.8 SP2 with an expert license.

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Other resources

Besides the built-in help, which can be accessed directly from IDA ICE and the exhaustive forum, several other valuable resources for IDA ICE exist. In the following, a non-exhaustive overview is given.

Bring et al., 1999 Bring et al., 1999 describe some of the fundamental simulation components used till today in IDA ICE. Sahlin et al., 2004 Sahlin et al., 2004 outline an early version of IDA ICE.

Tutorials and Webinars

Please note that the authors take no responsibility if the link source changes and is no longer available.

English tutorials

IDA ICE Tutorial Part 1: <https://www.youtube.com/watch?v=t9B8pPSN-pM>

IDA ICE Tutorial Part 2: <https://www.youtube.com/watch?v=zY0xG71sTLo>

IDA ICE Tutorial Part 3: https://www.youtube.com/watch?v=WeXzxoXr_s0

IDA ICE Tutorial Part 4: <https://www.youtube.com/watch?v=gavGMnaL8gk&t=41s>

Swedish tutorials

IDA ICE Guide: <https://www.youtube.com/watch?v=p-qr1tao-UQ>

Documentation provided by EQUA

http://www.equaonline.com/iceuser/new_documentation.html

EQUA webinars

Parametric modelling and graphical scripts (first 20 minutes of video):
<https://www.youtube.com/watch?v=Qs6tGDpY44k>

Webinars: <https://www.youtube.com/user/EQUAsimulation/videos>

Validation reports

http://www.equaonline.com/iceuser/new_validationreports.html

General tips for working with IDA ICE

IDA ICE resources

One can define so-called project resources in IDA ICE. They function as a template for various objects. The best way to create a resource differs slightly depending on the object. For all objects but zones, the best way is to create one instance with the desired properties, then go to the "outline" tab, right-click on the object, and select "new resource". For zones, one has to right-click on an existing zone template (In "outline" under IDA resources) and select "New Resource". The main benefit of these templates is that one can easily create multiple objects with the same properties. Also, if not manually changed, all instances will update automatically if the template is changed. This is very useful for the parametric variation of multiple objects simultaneously, as described in the Section Parametric modelling.

Geometry

When modelling multi-floor buildings, it is important to ensure that the ceiling/floor is located appropriately. Furthermore, it is essential to check that the "Envelope area definition" is set correctly in the Thermal bridges' menu on the General tab before starting to model. Commonly the option "Overall internal" is used.

Multiple instances of IDA ICE and multiple parallels

Apart from running multiple simulations at the same time, it is possible to run multiple instances of IDA ICE at the same time. Assuming IDA ICE is installed in "C:\Program Files (x86)", the steps to achieve this are as follows:

- Copy the IDA ICE icon to the desktop.
- Right-click on the icon → properties
- Change the TARGET from
 - "C:\Program Files (x86)\IDA\bin\lice.exe" to
 - "C:\Program Files (x86)\IDA\bin\lice.exe" -C XX -L "*label*"
 - "XX" can be any kind of number.
 - "*Label*" can be any kind of string, e.g., "Instance 1" so one is able to keep track of the simulations.

One can now run multiple instances of IDA ICE. Furthermore, it is possible to run each parametric run in each instance. Therefore, it is first necessary to set the number of cores for parallel computations accordingly. For example, if one has 12 cores and wants to run four independent instances, one can run three parametric simulations simultaneously for each instance. When changing the number of cores for parallel computations, it is advisable to do so in the "original" instance, as changing it in the sub-instances is sometimes ignored.

This workflow can be advantageous for running parametric simulations for multiple independent models. Each model takes longer to simulate, but the process requires less intervention. As for parametric simulations in general, it is essential to consider that the

number of available CPU cores and the available RAM can be the limiting factor for parallel computations. Furthermore, depending on the number of logged outputs, the hard drive capacity is a factor that should be considered.

Working with climate data

This section briefly shows the visualisation of the climate data imported into the model. Weather data can be visualised on the "General" tab of the building overview (Figure 1).

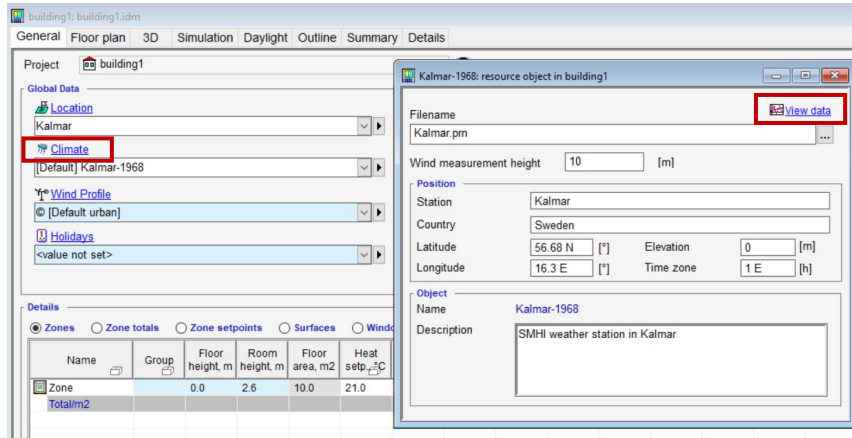


Figure 1 Steps to visualise climate data.

To visualise a single quantity, one needs to double-click the legend text of the quantity (Figure 2).

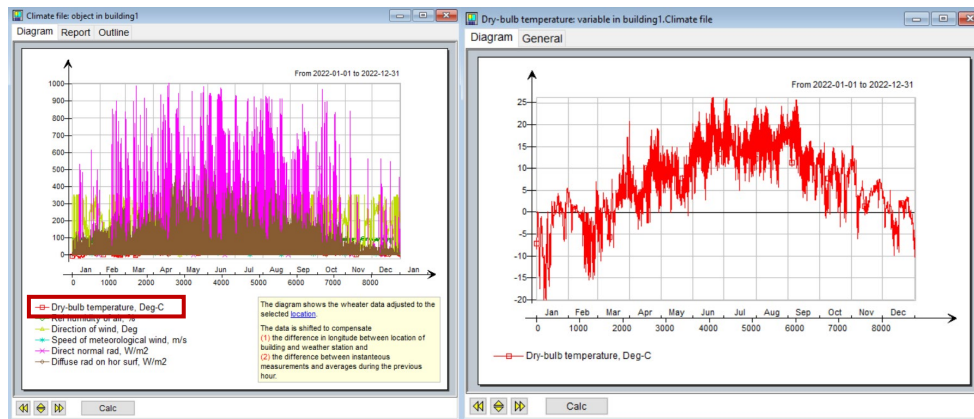


Figure 2 Steps to visualise a specific quantity of the climate data.

The "Time slice" option (Figure 3) can be used to visualise a specific period.

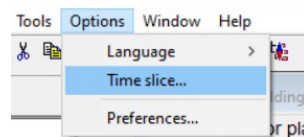


Figure 3 Time slice option usable to control the timespan of the displayed quantity.

User-defined parameters and schedules

Logging user-defined parameters

To log any parameter, one needs to open either the supervisory control (on the building "General" tab) or the zone controller (within a zone on the "Advanced Tab") (Figure 4)



Figure 4 Examples of a supervisory control on the building level and a zone control

To log into a non-existent output file, "OUTPUT-FILE" from the Utility tab (Figure 5) must be added.

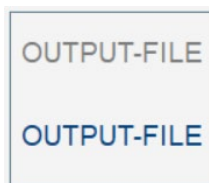


Figure 5 Output file icon for graphical modelling

The desired parameters are selected with "LinkRef", and then this value must be multiplied by the value 1 because otherwise, the parameters are not logged (Figure 6).

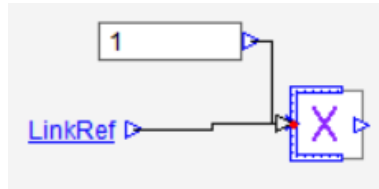


Figure 6 Example of a via LinkRef linked parameter. To be logged, this parameter must be multiplied by 1.

The output of the multiplier (OUTSIGNAL) can be logged to the Output-file created or one of the existing Output-files (Figure 7). From the supervisory control, logging into zone-related Output-files is impossible.

OUTSIGNAL	0.0			OUTPUT-FILE	Output signal
INSIGNAL[1:2]	{0.0 0.0}			[off]	Input signals
TEMP[1:2]	{0.0 0.0}			[off]	Temporary vector (to avoid rep...

Figure 7 Example of a multiplier where the output is logged to 'OUTPUT-FILE'

Creating variable schedules

Creating variable schedules can be advantageous when occupants or equipment should react to varying boundary conditions such as the indoor temperature. In the following example (Figure 8), the four occupants shall leave the zone gradually if the temperature

surpasses 25 °C. At 27°C, the zone should be empty, and people start returning when the temperature falls below 27 °C. One first creates a "Zone controller" for the desired zone to facilitate this. The next step is to create the needed condition with the graphical components. For this example, the linear segment controller is used. Below 25 °C, all occupants are in the zone (y coordinate is 1), and above 27 °C, no occupants are in the zone. Between 25 °C and 27 °C, occupants leave or return linearly.

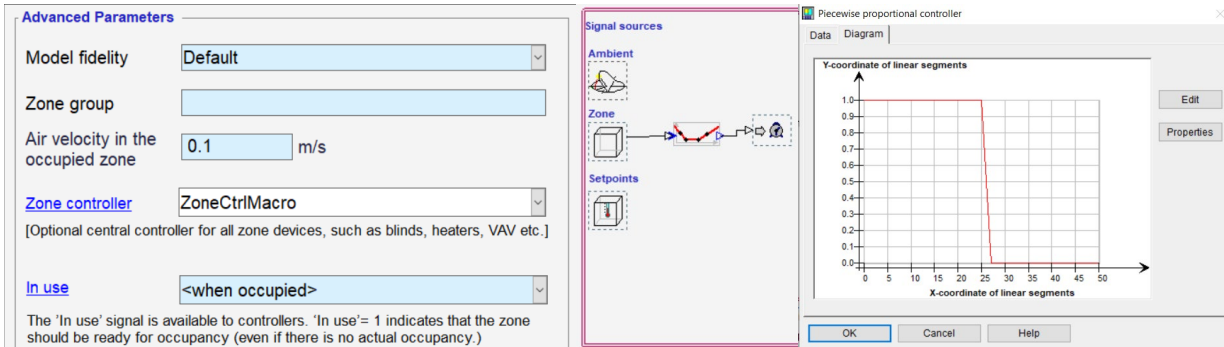


Figure 8 Steps to create a variable schedule.

Plotting a graph with the operative temperature and the occupancy (Figure 9) confirms that the schedule works as intended. When creating the schedule within the zone, it will be only available in this particular zone. To make a schedule available to all zones, it must be created within the supervisory control.

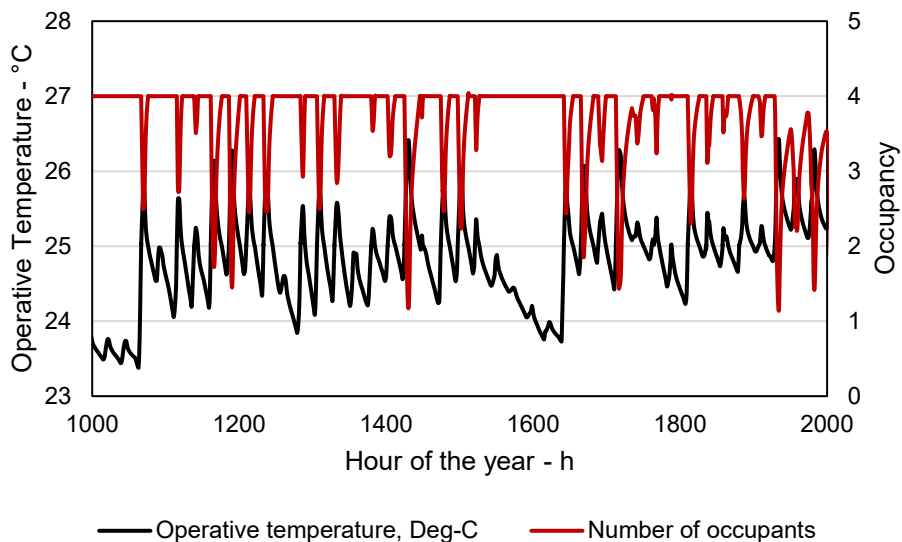


Figure 9 Variable schedule. Occupants leave the room when the indoor temperature surpasses 25°C.

BIM - Import

Integrating IDA ICE into the process of building information modelling is possible. Therefore, a BIM model is needed, which was created, for example, with *ArchiCAD* or *Revit*. Some BIM-generating tools provide plug-ins or already integrated programs for early-stage design modelling, such as *Insight 360* in *Revit*. The plug-ins are usually limited but do not require as much information as IDA ICE. The BIM geometry and some additional information can be exported for detailed design modelling. Common formats are IFC or GBXML, whereby IDA ICE uses IFC. The export files contain information such as zones, surfaces, constructions, fenestration, and the buildings' surroundings. Sometimes geometries are too complex models to be imported without significant processing in IDA ICE or creating errors. Therefore, BIM corrective tools can smooth the process between the BIM program and the simulation program. One example is *SimpleBIM* (license needed). For simple models, files can be imported directly into the IDA ICE. The process within the program is described in the next paragraph. Exporting the results to Excel or conducting post-processing within IDA ICE is possible. Result visualisation within Revit is not possible. *SimpleBIM* offers the possibility to visualise the results attached to the model geometry.

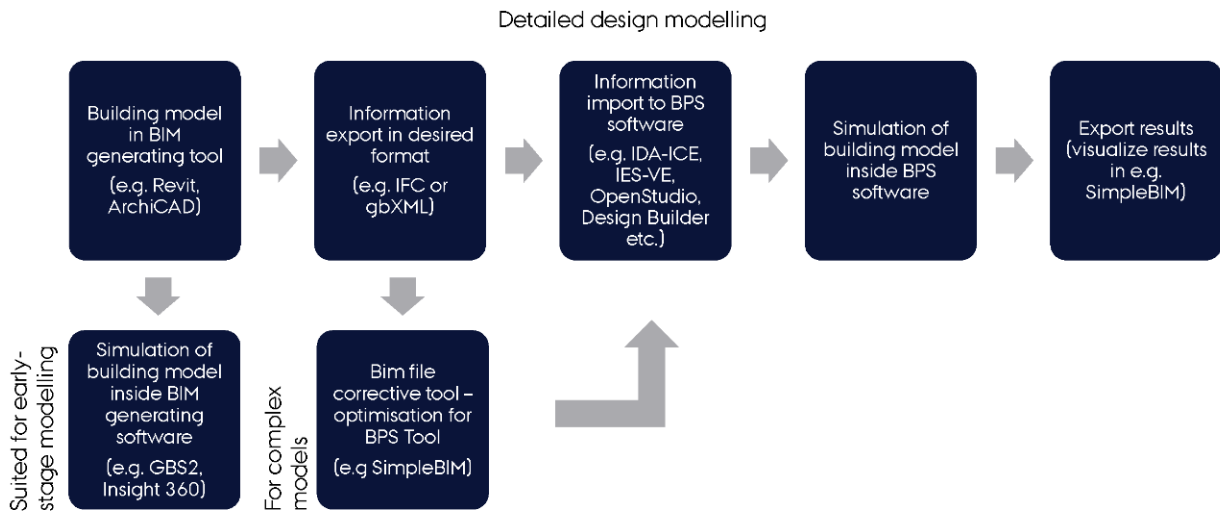


Figure 10 Workflow BIM to BPS adapted from (Kamel, Memari 2019)

Example workflow – from Revit to IDA ICE

Process in Revit

- Define project north and true north
- Set project to project north
- It is advantageous if the global origin of the model is close to the building (otherwise, the building might be a bit hard to find in IDA ICE)
- Define rooms/spaces of areas you want to simulate
- Check that all room-adjacent constructions (incl. thickness of layers) are defined

- Check that the function of all external constructions is set to 'exterior'
- Check that the function of all internal construction is set to 'interior'
- Thermal properties of materials are not exported
- U-values of the element are exported
 - IDA ICE can/will not use this information
- Export IFC file
 - Supported formats: IFC 2x, IFC 2x2 and IFC 2x3 (IFC2x3 Coordination View Version 2.0)

Process in IDA ICE

Before importing the IFC file

- Create new project
 - save this file locally on your computer
 - saving in the cloud can corrupt the file
- Make all settings on "General tab" building-related parameters
 - Location/Climate/windprofile
 - Thermal bridges/Infiltration/pressure coefficients
 - Optional: holidays, extra energy and losses, ground properties
 - Check if system parameters match your assumptions
 - Defaults → set generator efficiencies (if you are interested in energy consumption)
 - Make settings for the air handling unit and plant
- Create all materials you will need for the simulation
 - General tab → Details → Materials right-click on one of the materials → new resource
- Adjust material properties of the new material
- Create zone templates for zones that occur more than once ("Floor plan" tab → ordinary zone → show/edit template → save as new template)
 - Here you need to define the internal heat load and schedules
- Edit preferences for IFC import → options → preferences → IFC Import
 - If you have many windows next to each other --> check "merge windows"
 - Others keep unchecked
- save this file as a template (backup)

Importing the IFC file

- On 'Floor plan' tab

- Import → IFC (3D BIM) → select file
- If there are more buildings inside the IFC file →select the relevant one
- On '3D' tab
 - Check if your model was imported correctly
- On 'Floor plan' tab
 - 'Level' → enter the height of the selected floor
 - 'IFC' → Mapping → Category 'Material' → map IFC data with created materials in IDA ICE (select material pair and click 'Map to selected')
 - Category 'Constructions' → Select relevant constructions → click 'Import from IFC'
 - Construction appears on the right if all materials were assigned
 - Category 'windows' → map windows with the IDA ICE resources
 - Category 'spaces' → map spaces with IDA-resources

Importing shading for use with the daylight module

When importing shading objects for use in the daylight module, one must split all elements that do not have the same properties into different files, examples are floors, walls, ceilings, window frames, etc.

Parametric modelling

Parametric modelling is highly useful for studying various cases, the influence of different parameters (Sensitivity and uncertainty analysis), or finding an optimal design. It is accessed from IDA ICE under "Tools" and the "Parametric runs".

In principle, any parameter can be varied, either by selecting it from the parametric run window (using the [+] button) (Figure 11) or by right-clicking on the parameter and selecting "Add to name of parametric run".

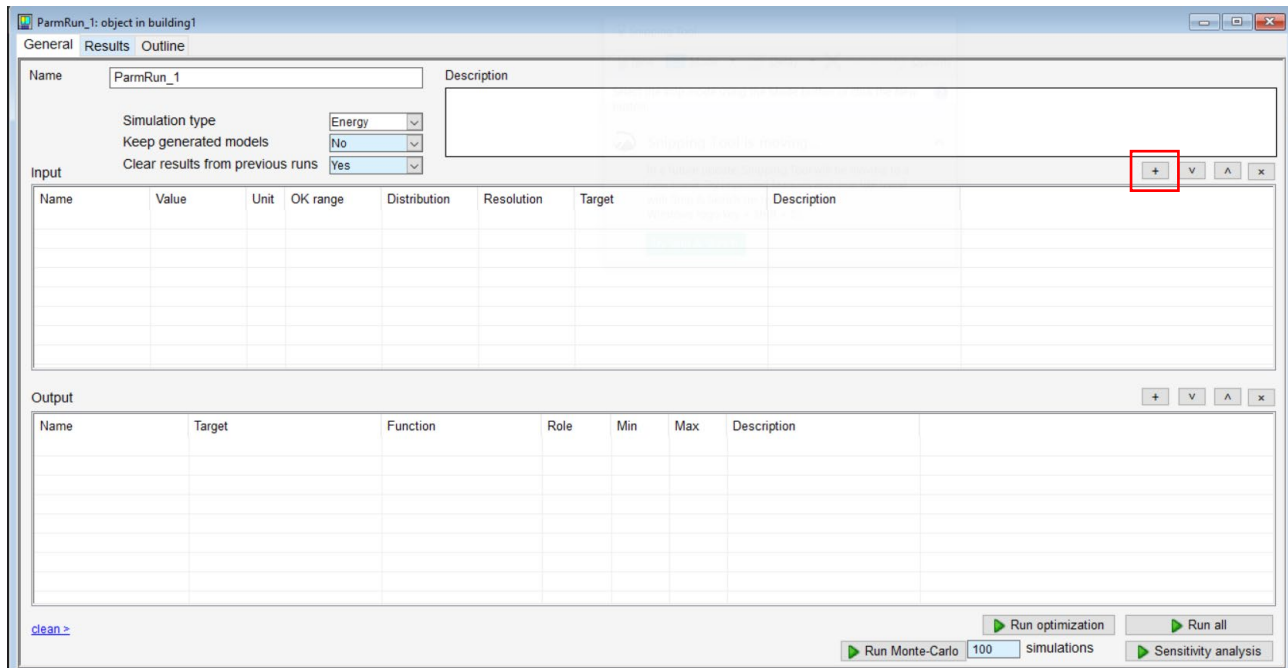


Figure 11 Parametric simulation window

Extended possibilities

The described basic capabilities can be easily extended. Firstly, by using IDA resources/templates (as described in the Section IDA ICE resources). If a template parameter is varied, the instances will use this updated parameter (unless the link was manually broken). Thus, this allows the variation of one parameter of multiple instances at once, e.g., the glazing of all windows.

Secondly, a graphical script (Section Graphical scripting) can be used to manipulate, e.g., the geometry of a model parametrically.

Thirdly one can define custom parameters. For this, a custom parameter must be first added in the parametric run window ([+] button)(Figure 11), then the possible values can be defined (see also the Section Sampling below). In the third step, the target is defined using the IDA code. An example where the thickness of the insulation layer in two wall types is varied simultaneously looks like this:

```
(:UPDATE [@]
((WALLDEF :N "External_wall") ((WALL-LAYER :N "Insulation") (:PAR :N THICKNESS :V _VALUE)))
((WALLDEF :N "External_wall_1") ((WALL-LAYER :N "Insulation")(:PAR :N THICKNESS :V _VALUE))))
```

WALLDEF defines that it is a wall definition (construction); the following string defines the name of the construction, in this example, "External_wall" and "External_wall1". *Wall-Layer* then defines that a construction layer is selected; again, the following string defines the layer name. After that, *Par* defined the parameter specified by the following string "Thickness" before *_VALUE* refers to the value (input) of the parametric run.

The fourth option is to define a parameter that depends on another parameter. This option is illustrated based on the following example: the window glazing should be selected based on the climate file. The following five steps are necessary to do this:

1. Right-click on the climate selection and add it to the parametric run.
2. Select the climates to be varied, for this case: Aalborg, Berlin, and Wien.
3. Add the glazing of a window/a window template etc.
4. Now press "alt" and left-click on the glazing range
5. Now write the following code:

```
(:EVAL (:COND ((== ["CLIMATE"] "DNK_AALBORG") (:RETURN ("Triple A1")))  
              ((== ["CLIMATE"] "DEU_BERLIN") (:RETURN ("Triple C1")))  
              ((== ["CLIMATE"] "AUT_WIEN-SCHWECHAT") (:RETURN ("Triple D1")))))
```

Here "CLIMATE" refers to the name of the parameter, the following string is the name of the climate file (e.g., "DNK_AALBORG"), and the last string is the value, which is returned, so in this case, the name of the glazing (e.g., "Triple A1). This can be applied to any parameters and combined with a graphical script.

Sampling

Sampling can be defined as discrete or continuous for numeric parameters, with continuous being either uniform or triangular. A discrete sampling is defined by writing the desired values in round parentheses, e.g., (0.1 0.2 0.3) in the "OK range" column. For continuous uniform or triangular distribution sampling, the upper and lower limits are written in brackets, e.g., [0 1], and the desired distribution and number of samples (resolution) are selected. Of course, one can also mimic different (more complex) distributions by sampling them beforehand and defining a discrete distribution. This also allows making sampling reproducible across different parametric runs

Post-processing

Parametric runs can quickly generate hundreds or thousands of different simulations. Thus, post-processing becomes an important task. In the following one, good practices for data processing are outlined.

Often more than the default information is needed, which makes external post-processing of the simulation results necessary. Thus, it is required to access all in the parametric run generated file and results. All generated models can be kept by setting the corresponding option in the parametric run window to "YES" **BEFORE** executing the parametric run. It is to be noted that this can, depending on the selected outputs and length of the simulation period, generate hundreds of gigabytes of files. Thus, it is recommended that only the needed outputs are logged. After the parametric run is completed, one must NOT save the

original file (from which the parametric simulation is started), as this deletes all results in the model files from the parametric run. One can now open one model from the results tap by double-clicking on it. Now the model's path can be looked up ("Save as" opens a Windows Explorer window with the current path of the Model). One can change the folder where the parametric run models are saved in IDA ICE "Options" → "Advanced" under the temporary folder path. Knowing the folder's location that contains all parametric models, the entire folder with all models and results generated during the parametric run can now be copied to a new location. Now one can save the original IDA ICE model again. The parametric models are saved as unpacked IDA ICE files named "run10001", "run10002", and so on. Now all results can be processed. All outputs are stored as .prn files, and tab-delimited text files. It is to be noted that IDA ICE uses not a fixed timestep for the simulation but a dynamic one. Thus, the results are not equidistant, and the precise timestamps can vary between the different models of the parametric run. Additionally, IDA ICE can save multiple results with the same timestamp, which needs to be considered particularly for control signals. A good practice is moving results with identical timestamps apart by a small amount, e.g., a small fraction of a second.

Graphical scripting

Graphical scripting can be used to change model parameters, which affect the build model, parametrically. Typical examples are material properties, the thickness of construction layers, or geometry manipulations.

For example, to manipulate the orientation of the building, the following steps are necessary:

1. Create an empty graphical script (gear symbol on yellow background)
2. Open the site properties and right-click on the orientation, then select mapping and the before-created graphical script and insert script output by left clicking
3. Add a local parameter in the graphical script and connect it to the script output

Now, this local parameter controls the orientation of the site.

Following same principle, other parameters such as material thicknesses of constructions can be changed either directly or depending on other values.

Changing the geometry of a zone is more complex but can be accomplished as follows:

1. Create an empty graphical script (gear symbol on yellow background)
2. Now set up a local parameter and an output parameter for each direction that should be changed, e.g. width, height etc.
3. Now right-click on every output parameter and name it: e.g., "Depth"
4. Now open the Outline of the Zone for the geometry should be modified
5. Select the Corners (Geometry → Corners)
6. Right-click on the corners and select "Mapping" → Edit link
7. Now select Advanced and write the following in the dialogue (Figure 12):

```
(:CALL MAKE-ARRAY '(4 2) ':INITIAL-CONTENTS ((0.0 0.5) (8.0 0.5) (8.0 ["Geometry" "Depth" X]) (0.0 ["Geometry" "Depth" X])))
```

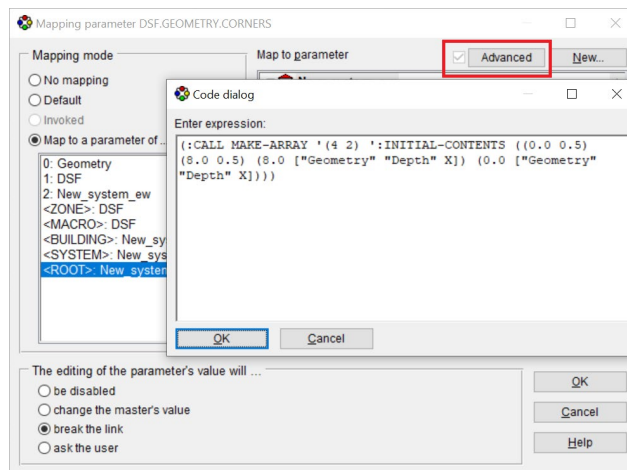


Figure 12 Example of Advanced parameter mapping to change the geometry of a zone.

Thereby an array is generated, which replaces the original array. INITIAL-CONTENTS refers to the original coordinates, which are then replaced with the new ones. In this example, the 0.5, which refers to the y-coordinate, is replaced with the values from the graphical script. "Geometry" refers to the name of the graphical script, and "Depth" is the name of the output parameter. One can also change the x-coordinate in the same manner.

It is important to consider that the building body does not change automatically if one changes the zone geometry. Thus, most likely, the building body must be adapted in the same manner. Usually, this works best by using the same local input and subtracting/adding a constant so that the output fits the building body, as shown in Figure 13.

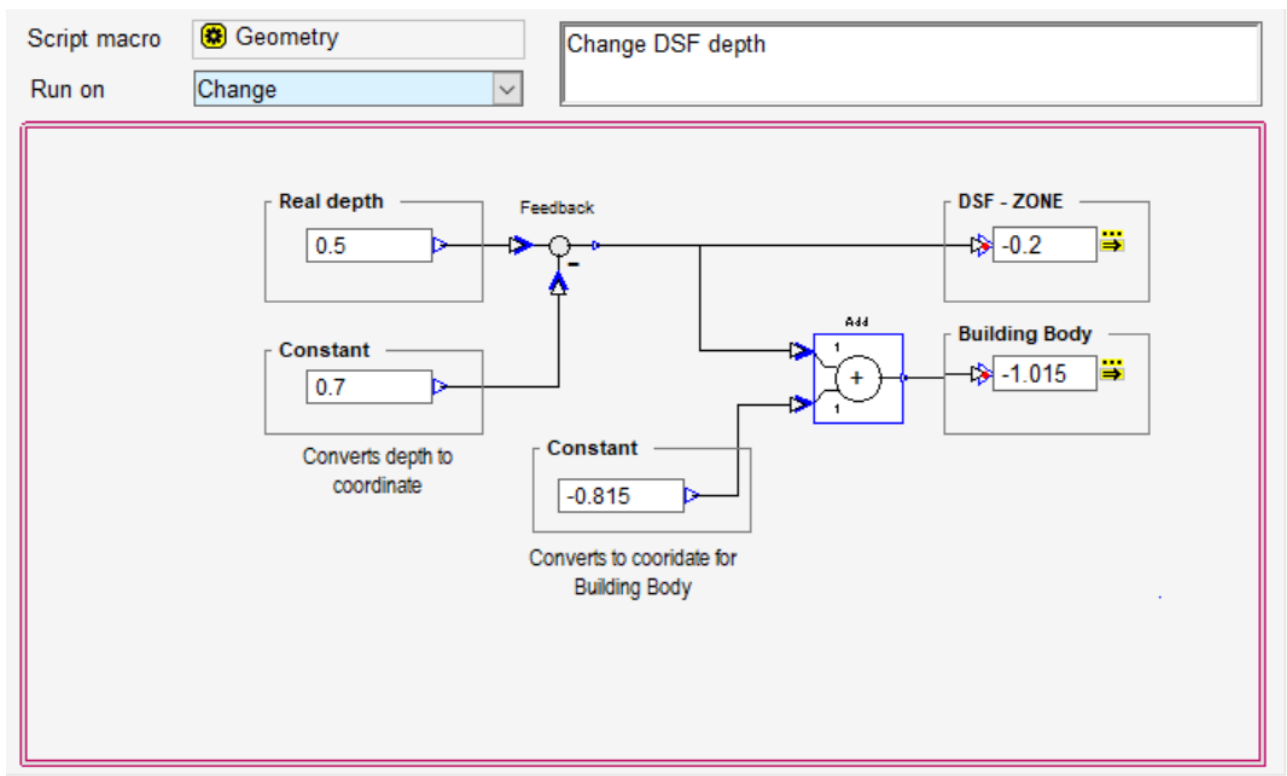


Figure 13 Example of graphical script to change the zone depth and adapt the building body accordingly.

Theoretical background of model objects

This chapter provides an overview of the theoretical aspects of some of the most used components. Further, it provides an overview of the available internal heat convection coefficient algorithms as they are frequently reported incorrect or incomplete in literature, e.g., Catto Lucchino et al., 2019 and Krusaa & Hviid, 2021

Climate conditions

Solar radiation

The diffuse solar irradiation on each surface is calculated in IDA ICE in the component (FACE), which uses, per default, the method by Perez et al., 1990, whereby also methods based on ASHRAE (Fundamentals 1997) and Kondratjev can be selected by the user (Bring et al., 1999). Based on the results of Loutzenhiser et al., 2007 where it was shown for IDA ICE that the method based on Perez et al., 1990 leads to the best agreement for diffuse solar irradiation on a southwest facade, this model was also chosen for this work. For the direct solar irradiation allocation to each surface, the solar position is calculated based on ASHRAE Fundamentals 1997 (Bring et al., 1999).

Wind velocity

The velocity at the roof height of the building is calculated in CLIMATE based on the wind velocity given in the climate file based on the following general expression based on ASHRAE Fundamentals 1997 (Bring et al., 1999).

$$v = a0_{coeff} \cdot v_{ref} \cdot \frac{h^{a_{exp}}}{h_{ref}} \quad [1]$$

Where v is the wind velocity at building height [m/s], v_{ref} is the wind velocity at reference height, [m/s], h is the height of the building, [m], h_{ref} is the reference height, [m], $a0_{coeff}$ is the wind profile coefficient, [-], a_{exp} is the wind profile exponent, [-].

Sky temperature

The sky temperature can be calculated based on two methods in the CLIMATE component. The first is a static relation, whereas the sky temperature is defined as 5°C below the air temperature. This model is used per default only if no sky cover is provided in the weather file but can also be directly selected by the user. If cloud cover is provided per default, the model based on Walton, 1983 and Clark & Allen, 1978 ("Walton-Clark-Allen model") is used.

Zone models

There are currently two-zone models implemented into IDA ICE, the simpler energy model (CESIMZON) and the more detailed climate model (CEDETZON). The main difference between these two models is that in the energy model, longwave radiation is modelled based on the mean radiant temperature and is distributed based on surface areas. Shortwave radiation is also distributed according to the surface area but weighted with their respective absorption factor. Further, this model simplifies all internal (adiabatic) constructions and thermal masses (furniture) into one active heat capacity. The CHTCs are only calculated for external constructions, windows and heated/cooled surfaces. For internal constructions, the CHTC is a user input parameter. (Bring et al., 1999)

In contrast, the detailed model (CEDETZON) uses a view factor calculation based on a routine by Li Yuguo 1992 (Bring et al., 1999) to distribute irradiation. However, this introduces the limitation that this model can only be applied to a rectangular room geometry, that all surfaces have to see each other and that obstacles within the room are ignored. The emitted and reflected irradiation within the zone is distributed using the net radiation method according to these view factors. It is to be noted that longwave irradiation originating from occupants and equipment is treated in the same manner for both zones. The position is not taken into account, and the distribution of longwave radiation before the first reflection is proportional to the surface area of the enclosing

Envelope models

Window models

Windows can be modelled in two ways: a simplified model (CEWIND) and a detailed model (DETWIND) based on ISO 15099:2003. In the following, only the detailed model is described. This model uses a pane-by-pane model, which calculates all thermal and optical properties of the window based on the individual panes and gas fillings in the cavities. Thereby also, angle-dependent optical properties of the window are calculated considering multiple reflections and the solar absorption of each pane. Further, even the glass panes' heat capacity is considered. As ISO 15099:2003 does not cover the angular dependent properties of single-pane windows (coated as well as uncoated), these are calculated based on ASHRAE Fundamentals 1997 ("Fresnel equation") (Hilliaho, 2017). Further, if all used glass panes and the sunshades have defined spectral data, optical properties are calculated for each wavelength, which are then integrated into averages according to EN 410 (EQUA Simulation AB, 2018). Shading from buildings or fixed fins is calculated in the WINSHADE object while shadings associated with the window, such as venetian blinds, are calculated in the window model.

Wall models

Four wall models are available: RCWall, fdwall, BDFWall and Adwall. RCWall uses an RC network model to calculate the behaviour of the wall. Thereby, the material layers are reduced to three (sometimes two) nodes by optimising parameters such as heat capacity at different nodes, the resistance between nodes and resistance on the sides. The advantage is that this model decreases its calculation time, and the accuracy is known, whereas the disadvantage is that it lacks physically meaningful temperatures inside the wall. Adwall is based on the RCWall and is used for adiabatic internal walls where heat transfer can be neglected (Bring et al., 1999).

fdwall and BDFWall are finite difference models of a multi-layer component. Each material layer is thereby discretised into n number of layers, and following a chain of serially connected heat capacities and thermal resistances is calculated. The difference is that BDFWall uses a FORTRAN subroutine for numeric integration using the implicit Backward Euler-Method or a Midpoint-Method, which both have high numerical stability. By default, the Backward Euler-Method is used by IDA ICE. The default wall model is BDFWall for walls with heat transfer and Adwall for walls without.

Airflow component models

IDA ICE has a fully integrated airflow network model. The components between two zones or one zone and the environment can be horizontal and vertical openings, leaks and supply and exhaust air terminals (Bring et al., 1999; Hilliaho, 2017). These components are seen as airflow paths and connect different control volumes as an idealised collection (Axley, 2001). IDA ICE thereby calculates the airflow based on pressure differences between the connected zones or the zone and the environment. For the pressure differences, temperature differences and wind are taken into account.

Large openings

Large vertical openings are, for example, interior or exterior doors, openings without doors and windows that can be opened. They can be placed on external walls facing outdoors and in-between two zones. Large horizontal zones can be placed in ceilings connecting zones but also into roofs. For all openings and windows, the C_d (default is 0.65) value can be determined.

Large vertical openings

The model used to calculate a bidirectional airflow between two zones (CeIVO) is based on the Bernoulli equation, where the orifice equation is the governing equation (Hayati et al., 2016).

In the model CeIVO, two different flow profiles are considered:

- a slanted profile in case the density is different between the zones
- a flat profile in case the density is the same

For slanted profiles, the mass flow depends on the level where the pressures are equal (neutral level). With the pressure difference at the top and the bottom, which are individually calculated, the mass flows in each direction through the opening can be calculated dependent on the profile shape. Finally, the net mass flow, the net heat flux, the net amount of fraction transport and the moisture transport are calculated. Detailed equations are given in Bring et al., 1999 under Large Vertical Openings. The equations of this publication are based on van der Maas, 1992.

Large horizontal openings

The bidirectional flow through a large horizontal rectangular opening (CeIHO) is modelled based on the density as well as the pressure difference above and below the opening. After both differences are calculated, the mass flow due to pressure differences is calculated. With the density differences, the volume flow is determined. Lastly, both flows are used to calculate the total mass flow, the convected heat, the convected contaminant fraction and convected moisture fraction.

Leakage components

In IDA ICE, different models are used to calculate infiltration, CeLeak for bidirectional infiltration between zones and environment and between two zones. For one-directional infiltration, MLeak is used. The infiltration between zones and the environment can be defined as general infiltration for the whole building but also for each zone individually. Between two zones, individual leakages are defined at each surface which is supposed to have a leakage. Thereby it can be chosen between a "pressure-driven flow" (CeLeak), which

is defined by the leak area at 4 Pa ($C_d=1$) or power-law coefficient, or a "given (pressure independent)(MLeak) flow", which is defined by a one-directional flow (l/s) and a schedule.

The mass flow is determined by pressure difference dependent, independent of the position - between zone and environment or between two zones. For both leak components, energy transfer, containment fraction, and moisture are calculated as well.

The aforementioned equivalent leakage area is the total area of all cracks in a structure and is calculated according to Charlesworth, 1988 Charlesworth, 1988 "*as the area of a sharp edge orifice which would pass the same volume flow as the building at given pressure difference*". It can be calculated using Equation [2].

$$EqLa = \frac{Q}{C_d \left[\frac{2\Delta P}{\rho} \right]^{0.5}} \quad (\text{Charlesworth, 1988}) \quad [2]$$

Where EqLa is the equivalent leakage area, [m^2], Q is the volume flow rate, [m^3s^{-1}], C_d is the discharge coefficient, [-], ρ is the density of air, [$kg\ m^3$] and ΔP is the pressure difference at 4 Pa, [Pa].

Radiation modelling

One shading calculation model (WINSHADE) exists for each object, such as a window. In this model, the shading from external objects (building, external shading) for the respective surface/object is generated for both direct and diffuse solar radiation. Thereby diffuse radiation from the sky is shaded, but the reflection from the ground is always considered to be not shaded by any external object (EQUA Simulation AB, 2018).

As solar radiation reaches the inside of a zone/room, its diffuse part is spread diffusely, whereas the direct part hits an exact location. Therefore, the whole window or opening is considered as a source and not just the part which is the actual source. The intensity is adjusted accordingly. After its first reflection from an opaque surface, direct radiation is also diffusely spread. Thereby, in the same manner, as for windows or openings, the whole surface is treated as the source. This modelling is for both internal as well as external components (EQUA Simulation AB, 2018).

Convective heat transfer coefficients

In general, convection only occurs in gases or liquids where heat is transported through flow. Thereby it is differentiated between natural and forced convection, where natural convection is the flow caused by buoyancy at constant pressure, and forced convection is the flow caused by the pressure difference (e.g. wind pressure). Natural convection can be laminar but also turbulent, whereas forced convection is mostly turbulent. The heat transfer at surfaces by convection is influenced by the following parameter: (Zürcher & Frank, 2018)

1. temperature difference between surface and air
2. velocity of the air
3. flow regime: laminar or turbulent
4. direction of the heat flow: horizontal, vertical up- or downwards

5. surface roughness
6. geometry and size of the object

In building energy modelling, various models were developed to reflect the processes of convection. Thereby, it is differentiated between external (e.g. outer surface of exterior wall) and internal (internal surfaces, e.g. internal walls) convection.

In IDA ICE, the external convective heat transfer coefficient is calculated in the FACE model, while the internal is calculated in the external FORTRAN subroutines *U_Film*.

External convective heat transfer coefficient

For the external convective heat transfer coefficients, no options are given. It is calculated based on Equation [3]:

$$h_c = 5.678 \left[a + b \left(\frac{V}{0.3048} \right)^n \right] \quad (\text{Clarke, 2001; Sahlin et al., 2004}) \quad [3]$$

Where V is the local wind velocity at the leeward side:

$$V = 0.3 + 0.05 \times V_f \quad (\text{Clarke, 2001; Sahlin et al., 2004}) \quad [4]$$

Where V_f is the free stream velocity in m/s.

If the free stream velocity is less than 2 m/s, the local wind velocity on the windward side of the building is 0.5m/s. Otherwise, the free stream velocity is multiplied by 0.25. The empirical coefficients and exponents are set according to Table 1 and are dependent on the velocity of the wind. IDA ICE thereby only uses the empirical coefficients and exponents for the 'rough' surface nature.

Table 1: Empirical coefficients and exponents for Equation [4] (Clarke, 2001) IDA ICE only uses 'rough' as surface nature.

	$V_f < 4.88$ m/s			4.88 m/s $\leq V_f < 30.48$ m/s		
Nature of surface	a	b	n	a	b	n
smooth	0.99	0.21	1.00	0.00	0.50	0.78
rough	1.09	0.23	1.00	0.00	0.53	0.78

Internal convective heat transfer coefficients

The way the convective heat transfer coefficients (CHTC) are calculated can be determined in the expert version of IDA ICE by setting the ConvType[1] in the zone model. There, it can be chosen between the following options:

- ConvType[1]=-1: Table values (BRIS model)
- ConvType[1]=0: Simple Natural Convection (SNC) model
- ConvType[1]=1: Detailed Natural Convection (DNC) model
- ConvType[1]=2: Ceiling diffuser (CD) model
- ConvType[1]=3: Max(BRIS Model, CD Model) (default)

- ConvType[1]=4: Max(DNC Model, CD Model)
- ConvType[1]=5: User defined values (only in the energy zone model)

The different algorithms are calculated in the external FORTRAN subroutine U_FILM.FOR. In the following subsections, the methods and algorithms to calculate the internal CHTC are presented, which can be chosen. For all models, the temperature difference is calculated as: $T_{air}-T_{srf}$. The surface orientation is: floor = 0°, ceiling = 180° and wall = 90°.

BRIS Model

When the BRIS Model is used, the CHTC is dependent on the temperature difference between the air and the surface and the slope of the surface (horizontal and vertical) (Bring et al., 1999). The CHTCs are shown in Figure 14 and also depend on the in Table 2 shown conditions.

Table 2 Heat transfer coefficients for BRIS with correction for small air flows.

coefficient	condition	position
Figure 14 Vertical $ \Delta T $	$ \alpha-90 <30$	wall
Figure 14 Horizontal with $-\Delta T$	$\alpha < 90$	floor
Figure 14 Horizontal with ΔT	otherwise	ceiling

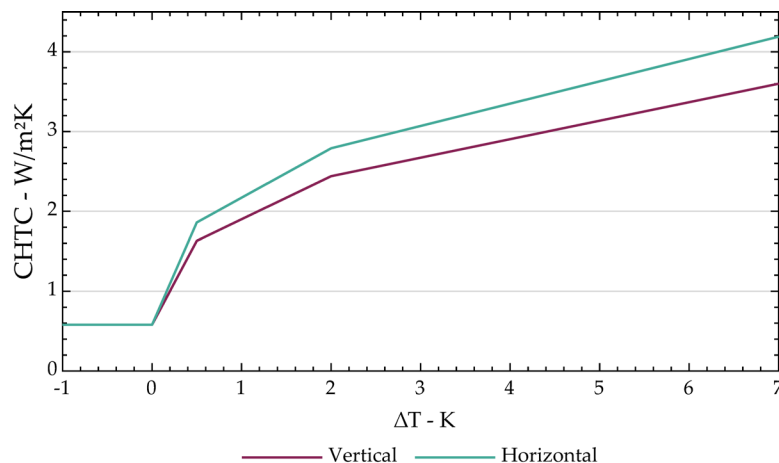


Figure 14 Convective heat transfer coefficient (BRIS) redrawn from (Bring, Sahlin et al. 1999)

Simple Natural Convection (SNC) Model

The natural heat transfer coefficients were obtained by Walton, 1983, who based them on data obtained from ASHRAE Fundamentals (1981). They subtracted a radiative component from the ASHRAE table values given for combined convection and radiation and converted them into metric units. This radiative component was 1.02 times the emissivity of 0.9. Table 3 shows the calculated values which are used in IDA ICE and also shows that, for horizontal surfaces, it is differentiated between reduced and enhanced convection. Enhanced convection mostly occurs when warm air is below a cold horizontal surface, or cold is above a warm horizontal surface. For reduced convection, it is the opposite, where it occurs when cold air is below a warm surface, or warm air is above a cold horizontal surface. Both enhanced and reduced convection, so more or less convective mixing is always in relation

to a vertical surface (Walton, 1983). It is to be noted that the values in the publication differ from the values used in IDA ICE in the second or third decimal. The reason for this is unknown.

Table 3: Convective heat transfer coefficients for SNC as used in IDA ICE.

coefficient	condition
$h=0.948$	If $(\Delta T > 0$ and $ \alpha < 10)$ or $(\Delta T < 0$ and $ \alpha - 180 < 10)$ Horizontal surface with reduced convection
$h= 4.040$	If $(\Delta T < 0$ and $ \alpha < 10)$ or $(\Delta T > 0$ and $ \alpha - 180 < 10)$ Horizontal surface with enhanced convection
$h= 3.076$	Else if $ \alpha - 90 < 10$ Vertical surface
$h= 2.281$	Else if $(\Delta T > 0$ and $\alpha < 90)$ or $(\Delta T < 0$ and $\alpha > 90)$ Tilted surface with reduced convection
$h= 3.870$	Else if $(\Delta T < 0$ and $\alpha < 90)$ or $(\Delta T > 0$ and $\alpha > 90)$ Tilted surface with enhanced convection

where ΔT is $T_{air} - T_{srf}$ and α is the angle relative to the horizontal floor

Detailed Natural Convection (DNC) Model

Walton, 1983 Walton, 1983 also defined the detailed natural convection coefficients. As the values he originally obtained from ASHRAE Fundamentals (1981) were inconsistent with those from the simple algorithm, he defined expressions that account for all surface tilts, as shown in Table 4.

Table 4 Convective heat transfer coefficients for DNC (Walton, 1983).

coefficient	condition
$h = \frac{9.482 \cdot \Delta T ^{\frac{1}{3}}}{7.283 - \cos(\alpha) }$	If $(\Delta T < 0$ and $\alpha < 90)$ or $(\Delta T > 0$ and $\alpha > 90)$ Upward and downward facing surface with enhanced convection
$h = \frac{1.810 \cdot \Delta T ^{\frac{1}{3}}}{1.382 + \cos(\alpha) }$	Otherwise upward and downward facing surface with reduced convection and vertical surfaces

where ΔT is $T_{air} - T_{srf}$ and α is the angle relative to the horizontal floor

Ceiling Diffuser (CD) Model

The CHTCs for the CD model were obtained by Fisher & Pedersen, 1997, who determined them in a full-scale experiment between 3 and 12 ACH. Thereby, the resulting correlations were related to the room inlet temperature. The expressions used by IDA ICE were related to the room outlet temperatures obtained in the experiment. Further, IDA ICE uses two

different algorithms to calculate the CHTC. When selecting ConvType[1]=2, the expressions used are given in Table 5. These do not include a correction for small ACH.

Table 5 Convective heat transfer coefficients for CD without correction for small air flows (Fisher & Pedersen, 1997).

coefficient	condition	position
$h = 3.873 + 0.082 \cdot ACH^{0.980}$	If $\alpha < 60$	floor
$h = 2.234 + 4.099 \cdot ACH^{0.503}$	Else if $\alpha > 120$	ceiling
$h = 1.208 + 1.012 \cdot ACH^{0.604}$	otherwise	wall

where ACH is the air change per hour, α is the angle relative to the horizontal floor

Table 6 shows the expressions used when selecting ConvType[1]=3 or ConvType[1]=4.

Table 6 Convective heat transfer coefficients for CD with correction for small airflows (From IDA ICE).

coefficient	condition	position
$h = 3.873 \cdot r + 0.082 \cdot ACH^{0.980}$	If $\alpha < 60$	floor
$h = 2.234 \cdot r + 4.099 \cdot ACH^{0.503}$	Else if $\alpha > 120$	ceiling
$h = 1.208 \cdot r + 1.012 \cdot ACH^{0.604}$	otherwise	wall

where ACH is the air change per hour, α is the angle relative to the horizontal floor and r is the $\min(5, ACH)/5$

Due to the use of two expression groups, it is possible that the results deviate between ConvType[1]=2, and ConvType[1]=3 and ConvType[1]=4 when CD-algorithm is chosen. The deviation can only occur until 5 ACH, as shown in the next subsection.

Comparison of internal convective heat transfer coefficients

Further, all relevant and above listed CHTC are compared for all surface orientations (Figure 15 – Figure 17). Note that the CD algorithm has a different x-axis as it is dependent on the ACH and not the temperature difference.

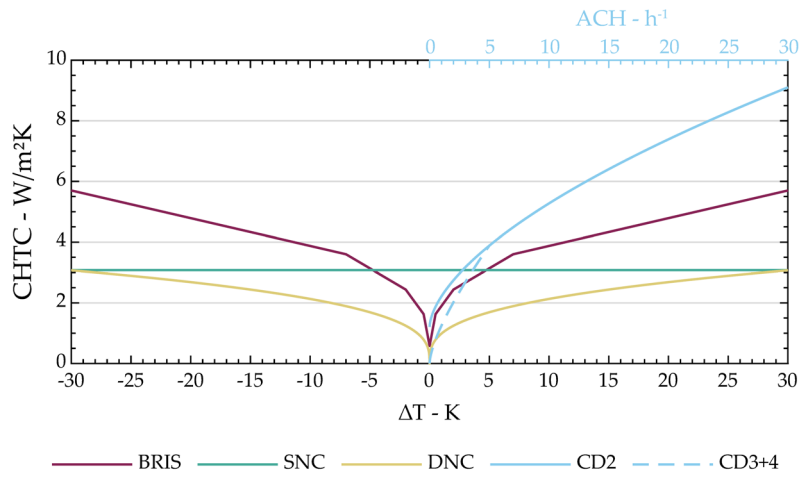


Figure 15 CHTC at wall (vertical surfaces) as used in IDA ICE

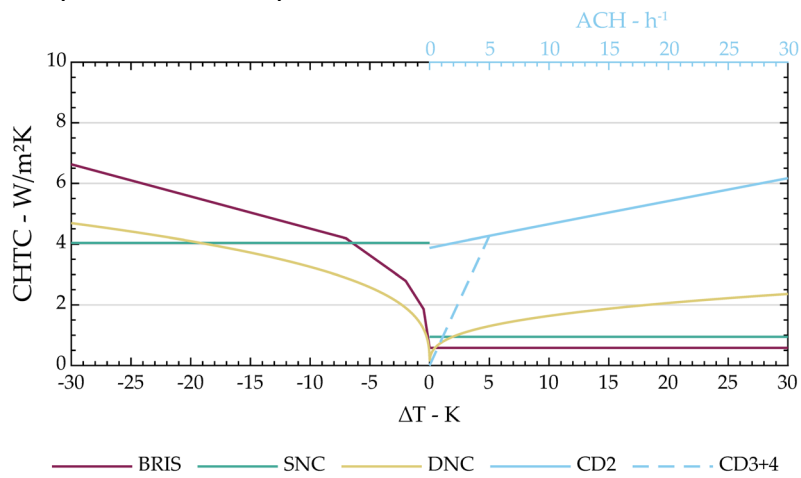


Figure 16 CHTC at floor as used in IDA ICE

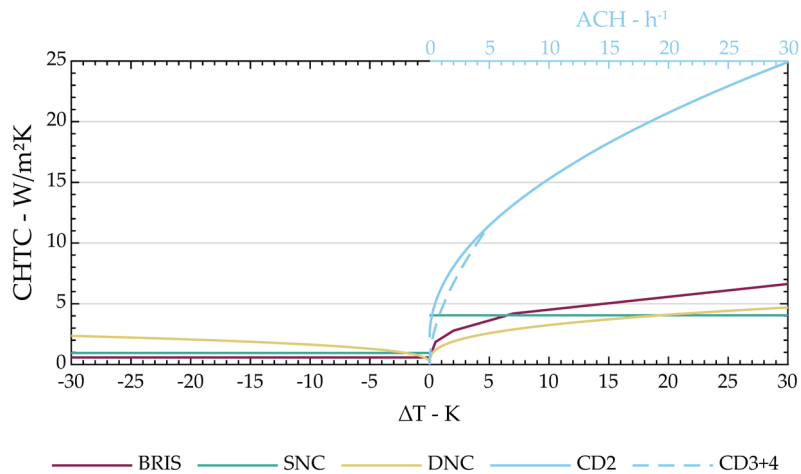


Figure 17 CHTC at ceiling as used in IDA ICE

Application – Changing CHTC

1. Build the model
2. Open the zone
3. Open the schematic
4. Open the zone model
5. Navigate to "Parameters"
6. Search and open for ConvType
7. Change [1] to desired CHTC
 - a. When choosing [1]=5 (only possible when the zone is set to "Energy", [7] - [9] are applied
 - i. ConvType[7] = h for floor
 - ii. ConvType[8] = h for ceiling
 - iii. ConvType[9] = h for wall
8. Run the simulation without building the model.

Recommendations

ACHs in IDA ICE are determined based on forced ventilation (mechanical ventilation), natural ventilation, and air exchange between zones. The air exchange between the zones gets exceptionally high for large vertical and horizontal zones. Thus, using a CHTC algorithm that determines its values based on ACH can lead to a too-high heat transfer in those cases (two or more zones connected by large vertical or horizontal openings). On the opposite side, algorithms based on ACH cannot capture, for example, recirculating (in one zone) flows, as no ACH is present. This can lead to large, unexpected deviations as a CHTC of 0 W/m² leads to no convective heat transfer between the surface and the room.

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