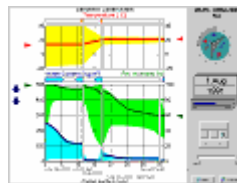# Welcome to WUFI

WUFI is a Windows-based program for the hygrothermal (i.e., heat and moisture) analysis of building envelope constructions. **WUFI** is an easy-to-use, menu-driven program for use on a personal computer which can provide customized solutions to moisture engineering and damage assessment problems for various building envelope systems.

The **WUFI** simulation model is a transient heat and mass transfer model which can be used to assess the heat and moisture distributions for a wide range of building material classes and climatic conditions.

With **WUFI** you can estimate the drying times of masonry and lightweight structures with trapped or concealed construction moisture, investigate the danger of interstitial condensation or study the influence of driving rain on exterior building components. The program can also help to select repair and retrofit strategies with respect to the hygrothermal response of particular roof or wall assemblies subjected to various climates. This allows the comparison and ranking of different designs with respect to total hygrothermal performance.

In addition, **WUFI** provides an instructive overview of the complex moisture transport phenomena occurring in construction assemblies, making the basic principles and interactions present during moisture transport more accessible and allowing both designers and architects insight into design decisions.

This design tool can also aid the development and optimization of innovative building materials and components. One example is that **WUFI** simulations led to the development of the smart vapor retarder; a successful application of a software tool to a practical moisture control problem.

• • •

Continue with Contents

HelpGeneral
$ Help General
+ 0005
K WUFI;ORNL;IBP

Contents

The following help topics give you a general overview of WUFI:

What is WUFI?
What Do I Get From WUFI?
How Do I Use WUFI?

These help topics provide in-depth discussion of selected items:

Details / Material Data
Details / Surface Transfer
Details / Climate Data

Here is an overview of WUFI's dialog structure:

Overview of WUFI's Dialog Structure

Here you'll find a discussion of the numerical methods used by WUFI, of WUFI's limits of applicability, of suitable choices of grids and time steps, of the reliability of the results etc.:

Details / WUFI

This list of Questions & Answers may help you to better understand the program and its application:

Q&A

This table lists the conversion factors used by WUFI to switch from SI to IP units and vice versa:

Conversion factor table

The versions table shows the differences between the various WUFI versions:

Version info

Hints for running WUFI calculations automatically are provided in the help topic

---

HelpContents
$ Contents
+ 0010
K on-line help contents;index;topics

Batch Job.

And this glossary defines some of the terms used in the program:

Glossary

Note: You may systematically browse all the help topics by using the browse buttons ">>" and "<<" of the Help window.

Continue with What is WUFI?

#$

Update history

Dec. 2006:
Neue Versionsnummer 4.1.
Neue Topics *.WAC-Format, *.WBC-Format, Langwelliger Strahlungsaustausch
Beschreibung der Ergebniskurven in "Ergebnisgrafiken" und "Kurven einfügen"
Neue Topics Hygrothermische Quellen, Hygrothermische Quellen editieren.
"Dialog: Messdaten" erweitert
"Dialog: Klimadatei auswählen (Karte)", "Details / Quellen für Klimadaten" überarbeitet und erweitert
6 neue Screenshots "Dialog: Klima"
F&A: Frage 25 entfernt
"Dialog: Aufbau" aktualisiert wg. Quellen u. Senken; neuer Screenshot
Hinweis: mögliche Mehrdeutigkeiten, wenn Klimadatei nicht mit vollem Pfad angegeben
Hinweis: mögliche Synchronisationsprobleme bei KLI-Dateien auf der rechten Seite
Windabhängige Wärmeübergangskoeffizienten: aktualisiert (KLI) und ergänzt (DAT, WBC, WAC)
"Langwelliger Strahlungsaustausch" umfangreich ausgebaut
Topic "langwellige Strahlungsemissionszahl" stark gekürzt (entfernter Teil steht jetzt in "Langwelliger Strahlungsaustausch"

Oct. 2005:
Neue Versionsnummer 4.01.
Schlagregenrose ist für *freistehende* Empfangsfläche berechnet.
Klimadaten für Helsinki, Jyväskylä und Sodankylä werden mit der *finnischen* Pro-Version geliefert.
Versionsinfo aktualisiert.
Neues Topic: Batch-Betrieb
Jetzt *9* kanadische Städte.

Apr. 2005:
Neue Versionsnummer 4.0.
Kleine Umformulierung bei Erklärung des sd-Wertes (Details / Water Vapor Diffusion
Conversion factor table: 'permeance' in 'permeability' korrigiert
Neue Klimaformate
Neue Dialoge: Klimaauswahl, Schnellgrafiken, Messdaten.
Film neu; Ausgabe|Film und Filmexport: keine online-Hilfe mehr.
Versionsinfo

Jan. 2003:
Conversion factor table hinzugefügt.
Erläuterung permeance/permeability erweitert.
'Hinweis' für TRY-Dateien hinzugefügt.
Neue Versionsnummer: 3.3.1.

Okt. 2002:
Beschreibung des neuen Dialogs "Options: Unit System" hinzugefügt (nur im englischen Hilfetext).
Korrektur der Beschreibung der Option "Standard" in den übrigen Options-Dialogen.

[#] UpdateHistory
[$] Update history

Änderung am Erscheinungsbild des Dialogs "Options Result Data" berücksichtigen.
Korrektur FAQ #24, Gl. für WOZ.
FAQ #13: Tabelle mit Anfangswassergehalten eingefügt.
Neue Versionsnummer 3.3

Okt. 2001:
Einige kosmetische Korrekturen
Änderungen am Erscheinungsbild des Dialogs Kurveneinstellungen.
Erläuterung der windabhängigen Wärmeübergangskoeffizienten.
Beschreibung "Dialog: Klima Außen" erweitert.
Neue Versionsnummer 3.2.

Aug 2001: einige Detailverbesserungen im Zuge der Erstellung des deutschen Hilfetextes.

What is WUFI?

WUFI is the acronym for "**W**ärme- **u**nd **F**euchtetransport **i**nstationär" ("Transient Heat and Moisture Transport").

WUFI is designed to calculate the simultaneous heat and moisture transport in one-dimensional multi-layered building components.

A comfortable Windows® user interface allows quick set-up of a calculation project, easy change of parameters for numerical experiments and comfortable viewing of the results as graphics or a 'film'.

The physical and numerical ideas underlying WUFI are developed and discussed in the doctoral thesis:

> Künzel, H.M.:
> Verfahren zur ein- und zweidimensionalen Berechnung des gekoppelten Wärme- und Feuchtetransports in Bauteilen mit einfachen Kennwerten.
> Dissertation Universität Stuttgart 1994
>
> (may be ordered from IBP: http://www.hoki.ibp.fhg.de/index.html)

or

> Künzel, H.M.:
> Simultaneous Heat and Moisture Transport in Building Components.
> One- and two-dimensional calculation using simple parameters.
> IRB Verlag 1995
>
> (may be ordered from IRB Verlag, Stuttgart: http://www.irb.fhg.de).

In the calculation of heat transport, WUFI takes into account:

- thermal conduction
- enthalpy flows through moisture movement with phase change
- short-wave solar radiation
- nighttime long-wave radiation cooling (with TRY, DAT, WAC and WBC weather data only).

Convective heat transport by air flows has been disregarded, since it is usually difficult to quantify and rarely one-dimensional.

Hilfe_Allgemein_C_UT1
$ What is WUFI?
+ 0020
K WUFI;Künzel;heat conduction;enthalpy flows;water vapor diffusion;phase change;short-wave;solar radiation;long-wave;radiation cooling;convective transport;air flow;solution diffusion;capillary conduction;surface diffusion;seepage flow;pressure differential;electrokinesis;osmosis;temperature;relative humidity;meteorological;

The vapor transport mechanisms included in WUFI are:

- vapor diffusion
- solution diffusion.

Again, convective vapor transport by air flows has been ignored.

The liquid transport mechanisms taken into account are:

- capillary conduction
- surface diffusion.

Seepage flow through gravitation, hydraulic flow through pressure differentials, as well as electrokinetic and osmotic effects have not been included.

The choice of temperature and relative humidity as driving potentials allows the use of simple, easily comprehensible storage and transport coefficients. These can thus readily be derived from standard material data if no measured data are available and utmost precision of the results is not required.

The boundary conditions for each time step are expressed in terms of meteorological data (temperature, relative humidity, driving rain, radiation), since in building physics these are the relevant parameters specifying the conditions at surfaces exposed to natural weather.
However, conditions for laboratory experiments (e.g. imbibition measurements) can also be expressed as 'meteorological' data.
Heat, moisture and air change sources may be specified within the component.

Continue with

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What Do I Get From WUFI?

Once you have furnished WUFI with the data it needs, it can calculate the temporal evolution of the temperature and moisture fields in the building component.

You will be given three types of results:

- **courses** which describe the temporal evolution of certain quantities, taken at specified locations or as mean values over specified layers.
  The following quantities are given as courses:

  - the **heat flux densities** through the interior and exterior surface, respectively,
  - the **temperatures** and **relative humidities** at monitoring positions of your choice (e.g. at the interior and exterior surfaces, or in the middle of an insulation layer etc),
  - the **mean moisture content** of each layer and the **total moisture content** of the entire building component.

- **profiles** which show the distribution of a quantity across the building component at a specified point in time.
  The following quantities are given as profiles:

  - the **temperature** across the building component,
  - the **relative humidity** across the building component,
  - the **moisture content** across the building component.

  WUFI automatically records the initial and final states as profiles. You can specify additional points in time for which you want to see profiles.

- a **film** which contains the profiles of all time steps.

You may save the calculation results together with the input data in the project file, so that you can re-examine the result graphs or the film later without repeating the calculation.
WUFI offers graphics functions that allow you to comfortably view the computed courses and profiles, and to edit and print the graphs.
The film viewer allows you to view the film at your leisure after completion of the calculation.

Continue with How Do I Use WUFI?

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How Do I Use WUFI

The following will guide you through the process of setting up and performing a calculation with WUFI, giving you a general impression of what you can do and how you can do it.

Collecting the Necessary Data
Defining the Assembly and the Numerical Grid
Setting Numerical Parameters
Summary: Preparing a Calculation
Performing the Calculation
Viewing the Results

Continue with Collecting the Necessary Data

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Collecting the Necessary Data

Of course, WUFI needs some data to perform the calculations. However, the equations built into WUFI have been formulated in terms of quantities that are well known or readily available or can easily be measured or estimated.

This is what WUFI needs:

- material data

  these quantities define the hygrothermal behaviour of the materials:

  Basic Data:

  - **bulk density** [kg/m³],

  - **porosity** [m³/m³],

  - **specific heat capacity of dry material** [J/kgK],

  - **thermal conductivity of dry material** [W/mK],

  - **water vapor diffusion resistance factor of dry material** [-]

  Hygric Extensions:

  - **moisture storage function** [kg/m³]
    as a <u>table</u> or <u>approximated</u> by sorption moisture at 80% RH (w_{80}) and free saturation (w_f),

  - **liquid transport coefficient for suction** [m²/s]
    as a <u>table</u> or <u>generated</u> from the water absorption coefficient (A-value),

  - **liquid transport coefficient for redistribution** [m²/s]
    as a <u>table</u> or <u>generated</u> from the water absorption coefficient (A-value),

---

[#] Hilfe_Allgemein_C_UT4
[$] Collecting the Necessary Data
[+] 0050
[K] material data;material properties;bulk density;porosity;heat capacity;heat conductivity;thermal conductivity;water vapor diffusion resistance factor;permeability;moisture storage function;liquid transport coefficient;suction;imbibition;redistribution;water absorption coefficient;A-value;heat conductivity supplement;thermal conductivity supplement;climate data;rain;solar radiation;temperature;relative humidity;barometric pressure;surface transfer coefficients;heat transfer coefficient;vapor diffusion thickness;sd-value;permeance;short-wave radiation absorptivity;long-wave radiation emissivity;rain water absorption factor;water vapor transfer coefficient;initial conditions

- **moisture-dependent thermal conductivity** [W/mK]
  as a <u>table</u> or <u>generated</u> from the moisture-induced thermal conductivity supplement,

- **moisture-dependent vapor diffusion resistance factor** [-]
  as a <u>table</u>.

These material data are further discussed in Details / Material Data.

The definition of the water vapor diffusion resistance factor (a.k.a. μ-value) and related quantities is discussed in Details / Water Vapor Diffusion.

For mathematical reasons, the **basic data** are required as a minimum for each calculation; otherwise, the transport equations are not fully defined.
The **hygric extensions** are refinements of the simulation model that are not mathematically required, but they may well be necessary to fully and appropriately describe the hygrothermal situation.

- climate data

  These quantities define the boundary conditions at the interior and exterior surfaces of the building component:

  - **rain load on the surface** [Ltr/m²h],
    as dependent on the inclination and orientation of the building component,

  - **short-wave (solar) radiation flux density** [W/m²],
    as dependent on the inclination and orientation of the building component,

  - **exterior air temperature** [℃],

  - **exterior relative humidity** (0..1),

  - **interior air temperature** [℃],

  - **interior relative humidity** (0..1),

  - mean **barometric pressure** [hPa] over the calculation period,

  - **atmospheric counterradiation** [W/m²], if radiation cooling is to be accounted for during the night.

  For each time step, WUFI reads these data from a climate file. Since the rain load and the radiation flux are directional quantities, they must be evaluated in dependence of the orientation and inclination of the building element. This evaluation can be done with a preprocessor or by WUFI itself during the calculation.

  In the former case, the processed data are written to a file of *.KLI type, in the latter case WUFI expects climate data in *.WET or *.TRY or *.DAT or *.WAC or *.IWC or *.WBC format.

You can create files with your own data in any of these formats in order to use them with WUFI.

Climate data and the climate file formats are further discussed in Details / Climate Data.

- surface transfer coefficients

  These quantities specify the coupling between the climate data and the conditions in the building component:

  - **heat transfer resistance** [m²K/W]
    for interior and exterior surface, respectively. The heat transfer resistance is the reciprocal of the heat transfer coefficient which may be more familiar to some users,

  - **vapor diffusion thickness**, a.k.a. sd-value [m]
    for interior and exterior surface, respectively;
    allows to account for the diffusion-retarding effect of paint coats, wallpapers, vapor retarders etc., if present, without the need to explicitly include these layers in the component assembly,

  - **short-wave (solar) radiation absorptivity** [-],

  - **long-wave (thermal) radiation emissivity** [-]
    (must often be neglected, since data on sky and ground counterradiation are rarely available),

  - **rain water absorption factor** [-]
    describes the reduction of rain water volume available for suction on non-horizontal surfaces, since some water splashes off on impact.

  The **water vapor transfer coefficients** are automatically calculated from the heat transfer resistances and need not be specified separately.

  The coefficients listed here are further discussed in Details / Surface Transfer Coefficients.

  The definition of the vapor diffusion thickness and related quantities is discussed in Details / Water Vapor Diffusion.

  WUFI offers lists of predefined common values of these coefficients for selection, but you may enter user-defined values as well.

- initial conditions

  - The temperature field must be initialised with **constant temperature** across the component or with an **initial temperature profile** (such as from measurements or previous simulations). Any profiles must be provided in a separate ASCII file.

- The moisture field must be initialised with **constant relative humidity** across the component or with individual **moisture contents for each layer** or with an **initial moisture profile** (such as from measurements or previous simulations). Any profiles must be provided in a separate ASCII file.

The initial conditions are further discussed in the help topic for the dialog "Inputs | Initial Conditions".

Continue with Defining the Assembly and the Numerical Grid

Back to How Do I Use WUFI?
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Defining the Assembly and the Numerical Grid

The assembly describes the one-dimensional series of layers which make up the entire building component. In this step you first define the sequence of layers, their thicknesses and material properties, then you subdivide it into small numerical grid elements.

The definition of the **layer sequence** and the **layer thicknesses** is done interactively with a graphical diagram of the assembly, or alternatively by entering the relevant data into a table.

Then you specify the **material data** for each layer. The material data need not be entered by hand if the material in question is contained in WUFI's material database. Just select the material in the database and transfer all the data.

WUFI comes complete with a database which offers a selection of materials for instant use. (Please note, however, that due to large variations in the materials and often incomplete or inconsistent literature data, the data provided here should not be taken as divine revelations. They are just intended to give you a starting point.)
You can supplement the database with your own materials.

The transport equations cannot be solved analytically. To allow a numerical treatment, the building component must be divided into discrete **grid elements**. WUFI can automatically generate a general-purpose grid which will suffice for most cases (you can select one of three degrees of fineness for the grid).

In special cases (e.g. severe interstitial condensation in a narrow region) you may need to adapt the grid manually. You can easily set up and manually edit the grid by using WUFI's grid editor. All grid data are entered into a table where each line represents a component layer. You can subdivide each layer and define expanding or contracting grids in order to tailor the local fineness of the grid to the demands of the simulation model:

For the discretisation of the transport equations, the values of the calculated quantities are assumed to be constant across each grid element. Therefore, the size of each element should be chosen so as to make this assumption approximately valid, depeding on the local conditions. In general, this requires the use of small elements in regions where steep moisture or temperature gradients are to be expected, and the use of larger elements in more placid regions to cut down on calculation effort.

[#] Hilfe_Allgemein_C_UT5
[$] Constructing the Numerical Grid
[+] 0060
[K] numerical method;grid;grid element;grid structure;discretisation;gradient;layer;component layer;expansion factor;expansion;contraction;database;

In general, steep gradients are to be expected close to the boundaries of a layer, i.e., close to the exterior and interior surfaces of the component because of the influence of climate conditions, and close to internal layer interfaces because of condensation. Less variation will occur in the middle of each layer.

Splitting up a layer into two or more sublayers with identical material parameters but different expansion factors (>1, <1)for the grid allows you to achieve a smooth, not necessarily symmetrical, expansion and contraction of the grid elements which can be adapted to the requirements in each individual layer.

The choice of a suitable grid is further discussed in Details / WUFI, details of how to set up a manual grid are described in the help topic for the "Assembly" dialog.

Continue with Selecting Numerical Parameters

Back to How Do I Use WUFI?
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Setting Numerical Parameters

There are some parameters controlling the numerical aspects of the calculation:

- You must specify a suitable **time step**. A time step of one hour is adequate for most cases (the choice of time steps is further discussed in "Details / WUFI").

- For special purposes, you may exclude either **heat** or **moisture transport** from the calculations.

  For example, you may thus easily determine the thermal transmittance of a wall with a complicated moisture distribution: specify the distribution as the initial moisture profile and prevent it from spreading by turning off moisture transport. Perform a calculation with constant climate, applying a suitable temperature gradient across the assembly until steady-state conditions are reached and record the resulting heat flow.

- You may also switch off **capillary conduction** only, in order to examine the importance of the remaining vapour diffusion.

- You may switch off **latent heat** effects (heat of fusion and/or heat of evaporation) to examine the extent to which they affect the results.

- In case WUFI reports problems with the accuracy of the results, you should tune WUFI to stricter **convergence criteria** or stronger **underrelaxation**, sacrificing some calculation speed.

  Possible numerical problems and countermeasures are further discussed in the on-line help for the dialog "Outputs | Status of Last Calculation" and in "Details / WUFI".

Continue with Summary: Preparing a Calculation

Back to How Do I Use WUFI?
Back to Contents

Hilfe_Allgemein_C_UT6
$ Selecting Numerical Parameters
+ 0070
K   numerical   control;heat   transport   calculation;moisture   transport
calculation;hygrothermal   special   options;capillary   transport   calculation;diffusion
transport calculation;latent heat;increased accuracy;adapted convergence

Summary: Preparing a Calculation

This is an overview of the steps that have to be taken before you can start a calculation.

- You may enter some optional information about the project and the case.

- You must define the assembly of the component (i.e. its layer sequence and the layer thicknesses) and you must enter the material data for the individual layers. The material data may be entered by hand or taken from the material database. Alternatively, a predefined assembly may be read from the construction database.

- You may specify heat, moisture or air change sources within the component.

- You may select monitoring positions, for which you want to be given the courses of temperature and relative humidity (the two surfaces of the building component are always monitored).

- You must specify the orientation, the inclination and the height of the building component.

- You must select the surface transfer coefficients for heat, vapor and liquid transport.

- You must specify the initial conditions, which describe the starting values of the temperature and moisture fields.

- You must specify the time interval for which the calculation shall be carried out. You may specify additional points in time for which you want to be given profiles.

- You may edit the parameters for the numerical control.

- You must define the climatic conditions on each side of the component by selecting a file with weather data or by having interior climate data derived from such a file, or by specifying schematic sine curves for the climate data.

- You may check your input by viewing data sheets of the component assembly, of the material data, or of a table summarizing other input.

- As a precaution, you should now save your input to a project file (*.W4P).

Hilfe_Allgemein_C_UT7
$ Summary: Preparing a Calculation
+ 0080
K project;case;assembly;component;layer;material data;material properties;material database;example case;construction database;monitor positions;orientation;inclination;height;surface transfer coefficients;initial conditions;climate file;climate (exterior);climate (interior);time interval;profiles;data sheets;save;calculation

- Now you can start the calculation.

Continue with Performing the Calculation

Performing the Calculation

When you have entered (and saved) all the necessary data, you can start the calculation. To do this,
- choose the menu item "Run | Run Calculation" to start the calculation for the current case, or
- choose the menu item "Run | Run all Calculations" to start the calculation for all the cases in the current project in succession, or
- choose the menu item "Run | Run Calculation with Film" to open the Calculation Dialog and click on the 'Start' button.

In the former two cases the screen just shows a progress bar so that you can estimate computing time; in the latter case, WUFI displays the calculated profiles at each time step, so that you can watch a sort of film showing the processes in the component. This film display is somewhat slower, of course, so that lengthy calculations should be done without film; on the other hand, you can immediately see what is happening.

During the calculation, WUFI wanders from the specified initial state through the evolution of the temperature and moisture fields, proceeding in discrete time steps, reading the changing boundary conditions from the climate file and writing the data of each step to a temporary result file. A progress bar allows you to estimate the remaining time needed for the calculation.

The calculation can be aborted at any time by a click on the stop button. The results accumulated so far are not lost and can be analysed.

If you have run the calculation with film, you can 'Close' the film screen after the calculation has ended.

After the calculation, a window "Status of Last Calculation" pops up, showing you a short summary of the calculation results. This window also contains some information that you should check to make sure that no serious convergence failure has occurred.

Important: If you want to keep the results, you must now write them to the project file by simply **saving** the project file again (make sure the options are set to save both input data and results in the project file).

Extensive calculations (such as parametric studies) can also be processed automatically as batch jobs.

Continue with Viewing the Results

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Viewing the Results

After the calculation (did you remember to save again?), you can display graphics showing the courses and profiles as curves:
- the Quick Graphs give a quick overview of the results, in particular for comparing two cases,
- the Result Graphs are formatted for printing and can be edited, reconfigured and tailored to your wishes in various ways.

You can also view the film again and at your leisure after the calculation. An export function creates a film file which can be displayed with a separate film viewer.

Finally, you can export the result data to ASCII files and process them with your favorite graphics or data analysis software.

Continue with Details / Material Data

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Details / Material Data

The heat and moisture fluxes permeating the building component are not only determined by its present and past conditions and the boundary conditions, but also and foremost by the conductive and capacitive properties of the individual materials. A discussion of the data needed by WUFI may help you to better understand the physics involved in the calculations.

There are basic data which are indispensable for a calculation. Other data may be optional, depending on the material and on the purpose of the calculation:

Details / Basic Material Data
Details / Moisture Storage Function
Details / Liquid Transport Coefficients
Details / Heat Conductivity, Moisture-dependent
Details / Diffusion Resistance Factor, Moisture-dependent

Some materials need special treatment:

Details / Air Layers
Details / Membranes

Continue with Details / Basic Material Data

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\# Hilfe_Allgemein_C_UT100
$ Details / Material Data
+ 1010
K material data;material properties

Details / Basic Material Data

These material data constitute an indispensable minimum without which a calculation is not possible:

- **Bulk density** [kg/m³],
  serves to convert the specific heat by mass to the specific heat by volume.

  The bulk density ρ_{bulk} is the ratio of the mass m of the sample and the total volume V_{tot} of the sample: ρ_{bulk} = m / V_{tot}.
  The true density ρ_{true}, by contrast, is the ratio of the mass of the sample and the volume taken up by the material matrix only: ρ_{true} = m / ($V_{tot} - V_{pores}$) = m / V_{true}.

  The bulk density should be available for virtually every building material. If not, it can be measured very easily. Since it only affects the specific heat value entering into the calculation, and hygrothermal simulations usually don't depend very sensitively on this value, it need not be known with great precision.

- **Porosity** [m³/m³],
  determines the maximum water content w_{max} (by multiplication by ρ_{water} = 1000 kg/m³).

  Since most calculations are not sensitive to the exact value of the maximum water content (you'll rarely encounter water contents above free saturation), it is usually sufficient to estimate it if no value is available for the material in question.
  The porosity can be estimated from the true density ρ_{true} and the bulk density ρ_{bulk}:
  ρ_{bulk} = m / V_{tot} = m / ($V_{true} + V_{pores}$) = ρ_{true} / (1 + V_{pores}/V_{true}) = ρ_{true} * V_{true}/V_{tot} = ρ_{true} * (1 − V_{pores}/V_{tot}) = ρ_{true} * (1 − porosity), therefore

  $$\text{porosity} = 1 - \rho_{bulk} / \rho_{true}.$$

  ρ_{true} can in turn be estimated from other materials which have the same composition but different bulk density, if their bulk density and porosity are known. Example: a cellular concrete brick with ρ_{bulk} = 600 kg/m³ and porosity = 0.72 has ρ_{true} = 600 / (1 − 0.72) kg/m³ = 2140 kg/m³. The porosity of a cellular concrete brick with ρ_{bulk} = 400 kg/m³ can then be estimated as porosity = 1 − 400/2140 = 0.81.

- **Heat capacity** [J/kgK],
  the specific heat capacity by mass of the dry material.

  Using the specific heat capacity *by mass* has the advantage that this value only depends on the chemical composition of the material, but not on its porosity. For example, cellular concrete bricks with bulk densities of 400 kg/m³ and 600 kg/m³ have the same specific heat capacity by mass.

  To convert into heat capacity by volume (which enters into the transport equations), WUFI multiplies the mass-specific heat capacity by the bulk density.

  Rough values are 850 J/kgK for mineral materials and 1500 J/kgK for organic materials. In most cases, these estimates will be sufficient since hygrothermal simulations usually don't depend very sensitively on this value.

  WUFI automatically allows for the additional heat capacity of the water content, if any.

- **Heat conductivity dry** [W/mK],
  the heat conductivity of the material in dry condition. A moisture-dependent heat conductivity is optional.

  Please note that experimentally measured heat conductivities of vapor-permeable materials may include the effect of vapor transport with phase change (i.e. water evaporating at one side of the specimen and condensing at the other side, thus in effect transporting latent heat without a corresponding heat flow being *conducted* across the specimen). Since WUFI explicitly computes this thermal effect of vapor flow, it should *not* be included in the heat conductivity, if possible. However, it is usually difficult or impossible to separate this effect out of the measured data.

  Furthermore, design values, such as the data given in German Standard DIN 4108, may already contain the contribution of a typical water content and, if so, are not strictly dry values.
  If you want to perform the calculation with a constant (i.e. not moisture-dependent) heat conductivity (for example because you have no detailed data on the moisture-dependence), you may use these design values to allow for moisture content at least in a crude approximation. However, if you explicitly use a table of moisture-dependent heat conductivities, you should make sure that the value for moisture content = 0 is really the dry value.

  On the other hand, hygrothermal simulations (in particular the resulting *moisture* contents and distributions) usually don't depend very sensitively on the precise values of the heat conductivities, so the difference may be generally negligible unless you are specifically interested in *heat* flows.

- **Diffusion resistance factor dry** [-]
  the diffusion resistance factor (µ-value) of the material in dry condition. The µ-value states by how much the diffusion resistance of the material in question is higher than that of stagnant air. A moisture-dependent µ-value is optional.

The definition of the μ-value and its relation to permeability are discussed in Details / Water Vapor Diffusion.

Please note that even if you do not explicitly use a moisture-dependent μ-value, WUFI will treat it as moisture-dependent for moisture contents above free saturation w_f. WUFI will reduce it in proportion to the moisture excess over w_f, until it reaches μ=0 at w_{max}. This reflects – in a first approximation - the fact that at very high moisture contents even the larger capillaries become clogged with water and can't contribute to vapor transport any more.

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Details / Moisture Storage Function

The moisture storage function

In a porous hygroscopic material, the surfaces of the pore system accumulate water molecules until a specific **equilibrium moisture content** corresponding to the humidity of the ambient air is reached. Due to the reduction of the saturation vapor pressure in the smaller capillaries, there is also some condensation which - at relative humidities above ca. 0.6 .. 0.8 - results in a marked increase of the equilibrium moisture.
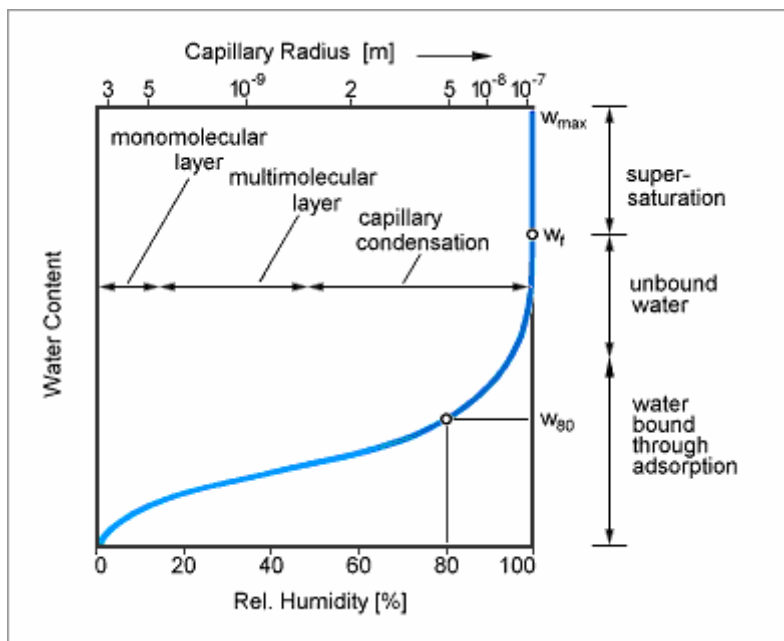
A capillary-active material in contact with water will take up this water until it reaches its **free saturation w_f**. This water content w_f corresponds to the moisture storage function at a relative humidity of 1 (=100%). Because of air pockets trapped in the pore structure, however, the free saturation is less than the **maximum water content w_{max}** which is determined by the porosity. Moisture contents exceeding w_f may e.g. result from condensation in a temperature gradient (especially in insulation materials; these are often not capillary-active and therefore have $w_f \approx 0$).

The free saturation w_f ranks among the standard material data and is known for most materials. The **'practical moisture content' w_{80}** that corresponds to the

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equilibrium moisture at a RH of 0.8 is another standard quantity.

The dependence of the moisture storage function on the temperature is marginal and is ignored in WUFI.

Measurement of the moisture storage function

Because of limitations of the respective measuring procedures, the moisture storage function has to be composed from sorption isotherms (up to ~ 0.9 RH) and pressure plate measurements (above 0.95 RH) [1]. The hysteresis between adsorption and desorption isotherms is usually not very pronounced, so that it is sufficient to use the adsorption isotherm. Where necessary, a mean isotherm may be used. Due to the measuring technique, the pressure plate measurements are 'desorption' measurements.

The moisture storage function in WUFI

In WUFI, the moisture storage function is described by means of a <u>table</u> with relative humidities and the corresponding moisture contents. The table may contain an arbitrary number of entries between which WUFI interpolates linearly.

Example: Sander sandstone

φ [-]	$w[kg/m^3]$
0	0
0.1	4.4
0.3	10.2
0.65	15.2
0.8	19.0
0.91	30.0
0.95	45.9
0.99	61.7
0.995	75.0
1.0	130.0

The pressure plate measurements would even allow a still finer subdivision of the table in the high-moisture region, but then at $\varphi \approx 1$ the curve would approach the ordinate so closely that its immensely steep slope might cause numerical problems. If the moisture transport across the interface between two capillary-active materials in capillary contact is to be calculated, however, the moisture storage function must be as detailed as possible in this region [2]. (If the capillary contact is non-ideal, an additional transfer resistance has to be taken into account [2]).

WUFI allows moisture contents in the supersaturated region, since these may well occur under condensation conditions. However, in this region there is no unique functional relation between relative humidity and moisture content. The relative humidity is always 1, and the moisture content varies between w_f and w_{max}.
The moisture content thus doesn't depend on the relative humidity, it is determined by the boundary conditions: it increases under condensation conditions and decreases under evaporation conditions. In order to treat these moisture contents above w_f, WUFI internally extends the table of each material by introducing an additional entry:

φ [-]   w[kg/m³]

...   ...
1.01 w_{max}

Relative humidities between 1 and 1.01 are only fictitious, of course, but they allow WUFI to assign a unique RH to each water content, as required by the moisture transport equations.

During the calculation WUFI performs iterations where it samples small regions of the tabulated curve. Very sharp bends in the curve may throw the iteration off and thus impede its convergence. In such a case, the curve should be smoothed by inserting additional points. A large number of entries may slow the search in the table, however.

Approximation of the moisture storage function

If the moisture storage function can be adequately described by the function

$$w = w_f \cdot \frac{(b-1) \cdot \varphi}{b - \varphi}$$

w   [kg/m³]   :   moisture content corresponding to relative humidity φ
w_f [kg/m³]   :   moisture content at free saturation
φ [-]   :   relative humidity
b   [-]   :   approximation factor,

then it is sufficient to specify w_{80} und w_f, in order to define the moisture storage function for WUFI (this is called 'approximation of the moisture storage function'). However, this condition is not met by all materials (e.g. some kinds of concrete).
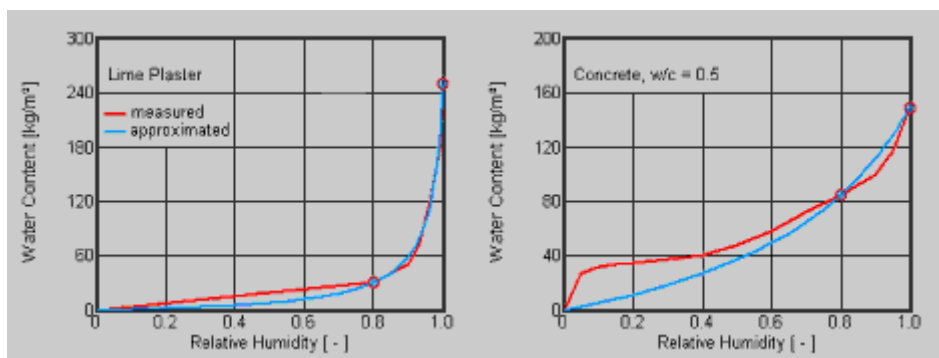
WUFI's default moisture storage function

The moisture storage function of non-hygroscopic materials (essentially insulating materials, but air layers as well) is theoretically more or less zero in the region φ = 0..1, whereas for φ = 1 it takes on some indefinite value between zero and w_{max}, so that no well-defined functional relationship exists. Because of numerical requirements, however, WUFI assigns a (low) artificial moisture storage function to

all materials for which the user did not define such a function.

So the results of a WUFI calculation will indicate some (low) moisture content even in materials for which you did not define a moisture storage function. These moisture contents are artificial and should be regarded with caution. Only when the moisture contents surpass the fictitious free saturation of ca. $0.05 \cdot w_{max}$, they have resulted from condensation phenomena which are independent from the choice of the moisture storage function. In that case the excess of the moisture content over w_f can with appropriate caution be regarded as a realistic measure of the amount of condensed moisture.

For discussion of some specific questions concerning the moisture storage function, see the Questions & Answers section.

Literature:

[1]   Krus, M.: Moisture Transport and Storage Coefficients of Porous Mineral Building Materials. Theoretical Principles and New Test Methods
       Fraunhofer IRB Verlag, 1996

[2]   Holm, A., Krus, M., Künzel, H.M.: Feuchtetransport über Materialgrenzen im Mauerwerk. Bauinstandsetzen 2 (1996), H. 5, 375 - 396.

Continue with Details / Liquid Transport Coefficients

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Details / Liquid Transport Coefficients

The predominant moisture transport mechanism in capillary porous materials is the capillary liquid transport. Although it is basically a convective phenomenon, in the context of building physics it is sufficiently accurate to regard the liquid transport in the pore spaces as a diffusion phenomenon:

$$g_w = -D_w(w) \cdot \text{grad } w$$

g_w	[kg/m²s]	:	liquid transport flux density
w	[kg/m³]	:	moisture content
D_w	[m²/s]	:	liquid transport coefficient,

where the liquid transport coefficient D_w is generally strongly dependent on the moisture content. The main reason why the liquid transport can adequately be described by a diffusion formula is that it correctly reproduces the linear increase of the imbibed amount of liquid over the square root of time.
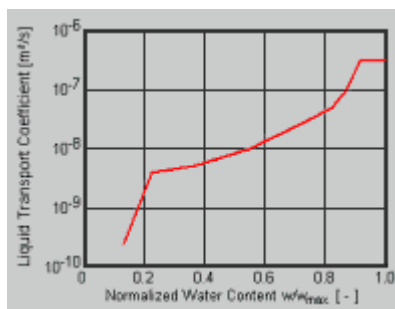
The liquid transport coefficient is not a pure material property, however - it depends on the material as well as the boundary conditions [1].

The **liquid transport coefficient for suction D_{ws}** describes the capillary uptake of water when the imbibing surface is fully wetted. In the context of building physics this describes rain on a facade or an imbibition experiment. The suction transport is dominated by the larger capillaries, since their lower capillary tension is more than compensated by their markedly lower flow resistance.

The **liquid transport coefficient for redistribution D_{ww}** describes the spreading of the imbibed water when the wetting is finished, no new water is taken up any more and the water present in the material begins to redistribute. In a building component, this corresponds to the moisture migration in the absence of rain. The redistribution is dominated by the smaller capillaries since their higher capillary tension draws the water out of the larger capillaries.

Since the redistribution is a slower process (taking place in the small capillaries with

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$ Details / Liquid Transport Coefficients
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K liquid transport coefficient;suction;redistribution;capillary;diffusion formula;square root of time;water absorption coefficient;A-value;generate;

their high flow resistance), the corresponding liquid transport coefficient is generally markedly less than the coefficient for suction.

WUFI therefore uses two distinct liquid transport coefficients for each capillary-active material which are used depending on the boundary conditions (rain / no rain). Each coefficient is entered in a separate table.

As a rough approximation, the liquid transport coefficients show a more or less exponential dependence on the moisture content. That is why WUFI uses a logarithmic interpolation between the table entries (i.e., linear in a semilogarithmic diagram; cf. the printable material data sheets).

The first entry in a table should be the pair (0 ; 0); the next entry then corresponds to the moisture content below which the liquid transport is negligible, i.e., the transport coefficients are zero. The logarithmic interpolation automatically results in interpolated values of zero for the coefficients below that threshold.

The last entry is also used for all higher moisture contents up to w_{max}. Although there is little capillary conduction above free saturation [2], there might be other transport mechanisms which could approximately be described by finite liquid transport coefficients (convection due to gravitation or pressure differentials etc.).

To allow for this kind of transport processes (if desired), WUFI accepts arbitrary liquid transport coefficients for this moisture region, too. In general, you will rarely encounter moisture contents in this region which is difficult to treat in calculation. By setting the last entry to zero, the capillary conduction in the moisture region above the last entry may be suppressed.

Example: Baumberger sandstone

w [kg/m³]	D_{ws} [m²/s]
0	0
31	2.5E-10
52	3.9E-9
84	5.2E-9
126	1.0E-8
168	2.8E-8
189	5.0E-8
200	1.0E-7
210	3.0E-7

This table states, among other things, that
- there is no capillary conduction at a moisture content below 31 kg/m³,
- at a moisture content of 40 kg/m³, the liquid transport coefficient for suction is 8.1E-10 m²/s (interpolated), and
- for all moisture contents above 210 kg/m³, a liquid transport coefficient of 3.0E-7 m²/s is being used.

During the calculation WUFI performs iterations where it samples small regions of the tabulated curve. Very sharp bends in the curve may throw the iteration off and thus impede its convergence. In such a case, the curve should be smoothed by inserting additional points. A large number of entries may slow the search in the

table, however.

Unfortunately, measured liquid transport coefficients are available only for a relatively small number of materials. The ability to at least **estimate** them from standard material data is therefore desirable.

In many cases, the increase of D_{ws} with increasing moisture content can be approximately described by an exponential function which, for most mineral building materials, spans about three powers of ten. Under these conditions, there is the following approximate relation between D_{ws} and the A-value A:

$$D_{ws}(w) = 3.8 \cdot (A / w_f)^2 \cdot 1000^{(w / w_f) - 1}$$

D_{ws}	[m²/s]	:	liquid transport coefficient for suction
A	[kg/m²√s]	:	water absorption coefficient
w	[kg/m³]	:	moisture content
w_f	[kg/m³]	:	free water saturation

In this way, WUFI can automatically generate a table with estimated liquid transport coefficients for suction. Only the water absorption coefficient needs to be entered, and WUFI will use it, the moisture storage function and the above formula to <u>generate</u> a table with the following entries:

w [kg/m³]	D_{ws} [m²/s]
0	0
w_{80}	$D_{ws}(w_{80})$
w_f	$D_{ws}(w_f)$

In the same way, WUFI can also generate an estimated table with liquid transport coefficients for redistribution. WUFI will create this:

w [kg/m³]	D_{ww} [m²/s]
0	0
w_{80}	$D_{ws}(w_{80})$
w_f	$D_{ws}(w_f)/10$

Please note that this method is just a rough estimate that proves successful in many cases, but which is not necessarily useful for all materials. Especially, there may be inaccuracies in the *shape* of the suction profiles. A generated table is just meant to be some assistance; you should not blindly rely on it. Future WUFI versions are planned to offer more sophisticated methods.

Please note that the water absorption coefficient here has SI units [kg/m²√s], whereas the relevant German standard uses [kg/m²√h]. Divide the latter values (e.g. 2.6 kg/m²√h for Baumberger sandstone) by 60 to get SI units (0.043 kg/m²√s).

Literature:

[1]   Krus, M.: Moisture Transport and Storage Coefficients of Porous Mineral Building Materials. Theoretical Principles and New Test Methods
Fraunhofer IRB Verlag, 1996

[2]   Krus, M., Künzel H.M.: Flüssigtransport im Übersättigungsbereich. IBP-Mitteilung 22 (1995), Nr. 270.

Details / Heat Conductivity, Moisture-dependent

The **heat conductivity** of the dry material is a basic material parameter and thus indispensable. If, in addition, the dependence of the heat conductivity on the moisture content must be taken into account, WUFI can optionally employ a table with the relevant data. WUFI interpolates linearly between table entries.

If a simple linear dependence of the heat conductivity on the moisture content is sufficient, a two-line table may be generated by entering the **moisture-induced heat conductivity supplement**. The linear interpolation in this table is then equivalent to

$$\lambda(w) = \lambda_o \cdot (1 + b \cdot w/\rho_s)$$

$\lambda(w)$	[W/mK]	:	heat conductivity of moist material
λ_o	[W/mK]	:	heat conductivity of dry material
ρ_s	[kg/m³]	:	bulk density of dry material
b	[%/m-%]	:	moisture-induced heat conductivity supplement

The supplement b gives the fractional increase [in %] of the heat conductivity per mass-% moisture. Its value depends on the material; in hygroscopic materials, however, it is largely independent of their bulk density.

Examples:

Material	Bulk Density [kg/m³]	λ [W/mK]	b [%/M.-%]
cellular concrete	400-800	0.09-0.19	4
lime silica brick	1800	0.7	8
expanded clay concrete, pumice concrete	1400-1800	0.5-1.0	4
light-weight concrete with EPS aggregate	300-900	0.07-0.28	3
normal concrete	2300	1.3-1.5	8
wood	400-700	0.08-0.15	1.5

In organic insulation materials, there is in general no linear relationship between the heat conductivity and the moisture content.

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[$] Details / Heat Conductivity, Moisture-dependent
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[K] heat conductivity;thermal conductivity;generate;heat conductivity supplement;thermal conductivity supplement;phase change;latent heat;

In this context, 'heat conductivity of moist materials' means exclusively the influence of stationary water on heat transport. Water vapor diffusion with phase change (evaporation and condensation of water) also contributes to heat transport, but this is allowed for by separate terms in the transport equations. However, since in the standard measurement techniques this effect of water vapor diffusion *is* usually included, results of measurements in the plate apparatus for permeable materials (e.g. mineral wool) have to be regarded with caution.

During the calculation WUFI performs iterations where it samples small regions of the tabulated curve. Very sharp bends in the curve may throw the iteration off and thus impede its convergence. In such a case, the curve should be smoothed by inserting additional points. A large number of entries may slow the search in the table, however.

Please note that *design values*, such as the data given in German Standard DIN 4108, may already contain the contribution of a typical water content and, if so, are not strictly dry values.
If you want to perform the calculation with a constant (i.e. not moisture-dependent) heat conductivity (for example because you have no detailed data on the moisture-dependence), you may use these design values to allow for moisture content at least in a crude approximation. However, if you explicitly use a table of moisture-dependent heat conductivities, you should make sure that the value for moisture content = 0 is really the dry value.

On the other hand, hygrothermal simulations (in particular the resulting *moisture* contents and distributions) usually don't depend very sensitively on the precise values of the heat conductivities, so the difference may be generally negligible unless you are specifically interested in *heat* flows.

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Details / Diffusion Resistance Factor, Moisture-dependent

The **diffusion resistance factor** (µ-value) of the dry material is a basic material parameter and thus indispensable. If, in addition, the dependence of the diffusion resistance factor on the moisture content must be taken into account, WUFI can optionally employ a table with the relevant data. WUFI interpolates linearly between table entries.

Please note, however, that in mineral building materials the (fictitious) decrease of the diffusion resistance factor with increasing moisture content is due to surface diffusion [1] and may therefore also be included in the capillary conduction. In this case, using a constant diffusion resistance factor and choosing appropriate liquid transport coefficients is more advisable.

During the calculation WUFI performs iterations where it samples small regions of the tabulated curve. Very sharp bends in the curve may throw the iteration off and thus impede its convergence. In such a case, the curve should be smoothed by inserting additional points. A large number of entries may slow the search in the table, however.

The definition of the diffusion resistance factor (µ-value) is discussed in Details / Water Vapor Diffusion.

Even if you do not explicitly use a moisture-dependent diffusion resistance factor, WUFI will treat it as moisture-dependent if the moisture content exceeds the free saturation w_f. For details see the discussion of the "Diffusion Resistance Factor Dry".

Literature:

[1]   Krus, M.: Moisture Transport and Storage Coefficients of Porous Mineral Building Materials. Theoretical Principles and New Test Methods Fraunhofer IRB Verlag, 1996

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Details / Air Layers

WUFI can also include air layers in the building component. It does not simulate the air convection (which would not make much sense in one dimension anyway), but it allows for the air layer as a resistance to heat and moisture flows.

In addition to heat conduction, in air layers heat can also be transferred by convection and radiation. In addition to water vapor diffusion, in air layers water vapor can also be transferred by convection. Since WUFI is primarily intended for solid materials, it only allows for heat conduction and water vapor diffusion (plus liquid transport, which is not relevant here). However, the additional transport phenomena can be included by adjusting the heat conductivity and the diffusion resistance so that the correct heat and vapor flows result from the calculation.

The method is based on the following considerations which are valid for **non-ventilated air layers**. (No general treatment is possible for **ventilated air layers**; they may even exhibit the same conditions as the exterior air. Building components outward from the air layer may then be disregarded except for their shielding of rain and radiation.)

The relative contributions of heat conduction, convection and radiation are dependent on the thickness and orientation of the air layer, the nature of the two surfaces and the temperature. Fortunately, the dependence on the temperature may be neglected in building physics. Furthermore, it suffices to distinguish between metallic and non-metallic surfaces. So if we restrict ourselves to, say, vertical air layers with non-metallic surfaces, we can simply determine (e.g. from measurements) a heat resistance $R_{non-met}$ which depends only on the air layer thickness and which comprises all transport phenomena.

Now, for WUFI the effective heat conductivity λ^* has to be chosen so that for an air layer with a given thickness the heat resistance as determined above results. Note: the thickness with wich the air layer is included in the assembly for calculation need not (but can) be identical with the real thickness, since the real thickness was already allowed for in the specific choice of $R_{non-met}$.

The heat resistance of an air layer with the desired thickness, orientation (vertical, horizontal) and surfaces (metallic, non-metallic) may be looked up in a relevant table. Let's choose non-metallic surfaces here and call this value $R_{non-met}$, since in building components non-metallic surfaces are predominant. We also choose an arbitrary thickness Δx^*, which shall be the thickness of the air layer as inserted in WUFI's component assembly. Then

$$R_{non-met} = \Delta x^* / \lambda^* ,$$

therefore

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[$] Details / Air Layers
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[K] air layers;convection;radiation;heat flow through air layers;moisture flow through air layers;heat resistance of air layers;diffusion resistance of air layers;moisture storage function of non-hygroscopic materials

$$\lambda^* = \Delta x^* / R_{\text{non-met.}}$$

Since water vapor diffusion and convective water vapor transport are based on analogous mechanisms as heat conductivity and convective heat transport, the coefficients describing vapor transport can be derived from the coefficients for heat transport, using similarity relations. For vapor flow, we have formally:

$$-g_v = D_c / \mu^* \cdot \Delta c / \Delta x^* = \Delta c / S$$

g_v	[kg/m²s]	:	water vapor diffusion flux density
D_c	[m²/s]	:	concentration-related diffusion coefficient
μ^*	[-]	:	effective water vapor diffusion resistance factor
c	[kg/m³]	:	water vapor concentration
Δx^*	[m]	:	effective layer thickness
S	[m³/s²Pa]	:	water vapor diffusion resistance,

therefore

$$\mu^* = D_c \cdot S / \Delta x^*$$

But we have

$$D_c = 0.083 \cdot (T/273)^{1.81} \approx 0.09 \quad [1],$$

and, because of similarity relations,

$$S \approx R_{\text{met}} / 3.5 \quad [2],$$

where we have to use the heat resistance R_{met} of air layers between *metallic* surfaces (i.e., without radiation), since we want to estimate the vapor diffusion resistance and there is no transport mechanism analogous to radiation involved, in contrast to the above case of heat transport.

Finally, we have the freedom to choose an arbitrary thickness Δx^* with which the layer is included in the component assembly for calculation, since the real thickness was already allowed for in the choice of the specific value for R_{met}.

$$\mu^* = 0.09 \cdot R_{\text{met}} / (3.5 \cdot \Delta x^*) = \mathbf{0.026 \cdot R_{\text{met}} / \Delta x^*}$$

For vertical air layers, $R_{\text{non-met}}$ and R_{met} may be taken from this table (interpolated after [3]):

thickness [cm]	$R_{\text{non-met}}$ [m²K/W]	R_{met} [m²K/W]
0	0	0
1	0.140	0.280
2	0.160	0.430
3	0.171	0.526

4	0.178	0.590
5	0.180	0.620
6	0.178	0.627
7	0.176	0.623
8	0.174	0.613
9	0.172	0.598
10	0.170	0.580
11	0.168	0.557
12	0.166	0.530
13	0.164	0.501
14	0.162	0.468
15	0.160	0.430

The other basic material parameters may be determined according to the following:

- if Δx^* was chosen not equal to the real thickness, multiplication of the 'bulk density' 1.29 kg/m³ by (real thickness)/Δx^* results in the correct heat capacity;

- the 'porosity' should be chosen very high (e.g. 0.999 m³/m³);

- the specific heat capacity by mass of the air layer is 1 kJ/kgK, even if Δx^* is chosen not equal to the real thickness.

For the graphical display of the component assembly, it will be advisable to choose Δx^* equal to the real thickness. Note however that if you want to repeat the calculation with an air layer of a different thickness, it is *not* sufficient to simply adapt the layer thickness in the component assembly. Instead, λ^* and μ^* have to be newly determined from scratch.

Regarding the 'moisture storage function' of air layers, see Details / Moisture Storage Function and the Questions & Answers section.

The definition of the diffusion resistance factor (µ-value) is discussed in Details / Water Vapor Diffusion.

Literature:

[1]   Schirmer, R.: Die Diffusionszahl von Wasserdampf-Luft-Gemischen und die Verdampfungsgeschwindigkeit, Beiheft VDI-Zeitschrift, Verfahrenstechnik (1938), H. 6, p. 170-177.
[2]   Illig, W.: Die Größe der Wasserdampfübergangszahl bei Diffusionsvorgängen in Wänden von Wohnungen, Stallungen und Kühlräumen, Gesundheitsingenieur 73 (1952), H. 7/8, p. 124-127.
[3]   Gösele, K., Schüle, W.: Schall·Wärme·Feuchte. Bauverlag 1989.

Continue with Details / Membranes

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Details / Membranes

Membranes may serve different purposes in building elements, such as airflow control, waterproofing, surface protection etc. Within the scope of one-dimensional hygrothermal simulations only **vapor retarders** and **vapor barriers** are of interest.

Generally, the only effect of these membranes is their water vapor diffusion resistance. At most, a membrane at the exterior surface may make itself additionally felt by its radiation absorptivity (for example, 0.9 for bituminous felt) and its rain water absorption factor (0 for watertight membranes), which are treated separately in WUFI. The thermal resistance of a membrane is usually negligible.

If the membrane is on the exterior or interior **surface**, its diffusion resistance may simply be allowed for by choice of an adequate vapor diffusion thickness for the surface.

A membrane **in the midst** of a building component, however, has to be explicitly included in the component assembly.

Generally, a membrane will have a thickness of a few hundredths to a few tenths of a millimeter. Since every layer of the assembly should be composed of at least ca. five grid elements, the individual grid elements of the membrane will be very small. For numerical reasons, neighbouring grid elements should not differ too much in their thickness; in the material layers adjacent to the membrane, this would necessitate a succession of smaller and smaller elements towards the membrane in order to avoid a large mismatch. The resulting large number of grid elements would impose a heavy burden on the calculation without any other benefit than to smooth the grid.

It is therefore preferable to use an **'effective'** membrane which is thicker than the real membrane and whose material data have accordingly been adapted to result in the correct heat and vapor diffusion fluxes. The membranes in the database that comes with WUFI have their data adjusted so that these membranes must be used as **1 mm thick** membranes in the component assembly.

The 'effective' membranes have the additional advantage that they are easier to identify in graphical representations of the component assembly.

The conversion is simple: Often you'll neither know the thickness of the membrane nor the diffusion resistance factor of its material, but the vapor diffusion thickness of the membrane (i.e. the thickness of a stagnant air layer with the same diffusion resistance). That's all you need: divide the vapor diffusion thickness by 1 mm or another convenient thickness, use the result as the diffusion resistance factor and insert the membrane with the chosen thickness in the component assembly.

The other basic material parameters are treated as follows:

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[$] Details / Membranes
[+] 1080
[K] membranes;diffusion resistance factor;water vapor diffusion resistance factor;sd-value

- if you happen to know the bulk density of the membrane material and the thickness of the membrane, you may determine the effective density as $\rho \cdot$ (real thickness) / (effective thickness) in order to adjust the heat capacity. Otherwise, choose a value that is small enough to result in a plausible heat capacity if multiplied by the specific heat capacity. (The heat capacity of a thin membrane is negligible, but you should take care that the heat capacity of the thicker effective membrane is negligible, too.)

- set the porosity to an arbitrary, preferably very small value (e.g. 0.001, since the usual membrane materials are not porous)

- if you know the specific heat capacity of the membrane material, enter this value unchanged. Otherwise enter e.g. 1500 J/kgK for organic materials

- if you know the heat conductivity of the membrane material and the thickness of the membrane, determine the effective heat conductivity as $\lambda \cdot$ (effective thickness) / (real thickness). Otherwise, choose a value that is large enough to result in a negligible heat resistance for the membrane.

The definitions of the vapor diffusion resistance factor (μ-value) and the vapor diffusion thickness (s_d-value) are discussed in Details / Water Vapor Diffusion.

Please note that replacing a thin layer with a thicker layer with effective material parameters is only permissible in *one-dimensional* calculations! In two-dimensional cases you also have heat and vapor flows *along* the membrane instead of only *across* it, and in general you can't use an arbitrary effective *length* of the membrane (e.g. a membrane wrapped around a rafter or one following a winding path through the assembly).

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Details / Surface Transfer

Starting from specified initial conditions, WUFI computes the temporal evolution of the temperature and moisture distributions in the building component. This evolution is determined not only by the underlying transport equations which govern the processes *in* the component, but also by the heat and moisture exchange with its surroundings. Thus there are heat and moisture flows through the surfaces, the direction and magnitude of which depend on the conditions in the component as well as on the conditions in the surroundings.

The surface transfer coefficents indicate to which extent the conditions in the surroundings affect the building component, especially the heat and moisture flows through its surfaces.

The following help topics offer a discussion of the surface transfer coefficients used by WUFI:

Details / Heat Transfer Coefficients and Resistances
Details / Water Vapor Transfer Coefficients
Details / Water Vapor Diffusion
Details / Surface Coatings
Details / Short-wave Radiation Absorptivity
Details / Long-wave Radiation Emissivity
Details / Rain Water Absorption Factor

Continue with Details / Heat Transfer Coefficients and Resistances

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Hilfe_Allgemein_C_UT200
$ Details / Surface Transfer
+ 2010
K surface transfer coefficients

Details / Heat Transfer Coefficients and Resistances

If a wall surface is warmer than its surroundings, it will give off heat. This heat transport is effected by several transport mechanisms: heat conduction through the air adjacent to the surface, convective transport by air flows, and emission of long-wave radiation. Detailed modelling of all these phenomena is extremely complicated, but fortunately it is not necessary in the context of building physics. For the temperature and flow situations encountered here, a simple proportionality with a constant coefficient is usually adequate:

$$q = \alpha \, (\vartheta_u - \vartheta_o)$$

q	[W/m²]	:	heat flux density
α	[W/m²K]	:	heat transfer coefficient
ϑ_u	[°C]	:	ambient temperature
ϑ_o	[°C]	:	surface temperature

The heat transfer coefficient consists of two parts:

$$\alpha = \alpha_k + \alpha_s$$

α_k	[W/m²K]	:	convective heat transfer coefficient
α_s	[W/m²K]	:	radiative heat transfer coefficient

convective heat transfer coefficient

The air adjacent to the component surface drains heat from the component by conductive and convective heat transport. Although these are two distinct transport phenomena, they are lumped together in the term of 'convective heat transfer'.

Right next to the wall, the air takes on the temperature of the wall surface. At some distance from the surface, the convective mixing of the air maintains a nearly constant temperature distribution which is determined by the indoor or outdoor climate. It's usually the latter temperature that is measured as the 'air temperature'.

However, the heat transfer from the wall surface to the adjacent air is not determined by the difference between the surface temperature and the 'air temperature' but by the smaller difference between the surface temperature and the temperature of the boundary layer. The heat flow is thus less than might be expected from the air temperature. This reduction of the heat flow is

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[#] Hilfe_Allgemein_C_UT200a
[$] Details / Heat Transfer Coefficients
[+] 2020
[K] heat transfer coefficient;heat transfer resistance;heat transfer (convective);heat transfer (radiative)

formally allowed for by introduction of a 'resistance'. The reciprocal of this resistance is the convective heat transfer coefficient in the above heat transport equation.

The numerical value of the c.h.t.c. is in a complicated way dependent on the temperature, the magnitude and direction of a possible air flow, the nature of the wall surface etc. Only rough values can be given for general cases. With free convection (by warming or cooling of the air) the c.h.t.c is in the range 3 to 10 W/m²K, with forced convection (by wind), in the range 10 to 100 W/m²K.

radiative heat transfer coefficient

A wall surface always exchanges long-wave thermal radiation with other surfaces in its surroundings. The corresponding heat flow depends on the temperatures (to the fourth power), the materials, the nature of the surfaces, the size and the geometrical arrangement of the involved surfaces.

Since in most cases the temperatures of the other surfaces are not known, they are for the purpose of calculations in building physics usually assumed to be identical to the known air temperature. Furthermore, three of the four powers of the temperature are lumped together with the r.h.t.c. (which thus becomes temperature-dependent), and the result is a simple linear relationship analogous to the convective heat transfer (see also the discussion of the long-wave radiation exchange).

The dependence on the material of the wall and the nature of the surface is negligible as long as the materials are non-metallic, which is usually the case in the context of building physics.

For two close, extended, parallel, plane, non-metallic surfaces the r.h.t.c. lies between ca. 3 and 6 W/m²K.

Please note that the r.t.h.c. only applies to radiation exchange between surfaces which are more or less at ambient temperature. Solar radiation (with a source temperature of 6000 K and a marked diurnal variation) is treated separately (see Details / Short-wave Radiation Absorptivity).

In compliance with recent changes in standardized terminology, WUFI now employs the **heat transfer resistance**, which is simply the reciprocal of the **heat transfer coefficient**.

For the sake of simplicity, WUFI uses either constant heat transfer resistances, or a very simple dependence on wind speed, since allowing for the ambient conditions in a detailed way would be very complex, and only in the rarest cases all the necessary boundary conditions are known.

WUFI offers the following heat transfer resistances for selection:

exterior heat transfer resistance:
- 0 m²K/W   for basements in direct contact with the surrounding soil
- 0.052 m²K/W   for pitched or flat roofs
- 0.056 m²K/W   for outer walls [1],
- (user-defined)

These average values do not apply to greatly exposed building components or building surfaces at great height, where correspondingly lower heat transfer resistances must be substituted.

interior heat transfer resistance:
- 0.13 m²K/W for basements, outer walls, roofs [2]
- (user-defined)

The interior h.t.r. in the region of corners or edges is generally higher than this average value. Should there be a stratification of temperature in a room, moisture transport calculations must not allow for this by a transfer resistance based on the mean temperature, since this results in an erroneous assessment of the moisture conditions at the interior surfaces. If a vertical room temperature profile is to be taken into account, this can only be done by specifying the boundary conditions as a function of height.

The heat transfer resistances only describe heat exchange with the ambient air or with surrounding surfaces which are at a temperature close (+/- several tens of degrees) to the temperature of the building component. For the heat load due to solar radiation, see Details / Short-wave Radiation Absorptivity.

Regarding the problem of nightly radiation cooling, see Details / Long-wave Radiation Emissivity.

The heat transfer resistances are entered in the dialog "Surface Transfer Coefficients".

Literature:

[1]   Schaube, H. und Werner, H.: Wärmeübergangskoeffizient unter natürlichen Klimabedingungen. IBP-Mitteilung 13 (1986), Nr. 109.

[2]   Erhorn, H. und Szerman, M.: Überprüfung der Wärme- und Feuchteübergangskoeffizienten in Außenwandecken von Wohnbauten. Gesundheitsingenieur 113 (1992), H. 4, S. 177-186.

Continue with Details / Water Vapor Transfer Coefficients

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Details / Water Vapor Transfer Coefficients

The water vapor transfer may be described in analogy to the heat transfer:

$$g_v = \beta_p (p_u - p_o)$$

g_v	[kg/m²s]	:	water vapor flux density
β_p	[kg/m²sPa]	:	water vapor transfer coefficient
p_u	[Pa]	:	ambient water vapor partial pressure
p_o	[Pa]	:	water vapor partial pressure at the surface

The reason for a resistance affecting water vapor transfer is the same as with heat transfer, namely the effect of a boundary air layer close to the wall surface.

Since the ambient conditions affect both boundary layers in analogous ways, there are similarity relations between water vapor transfer and heat transfer, so that β_p may be obtained from the following equation (with the numerical value valid only for the SI units quoted above):

$$\beta_p = 7 \cdot 10^{-9} \; \alpha_k \; [1]$$

α_k [W/m²K]   :   convective heat transfer coefficient

This requires to estimate the convective component α_k of the heat transfer coefficient α. WUFI uses the following estimate (in FORTRAN notation):


```
ALFAWC = ALFAW - 6.5                            ! EXTERIOR
ALFAEC = ALFAE - 4.5                            ! INTERIOR
ALFMIN = 3.5
BETAW  = 7.E-9 * DMAX1(ALFMIN, ALFAWC)    ! EXTERIOR
BETAE  = 7.E-9 * DMAX1(ALFMIN, ALFAEC)    ! INTERIOR
```


The suffix `W` refers to the exterior surface; `E`, to the interior surface; and `C`, to the convective component.

For example, the water vapor transfer coefficients 8.0E-8 (exterior) and 2.2E-8 kg/m²sPa (interior) result from WUFI's default heat transfer resistances of 0.056 and 0.13 m²K/W, respectively.

[#] Hilfe_Allgemein_C_UT200b
[$] Details / Water Vapor Transfer Coefficients
[+] 2030
[K] water vapor transfer coefficient;heat transfer coefficient

Literature:

[1]   Illig, W.: Die Größe der Wasserdampfübergangszahl bei Diffusionsvorgängen in Wänden von Wohnungen, Stallungen und Kühlräumen, Gesundheitsingenieur 73 (1952), H. 7/8, p. 124-127.

Continue with Details / Water Vapor Diffusion

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Details / Water Vapor Diffusion

This help topic discusses several physical quantities used to describe water vapor diffusion, since these quantities and their interrelationships may not be familiar to all WUFI users.

Water vapor diffusion resistance factor, μ-value

Diffusion of water vapor in air can be described by the equation

$g_v = -\delta * dp/dx$ (in air),

g_v	[kg/m²s]	:	water vapor flux density
p	[Pa]	:	water vapor partial pressure
δ	[kg/(msPa)]	:	water vapor diffusion coefficient in air,

where

$\delta = 2.0 \cdot 10^{-7} \, T^{0.81} / P_L$ [1]

T	[K]	:	absolute ambient temperature
P_L	[Pa]	:	ambient atmospheric pressure.

In porous building materials, diffusion likewise takes place in air (in the pore spaces), but it is impeded by the reduction of the accessible cross-section, adsorption effects at the pore walls and the tortuosity of the pore paths. In the context of building physics, it is admissible to allow for this by simply introducing a **diffusion resistance factor** μ:

$g_v = -(\delta/\mu) * dp/dx$ (in porous material),

μ	[-]	:	water vapor diffusion resistance factor.

Retaining δ as a separate coefficient in the above equation has the advantage that it already describes the temperature and pressure dependence of water vapor diffusion and μ is therefore practically independent of temperature and pressure, i.e. it is a constant which only depends on the material in question.

However, measurements of μ which are performed at different levels of relative humidity (dry-cup and wet-cup) may result in different values for one and the same material. This is due to surface diffusion which becomes noticeable at higher

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Hilfe_Allgemein_C_UT200b2
$ Details / Water Vapor Diffusion
+ 2040
K water vapor diffusion;water vapor diffusion resistance factor;diffusion resistance factor;mu-value;vapor diffusion thickness;sd-value;permeance;permeability;perm;dry-cup;wet-cup

humidities but is more properly treated as liquid transport [2]. This additional moisture transport is usually not separated out in the analysis of the measurements and, lumped together with vapor diffusion, reduces the apparent diffusion resistance, resulting in a lower μ-value. In these cases, it is more appropriate to use a constant μ-value and to adjust the liquid transport coefficients to include surface diffusion. However, WUFI also allows to use a moisture-dependent μ-value to simplify the treatment of cases where this distinction can be neglected.

The μ-value represents the ratio of the diffusion coefficients of water vapor in air and in the building material and has therefore a simple interpretation: it is the factor by which the vapor diffusion in the material is impeded, as compared to diffusion in air. For very permeable materials, such as mineral wool, the μ-value is thus close to 1, whereas it increases for materials with greater diffusion resistance.

The following table lists μ-values for some common materials:

| | μ-value | |
	dry-cup (3% - 50% RH)	wet-cup (50%-93% RH)
cellular concrete	7.7	7.1
lime silica brick	27	18
solid brick	9.5	8.0
gypsum board	8.3	7.3
concrete (B25)	110	150 (*)
cement-lime plaster	19	18
lime plaster	7.3	6.4
Saaler sandstone	60	28
Baumberger sandstone	20	17
Worzeldorfer sandstone	38	22

(*) the increase of the μ-value in the wet-cup measurement of concrete is probably due to swelling effects [3].

Vapor diffusion thickness, s_d-value

Assuming constant temperature and μ-value, the diffusion flow through a material

layer with thickness $\Delta x = s$ is

$$g_{v\_mat} = -\delta/\mu * \Delta p/\Delta x = -\delta/(\mu*s) * \Delta p,$$

whereas the diffusion flow through an air layer ($\mu=1$) with thickness s_d is

$$g_{v\_air} = -\delta/\mu * \Delta p/\Delta x = -\delta/(1*s_d) * \Delta p = -\delta / s_d * \Delta p.$$

Dividing the former equation by the latter yields

$$g_{v\_mat} / g_{v\_air} = s_d / (\mu*s).$$

If the air layer is to be chosen so that its vapor diffusion resistance is the same as that of the material layer of thickness s (and therefore $g_{v\_mat} = g_{v\_air}$), then its thickness s_d must be

$$s_d = \mu*s.$$

For a material layer with diffusion resistance factor μ and thickness s, the product $\mu*s$ thus gives the thickness which an air layer would need in order to have the same diffusion resistance. This **"s_d-value"** or **"vapor diffusion thickness"** expresses the diffusion resistance of a layer in a form which is easily understood and applied.

For some building components, only their diffusion resistance is of importance but not their μ-value and their thickness separately. They may then simply be specified in terms of their s_d-value. Also, measuring the s_d-value does not require to determine the thickness of the sample.
In particular, the s_d-value is used to characterise vapor retarders ($s_d \geq 10$ m), vapor barriers ($s_d \geq 1000$ m) and surface coatings (mineral paints: $s_d \approx 0.04$ m, oil paints: $s_d = 1.0 .. 2.6$ m), where it can be difficult to determine their thickness properly.

Permeance, Permeability

Rearranging

$$g_v = -\delta/\mu * \Delta p/\Delta x$$

and taking absolute values yields

$$g_v/\Delta p = \delta/\mu * 1/\Delta x = \delta/s_d \quad [kg/(m^2 s Pa)].$$

The leftmost term is the **permeance** Δ of the layer. In Inch-Pound units the permeance is measured in **perm**. One perm is one grain (avoirdupois) of water vapor per hour flowing through one square foot of a layer, induced by a vapor pressure difference of one inch of mercury across the two surfaces. In SI units, this corresponds to 57.45e-12 kg/(m²sPa) [4]. Therefore, with Δ expressed in perm:

$$57.45e\text{-}12*\Delta = \delta/s_d \quad [kg/(m^2 s Pa)], \text{ or}$$
$$s_d = \delta/(57.45e\text{-}12*\Delta) \quad [m].$$

For a reference temperature of 5°C and a barometric pressure of 1013.25 hPa, δ has the value 1.884e-10 kg/(msPa) (see above), and we obtain

s_d = 3.28/Δ,

where Δ is expressed in perm and s_d in m.

The permeance describes a property of a specific construction layer with a given thickness. Multiplying the permeance by the layer thickness Δx yields the **permeability Π** [perm in] of the layer material:

$g_v * \Delta x / \Delta p = \delta / \mu$.

The conversion factor for the left side is now 57.45e-12 [kg/(m²sPa)]/[perm] * 0.0254 [m]/[in] = 1.459e-12 [kg/(msPa)]/[perm in]:

1.459e-12*Π = δ/μ [kg/(msPa)],

and with the same reference value for δ as above:

7.744e-3*Π = 1/μ [-], or

μ = 129 / Π [-],

where Π is expressed in perm inch and μ is dimensionless.

Literature:
[1]   Schirmer, R.: Die Diffusionszahl von Wasserdampf-Luft-Gemischen und die Verdampfungsgeschwindigkeit, Beiheft VDI-Zeitschrift, Verfahrenstechnik (1938), H. 6, p. 170-177.

[2]   Krus, M.: Moisture Transport and Storage Coefficients of Porous Mineral Building Materials. Theoretical Principles and New Test Methods Fraunhofer IRB Verlag, 1996

[3]   Holm, A., Krus, M., Künzel, H.M.: Concrete from the viewpoint of moisture technology: Parameters and mathematical approaches to the evaluation of climatic effects in external structural elements made of concrete To be published in Concrete Science and Engineering

[4]   ASHRAE Terminology of Heating, Ventilation, Air Conditioning, & Refrigeration, 2nd ed. 1991

Details / Surface Coatings

Walls may have a surface 'coating' which does not affect their thermal behaviour but impedes water vapor diffusion, e.g. paint coats, wallpapers, vapor retarders, laminations, an impregnation which alters the pore space close to the surface etc.

Instead of including a separate, often extremely thin layer in the component assembly, you may allow for its effect on water vapor transport in these cases by only applying a separate diffusion resistance at the surface. This resistance is specified in terms of the thickness of a stagnant air layer with the same diffusion resistance, i.e. you enter the corresponding vapor diffusion thickness (s_d-value).

Thus, you may simulate the effect of a vapor retarder by setting the v.d.t. to 10 m (e.g.) at the respective surface. But more massive components like gypsum board ($s_d \approx 0.1$ m) or renderings may also be replaced by their s_d-value, as long as their effect on the hygrothermal behaviour of the entire building component is limited to their diffusion resistance.

If you nevertheless want to explicitly include membranes or other thin surface layers in the component assembly, please refer to the notes in Details / Membranes.

Because of the boundary air layer which exists at every wall surface, there is always some surface transfer resistance to the water vapor diffusion flow (cf. Details / Water Vapor Transfer Coefficients). The s_d-value discussed here only describes an *additional* resistance that is caused by factors like those enumerated above. That is, WUFI adds the resistance resulting from the internally computed natural water vapor transfer coefficient and the s_d-value due to some coating (if any) to arrive at the total water vapor transfer resistance used in the calculation. So for an ordinary naked wall surface, simply set $s_d = 0$ m.

The definition of the vapor diffusion thickness (s_d-value) is discussed in Details / Water Vapor Diffusion.

The vapor diffusion thicknesses of surface coatings (if any) are entered in the dialog "Surface Transfer Coefficients". There, WUFI offers a list of predefined coatings with their respective vapor diffusion thicknesses for selection; a user-defined value may be entered as well.

Please note that if you select, say, a metal foil from the list, **only** the sd-value at the component surface is set accordingly; **other** properties of the foil, such as its low radiation absorptivity or its impermeability to rain, must be specified separately by setting the appropriate surface properties.

[#] Hilfe_Allgemein_C_UT200c
[$] Details / Surface Coatings
[+] 2050
[K] vapor diffusion thickness;sd-value;permeance;surface coating;water vapor transfer coefficient

Continue with

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Details / Short-wave Radiation Absorptivity

The heat transfer coefficients already contain a component which describes the long-wave radiation exchange with other surrounding surfaces. The temperature of these surfaces is assumed to be approximately equal to the air temperature.

The solar radiation, however, which shows a pronounced diurnal variation, can by no means be related to the air temperature. Since its effect on the surface temperatures cannot be neglected, it must be treated separately.

Whereas the radiation exchange between the building component and the surroundings (T ≈ 300 K) essentially takes place in the infrared, the spectrum of the solar radiation (T ≈ 6000 K) also contains a considerable amount of short-wave radiation. For this reason, the solar radiation is here also simply called 'short-wave radiation'.

The short-wave radiation absorptivity indicates the fraction of the total (i.e., long- and short-wave) solar radiation incident on the component surface which is absorbed:

$$q = a_s \cdot I$$

q	[W/m²]	:	heat flow due to solar radiation
a_s	[-]	:	'short-wave' radiation absorptivity
I	[W/m²]	:	solar radiation vertical to component surface

WUFI calculates the radiation load vertical to the surface from the data in the climate file, multiplies it - if positive - by the s.r.a. and applies the result as a heat source to the component. (If the radiation load computed from the climate data is negative, it is multiplied by the long-wave radiation emissivity.)

Examples:

plaster, white (aged)	0.4
roof tile, red	0.6
klinker brick, dark red	0.7
roof tile, brown	0.8
bituminous roof covering	0.9
wood (spruce):	
untreated	0.4
weathered (silver-gray)	0.7
painted brown	0.8

[#] Hilfe_Allgemein_C_UT200d
[$] Details / Short-wave Radiation Absorptivity
[+] 2060
[K] absorption (radiation);short-wave radiation absorptivity;short-wave;absorptivity;solar radiation;

Schilf sandstone:
dry	0.7
wet	0.85

red Main sandstone	0.75

sandstone with patina	0.9

WUFI offers a list of predefined surfaces with their respective short-wave absorptivities for selection, a user-defined value may be entered as well.

The absorptivity coefficients are entered in the dialog "Surface Transfer Coefficients".

Details / Long-wave Radiation Emissivity

For non-metallic component surfaces, the long-wave radiation emissivity is usually 0.9 or thereabout.

WUFI automatically determines the long-wave emissivity from the type of surface selected for the short-wave absorptivity or employs user-defined values for both.

The emissivity coefficients are entered in the dialog "Surface Transfer Coefficients".

Continue with Details / Rain Water Absorption Factor

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Details / Rain Water Absorption Factor

The r.w.a.f. takes into account that some of the rain water hitting an inclined surface splashes off on impact and is therefore not available for capillary suction.

WUFI calculates the rain load on the component from the data in the climate file and multiplies it by the r.w.a.f. The resulting rain quantity is offered to the component for capillary suction. (The component may imbibe the offered quantity or less, but not more).

The r.w.a.f. depends on the roughness, orientation and inclination of the surface, and on the nature of the precipitation (rain, snow…).

With horizontal surfaces, the r.w.a.f. is usually one, since the scattered drops fall back to the surface.

With vertical surfaces, it is nearly zero for snow and hail, for other conditions it must be estimated. A value of 0.7 might be a good starting point.

Since most component surfaces - with the exception of unrendered masonry and natural stone facades - only have a moderate water absorption, they cannot imbibe all the offered water anyway. In these cases, an exact knowledge of the rain quantity is not essential (whereas the *duration* of the rain is still important) and estimates for the r.w.a.f. and the position-specific driving rain coefficients may be sufficient.

WUFI automatically determines the r.w.a.f. from the inclination and the construction type; a user-defined value may be employed as well.

The rain water absorption factor is entered in the dialog "Surface Transfer Coefficients".

Continue with Details / Climate Data

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Hilfe_Allgemein_C_UT200f
$ Details / Rain Water Absorption Factor
+ 2080
K rain water absorption factor

Details / Climate Data

Starting from specified initial conditions, WUFI computes the temporal evolution of the temperature and moisture distributions in the building component. This evolution is determined not only by the underlying transport equations which govern the processes *in* the component, but also by the heat and moisture exchange with its surroundings. Thus there are heat and moisture flows through the surfaces, the direction and magnitude of which depend on the conditions in the component as well as on the conditions in the surroundings. The latter are described by the **boundary conditions**.

Since WUFI has been developed specifically for application in building physics, the surrounding medium is the ambient air (outdoor air, indoor air). Since it is furthermore designed to calculate the behaviour of building components exposed to the weather, it seems natural to describe the condition of the surrounding air in terms of **meteorological** parameters like temperature, relative humidity, solar radiation etc. In this way, WUFI keeps in close touch with building practice and can use existing measured data.

The choice of expressing the boundary conditions in terms of meteorological parameters does not prevent you from applying WUFI to laboratory investigations like imbibition or drying experiments, since the laboratory conditions can be expressed in meteorological terms as well.

WUFI needs the following climate data for each time step:

- the **rain** load vertically incident on the exterior surface in [Ltr/m²h]. For the determination of this rain load, the inclination and orientation of the surface must be taken into account.

- the solar **radiation** vertically incident on the exterior surface in [W/m²]. For the determination of the amount of radiation, the inclination and orientation of the surface must be taken into account.

- the **temperature** of the exterior air in [℃]

- the **relative humidity** of the exterior air (0..1)

- the **temperature** of the interior air in [℃]

- the **relative humidity** of the interior air (0..1)

- the **barometric pressure** in [hPa]. Since the barometric pressure has only a minor effect on the calculation, specification of a mean value over the

---

calculation period can be sufficient.

- the long-wave **atmospheric counterradiation** [W/m²], if radiation cooling is to be accounted for during the night.

The weather file may contain measured weather data (such as IBP weather data), or synthetic but realistic weather data (such as the old Test Reference Years), or completely artificial data (which describe, for example, a laboratory experiment).

Since WUFI's main application is the investigation of the hygrothermal behavior of building components exposed to natural weather, it is set up to read files that contain measured weather data. However, measured data can not always be used directly:

As mentioned above, WUFI needs the rain load and the radiation load incident on the wall or roof surface under investigation. Since rain and radiation are directed quantities, these loads depend on the orientation and the inclination of the individual building component. Unfortunately, in conventional weather measurements they are usually only recorded for horizontal surfaces.
It is possible, however, to compute the fractions of rain and radiation hitting the surface from conventional weather data. The rain load can be determined from the normal rain and the wind velocity and direction. The amount of radiation can be determined from the global (or direct) and diffuse radiation incident on a horizontal surface. WUFI performs these conversions automatically and the user only needs to supply the conventionally measured weather data. In the current WUFI version, this requires a file in ***.WET** or ***.TRY** or ***.DAT** or ***.WAC** or ***.IWC** format. Depending on the format, files provided by the user (as opposed to the files supplied with WUFI or files pre-registered in the database) may also require a supporting ***.AGD** file which supplies geographical data on the climate location.

On the other hand, WUFI can also read files which directly contain the required rain and radiation loads as determined for the specific surface in question, so that no further conversion is necessary. This may be convenient if
- you want to convert the weather data with more sophisticated algorithms than WUFI does, or if
- you want to employ data that have been directly measured at the surface in question and thus need not be converted, or if
- you want to use data synthesized by your own climate simulator, or if
- you want to use data which describe the conditions of a laboratory experiment,
- etc.

These files must be in ***.KLI** format.

The following sections explain these file formats in detail:

Details / The *.WET Format for Climate Data

Details / The *.TRY Format for Climate Data

Details / The *.DAT Format for Climate Data

Details / The *.WAC Format for Climate Data

Details / The *.IWC Format for Climate Data

The method used by WUFI to convert radiation data is described in the Questions & Answers section.

Some of the files supplied with WUFI are restricted to use with WUFI only and thus have the proprietary binary *.WBC format.

Continue with Details / The *.WET Format for Climate Data

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Details / The *.WET Format for Climate Data

You can use existing IBP weather files (file format *.WET) to perform WUFI calculations; you can also convert your own weather data to that format and use them.

IBP weather files contain 21 lines of header which explain the meaning of the different data columns and an arbitrary number of lines with hourly weather data. WUFI skips the header.

Example:

```
 Spalte 1: Tag                                    Revision 1
        2: Monat
        3: Jahr
        4: Uhrzeit
        5: Aussentemperatur IBP
        6: Temperatur schwarze Oberflaeche
        7: Temperatur weisse Oberflaeche
        8: Temperatur Erdoberflaeche
        9: Temperatur 50 cm unter Erdoberflaeche
       10: Temperatur 1 m unter Erdoberflaeche
       11: Globalstrahlung
       12: Diffusstrahlung
       13: West-Strahlung
       14: Rel. Luftfeuchte
       15: Luftdruck
       16: Windgeschwindigkeit
       17: Normalregen Wippe
       18: Normalregen Tropfer
       19: Schlagregen Wippe
       20: Schlagregen Tropfer
    21-37: Windrichtung Haeufigkeiten
 01 01 91 01 -0.855E+01 -0.114E+02 -0.113E+02 -0.106E+01 ...
 01 01 91 02 -0.923E+01 -0.115E+02 -0.116E+02 -0.113E+01 ...
 01 01 91 03 -0.875E+01 -0.113E+02 -0.112E+02 -0.122E+01 ...
 01 01 91 04 -0.911E+01 -0.107E+02 -0.107E+02 -0.131E+01 ...
 01 01 91 05 -0.768E+01 -0.102E+02 -0.103E+02 -0.138E+01 ...
 01 01 91 06 -0.826E+01 -0.106E+02 -0.105E+02 -0.146E+01 ...
 01 01 91 07 -0.947E+01 -0.118E+02 -0.116E+02 -0.163E+01 ...
 01 01 91 08 -0.116E+02 -0.130E+02 -0.131E+02 -0.186E+01 ...
 01 01 91 09 -0.900E+01 -0.110E+02 -0.116E+02 -0.205E+01 ...
 01 01 91 10 -0.752E+01 -0.580E+01 -0.781E+01 -0.209E+01 ...
 01 01 91 11 -0.521E+01 -0.155E+01 -0.435E+01 -0.190E+01 ...
 01 01 91 12 -0.405E+01  0.845E-01 -0.206E+01 -0.159E+01 ...
 01 01 91 13 -0.250E+01  0.567E+01 -0.267E+00 -0.129E+01 ...
 01 01 91 14 -0.702E+00  0.117E+02  0.383E+00 -0.103E+01 ...
etc.
```

(for formatting reasons, the data lines cannot be reproduced here in their entirety. Please refer to the file IBP1991.WET you received with WUFI for a complete

---

[#] Hilfe_Allgemein_C_UT300a
[$] Details / The *.WET Format for Climate Data
[+] 3020
[K]   climate   data;climate   file;weather   data;weather   file;IBP   weather file;generate;temperature;temperature   (surface);temperature   (ground);global radiation;diffuse   radiation;western   radiation;relative   humidity;barometric pressure;wind velocity (scalar);normal rain;driving rain;wind direction distribution

example).

The format of the data is free; the only requirement is that a PASCAL program (like WUFI) must be able to read the data.
The file need not conform to a specific column format (as in FORTRAN), the number of decimal places does not matter, floating point numbers need not be in exponential format etc.

The number type `real/integer` has to be adhered to, however. The individual numbers must be separated by blanks, not tabulators.

The fact that the floating point numbers in the example all start with a zero is irrelevant (they were created with a FORTRAN program which likes to write numbers this way).

The data in detail:

• **Day, month, year, hour** (`integer`):

The IBP files contain hourly mean values of the measured data. These time stamps indicate the point in time when each measuring interval of one hour was finished and the measured mean values recorded. I.e., the data line starting with `01 01 91 04` contains the mean values for the hour from 03:00 to 04:00 on January 1, 1991.

Since its data are real-life data, an IBP weather file may contain an intercalary day (February 29). WUFI however knows nothing about intercalary days (at least in the present version). These must be deleted from files you want to use for WUFI calculations.

The time count always refers to winter time (CET). There is no daylight saving time.

• **Exterior air temperature** (`real`):

the temperature of the exterior ambient air in [°C]. It is used without change as the exterior air temperature in the WUFI calculation.

• Temperature of black surface (`real`):
• Temperature of white surface (`real`):

Surface temperatures of west-facing test facade elements painted black ($a_s \approx$ 0.9) and white ($a_s \approx 0.4$), respectively.
These may optionally be read instead of the exterior air temperature.

• Temperature of Ground Surface (`real`):
• Temperature 50 cm below Ground Surface (`real`):
• Temperature 1 m below Ground Surface (`real`):

Soil temperatures at various depths in [°C].
These may optionally be read instead of the exterior air temperature.

• **Global radiation** (`real`):

the sum of the direct and diffuse components of the solar radiation incident on a horizontal surface; in [W/m²].

- **Diffuse radiation** (real):
  the diffuse component of the solar radiation incident on a horizontal surface; in [W/m²].

  Subtracting the diffuse radiation from the global radiation results in the direct radiation. From this, the direct normal radiation can be calculated, i.e., the amount of radiation incident on a surface that is orthogonal to the ray direction. This calculation requires knowledge of the time and geographical location of the measurement, since the corresponding position of the sun has to be determined [2].

  The direct normal radiation can then be used to calculate the direct radiation incident on a surface with arbitrary orientation and inclination. Addition of the appropriate fraction of diffuse radiation results in the global radiation incident on the building component.

  These calculations are automatically done by WUFI during a simulation run.

  WUFI uses a simplified radiation model which treats the diffuse radiation as isotropic and ignores the albedo of the ground. If you are more demanding or want to allow for local specifics (like shadows etc.), you can perform the conversion yourself and feed the results to WUFI via a *.KLI file.

- **Western radiation** (real):
  the global radiation measured with a west-facing solarimeter; in [W/m²].
  Optionally, the radiation component impinging on a (west-facing) facade may directly be read from this column. No conversion is then necessary as would be the case if global and diffuse radiation were used as data source.

- **Relative humidity** (real):
  the relative humidity of the ambient air (0..1). Used by WUFI without change as the exterior relative humidity.

- **Barometric pressure** (real):
  the ambient air pressure reduced to sea level; in [hPA].

- **Wind velocity** (real):
  the scalar mean of the wind velocity; in [m/s]. It is needed to compute the driving rain from the normal rain.

  The scalar mean of the wind velocity is the mean value of the readings of an anemometer without the directions taken into account. For example, if for an hour the wind is blowing at 2 m/s but at the same time steadily travelling through all the direcions, then the scalar mean is 2 m/s, whereas the vectorial mean is 0 m/s.

  In the vectorial mean, some vector components may cancel. Thus, the scalar mean is greater than (or at least equal to) the vectorial mean.

  The IBP weather files also contain information about the distribution of the wind directions (see below). This allows to ignore components that come from 'behind' (and don't contribute to the rain load) and to weight the remaining

directions according to the angle they make with the surface.

- **Normal rain / tipping bucket** (`real`):
- **Normal rain / droplet counter** (`real`):
    the normal rain (i.e., the rain incident on a horizontal surface in open area) during one hour, measured with a tipping bucket and a droplet counter rain gauge, respectively; in [Ltr/m²h] or, equivalently, [mm/h].

    WUFI uses the readings of the droplet counter, since it is in general more reliable.

    The rain load on a wall is determined by the driving rain rather than the normal rain. The driving rain can be estimated from the normal rain and the wind velocity:

    The rain coefficients R1 and R2 in the dialog "Orientation / Inclination / Height" serve to estimate the driving rain load on a surface of arbitrary orientation and inclination from data on normal rain, wind velocity and wind direction distributions, using the relation

    rain load = rain · (R1 + R2 · wind velocity),

    where 'rain' is the normal rain and 'wind velocity' is that component of the mean wind velocity (measured at a height of 10 m, in open area), which is orthogonal to the building surface. This component is determined from the scalar mean of the wind velocity (see above) and the wind direction distribution (see below).

    R1 and R2 are strongly dependent on the specific location on the building facade. If calculations are to be compared to actual measurements, these coefficients should be experimentally determined for that location.

    If they cannot be measured, only a very rough estimate is possible. For vertical surfaces, R1 is zero. R2 is about 0.2 s/m for free-standing locations without influence from surrounding buildings etc.; it is markedly less in the center of a facade (e.g. 0.07 s/m); it may even be greater at exposed locations of a building (near edges and corners) [1].

- Driving rain / tipping bucket (`real`):
- Driving rain / droplet counter (`real`):
    the driving rain load on a west-facing wall, measured at a height of 1.50 m with a tipping bucket and a droplet counter rain gauge, respectively. In [Ltr/m²h] or, equivalently, [mm/h].

    WUFI uses the readings of the droplet counter, since it is in general more reliable.

    The values in this column can optionally be read and used for the variable 'rain' in the formula for the rain load (see above: normal rain). Set R1 to 1 and R2 to zero; the resulting rain load will then directly be the measured driving rain.

- **Wind direction distribution** (`17 * integer`):
    the frequency of wind directions, binned into sectors of 22.5° each.

The wind direction is averaged over 2 minutes and the counter of the corresponding sector then increased by one. A special counter is registering calms. The sum of all counts during one hour should thus be 30 if no interruption of the measurements has occured.

The individual counters are assigned to the following directions:

NNE-NE-ENE-E-ESE-SE-SSE-S-SSW-SW-WSW-W-WNW-NW-NNW-N-calm

For the calculation of the driving rain load, the contributions of the different directions are determined individually and then summed up. Wind coming 'from behind' does not contribute to the rain load and is ignored.

A *.WET file supplied by the user must be accompanied by a *.AGD file which contains geographical information on the climate location.

Literature:
[1]   Künzel, H.M.: Bestimmung der Schlagregenbelastung von Fassadenflächen. IBP-Mitteilung 21 (1994), Nr. 263

[2]   VDI 3789 Umweltmeteorologie, Blatt 2: Wechselwirkungen zwischen Atmosphäre und Oberflächen; Berechnung der kurz- und der langwelligen Strahlung. Entwurf, Dezember 1992

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Details / The *.TRY Format for Climate Data

You can use existing TRY weather files (file format *.TRY) to perform WUFI calculations; you can also convert your own weather data to that format and use them.

This format was used by the German National Weather Service DWD for the test reference years published in 1986 (the new test reference years, published in 2004, are in *.DAT format). Also, this format was used for some of the climate files supplied with WUFI.

> The 1986 test reference years (TRY) cannot be purchased from DWD any more (they have been replaced by the 2004 test reference years), but existing old TRY can still be used with WUFI. They contain synthetic hourly climate data which - based on seasonal mean values and long-term annual mean values - represent typical weather conditions for different geographical regions [1]
>
> Please note that these (1986) test reference years may be of limited usability for calculating the moisture balance of building components, since they have been designed for thermal simulations only. The total amount of precipitation is reproduced correctly, but the number of hours with precipitation is overestimated [2]. With building materials of low absorptive capacity, however, the duration of precipitation is more important than the amount of precipitation.

WUFI can read two different variants of the TRY format: the IBP variant and the DWD variant.

IBP variant

TRY weather files consist of 24 lines of header and 8760 lines of weather data in hourly intervals.

Example:

```
TRY FUER MUENCHEN (KLIMAREGION 9)
STATIONSNUMMER 10866
GEOGR. BREITE: 48.13 GRAD   GEOGR. LAENGE: 11.72 GRAD
STATIONSHOEHE 530 METER

FORMAT(I5,1X,F4.2,1X,I3,2(1X,F4.1),1X,A2,1X,F6.2,1X,F6.1,1X,F5.1,1X,
F4.2,2I4,1X,E9.3,2I4)
REIHENFOLGE DER PARAMETER:
STATIONSNUMMER
BEDECKUNG(0....1)
WINDRICHTUNG (GRAD)
WINDGESCHWINDIGKEIT, SKALARES MITTEL (M/S)
WINDGESCHWINDIGKEIT,VEKTORIELLES MITTEL (M/S)
```

$ Details / The *.TRY Format for Climate Data

+ 3030

K climate data;climate file;weather data;weather file;TRY weather file;test reference year;IBP;DWD;wind direction;wind velocity (scalar);wind velocity (vectorial);normal rain;driving rain;barometric pressure;temperature;relative humidity;direct radiation;diffuse radiation;counterradiation;

```
WETTER ZUM TERMIN (SCHLUESSEL)
NIEDERSCHLAG DER LETZTEN STUNDE (MM)
LUFTDRUCK (HPA)
TEMPERATUR (GRAD CELSIUS)
RELATIVE FEUCHTE (0....1)
DIREKTE SONNENSTRAHLUNG, STUNDENMITTEL (W/M**2)
DIFFUSE HIMMELSSTRAHLUNG, STUNDENMITTEL (W/M**2)
HELLIGKEIT, STUNDENMITTEL (LUX)
LANGWELLIGE AUSSTRAHLUNG, STUNDENMITTEL (W/M**2)
ATMOSPHAERISCHE GEGENSTRAHLUNG, STUNDENMITTEL (W/M**2)

10866  .63 270  4.1  3.1  1    .01  950.7  -1.0 .80   0    0 0.          -279 231
10866 1.00 270  2.0  1.5       .35  950.8  -1.1 .84   0    0 0.          -279 251
10866 1.00 250  5.1  4.6       .64  951.0  -1.0 .89   0    0 0.          -279 272
10866 1.00 250  3.1  2.6 73    .91  951.2   -.9 .93   0    0 0.          -279 275
10866 1.00 270  5.1  4.6       .25  951.5   -.9 .94   0    0 0.          -279 277
10866  .88 270  5.1  4.6       .20  951.9   -.9 .93   0    0 0.          -279 270
10866 1.00 270  6.1  5.6 71    .23  952.7  -1.0 .93   0    0 0.          -279 270
10866 1.00 290  5.1  4.1       .02  953.7  -1.1 .95   0    0 0.          -279 276
10866  .88 290  5.1  4.1       .02  954.8  -1.2 .96   0   19 .221E+04-278 270
10866  .88 290  4.6  4.1 22    .02  955.7  -1.0 .93   0   65 .751E+04-279 263
10866  .75 270  5.1  4.6      0.00  956.0   -.6 .84   0   98 .115E+05-280 255
10866  .38 270  6.1  5.6      0.00  956.0   -.2 .75 102  110 .206E+05-281 227
```
etc.

WUFI skips the header, with the exception of lines 3 and 4, from which it reads the geographical position of the measuring site.

Since the file format is a remnant from the FORTRAN era, the column-oriented structure of the file has to be followed strictly. It is not necessary, however, to stick to the exact floating point format of the numbers themselves: for example, WUFI reads columns 42-47 as a `string` and then converts it to a `real` number.

A TRY file contains 8760 data lines with hourly weather data. The first one of these consists of the mean weather data for the hour from 0:00 to 1:00 CET on January 1. There is no intercalary day (February 29).

The meaning of the weather data in detail:

• Column 1-5: site ID.
  Not used by WUFI.

• Column 6-10: cloud cover (0..1).
  Currently not used by WUFI.

• Column 11-14: **wind direction [degrees] (0..360)**.
  Counted clockwise from north (0°) over east (90°).

• Column 15-19: wind velocity, scalar mean [m/s].
  Not used by WUFI.

• Column 20-24: **wind velocity, vectorial mean [m/s]**.
  Since no wind direction distributions are provided in the TRY files, this loss of information must be compensated by using the vectorial mean instead of the scalar mean.

The vectorial mean of the wind velocity is the mean value of the readings of an anemometer with the directions taken into account. For example, if for an hour the wind is blowing at 2 m/s but at the same time steadily travelling through all the directions, then the vectorial mean is 0 m/s, whereas the scalar mean is 2 m/s.

In the vectorial mean, some vector components may cancel. Thus, the vectorial mean is always less than (or at most equal to) the scalar mean.

If only the mean direction and velocity are provided, no individual treatment of specific directions is feasible anymore. Therefore, it is not possible to disregard wind directions which hit the building component from behind and thus don't contribute to the rain load. In a driving rain situation, however, the wind will mostly blow from a narrow range of directions, so that the mean direction will be reasonably representative.

- Column 25-27: DWD code for regular weather observations.
  Not used by WUFI.

- Column 28-34: **precipitation during the last hour [mm]**.
  The rain load on a wall is determined by the driving rain rather than the normal rain. If no measured data on the driving rain are available, it can be estimated from other data.

  The rain coefficients R1 and R2 in the dialog "Orientation / Inclination / Height" serve to estimate the driving rain load on a surface of arbitrary orientation and inclination from data on normal rain, wind velocity and wind direction, using the relation

  rain load = rain · (R1 + R2 · wind velocity),

  where 'rain' is the normal rain and 'wind velocity' is that component of the mean vectorial wind velocity (measured at a height of 10 m, in open area), which is orthogonal to the building surface.

  R1 and R2 are strongly dependent on the specific location on the building facade. If calculations are to be compared to actual measurements, these coefficients should be experimentally determined for that location.

  If they cannot be measured, only a very rough estimate is possible. For vertical surfaces, R1 is zero. R2 is about 0.2 s/m for free-standing locations without influence from surrounding buildings etc.; it is markedly less in the center of a facade (e.g. 0.07 s/m); it may even be greater at exposed locations of a building (near edges and corners) [1].

- Column 35-41: **ambient air pressure at height of location [hPa]**.
  The actual (i.e. not reduced to sea level) barometric pressure at the measurement location. The barometric pressure affects the vapor diffusion coefficient in air.

- Column 42-47: **air temperature [°C]**.
  Adopted by WUFI without change as the exterior air temperature.

- Column 48-52: **relative humidity [-] (0..1)**.
  Adopted by WUFI without change as the exterior relative humidity.

- Column 53-56: **direct solar radiation [W/m²]**.
  The direct component of the solar radiation (i.e. received directly from the sun) incident on a horizontal surface.

  From this, the direct normal radiation can be calculated, i.e., the amount of radiation incident on a surface that is orthogonal to the beam direction [3]. This calculation requires knowledge of the time and geographical location of the measurement, since the corresponding position of the sun has to be determined.

  The direct normal radiation can then be used to calculate the direct radiation incident on a surface with arbitrary orientation and inclination. Addition of the appropriate fraction of diffuse radiation results in the global radiation incident on the building component.

  These calculations are automatically done by WUFI during a simulation run. WUFI uses a simplified radiation model which treats the diffuse radiation as isotropic and ignores the albedo of the ground. If you are more demanding or want to allow for local specifics (like shadows etc.), you can perform the conversion yourself and feed the results to WUFI via a *.KLI file.

- Column 57-60: **diffuse sky radiation [W/m²]**.
  The diffuse component of the solar radiation (scattered by the atmosphere or clouds), incident on a horizontal surface.

- Column 61-70: illuminance [lux].
  Not used by WUFI.

- Column 71-74: long-wave radiative emission [W/m²].
  Not used by WUFI.

- Column 75-78: **atmospheric counterradiation [W/m²]**.
  The thermal radiation of the atmosphere, incident on a horizontal surface.
  Please refer to Details / Long-wave Radiation Exchange for a description of how to use counterradiation data and what to do if you have no counterradiation data.

DWD variant

Example:

```
TRY ZUERICH WARM 1998 DWDTRY-FORMAT V1
STATION: ZUERICH
LAGE: 47.38 GRAD N.<- B.  8.57 GRAD O. <- L.  556 METER UEBER NN
DATUM DER ERSTELLUNG: MAI 2001   AENDERUNGSNUMMERN: 0-0

FORMAT(I1, 3I2, 1X, F4.2, 1X, I3, 2(1X,F4.1), 1X, I2, 1X, F4.1, 1X,
      F6.1, 1X, F5.1, 1X, F4.2, 1X, I4, 1X, I4, 1X, I7, 1X, I4, 1X, I4)
REIHENFOLGE DER PARAMETER:
AENDERUNGSNUMMER/TAG/MONAT/STUNDE
BEDECKUNG IN ACHTEL (0.0 ... 1.0)                       [-]
WINDRICHTUNG, N UEBER O POSITIV                         [GRAD]
WINDGESCHWINDIGKEIT, SKALARES MITTEL                    [M/S]
WINDGESCHWINDIGKEIT, VEKTORIELLES MITTEL                [M/S]
WETTER ZUM TERMIN (DWD-SCHLUESSEL)                      [-]
NIEDERSCHLAG                                            [MM/H]
LUFTDRUCK AUF STATIONSHOEHE                             [HPA]
```

```
LUFTTEMPERATUR                                              ['C]
RELATIVE LUFTFEUCHTE (0.0 ... 1.0)                          [-]
DIREKTE SONNENSTRAHLUNG AUF HORIZONTALER FLAECHE            [W/M**2]
DIFFUSE HIMMELSSTRAHLUNG AUF HORIZONTALER FLAECHE           [W/M**2]
HELLIGKEIT AUF HORIZONTALER FLAECHE                         [LUX]
LANGWELLIGE AUSSTRAHLUNG AUF HORIZONTALER FLAECHE           [W/M**2]
ATMOSPHAERISCHE GEGENSTRAHLUNG AUF HORIZONTALER FLAECHE     [W/M**2]

0 1 1 1 0.50  76 0.7 0.7     0.0 949.4  1.0 0.93    0    0    0 -288
268
0 1 1 2 0.50  90 0.7 0.7     0.0 949.6  1.1 0.93    0    0    0 -289
269
0 1 1 3 0.50 124 0.6 0.6     0.0 949.9  1.3 0.93    0    0    0 -290
270
0 1 1 4 0.50  90 0.3 0.3     0.0 949.7  1.1 0.94    0    0    0 -289
270
0 1 1 5 0.38   0 0.2 0.2     0.0 949.6  1.0 0.94    0    0    0 -288
257
0 1 1 6 0.38  27 0.3 0.3     0.0 949.7  0.9 0.93    0    0    0 -288
256
0 1 1 7 0.38  18 0.4 0.4     0.0 949.9  0.8 0.93    0    0    0 -287
256
0 1 1 8 0.38  18 0.5 0.5     0.0 950.3  0.7 0.93    2    0    0 -287
255
0 1 1 9 0.50  39 0.7 0.7     0.0 950.8  0.7 0.93    0   25    0 -287
267
0 1 110 0.63  27 0.6 0.6     0.0 951.1  1.3 0.91   14   86    0 -290
281
0 1 111 0.63 256 0.5 0.5     0.0 950.8  2.5 0.87   38  159    0 -295
285
0 1 112 0.75 231 0.8 0.8     0.0 950.3  3.9 0.80   38  198    0 -301
299
```

The difference between the IBP variant and this one lies only in the different header and the slightly different column format. The data are the same as in the IBP variant.

- Column 1:   update index (not used by WUFI)
- Column 2-3:   day (not used by WUFI)
- Column 4-5:   month (not used by WUFI)
- Column 6-7:   hour (not used by WUFI)
- Column 8:   blank
- Column 9-12:   cloud cover in eighths (currently not used by WUFI)
- Column 13:   blank
- Column 14-16:   **wind direction [degree]**
- Column 17:   blank
- Column 18-21:   wind velocity, scalar mean [m/s] (not used by WUFI)
- Column 22:   blank
- Column 23-26:   **wind velocity, vectorial mean [m/s]**
- Column 27:   blank
- Column 28-29:   DWD code for regular weather observations (not used by WUFI)
- Column 30:   blank
- Column 31-34:   **precipitation [mm/h]**
- Column 35:   blank
- Column 36-41:   **air pressure at height of location [hPa]**
- Column 42:   blank
- Column 43-47:   **air temperature [°C]**
- Column 48:   blank
- Column 49-52:   **relative humidity [-] (0..1)**
- Column 53:   blank
- Column 54-57:   **direct solar radiation on horizontal surface [W/m²]**

- Column 58:   blank
- Column 59-62:   **diffuse sky radiation on horizontal surface [W/m²]**
- Column 63:   blank
- Column 64-70:   illuminance on horizontal surface [lux] (not used by WUFI)
- Column 71:   blank
- Column 72-75:   long-wave emission from horizontal surface [W/m²] (not used)
- Column 76:   blank
- Column 77-80:   **atmospheric counterradiation on horizontal surface [W/m²]**

A *.TRY file supplied by the user must be accompanied by a *.AGD file which contains additional geographical information on the climate location.

Literature:

[1]   Blümel, K. et al.: Entwicklung von Testreferenzjahren (TRY) für Klimaregionen der Bundesrepublik Deutschland. BMFT-Forschungsbericht T 86-051.

[2]   Künzel, H.M.: Regendaten für die Berechnung des Feuchtetransports. IBP-Mitteilung 21 (1994), Nr. 265.

[3]   VDI 3789 Umweltmeteorologie, Blatt 2: Wechselwirkungen zwischen Atmosphäre und Oberflächen; Berechnung der kurz- und der langwelligen Strahlung. Entwurf, Dezember 1992

Details / The *.DAT Format for Climate Data

The German National Meteorological Service DWD uses the *.DAT format for the new test reference years (published in 2004 [1]; the old test reference years [2] were in *.TRY format).
You can use existing *.DAT files (such as those offered by DWD) for a WUFI calculation, but you can also convert your own weather data to this format and use them for a calculation.

Note: as the test reference years are mainly intended as a basis for energy consumption calculations, the new test reference years **do not have rain data** any more and thus are not suitable for hygrothermic simulations in which the effect of rain is an essential factor.

Example:

```
13       1    1    1    1   8     0        0.0       3.6       968.7       5.0       97     61
318   -332   3
13       1    1    1    2   8   230        2.0       4.1       968.1       5.1       95     60
320   -334   3
13       1    1    1    3   8   230        3.0       4.2       968.1       5.1       95     60
321   -335   3
13       1    1    1    4   8   270        1.0       4.0       968.2       5.1       97     21
320   -334   3
13       1    1    1    5   8   190        1.0       4.2       967.9       5.1       95     10
321   -335   3
13       1    1    1    6   8   320        1.0       4.2       968.4       5.2       97     25
321   -335   3
13       1    1    1    7   8   250        1.5       4.6       969.0       5.5      100      2
323   -336   3
13       1    1    1    8   8   270        1.5       4.4       969.0       5.2       95     21
289   -333   3
13       1    1    1    9   7   280        0.5       4.3       969.4       5.3       98            4     29 2
270   -331   3
13       1    1    1   10   8   240        1.5       4.1       969.6       5.2       97   60     0     27 1
320   -334   3
13       1    1    1   11   7   230        2.0       4.3       969.5       5.0       93   21    19    108 2
292   -333   6
13       1    1    1   12   8   270        2.5       5.3       969.2       5.1       89            0     76 1
327   -340   3
13       1    1    1   13   8   270        4.6       5.1       969.4       4.9       86   60     0     31 1
326   -339   3
13       1    1    1   14   8   280        3.6       4.5       969.8       4.7       86   21     0     48 1
289   -334   3
13       1    1    1   15   8   290        5.1       3.4       971.1       4.4       87   25     0     57 1
317   -331   3
13       1    1    1   16   7   300        5.1       3.0       971.9       4.3       87    1     0      1 2
281   -326   3
13       1    1    1   17   6   300        3.6       2.4       973.0       4.0       84
266   -323   3
13       1    1    1   18   5   330        1.0       2.4       973.2       3.8       82
266   -323   3
13       1    1    1   19   7   270        1.0       1.9       973.3       3.9       87      3
291   -322   3
```

Hilfe_Allgemein_C_UT300d
$ Details / The *.DAT format for Climate Data
+ 3050
K climate data;climate file;weather data;weather file;DAT;DAT weather file;test reference year;cloud cover;wind direction;wind velocity;barometric pressure;temperature;air temperature;relative humidity;direct radiation;diffuse radiation;counterradiation;

```
13       1    1    1   20    7    270         1.5         1.2         973.6         3.8         88
287    -319   3
13       1    1    1   21    7    260         1.5         0.7         974.1         3.8         91
285    -317   3
13       1    1    1   22    4    230         1.5         0.4         974.0         3.8         93
240    -312   3
13       1    1    1   23    4    240         1.5        -0.2         974.0         3.6         94
242    -310   6
13       1    1    1   24    8    250         1.0        -0.1         974.1         3.8         96    73
300    -314   3
```

- Column 1-2: TRY region {1..15}.
  Not used by WUFI.

- Column 3-4: blank.

- Column 5-8: Information on location of measurement {1; 2}.
  Not used by WUFI.

- Column 9-10: blank.

- Column 11-12: **Month** {1..12}.

- Column 13-14: blank.

- Column 15-16: **Day** {1..28, 30, 31}.

- Column 17-18: blank.

- Column 19-20: **Hour (CET)** {1..24}.

- Column 21-22: blank.

- Column 23: Cloud cover [octa] {0..8; 9}.
  Fraction of the sky covered with clouds (9=not determined, e.g. because of fog).
  Currently not used by WUFI.

- Column 24-25: blank.

- Column 26-28: **Wind direction** [°] {0; 10..360; 999},
  90°=east,..., 360°=north;
  0=calm, 999 = variable.

- Column 29-30: blank.

- Column 31-36: **Wind speed** [m/s].

- Column 37-38: blank.

- Column 39-44: **Air Temperature** [°C].

- Column 45-46: blank.

- Column 47-53: **Barometric pressure** [hPa],
  at station height.

- Column 54-55: blank.

- Column 56-61: Water vapor content or mixing ratio [g/kg].
    Not used by WUFI.

- Column 62-63: blank.

- Column 64-66: **Relative humidity** [%] {1..100}.

- Column 67-68: blank.

- Column 69-70: Code for current weather conditions {0..99}.
    Not used by WUFI.

- Column 71-72: blank.

- Column 73-76: **Direct solar irradiance B** [W/m^2],
    impinging on a horizontal surface.
    Directed downwards: positive;
    Zeros: may result from rounding small irradiances,
    Blanks: sun below horizon; no irradiance possible.

- Column 77-78: blank.

- Column 79-82: **Diffuse solar irradiance D** [W/m^2],
    impinging on a horizontal surface.
    Directed downwards: positive;
    Blanks: sun below horizon; no irradiance possible.

- Column 83: blank.

- Column 84: Information whether B and/or D measured/calculated {1; 2; 3; 4}.
    Not used by WUFI

- Column 85-86: blank.

- Column 87-90: **Irradiance of atmospheric thermal radiation** [W/m^2],
    "atmospheric counterradiation",
    impinging on a horizontal surface.
    Directed downwards: positive.

    Please refer to Details / Long-wave Radiation Exchange for a description of how to use counterradiation data and what to do if you have no counterradiation data.

- Column 91-92: blank.

- Column 93-97: **Irradiance of terrestrial thermal radiation** [W/m^2],
    i.e., specific emission of thermal radiation from the ground, including the reflected atmospheric counterradition,
    impinging on a horizontal surface.
    Directed upwards: negative.

Please refer to Details / Long-wave Radiation Exchange for a description of how to use terrestrial emission data and what to do if you have no emission data.

• Column 98-99: blank.

• Column 100: Quality bit for the long-wave irradiances {1..8}.
  Not used by WUFI.

A *.DAT file supplied by the user must be accompanied by a *.AGD file which contains geographical information on the climate location.

Literature:

[1]   Christoffer, J., Deutschländer, Th., Webs, M.: Testreferenzjahre von Deutschland für mittlere und extreme Witterungsverhältnisse TRY, Offenbach 2004.

[2]   Blümel, K. et al.: Entwicklung von Testreferenzjahren (TRY) für Klimaregionen der Bundesrepublik Deutschland. BMFT-Forschungsbericht T 86-051.

Details / The *.WAC Format for Climate Data

The **W**UFI **A**SCII **C**limate format, introduced in version 4.1, is a flexible text format for climate data.

The file consists of columns for the different weather elements. Number, content and sequence of these columns are not fixed and may be chosen as needed. Header lines describe the contents of the columns.

A detailed specification of this format will be provided in a future version of the on-line help.

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Hilfe_Allgemein_C_UT300_WAC
$ Details / The *.WAC Format for Climate Data
+ 3052
K WAC

Details / The *.IWC Format for Climate Data

This climate data format is being used by ASHRAE for the "International Weather Year for Energy Calculation (IWEC)" files.
WUFI can read these files; but since the file format is quite complex, contains many quantities not needed for hygrothermal simulations and treats some of the needed quantities (e.g. rain) only in a semi-quantitative way, it is not recommended to convert your own data to this format in order to use them with WUFI. The format is therefore not described here

Note: the IWEC weather data do not contain quantitative rain data but only a rain indicator reporting rain intensity categories like "light", "moderate", "heavy", etc. As long as it has not been worked out which representative hourly quantities corresponding to these categories should be used in hygrothermic simulations, WUFI will **not use rain data** in calculations performed with *.IWC files.

Continue with Details / The *.WBC-Format for Climate Data

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Details / The *.WBC Format for Climate Data

The **W**UFI **B**inary **C**limate file format is a proprietary format for climate files which the provider of the data wanted to be usable with WUFI only.

Continue with Details / The *.KLI-Format for Climate Data

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Hilfe_Allgemein_C_UT300_WBC
$ Details / The *.WBC Format for Climate Data
+ 3057
K WBC

Details / The *.KLI Format for Climate Data

As already noted in the introduction to the climate topic, WUFI needs the following climate data for each time step:

- the **rain** load vertically incident on the exterior surface in [Ltr/m²h]. For the determination of this rain load, the inclination and orientation of the surface must be taken into account.

- the solar **radiation** vertically incident on the exterior surface in [W/m²]. For the determination of the amount of radiation, the inclination and orientation of the surface must be taken into account.

- the **temperature** of the exterior air [°C]

- the **relative humidity** of the exterior air [-] (0..1)

- the **temperature** of the interior air [°C]

- the **relative humidity** of the interior air [-] (0..1)

- the **barometric pressure** [hPa]. Since the barometric pressure has only a minor effect on the calculation, specification of a mean value may be sufficient.

If direct measurements are not available, the rain load can be determined from the normal rain and the wind velocity and direction. The radiation load can be determined from the global (or direct) and diffuse radiation incident on a horizontal surface.

When measured weather data are used, which do not directly contain the required rain and radiation data, but rather the normal rain and the solar radiation incident on a horizontal surface, WUFI can do this conversion automatically during the calculation, so you only need to specify the appropriate climate file for use in the calculation and the orientation and inclination of the building component.

On the other hand, you may wish to provide WUFI directly with the required data, for example because you have measured them or because you want to employ different conversion algorithms than those used by WUFI. In this case, write these data to a WUFI climate file *.KLI and specify this file for use in the calculation.

This is an example for the first few lines of a WUFI climate file:

```
$WUFI$  1.1.1991_0.00 – 1.1.1992_0.00
Azimut : 90 °, Neigung : 90 °, Abgeleitet von ibp1991.wet
9.33600000000000E+0004
```

Hilfe_Allgemein_C_UT300c
$ Details / The *.KLI Format for Climate Data
+ 3060
K   KLI;climate data;climate file;weather data;weather file;temperature;relative humidity;barometric pressure

time	rain	radiation	ϑ_a	φ_a	ϑ_i	φ_i
1	0	0	-8.60	0.87	20	0.50
2	0	0	-9.20	0.85	20	0.50
3	0	0	-8.80	0.87	20	0.50
4	0	0	-9.10	0.85	20	0.50
5	0	0	-7.70	0.82	20	0.50
6	0	0	-8.30	0.81	20	0.50
7	0	0	-9.50	0.80	20	0.50
8	0	0	-11.60	0.79	20	0.50
9	0	18.40	-9	0.86	20	0.50
10	0	62.10	-7.50	0.86	20	0.50
11	0	104	-5.20	0.85	20	0.50
12	0	145	-4.10	0.77	20	0.50

[...]

↑ time ↑ rain ↑ radiation ↑ ϑ_a ↑ φ_a ↑ ϑ_i ↑ φ_i

The climate file essentially consists of a table, with each line containing all required climate data (rain, radiation, exterior temperature, exterior relative humidity, interior temperature, interior relative humidity) for a certain interval of time.

The format of the data is free. The only requirement is that a PASCAL program (like WUFI) must be able to read the numbers. All data are read as `real` numbers. The entries in each line are separated by blanks.

The three header lines are further discussed below.

The time structure of the climate data is defined by a **relative hour count** (given by the first entry in each line). This count is relative to a **starting date** (given in the first header line).

Imagine the climate file has been created by a fictitious data logger which has started the measurement at the starting date. At the end of each measuring interval (the intervals need not be equidistant) it has recorded the mean values over that interval and has added the total duration of the measurement so far as a time stamp.

The starting date of the calculation must be in the time interval covered by the climate file (i.e., it must be equal to or later than the starting date of the climate file and earlier than its ending date).

The calculation may go beyond the end of the climate file (i.e., the ending date of the calculation may be later than the ending date of the climate file); the climate file is then read again from the beginning (as often as necessary).

The format of the starting date is:

day.month.year_hour.fraction   e.g. "1.1.2000_14.5".

Fractions of hours are decimal fractions: "1.1.2001_0.5" means half an hour past midnight. The format allows two decimal places for the fraction.

The choice of the time step for the climate file should be suitably coordinated with the choice of the time step for the calculation. The simplest choice is to use equidistant time intervals in the climate file and to set the time step for the calculation to the same size.

If you want to use a different calculation time step, you should choose it so that it divides the climate time intervals exactly. Otherwise, WUFI adjusts each time step so that it *does* divide the current (*) climate interval exactly.

(* since the climate file need not have equidistant time intervals.)

Examples:

	climate time interval	calculation time step entered by user	calculation time step adjusted by WUFI		because
a)	1 h	1 h	1	h	1 * 1 = 1
b)	40 h	6 h	5.714	h	7 * 5.714 = 40
c)	42 h	6 h	6	h	7 * 6 = 42
d)	44 h	6 h	6.286	h	7 * 6.286 = 44
e)	6 h	44 h	6	h	1 * 6 = 6

Examples for climate files

• **Example 1:**

Start: 3.4.1994, 0.0

time	rain	rad.	ϑ_a	φ_a	ϑ_i	φ_i
1	0	0	5.9	0.80	21.1	0.76
2	0	0	5.2	0.86	21.0	0.76
24	0	121.0	11.1	0.63	20.9	0.76
....	...	...	...	...	...	...

These climate data mean that the measurement was started on April 3, 1994, at midnight, the mean exterior temperature was 5.9°C between 0:00 and 1:00, 5.2°C between 1:00 and 2:00, and 11.1°C in the 22-hour-interval between 2:00 and 24:00.

• **Example 2:**

Start: 1.1.1991, 0.0

time	rain	rad.	ϑ_a	φ_a	ϑ_i	φ_i
744	0.09	35.7	−2.4	0.77	20.4	0.35
1416	0.03	58.9	−4.4	0.78	19.7	0.49

| 2160 | 0.14 | 48.3 | 5.4 | 0.83 | 20.9 | 0.38 |
| .... | ... | ... | ... | ... | ... | ... |

This climate file contains monthly means. The first line gives the mean values for the interval from 1.1.1991 0:00 to 31.1.1991 24:00, etc.

• **Example 3:**

Start: 31.1.1997, 10.93

time	rain	rad.	ϑ_a	φ_a	ϑ_i	φ_i
500	1000	0	20	1	20	0.8

This one-line climate file might be used to simulate an imbibition experiment in the laboratory.
Starting on 31.1.1997 10h56m (=10.93 decimal), the laboratory climate stays constant for 500 hours. Since WUFI can read a climate file repeatedly, the time could also be entered as 1 hour. The same line would then be read over and over again. No time step larger than 1 hour would then be possible, however (see above; any different time step would be adjusted down to 1 h).

(The imbibing surface is treated here as the 'exterior' surface, the imbibed water is offered as 'rain' in a quantity that is sure to surpass the quantity of water imbibed per hour. Also see the relevant discussion in the Questions & Answers section.).

• **Example 4:**

Start: 23.1.1998, 10.50

time	rain	rad.	ϑ_a	φ_a	ϑ_i	φ_i
1215	1000	0	21	1	20	0.80
3410	0	0	21	0.65	20.5	0.82

This climate file might be used to simulate an imbibition experiment with subsequent drying in the laboratory.
The experiment started on January 23, 1998 at 10:30. The specimen was imbibing for 1215 hours and was then left to dry for (3410 - 1215 =) 2195 hours.

How to create your own KLI files

If you want to use your own weather data for a WUFI calculation, you can simply convert them to either the WET or the TRY or the DAT format and use them directly in this form for the calculation.

If your rain and radiation data have already been determined for the surface in question, a directional conversion is not necessary, and you can write these data to a KLI file and use them in this form for the calculation.
The KLI format also comes handy if you want to use other conversion methods, if you want to use measured interior climate data etc.

In such a case, you just need to write an ASCII file which conforms to WUFI's *.KLI format: three header lines first, then one line of climate data for each time step.
For this, you may use any editor program that allows you to write the data in a pure ASCII format, for example a text editor such as the Windows notepad, or a self-written program which computes or converts the data in the desired manner and then writes them to a file.
If you are using Excel to create a KLI file, save the data using one of the ASCII formats *.TXT or *.PRN, since WUFI cannot read the proprietary Excel format *.XLS; then rename the file to the extension *.KLI.

Please note that the second header line of the KLI format has to contain data at certain positions so that WUFI can read them (it is much longer than can be displayed in most ASCII editors, which is not immediately obvious because of the large blank spaces between the data). The simplest way to obtain such a line is to copy to your own file one from a KLI file supplied with WUFI. The information contained in that line is then not correct for your file, but this does not affect the calculation (it is information about the parameter settings used for generating the file and is not used during the calculation).

The tool `KLI_Create.exe` in the `Tools` folder may be useful when you want to create a *.KLI file with monthly average values for temperature and humidity, no rain and no radiation.

Continue with Details / The *.AGD File

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Details / The *.AGD File

The climate files usually contain the solar radiation impinging onto a horizontal surface (exception: *.KLI files). If a hygrothermic simulation of a non-horizontal building component shall include the effect of solar radiation, the **radiation component** impinging on the surface must be determined for each time step, depending on the surface's orientation and inclination. This requires computing the sun's position in the sky for that time step, and therefore WUFI needs information on the **geographical coordinates** and the **time zone** of the location where the weather data were measured.

Depending on the climate file format, this information may not be present in the file itself and must then be supplied separately.
For the climate files delivered with WUFI, the information is either present in the files or it has been listed in the database. For climate files created by the user, it may be necessary to also create a corresponding *.AGD file ("additional geographic data").

Example (cf. `example.agd` in the `Projects` folder):

```
Additional Geographic Data
Showing data for Holzkirchen as an example
Longitude,Latitude  [°] (East,North is Positiv)
HeightAMSL          [m]
TimeZone            [hours from UTC]

[WUFI]
Longitude=11.73
Latitude=47.88
HeightAMSL=680
TimeZone=1
```

The lines preceding the section marker `[WUFI]` will be ignored and may contain any commets. The section `[WUFI]` lists those data describing geographical longitude, geographical latitude, height above mean sea level and time zone that are missing in the climate file itself. These are in particular:

File format:	Longitude	Latitude	Height	TimeZone
*.WET	x	x	x	x
*.TRY	-	-	-	x
*.DAT	x	x	x	x
*.IWC	-	-	-	-
*.KLI	-	-	-	-
*.WBC	-	-	-	-

Hilfe_Allgemein_C_UT300f
$ Details / The *.AGD File
+ 3070
K AGD;AGD file;geographical coordinates;height;time zone;UTC;Greenwich

The "TimeZone" is indicated by the difference between the time zone of the measurement location and the Greenwich time zone (UTC) in hours (examples: Central European Time = 1; Eastern Standard Time = -5).

If the AGD file contains data that are already present in the climate file, but with different values, WUFI uses the values from the climate file.

The name of the AGD file must be the name of the corresponding climate file, with the extension `.AGD` added, e.g. `Aberystwyth.TRY.AGD`. WUFI expects the file in the same folder as the corresponding climate file.

Continue with

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Details / Sources for Climate Data

Several climate files are supplied with WUFI. The following are some sources offering weather data for additional locations. WUFI can read the respective file formats; the user must judge to which degree these data are useful and appropriate for his specific application.

Test reference years:

The German National Meteorological Service DWD offers test reference years for all climatic regions in Germany, representing typical as well as extreme weather situations:

> "New **T**est **R**eference **Y**ears (TRYs) have been worked out for Germany. Test Reference Years are datasets of selected meteorological elements for each hour of the year. They provide climatological boundary conditions for simulating calculations on an hourly basis, in the first place for the operation of heating and air conditioning systems. On the basis of a factor and cluster analysis the Federal Republic has been divided into 15 regions. For each region a representative station has been determined and a Test Reference Year has been prepared. They replace the previous Test Reference Years of the old West German states. For those states which acceded to the Federal Republic after unification such datasets are available for the first time. A Test Reference Year contains characteristic weather data of a representative year. The weather sequences have been chosen on the basis of an analysis of the Grosswetterlagen in such a way that the seasonal mean values of the individual meteorological elements (especially of temperature and humidity) of the representative stations mainly correspond with their 30-years mean values. As heating and air conditioning equipment also have to be designed for extreme situations, additional datasets with the same data structure for a very cold winter (December 1984 to February 1985) and an extremely hot summer (June to August 1983) have been compiled."

> (http://www.dwd.de/de/wir/Geschaeftsfelder/KlimaUmwelt/Leistungen/Statistiken/TRY/TRY.htm)

Unfortunately, these new test reference years (as opposed to the 'old' test reference years of 1986) do not contain precipitation data any more. They are thus not suitable for investigations involving the influence of rain.

The representative stations for the test reference years have already been predefined in WUFI's climate selection map. Just copy the respective files into WUFI's `Climate` folder, on the next start WUFI will recognize the files. They can then easily be selected via the climate selection map.

METEONORM:

The Swiss METEOTEST company has developed METEONORM, a program for creating synthetic hourly weather data, based on measured long-term mean values:

> "METEONORM 5.0 (Edition 2003) is based on over 18 years of experience in the development of meteorological databases for energy applications. It is a comprehensive meteorological

---

reference, incorporating a catalogue of meteorological data and calculation procedures for solar applications and system design at any desired location in the world. METEONORM addresses engineers, architects, teachers, planners and anyone interested in solar energy and climatology.
...
Several databases from different parts of the world have been combined and checked for their reliability. In the present version, most of the data is taken from the GEBA (Global Energy Balance Archive), from the World Meteorological Organization (WMO/OMM) Climatological Normals 1961–1990 and from the Swiss database compiled by MeteoSwiss.
Monthly climatological (long term) means are available for the following parameters:

- global radiation
- ambient air temperature
- humidity
- precipitation, days with precipitation
- wind speed and direction
- sunshine duration

...
For many regions of the world, measured data may only be applied within a radius of 50 km from weather stations. This makes it necessary to interpolate parameters between stations. Interpolation models for solar radiation, temperature and additional parameters, allowing application at any site in the world, are included in the software.
...
From the monthly values (station data, interpolated data or imported data), METEONORM calculates hourly values of all parameters using a stochastic model. The resulting time series correspond to "typical years" used for system design.

(http://www.meteotest.ch/en/mn_description?w=ber)

Note: METEONORM can create files in the TRY format which can be directly read by WUFI.

Austrian Test Reference Years

In addition to the three weather files included with WUFI, weather data for numerous other Austrian locations are available.

The distributor for these data is

QUADRUPLE-M Elsässer GmbH
Technisches Büro für Bauphysik
GF Dr. Manfred Elsässer
Erzherzog-Eugen-Straße 14/1
A-6020 Innsbruck

Tel. und Fax   +43 512 251401
Fax   +43 512 378550
Mobil   +43 664 4324814
E-mail   office@quad-m.at oder manfred.elsaesser@uibk.ac.at

ASHRAE CD-ROM: International Weather for Energy Calculations (IWEC)

"Contains "typical" weather data in ASCII format, suitable for use with building energy simulation programs, for 227 locations outside the USA and Canada. The files are derived from up to 18 years of DATSAV3 hourly weather data originally archived at the National Climatic Data Center. The weather data are supplemented by solar radiation estimated on an hourly basis from earth-sun geometry and hourly weather elements, particularly cloud amount information.

This CD is the result of ASHRAE Research Project 1015. The CD contains the user's manual and complete research report in PDF, the weather data in printable ASCII format and a version of Adobe Acrobat Reader. To run Acrobat Reader, a 486 or Pentium-based computer and either Microsoft Windows 95 or Windows NT 3.5 or later is required. Will also run on a Macintosh. For Windows 95 and NT, 8MB or RAM (16MB recommended) and 10MB of free hard-disk space are required."

(http://resourcecenter.ashrae.org/store/ashrae/newstore.cgi?itemid=9448&view=item&page=1&loginid=2167053&words=iwec&method=and&)

Note: the IWEC weather data do not contain quantitative rain data but only a rain indicator reporting rain intensity categories like "light", "moderate", "heavy", etc. As long as it has not been worked out which representative hourly quantities corresponding to these categories should be used in hygrothermic simulations, WUFI will **not use rain data** in calculations performed with *.IWC files.

The CD contains files for the following locations:

NOR:	Bergen, Oslo/Fornebu	SAU:	Riyadh
SWE:	Kiruna, Ostersund/Froson, Karlstad, Stockholm/Arlanda, Goteborg, Landvetter	ARE:	Abu Dhabi
		PAK:	Karachi
FIN:	Tampere, Helsinki	IND:	New Delhi, Ahmadabad, Calcutta, Nagpur, Bombay, Goa/Panaji, Madras, Trivandrum
GBR:	Aberdeen/Dyce, Oban, Leuchars, Aughton, Finningley, Hemsby, Birmingham, London/Gatwick, Jersey/Channel Islands, Belfast		
		MNG:	Ulaangom, Ulaanbataar
		MAC:	Macau
		TWN:	Taipei
IRL:	Valentia Observatory, Kilkenny, Birr, Dublin, Clones, Belmullet, Malin	PRK:	Ch'ongjin, P'yongyang, Haeju
ISL:	Reykjavik	KOR:	Kangnung, Inch'on, Ulsan, Kwangju
DNK:	Copenhagen	JPN:	Sapporo, Matsumoto, Nagoya, Tokyo/Hyakuri, Miho (CIV/JASDF), Shimonoseki, Osaka, Kagoshima, Tosashimizu
NLD:	Amsterdam, Groningen, Beek		
BEL:	Oostende, Brussels, Saint Hubert		
CHE:	Geneva		
FRA:	Brest, Paris/Orly, Nancy, Strasbourg, Nantes, Dijon, Clermont-Ferrand, Lyon, Bordeaux, Montpellier, Marseille, Nice	THA:	Bangkok
		MYS:	George Town, Kota Baharu, Kuala Lumpur
		SGP:	Singapore
ESP:	Santander, Barcelona, Madrid, Valencia, Palma, Sevilla	VNM:	Hanoi
		CHN:	Harbin, Urumqi, Lanzhou, Shenyang, Beijing, Kunming, Shanghai, Guangzhou
PRT:	Lajes, Porto, Coimbra, Faro, Evora, Braganca		
DEU:	Hamburg, Bremen, Berlin, Dusseldorf, Koln, Frankfurt am Main, Mannheim, Stuttgart, Munich	MAR:	Casablanca/Nouasser
		DZA:	Algiers
		TUN:	Tunis
AUT:	Linz, Vienna/Schwechat, Innsbruck, Salzburg, Graz	SEN:	Dakar
		LBY:	Tripoli
CZE:	Prague, Ostrava	EGY:	Cairo, Aswan
SVK:	Bratislava, Kosice	KEN:	Nairobi
POL:	Kolobrzeg, Poznan, Warsaw, Krakow	MDG:	Antananarivo
HUN:	Szombathely, Debrecen	ZWE:	Harare
SVN:	Ljubljana	ZAF:	Johannesburg, Cape Town
BIH:	Banja Luka	MEX:	Mexico City, Veracruz, Acapulco
YUG:	Belgrade, Podgorica	CUB:	Havana
ROM:	Cluj-Napoca, Timisoara, Galati, Bucharest, Craiova, Constanta	MTQ:	Fort-de-France
		COL:	Bogota
BGR:	Varna, Sofia, Plovdiv	VEN:	Caracas
ITA:	Torino, Milan, Venice, Genova, Pisa, Rome, Naples, Brindisi, Palermo, Messina	BRA:	Belem, Recife, Brasilia, Sao Paulo
		ECU:	Quito
		PER:	Lima, Cuzco, Arequipa
GRC:	Thessaloniki, Andravida, Athens	BOL:	La Paz
TUR:	Istanbul, Ankara, Izmir	CHL:	Antofagasta, Easter Island, Santiago, Concepcion, Punta Arenas
CYP:	Larnaca		
RUS:	Arkhangel'sk, Yakutsk, Saint-Petersburg, Moscow, Ekaterinburg, Omsk, Samara, Irkutsk, Chita	PRY:	Asuncion
		URY:	Montevideo
		ARG:	Buenos Aires
LTU:	Kaunas	FJI:	Nadi
BLR:	Minks	NZL:	Auckland, Wellington, Christchurch
UKR:	Kiev, Odessa	AUS:	Darwin, Learmonth, Port Hedland, Brisbane, Perth, Adelaide, Sydney, Melbourne, Canberra
KAZ:	Semipalatinsk		
UZB:	Tashkent		
SYR:	Damascus	BRN:	Bandar Seri Begawan
ISR:	Jerusalem	MYS:	Kuching
		PHL:	Manila

Japanese Weather Data

Weather data for 842 Japanese locations are available (Expanded AMeDAS Weather Data).

The distributor for these data is

Ecology/Economy/Energy/Experience/External Insulation

E I, Ltd. (E-Information, Ltd.)

Environmental Construction Consultant

Masazumi Horiuchi
President

TOKYO   3-16-6-302 Toranomon, Minato-ku, Tokyo 105-0001
SAPPORO   11-11-10 Sumikawarokujo, Minami-ku, Sapporo 005-0006 Tel.&Fax.+81-11-581-7006
(Both offices)   Mobile 090-3773-1021 E-mail e-info@ace.ocn.ne.jp

http://f-ei.jp/archives/wufi_pro

These locations have already been predefined in WUFI's climate selection map (see there for a list of locations). Just copy the respective files into WUFI's `Climate` folder; on the next start WUFI will recognize the files. They can the easily be selected via the climate selection map.

Continue with Details / Long-wave radiation exchange

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Details / Long-wave Radiation Exchange

Introduction

The temperatures of exterior surfaces are determined by heat flow due to heat conduction within the component, by convective heat exchange with the ambient air and, last not least, by **radiation exchange** with the surroundings.

Short-wave radiation (with wavelengths around 0.5 - 1 µm) comes from the sun, reaches intensities up to about 1000 W/m² and shows a pronounced daily variation, being absent at night. Building components absorb short-wave radiation, but they do not emit it themselves.
Long-wave radiation (with wavelengths around 10 µm) is emitted as thermal radiation by terrestrial objects (such as walls, the ground etc.), reaches intensities of several hundred W/m² (depending on the temperature of the emitting surface) and is always present. Building components absorb long-wave radiation emitted from other objects, but they also emit such radiation themselves and are thus in continuous radiation exchange with their surroundings. The long-wave portion present in the solar radiation is completely negligible in comparison with the long-wave radiation emitted by terrestrial sources, since the solar disk is a source with much smaller angular extension.

Since the terrestrial objects involved in the radiation exchange tend to have mutually similar temperatures, their long-wave radiation exchange is quite balanced, and despite the considerable amounts of energy passed back and forth, the exchanged **net radiation flows** are comparatively low. The equation describing the long-wave radiation exchange contains the involved absolute temperatures to the fourth power, but because of the relatively small temperature differences, it can be linearized in good approximation. The energy flow is then proportional to the temperature difference of the involved objects:

$$E = \varepsilon_1 \cdot \sigma \cdot T_{surroundings}^4 \quad - \varepsilon_2 \cdot \sigma \cdot T_{surface}^4 \quad \approx a_{rad} \cdot \Delta T$$

and it thus behaves quite like the convective heat flow between the surface and the ambient air:

$$q = a_{conv} \cdot \left(T_{air} - T_{surface} \right)$$

Assuming that the surrounding objects have approximately air temperature and that all objects have similar emissivities, the two equations can be combined into one equation describing the total heat flow caused by convection and radiation (see also the discussion of the heat transfer coefficient):

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$$q = \left(\alpha_{conv} + \alpha_{rad}\right) \cdot \Delta T = \alpha \cdot \Delta T$$

In building physics this approximation equation is usually used for computing the heat exchange; it is thus not necessary to allow explicitly for long-wave radiation exchange. WUFI, too, usually computes the heat exchange with the surroundings in this way.

Nighttime radiation cooling

Even if a component surface has the same temperature as the terrestrial surroundings, it nevertheless suffers some long-wave **radiation loss**. This is because it exchanges radiation not only with the terrestrial surroundings but also with the sky; that is, with the atmosphere as radiation exchange partner. However, the constituents of the atmosphere are poor thermal emitters: the biatomic molecules N_2 and O_2 emit almost no thermal radiation at all, and only the trace amounts of the so-called greenhouse gases (water vapor, CO_2, O_3 etc.) are able to emit long-wave radiation because of their molecular structure.

They are very efficient emitters, but unlike solids and liquids which emit a continuous radiation spectrum ("Planck spectrum"), gases only emit line spectra with considerable **gaps** around certain wavelengths. Thus, compared to the radiation emitted by a solid with the same temperature, the total radiation emitted by the atmosphere is less by the amount missing in the gaps.

Therefore, while a component surface radiates its **long-wave emission** evenly into the whole half space, only the radiation it receives from the solid angle occupied by terrestrial objects (the so-called **terrestrial counterradiation**) has comparable intensity. The long-wave radiation received from the solid angle occupied by the sky (the so-called **atmospheric counterradiation**), on the other hand, has usually less intensity than the emission radiated towards the sky - even if the atmosphere and the emitting surface have the same temperature. Thus a component surface emits more radiation than it receives from the surroundings as a whole, and it suffers a continuous heat loss.

By day, this heat loss is not noticeable because of the heat gained by incident solar radiation. By night, however, the loss is not compensated and usually causes **cooling** of the surface **below ambient air temperature** ("overcooling"). Dew deposition and the risk of algae and mold growth may result.

Clouds consist of water droplets or ice crystals which emit a complete Planckian spectrum. If there are clouds in the sky, they may partially or completely compensate the radiation deficit of the atmosphere. Thus, besides temperature and water vapor content, the intensity of the atmospheric counterradiation strongly depends on the current amount of **cloud cover**. Typical values at temperate latitudes for the counterradiation emitted by a cloudless sky range between about 180 W/m² (cold, dry air) and about 400 W/m² (warm, humid air). With a closed opaque cloud cover, the sky behaves like a Planckian emitter whose temperature is equal to the dew point temperature of the air.

The extent of the radiation losses (and thus of the overcooling) also depends on the **inclination** of the surface. Horizontal surfaces (e.g. flat roofs) exchange radiation with the sky only and thus overcool very strongly. Vertical surfaces (e.g. facades) only suffer a loss towards a part of their field of view while the exchange with the

remaining (namely, terrestrial) part of their field of view is usually quite balanced.

Surfaces with low **thermal inertia** (e.g. surfaces of ETICS) are overcooling stronger during a night than surfaces with larger thermal capacity (e.g. surfaces of massive walls).

Radiation components

If overcooling occurs, the radiative and convective heat flows at the surface go in opposite directions: radiative power is lost from the surface towards the sky, while the convective heat flux flows from the (warmer) ambient air towards the (cooler) surface. This situation cannot be treated with the simplified formula (see above)

$$q = (a_{conv} + a_{rad}) \cdot \Delta T = a \cdot \Delta T$$

which rests on the premise that both energy flows go in the same direction. If overcooling shall be modelled in a simulation, the radiation part must therefore be removed again from the heat transfer coefficient, and long-wave radiation exchange must be computed separately from convective heat exchange. It will be advantageous to combine short- and long-wave radiation exchange into a single comprehensive radiation balance.

If the user instructs WUFI to use such a complete radiation balance, it accounts for the following **short- and long-wave radiation components** (cf. [2]):
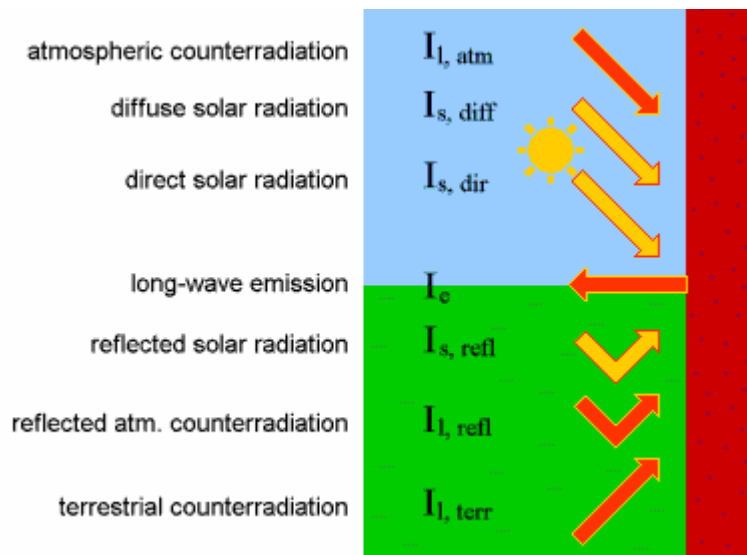
direct solar radiation:
   the fraction of solar radiation which comes directly from the sun, as incident on the building surface. WUFI uses the position of the sun and the orientation and inclination of the surface to compute it from the direct horizontal solar radiation, which in turn can be read from the weather file or can be computed from global and diffuse solar radiation.

diffuse solar radiation:
   the fraction of solar radiation scattered by the atmosphere and by clouds, incident from all directions.
   This value has to be multiplied by the viewing fraction of the sky (see below); the

result is the component of diffuse solar radiation incident on the building surface.

reflected solar radiation:
the short-wave radiation which reaches the building surface after having been reflected by the ground or other terrestrial objects. This value is computed from the sum of direct and diffuse solar radiation, and the terrestrial short-wave reflectivity.
It then has to be multiplied by the viewing fraction of the terrestrial surroundings (see below); the result is the component of reflected solar radiation incident on the building surface.

atmospheric counterradiation:
the long-wave radiation emitted by the sky (atmosphere + clouds).
Depending on the weather file type it may be read directly from the file, or it may be estimated from other weather elements and the cloud cover, using an empirical counterradiation model. Some file types contain hourly values for the cloud cover, otherwise the user can specify a fixed value for the cloud cover (strongly degrading the quality of the counterradiation estimates).
These counterradiation values have to be multiplied by the viewing fraction of the sky (see below); the result is the component of atmospheric counterradiation incident on the building surface.

reflected atmospheric counterradiation:
the atmospheric counterradiation which reaches the building surface after having been reflected by the ground or other terrestrial objects. This value is computed from the atmospheric counterradiation and the terrestrial long-wave reflectivity.
It then has to be mulitplied by the viewing fraction of the terrestrial surroundings (see below); the result is the component of reflected atmospheric counterradiation incident on the building surface.

terrestrial counterradiation:
the long-wave radiation emitted by the terrestrial surroundings.
Depending on the weather file type it may be read directly from the file, or it may be estimated from the ambient temperature and the emissivity of the terrestrial surroundings (e.g. the ground), using the Stefan-Boltzmann law (it is assumed that the effective temperature of the objects in the terrestrial surroundings is equal to the ambient air temperature).
These counterradiation values have to be multiplied by the viewing fraction (see below) of the terrestrial surroundings; the result is the component of terrestrial counterradiation incident on the building surface.

long-wave emission:
the long-wave radiation thermally emitted by the exterior surface of the building component. It only depends on the temperature and the long-wave emissivity of the surface.

Simplified WUFI method (recommended for most applications):

The transport equations used by the previous WUFI versions (and by WUFI 4.1 in the default simplified calculation mode) offer two mechanisms for heat addition or removal: heat exchange with the ambient air (across the exterior and the interior surface), and a heat source or sink at the exterior surface. (A third mechanism, heat liberated by latent heat effects is ignored in this section).

This simplified calculation mode accounts for the long-wave radiation exchange by

using a heat transfer coefficient which includes some long-wave contribution, as discussed above. Convective heat flow and long-wave exchange are thus treated collectively as heat exchange with the ambient air.

In contrast, the short-wave (solar) radiation is treated as a heat source at the component surface whose source strength is given by the irradiation incident on the surface, multiplied by the short-wave absorptivity.

If the specified weather file has another format than *.TRY or *.DAT, then WUFI does not distinguish between day and night. At night, merely the heat source (due to radiation) is zero since then there is no solar radiation. No overcooling can result.

However, if a weather file in test reference year format (*.TRY or *.DAT) is used, WUFI tries to account for overcooling in a rudimentary way at least, and for this it uses the following simplified method:

- During the day WUFI only indirectly accounts for long-wave exchange by using a heat transfer coefficient which contains some long-wave contribution. The short-wave (solar) radiation is treated as a (positive) heat source. In order to distinguish day from night, WUFI looks at the diffuse solar radiation: if such radiation is present, it's "day".

- If the diffuse solar radiation is zero, WUFI switches to "night" mode: before performing the next time step it estimates the nighttime thermal net emission of the component surface (inclination angle β) as

$$net\ emission = \left(5.67 \cdot 10^{-8} \cdot T_{Air}^4 \ - atm.\ counterradiation\right) \cdot cos\left(\frac{\beta}{2}\right)$$

Since the temperature of the emitting surface is not yet known before the time step is performed, it is replaced by the exterior air temperature which is known from the weather file (this approximation is roughly admissible by night; by day it would usually be very wrong). Furthermore it is assumed that the radiation exchange with the terrestrial part of the field of view is exactly balanced. The cosine factor describes the sky part of the field of view.

This net radiation loss is given a negative sign and is then treated as a heat source (actually a heat sink) at the surface. WUFI's computation core decides on the basis of the sign whether the radiation intensity it was handed over is solar radiation (positive sign) or long-wave emission (negative sign). Solar radiation is multiplied by the short-wave absorptivity of the surface, long-wave emission is multiplied by the long-wave emissivity of the surface.

Since during the night the long-wave exchange *is* explicitly accounted for (albeit in a very approximate way) the long-wave contribution should be removed from the exterior heat transfer coefficient. In the current implementation this is, however, not done.

Conclusion: if WUFI works in the simplified radiation exchange mode (which is the default) and if the weather file is in *.TRY or *.DAT format, it can produce rudimentary results for nighttime overcooling. No quantitatively correct results can be expected, however.

Note for the user:
If WUFI works in the simplified radiation exchange mode (default) and the weather data are read from a *.TRY or *.DAT file, it will automatically determine the nighttime net emission with the above formula and treat the result as a heat loss.

If you convert your own weather data to one of these formats but have no atmospheric counterradiation data, you **must not simply fill the respective column with zeros**. Otherwise the thermal emission of the component will remain uncompensated by counterradiation and the resulting overcooling will be much too strong. Instead, you may

- use empirical formulas (e.g. [1]) to estimate the counterradiation from other weather elements, if you have data on the cloud cover,

or

- fill the counterradiation column with the expected thermal emission (set surface temperature := air temperature, see emission formula above), so that in the calculation emitted and absorbed thermal radiation cancel. With these weather data you will get no overcooling at all, but at least you will get no wrong overcooling.

or you can

- fill the counterradiation column with zeros, but then you *must* also set the long-wave emissivity of the component surface to zero, in order to suppress long-wave exchange altogether. Of course, no overcooling will result here either.

New: explicit full radiation balance (for advanced users):

The full radiation balance mode has been introduced in WUFI 4.1 [3]; in principle it allows the quantitative computation of nighttime overcooling. You can activate this mode by enabling the option "Explicit Radiation Balance" in the dialog "Surface Transfer Coefficients".

Note: the degree of overcooling is determined by the net long-wave emission. This number is the difference of two relatively large numbers: the surface emission and the total counterradiation. Uncertainties in the terrestrial or atmospheric counterradiation values (due to measurement issues, imperfections in the formulas used to estimate them, etc.) may therefore strongly perturb the results. So far, we have not much experience to assess the involved sensitivities. For the time being this calculation mode should therefore be considered experimental. Users who do not wish to delve into the details of this subject may prefer to use the simplified mode instead (see above) which is perfectly adequate for most purposes.

In this mode the long-wave radiation components are determined explicitly, whether by day or by night. They are combined with the short-wave radiation components into a collective heat source at the surface which may have positive or negative source strength, depending on the overall radiation balance.

The exterior heat transfer coefficient must then strictly contain only the convective part. You may subtract the long-wave part yourself or leave that to WUFI (WUFI will subtract 6.5 W/m²K). Tell WUFI in the dialog "Surface Transfer Coefficients" whether the number you entered contains the long-wave part or not.

WUFI computes the balance of all the radiation components as follows:

$$I = a \cdot I_s + \varepsilon \cdot I_l - I_e$$

I [W/m²]   net radiation at the component surface
a [-]   short-wave radiation absorptivity of the surface
I_s [W/m²]   short-wave solar radiation
ε [-]   long-wave emissivity and absorptivity of the surface
I_l [W/m²]   long-wave counterradiation
I_e [W/m²]   long-wave emission of the surface

A positive I results in a heating of the surface, a negative value causes cooling. For the radiation components I_s and I_l we have

$$I_s = I_{s,dir.} + g_{atm.} \cdot I_{s,diff.} + g_{terr.} \cdot I_{s,refl.}$$

$I_{s,dir.}$ [W/m²] direct solar radiation incident on the component surface
g_{atm} [-]   atmospheric viewing fraction
$I_{s,diff}$ [W/m²] diffuse solar radiation
$g_{terr.}$ [-]   terrestrial viewing fraction
$I_{s,refl.}$ [W/m²] solar radiation reflected by the ground

$$I_l = g_{atm.} \cdot I_{l,atm.} + g_{terr.} \cdot (I_{l,terr.} + I_{l,refl.})$$

$I_{l,atm}$ [W/m²] atmospheric counterradiation
$I_{l,terr.}$ [W/m²] terrestrial counterradiation
$I_{l,refl.}$ [W/m²] atmospheric counterradiation reflected by the ground

The two viewing fractions are computed by

$$g_{atm.} = \cos^2(\frac{\beta}{2})$$

$$g_{terr.} = 1 - g_{atm.}$$

β [°]   Inclination of the component (90° for a vertical wall)

The equations for I_s and I_l contain each three radiation components; usually not all of them are present in the weather files. However, if, for example, only $I_{s,diff}$ and $I_{l,atm}$ are in the file and the direct radiation on a horizontal plane $I_{s,dir,h}$ is available, then the unknown radiation components can be computed as follows:

$$I_{s,refl.} = \rho_{s,terr.} \cdot (I_{s,dir.,h} + I_{s,diff.})$$

$\rho_{s,terr.}$ [-] short-wave reflectivity of the ground

$$I_{l,terr.} = \varepsilon_{l,terr.} \cdot \sigma \cdot T_{terr.}^4$$

σ [W/m²K⁴] Stefan-Boltzmann constant
$\varepsilon_{l,terr.}$ [-]   long-wave emissivity of the ground
$T_{terr.}$ [K]   temperature of the ground

$$I_{l,refl.} = \rho_{l,terr.} \cdot I_{l,atm.}$$

$\rho_{l,terr.}$ [-] long-wave reflectivity of the ground

By night, the temperature of the ground may be assumed to be approximately equal to the exterior air temperature. The direct radiation $I_{s,dir}$ can also be determined from $I_{s,dir,h}$ once the position of the sun has been computed.

All the radiation components mentioned so far are in general explicitly known before the simulation, or WUFI can determine them using the above formulas. They do not depend on the as yet unknown results of the simulation. The single exception is the long-wave emission which depends on the temperature of the component surface via the Stefan-Boltzmann law:

$$I_e = \varepsilon \cdot \sigma \cdot T_{Sur}^4$$

T_{Sur} [K]   Temperature of the component surface

This nonlinear relation must be linearised to be usable in linear equation systems such as those solved by WUFI. For this purpose it is developed into a linear Taylor series. The expansion point is the (known) current surface temperature which resulted from the last time step:

$$I_{e,lin} = \varepsilon\sigma T_0^4 + 4\varepsilon\sigma T_0^3 \cdot (T - T_0)$$

$I_{e,lin}$ [W/m²] linearised emission
T_0 [K]   temperature of the surface before the iteration step (known)
T [K]   temperature of the surface after the iteration step (to be solved for)

All these computations are performed by WUFI itself if "Explicit Radiation Balance" has been enabled. However, to do this WUFI needs some additional parameters which you can enter in the dialog "Surface Transfer Coefficients":

The meaning of the reflectivities and emissivities is explained by the above formulas. The sum of the ground long-wave emissivity and reflectivity should be 1.

A constant cloud index (i.e. fraction of the sky covered by clouds) entered here is used for a rough estimate of atmospheric counterradiation if no measured values are available and the hourly cloud cover data needed for estimating the counterradiation with a model are not available either (e.g. always when a weather file in WET format is used).

The following weather files included with WUFI contain neither atmospheric counterradiation data nor data on the cloud cover. If you want to use them nevertheless for calculations with full radiation balance, you have to specify an appropriate constant cloud index:
- Espoo
- Kolobrzeg
- Warsaw
- Krakov
- Innsbruck
- Graz
- Vienna
- Lisbon
- Kassel
- Grenoble

Weather data and user input needed for a successful explicit radiation balance are quite complex. You can check the results in detail by examining individual radiation components; all the components mentioned above can be accessed via ASCII export or in the result graphs.

Literature:
[1]   Blümel, K. et al.: Entwicklung von Testreferenzjahren (TRY) für Klimaregionen der Bundesrepublik Deutschland. BMFT-Forschungsbericht T 86-051.

[2]   VDI 3789 Umweltmeteorologie, Blatt 2: Wechselwirkungen zwischen Atmosphäre und Oberflächen; Berechnung der kurz- und der langwelligen Strahlung. Entwurf, Dezember 1992

[3]   Kehrer M., Schmidt Th.: Temperaturverhältnisse an Aussenoberflächen unter Strahlungseinflüssen. Proceedings BauSIM 2006, 9.-11. Okt. 2006, TU München

Continue with Overview of WUFI's Dialog Structure

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Overview of WUFI's Dialog Structure
with hyperlinks to the corresponding help topics.

This list contains a description of all menu items and of all dialogs, including dialogs which are not directly accessible via the menus, but as sub-dialogs of other dialogs:

Project:

- **New Project**
  Wipes WUFI's memory clean and starts a new project. The project dialog opens which you can use as a memo pad for some administrative project info.

- **New Case**
  Creates a new case within the current project. The case dialog opens which lets you enter a case name and remarks, and which offers a tool for copying selected data over from other cases, if any exist.

- **Remove Selected Case**
  Serves to delete cases which are not needed any more.

- **Open**
  Displays the usual 'Open' dialog from which you can open existing project files (which contain the input data and the calculation results, if any).

- **Reopen**
  Displays a list of projects you have previously worked with so that you can easily open them by simply selecting them from this list.

- **Save**
  Saves the input data and (after a calculation has been performed) the calculation results to the project file. (You *should* save the project before a calculation in case something goes wrong; you *must* save again after the calculation if you want to keep the results for later).

- **Save As**
  Saves the project file under a new name.

- **Close**
  Closes WUFI. But why should you want to?

Inputs (these dialogs are also directly accessible from the project explorer on the left side of the screen)**:**

- **Assembly / Monitor Positions**
  Here you define the assembly of the building component by specifying the

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layer sequence and the layer thicknesses as well as the material parameters of the individual layers. You can also select an appropriate numerical grid and monitoring positions.

- ° **Material Data**
  This dialog displays the material data for the highlighted layer.

- ° **Material Database**
  In this dialog you can select the material data for the highlighted layer from the material database.

- ° **Example Cases**
  In this dialog you can select an assembly from the construction database and transfer it to the assembly dialog.

- ° **Hygrothermal Sources**
  You can specify heat, moisture and air change sources (or sinks) for the highlighted layer.
  - ° **Edit Hygrothermal Sources**
    Specify the location and the properties of the sources.

- **Orientation / Inclination / Height**
  This dialog serves to define the orientation, inclination and height of the building component. These data are needed to calculate the rain and radiation loads incident on the surface.

- **Surface Transfer Coefficients**
  In this dialog you define the surface transfer coefficients, such as the heat transfer coefficient, the radiation absorptivity etc.

- **Initial Conditions**
  The initial temperature and moisture distributions are specified in this dialog (e.g. a dry component or one with trapped construction moisture).

  - ° **Initial Moisture**
  - ° **Initial Temperature**
    These dialogs serve to specify initialisation files which describe the initial moisture and/or temperature profiles in the component, if these are to be read from files.

- **Calculation Period / Profiles**
  Here you tell WUFI for which period of time the simulation shall be carried out (e.g. the simulation is to span one year, starting in early summer).

- **Numerics**
  The options offered by this dialog allow you to control the way the calculation is done.

- **Exterior Climate**
  This dialog serves to specify the weather acting on the left side of the component.

- **Interior Climate**
  This dialog serves to specify the weather acting on the right side of the component.

° **Select Climate File (from map)**
° **Select Climate File (file browser)**
Use these subdialogs to select a climate file.

° **Detailed Options**
Depending on the climate file type, additional options may be available.

Run

• **Run Calculation**
Starts the calculation for the current case, but shows only a progress bar instead of the film.

• **Run all Calculations**
Starts the calculation for all cases in the project in succession and only shows a progress bar instead of the film.

• **Run Calculation with Film**
Open this dialog to start the calculation and watch the thermal and hygric processes going on in the component during the simulation (the 'film').

° **Run Calculation - Properties**
This subdialog lets you configure the film display.

Outputs

• **Qick Graph**
The quick graphs give you a quick overview of the calculation results.

• **Input Data Summary / Last Calculation**
This dialog displays data sheets with the input data (such as the assembly and the material data) and a summary of the calculation results, formatted for printing.

° **Input Data Summary – Options**
Use this dialog to select the data that shall be included in the Input Data Summary.

• **Status: Last Calculation**
This dialog displays a short summary of the calculation results.

• **Result Graphs**
This dialog displays the calculation results in the form of graphs showing courses and profiles, formatted for printing.

° **Page Setup**
This dialog allows you to edit the name of the highlighted graphics page.

° **Graph Setup, Courses**
Here you can edit the settings for a graph that displays courses.

° **Graph Setup, Profiles**
Here you can edit the settings for a graph that displays profiles.

° **Curves Setup**
Here you can edit the settings for a curve.

° **Insert Curves**
Here you can assign a curve to the current graph.

° **Delete Curves**
Here you can remove a curve from the current graph.

• **View Film**
This dialog displays the calculation results in the form of a film showing the thermal and hygric processes in the building component as an animation.

• **Measured Data**
Here you can specify a file with measured data. You can configure the result graphs to show them together with the WUFI results, allowing easy comparison of calculation and measurement.

• **ASCII Export**
Instead of viewing the results with WUFI's graphics screen, you may also write them to an ASCII file and analyse them on your own.

• **Export Film**
You can export the film and display it with an external film viewer (*in WUFI Pro only*).

Options

• **Unit System**
Switch between SI and IP units.

• **Warnings**
Tell WUFI which events shall cause a warning.

• **Result Data**
Exclude the calculated courses/profiles or the film data from being saved in the project file.

Database

• **Database Materials**
View the material data contained in the materials database or add your own materials.

° **Database Materials – New Material**
Define a new material for inclusion in WUFI's materials database.

° **Database Materials – Change Material**
Edit one of the materials you have added to the database. (The predefined materials in the database cannot be edited.)

° **Database Materials – Delete**
Delete from the database one of the materials you have added. (The predefined materials in the database cannot be deleted.)

° **Database Materials – Edit Catalog**
Add or edit a database catalog

• **Database Constructions**
View the constructions contained in the constructions database or add your own constructions.

° **Database Constructions – New Construction**
Define a new construction for inclusion in WUFI's constructions database.

° **Database Constructions – Change Construction**
Edit one of the constructions you have added to the database. (The predefined constructions in the database cannot be edited.)

° **Database Constructions – Delete**
Delete from the database one of the constructions you have added. (The predefined constructions in the database cannot be deleted.)

° **Database Constructions – Edit Catalog**
Add or edit a database catalog

?
The on-line help. The contents page is here.

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The following menu items are also available via the toolbar buttons:

Create New Project

Open Project File

Save Project File

Create New Case

Remove Case

Run Calculation for current case without film display

Run Calculation for all cases in the project without film display

Run Calculation with film display

Show Summary of Input Data

Show Status of Last Calculation

Show Result Graphs

View Film

Open On-Line Help

Continue with Dialog: Project

Go to Contents

Dialog: Project

This dialog serves as a memo pad for some useful administrative project information which can thus be kept together with the calculated results.
All these inputs are optional; they have just an informative character.

Next dialog: Case

Go to Overview of WUFI's Dialog Structure
Go to Contents

Dialog: Case
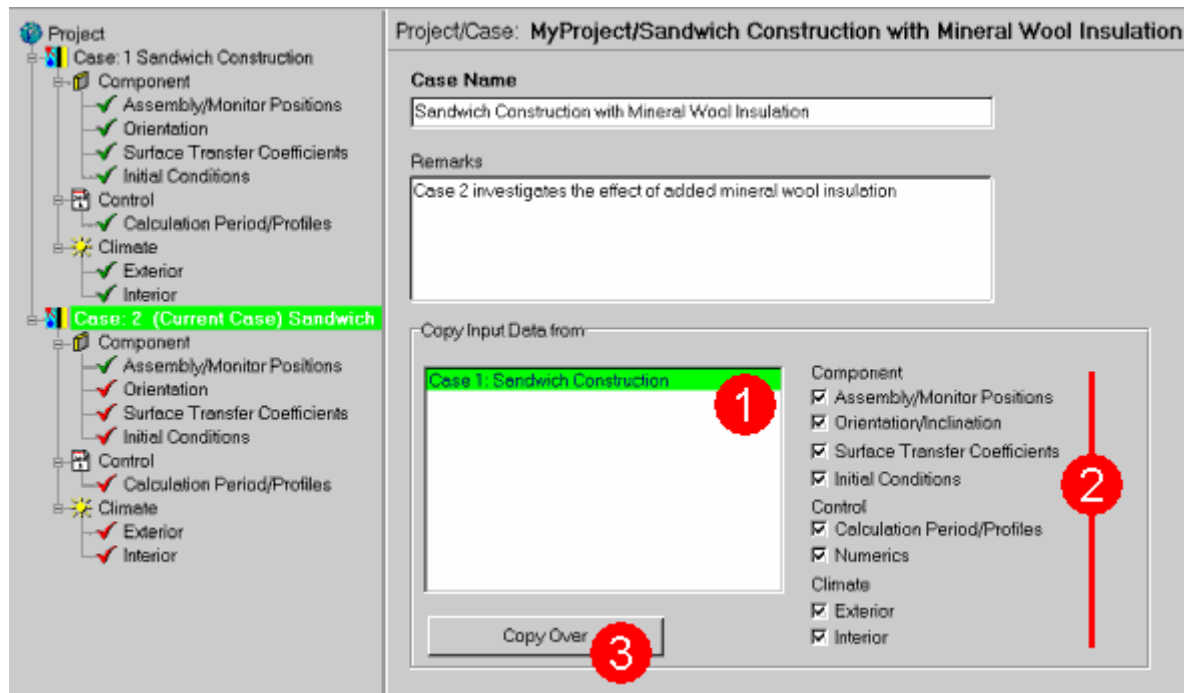
A project file may contain several different cases. This is useful for managing projects which require a series of calculations that cover the same general subject but are slightly different from each other (e.g. parametric studies). In principle, all the cases in a project are independent, however.

A new case is created either with the "New Case" button ⊞ in the toolbar or with the "New Case" item in the "Project" menu.

In this dialog, you can assign a **"Case Name"** to the current case which is used to identify that case and which appears as the title for the film or graphics display. You can also enter additional information, such as any **"Remarks"** on the case. All these inputs are optional. They have just an informative character and can help you later to identify the studied problem.

This dialog also helps you in creating a new case. When you create a new case , the Case dialog panel appears and allows you to copy data from existing cases.
The selection list **"Copy Input Data from:"** **(1)** shows existing cases of the current project. Select the case with the desired data and mark in area **(2)** the checkboxes for the data you want to copy. A click on the button **"Copy Over"** **(3)** transfers all the selected data to the new case.
You can also use this feature to copy data between already existing cases. Deselected data **(2)** will then not overwrite existing ones.

You may create an arbitrary number of cases in a project, but since all the

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+ 5030
K case;project

calculation results are saved in the same project file together with the input data (unless this option is deselected), the project file may become unmanageably large when it contains many cases.

> Version notice: WUFI Pro allows an arbitrary number of cases; in WUFI light and WUFI ORNL/IBP a maximum of two cases can be created.

Next dialog: Assembly / Monitor Positions

Go to Overview of WUFI's Dialog Structure
Go to Contents

Dialog: Assembly / Monitor Positions
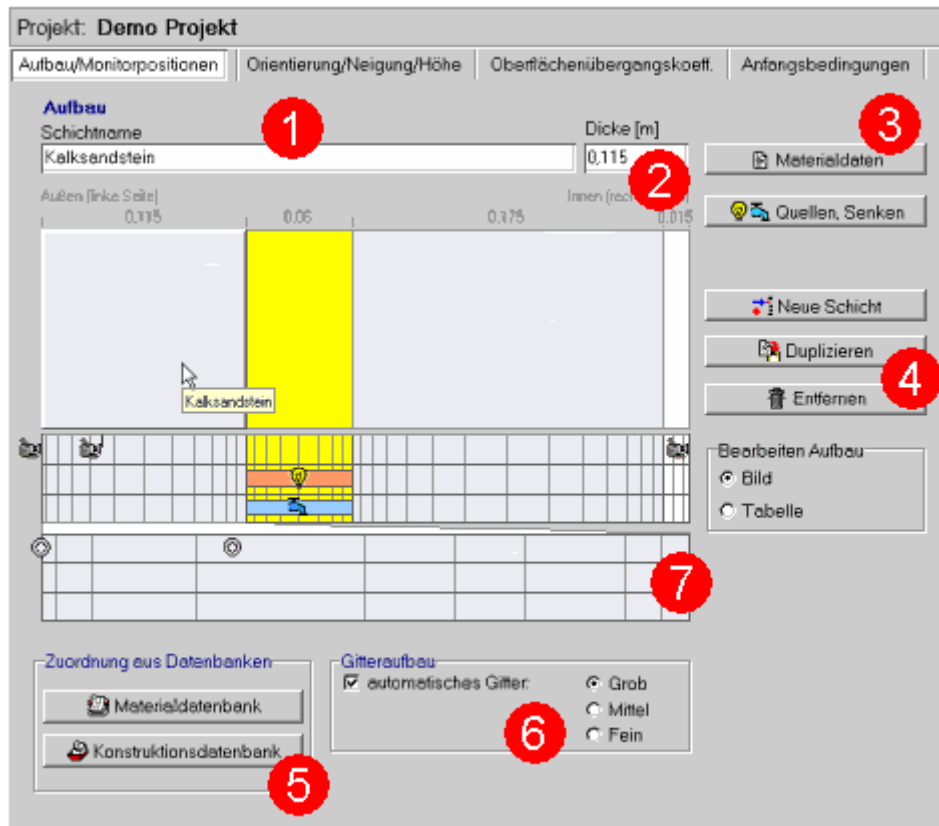
This is the central dialog where you define the assembly of the component you want to study. That is, you specify the geometry of the component (the layer sequence and the layer thicknesses) and the material parameters of the individual layers. Furthermore, you can select an appropriate numerical grid, specify an arbitrary number of monitoring positions for later analysis and insert heat, moisture and air change sources.

The assembly is graphically represented in the center of the dialog panel. The exterior side of the component is to the left, the interior side is to the right.

Create a new layer with the **"New Layer"** button **(4)** or by duplicating an existing layer with the **"Duplicate"** button **(4)**. Drag it to the desired location within the assembly. Then key in the **"Layer Name" (1)** and the layer **"Thickness" (2)**, and enter its **"Material Data" (3)** or select the material data from the WUFI **"Material Database" (5).** When all layers are in place, select the fineness of the **numerical grid** the assembly shall be divided into **(6)**.

Within the assembly, you may insert heat, moisture and air change **sources (7)**. You may also specify an arbitrary number of **monitoring positions (7)** for which you

---

want to be given the courses of temperature and relative humidity.

Instead of using the graphical interface, you may also do all of the above in a numerical table (see below).

"Layer Name" (1):

The name of the layer. You'll usually want to enter the name of the material.

"Thickness" (2):

The thickness of the layer in meters.

Hint: The membranes contained in the database must be entered as 1-mm-thick layers; their material data have been adapted accordingly.

"Material Data" (3):

Press this button to open a dialog which allows you to enter, edit or view the material data for the highlighted layer.
Instead of entering the data by hand in this dialog, you may also transfer a complete data set from the material database **(5)**.

Hint: press the right mouse button while the cursor points to one of the layers in the assembly diagram to see a little pop-up window with the basic material data of the respective material.

"New Layer, Duplicate, Delete" (4):

These buttons serve to edit the layer structure of your assembly.
You can add a **"New Layer"** which will always be inserted at the interior side of the assembly. Use the mouse to drag it to the desired location.
You can also **"Duplicate"** the highlighted layer or **"Delete"** a redundant layer.

Version notice: WUFI Pro allows 120 layers, WUFI light allows 10, WUFI ORNL/IBP allows 10.

"Assign from" (5):

"Material Database":

Press this button to open a dialog where you can select predefined material data and assign them to a layer in the assembly.

Select the appropriate **"Source"** and **"Catalog"** of the database and, from this catalog, the desired material. For most materials a list of typical thicknesses is available. A click on the **"Assign"** button will transfer the material data to the highlighted layer in the current assembly.

You cannot edit the predefined materials in the database, but you may add your own materials. Use the material database editor for this purpose.

"Example Cases":

Press this button to open a dialog where you can select predefined standard assemblies or parts of assemblies to transfer them to the current assembly.

Select the appropriate **"Source"** and **"Catalog"** of the database and, from this catalog, the desired construction. By pressing the **"Assign"** button you can replace the current assembly with the selected construction. You may then edit the new assembly as desired.

You cannot edit the predefined assemblies in the database, but you may add your own assemblies. Use the constructions database editor for this purpose.

"Grid" (6):

As soon as thicknesses have been defined for all layers of the assembly, WUFI automatically generates the **grid** which is necessary for the numerical treatment of the heat and moisture transport equations.

You can choose a coarse, a mean or a fine grid structure. The grid should be chosen fine enough so that the computed temperature and moisture distributions across the assembly can be appropriately resolved, especially where steep gradients or pronounced curvatures exist in the temperature or moisture profiles. The occurrence of such gradients or curvatures depends on the type of the assembly, the material properties and the boundary conditions. If in doubt, start the calculation with the **mean** grid, watch the temperature and moisture profiles for kinks due to poor resolution and choose the **fine** grid if necessary.
If the temperature and moisture profiles are smooth enough, you may choose the **coarse** grid which reduces computing time.

The **automatic**ally generated grid should usually be sufficient. In rare cases (such as severe interstitial condensation at layer interfaces or large temperature gradients across layers with low diffusion resistance and high moisture content, e.g. wet mineral wool), a more refined grid layout may be necessary. The manual **grid editor** allows you to define a tailor-made grid (see below).

"Sources, Sinks"(7):

As soon as WUFI has enough information about the geometry of the assembly to generate the automatic numerical grid, it displays the grid below the assembly graph. The upper part of the grid display shows the grid across the entire width of the assembly, the lower part shows a magnified view of the grid for the highlighted layer.

Click on the middle or bottom part of the magnified grid or click on the button **"Sources, Sinks"** to pop up a dialog which allows you to specify heat, moisture or air change sources in the highlighted layer.

Version notice: in WUFI light no sources can be specified. WUFI ORNL/IBP allows no

sources except one moisture source.

"Monitor positions" (7):

You can define an arbitrary number of **monitoring positions (7)** for which you want to be given the courses of temperature and relative humidity. They can be very useful if you want to study the hygrothermal conditions inside a building component.

The courses for temperature and relative humidity at the two surfaces are automatically monitored. You may define additional monitoring positions by clicking on the appropriate grid elements in the upper part of the magnified grid display. A second click on the grid element removes the monitoring position.

Version notice: only WUFI Pro allows an arbitrary number of monitoring positions; WUFI light is restricted to the two component surfaces; WUFI ORNL/IBP allows two user-defined monitoring positions.

"Edit Assembly by:" (8)

Instead of using the graphical interface, you may also do all of the above by editing the respective numerical table.

• • •

Defining the Assembly by Editing the Assembly Table
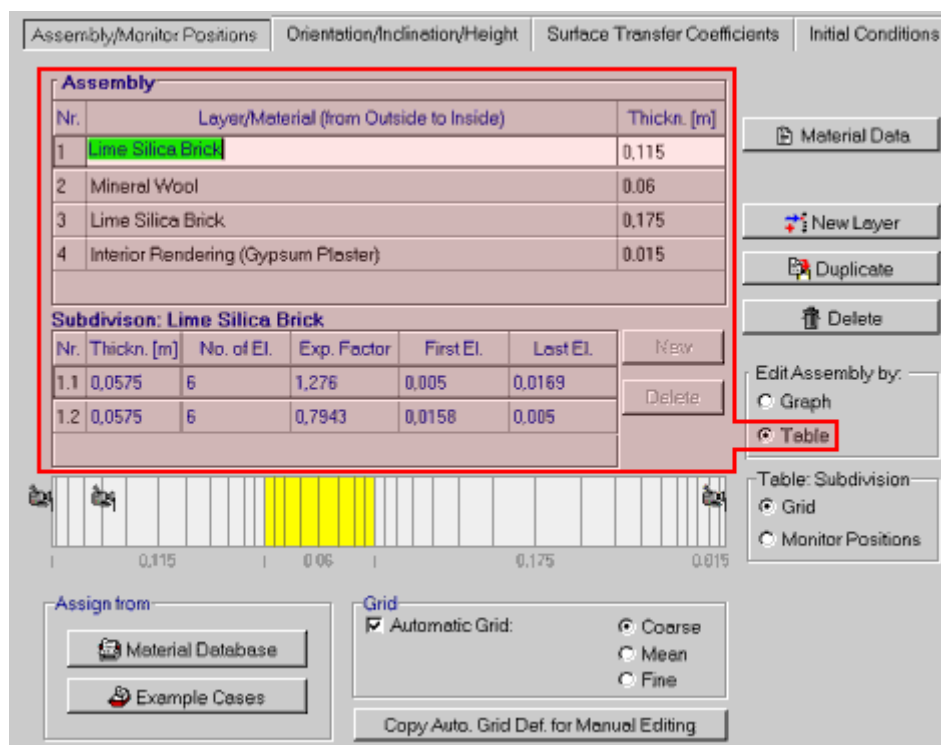
By selecting **"Table"** from the **"Edit Assembly by:"** options, you display the *tabulated* layer assembly instead of the *graphical* display.

Again, you can create a **"New Layer"** or **"Duplicate"** and **"Delete"** layers. You can give them a name and specify their **"Thickness"**.

The outermost layer of the component must be entered in the first line of the table, the innermost layer in the last line.

A second table displays a possible **"Subdivision"** of the highlighted layer. The entries in this table define the numerical grid. As long as the **"Automatic Grid"** option is selected, the entries of this table are created by WUFI and cannot be edited. In order to manually edit this table, see below.

● ● ●

Defining the Numerical Grid by Editing the Grid Table
   Version notice: manual editing of the grid is only available in WUFI Pro.
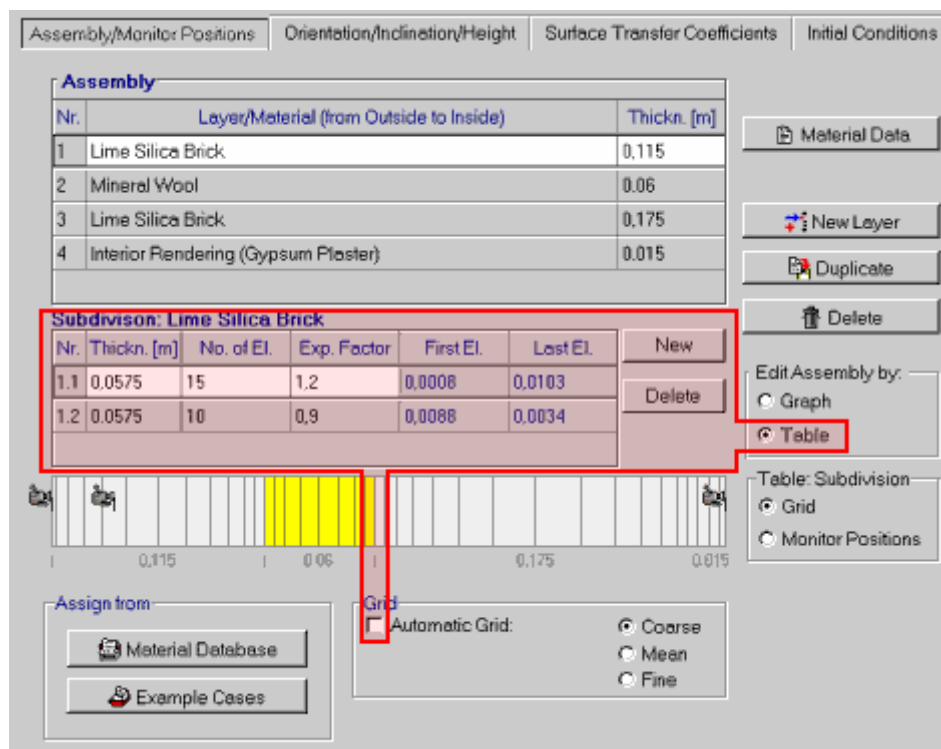
It may be necessary in some cases to override WUFI's automatic grid and to define a manual grid. For a discussion of how to detect such a situation, see "Dialog: Status of Last Calculation". For details on the choice of a suitable grid see Details / WUFI.

In order to manually edit the numerical grid, select **"Table"** in the **"Edit Assembly by:"** options; this will display the *tabulated* layer assembly instead of the *graphical* display. Then deselect **"Automatic Grid"** in the **"Grid"** options; this will permit you to edit the **"Subdivision"** table.

About the numerical grid:

The transport equations cannot be solved analytically. To allow a numerical treatment, the building component must be divided into discrete grid elements.

For the discretisation, the values of the calculated quantities are assumed to be constant across each grid element. Therefore, the size of each element should be chosen according to the local conditions so as to make this assumption valid. In general, this requires the use of small elements in regions where steep moisture or temperature gradients are to be expected, and the use of larger elements in more placid regions to cut down on calculation effort.

In general, steep gradients are to be expected close to the boundaries of a layer, i.e., close to the exterior and interior surfaces of the component because of the influence of climate conditions, and close to internal layer interfaces because of condensation. Less variation will occur in the middle of each layer.

WUFI permits the flexible definition of a grid which can be adapted to the requirements of the situation at hand. In each layer, the size of the individual grid elements can be kept constant, or it can continuously be increased or decreased by definition of an 'expansion factor'. Splitting up a layer into two or more sublayers with identical material data but different expansion factors (>1, <1) allows you to achieve a smooth, not necessarily symmetrical, expansion and contraction of the grid elements which can be adapted to the requirements in each individual layer.

Each line in the **"Subdivision"** table represents a sublayer of the highlighted layer in the **"Assembly"** table.

"Thickn. [m]":

The thickness of each sublayer, in meters. The thicknesses of the sublayers must sum up to the total thickness of the layer; apart from that, their thicknesses are arbitrary.

"No. of El.":

The number of grid elements the sublayer is composed of for the calculation.

The smaller the elements are, the smaller is the error produced by the discretisation. The larger number of elements then also increases computing time, however. In general, you should use smaller elements mainly for locations where great temperature or moisture gradients are to be expected.

Each sublayer must contain at least two grid elements. The entire assembly must not contain more than 100 elements.

"Exp. Factor":

The ratio of the thicknesses of two adjacent grid elements.

You might want to use different thicknesses of grid elements for different locations in a layer, depending on the local requirements. For example, at the exterior surface of the outermost layer, great temperature and moisture gradients are to be expected, so that small elements are advisable. In the middle of a sufficiently thick layer, in contrast, these quantities will only show a weak spatial variation, so that one can afford to use larger elements.

The expansion factor states by how much each element is thicker than its outwardly neighbour. Thus, the thicknesses of the elements of a sublayer constitute a geometric sequence.

Since in general the gradients in the middle of a layer are smaller than at its boundaries, you may first expand and subsequently compress the elements in a thick layer by splitting up this layer into two sublayers with different expansion factors (>1, <1).

For complicated situations you may define as many sublayers as required. On the other hand, if you only want to employ a grid with constant-sized grid elements, define only one sublayer and an expansion factor of 1.

"First El., Last El.":

WUFI automatically shows you the thickness of the first and the last element of each sublayer. You should adapt these elements so that their thicknesses are not too much different from the thicknesses of the boundary elements of the neighbouring layers; this smooth transition between the layers is desirable for numerical reasons.

The following **example** shows a possible choice for a manual grid.

The outer leaf of the sandwich construction has been subdivided into three sublayers with expanding, constant and contracting grids, respectively (you will rarely need such an elaborate subdivision, however).

The mineral wool layer simply employs one sublayer with an equidistant grid (we assume that test calculations have shown that no condensation takes place in the insulation layer and no major gradients in the moisture profiles occur therefore).

The inner leaf contains two sublayers whose grids expand and contract (this is the standard use of the sublayers. The automatic grid splits every layer into two sublayers in this way).

The interior rendering simply consists of one sublayer with a slightly contracting grid.

• • •
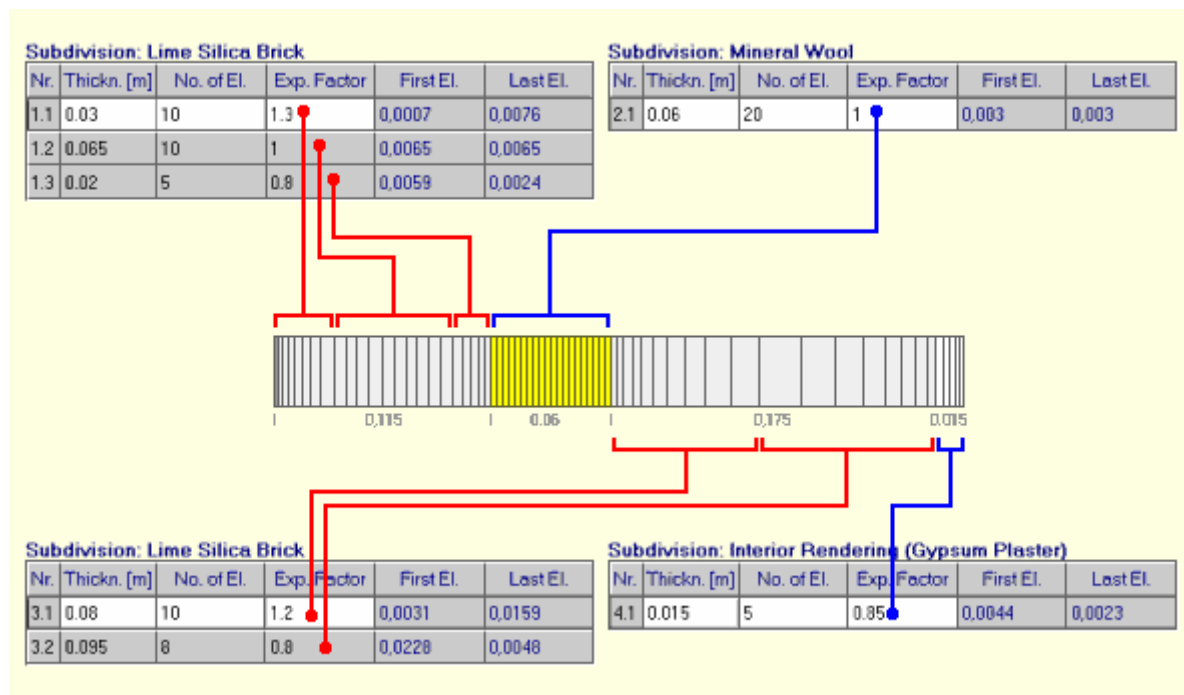
Defining Monitoring Positions by Editing the Monitoring Positions Table
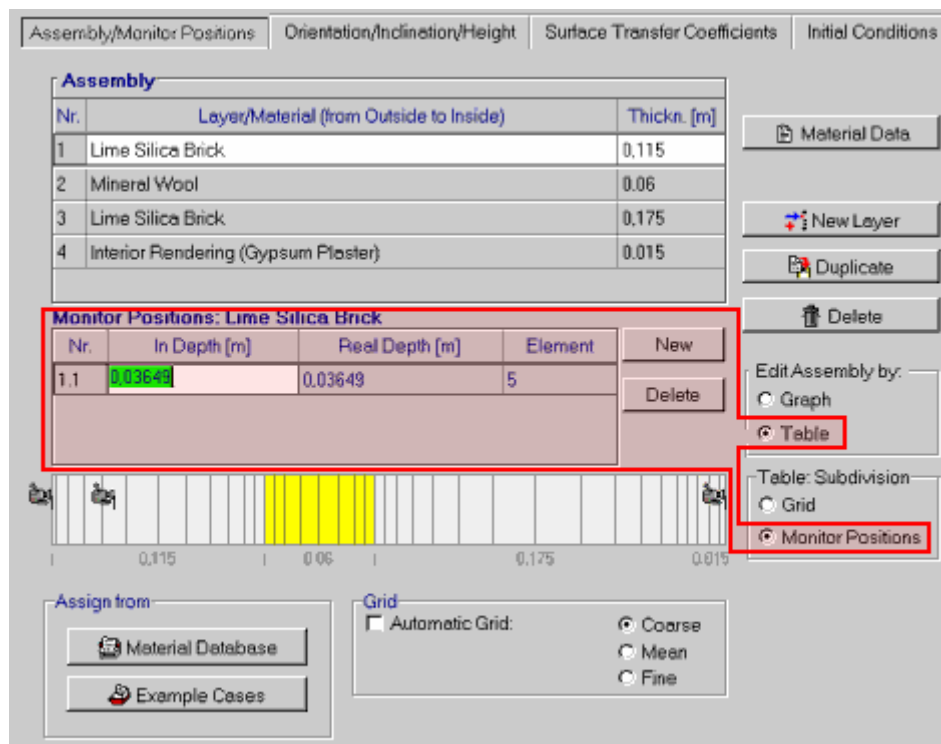
You can easily assign a **monitor** to a grid element by clicking on the respective element in the graphical assembly display. However, if you need to define a monitoring position at a specific depth of the layer, it is not easy to see which grid element corresponds to that depth. In the monitoring positions table you can enter

this depth numerically.

In order to edit the monitoring positions numerically, select **"Table"** in the **"Edit Assembly by:"** options; this will display the *tabulated* layer assembly intead of the *graphical* display. Then select **"Monitor Positions"** in the **"Table: Subdivision"** options; this will permit you to edit the **"Monitor Positions"** table.

You can create **"New"** monitoring positions or **"Delete"** existing ones with the respective buttons.

"In Depth [m]:"

Enter the depth of the current layer at which the monitor shall be placed.

"Real Depth [m]:"

WUFI computes the hygrothermal quantities for the center of each grid element. Consequently, it can only output data for this point. In general, your desired monitoring position will not coincide with one of these center points. WUFI therefore selects the nearest center point and tells you where the monitor has actually been put.

"Element":

The grid element into which the monitor has been placed.

Next dialog: Material Data

Go to Overview of WUFI's Dialog Structure
Go to Contents

Dialog: Material Data

In this subdialog you can enter, edit or view the material data for the highlighted layer.

Version notice: entering and editing material data is only available in WUFI Pro.

For a detailed discussion of the material data, please consult Details / Material Data.

"Layer/Material Name":

The name of the current material, as defined in the assembly. Use the drop-down list to switch between the materials of the current assembly without closing and reopening this dialog.

"Basic Values"
"Bulk Density [kg/m³]",
"Porosity [m³/m³]",
"Specific Heat Capacity, Dry [J/kgK]",
"Thermal Conductivity Dry [W/mK]",
"Water Vapor Diffusion Resistance Factor [-]":

DialogMaterialData
$ Dialog: Material Data
+ 5050
K material data;material properties;material database;bulk density;porosity;heat capacity;thermal capacity;heat conductivity;thermal conductivity;thermal conductivity supplement;heat conductivity supplement;water vapor diffusion resistance factor;diffusion resistance factor;moisture storage function;moisture retention function;approximate;liquid transport coefficient;suction;redistribution;water absorption coefficient;A-value;generate

These basic material data are required as a minimum for a calculation.

"Optional Parameters":
Some of the material data in the following section "Optional Data" are difficult to acquire, but WUFI offers means to approximate or generate them from standard data which can easier be collected. These standard data are then **"Optional Parameters"** which may be required, depending on the settings in the "Optional Data" dialog.

The optional parameters are discussed in the respective topics of the following section:

"Optional Data":
Enter the optional material data in these tables (if required).

The optional material data comprise the moisture storage function of the material, the liquid transport coefficients, the moisture-dependent thermal conductivity and the moisture-dependent vapor diffusion resistance factor.

The optional data are always entered in tables. However, you can have WUFI automatically create some of these tables by entering other related data from which the tables can be generated.

"Moisture Storage Function":
Enter the moisture storage function of the material, i.e. the moisture contents [kg/m³] which result from exposition to certain relative humidities (0..1).

If detailed tabulated data are not available, but the moisture retention function of the material can be adequately described by an approximation function, you can check the option **"Approximate"** and enter

- the sorption moisture corresponding to 0.8 RH, w_{80} (**"Reference Water Content [kg/m³]"**, nowadays determined according to German standard DIN 52620) and
- the **"Free Water Saturation [kg/m³]"** w_f

in the additional table **"Optional Parameters"**. WUFI then uses an analytical moisture storage function which passes through these two points and zero.

For non-hygroscopic materials, just leave the table of the moisture storage function empty. For numerical reasons, however, WUFI needs a defined moisture storage function; it then internally uses a default function which allows for the very low sorption moisture of non-hygroscopic materials. For details on this default moisture storage function see the Questions & Answers section.

"Liquid Transport Coefficient - Suction"
"Liquid Transport Coefficient - Redistribution":
Enter the liquid transport coefficients in this table - separately for suction and redistribution.

If the liquid transport coefficients for the material at hand are not known, you can have WUFI automatically generate a table by estimating the coefficients from the water absorption coefficient (A-value) which is known for most materials or at least easily measurable.

To this end, check the option **"Generate"** and enter the A-value in the additional table **"Optional Parameters"** (*in [kg/m²√s]; the relevant German standard uses the non-SI units [kg/m²√h]. Division by 60 converts such values to SI*). WUFI automatically generates a three-line table with the corresponding estimated liquid transport coefficients.

Please note that only a rough estimate is possible which proves successful in many cases, but which is not necessarily useful for all materials. Especially, there may be inaccuracies in the *shape* of the suction profiles. Generating is just meant to be some assistance; you should not blindly rely on it. Future WUFI versions are planned to offer more sophisticated methods.

Remarks on generating:

The estimate of the liquid transport coefficients from the A-value also uses the moisture contents w_{80} and w_f. If the moisture storage function is being approximated from w_{80} and w_f (see above), the two values are directly taken from these two entries; otherwise they are calculated from the corresponding table - by interpolation, if necessary.

If no moisture storage function has been defined as yet, generating is not possible - the table remains empty (but you can already enter the A-value).

If the moisture storage function is modified after generating, the generated table adapts automatically. Please note, therefore, that modification of a material property can also change another property as a side effect without this being immediately evident.

If you want to generate both the tables for suction and those for redistribution, both must of course be derived from the same A-value - the two tables therefore share this text box. Note that here, too, a modification intended to change one coefficient may entail changes in the other one (if you are generating only one of the tables and editing the other one by hand, the non-generated table is not affected by a modification of the water absorption factor, of course).

"Thermal Conductivity, Moisture-dependent":
Enter the heat conductivity of the material as a function of its moisture content if you want to allow for this.

If you are satisfied with a simple linear dependence of the heat conductivity on the moisture content, you can have WUFI automatically generate a two-line table by entering the moisture-induced heat conductivity supplement.

To this end, check the option **"Generate"** and enter the supplement in the additional table **"Optional Parameters"** (in [%/m-%]). WUFI automatically generates a two-line table with the heat conductivities resulting for the dry

condition and the maximum water content. Heat conductivities for intermediate moisture contents are linearly interpolated during the calculation.

Remarks on Generating:

The evaluation of the heat conductivity for maximum water content also uses the basic material properties bulk density, porosity and heat conductivity dry. If these values are modified after generating, the generated table adapts automatically. Please note, therefore, that modification of a material property can also change another property as a side effect without this being immediately evident.

If the required basic material data have not all been defined as yet, generating is not possible - the table remains empty (but you can already enter the supplement).

"Water Vapor Diffusion Resistance Factor, Moisture-dependent":
Enter the diffusion resistance factor of the material as a function of moisture content if you want to allow for this.

General remarks on approximating and generating:

For all optional material properties - except the diffusion resistance factor - WUFI is holding two tables in memory: one table created by hand (editable), and one generated table (non-editable). You can work on both tables in parallel; which of both is used for the calculation depends on whether the option **"Approximate"** or **"Generate"** is activated at the start of the calculation, or not.

By activating or deactivating the option, you can switch between the two kinds of tables. The unused table remains inactive in background.

You can use the **"Copy"** button to copy the generated table line by line to the editable table and work on it there by hand.

"Color":

Select the color of the material for the graphical assembly display.

"Typical Built-In Moisture [kg/m³]":

A typical application for WUFI is a calculation to determine the time it takes a newly-built wall to dry out. If a typical initial moisture content for the current material is known, you can enter it here. Assigning the initial moisture contents to the individual layers then only takes one click on a button in the "Initial Conditions" dialog.

"Layer Thickn. [m]":

A quick way to edit the layer thickness without going back to the assembly editor.

"Paste into Material Database":

Opens the "New Material" dialog of the material database which allows you to write the current material data to the material database for quick and easy use in other assemblies.

Next dialog: Material Database

Go to Overview of WUFI's Dialog Structure
Go to Contents

Dialog: Material Database

In this dialog you can select the material data for the highlighted assembly layer from the material database.

The material data are organized by **Sources** and by **Catalogs (1)**.
The source indicates the institution which has provided the data. You may select "All sources" in order to see all data, or you may select only one source if only a subgroup of data is relevant to your investigation.
For each source, the data have been organized in catalogs which comprise a specific category of building materials each (e.g. "Plasters and Mortars", "Insulation Materials", etc). Select "All catalogs" to view all materials of the selected source.

The materials contained in the selected sources and catalogs are displayed in the **materials list (2)**. You may **"Sort"** the materials by name or by one of the basic material parameters.

The following data are displayed for each material:

DialogMaterialDatabase
$ Dialog: Material Database
+ 5060
K material data;material properties;material database;source (database);catalog (database)

- The **basic parameters** of the materials are displayed in the list itself.
- For some materials typical **thicknesses** are specified in a separate list box.
- The large display panel on the right side of the screen **(3)** displays the optional material parameters of the highlighted material, complete with data tables and graphical curves. If you uncheck the **"Show Optional Parameters"** checkbox, this display panel vanishes and you can view the materials list more comfortably, in particular if you are using a smaller screen.

A double-click on a material in the list or a click on the **"Assign"** button **(4)** will transfer the material data (and thickness, if available) of the highlighted material to the highlighted layer of the assembly.

For a discussion of the material data, please consult Details / Material Data.

The predefined materials in the database are read-only and cannot be edited. However, you can add your own materials to the database.

Please note: the database contains typical data for typical materials which are therefore suited to the investigation of typical situations.
The large variations often found in different batches of the same material or in equivalent materials of different manufacturers, and the influence of different standards of workmanship applied in different cases may lead to variations in the hygrothermal behavior of the investigated components.
When comparing simulations with real-life cases or drawing far-reaching (and maybe expensive) conclusions from simulations, you should be aware of possible sensitive reactions of the results on uncertainties or variations in the input data. It may be necessary to determine some input data very precisely to get a reliable result, while other input data may have no discernible effect on the results. Of course, you can use WUFI to perform a sensitivity analysis and to determine how sensitively the result depends on variations in the input data.

Dialog: Example Cases
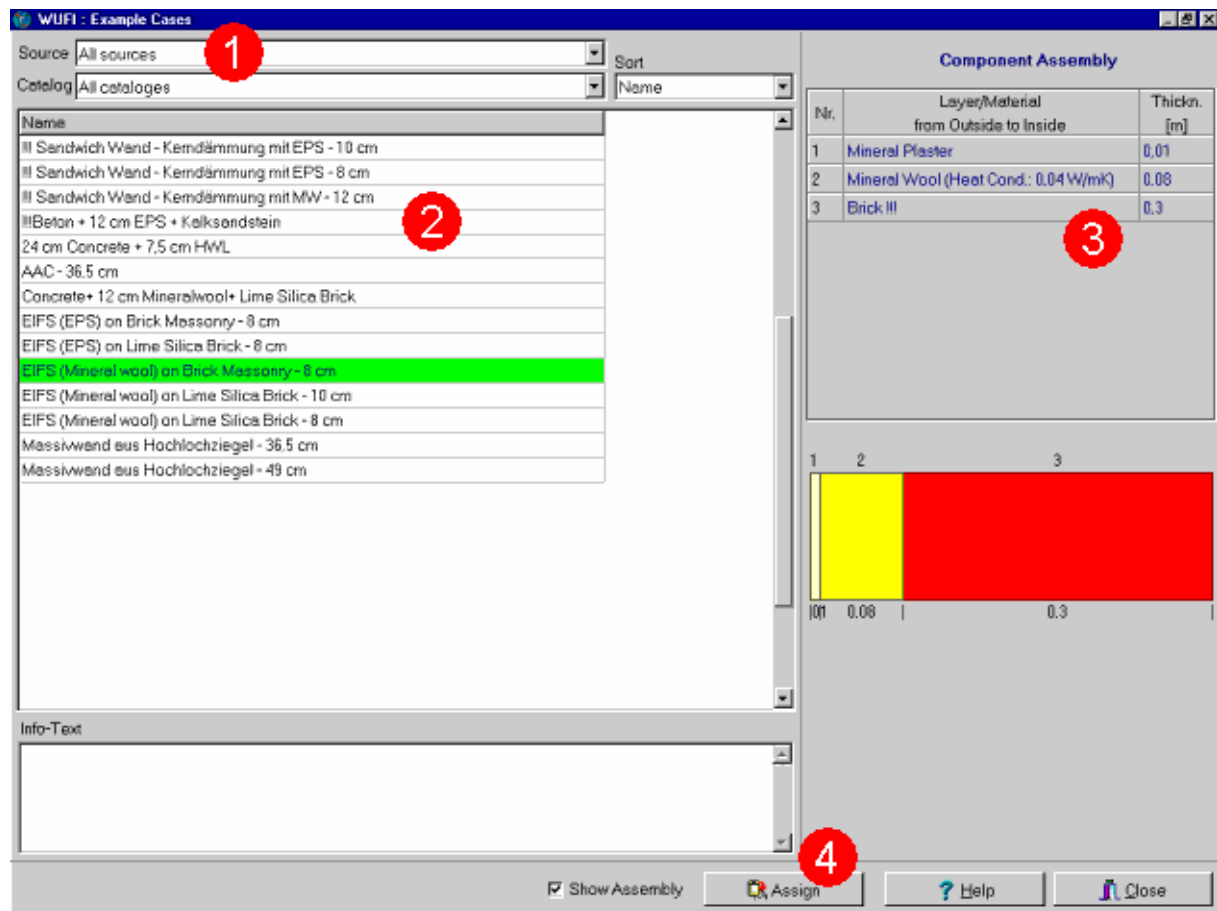
In this dialog you can select a predefined assembly from the construction database and transfer it to the layer assembly.

The constructions are organized by **Sources** and by **Catalogs (1)**.
The source indicates the institution which has provided the construction. You may select "All sources" in order to see all constructions, or you may select only one source if only a subgroup of constructions is relevant to your investigation.
For each source, the constructions have been organized in catalogs which comprise a specific category of constructions each (e.g. "Facades" etc). Select "All catalogs" to view all constructions of the selected source.

The constructions contained in the selected sources and catalogs are displayed in the **constructions list (2)**. You may **"Sort"** the materials by name.

The large display panel on the right side of the screen **(3)** displays the detailed assembly of the highlighted construction, both as a table and as an assembly

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diagram. If you uncheck the **"Show Assembly"** checkbox, this display panel vanishes and leaves more place for the constructions list.

A double-click on a construction in the list or a click on the **"Assign"** button **(4)** will transfer the highlighted construction to the layer assembly.

The predefined constructions in the database are read-only and cannot be edited. However, you can add your own constructions to the database.

Next dialog: Hygrothermal Sources

Go to Overview of WUFI's Dialog Structure
Go to Contents

Dialog: Hygrothermal Sources
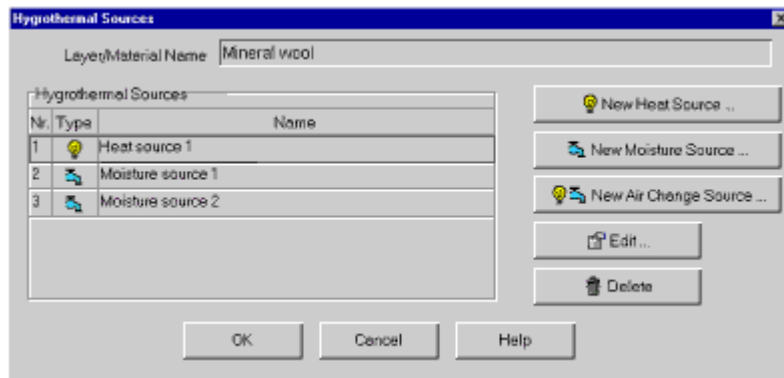
You can specify **heat**, **moisture** and **air change sources** (or **sinks**) for the highlighted layer. Each layer has a list of associated sources/sinks. Use this dialog to edit the list.

In order to add a new source/sink to the list, click on the button **"New Heat Source"**, **"New Moisture Source"** or **"New Air Change Source"**, as appropriate. A new source/sink of the corresponding type will be added to the list, and a dialog pops up where you can specify the properties of the source/sink.

In order to change the properties of an existing source/sink, highlight it in the list and click on the **"Edit"** button to open the edit dialog.

The **"Delete"** button serves to remove sources/sinks from the list.

> Version notice: in WUFI light no sources can be specified. WUFI ORNL/IBP allows no sources except one moisture source.

Next dialog: Edit Hygrothermal Sources

Go to Overview of WUFI's Dialog Structure
Go to Contents

DialogHygrothermischeQuellen
$ Dialog: Hygrothermal Sources
+ 5074
K hygrothermal sources;sources;heat source;heat sources;moisture source;moisture sources;air change source;air change sources

Dialog: Edit Hygrothermal Sources
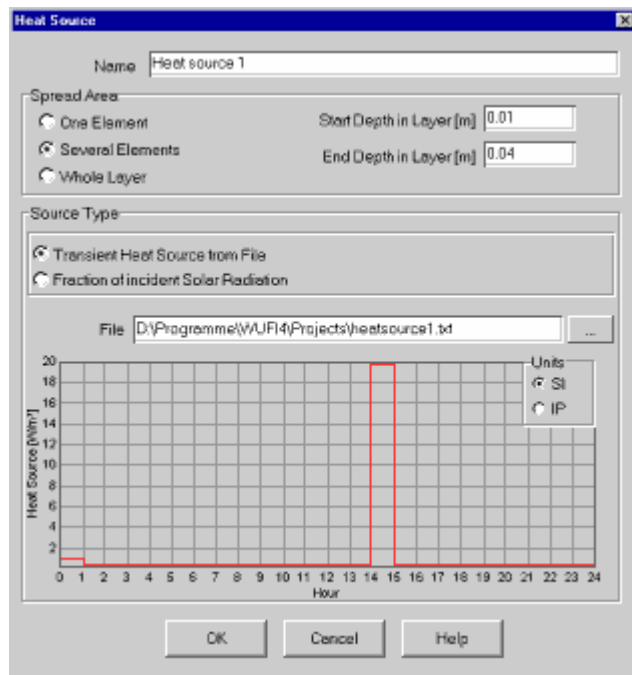
This dialog serves to specify the location and the properties of the sources you have added to the current layer. A sink is simply a source with negative source strength.

First, you have to specify **the location and the extent** of the source. A source may be point-like or extended. Accordingly, select whether the source shall be spread over **one grid element**, **several grid elements** or the **whole layer**.
In the first case, specify the depth of the source in the layer; in the second case, specify the start depth and the end depth of its extension in the layer (in meters, counted from the left surface of the layer). WUFI will assign the source to the closest grid element(s). If the source is to extend over the whole layer, it will be distributed evenly over all grid elements of the layer.

Several heat or moisture sources may reside in one layer. However, heat sources may **not overlap** each other, and moisture sources may not overlap each other either. Two neighboring sources for which you have specified non-overlapping extents may still happen to overlap if WUFI assigns their respective ends to the same grid element (error message: **"overlapping sources"**). In this case you must adjust the positions of the sources slightly.
An air change source contains both a heat and a moisture source, and it always extends over the whole layer. Thus, in such a layer no more heat, moisture or air change sources are allowed.

Furthermore, you have to specify **how the source strength behaves in time**:

DialogHygrothermischeQuellenEditieren
$ Dialog: Edit Hygrothermal Sources
+ 5076
K   hygrothermal   sources;sources;sinks;heat   source;heat   sources;moisture source;moisture   sources;air   change   source;air   change   sources;diverging results;overlapping sources

- For **heat sources** the source strength may be read from a file, or it may be derived from the weather conditions as a specified fraction of the incident solar radiation.

- For **moisture sources** the source strength may be read from a file, or it may be derived from the weather conditions as a specified fraction of the incident driving rain.

- For **air change sources** the source strength is read from a file. According to the specified air changes, an air change source replaces part of the air at its location by outdoor air. Depending on the temperature and humidity conditions in the component and in the outdoor air, heat and moisture may be transported into or out of the component. For details on how WUFI computes the source strength from the air changes see the appendix below.

Files controlling the source strength are text files with one column for the time axis (in h; values must be in ascending order) and one column for the source strength (in W/m² for heat sources, kg/s m² for moisture sources and 1/h for air change sources; the decimal separator is always the decimal *point*, independent or your system settings).

The time column indicates the point in time until which the corresponding source strength prevails. For example, a file for a heat source may have the content

```
 1      1
14    0.2
15     20
24    0.2
```

This files specifies that for one hour (i.e. until the end of the first hour) the source strength is 1 W/m². Then for 13 hours (until the end of hour 14) it is 0.2 W/m², for another hour (until the end of hour 15) it is 20 W/m², and finally for 9 hours (until the end of hour 24) it is 0.2 W/m² again. This curve is shown in the above screenshot.

The file is read as often as necessary, starting over when its end is reached. The example file thus describes a behavior which repeats daily. Of course, a file may also contain a time period of, say, two hours, or a whole year.

Note: if a moisture source/sink is being used, it may happen that it tries to put water into a layer which is already completely filled, or it may try to remove water from a layer which has already dried up. Both attempts must fail as this is physically not possible and there is no mathematical solution for the transport equations in this situation. In such a case, WUFI stops the calculation and indicates **"diverging results"**. You may be able to avoid the problem by spreading the source/sink over a wider area, otherwise you must decrease the source/sink strength.

Version notice: in WUFI light no sources can be specified. WUFI ORNL/IBP allows no sources except one moisture source.

Appendix: Determination of the source strengths of an air change source

The source strength of a heat or moisture source is directly determined by the user, or it is directly derived from the weather conditions as a user-defined fraction of

solar radiation or driving rain. In the case of an air change source, however, the user only specifies the air changes per hour and WUFI determines from this and some boundary conditions the heat and moisture source strengths of the air change source. This is done as follows:

Determination of the air change heat source:

$$Q_t = \rho_{out} \cdot \frac{ACH}{3600} \cdot d_{cavity} \cdot C_{p,Air} \cdot (T_{out} - T_{cavity})$$

Q_t:	heat source strength [W/m²]
ρ_{out}:	density of the outdoor air [kg/m³]
ACH:	air change rate of the cavity [1/h]
d_{cavity}:	thickness of the cavity [m]
$C_{p,Air}$:	specific heat capacity of dry air at constant pressure [J/kg K] (moisture neglected)
T_{out}:	outdoor temperature [K]
T_{cavity}:	cavity temperature [K] (mean value of all involved grid elements)

Determination of the air change moisture source:

$$Q_m = \frac{ACH}{3600} \cdot d_{cavity} \cdot (c_{out} - c_{cavity})$$

Q_m:	moisture source strength [kg/m²s]
c_{out}:	water vapor concentration of the outdoor air [kg/m³]
c_{cavity}:	water vapor concentration of the cavity air [kg/m³] (mean value of all involved grid elements)
	The water vapor concentrations are determined from the respective air temperatures and relative humidities.

Next dialog: Orientation / Inclination / Height

Go to Overview of WUFI's Dialog Structure
Go to Contents

Dialog: Orientation / Inclination / Height

This dialog panel serves to define the orientation, inclination and positioning of the building component.

These specifications are necessary if the boundary conditions acting on the **left** side of the component are being read from a file of *.WET, *.TRY, *.DAT, *.WAC, *.IWC or *.WBC type. In all other cases solar radiation and rain either do not occur, or they have already been converted for the orientation and inclination in question. The dialog is then deactivated.

The **orientation (1)** is the compass direction towards which the building component is facing. It is needed for calculating the rain and radiation loads incident on the surface.

You can choose between eight predefined directions:

N – NE – E – SE – S – SW – W - NW

Enter the orientation by clicking on the compass display or by selecting it from the drop-down list.

Version notice: WUFI light and WUFI ORNL/IBP are restricted to the four cardinal directions.

DialogOrientierung
$ Dialog: Orientation / Inclination / Height
+ 5080
K   orientation;inclination;height;positioning;compass   direction;rain   coefficients;rain load;driving rain load;radiation load

The **inclination (2)** is the angle at which the surface is tilted with respect to the horizontal. It is needed for calculating the rain and radiation loads incident on the surface.

You can enter arbitrary inclinations between 90° (wall) and 0° (flat roof) by
- dragging the building component symbolized in the graphical display to the desired inclination,
- entering the inclination into the text box,
- entering the inclination by means of the spin control next to the text box.

Version notice: WUFI light and WUFI ORNL/IBP only allow the inclinations 0° and 90°.

The **driving rain coefficients (3)** are used to estimate the driving rain load on the building component. The rain load on a wall is determined by the driving rain rather than the normal rain. Two different methods are offered by WUFI:

- The **driving rain coefficients R1 and R2** serve to estimate the driving rain load on a surface of arbitrary orientation and inclination from data on normal rain, wind velocity and mean wind direction, using the relation

    Driving rain load = rain · (R1 + R2 · wind velocity),

  where 'rain' is the normal rain and 'wind velocity' is that component of the mean wind velocity (measured at a height of 10 m, in open area), which is orthogonal to the building surface. This component is determined from the mean wind velocity and the mean wind direction. The data on normal rain, wind velocity and wind direction are read from the selected weather file.

  R1 and R2 are strongly dependent on the specific location on the building facade. For vertical surfaces, R1 is zero. R2 is about 0.2 s/m for free-standing locations without influence from surrounding buildings etc.; it is markedly less in the center of a facade (e.g. 0.07 s/m); it may even be greater at exposed locations of a building (near edges and corners).

  If you have selected an inclination of 90° for your component, WUFI offers you a few predefined rain coefficients: one for a low building and three for different **height**s on a tall building. Advanced 3-D computational fluid dynamics simulations of droplet flow have been used by [Karagiozis and Hadjisophocleous, 1997] to determine these coefficients. Select the coefficients by clicking on the graphical building symbols or by choosing them from the drop-down list.

  Of course, you can also enter arbitrary rain coefficients in the text boxes. In particular, you can use experimental values that have been measured for a specific location.

  If you have selected another inclination than 90°, the situation becomes too complex to be cast into a simple multiple-choice option list. In this case WUFI defaults to the rain coefficients R1=1 and R2=0 (i.e. rain load = normal rain). It is then up to you to determine and enter appropriate rain coefficients.

- Alternatively, the driving rain load on a vertical wall can be estimated with the method of **ASHRAE Standard 160P** "Design Criteria for Moisture Control in Buildings" (Draft July 2006):

This method uses the relation

Driving rain load = rain · F_E · F_D · 0.2 s/m · wind speed,

where 'rain' is the rainfall intensity on a horizontal surface in mm/h and 'wind speed' is that component of the mean wind velocity (measured at a height of 10 m, in open area), which is orthogonal to the building surface. This component is determined from the mean wind velocity and the mean wind direction.

The value 0.2 s/m is an empirical constant. The **rain exposure factor F_E** depends on the surrounding terrain and the height of the building. ASHRAE Standard 160P recommends the following values:

Terrain:	open	medium	sheltered
Height < 10 m:	1.3	1.0	0.7
10 - 15 m:	1.3	1.1	0.8
15 - 20 m:	1.4	1.2	0.9
20 - 30 m:	1.5	1.3	1.1
30 - 40 m:	1.5	1.4	1.2
40 - 50 m:	1.5	1.5	1.3
>50 m:	1.5	1.5	1.5

Open exposure also includes hilltops, coastal areas and funneled wind (e.g. from tall buildings nearby). Sheltered exposure includes shelter from trees, nearby buildings, or a valley.

The **rain deposition factor F_D** describes the influences of the building itself. ASHRAE Standard 160P prescribes the following estimated values:

Walls on a pitched roof building:	F_D = 0.5
Walls on a flat roof building:	F_D = 1
Walls subject to rain runoff:	F_D = 2

Rain runoff onto walls may occur from roofs or impermeable surfaces, such as windows.

Note: Since most component surfaces - with the exception of unrendered masonry and natural stone facades - only have a moderate water absorption, they cannot imbibe all the offered water anyway. In these cases, an exact knowledge of the driving rain quantity is not essential (whereas the *duration* of the rain is still important) and fairly plausible estimates for the driving rain load are usually sufficient (the same is true for the rain water absorption factor).

Version notice: in WUFI light and WUFI ORNL/IBP no user-defined driving rain

coefficients R1 and R2 can be entered. In WUFI light the driving rain load estimate according to ASHRAE Standard 160P is not available, in WUFI ORNL/IBP it can only be used with predefined parameters.

Dialog: Surface Transfer Coefficients

The surface transfer coefficients indicate to which extent the conditions in the surroundings affect the building component, especially the heat and moisture flows through its surfaces.

WUFI uses the following surface transfer coefficients:

"Exterior surface":

- The **"Heat Resistance [m²K/W]"** (the reciprocal of the heat transfer coefficient [W/m²K]),
  which governs the convective and (long-wave) radiative heat exchange between the component and the surroundings.

  You can select between a constant coefficient (which is sufficient for most cases) and a wind-dependent coefficient.

  If you have activated the option **"wind-dependent"**, WUFI determines the heat transfer coefficient as follows, in dependence of the format of the selected climate file:

  ° **TRY** and **IWC** format:

    If the inclination of the component is greater than 10° and the surface of the component is facing away from the mean wind direction (i.e. leeward

---

conditions):

$\alpha = 0.33 * v\_wind + 4.5 + 6.5$ [W/m²K].

Else (windward conditions):

$\alpha = 1.6 * v\_wind + 4.5 + 6.5$ [W/m²K].

4.5 W/m²K is the convective heat transfer coefficient for v_wind = 0 m/s and 6.5 W/m²K ist the radiative component.

° **DAT format:**

Same method as with TRY, but DAT files may also indicate variable wind (wind direction "999"). In this case, the average of leeward and windward conditions is used.

° **WET format:**

Instead of a general mean wind direction, the WET format offers detailed information about the frequency of different wind directions during the hourly measurement interval.

If the inclination of the component is less than 10° (i.e. permanent windward conditions):

$\alpha = 1.6 * v\_wind + 4.5 + 6.5$ [W/m²K].

Else:

$\alpha = $ weight_windward * (1.6 * v_wind + 4.5 + 6.5) + weight_leeward * (0.33 * v_wind + 4.5 + 6.5) [W/m²K].

The weighting factor weight_windward is the sum of the components of the measured wind directions perpendicular to the component surface and weighted according to their duration.
Weight_leeward is (1 – weight_windward).

4.5 W/m²K is the convective heat transfer coefficient for v_wind = 0 m/s and 6.5 W/m²K ist the radiative component.

° **WAC and WBC Format:**

Same method as with TRY if the file contains wind direction and wind speed (scalar or vectorial). Otherwise, no wind-dependent heat transfer coefficient can be determined, and WUFI simply uses the value in the text box.

° **KLI format:**

This format does not contain any information about wind speed or direction, so that no wind-dependent heat transfer coefficient can be determined, and WUFI simply uses the value in the text box.

The heat transfer resistance is the reciprocal of the heat transfer coefficients determined in these ways.

Note: the resulting values of the heat resistance over time can be output as an ASCII export or as a curve in the result graphs. This allows you to access the values determined by WUFI.

"includes long-wave radiation part":
With this checkbox you can tell WUFI whether the user-defined heat resistance you entered contains a component due to long-wave radiation or not. All the predefined values in the drop-down list contain such a component.
This option becomes relevant if you want to do a computation with full long-wave radiation balance (otherwise, it is not enabled). For details please refer to the help topic Long-Wave Radiation Exchange.

- The **"S$_d$-value [m]"**,
of any paint coats, wallpapers, vapor retarders etc. (if present) which allows to account for their diffusion-retarding effect without the need to explicitly include these very thin layers in the component assembly.
If there is no such coating on your building component, or any coating has been included in the assembly as a separate layer, select "No coating".
The normal water vapour transfer resistance which is due to the boundary air layer is always automatically allowed for by WUFI and need not be included in the sd-value.
Please refer to the on-line help topic Details / Surface Coatings for further details on the use of this option.

- The **"Short-Wave Radiation Absorptivity [-]"**,
which determines the fraction of total incident (short-wave) solar radiation that is absorbed by the component.

- The **"Long-Wave Radiation Emissivity [-]"**,
which describes the efficiency of long-wave emission.

In building physics, the long-wave radiation exchange between the component and its surroundings is usually accounted for by appropriately increasing the heat transfer coefficient. This is accurate enough for most applications, only details like nighttime radiative cooling and subsequent dew deposition and mold growth risk cannot be handled this way.
If you can do without nighttime cooling, we recommend to set the long-wave emissivity to zero.
Otherwise, enter the emissivity of the component's surface. But then you must make sure that WUFI is working in the appropriate calculation mode and that you are using appropriate weather data (including, in particular, data on the long-wave radiation exchange). For details, see the topic Long-wave Radiation Exchange. Because of the relatively large amounts of energy involved in the long-wave exchange, insufficient attention to these details may produce inaccurate results.

If you want WUFI to work in the calculation mode with explicit radiation balance, you can **enable** this mode here and set some parameters:

"Ground Short-Wave Reflectivity": gives the fraction of short-wave global radiation reflected by the terrestrial surroundings. Needed for the radiation conversion for inclined surfaces.

"Ground Long-Wave emissivity": gives the effective emissivity of the terrestrial surroundings. Needed for computing the thermal emission of the surroundings.

"Ground Long-Wave Reflectivity": gives the effective reflectivity of the terrestrial surroundings. Needed for computing the fraction of atmospheric counterradiation which is reflected by the surroundings.

"Cloud index": gives the fraction of sky which is covered with clouds. Allows estimating the atmospheric counterradiation if no measured data are available.

For further details on these parameters, please refer to the topic Long-Wave Radiation Exchange.

- The **"Rain Water Absorption Factor [-]"**,
  which takes into account that some of the rain water hitting the wall surface splashes off on impact and is not available for capillary absorption. For ordinary walls, WUFI uses a value of 0.7, which is adequate for most cases. You may select "No absorption", however, if the facade is protected from rain and no rain absorption shall take place at all.

"Interior Surface":

- The **"Heat Resistance [m²K/W]"** (the reciprocal of the heat transfer coefficient [W/m²K]),
  which governs the convective and (long-wave) radiative heat exchange between the component and the surroundings.

- The **"S$_d$-Value [m]"**,
  of any paint coats, wallpapers, vapor retarders etc. (if present) which allows to account for their diffusion-retarding effect without the need to explicitly include these layers in the component assembly.
  If there is no such coating on your building component, or any coating has been included in the assembly as a separate layer, select "No coating".
  The normal water vapour transfer resistance which is due to the boundary air layer is always automatically allowed for by WUFI and need not be included in the sd-value.
  Please refer to the on-line help topic Details / Surface Coatings for further details on the use of this option.

For all of these coefficients WUFI offers you predefined values which you can select from a drop-down list. You may enter user-defined values as well.
The type of building element selected for the exterior heat resistance also determines the interior heat resistance and the rain water absorption factor.
Version notice: user-defined values can be entered in WUFI Pro only.

The use of the heat resistance instead of the heat transfer coefficient reflects recent changes of nomenclature in relevant standards.

Next dialog: Initial Conditions

Dialog: Initial Conditions

In this dialog the initial temperature and moisture distributions are defined (e.g. a dry component or one with trapped construction moisture).

You can specify
- a **constant initial relative humidity** across the component
  or
- different **initial water contents** for different **layers**
  or
- an arbitrary initial moisture profile, i.e. different **initial water contents** for different **grid elements**,

- a **constant initial temperature** across the component
  or
- an arbitrary initial temperature profile, i.e. different **initial temperatures** for different **grid elements**.

"Constant Across Component":

For **"Initial Moisture in Component"** you can enter the desired value of the **initial relative humidity** in the text box (e.g. 0.8 for a practical moisture content corresponding to the equilibrium moisture at 80% RH). WUFI then initialises the individual layers with a **"Water Content"** which it calculates from the entered RH, using the moisture storage function of the corresponding materials.

Note that this may result in different water contents in the different layers, as dependent on the different moisture storage functions. However, this is a quite realistic initial condition, since it is the *relative humidity* which tends to assume a constant level across different layers in equilibrium, not the *water content* (this is because the relative humidity is uniquely related to the capillary pressure which tries to equilibrate).

The resulting water contents are displayed in the assembly table in the lower half of the dialog, but they can not be edited in the table.

For **"Initial Temperature in Component"** you can enter the desired value in the text box. All grid elements of the temperature field will be initialised with this value at the start of the calculation. Such a constant temperature profile will be adequate for most cases occurring in building physics since the temperature profile adapts to the prevailing boundary conditions in a few hours anyway.

Version notice: user-defined initial values can be entered in WUFI Pro only.

"In each Layer":

For **"Initial Moisture in Component"** you can enter an individual **"Water Content"** for each layer of the assembly. Edit the relevant text boxes of the assembly table in the lower half of the dialog. This option is particularly useful for specifying construction moisture contents for the different layers.

If you have specified a **"Typical Built-In Moisture"** for the materials in the Material Data Dialog, just press the button **"Assign Typical Built-In Moisture"** in order to fill the text boxes with the respective values.

For **"Initial Temperature in Component"** there is no such option, since the temperature profile adapts to the prevailing boundary conditions in a few hours anyway and there is no point in specifying a step-like profile which is too crude for

any physical purpose on the one hand and dissipates within a few hours on the other hand. If you want to employ a more sophisticated initial profile than a constant temperature, use the next option.

Version notice: the option "In each Layer" is only available in WUFI Pro.

"Read from File":

In this case WUFI reads the **"Initial Moisture in Component"** from a file which contains the desired initial moisture profile (e.g. as measured or computed in an earlier WUFI run).

Enter the filename into the text box or open a **"File"** list from which you can select the file.

At the start of the calculation, WUFI then reads the initial moisture profile from the specified ASCII file. This file must consist of two columns. The first column contains the x-coordinates in meters, the second column, the corresponding moisture contents in kg/m³.

Example:

        0.0010   14.6
        0.0022   14.8
        0.0036   14.9
        ...   ...

The x-coordinates need not be equidistant and need not be identical with the x-coordinates of the grid elements. WUFI evaluates the moisture content of an element by linear interpolation if necessary.

This option also allows you to continue one calculation with another calculation. Write the last calculated moisture profile to an ASCII file and use it as the initialisation file for the next calculation.

For the **"Initial Temperature in Component"** you may specify an initial profile in exactly the same way as for the initial moisture.

Version notice: the option "Read from File" is only available in WUFI Pro.

Dialog: Initial Moisture
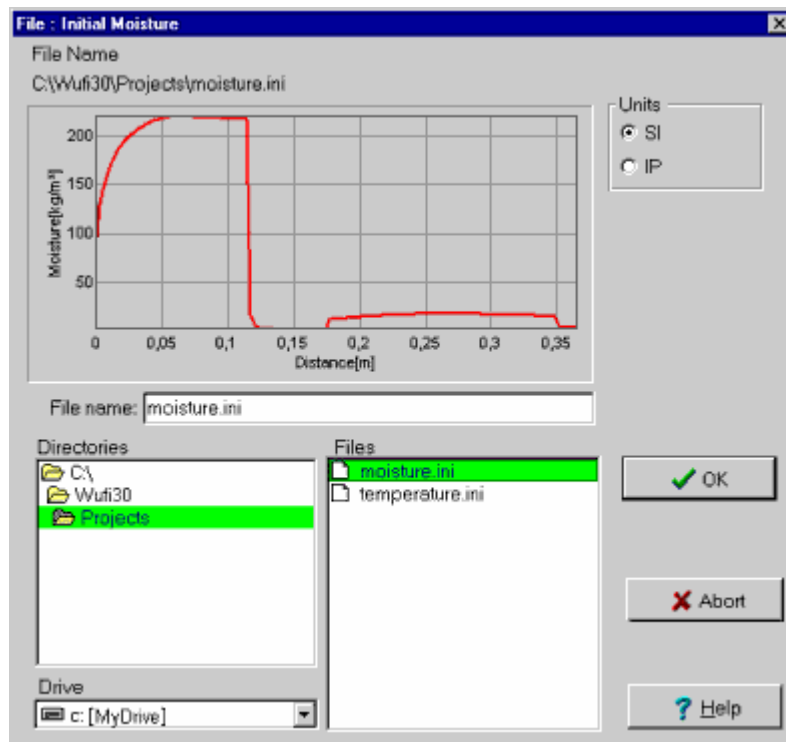
Use this dialog to search for ASCII files which describe the initial moisture profile of your building component.

As soon as you select one of the files in the **"Files"** list, WUFI reads that file and displays the profile, so you can confirm that this is the file you want.

Note: In this dialog WUFI only displays files with the extension *.INI. If you want to use files with a different extension, you can explicitly type in the path and filename in the "Initial Conditions" dialog.

Next Dialog: Initial Temperature

Go to Overview of WUFI's Dialog Structure
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Dialog: Initial Temperature

Use this dialog to search for ASCII files which describe the initial temperature profile of your building component.

As soon as you select one of the files in the **"Files"** list, WUFI reads that file and displays the profile, so you can confirm that this is the file you want.

Note: In this dialog WUFI only displays files with the extension *.INI. If you want to use files with a different extension, you can explicitly type in the path and filename in the "Initial Conditions" dialog.

Next Dialog: Calculation Period / Profiles

Go to Overview of WUFI's Dialog Structure
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DialogInitialTemperature
$ Dialog: Initial Temperature
+ 5120
K temperature (initial);INI

Dialog: Calculation Period / Profiles

Here you tell WUFI for which period of time the simulation shall be carried out (e.g. the simulation is to span one year, starting in early summer).

Enter the **"Start"** date and the **"End"** date in the table.
WUFI calculates the courses for the time interval between the starting and the ending date. For both dates, profiles are also output.
You can get additional profiles for intermediate dates by inserting these dates in the timetable (such as Profile 2 and Profile 3 in the above screenshot).

Most climate files represent typical climates and not individual years (e.g. "1995"). Therefore, any year number may be entered for the date.

If the calculation period extends beyond the end of the year, WUFI starts reading the same climate file again from the beginning.
If the calculation period spans more than one year, WUFI reads the same climate file repeatedly.

You may also enter the size of the **"Time Steps"** used by WUFI during the calculation. Basically, there are no restrictions on the size of the time steps, but please note that the time step cannot be larger than the climate data interval.

DialogZeit_Profile
$ Dialog: Calculation Period / Profiles
+ 5130
K calculation period;profiles;start date;end date;climate data;time step

If you are using hourly climate boundary conditions, a time step of one hour is sufficient. For moisture transport calculations in building physics, time steps between ca. 10 minutes and ca. 24 hours may be adequate, depending on the problem at hand. With smaller time steps, computing time increases markedly, with larger time steps, the results may become inaccurate.

The simplest choice is to set the time step for the calculation equal to the time intervals in the climate file. If you want to use a different time step, you should choose it so that it divides the climate time intervals exactly. Otherwise, WUFI adjusts each time step so that it *does* divide the current climate interval exactly. This is further discussed in "Details / The *.KLI Format for Climate Data".
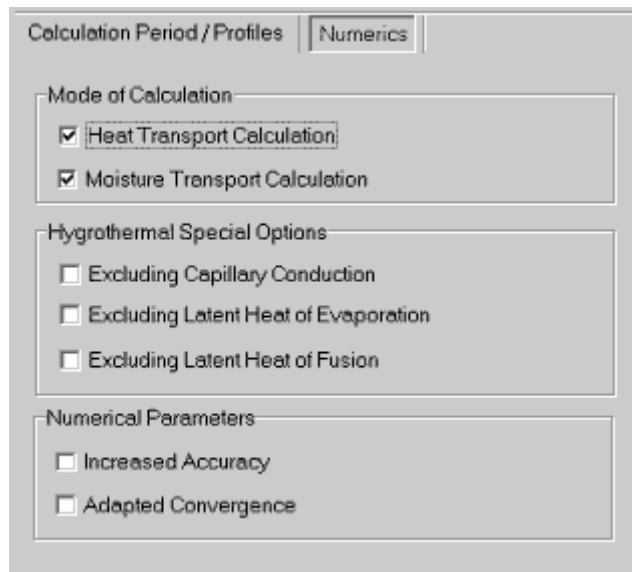
A general discussion regarding the choice of an appropriate time step size can be found in "Details / WUFI".

Version notice: Start and end of calculation and time step are user-editable only in WUFI Pro. Additional profiles are available only in WUFI Pro. In WUFI light and WUFI ORNL/IBP the calculation is restricted to two years.

Dialog: Numerics

The options offered by this dialog allow you to control the way the calculation is done.

"Mode of Calculation":

"Heat Transport Calculation"
"Moisture Transport Calculation":
Decide whether heat and/or moisture transport shall be allowed in the calculation.

In general, you will have activated both; an example for a case where it is useful to switch off moisture transport is the determination of the heat transmission coefficient of a building component with a complicated measured moisture profile:

To this end, write the moisture profile to a file *.INI, define it as the initial moisture content and switch off the moisture transport calculation in the present window "Control : Numerics" to keep the profile from dissolving.

Create a *.KLI file with a suitable constant temperature difference across the component, start the calculation and wait until steady-state conditions have been reached. After the calculation, obtain the heat transmission resistance from the resulting steady heat flow.

"Hygrothermal Special Options":

"Excluding Capillary Conduction":

DialogNumerics
$ Dialog: Numerics
+ 5140
K numerics;heat transport;moisture transport;capillary conduction;latent heat of evaporation;latent heat of fusion;increased accuracy;adapted convergence

Capillary conduction can be switched off separately; moisture transport is then only effected by vapour diffusion. Thus you can examine the contributions of both transport mechanisms to the total transport.

If the **"Moisture Transport Calculation"** has been deactivated altogether, there is of course no capillary conduction anyway, independent of this option.

"Excluding Latent Heat of Evaporation",
"Excluding Latent Heat of Fusion":
If you want to examine the importance of latent heat effects, you can switch them off and compare calculations with and without latent heat.

"Numerical Parameters":

"Increased Accuracy",
"Adapted Convergence":
If a calculation should suffer from numerical problems (recognisable by a great number of convergence failures or a bad water balance) and a revised grid can't solve the problems, you can try to improve the calculation with the help of these options. In general, increased accuracy is more effective than adapted convergence. With any of these options computing time increases, of course.

Before using these options, you should check if the numerical grid is well adapted to the problem at hand. These points are further discussed in the help topic for the dialog "Status of Last Calculation" and in "Details / WUFI".

Version notice: the numerical options are enabled only in WUFI Pro.

Next dialog: Climate

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Dialog: Climate

At its surfaces the building component is exposed to the **climatic boundary conditions** which have a profound effect on its hygrothermic behaviour. As discussed in Details / Climate data, WUFI needs for each time step data on the rain and radiation load, on the exterior and interior temperature and on the exterior and interior relative humidity.

A one-dimensional building component has a **left surface** and a **right surface**. Each of the two surfaces must be assigned its respective boundary conditions:

The boundary conditions may be given as hourly data read from a climate file (used as exterior climate) or as interior conditions derived from a climate file (used as interior climate) or as schematic yearly sine curves (used as exterior or interior climate).

The exterior and/or interior climates may be freely assigned to the left or right side of the component (so you might even have exterior climates on both sides or interior climates on both sides). The only **restriction** is: climate files that contain **rain and solar radiation** must be assigned to the **left side**.

Version notice: this interchangeability only applies to WUFI Pro. In WUFI light and WUFI ORNL/IBP the left side can only be assigned climate files and the right side can only be assigned sine curves.

"Map/File":

F_Climate
$ Dialog: Klima
+ 5150
K climate;climate data;climate file;weather;weather data;weather file;boundary conditions;exterior climate;interior climate;climate analysis;radiation rose;driving rain rose;DIN EN ISO 13788;prEN 15026;moisture load;humidity class;relative humidity;temperature;sine curve;rain;driving rain;radiation;solar radiation
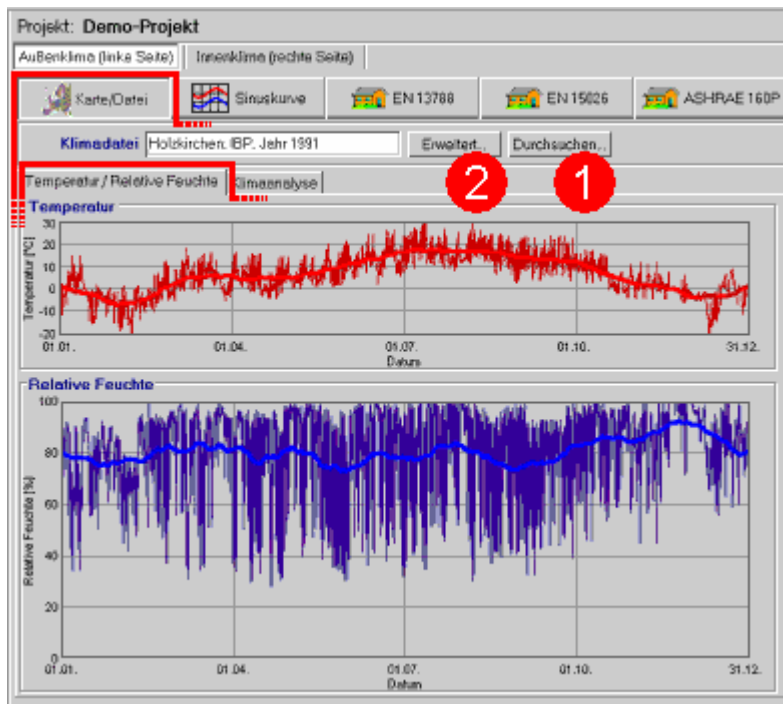
Choose this option if the boundary conditions are to be read from a **climate file**.
The button **"Browse..."** **(1)** opens a dialog in which you can select the desired climate file on a map or through a file open dialog.
The button **"Details..."** **(2)** opens a subdialog which offers additional options, depending on the climate file format (e.g. to use measured surface or ground temperatures etc.).

Once you have selected a climate file, WUFI will plot the temperature and the relative humidity. The thin curves show the data read from the climate file, the bold curves represent the centered moving monthly means for easier visual accessibility.

If you have assigned the climate file to the left side of the component (the one that can absorb rain and solar radiation) you may also have a **climate analysis** performed.
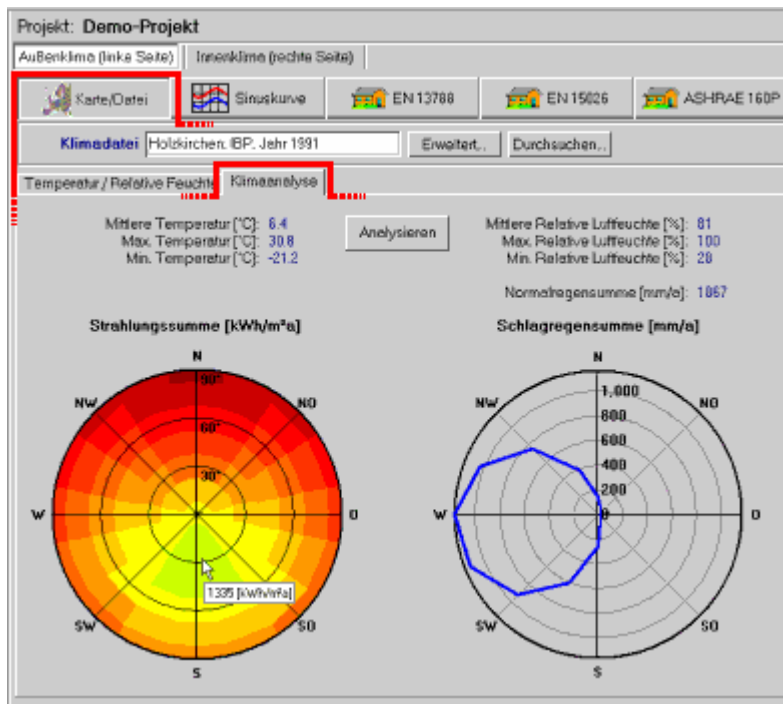
Click on the button **"Analyze"** to start the analysis. WUFI will display the minimum, maximum and mean values of temperature and relative humidity, the normal (i.e. vertical) rain sum and the directional distributions of solar radiation and driving rain:

The radiation rose shows the yearly sum of global radiation for receiving surfaces with different orientations and inclinations, the driving rain rose shows the yearly sum of driving rain on free-standing vertical surfaces (R2 = 0.2 s/m) with different orientations.

These data will give you an overview of the most important characteristics of the selected year. In particular, the radiation and rain roses show the directions from which the radiation and rain loads on the facade are mainly to be expected.

> ***.KLI** files can not be analyzed, since their radiation and rain data have already been converted for a fixed orientation and inclination.
>
> The analysis of ***.WET** files is independent of any options you may have selected in the **"Details..."** subdialog; that is, the temperature analysis always reads the air temperature from the file, the radiation analysis always reads the global and diffuse radiation on a horizontal surface and the driving rain analysis always reads the normal rain and the wind speed and direction.

If the boundary conditions assigned to the **left** side of the component are being read from a climate file of *.WET, *.TRY, *.DAT, *.WAC, *.IWC or *.WBC type, you also need to specify the orientation and inclination of the facade so that WUFI can convert rain and solar radiation for that direction. In all other cases either rain and radiation are irrelevant, or they have already been converted for the proper orientation and inclination (*.KLI).

Note: if a *.KLI file assigned to the right side of the component has a time step which is different from the time step of the climate on the left side (even if this is only due to rounding, e.g. 0.1667 h versus 0.167 h), there may be synchronisation problem between the two sides. In such a case you should let WUFI read the boundary conditions for both sides from *one* *.KLI file, if possible.

"Sine Curves":
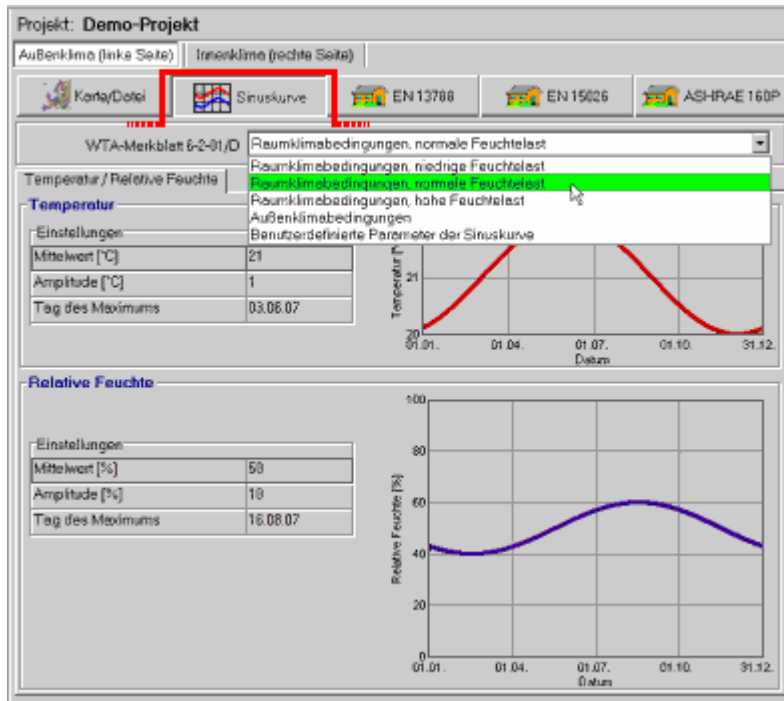
In some cases it is sufficient to ignore short-term fluctuations of the boundary conditions and to consider only their long-term (e.g. yearly) trend (this is only possible if the highly variable quantities rain and solar radiation play no role anyway). Temperature and relative humidity may then be modelled by simple **sine curves** with yearly period, or even by **constant** values.

These conditions are usually met by the **interior climate**: the daily variations of indoor temperature and humidity are strongly damped by the heat and sorption capacities of the furnishings; the remaining fluctuations do not penetrate far into the building components and only have a negligible effect on their hygrothermal behaviour. If the component is not affected by rain and solar radiation, and if its hygrothermal capacity is large enough, even the **exterior climate** may be modeled in this simplified way.

WUFI generates the **temperature** as a sine wave with one-year period from the yearly **mean value**, the **amplitude** and the **day of maximum** specified by the user.

The default values suggested for indoor conditions (mean temperature: 20°C, amplitude: 1°C) correspond to typical temperatures in residential homes, as determined by measurements [1].

The default values suggested for exterior conditions (mean temperature: 9°C, amplitude: 9°C) correspond to typical conditions in Germany [1].

Version notice: default values for exterior conditions are only available in WUFI Pro.

WUFI generates the **relative humidity** as a sine wave with one-year period from the yearly **mean value**, the **amplitude** and the **day of maximum** specified by the user.

The default values suggested for indoor conditions correspond to the average humidities in residential homes under low, normal and high moisture load [1].

The moisture load is the difference between the water vapor concentrations of the indoor and the outdoor air. It depends on the indoor moisture production and the air change rate.

$$\text{moisture load [g/m}^3\text{]} = \text{moisture production [g/m}^3\text{h]} / \text{air change rate [1/h]}.$$

The default values suggested for exterior conditions(mean value: 80%, amplitude: 8%) correspond to typical conditions in Germany [1].

If you wish to use other values than the defaults, choose **"User-Defined Sine Curve Parameters"** from the drop-down list and enter your values in the text boxes which can now be edited. If you want to simply use constant values, you may hide the text boxes for amplitude and day of maximum by checking the option **"constant"**.
Version notice: only WUFI Pro accepts user-defined sine parameters.

If this option is used for the boundary conditions on the **left** side of the component, no orientation and inclination needs to be specified, since there is neither rain nor solar radiation.

Literature:
[1] WTA-Merkblatt 6-2-01/D: Simulation wärme- und feuchtetechnischer Prozesse.

"EN 13788":
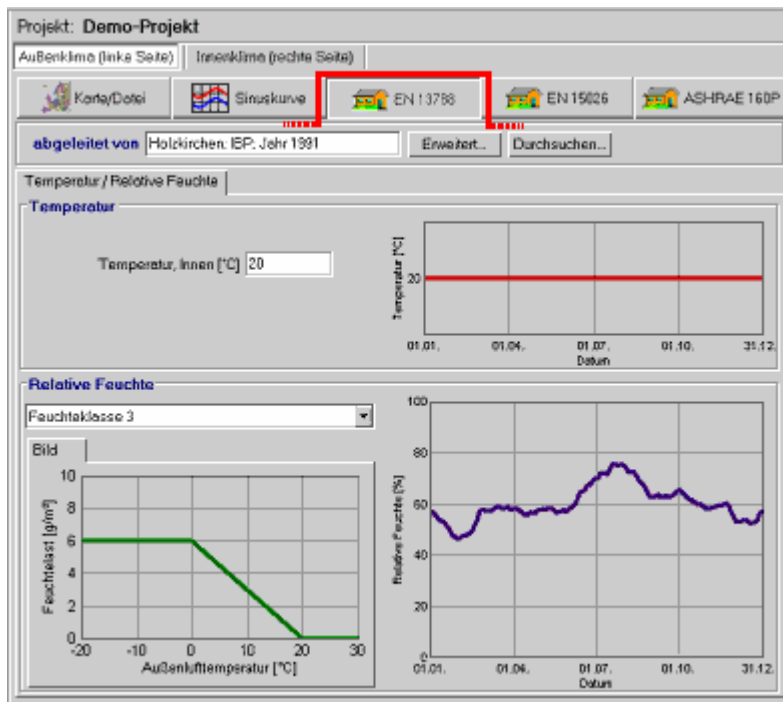
With this option you can derive the interior climate from the exterior climate, using the algorithm specified by **DIN EN ISO 13788**.

If this interior climate has been assigned to the right side of the component, and a climate file has already been assigned to the left side as the exterior climate, then you just need to check the option **"Use Left Climate"** to have the interior climate derived from that file; this will be the standard case:

Instead, you may also derive the interior climate not from the climate file assigned to the left side, but from some completely independent file. To do this, uncheck the option **"Use Left Climate"**, and select the desired climate file through the button **"Browse..."**. It is up to you to decide whether this makes sense or not.

If the interior climate to be derived has been assigned to the left side of the component, the climate file from which it is to be derived must always be explicitly specified via **"Browse..."**.

For the relative humidity, you may select one of four predefined **humidity classes** from the drop-down list. You may also specify your own moisture load function by selecting **"User-defined"** from the drop-down list: there appears a table where you can enter your values for the function.

Method of calculation:

The relative humidity for the interior climate is determined from the interior air temperature (held fixed) and the absolute humidity Ni of the interior air. For Ni, we have:

$Ni = Na + \delta N$

Ni: interior absolute humidity,
Na: exterior absolute humidity
δN: moisture supplement, determined from θa by means of the moisture load function Na.

$Na = \varphi a * absolute\text{-}humidity\text{-}at\text{-}saturation(\theta a)$

θa: monthly centered moving mean of exterior air temperature
φa: monthly centered moving mean of exterior relative humidity

If this option is used for the boundary conditions on the **left** side of the component, no orientation and inclination needs to be specified, since there is neither rain nor solar radiation.

Version notice: this option is only available in WUFI Pro.

"prEN 15026":
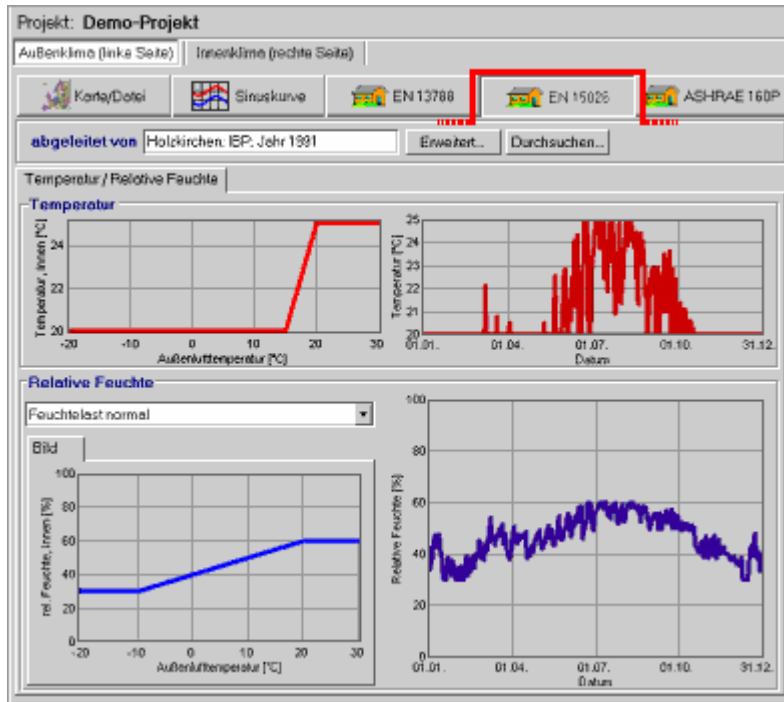
With this option you can derive the interior climate from the exterior climate, using the algorithm specified by **prEN 15026**.

If this interior climate has been assigned to the right side of the component, and a climate file has already been assigned to the left side as the exterior climate, then you just need to check the option **"Use Left Climate"** to have the interior climate derived from that file; this will be the standard case:

Instead, you may also derive the interior climate not from the climate file assigned to the left side, but from some completely independent file. To do this, uncheck the option **"Use Left Climate"**, and select the desired climate file through the button **"Browse..."**. It is up to you to decide whether this makes sense or not.

If the interior climate to be derived has been assigned to the left side of the component, the climate file from which it is to be derived must always be explicitly specified via **"Browse..."**.

The interior air temperature is determined from the exterior air temperature by means of a transfer function; the interior relative humidity is also determined from the exterior air temperature by means of a transfer function:

θi = temperature-function(θa),
φi = humidity-function(θa).

θi: interior air temperature,
φi: interior relative humidity,
θa: daily centered moving mean of the exterior air temperature

For the relative humidity, you may select one of two predefined **moisture load**s from the drop-down list ("normal" and "high").

If this option is used for the boundary conditions on the **left** side of the component, no orientation and inclination needs to be specified, since there is neither rain nor solar radiation.

Version notice: this option is only available in WUFI Pro.

"ASHRAE 160P"
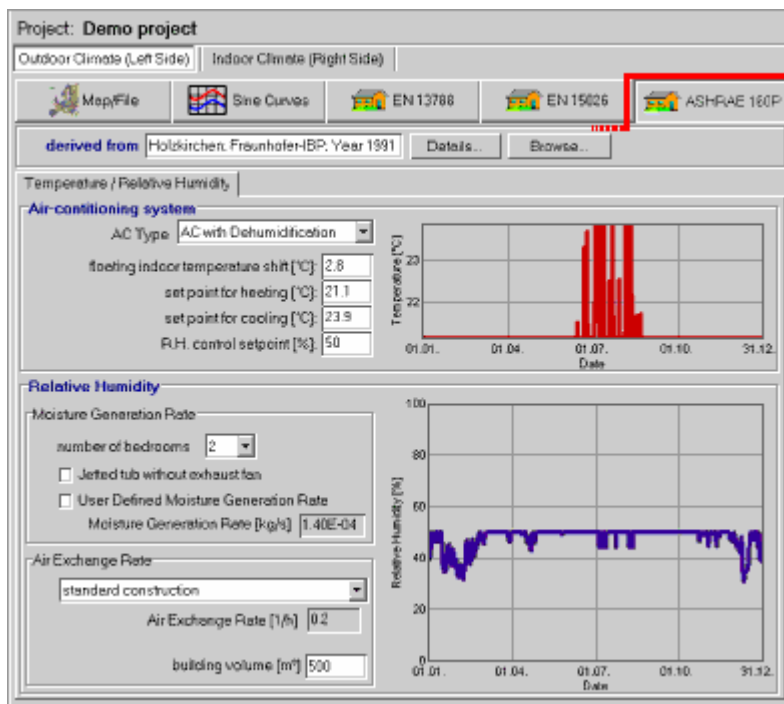
With this option you can derive the interior climate from the exterior climate, using the algorithm specified by **ASHRAE Standard 160P**.

For details please refer to: ASHRAE Standard 160P, "Design Criteria for Moisture Control in Buildings" (Draft July 2006). WUFI determines the indoor climate by the method illustrated in "Flowchart 3. Indoor design humidity, intermediate method".

Version notice: this option is not available in WUFI light. In WUFI ORNL/IBP only the predefined parameters can be used.

Next dialog: Select Climate File (Map)

Go to Overview of WUFI's Dialog Structure
Go to Contents

Dialog: Select Climate File (from map)
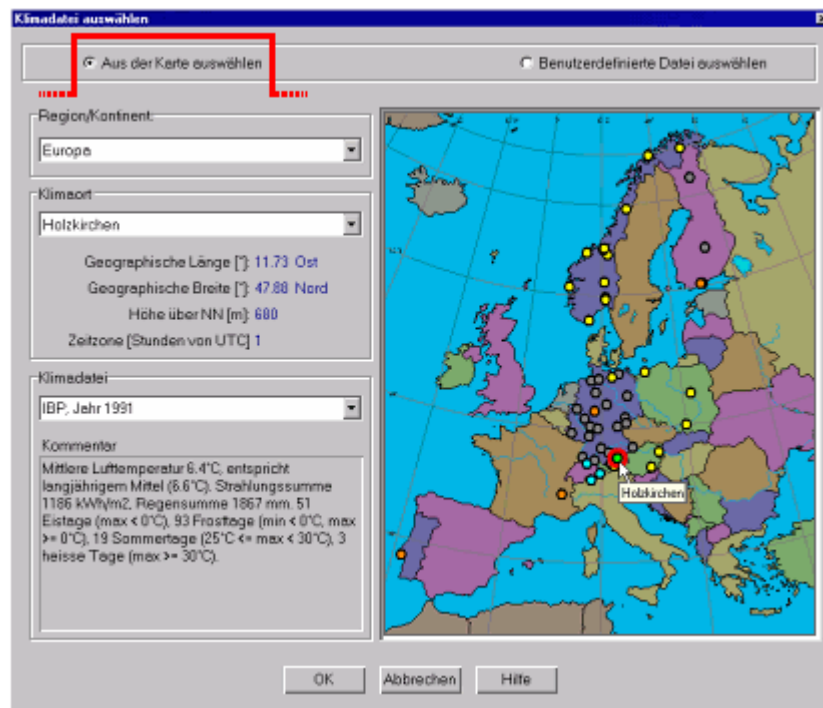
Those locations for which climate files are supplied with WUFI and some predefined locations for which climate files are available from other sources can be selected from this dialog's **maps** with a simple mouse click.
To select climate files created by yourself or acquired otherwise, please use the option **"Select user-defined file"**.

You may **zoom** into the maps by dragging open a zoom frame from upper left to lower right at the desired location. You may **pan** a zoomed map with the right mouse button held down. You may zoom out by dragging open a zoom frame from lower right to upper left.

"Region/Continent":

Select the desired map. Currently Europe, North America and Japan are available.

"Location":

This drop-down list contains all the locations on the map in alphabetic sequence and offers an alternative way of selecting a location.

F_ClimateFileSelectMap
$ Dialog: Select Climate File (Map)
+ 5160
K climate;weather;climate file;weather file;map

"Climate file",

If several files are available for a location (e.g. one warm and one cold year), you must select here the desired file.

"Remarks":

If comments or remarks are available for the selected file, they can be displayed here.

*

Currently, the following climate files are supplied with WUFI:
• Holzkirchen (1991),
• Kassel,
• Vienna, Graz, Innsbruck
• Zürich, Davos, Locarno (one 'warm' and one 'cold' year each),
• Warsaw, Krakow, Kolbrzeg
• Grenoble
• Lissabon
• Espoo (in the Finnish Pro version also Helsinki, Jyväskylä und Sodankylä)
• 12 Norwegian cities
• 55 US-American cities (the 10%-coldest and the 10%-warmest year selected from 30 years),
• 9 Canadian cities (some of them with one warm and one cold year)
• 7 Japanese cities.

Version notice: only WUFI Pro has all these files; WUFI light has a few of them, depending on the language; WUFI ORNL/IBP has the North-American cities.

The Holzkirchen weather data are supplied by IBP, other data are courtesy of Mr. William Seaton, ASHRAE (USA and Canada), Dr. K. Krec, Büro für Bauphysik (Austria), Dr. Ghazi Wakili, EMPA (Switzerland), Dr. W. Haupt, Uni GH Kassel (Kassel), CSTB (Grenoble), FEUP, Uni Porto (Lisbon), VTT (Finland) NBI/NTNU (Norway), TU Lodz (Poland) and the Architectural Institute of Japan (AMeDAS data for Japan).

The colors of the available locations indicate the file format of the respective weather files. Predefined locations for which weather data can be purchased separately are grey. Please copy such a file into WUFI's Climate folder; on the next start WUFI will recognize the file and display the location in color.
WUFI is prepared to read the Test Reference Years from the German Weather Service DWD, both the 'old' (Blümel et al., 1986, *.TRY; not offered any more by DWD) and the 'new' files (Christoffer et al., 2004, *.DAT).
There are also 842 predefined locations for Japan (depending on the WUFI version, data for one or seven locations are included with WUFI).
See Details / Sources for Climate Data for where to purchase such files.

The Holzkirchen climate file currently supplied with WUFI contains the measured data from 1991 which is considered typical for Holzkirchen. Future WUFI versions may come with two Hygrothermal Reference Years representing different stress situations for building components.

Next dialog: Select Climate File (File Browser)

Dialog: Select Climate File (File Browser)
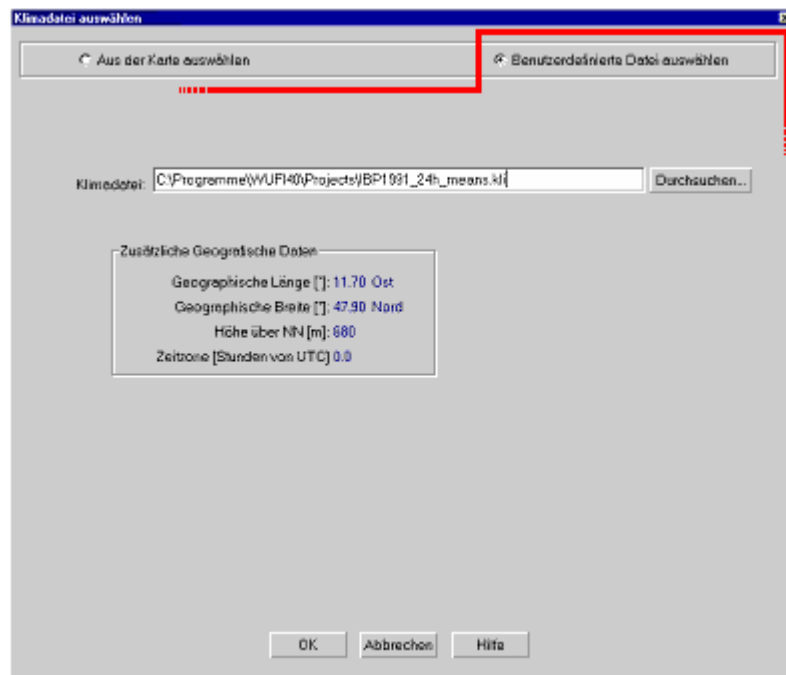
This dialog serves to select a user-defined climate file for the calculation. The files supplied with WUFI can be selected from maps.
Version note: this dialog is only available in WUFI Pro.

"Browse...":

This button opens a file dialog in which you can select the desired file.

"Additional Geographic Data":

To be able to convert the solar radiation data contained in the climate files for receiving surfaces at arbitrary orientation and inclination, WUFI needs to compute the position of the sun in the sky, and for this it must know the geographic coordinates and the time zone of the climate location.
Since most climate file formats do not contain these data, they must be provided by some other means. For the files supplied with WUFI they have been filed in the database. For each user-defined climate file the user must create an *.AGD file with the relevant supplementary data.

Note: We recommend to always specify the climate file with its full path. Otherwise ambiguities might arise, especially if the climate file is accompanied by an *.AGD file.

F_ClimateFileSelectFile
$ Dialog: Select Climate File (File Browser)
+ 5170
K climate;weather;climate file;weather file;AGD

Next dialog: Climate: Detailed Options

Dialog: Climate: Detailed Options

Some climate formats offer additional options:

*.WET files:
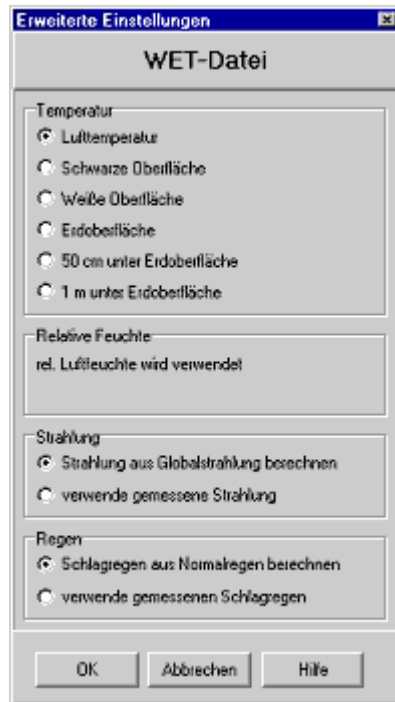
*.WET files can contain additional measured data that might be useful for a hygrothermic simulation:

"Temperature":

> *.WET files may contain several columns with measured temperatures. WUFI usually reads and uses the air temperature. However, it may optionally read and use surface temperatures of a white and a black facade or the ground temperatures at different depths.
>
> **"Black surface",**
> **"White surface":**

A *.WET file created for Holzkirchen contains the **measured surface temperatures** of a 'white' ($a_s \approx 0.4$) and a 'black' ($a_s \approx 0.9$) west-facing facade specimen modeled after an ETICS. If you want to expose your component to the same surface temperatures, select the respective option and set the heat transfer resistance for the exterior surface to zero. WUFI then reads the corresponding temperature from the file and uses it as the 'exterior air temperature' for the calculation; the vanishing heat transfer resistance takes care that the surface assumes the same temperature.

Using measured surface temperatures also requires proper treatment of other climate quantities:

"Relative humidity":
The relative humidity in the climate file is based on the temperature contained in the column 'Exterior air temperature'. If, instead, one of the surface temperatures is used as the 'air' temperature, this combination will result in wrong water vapor partial pressures at the component surface. The option **"Adjust relative humidity"** adjusts the relative humidity read from the file so that the correct partial pressures result at the surface.

"Radiation":
If the surface temperature of the component has been set to assume the measured surface temperature, **"No radiation"** must be used for the calculation, since the thermal effect of the solar radiation is already included in the measured temperature.

"Ground surface":

For calculating heat transport within the ground it may be helpful to use **measured ground surface temperatures** as boundary conditions. Select this option and set the heat transfer resistance for the exterior surface to zero. WUFI then reads the corresponding temperature from the file and uses it as the 'exterior air temperature' for the calculation; the vanishing heat transfer resistance takes care that the surface assumes the same temperature.
The ground surface temperatures recorded in Holzkirchen are measured a few centimeters below the actual surface.
Using measured ground surface temperatures also requires proper treatment of other climate quantities:

"Relative humidity":
The relative humidity in the climate file is based on the temperature contained in the column 'Exterior air temperature'. If, instead, the ground surface temperature is used as the 'air' temperature, this combination will result in wrong water vapor partial pressures at the component surface. The option **"Adjust relative humidity"** adjusts the relative humidity read from the file so that the correct partial pressures result at the surface.

"50 cm below ground surface",
"1 m below ground surface":

For the hygrothermal simulation of a component in contact with the ground (e.g. a cellar wall) it may be helpful to use **measured ground temperatures** as boundary conditions. Select the respective option and set the heat transfer resistance for the exterior surface to zero. WUFI then reads the corresponding temperature from the file and uses it as the 'exterior air temperature' for the calculation; the vanishing heat transfer resistance takes care that the surface assumes the same temperature.

If you want to allow for the thermal effect which the component has on the ground temperatures, insert a sufficiently thick layer of soil in front of the component and set the 'exterior surface' of this layer to the measured temperatures.

Using measured ground temperatures also requires proper treatment of other climate quantities:

"Relative humidity":
The soil usually has a fairly **"constant relative humidity"**; if plant cover is present, the humidity is at least about 99%, since otherwise the plants could not overcome the soil's hydraulic tension and were not able to draw water from the ground. For simulation of components in contact with the ground, WUFI therefore uses a constant relative humidity as boundary condition whose value you can enter according to your wishes.

"Radiation":
Since there is **"no radiation"** within the ground, the solar radiation data from the climate file are ignored.

"Rain":
Since there is **"no rain"** within the ground, the rain data from the climate file are ignored. If you want to simulate the uptake of (pressureless) ground water, it would be preferable to use an appropriately tailored *.KLI file.

"Relative humidity":

Depending on the selected temperature option (see above) it may be necessary to adjust the relative humidity for a different temperature level or to set it constant.

"Radiation":

Depending on the selected temperature option (see above) it may be necessary to suppress solar radiation.

Otherwise you have the option to bypass the usual conversion of solar radiation for the specific orientation and inclination of your facade, and to directly read and use radiation data measured on the facade (if available).

"Rain":

Depending on the selected temperature option (see above) it may be necessary

to suppress rain.

Otherwise you have the option to bypass the usual conversion from normal rain to driving rain and to directly read and use rain data measured on the facade (if available).
For this purpose, set the rain coefficients to R1=1 and R2=0.

Also, see Details / The *.WET Format for Climate Data for details.

*.KLI files:

*.KLI files contain data describing the **outdoor climate** (rain, radiation, air temperature, relative humidity) and data describing the **indoor climate** (air temperature, relative humidity). If you assign a *.KLI file to the left side of a component, WUFI usually reads the outdoor climate data from the file; if you assign a *.KLI file to the right side of a component, WUFI usually reads the indoor climate data. This dialog allows you to override these choices. Rain and radiation will then be ignored.

*.TRY, *.DAT, *.WAC, *.IWC, *.WBC files:

No options are available for these file types.

Next dialog: Run Calculation with Film

Go to Overview of WUFI's Dialog Structure
Go to Contents

Dialog: Run Calculation with Film
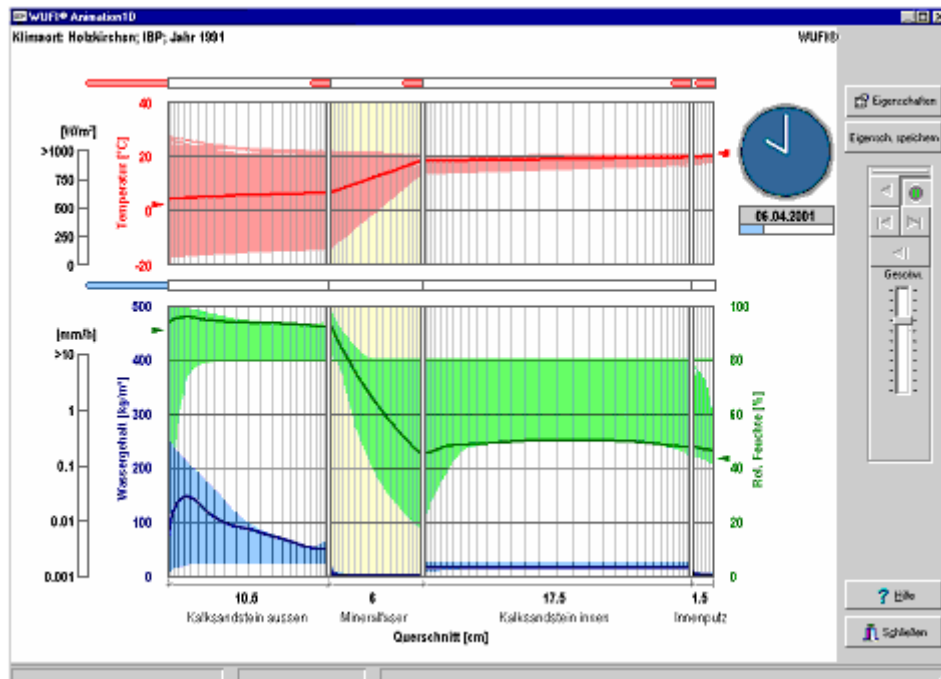
This full-screen dialog displays the results of the calculation, while in progress, in the form of a film showing the thermal and hygric processes in the building component as an animation.

Use the **control buttons** to

start the calculation,

pause and resume the calculation,

single-step through the calculation.

After the calculation has finished, you may view the film again: choose Outputs | View Film to start a film viewer which offers additional options for operation and analysis.

The **speed slider** allows you to slow the display down (for demonstration purposes). Drag the slider with the mouse or adjust it with the cursor keys or the

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F_Film
$ Dialog: Run Calculation with Film
+ 5190
K   calculation;simulation;film;start   calculation;pause   calculation;resume calculation;temperature;water   content;moisture   content;relative   humidity;vapor pressure;boundary   conditions;interior   climate;exterior   climate;solar radiation;rain;heat flux;moisture flux;heat flux density;moisture flux density;mass flux density;mass-percent

PageUp/PageDown or Home/End keys.
If the speed is set too high, the film viewer may start to skip 'frames'.

The **clock** and the **calendar** show you the current date the film display has reached.

In the left part of the screen, the temporal sequence of the hourly profiles of temperature, relative humidity / vapor pressure and water content is displayed as a **film**. The selection of the curves to be displayed, the adjustment of the axes and editing of other settings are done in a subdialog which can be reached by pressing the button "Properties".

The **temperature** (red) is displayed in a separate diagram.
Water content (blue) and **relative humidity / vapor pressure** (green) are displayed in the same diagram. The left Y-axis corresponds to the water content, the right Y-axis, to the relative humidity / vapor pressure.

You can **zoom** into the component by dragging open a zoom frame from upper left to lower right. To zoom out, drag open a zoom frame from lower right to upper left.
Point the cursor at one of the curves to see the **x-coordinate** and the **curve value displayed** in the status bar.

The current **boundary conditions** (air temperatures and relative humidities / vapor pressures) are indicated by red and green arrows, respectively, at the sides of the diagrams. The left climate may include radiation and rain whose intensities are displayed by the respective bar indicators.

Above the diagrams the **heat and moisture flows** across the two component surfaces and the inner material interfaces are indicated by arrows whose length depends on the strength of the respective flow (these arrows are further discussed in the online help for the subdialog "Properties").

Point the cursor at one of the arrows to see the **flux value displayed** in the status bar.

At the exterior surface, the heat flow indicated by the arrows includes the incident solar radiation,
> which is what the viewer intuitively expects in general. Note, however, that electromagnetic radiation is not really a heat flow, and in the Result Graphs only the proper heat flows are displayed. While incident solar radiation will create a large 'heat flow' arrow in the positive x-direction, what really happens is that the radiation is absorbed in the material and becomes converted to heat, most of which flows as a *proper* heat flow out of the component, in negative x-direction.
> This is further discussed in the Questions & Answers section.

The moisture flow is the sum of diffusion flow and capillary flow.

You can speed up the calculation by performing it without film. Choose "Run | Run Calculation" instead of "Run | Run Calculation with Film". WUFI then only displays a progress bar:
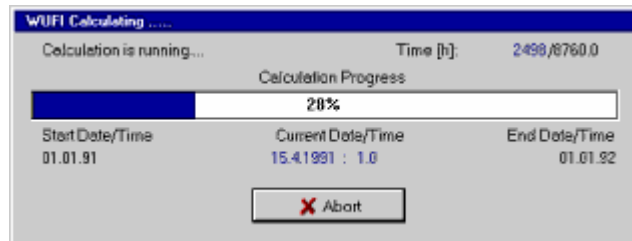
Next dialog: Film: Properties

Dialog: Film: Properties

This subdialog serves to customize the film display.

"General":
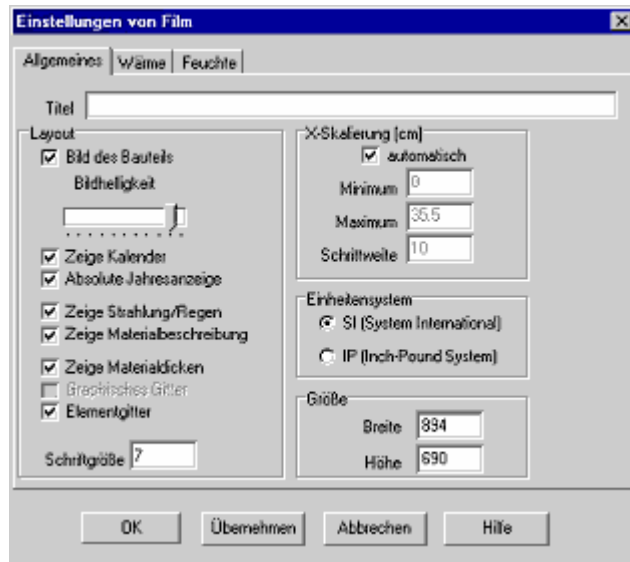
"Title":
  Enter a title that will be displayed above the component in the film.

"Layout":

  "Picture of component":
    Check this option to tint the graphical display of the component with the colors specified for the individual layers. The slide bar "Picture Lightness" adjusts the color saturation.

  "Show calendar":
    You may show or hide clock and calendar.

  "Display absolute years":
    Uncheck this option to display the years in the calendar as a relative count "1, 2, 3,...", even if you have entered specific years for the calculation period (e.g. from 2004 to 2012).

  "Show radiation/rain":
    Show or hide the bar indicators for solar radiation and rain.

  "Show layer description":
    Show the material name below each layer of the graphical component

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display, or hide it.

"Show layer thickness":
Show the layer thickness below each layer of the graphical component display, or hide it.

"Element grid":
Show or hide the numerical grid.

"Font size":
Adjust the size of the font used in the graphical display.

"X-Scale [cm]":
You may specify a scale for the x-axis or rely on WUFI's automatic scaling.

"Unit system":
You can switch between SI and IP units.

"Size":
You can specify the size of the film window in pixels.

"Heat":
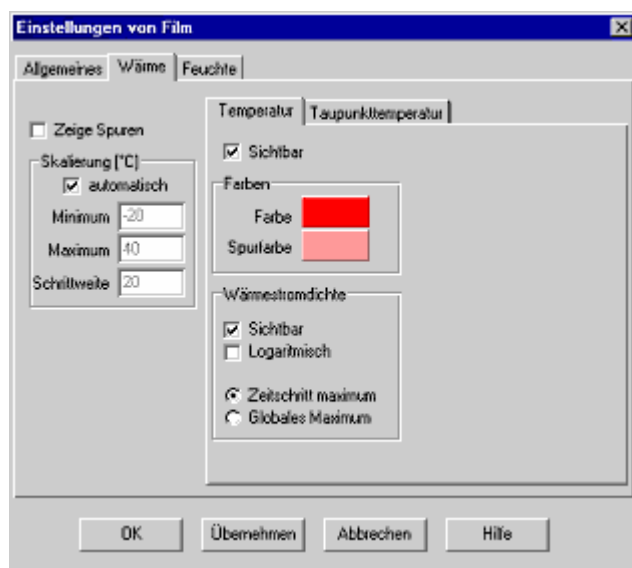
"Show traces":
Check this option in order to tint the area swept by the curves. This is useful for a quick overview of the extremal values that have occured at each loction of the component.

"Scale [°C]:"
You may specify a scale for the y-axis or rely on WUFI's automatic scaling.

"Temperature":

"Visible":
Switch display of the temperature curve on or off.

"Colors":

Select the colors for the temperature curve and its traces.

"Heat flux":

"Visible":
Switch the flux arrows above the graphical component display on or off.

"Logarithmic":
If the heat fluxes are very different, the linear display only shows the largest arrows. The logarithmic display softens the differences.

"Time step maximum",
"Global maximum":
Since the intensity of the fluxes within the component may vary over several orders of magnitude, it is not possible to predefine an all-purpose length scale for the flux arrows.

The option **"Time step maximum"** scales the maximum arrow length to the largest flux value occurring at the current time step (i.e. at every time step there is always at least one arrow that has maximum length).

The option **"Global maximum"** scales the maximum arrow length to the largest flux value that has occurred in the component so far.

The option "global" allows to compare fluxes at different times (unless occurrence of a new maximum flux requires a rescaling), but after a large flux has occurred, small fluxes may be displayed by such small arrows that they are hardly recognizable. The option "time step" always adapts the scale length to the current processes in the component.

"Dew point":
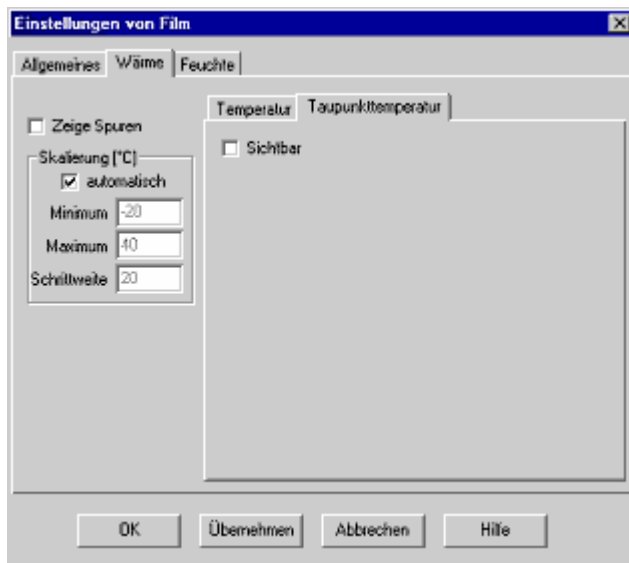
"Visible":
Switch display of the dew point curve on or off.

"Colors":

Select the colors for the dew point curve and its traces.
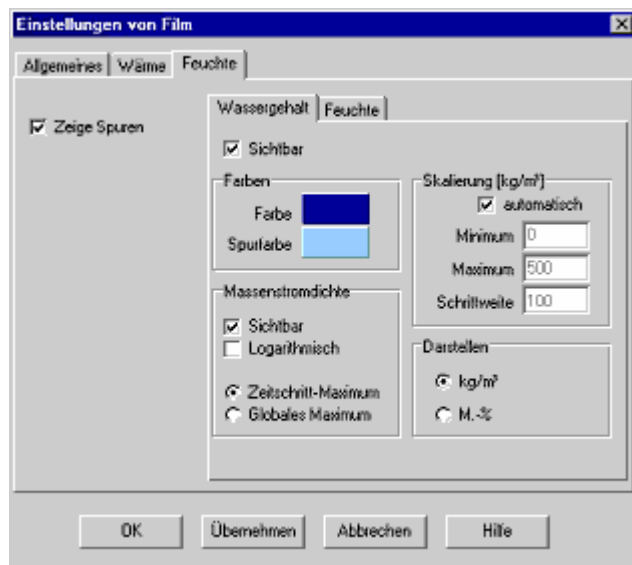
"Moisture":

"Show traces":
Check this option in order to tint the area swept by the curves. This is useful for a quick overview of the extremal values that have occured at each loction of the component.

"Water content":

  "Visible":
  Switch display of the water content curve on or off.

  "Colors":
  Select the colors for the water content curve and its traces.

  "Moisture flux":

    "Visible":
    Switch the flux arrows above the graphical component display on or off.

    "Logarithmic":
    If the moisture fluxes are very different, the linear display only shows the largest arrows. The logarithmic display softens the differences.

    "Time step maximum",
    "Global maximum":
    Since the intensity of the fluxes within the component may vary over several orders of magnitude, it is not possible to predefine an all-purpose length scale for the flux arrows.

    The option **"Time step maximum"** scales the maximum arrow length to the largest flux value occurring at the current time step (i.e. at every time step there is always at least one arrow that has maximum length).

The option **"Global maximum"** scales the maximum arrow length to the largest flux value that has occurred in the component so far.

The option "global" allows to compare fluxes at different times (unless occurrence of a new maximum flux requires a rescaling), but after a large flux has occurred, small fluxes may be displayed by such small arrows that they are hardly recognizable. The option "time step" always adapts the scale length to the current processes in the component.

"Scale [kg/m^3]":
You may specify a scale for the y-axis or rely on WUFI's automatic scaling.

"Display":
You can have the water content displayed in units of kg/m^3 or in mass-percent.

"Humidity":
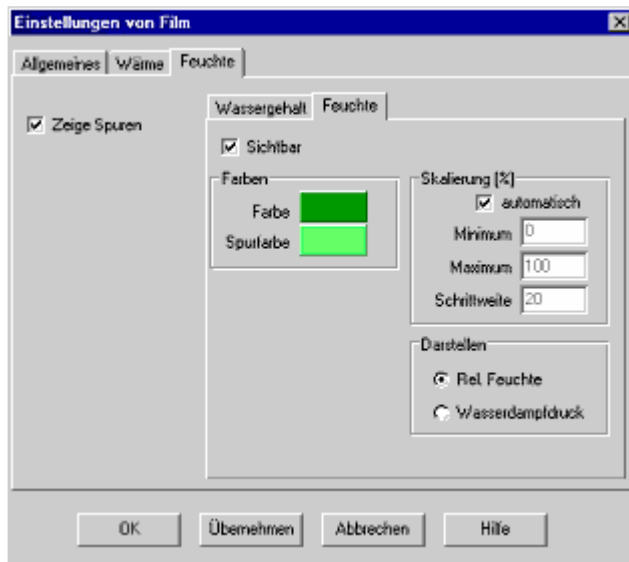
"Visible":
Switch display of the relative humidity curve on or off.

"Colors":
Select the colors for the relative humidity curve and its traces.

"Scale [%]":
You may specify a scale for the y-axis or rely on WUFI's automatic scaling.

"Display":
You can select either the relative humidity or the vapor pressure for display.

Next dialog: Quick Graph

Go to Overview of WUFI's Dialog Structure

Go to

Dialog: Quick Graph
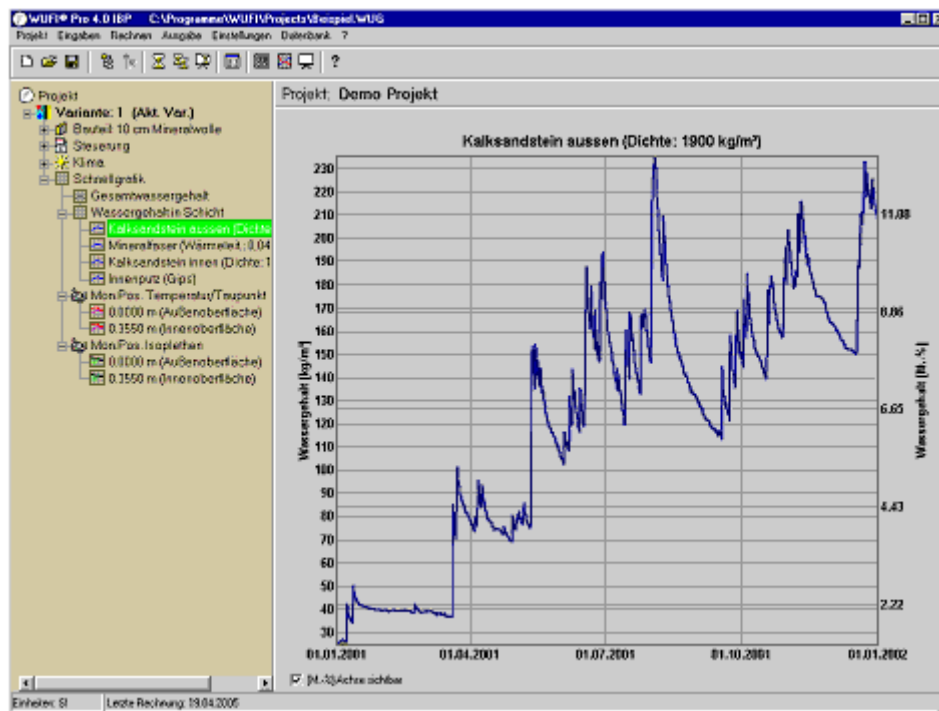
After the calculation you can access the quick graphs through the project explorer. These graphs give you a quick overview of the calculation results (as an alternative, the result graphs have nicer formatting and numerous configuration options, but they are slower).

You can **pan** a quick graph with the right mouse button held down.

You can **zoom** into a quick graph by dragging open a zoom frame from upper left to lower right at the desired location. You can zoom out by dragging open a zoom frame from lower right to upper left.

The right mouse button opens a pop-up menu:
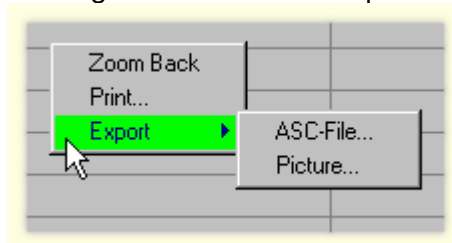
"Zoom back":
   Zoom out to the graph's original size.

"Print...":
  Print the graph.

"Export":
  Export the graph to an ASCII file or as a picture in bitmap or metafile format.
  Version notice: these export options are only available in WUFI Pro.

A specialty of the quick graphs are two graphs plotting the surface temperatures of each time step against the corresponding relative humidities:
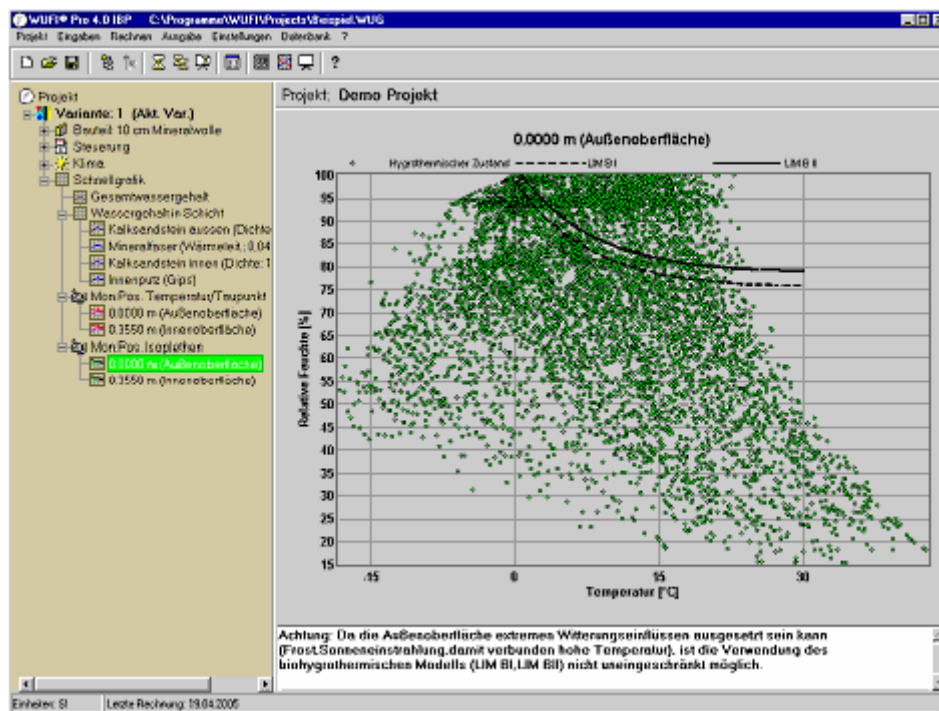
Each point in this graph represents the hygrothermal conditions at the left or right surface of the component at a certain time.

The graph also shows the **limiting isopleths** for building materials, LIM B I and LIM B II, below which no **mould growth** is usually to be expected [1]. If the conditions lie above the limiting isopleths for a longer period of time, mould growth may be possible, but additional criteria are needed for a firm assessment. In particular, this applies to the exterior surface where environmental conditions may very efficiently prevent mould growth (killing mould through high temperatures or UV exposure, washing spores off through rain etc.), although it would be possible according to the simple isopleth model.

This graph therefore allows a quick assessment whether mould growth is unlikely (conditions always below the corresponding LIM), or whether more detailed investigations are needed for a definitive evaluation (conditions above the corresponding LIM for longer periods of time).

LIM B I: bio-utilizable substrate, e.g. wall paper, plaster board; products made from easily degradable material, material for permanently elastic joints, etc.

LIM B II: substrates with porous structure, e.g. plasters, mineral building materials,

some woods, insulating materials not belonging to group I, etc. If strongly contaminated, these materials belong to group I.

Literature:
[1] Sedlbauer, K.: Vorhersage von Schimmelpilzbildung auf und in Bauteilen; Dissertation, Uni Stuttgart, 2001

Next dialog: Input Data Summary - Options

Dialog : Input Data Summary - Options

Use this dialog to select the data that shall be included in the "Input Data Summary".

"Available Outputs":
Select from this list the data to be included in the summary pages. Then use the "<" button to transfer the selected items to the "Selected Outputs" list.

"Selected Outputs":
The items contained in this list will be shown on the summary pages.
In order to remove an item, select it and transfer it to the "Available Outputs" list with the ">" button.
You may also change the order of the items by dragging them to the desired place in the list.

"Selected Material Data Sheets":
This list contains the different materials from the component assembly. Select the materials for which data sheets shall be shown in the summary (of course this requires that you have the "Material Data" selected for output).

"Standard":
Check this option to make the above selection permanent for the current project.

Version notice: these options are only available in WUFI Pro.

Next dialog: Status of Last Calculation

Go to Overview of WUFI's Dialog Structure
Go to Contents

DialogInputDataSummaryOptions
$ Dialog : Input Data Summary - Options
+ 5220
K Summary

Dialog: Status of Last Calculation
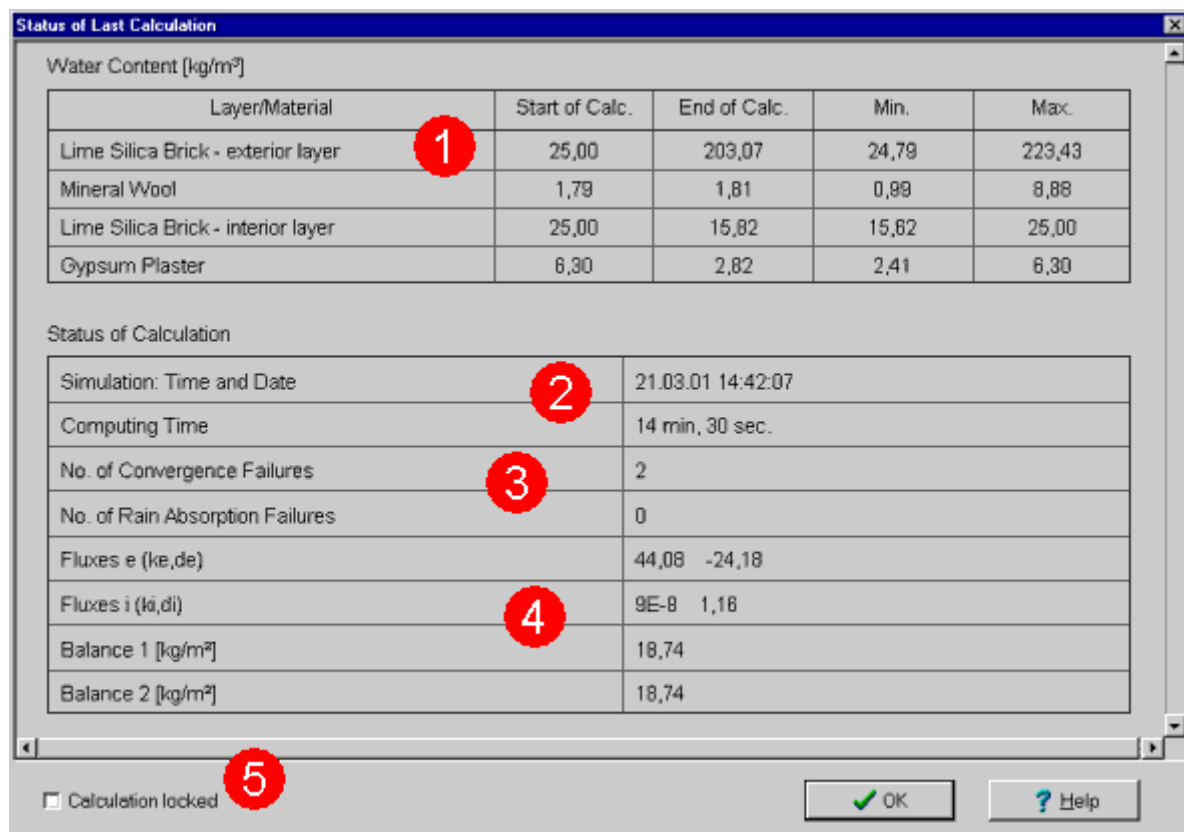
This dialog displays a short summary of the calculation results.

"Water Content" (1):

For each layer WUFI displays the initial water content, the final water content, and the minimum and maximum water contents that occurred during the calculation.
This allows you a quick first assessment of what happened to the component during the simulation (e.g., it dried out or accumulated water etc).

"Status of Calculation":

"Simulation: Time and Date" (2):

The time and date when the simulation was performed.

DialogStatusOfLastCalculation
$ Dialog: Status of Last Calculation
+ 5230
K status;water content;moisture content;computing time;convergence failure;rain absorption failure;water balance;balance;

"Computing Time" (2):

The time it took WUFI to perform the calculation.

"No. of Convergence Failures" (3):

WUFI uses an iterative method for the solution of the transport equations. Sometimes, the convergence is very slow and WUFI reaches the maximum allowed number of iterations without the interim solutions meeting the termination criteria.

In this case, the iteration is stopped and the convergence achieved so far compared to somewhat relaxed criteria. If these are met, WUFI accepts the results and continues with the next time step. If the criteria are not met, WUFI also accepts the result and continues with the calculation, but the number of convergence failures is increased by one.

The total number of convergence failures is a first hint concerning the reliability of the results. The fact that a convergence failure has been registered does not tell, however, how large the remaining error was when the iteration was stopped.

It is quite possible that the termination criteria were missed by a small margin only and the convergence failure is therefore irrelevant; this is usually the case.

Sometimes it is also possible, however, that a numerical instability has developed and the iteration steps drift farther and farther away from the real solution. Then the solution left by the aborted iterations is only a bad (in rare cases very bad) approximation for the solution of the transport equations. This often reveals itself by water appearing or disappearing in the middle of the component, without the boundary conditions having called for such behaviour. The results are sudden jumps in the course of the water content and a bad water balance (see below).

The criteria for a convergence failure have been adjusted to be very sensitive. Experience shows that in general a few convergence failures are harmless. If you have calculated over one year, one or two convergence failures are in general nothing to worry about.
Numerical instabilities, however, usually announce their arrival by a generally higher number of convergence failures. Fifty convergence failures per year are possibly (but not always) indicating a problem.

A better indicator for the quality of the results is the water balance (see below).

"No. of Rain Absorption Failures" (3):

WUFI uses an iterative method to determine the amount of water absorbed when rain hits the component surface,
because there may be less rain than the component can theoretically absorb during the time step. This limitation imposed by the amount of rain has to be allowed for, but the amount actually absorbed can only be determined iteratively; see question #16 in the Questions&Answers section).

It is possible although very rare that convergence is too slow and WUFI reaches the maximum allowed number of iterations without the interim solutions meeting the termination criteria.

In this case, the iteration is stopped, WUFI accepts the results and continues with the next time step, but the number of rain absorption failures is increased by one.

This is usually no reason to worry, since a rain absorption failure normally doesn't mean the result of the time step is terribly wrong, it only means that the termination criteria – which are somewhat arbitrary anyway – haven't been met. The result of the time step is usually well acceptable in view of all the simplifications and approximations that go into such a simulation model in the context of building physics.

"Fluxes e (ke, de)",
"Fluxes i (ki, di)" **(4)**:

    the total amount of water which flows into or out of the component during the calculation.

        ke   : by capillary transport at the exterior surface,
        de   : by vapour transport at the exterior surface,
        ki   : by capillary transport at the interior surface,
        di   : by vapour transport at the interior surface.(*)

        positive   : indoor direction (positive X-direction),
        negative : outdoor direction (negative X-direction).

These moisture flows serve to calculate the moisture balance (see below).

Please note: These are not the moisture flows *through* the surface, but the flows between the surface and the component. It may happen that water condenses at a cold surface in such amounts that the absorption capacity of the building material is surpassed and the water runs off at the surface. This run-off 'disappears' for the calculation, so that the amount of water arriving at the surface from the environment may not be identical to the amount entering into the component from the surface.

Therefore the above moisture flows are not evaluated at the surfaces but at the boundaries between the first and the second, and between the next-to-last and the last grid element. This has to be borne in mind if the above numbers are to be interpreted, especially if the first or last element has some appreciable thickness.

(*) It is also the reason why the above definition just vaguely says "at the surface" instead of "through the surface".

So do not wonder, for instance, if you get a non-zero capillary flow ki at the interior surface, although it certainly never rains there. This is a capillary flow closely (half an element) below the surface.

"Balance 1 [kg/m²]",
"Balance 2 [kg/m²]" (4):

   the change in 'total water content' during the calculation, and the sum of the 'surface flows' (ka+da-ki-di, see above).

   Ideally, these two numbers should be identical, since any change in the total water content must result from moisture being transported through the surfaces. Rounding errors and convergence problems may cause discrepancies, however.
   If the discrepancies become too large, you should repeat the calculation with appropriate modifications (see below).

   Please note: for the reasons discussed above, the first and the last grid element are not allowed for in the determination of this 'total water content' so that it is less than the total water content you get as the official result of the calculation. Therefore, the change in the 'total water content' may also slightly differ from what you infer from the official results, especially if the first or last element has some appreciable thickness.

   These numbers are only meant to provide a consistency check on the numerical calculation. Analyses of the water content and the surface flows should be done using the calculation results themselves only.

   If you get too many convergence failures or a bad water balance, you should check whether your choice of the numerical grid is indeed appropriate for the project at hand. A typical problem, for instance, are condensation phenomena at a layer boundary or at a surface, so that steep water content gradients occur which can not be represented adequately if the grid is too coarse at that location. You may need to use the fine grid option or to adapt the grid manually.

   This is further discussed in "Details / WUFI", in "Dialog: Assembly / Monitor Positions", in "Dialog : Numerics" and in the Questions & Answers section.

"Calculation locked" (5):

   If after a calculation you inadvertently restart it, the existing results are overwritten and lost. There is a security query, but if you want to avoid any risk, lock the calculation and save the project file once more (to make the lock permanent).

   This is especially advisable if the results of long and tedious calculations shall be demonstrated in a hectic atmosphere...

Next dialog: Result Graphs

Dialog: Result Graphs
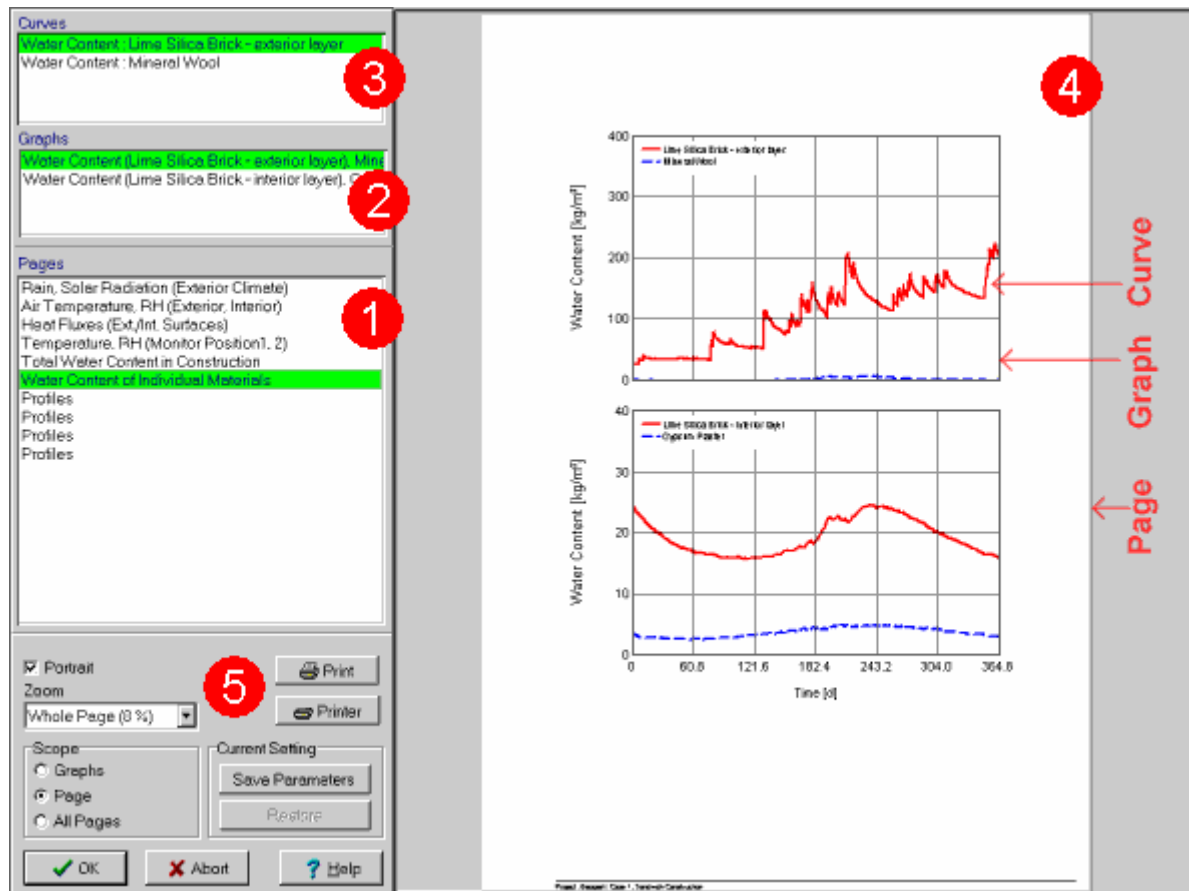
Of course, after the calculation you want to see the results. Besides the possibility to display a film, WUFI also offers the traditional display of the results as curves representing courses and profiles, formatted for printing.

You can view, edit and print graphics showing the calculated courses and profiles as well as the boundary conditions.

To this end, the graphics are assigned to several **pages** which hold one or several **graphs** each. Each graph displays one or several **curves**.

WUFI automatically assigns the most important curves to appropriate graphs and the graphs to appropriate pages (see below how to display other curves). So you don't need to do anything; just open the present dialog **"Result Graphs"** and view the individual results with a mouse click. You can choose from:

"Pages" (1):

DialogResultGraphs
$ Dialog: Result Graphs
+ 5240
K results;result graphs;film;courses;profiles;climate
data;pages;graphs;curves;scope;zoom factor;clipboard;meta file;EMF

This list shows all available pages.

Select the page you want to view or edit. WUFI immediately displays it in the right half of the screen **(4)**.

A double-click on a page name in the list opens the subdialog "Page Setup" where you can edit the name of the page.

A right-click anywhere in the page list opens a context menu which allows you to edit the content of the page list:
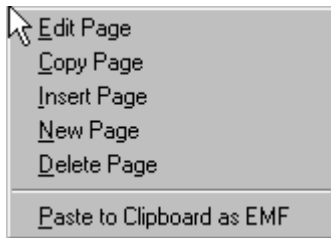
"Edit Page":

Opens the subdialog "Page Setup" where you can edit the name of the page.

"Copy Page":

Copies the highlighted page to an internal clipboard (not the Windows clipboard).

"Insert Page":

Inserts the page in the internal clipboard in front of the highlighted page. This allows you to change the order of the pages in the list, or to create a copy of a page.
Hint: In order to insert a page in the last place of the list, insert it before a temporary *new* page which will always be created at the end of the list.

"New Page":

Inserts an empty page at the end of the page list.

"Delete Page":

Deletes the highlighted page.

"Paste to Clipboard as EMF":

Copies the highlighted page or graph (depending on the "Scope" setting) to the Windows clipboard, in EMF (=Windows Enhanced Meta File) format. From there you can import it into any graphics editing program (such as Paintshop Pro, Photoshop etc).

Version notice: the editor functions are available in WUFI Pro only.

"Graphs" (2):

This list shows all the graphs on the selected page.

Select the graph you want to view or edit. WUFI immediately displays it in the right half of the screen **(4)** (if the "Scope" is one graph only, otherwise all graphs on the page will be displayed anyway).

A double-click on a graph name in the list or on the displayed graph **(4)** opens the subdialog (either "Graph Setup: Courses" or "Graph Setup: Profiles") where you can edit the settings of the graph.

A right-click anywhere in the graph list opens a context menu which allows you to edit the content of the graph list:
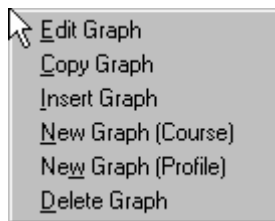
"Edit Graph:"

Opens the subdialog (either "Graph Setup: Courses" or "Graph Setup: Profiles") where you can edit the settings of the graph.

"Copy Graph":

Copies the highlighted graph to an internal clipboard (not the Windows clipboard).

"Insert Graph":

Inserts the graph in the internal clipboard in front of the highlighted graph. This allows you to change the order of the graphs in the list, to create a copy of a graph or to move a graph between pages.
Hint: In order to insert a graph in the last place of the list, insert it before a temporary *new* graph which will always be created at the end of the list.

"New Graph (Course)":
"New Graph (Profile)":

Inserts an empty graph at the end of the list. Choose the type of graph according to the type of the curves you want to display.

"Delete Graph":

Deletes the highlighted graph.

Version notice: the editor functions are available in WUFI Pro only.

"Curves" (3):

This list shows all the curves in the selected graph.

A double-click on a curve name in the list opens the subdialog "Curves Setup" where you can edit the settings of the curve.

A right-click anywhere in the curve list opens a context menu which allows you to edit the content of the curve list:
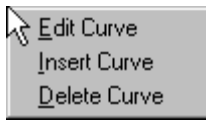
"Edit Curve:"

Opens the subdialog "Curves Setup" where you can edit the settings of the curve.

"Insert Curve":
Opens the subdialog "InsertCurves" from which you can select a curve for insertion into the curve list.

"Delete Curve":

Deletes the highlighted curve.

Version notice: the editor functions are available in WUFI Pro only.

"Portrait" (5):

Check this option to get the pages in portrait orientation; uncheck it to get them in landscape orientation.

"Zoom" (5):

Select the zoom factor of the displayed page (20% .. 200%. "Page Width" will use exactly the width of the display area **(4)**; "Whole Page" will use exactly the height of the display area **(4)**).

"Scope" (5):

Decide if WUFI is to draw one **graph** only or the whole **page**. The option **"All Pages"** applies to printer output only.

"Print" (5):

Press this button to print the current graph or page or all pages (depending on the "Scope" setting).

"Printer" (5):

Press this button to open a subdialog where you can edit the printer settings.

"Current Setting" (5):

> **"Save Parameters":**
>
> Saves the current graphics settings.
>
> For example, suppose you are doing several calculations in a row in order to perform a parameter study, and it is convenient to display the temperature at monitoring position #5 at an enlarged scale. After each calculation, WUFI switches back to the original settings and you would have to edit the scale of the diagram again and again. Saving the parameters with this button allows you to restore them quickly after a new calculation run.
>
> **"Restore":**
>
> Restores the previously saved graphics settings.
>
> Please note: this function expects that the output of the successive calculation runs is similar enough for the old settings to be meaningful. For example, if the saved settings contain temperature courses for 5 monitoring positions and in subsequent runs you only compute courses for 3 monitoring positions, then WUFI does not know what to do if you attempt to restore the graphics settings.
> So please be careful if you change major things between runs (like changes in the layer assembly, the monitoring positions etc.) and keep in mind in these cases that even if WUFI does restore the graphics settings, the "third curve in the second graph on page five" may represent something different now.

The following curves are displayed automatically:

- **Rain:**
  the driving rain load incident on the component surface, as dependent on the inclination and orientation of the component (and not yet multiplied by the rain water absorption factor)

- **Radiation:**
  ° Solar Radiation:
    the solar radiation incident on the component surface, as dependent on the inclination and orientation of the component (and not yet multiplied by the short-wave radiation absorptivity)
  ° Counterradiation:
    the sum of terrestrial and atmospheric counterradiation incident on the component surface, as dependent on the inclination of the component (and not yet multiplied by the long-wave radiation emissivity which determines the absorbed fraction of the incident radiation)
  ° Long-wave emission:
    the thermal radiation emitted by the component surface

- **Air Temperature:**
  the air temperatures on both sides of the component

- **Relative Humidity:**

the relative humidities of the air on both sides of the component

• **Heat Fluxes:**
the heat flux densities through both surfaces of the component

• **Moisture Fluxes:**
the moisture flux densities (liquid transport + vapor transport) through both surfaces of the component

• **Temperature, Relative Humidity (Monitoring Position xx):**
the variation in time of temperature and relative humidity at the monitoring positions

• **Water Content of Individual Materials:**
the water content of the individual material layers of the component (different layers which contain the same material are represented by different curves)

• **Total Water Content in Construction:**
the water content in the entire component,

as well as the profiles of **temperature**, **relative humidity** and **water content** for beginning and end of the calculation, and for further selected points in time, if any have been specified.

In addition, **further curves** can be displayed, such as the different radiation components, the variation in time of the heat transfer and vapor transfer coefficients, the heat and moisture fluxes between the layers, the source strengths of heat or moisture sources, the barometric pressure etc.
In order to display these curves, create a new page by right-clicking in the "Pages" list, create a new graph on that page by right-clicking on the "Graphs" list and a new curve in this graph by right-clicking on the "Curves" list. For the first curve assigned to the graph you can select the type of curve (e.g. temperature, moisture source etc.). A list will then display the available curves of this type for selection.

Next dialog: Page Setup

Go to Overview of WUFI's Dialog Structure
Go to Contents

Dialog: Page Setup
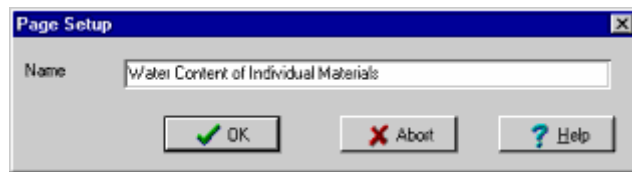
This dialog allows you to edit the name of the highlighted graphics page.

Version notice: the editor functions are available in WUFI Pro only.

Next dialog: Graph Setup, Courses

Go to Overview of WUFI's Dialog Structure
Go to Contents

DialogPageSetup
$ Dialog: Page Setup
+ 5250
K pages

Dialog: Graph Setup, Courses

Here you can edit the settings for a graph that displays courses:

"Name:"

The name of the graph as it appears in the graphs list.

"Position":

**"Top Margin [cm]",
"Left Margin [cm]":**

Enter the distance of the top left corner of the graph from the top or left edge, respectively, of an A4 page.

**"Height [cm]",
"Width [cm]":**

Enter the height and the width of the graph.

"Legend Box":

DialogGraphSetupCourses
$ Dialog: Graph Setup, Courses
+ 5260
K graphs;courses
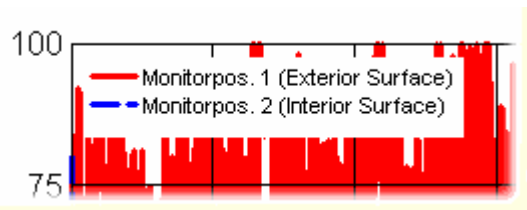
If several curves are in the same graph, they are identified by a legend (see "Dialog: Curves Setup"), which is written to a legend box, i.e. a white rectangular area in the graph which covers any curves or grid lines to prevent them from interfering with the legend text.

"X [cm]",
"Y [cm]":

Define the position of the top left corner of the legend box relative to the top left corner of the graph. The size of the legend box is automatically adjusted to accommodate the legend text.

"X-Axis (Time)":

"Start",
"End":

The starting date of the graphical display is identical with the starting date of the calculation, the ending date is obtained from the starting date and the number of calculated hours. If you have stopped the calculation prematurely, the ending date is earlier than the ending date for the calculation you entered in "Calculation Period / Profiles".

You can edit these dates if you only want to see part of the calculated courses.

"Unit":

Select the unit for the time axis. You can choose from hours, days and years.

"Start = 0":

By default, the time axis is labeled by a continuous time count in the specified units, starting with zero, which corresponds to the starting date of the calculation.
If you are displaying only part of the calculated time interval (by editing the Start or End settings), the time axis may begin with a value different from zero. In case you do not want this for some reason, this option allows you to renumber the time axis so that it does begin with zero.

"Min.",
"Max.":

These two fields show you the start and the end of the time interval to be displayed, in the selected units. In order to change these values, edit the Start and End fields.

"dX":

Enter the desired subdivision of the time axis.

"Description",
"Unit":

Enter a text label and a unit descriptor for the time axis. The automatic default for the unit field is a one-letter descriptor for the units you selected in the "Unit" field above, but you may edit it as you please.

"All Courses":

Check this option if the time axis settings for this graph shall be copied to all other graphs with courses.

"Display":

Uncheck this option if no labels or numbering of the time axis shall be displayed.

"Y-Axis":

"Min.",
"Max.",
"dY":

Enter the value range and the subdivision of the Y-axis. To the right of these fields, WUFI displays the minimum and maximum values of the combined curves in the current graph to help you in selecting appropriate values.

"Vol-%":

If the graph contains water content curves, this option allows you to switch the units from [kg/m³] to [Vol-%].

"Description",
"Unit:"

Enter a text label and a unit descriptor for the Y-axis.

"All ... Courses":

Check this option if the Y-axis settings for this graph shall be copied to all other images with courses of the same kind (e.g. relative humidities, temperatures etc).

"Display":

Uncheck this option if no labels or numbering of the Y-axis shall be displayed.

"Average over [h]":

For the graphical display, you can choose to show time-averages of the

calculation results. For instance, if you are only interested in daily means anyway, or if you want to reduce the data load on the printer.

Enter in the text box the number of hours over which the averages shall be computed

Version notice: the editor functions are available in WUFI Pro only.

Dialog: Graph Setup, Profiles

Here you can edit the settings for a graph that displays profiles:

"Name:":
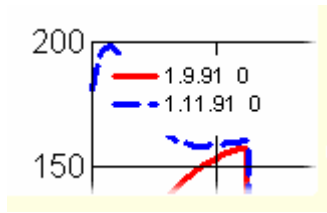
The name of the graph as it appears in the graphs list.

"Position":

"Top Margin [cm]",
"Left Margin [cm]":

Enter the distance of the top left corner of the graph from the top or left edge, respectively, of an A4 page.

"Height [cm]",
"Width [cm]":

Enter the height and the width of the graph.

"Legend Box":

Profile curves are identified by a legend (see "Dialog: Curves Setup"), which is written to a legend box, i.e. a white rectangular area in the graph which covers any curves or grid lines to prevent them from interfering with the legend text.

"X [cm]",
"Y [cm]":

Define the position of the top left corner of the legend box relative to the top left corner of the graph. The size of the legend box is automatically adjusted to accommodate the legend text.

"X-Axis":

"Min.",
"Max.",
"dX":

Enter the value range and the subdivision of the X-axis (in cm). To the right of these fields, WUFI displays the minimum and maximum values occurring in the assembly to help you in selecting appropriate values.

"Start = 0":

By default, the X-axis is labeled by a continuous count, starting with zero, which corresponds to the exterior surface of the assembly.
If you are displaying only part of the assembly cross-section (by editing the Min. or Max. settings), the axis may begin with a value different from zero. In case you do not want this for some reason, this option allows you to renumber the X-axis so that it does begin with zero.

"Description",
"Unit":

Enter a text label and a unit descriptor for the X-axis.

"All Profiles":

Check this option if the X-axis settings for this graph shall be copied to all other graphs with profiles.

"Display":

Uncheck this option if no labels or numbering of the X-axis shall be displayed.

"Y-Axis":

**"Min.",
"Max.",
"dY":**

Enter the value range and the subdivision of the Y-axis. To the right of these fields, WUFI displays the minimum and maximum values of the combined curves in the current graph to help you in selecting appropriate values.

"Vol-%":

If the graph contains water content profiles, this option allows you to switch the units from [kg/m³] to [Vol-%].

**"Description",
"Unit:"**

Enter a text label and a unit descriptor for the Y-axis.

"All ... Profiles":

Check this option if the Y-axis settings for this graph shall be copied to all other images with profiles of the same kind (e.g. relative humidities, temperatures etc).

"Display":

Uncheck this option if no labels or numbering of the Y-axis shall be displayed.

Version notice: the editor functions are available in WUFI Pro only.

Dialog: Curves Setup
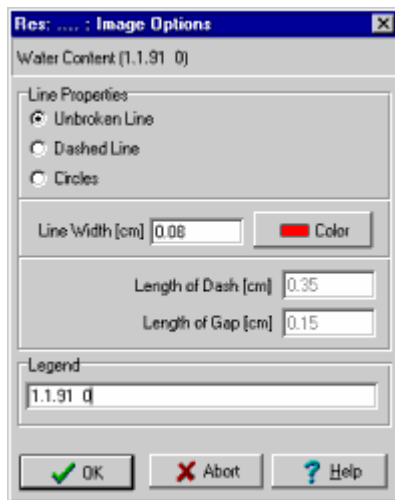
Here you can edit the settings for a curve.

The top info field displays the name WUFI assigned to the curve when it defined the automatic graphics settings.

"Line Properties":

>   **"Unbroken Line",**
>   **"Dashed Line",**
>   **"Circles":**
>
>>   You may connect the data points with an unbroken line or a dashed line, or you may display them as unconnected circles.
>
>   **"Line Width [cm]":**
>
>>   Enter the width with which (*ouch*) the curve is to be drawn.
>
>   **"Color":**
>
>>   Select the color with which the curve is to be drawn.
>
>   **"Length of Dash [cm]",**
>   **"Length of Gap [cm]":**
>
>>   Enter the length of the dashes and the distance between the dashes if the line style is "Dashed Line".

\# DialogCurvesSetup
$ Dialog: Curves Setup
+ 5280
K curves

"Legend:

Enter the legend text which serves to identify the curve in the graph.

Version notice: the editor functions are available in WUFI Pro only.

Next dialog: Insert Curves

Go to Overview of WUFI's Dialog Structure
Go to Contents

Dialog: Insert Curves
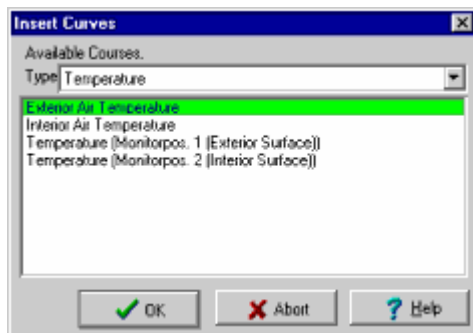
This dialog serves to select the curves which are to be displayed in the graph whose name is highlighted in the "Graphs" list.

Each graph can only contain curves of the same type, i.e. only temperatures or water contents etc. Otherwise, the axis labeling would require much more elaborate editing features than WUFI can offer in the dialogs for the graph settings (for courses or profiles).
If you need to have curves of different types in the same graph, you can export the calculation results to an ASCII file and use other software to create graphics.

If the graph contains no curves (either because you deleted them or because you created a new graph), then you can select the desired **"Type"** of the graph by selecting it from the drop-down list.
WUFI then displays the available curves of this type in the curves list. Select as many as you wish for inclusion in the graph.
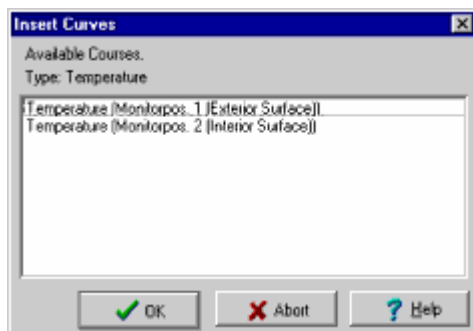
If the graph already contains curves, its type is fixed and WUFI only displays the available curves of the same type which are not yet in the graph. Select as many as you wish for inclusion in the graph.

Version notice: the editor functions are available in WUFI Pro only.

DialogInsertCurves
$ Dialog: Insert Curves
+ 5290
K curves

The following curve types and curves are available:

- **Temperature:**
  the air temperatures on both sides of the component and the temperatures at the monitoring positions, in °C.

- **Relative Humidity:**
  the relative humidities of the air on both sides of the component and the relative humidities at the monitoring positions, in %.

- **Volume-related Water Content:**
  the water content of the individual material layers of the component (different layers which contain the same material are represented by different curves), in kg/m^3.

- **Heat Flux:**
  the heat flux densities through both surfaces of the component and between the component layers, in W/m^2.

- **Rain:**
  the driving rain load incident on the component surface, as dependent on the inclination and orientation of the component (and not yet multiplied by the rain water absorption factor), in Ltr/m^{2}h.

- **Radiation:**
  - **Solar Radiation (Exterior Climate):**
    the solar radiation incident on the component surface, as dependent on the inclination and orientation of the component (and not yet multiplied by the short-wave radiation absorptivity), in W/m^2.

  - **Direct Solar Radiation (Exterior Climate):**
    the direct portion of the solar radiation (coming straight from the sun) incident on the component surface, as dependent on the inclination and orientation of the component (and not yet multiplied by the short-wave radiation absorptivity), in W/m^2.

  - **Diffuse Solar Radiation (Exterior Climate):**
    the diffuse portion of the solar radiation (scattered towards the sensor by the atmosphere and by clouds) incident on the component surface, as dependent on the inclination and orientation of the component (and not yet multiplied by the short-wave radiation absorptivity), in W/m^2.

  - **Reflected Solar Radiation (Exterior Climate):**
    the portion of the global solar radiation reflected by the ground and incident on the component surface, as dependent on the inclination of the component (and not yet multiplied by the short-wave radiation absorptivity), in W/m^2.

  - **Counterradiation (Exterior Climate):**
    the sum of terrestrial and atmospheric counterradiation incident on the component surface, as dependent on the inclination of the component (and not yet multiplied by the long-wave radiation emissivity which determines the absorbed fraction of the incident radiation), in W/m^2.

  - **Atmospheric Counterradiation (Exterior Climate):**
    the atmospheric counterradiation incident on the component surface, as

dependent on the inclination of the component (and not yet multiplied by the long-wave radiation emissivity which determines the absorbed fraction of the incident radiation), in W/m^2.

° **Ground Counterradiation (Exterior Climate):**
the terrestrial counterradiation incident on the component surface, as dependent on the inclination of the component (and not yet multiplied by the long-wave radiation emissivity which determines the absorbed fraction of the incident radiation), in W/m^2.

° **Reflected Atmospheric Counterradiation (Exterior Climate):**
the portion of the atmospheric counterradiation reflected by the ground and incident on the component surface, as dependent on the inclination of the component (and not yet multiplied by the long-wave radiation emissivity which determines the absorbed fraction of the incident radiation), in W/m^2.

° **Long-wave Emission of Component:**
the thermal radiation emitted by the component surface, in W/m^2.

• **Area-related Water Content:**
the water content in the entire component, in kg/m^2

• **Heat Transfer Coefficient:**
The variation in time of the heat transfer coefficients at both surfaces (they are not constant if specified as wind-dependent), in W/m^{2}K.

• **Vapor Transfer Coefficient:**
The variation in time of the water vapor transfer coefficients at both surfaces (they are not constant if the heat transfer coefficients are specified as wind-dependent), in kg/m^{2}sPa.

• **Moisture Flux:**
The moisture flux densities through the two surfaces of the component and between its individual layers. In each case one curve for the capillary (i.e. liquid) flux, one for the diffusion (i.e. vapor) flux and one for the sum of both, in kg/m^{2}s.

• **Heat Source:**
The variation in time of the source strength of the user-defined heat sources within the component (if any), in W/m^2.

• **Moisture Source:**
The variation in time of the source strength of the user-defined moisture sources within the component (if any), in kg/m^{2}s
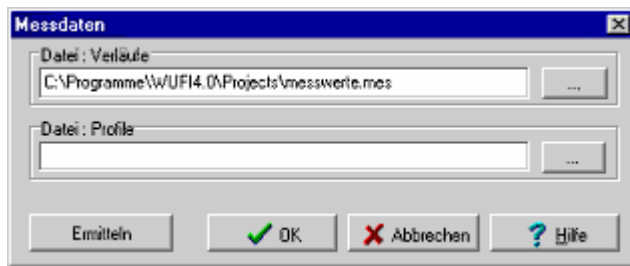
• **Pressure:**
The barometric pressure of the ambient air and the water vapor partial pressures at the monitoring positions, in hPa.

If you have specified external measured data for inclusion in the result graphs, the corresponding curves are also offered for selection.

Next dialog: Measured Data

Dialog: Measured Data

This dialog serves to specify ASCII files with measured courses or profiles which you want to display in the result graphs, together with the calculation results. This allows a direct comparison of calculation and measurement.

Clicking on the button **"..."** will open a file dialog for selecting the file with the measured data. Then click on the button **"Import"** to add the data to the calculation results in memory. WUFI expects the file extension *.MES.

In order to add imported curves to a diagram, right-click in the curves list of the respective diagram to open the subdialog Insert Curves and select the desired curve among those offered in the list. The imported data are included in all lists since they have no specified curve type.

The files for the measured courses are text files with one column for the time axis (in hours) and one or several columns for the measured data (in the units used by WUFI for this curve type).

The files for the measured profiles are text files with one column for the x coordinate (in cm) and one or several columns for the measured data (in the units used by WUFI for this curve type).

Example: water contents of drying lime silica brick masonry were measured at six points in time, spread over four years. Compare the measurements, taken at two locations each time , with the results of a calculation:

Drying.mes:

```
 2074    80    97
 2502    78    93
10027    45    49
18914    21    26
27504    18    27
32056    21    28
```
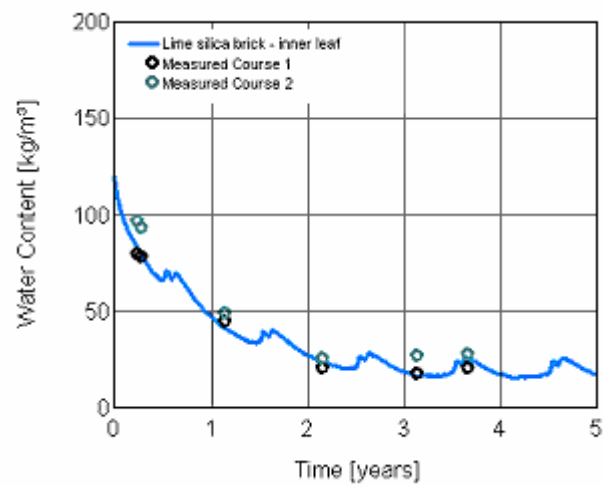

F_Messdaten
$ Dialog: Messdaten
+ 5300
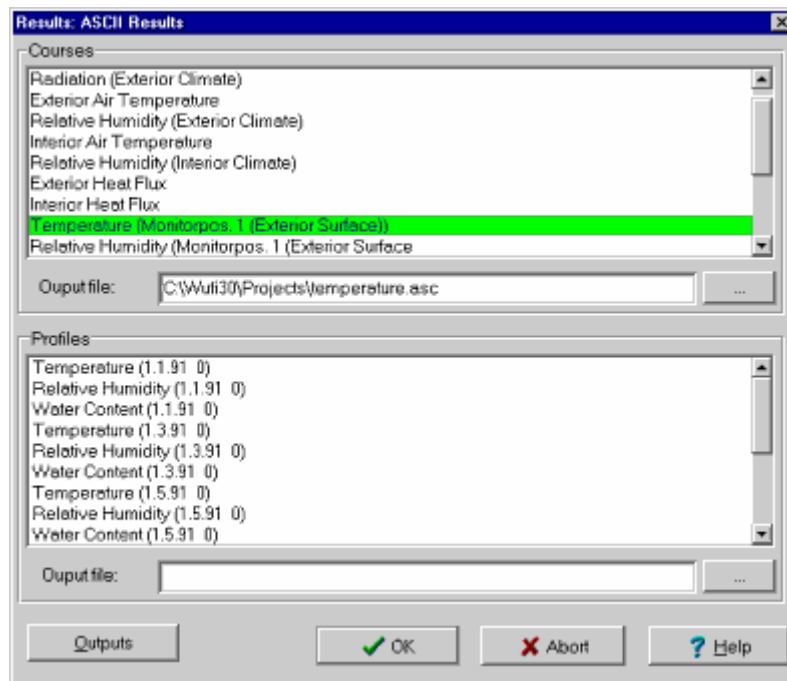K measured data;measured course;measured courses;measured profile;measured profiles

Next dialog: ASCII Export

Dialog: ASCII Export

Instead of viewing the results as graphics, you may also write them to an ASCII file and analyse them on your own.

"Courses":
"Profiles":

  Select from these lists the courses and profiles you want to have output.

  Select a single curve with a mouse click.
  If you want to select a contiguous range, first select the curve at one end and then – with the shift key pressed – the curve at the other end.
  If you want to select several non-contiguous curves, select these one after the other with the control key pressed.

  To deselect a curve, click on it with the control key pressed.

"Output file":

  Enter the (path and) name of the target files for courses and profiles, respectively, in these text boxes. If you want to use an existing file name or need to search for a directory, you may also press the button to open a "Save As" dialog.

DialogASCIIExport
$ Dialog: ASCII Export
+ 5310
K ASCII export;ASCII;export

"Output":

This button starts the export of the selected data to the specified ASCII file(s).

WUFI writes an ASCII file with several columns. The first column contains an hour count (courses) or X-coordinates in meters (profiles), the other columns contain the selected calculation results in the sequence of the selected list. The available curves are further described in the list of the curves available for the result graphs.

The results are output in the form in which they have been computed. They are not affected by the graphics settings (averaging, display of only part of the results etc).

The temperature and/or water content profiles of the last (or any other) calculation step may be used as initial temperature and/or water content profiles for the next calculation. In this way, an extended calculation may be broken up into smaller, easier manageable parts, or material parameters may be edited between successive runs in order to simulate aging etc.

Next dialog: Options Unit System

Go to Overview of WUFI's Dialog Structure
Go to Contents

Dialog: Options Unit System
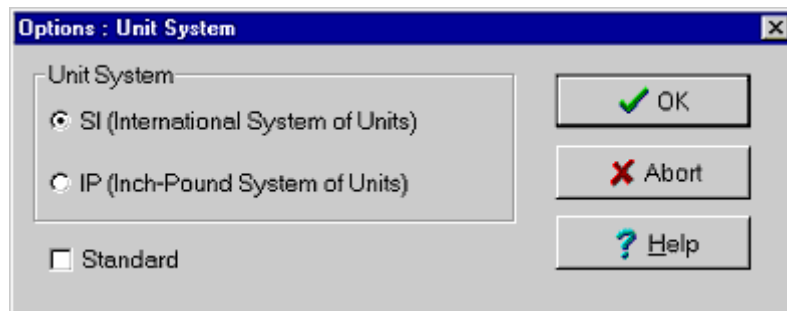
"SI (International System of Units)"
"IP (Inch-Pound System of Units)":

In the English WUFI version you can switch between SI und IP units.

Internally, WUFI always uses SI units. If IP units are selected, the user interface converts the project data from IP to SI for the calculation and converts the calculation results from SI to IP for display.

Please note: If the unit system is changed while there are data in the project, the converted values may have more decimal places than the original values and must then be rounded to fit into the text boxes. If they are converted back, these rounded values may not exactly reproduce the original values.
You should therefore avoid unnecessary switching between unit systems if data have already been entered into the project; it is advisable to select the units before entering any data.
The data are written to the project file in whatever units are selected at the time of saving, so IP data can be saved without any rounding problems.

"Standard":

Check this option to make the selected unit system the default for the next time WUFI is run.

Next dialog: Options Warnings

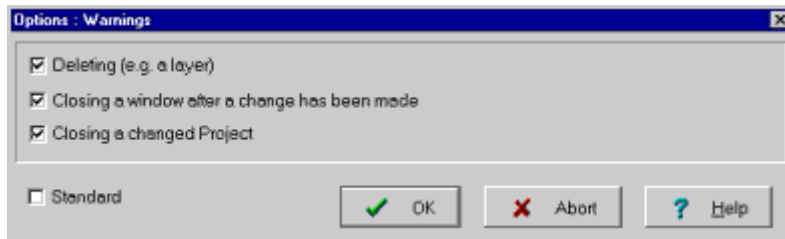Go to Overview of WUFI's Dialog Structure
Go to Contents

DialogOptionsUnitSystem
$ Dialog: Options Unit System
+ 5320
K units;unit system;SI;IP

Dialog: Options Warnings

Tell WUFI in this dialog which events shall cause a warning:

"Deleting (e.g. a layer)"

  Some data are entered in tables (e.g. the layer assembly). Each table has editor buttons which allow you to create new entries, copy them etc.
  When you **delete** a table entry and this option is checked, WUFI asks you whether you really want to delete it.

"Closing a window after a change has been made"

  Most of the editing is done in the large dialog panels which are accessed via the project explorer. Some subdialogs however use pop-up windows.
  When you **close** such a window with the **"OK"** button, any changes you made are accepted and the window will be closed without comment.
  When you **close** the window with the **"Abort"** button, any changes you made are discarded. If this option is checked, WUFI asks you whether you really want to discard the changes.

"Closing a changed project"

  When you **close** a project (i.e. you close WUFI or you open a new project) any changes you have not saved will be lost. If this option is checked, WUFI asks you whether you really want to discard the changes.

"Standard":

  Check this option in order to make the above settings the default for the next time WUFI is run.
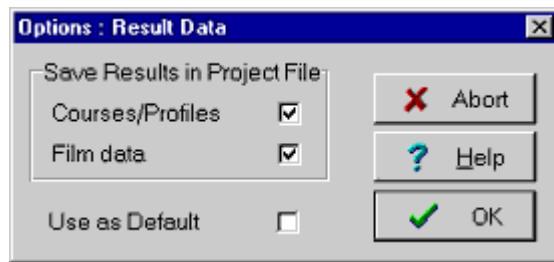
Next dialog: Options Result Data

Go to Overview of WUFI's Dialog Structure

Go to

Dialog: Options Result Data

The project file *.WUG contains all the input data plus – when re-saved after the calculation – the calculation results (courses, profiles and film). This file may thus become quite large.

You can reduce the file size (for archiving purposes or to give only the input data to someone else) by excluding the **courses and profiles** and/or the **film** from being saved in the project file.

Check the **"Use as Default"** option if the above settings shall be the default for the next time WUFI is run.

Next dialog: Database Materials

Go to Overview of WUFI's Dialog Structure
Go to Contents

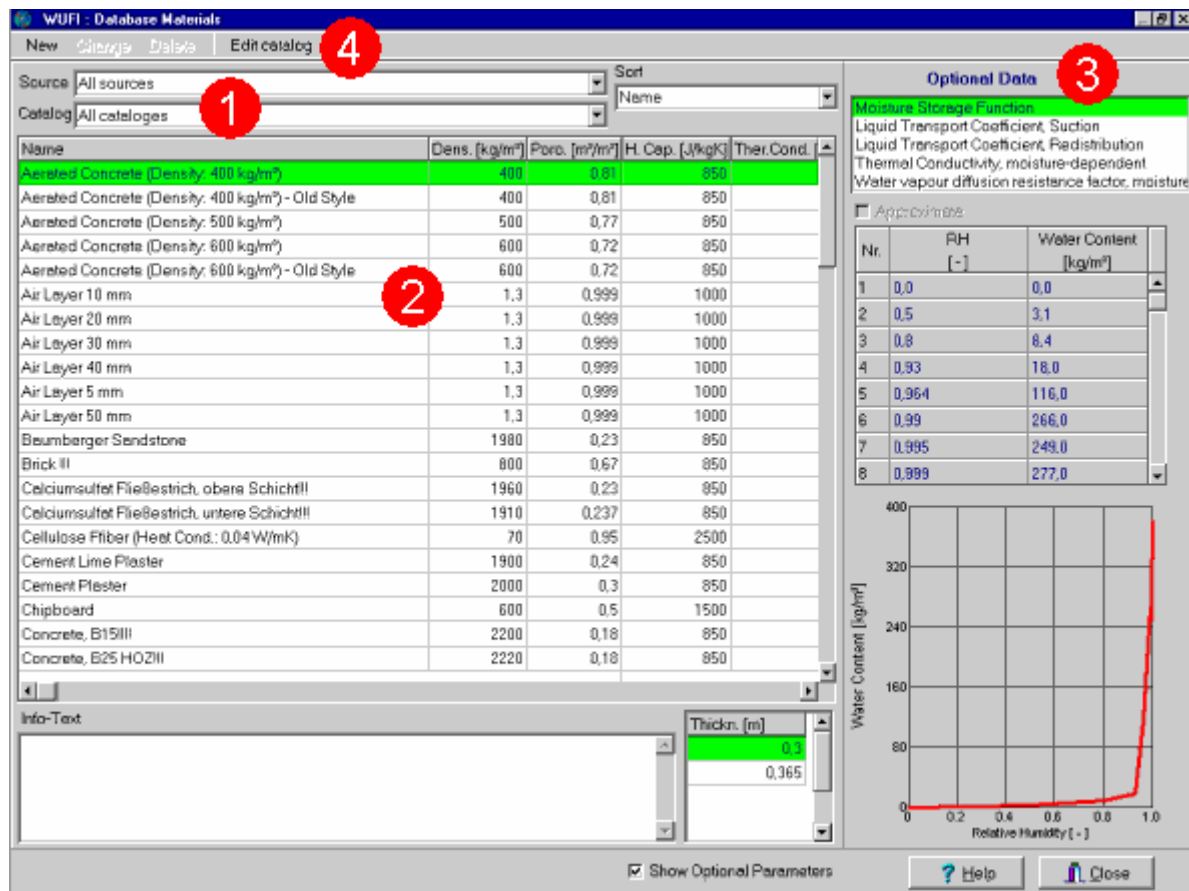### Dialog: Database Materials

In this dialog you can view the material data contained in the materials database. You also can add and edit your own materials (you can not edit the predefined materials).

> In order to assign material data from the database to the current construction assembly, use the dialog "Material Database", which can be accessed from the "Assembly" dialog via the "Material Database" button.

The material data are organized by **Sources** and by **Catalogs (1)**.
The source indicates the institution which has provided the data. You may select "All sources" in order to see all data, or you may select only one source if only a subgroup of data is relevant to your investigation.
For each source, the data have been organized in catalogs which comprise a specific category of building materials each (e.g. "Plasters and Mortars", "Insulation Materials", etc). Select "All catalogs" to view all materials of the selected source.

The materials contained in the selected sources and catalogs are displayed in the

---

DialogDatabaseMaterials
$ Dialog: Database Materials
+ 5350
K database materials;materials;source (database);catalog (database)

materials list (2). You may **"Sort"** the materials by name or by one of the basic material parameters.

The following data are displayed for each material:
• The **basic parameters** of the materials are displayed in the list itself.
• For some materials typical **thicknesses** are available which are specified in a separate list box.
• The large display panel on the right side of the screen **(3)** displays the optional material parameters of the highlighted material, complete with data tables and graphical curves. If you uncheck the **"Show Optional Parameters"** checkbox, this display panel vanishes and you can view the materials list more comfortably on a smaller screen.

For a discussion of the material data, please consult Details / Material Data.

The predefined materials in the database are read-only and cannot be edited. However, you can add your own materials to the database. To do this, first create your own catalog with the **"Edit catalog"** button **(4)** :
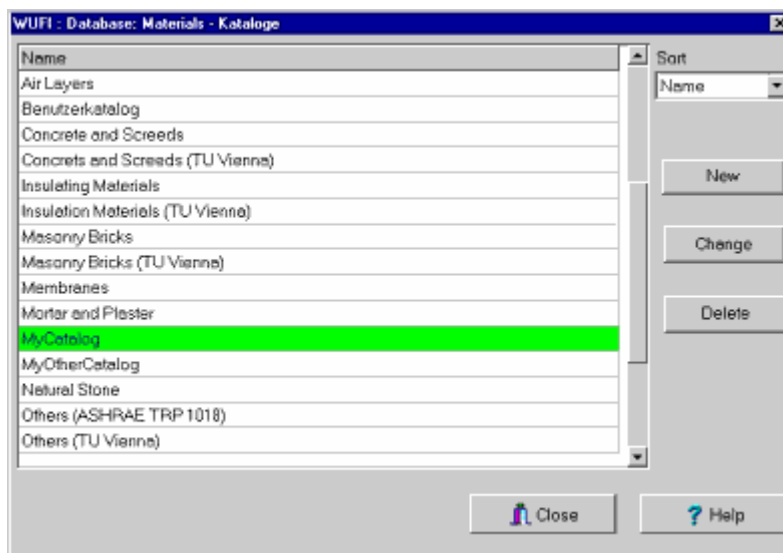
The catalog editor subdialog displays a list of the catalogs in the database. The predefined catalogs are read-only, but you can create a **"New"** catalog, **"Change"** the names of your catalogs and **"Delete"** your catalogs.

In order to enter a new material into the database, open the "New Material" subdialog with the **"New"** button **(4)**, enter the material data and assign them to one of your catalogs.

In order to edit one of your materials, select it in the materials list **(2)** and use the **"Change"** button **(4)** to edit the material data or the **"Delete"** button **(4)** to remove the material.

Next dialog: Database Materials – New Material

Go to
Go to

Dialog: Database Materials – New Material

This subdialog serves to create or edit a user-defined material in the material database. It contains several tab sheets.

"New Material":

In this tab sheet you can enter, edit or view the data for the highlighted material.

For a detailed discussion of the material data, please consult Details / Material Data.

"Name":

The name of the material.

"Basic Values"
"Bulk Density [kg/m³]",
"Porosity [m³/m³]",
"Specific Heat Capacity, Dry [J/kgK]",
"Thermal Conductivity Dry [W/mK]",
"Water Vapor Diffusion Resistance Factor [-]":

These basic material data are required as a minimum for a calculation.

"Optional Parameters":
Some of the material data in the following section "Optional Data" are difficult to acquire, but WUFI offers means to approximate or generate them from standard data which can easier be collected. These standard data are then **"Optional Parameters"** which may be required, depending on the settings in the "Optional Data" dialog.

The optional parameters are discussed in the respective topics of the following section:

"Optional Data":
Enter the optional material data in these tables (if required).

The optional material data comprise the moisture storage function of the material, the liquid transport coefficients, the moisture-dependent thermal conductivity and the moisture-dependent vapor diffusion resistance factor.

The optional data are always entered in tables. However, you can have WUFI automatically create some of these tables by entering other data from which the tables can be generated.

"Moisture Storage Function":
Enter the moisture storage function of the material, i.e. the moisture contents [kg/m³] which result from exposition to certain relative humidities (0..1).

If detailed tabulated data are not available, but the moisture retention function of the material can be adequately described by an approximation function, you can check the option **"Approximate"** and enter

- the sorption moisture corresponding to 0.8 RH, w_{80} (**"Reference Water Content [kg/m³]"**, nowadays determined according to German standard DIN 52620) and
- the **"Free Water Saturation [kg/m³]"** w_f

in the additional table **"Optional Parameters"**. WUFI then uses an analytical moisture storage function which passes through these two points and zero.

For non-hygroscopic materials, just leave the table of the moisture storage function empty. For numerical reasons, however, WUFI needs a defined moisture storage function; it then internally uses a default function which allows for the very low sorption moisture of non-hygroscopic materials. For details on this default moisture storage function see the Questions & Answers section.

"Liquid Transport Coefficient - Suction"
"Liquid Transport Coefficient - Redistribution":
Enter the liquid transport coefficients in this table - separately for suction and redistribution.

If the liquid transport coefficients for the material at hand are not known, you can have WUFI automatically underline generate a table by estimating the coefficients from the water absorption coefficient (A-value) which is known for most materials or at least easily measurable.

To this end, check the option **"Generate"** and enter the A-value in the additional table **"Optional Parameters"** (*in [kg/m²√s]; the relevant German standard uses the non-SI units [kg/m²√h]. Division by 60 converts such values to SI*). WUFI automatically generates a three-line table with the corresponding estimated liquid transport coefficients.

Please note that only a rough estimate is possible which proves successful in many cases, but which is not necessarily useful for all materials. Especially, there may be inaccuracies in the *shape* of the suction profiles. Generating is just meant to be some assistance; you should not blindly rely on it. Future WUFI versions are planned to offer more sophisticated methods.

Remarks on generating:

The estimate of the liquid transport coefficients from the A-value also uses the moisture contents w_{80} and w_f. If the moisture storage function is being approximated from w_{80} and w_f (see above), the two values are directly taken from these two entries; otherwise they are calculated from the corresponding table - by interpolation, if necessary.

If no moisture storage function has been defined as yet, generating is not possible - the table remains empty (but you can already enter the A-value).

If the moisture storage function is modified after generating, the generated table adapts automatically. Please note, therefore, that modification of a material property can also change another property as a side effect without this being immediately evident.

If you want to generate both the tables for suction and those for redistribution, both must of course be derived from the same A-value - the two tables therefore share this text box. Note that here, too, a modification in one spot may entail changes elsewhere (if you are generating only one of the tables and editing the other one by hand, the non-generated table is not affected by a modification of the water absorption factor, of course).

"Thermal Conductivity, Moisture-dependent":
Enter the heat conductivity of the material as a function of its moisture content if you want to allow for this.

If you are satisfied with a simple linear dependence of the heat conductivity on the moisture content, you can have WUFI automatically generate a two-line table by entering the moisture-induced heat conductivity supplement.

To this end, check the option **"Generate"** and enter the supplement in the additional table **"Optional Parameters"** (in [%/m-%]). WUFI automatically underline generates a two-line table with the heat conductivities resulting for the dry

condition and the maximum water content. Heat conductivities for intermediate moisture contents are linearly interpolated during the calculation.

Remarks on Generating:

The evaluation of the heat conductivity for maximum water content also uses the basic material properties bulk density, porosity and heat conductivity dry. If these values are modified after generating, the generated table adapts automatically. Please note, therefore, that modification of a material property can also change another property as a side effect without this being immediately evident.

If the required basic material data have not all been defined as yet, generating is not possible - the table remains empty (but you can already enter the supplement).

"Water Vapor Diffusion Resistance Factor, Moisture-dependent":
Enter the diffusion resistance factor of the material as a function of moisture content if you want to allow for this.

General remarks on approximating and generating:

For all optional material properties - except the diffusion resistance factor - WUFI is holding two tables in memory: one table created by hand (editable), and one generated table (non-editable). You can work on both tables in parallel; which of both is used for the calculation depends on whether the option **"Approximate"** or **"Generate"** is activated at the start of the calculation, or not.

By activating or deactivating the option, you can switch between the two kinds of tables. The unused table remains inactive in background.

You can use the **"Copy"** button to copy the generated table line by line to the editable table and work on it there by hand.

"Typical Built-In Moisture [kg/m³]":

A typical application for WUFI is a calculation to determine the time it takes a newly-built wall to dry out. If a typical initial moisture content for the current material is known, you can enter it here. Assigning the initial moisture contents to the individual layers then only takes one click on a button in the "Initial Conditions" dialog.

"Color":

Select the color of the material for the graphical assembly display.

"Thicknesses":
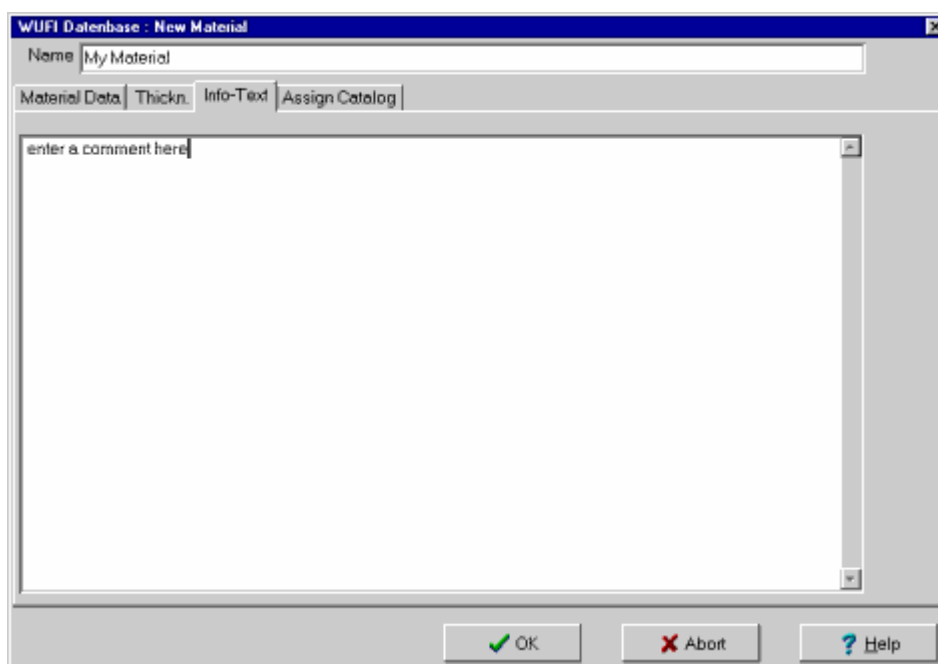
If there exist typical thicknesses for this building material, enter them into this list. They will be displayed on the database screen and you can assign a selected thickness to the highlighted assembly layer together with the material data, so you need not edit the thickness manually in the assembly dialog.

"Info-Text":

Here you may enter any info or remarks on the material.

"Assign Catalog":
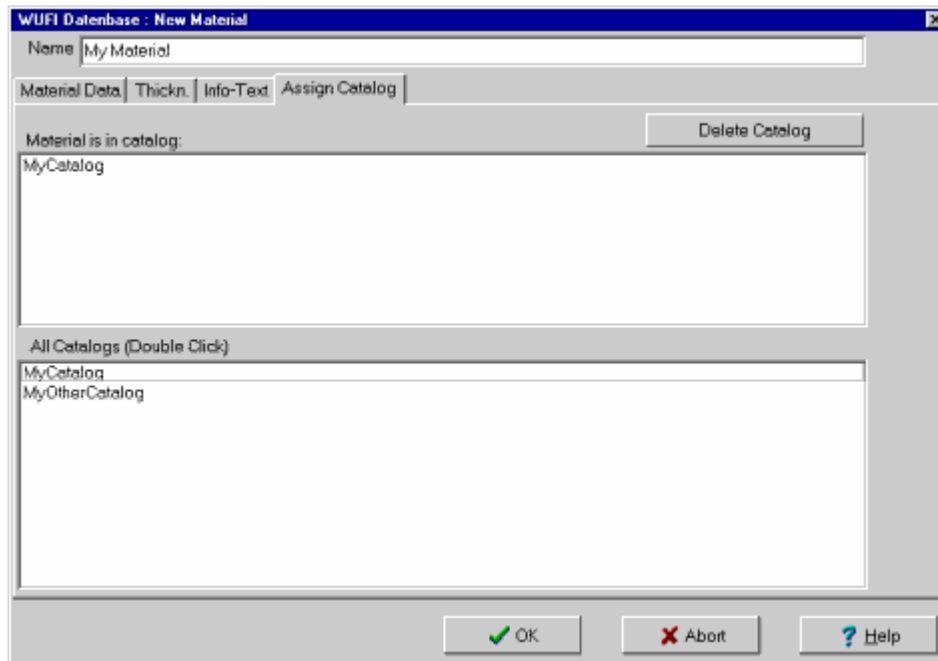
The material needs to be assigned to (at least) one of the catalogs. This tab sheet displays a list of **All Catalogs** that are user-defined (you cannot assign a material to one of the predefined catalogs).

Double-click on the catalog(s) to which you want to assign the material. These catalogs are transferred to the **"Material is in Catalog"** list. The material will be assigned to all catalogs in this list.
Use the **"Delete Catalog"** button to remove the highlighted catalog from this list (in order to *delete* the catalog from the *database*, use the "Edit Catalog" dialog.

The material will be added to the database when you close this dialog with the "OK" button.

Next dialog: Database Constructions

Go to Overview of WUFI's Dialog Structure
Go to Contents

Dialog: Database Constructions
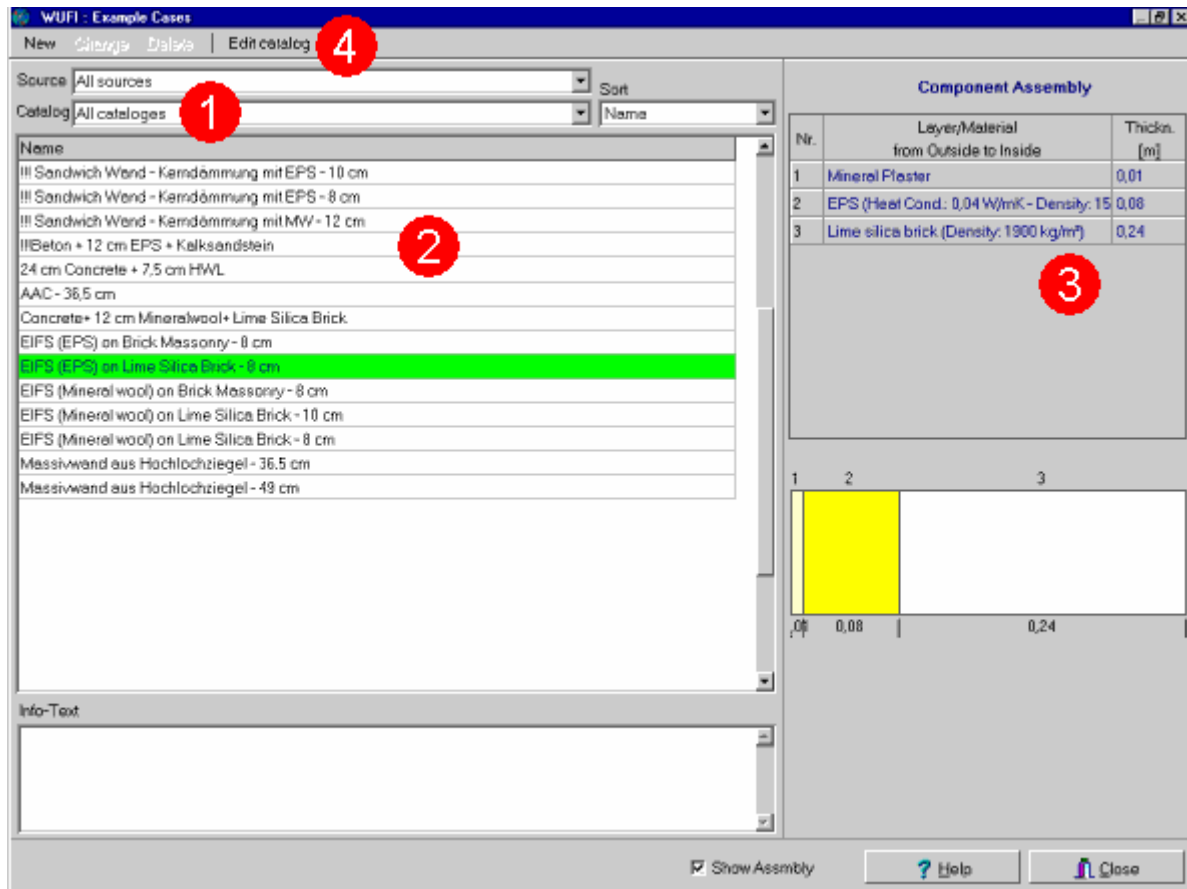
In this dialog you can view the constructions contained in the constructions database. You also can add and edit your own constructions (you can not edit the predefined constructions).

In order to assign constructions from the database to the current construction assembly, use the dialog "Example Cases", which can be accessed from the "Assembly" dialog via the "Example Cases" button.

The constructions are organized by **Sources** and by **Catalogs (1)**.
The source indicates the institution which has provided the construction. You may select "All sources" in order to see all constructions, or you may select only one source if only a subgroup of constructions is relevant to your investigation.
For each source, the constructions have been organized in catalogs which comprise a specific category of constructions each (e.g. "Facades", "EIFS", etc). Select "All catalogs" to view all constructions of the selected source.

DialogDatabaseExampleCases
$ Dialog: Database Example Cases
+ 5370
K database constructions;construction;example cases;source (database);catalog (database)

The constructions contained in the selected sources and catalogs are displayed in the **constructions list (2)**. You may **"Sort"** the constructions by name or leave them unsorted.

For each construction the display panel **(3)** shows:
• an assembly table which lists the different layers and their thicknesses,
• a graphical representation of the assembly.

If you uncheck the **"Show Assembly"** checkbox, this display panel vanishes and you can view the constructions list more comfortably on a smaller screen.

The predefined constructions in the database are read-only and cannot be edited. However, you can add your own constructions to the database. To do this, first create your own catalog with the **"Edit catalog"** button **(4)** :
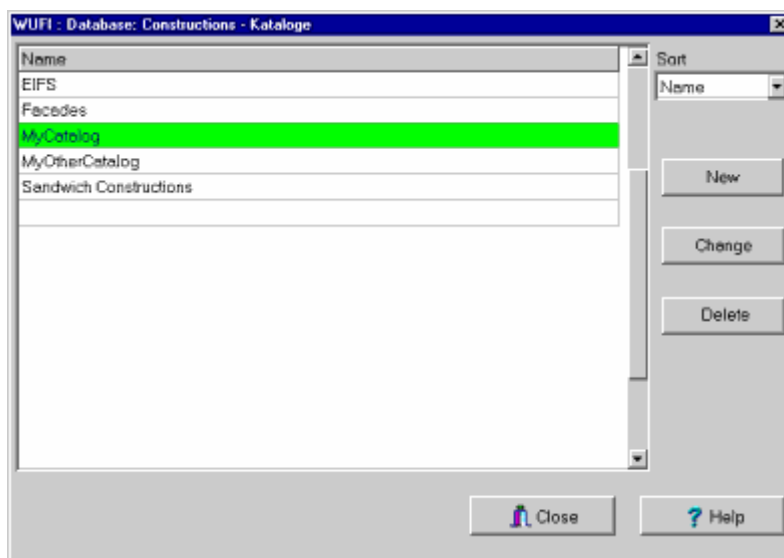
The catalog editor subdialog displays a list of the catalogs in the database. The predefined catalogs are read-only, but you can create a **"New"** catalog, **"Change"** the names of your catalogs and **"Delete"** your catalogs.

In order to enter a new construction into the database, open the "New Construction" subdialog with the **"New"** button **(4)**, enter the construction and assign it to one of your catalogs.

In order to edit one of your constructions, select it in the constructions list **(2)** and use the **"Change"** button **(4)** to edit the construction data or the **"Delete"** button **(4)** to remove the construction.

Next dialog: Database Constructions – New Construction

Go to Overview of WUFI's Dialog Structure
Go to Contents

Dialog: Database Constructions – New Construction

This subdialog serves to create or edit a user-defined construction in the constructions database. It contains several tab sheets.

"Layer Assembly":

In this tab sheet you can enter, edit or view the highlighted construction.

"Name:"

Enter the name of the construction.

"Layer/Material":

You define the construction by editing this assembly table. This is done with the following tools:

"Material Database":

This button opens the material database screen. Select the desired material and transfer it to the assembly with a double-click or by pressing the **"Assign"**

---

button.

"Material from Database":

Use this drop-down list to specify where the material transferred from the materials database (see above) shall go:

- **"Add as new Layer":**
  The material will be inserted as a newly created layer at the end of the table.

- **"Insert as new Layer":**
  The new material will be inserted as a newly created layer in front of the highlighted layer.

- **"Replace Data of Layer":**
  The new material will replace the material of the highlighted layer.
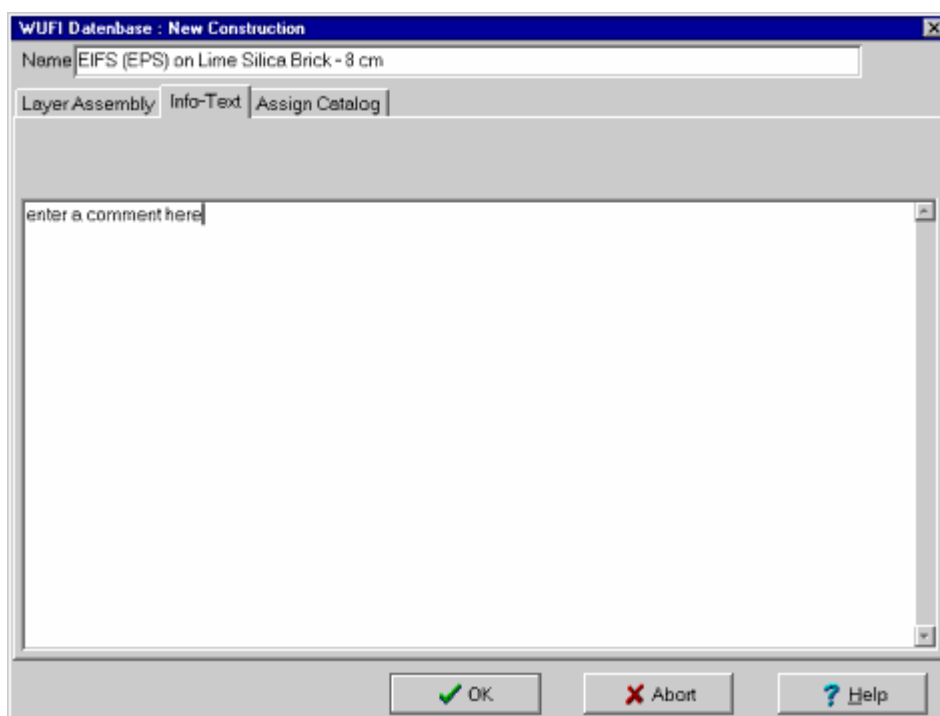
"Delete:"

Remove the highlighted layer from the table.

"Thickn. [m]":

Enter the thickness of the layer. You need not enter the thickness manually if you have transferred it from the material database together with the material data.

"Info-Text":

Here you may enter any info or remarks on the construction.

"Assign Catalog":
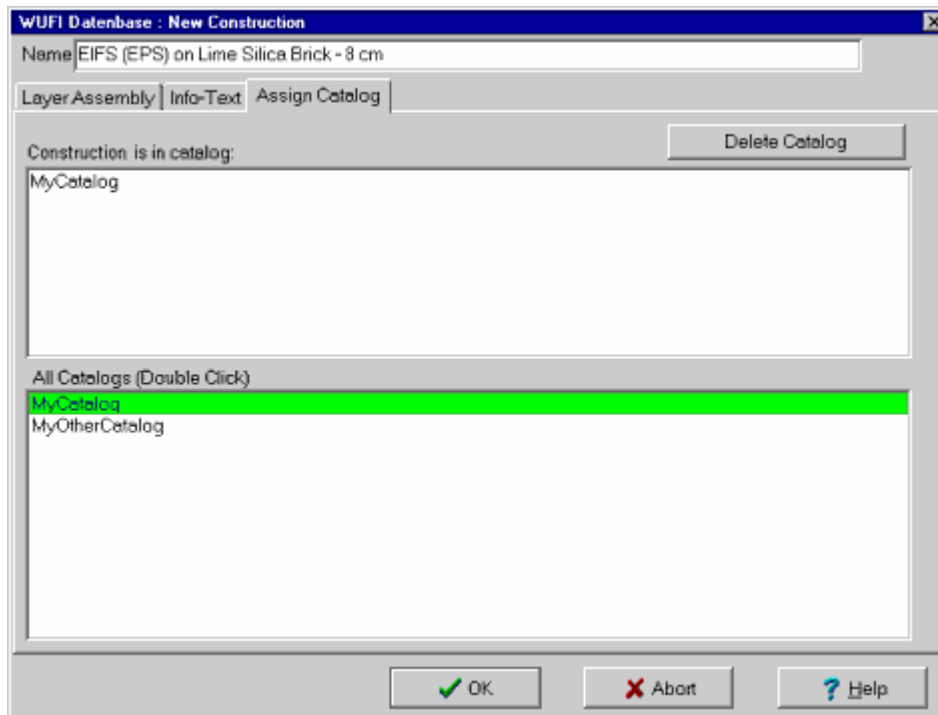
The construction needs to be assigned to (at least) one of the catalogs. This tab sheet displays a list of **All Catalogs** that are user-defined (you cannot assign a construction to one of the predefined catalogs).

Double-click on the catalog(s) to which you want to assign the construction. These catalogs are transferred to the **"Material is in Catalog"** list. The construction will be assigned to all catalogs in this list.
Use the **"Delete Catalog"** button to remove the highlighted catalog from this list (in order to *delete* the catalog from the *database*, use the "Edit Catalog" dialog.

The construction will be added to the database when you close this dialog with the "OK" button.

Continue with: Details / WUFI

Details / WUFI

WUFI is a computer program for the calculation of the simultaneous heat and moisture transport in multi-layer building components. It has repeatedly been validated by comparison with experimental results.

Sander Sandstone
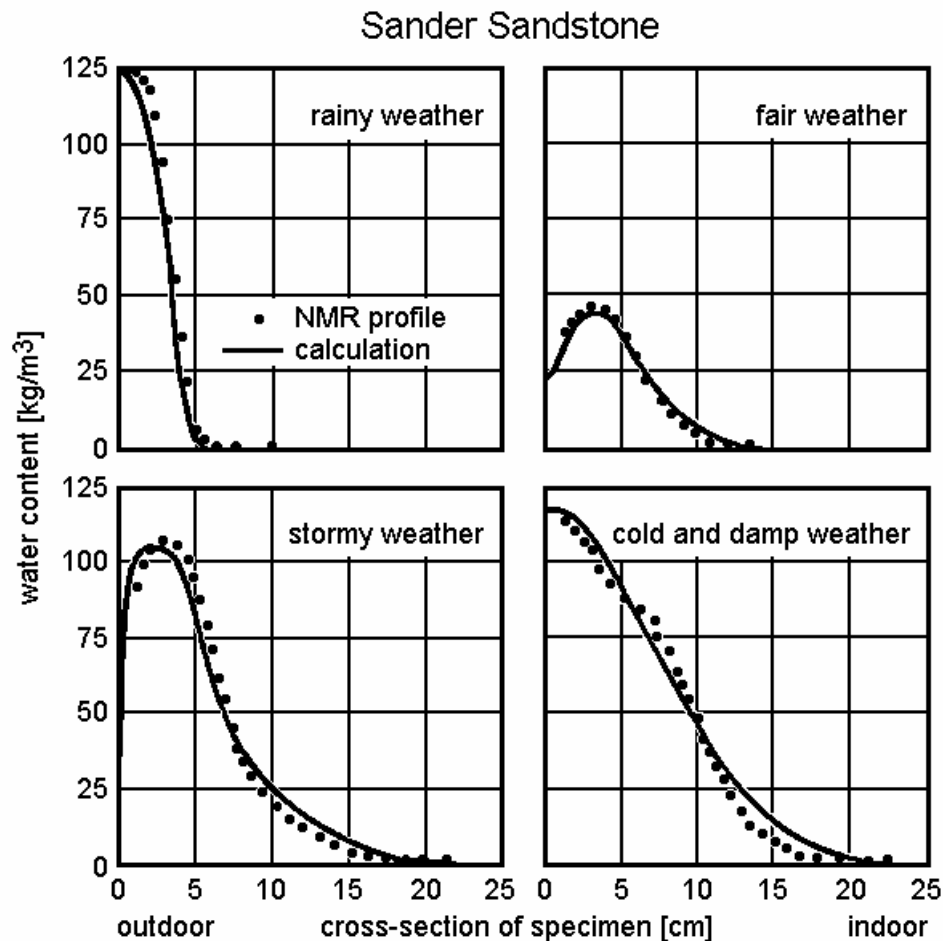
Nevertheless, WUFI also has its limitations. As with every tool, you should be aware of what WUFI can do and what it can not.

The fact that WUFI's results have been *calculated by a computer* does not make them infallible. You should check every result for plausibility. There are numerous circumstances that can degrade the quality of a calculation or even render it worthless (a slightly inaccurate result may be more dangerous than a totally wrong one since it may not be easily recognized as such). Some possible problems are

• program errors
• input errors
• insufficient knowledge of the required data
• limitations of the underlying mathematical model
• numerical problems.

These items will be discussed in the following.

Program Errors

WUFI has been tested comprehensively and should not contain any errors that might affect the calculation results. Considering its complexity, it can not be ruled out, however, that problems might arise under certain circumstances. Please report any problems to IBP.

Input Errors

Having entered all data, save them to a project file in order to have a status quo and recheck the entries in all the dialogs in the sequence of the menus to make sure they are correct. Display overviews of the material data, the object assembly and the other input with the dialog "Input Data Summary" (in the menu "Outputs").

Refer to the detailed explanations provided in the on-line help to make sure that WUFI's interpretation of the material data, surface transfer coefficients etc. is the same as yours.
Note there are possible side effects if you are generating tables from standard data.

Insufficient Knowledge of the Required Data

It often happens that material data, coefficients or boundary conditions required for the calculation are not well known. Do not try under these circumstances to obtain a 'precise' result.

Instead, estimate the possible variation range of the input data and perform some representative calculations for this range. From the variation in the results you may see if those aspects of the results which you are interested in are affected by the uncertainty or not. In the latter case, they may be usable nevertheless; in the former case, a more precise determination of some input data may be necessary.

Actually, in cases where you have 'reliable' data at your disposal, you should bear in mind that in practice there are also variations in the materials or workmanship which might cause deviations from your theoretical results.

It can be more instructive to know the effect of the variations of an estimated parameter on the results than to use 'precise' input to arrive at a single numerical result of unknown reliability.

Limitations of the Mathematical Model

The complex hygrothermal processes in a building component need to be simplified to make their simulation accessible to present-day computers. WUFI has been designed for the most important applications in building physics [1], but several limitations had to be accepted.

WUFI only deals with one-dimensional processes. Situations that cannot be adequately reduced to one dimension (e.g. geometrical thermal bridges, rising damp etc.) cannot be treated by WUFI and must be left to the two-dimensional version WUFI 2D.

Several transport phenomena have been neglected (cf. What is WUFI?), that is why e.g. air flows in the component, uptake of ground water under hydrostatic pressure etc. cannot be calculated.

The interdependence of salt and water transport has not been allowed for.

The interface between two capillary-active materials (e.g. rendering/brick) is treated as ideally conducting, whereas in reality there often is a transfer resistance which may reduce the moisture transport considerably. This resistance may be simulated by introducing an interface layer (ca. 1 mm thick) with adequately adjusted liquid transport coefficients [2].

Some materials do not conform to the simplified transport equations. Wood and concrete are changing their material data dependent on their present and past moisture content - the imbibed amount of water does not increase as the square root of time. The consequences of this fact may be negligible or serious - depending on the component assembly and the boundary conditions. Here only a comparison with samples exposed to natural weather can show whether the calculation results are reliable or not. The material data should be determined under boundary conditions similar to practical use.

If a material has a pronounced hysteresis in its moisture storage function, it may not be sufficient to use an averaged moisture storage function for the calculation.

The enthalpy flows resulting from the transport of liquid water across a temperature differential are ignored; i.e., cold rain water does not cool the surface of a building component in the calculation. The cooling effect by the subsequent evaporation of the imbibed water - which is considerably greater in general - is correctly included, however.

For simplicity, the heat transfer coefficients are treated as constant or exhibiting a simple predefined dependence on wind speed. Regarding the simplified radiation exchange with the surroundings, see Details / Surface Transfer.

In the dissertation [1], on which WUFI is based, you can find an extensive discussion of the mathematical model.

Numerical Problems

If boundary conditions relevant to building physics are to be applied, the coupled differential equations describing heat and moisture transport can only be solved numerically .

Ideally, only the programmers and the computer should worry about the details of the numerical method. Unfortunately, present numerical methods are not advanced enough as to be able to automatically and perfectly adapt themselves to every problem. So it's up to you, the user, to do part of the work that ideally should be done by the computer itself: you have to define a numerical grid and to choose a suitable time step.

- How to choose a suitable numerical grid

For a numerical treatment, the differential equations have to be discretised, i.e. the continuous heat and moisture fields decribed by the equations are evaluated at a number of separate points only. To this end, a suitable method is used to reduce the differential equations to a system of algebraic equations which describes the interdependence of those points and which can be treated numerically.

WUFI uses the method of 'finite volumes'. This method first formulates the differential equations in terms of balance equations for heat and moisture and then derives the algebraic equations in a way which makes sure that the heat and moisture balances remain preserved for every element of the numerical grid. That is, the variation of a physical quantity in each grid element is strictly consistent with the amount of that quantity that flows into or out of the element through the element boundaries ("conservative discretisation").

Since the balances are preserved in every individual grid element, they are also preserved in the whole assembly as the sum of all grid elements. This is valid for all possible grids - not only in the limit of an infinite number of grid elements.

Through this mathematical procedure, WUFI has a *physical* principle (conservation of energy and mass) built right into its heart and thus shows a very *robust* behaviour regarding the choice of the grid.

This compliance with a basic physical principle means that even coarse, wide-meshed grids can be expected to give physically realistic results.

However...
Instead of the continuous heat and moisture fields, WUFI only knows their values at separate points. The farther these points are spread, the less the complete fields can be derived from them. And the less well a field is known, the less precise are predictions of its behaviour in the next time step.

Furthermore...
Another problem is that two transport equations have to be solved: for heat and moisture. They can only be solved one after the other, although in reality they are continuously affecting each other (e.g., a condensation process is a vapour sink and a water source as well as a heat source; the heat conductivity may be moisture-dependent etc.).

Therefore, a solution step for the temperature cannot allow for the change in moisture content which in reality happens during the same time step. The result for the temperature is thus not entirely accurate. The following solution step for the moisture has the same problem.

Repeating the solution step for the temperature, now taking the new moisture field as a basis (which is slightly inaccurate but certainly better than the original unevolved moisture field) results in a better accuracy of the resulting temperature field. Continued alternating repetitions of these steps (iteration) finally result in temperature and moisture fields that sufficiently approach the desired solutions of the transport equations (convergence).

Under certain circumstances, however, this convergence may be so slow that WUFI has to stop the iteration (cf. convergence failure). Then the heat and moisture fields attained so far do individually satisfy their respective balance equation, but their interdependence has not yet fully developed.

In nearly all those cases, the remaining error is negligible in the context of building physics. If the grid is not well adapted, it may happen, however, that a poor representation of the temperature field cannot adjust itself the way the poorly represented moisture field requires it - the convergence may then be seriously hampered or even impossible. In this case, markedly inaccurate fields may be left after the stop of the iteration. Occasionally, fluctuations in the numerical values may even overload the numerics and produce results that do not conform to the balance equations.

Such a case is very rare, but you should recognise it if it happens. For this purpose, WUFI displays a water balance after the calculation has finished; if you are viewing the film, you can also see 'flutter' appearing in the curves for no apparent reason. As discussed above, you should then first check if the choice of the grid could be responsible for the problems and adapt it accordingly. If that fails, you may try stricter numerical parameters (convergence failures are further discussed in the "Questions and Answers" section).

Unfortunately, there are presently no common methods which can reliably recognise that kind of problem during the calculation and adapt the grid on the fly - you have to remedy this shortcoming by using your own insight into the problem at issue and define the grid yourself. There are no fixed recipes for this, but a few general rules:

For the discretisation, the values of the calculated quantities are assumed to be spatially constant across each grid element. Therefore, the size of each element should be chosen so as to make this assumption valid according to the local conditions. In general, this requires the use of small elements in regions where steep moisture or temperature gradients are to be expected, and the use of larger elements in more placid regions to cut down on calculation effort.

In case of doubt, you should prefer a larger number of smaller elements to a few large ones as long as you can tolerate the computing time.

In general, steep gradients are to be expected close to the boundaries of a layer, i.e., close to the exterior and interior surfaces of the building component because of the influence of climate conditions, and close to internal layer interfaces because of interstitial condensation. Less variation will occur in the middle of a layer.
Splitting up a layer into two layers with identical material data but different expansion factors (>1, <1) allows you to achieve a smooth, not necessarily symmetrical, expansion and contraction of the grid elements which can be adapted to the requirements of each individual layer.

For numerical reasons, neighbouring elements should not differ too much in size. This requires in particular that boundary elements of neighbouring layers be matched, at least approximately.

View a film of the calculation and see if there are noticeable kinks in the curve. Refine the grid in those spots.

To be sure that a suitable grid was chosen for the calculation, you may repeat the same calculation with double the number of grid elements. If the result remains the same, the first grid already was well adapted.

Example 1:

An impressive example of what kind of gradients may occur close to layer boundaries can be seen in the case of construction moisture drying out of a cellular concrete flat roof with mineral wool insulation. During the cold season, the moisture migrates up through the permeable mineral wool and condenses at the impermeable roof membrane in amounts that are not only a problem for the insulation quality but for the numerics as well. In such a case it is imperative to have very fine grid elements close to the roof membrane, while a relatively coarse grid is sufficient in the cellular concrete.
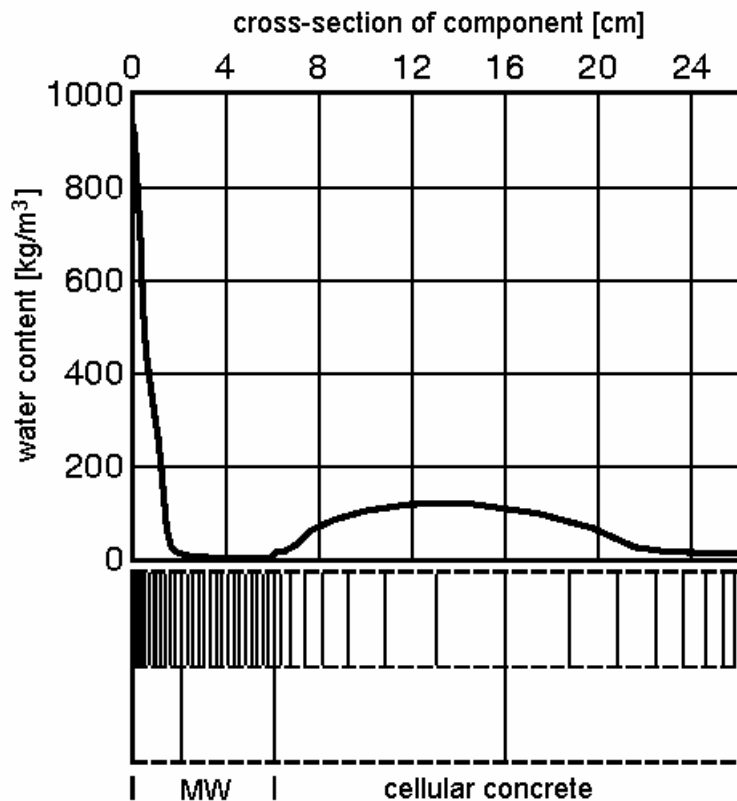
Example 2:

The following image shows how the calculation results may be affected if the grid is too coarse. A 10-cm-long prismatic lime silica brick specimen, sealed on the sides and one face, was saturated with water and then left to dry in a climate chamber. In a WUFI calculation, the liquid transport coefficients and the water vapour transfer coefficient were adjusted until good agreement with the measurements was reached. The diagram shows such a calculation using 20 equidistant grid elements (solid line) and another calculation with the same material data, but using only 5 grid elements.

Obviously, the latter grid is too coarse. Note however, that despite the remarkably small number of 5 grid elements, the results are not *entirely* inaccurate!

Note: the equidistant grids with 20 and 5 elements, respectively, have been used here for demonstration purposes only. A better choice would be an expanding grid with small elements close to the drying surface and larger elements close to the sealed surface.

Lime Silica Brick, Drying

○ measurement
calculation with
—— 20
-- 5
grid elements

mean water content [kg/m³] vs time [h]
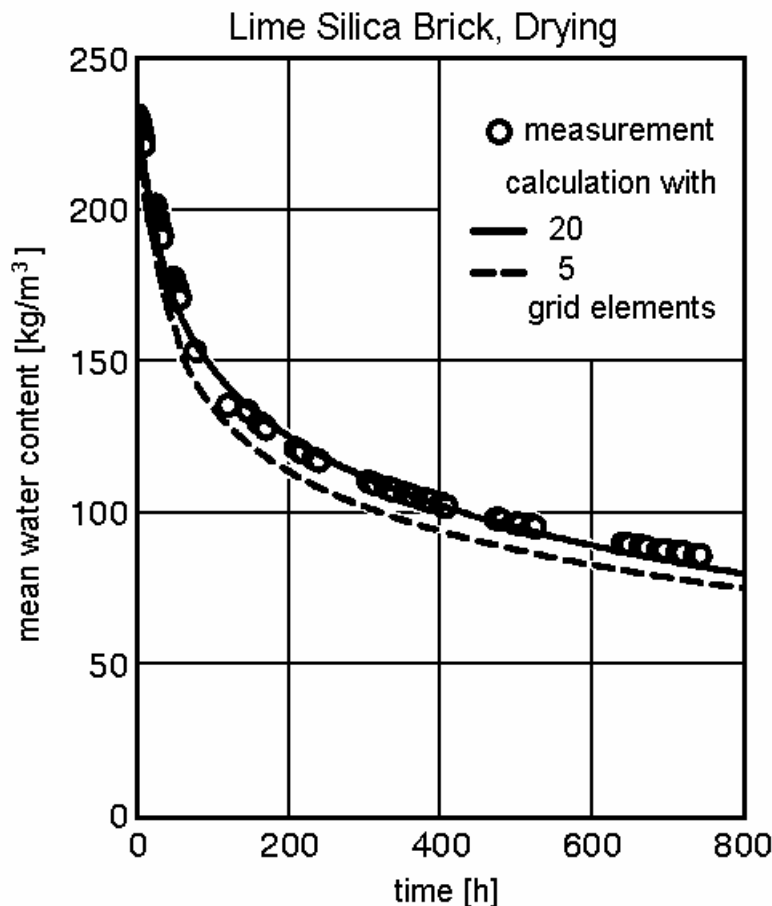
- How to choose a suitable time step

The temporal evolution of the building component, too, has to be discretised for the numerical treatment - the temperature and moisture fields are calculated for separate, discrete points of time only. The solution algorithm starts with the present fields and calculates from them the new fields for the next point in time which is one time step later.

The derivation of this algorithm leads to a time integral over the dependent variable (temperature or moisture) which has to be approximated by an expression that can be treated numerically. To this end it is necessary to know the behaviour of these variables as a function of time - but it's that unknown time-dependent behaviour because of which we are undertaking the calculation!

Therefore, assumptions have to be made about the unknown time-dependent behaviour. These choices determine the method to be used.

The simplest choice is the assumption that at each grid point the variable in question always has the same constant value during the time step it had at its beginning - and then 'suddenly' at the end of the time step jumps to the newly calculated value. Example: the heat flows between a grid point and its two next neighbours resulting from the present temperature field are determined. It is then assumed that these flows remain unchanged during the time step and from the resulting increase or decrease of heat the new temperature at the grid point is calculated. Since the calculation involves only the known temperatures of the two

neighbouring points, it can be separately done for each and any grid point. This is the explicit scheme.

On the other hand, one may use those values for the variables during the entire time step which they will have at the end of the step. This does not require clairvoyance but the solution of a system of equations. The final temperature of the grid point in question depends on the heat flows which depend on the final temperatures of the neighbouring points which in turn depend on the final temperatures of *their* neighbouring points etc. etc. At both ends, this chain is terminated by the known boundary conditions, and the whole of this constitutes a system of equations: there exists a unique solution which can, however, only be found by solving the problem for all grid points simultaneously. This is the implicit scheme.

If during the time step the variables are set to the mean value beween their initial and final values (which corresponds to the time-average if the change is linear), the result is the widely used Crank-Nicolson scheme. In addition, there are a number of other schemes not discussed here.

The explicit scheme is the simplest one. However, its stability reqires that the width of the time step is below some upper limit which depends on the spatial discretisation. A high spatial resolution thus requires very small time steps which result in a very high, often not tolerable computation load.

The implicit scheme is somewhat more complex since an entire system of equations has to be solved for every time step. However, it has the advantage of being stable for *all* time step widths. The computation load is thus markedly reduced since much wider time steps can be used without numerical problems.

The Crank-Nicolson scheme is of higher order and therefore theoretically more precise than the other two schemes. In the case of non-linear transport coefficients, however, it is prone to numerical oscillations which might produce physically unrealistic results. Furthermore, for applications in building physics, where material data and boundary conditions often are only known with limited accuracy, lower-order methods are perfectly sufficient.

For these reasons, WUFI uses the implicit scheme (which is also called "fully implicit" in order to distinguish it from partially implicit schemes like Crank-Nicolson).

The implicit scheme also has the advantage that it is a physically more realistic approximation for wide time steps: the change of a variable exposed to constant boundary conditions often has an exponential character; with its larger variation at the beginning of the time step and smaller variation at its end, this behaviour is closer to the implicit scheme than to the linear variation in the case of Crank-Nicolson or even the constant behaviour in the case of the explicit scheme. If the time steps are small enough, however, any physical quantity varies more or less linearly - and is then better represented by Crank-Nicolson.

Example 1:

A 36.5-cm-thick brick wall, treated as homogeneous, initially has a temperature of 30°C. At time t=0, the ambient air temperature suddenly drops to 10°C.

The following table shows the temperature in the centre plane of the wall after 20 hours, calculated with 50 equidistant grid elements and time steps between 0.1 and 10 hours, compared to the exact solution:

exact   18.5 °C

WUFI:
0.1   18.5 °C
0.5   18.6 °C
1 h   18.7 °C
5 h   19.5 °C
10 h   20.3 °C

With very short time steps, the result is virtually exact; a time step of one hour still produces a very good result. With increasing time steps, however, the changes in temperature *during* the step are less and less well taken into account.

Brick Masonry, Cooling
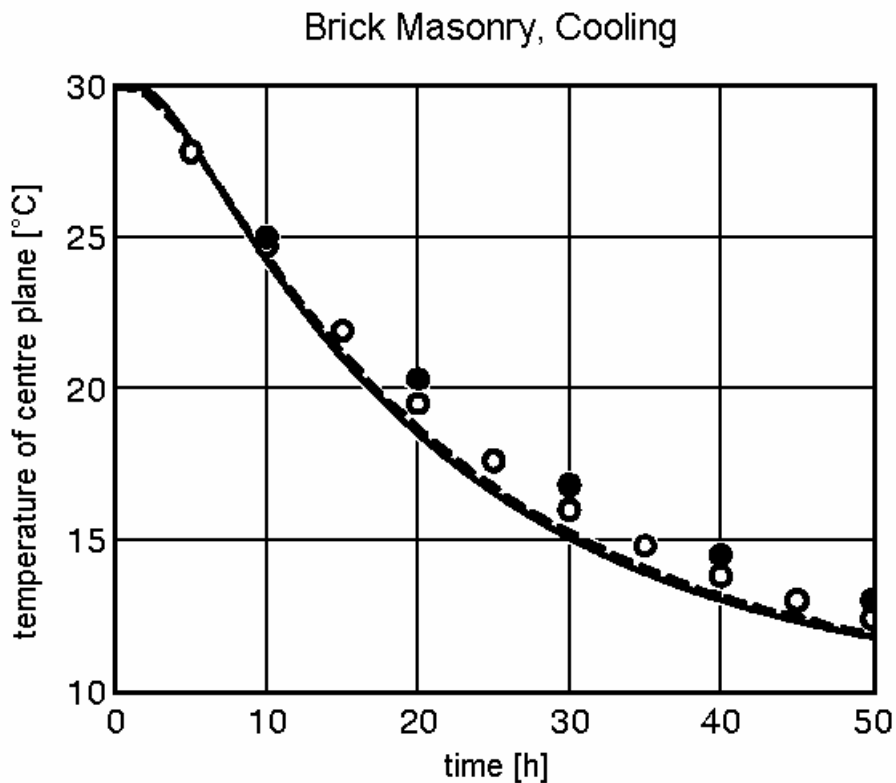
In the diagram, the exact course of the temperature in the centre plane is shown as a solid line, the calculation with a time step of one hour, as a dashed line, and the calculations with time steps of 5 and 10 hours as open and filled dots, respectively.

Example 2:

An imbibition experiment is performed with a prismatic specimen of Baumberger sandstone, sealed on the flanks and one face; the unsealed face of the specimen is completely wetted with water (by setting the 'rain' in the climate file to a very high value).

The numerical imbibition experiment is conducted over two time intervals and with various time steps, then the water absorption coefficient (A-value) is determined from the imbibed amount of water.

The grid contained 100 equidistant grid elements, distributed across 6 cm and 20 cm of the specimen length, respectively. Diffusion transport was not allowed for.

The numerically exact A-value for the liquid transport coefficients used here is 0.0426 kg/m²√s (obtained by a method which is independent of any grid widths and time steps).

time step [h]	A-value [kg/m²√s] after	
	10 h	100 h
0.5	0.0427	0.0428
1	0.0426	0.0428
2	0.0424	0.0428
5	0.0419	0.0427
10	0.0408	0.0426
20	-	0.0425
50	-	0.0419
100	-	0.0408

In this example, the result is only very weakly dependent on the choice of the time step.

Of course, the results are given to three significant digits for comparison purposes only - because of measurement uncertainties the A-value of the actual specimen from which the liquid transport coefficients were taken may slightly differ from these calculated results.

The two different calculation intervals also serve to illustrate the accumulation of numerical errors (see below).

The diagram shows the suction profile after 100 hours. The 'exact' solution is shown as a solid line, the WUFI calculation, as a dotted line. The agreement is nearly perfect; only in the lower part of the curves, it becomes evident that WUFI's finite grid resolution cannot represent arbitrarily steep moisture gradients.

Baumberger Sandstone, Suction
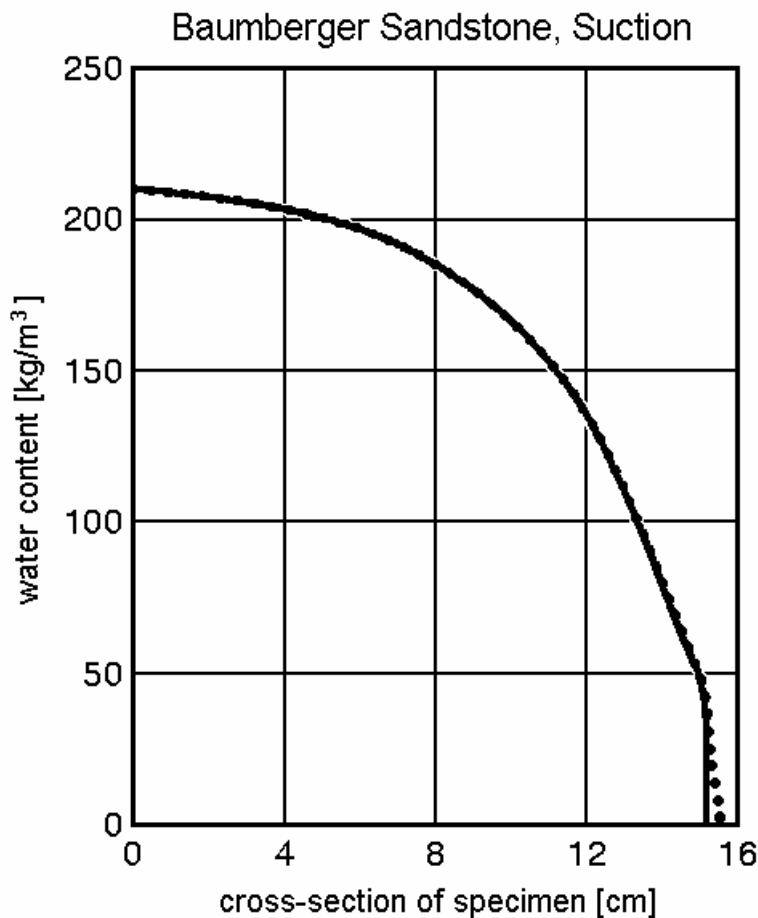
There is also a non-numerical aspect to the choice of the time step. WUFI assumes that the boundary conditions read from the climate file are prevailing as constant values during the time step. For natural weather, this is only true as an approximation. Some thought should be given to the validity of this approximation.

For applications in building physics, it turns out that generally a time step of one hour is adequate. This is fortunate since measured weather data often are not available with higher temporal resolution than hourly mean values.

Shorter time steps should be required in special cases only. The adequacy of longer time steps has to be decided case by case. They must not be used if solar gains play a noticeable role.

The solar radiation shows a very pronounced diurnal variation. Because of the hygrothermal inertia of a building component, short-lived fluctuations in the radiation intensity - e.g. because of drifting clouds - have no major effect and may be 'smoothed away' in an average value. The systematic variation of the radiation intensity over several hours, however, cannot be damped by the inertia of the component and leads to corresponding variations in temperature. Because of the exponential dependence of the water vapour saturation pressure on the temperature even short-lived *temperature* peaks should not be averaged away - the evaporation resulting from a mean temperature is too low [1].

Similar arguments apply to rain: if the component can absorb even a moderate amount of moisture by capillary conduction, a sufficiently accurate duration of rain events in the climate data may be decisive for a realistic calculation of the moisture balance; the same amount of 'mean rain' distributed over 24h would probably yield completely meaningless simulation results.

In other cases - e.g. diffusion calculations in shaded building components sheltered from rain - use of daily or even monthly mean values may be adequate.

There is no point in using smaller time steps than the time interval over which the boundary conditions are assumed to be constant. For example, if you have hourly mean values of the weather data, a time step of one hour is sufficient - smaller time steps do not increase accuracy.

To be sure that a suitable time step was chosen for the calculation, you may repeat the same calculation with other time steps - the results should not change noticeably.

- Accumulated and damped errors

A building component which is exposed to periodic boundary conditions approaches a "periodic steady" condition, i.e. a series of conditions repeating with the period of the boundary conditions. This periodic steady condition is independent of the initial condition of the building component - it has completely forgotten its earlier conditions.

This forgetfulness also applies to 'inaccurate' conditions: if during a calculation a temperature or moisture field has not been accurately calculated at one time step (e.g. because of a convergence failure), its effect on the subsequent time steps will wear off more and more until finally the calculation will proceed as if the error never had happened.

The natural weather is not strictly periodic, but in the long run it leads to a 'typical' condition of the building component which also shows a certain forgetfulness.

Therefore, numerical inaccuracies do not necessarily always accumulate and render the result useless after a sufficiently long calculation. In fact, the longer the calculation is running, the less it suffers from earlier inaccuracies. This is simply a consequence of the natural physical behaviour of a building component.

Of course, this only applies if the inaccuracies do not occur systematically or regularly, and if the calculation interval is sufficiently long compared to the memory of the building component. A massive moist concrete wall will take years to dry out and to reach a periodic steady state - and since the process of drying is always proceeding in the same direction, the inaccuracies may also occur in the same direction and possibly accumulate nevertheless.

Example:

The diagram shows the course of the mean water content of a facade test element with unrendered brick masonry (24 cm thick) which has been exposed to Holzkirchen's copious driving rain. The solid line represents a WUFI calculation with an initial moisture content of 100 kg/m³ (10 vol-%), assumed constant across the wall. The dashed line shows another calculation with an initial moisture content of 50 kg/m³ (5 vol-%). The drier brick absorbs more water during a rain period, so that the mean water contents of the two specimens become indistinguishable after about 50 days.

Brick Masonry, Exposed to Natural Weather
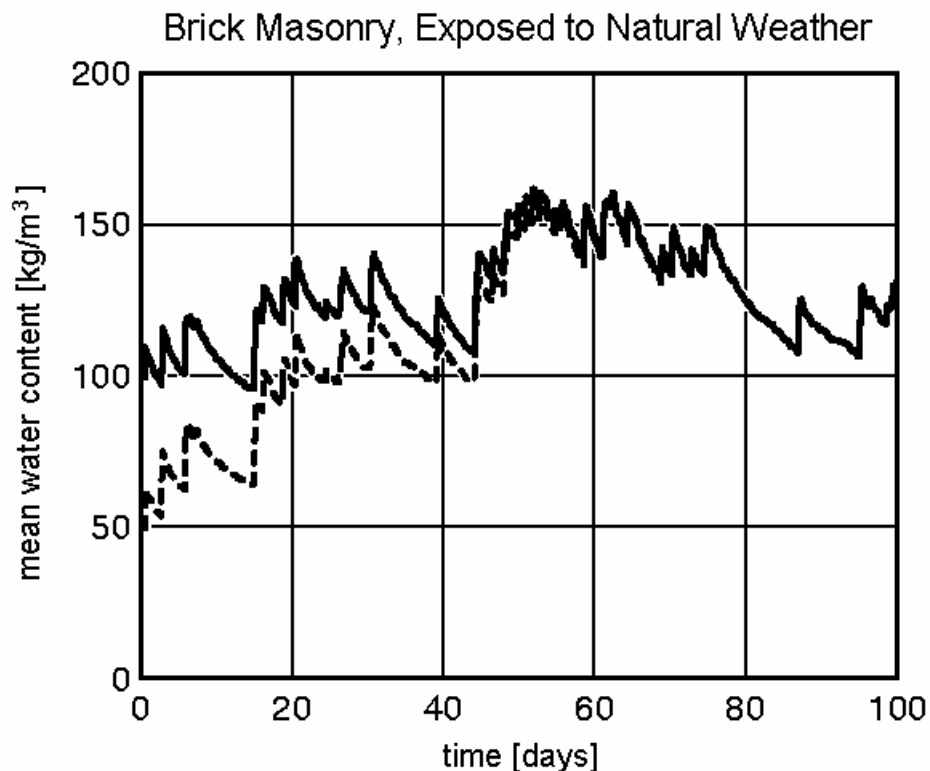
Conclusion

The foregoing discussion was to show you that WUFI has a remarkable stability in its calculations, but it nevertheless also has its limitations and, in addition, is dependent on a certain insight of the user into specific numerical and physical details.

Hopefully, it will help you to successfully apply WUFI in its proper scope.

Literature:

[1]   Künzel, H.M.:
       Simultaneous Heat and Moisture Transport in Building Components.
       One- and two-dimensional calculation using simple parameters.
       IRB Verlag 1995

[2]   Holm, A., Krus, M., Künzel, H.M.: Feuchtetransport über Materialgrenzen im
       Mauerwerk. Bauinstandsetzen 2 (1996), H. 5, 375 - 396.

Continue with Questions & Answers

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Q&A

Questions and Answers

(1):
Where can I find material data for materials which are not included in the database?

Unfortunately, finding material data for hygric simulations can prove difficult since there are no standard collections of such data as yet. While thermal data can be found in many books, hygric data are sparse and hard to come by.

A collection of design values for heat conductivity (including the effect of practical moisture content) and diffusion resistance factors is listed in German standard DIN 4108-4 and numerous textbooks on building physics. The new DIN EN 12524 lists thermal as well as basic hygric design values for building materials.

An extensive list of "NIST Heat Transmission Properties of Insulating and Building Materials" is available on-line at http://srdata.nist.gov/insulation/

Moisture storage functions and liquid transport coefficients may be estimated from the standard parameters w_f, w_{80} and the A-value which may also be found in some textbooks (at least for selected materials) and data sheets or can be measured relatively easily.

Occasionally, some data may be found scattered through the specialised literature, but there is no systematic way to retrieve them.

Sometimes the manufacturer may be able to provide material data. Some laboratories (including IBP) can measure the required data if samples are provided.

(2):
Where can I find climate data?

Hourly climate data which include rain are even harder to find than material data.
IBP offers one year of hourly weather data with WUFI (the file can also be downloaded from the IBP website). These data from 1991 are considered fairly representative for the climate of the Holzkirchen region.
IBP will also provide data for one 'cold' and one 'warm' year from the Holzkirchen region which can be used with WUFI.
In addition, weather data for three Swiss cities (Zurich, Davos, Locarno; one warm and one cold year each) and, in the English version, for 53 North American cities are provided with the professional WUFI version.

Another source of hourly weather data are the Test Reference Years of the Deutscher Wetterdienst DWD. They even cover all 12 climate regions of the former West Germany. They are not cheap, however, and since they were primarily intended for heating and energy consumption investigations, the simulated rain in these files is not as realistic as would be desirable for hygric simulations involving driving rain.
The newly developed TRYs from the DWD do cover all of Germany but don't contain any rain data.

If the situation of a specific object is to be investigated, it may be necessary to measure the weather in-situ anyway.

(3):

I'm trying to collect weather data for a specific location. I noticed that WUFI's climate generator tool needs the geographic coordinates (latitude and longitude) in order to convert the radiation data. Can I convert radiation data measured somewhere else to my location by entering the appropriate coordinates?

No. In order to correctly evaluate the amount of radiation incident on a surface with specific orientation and inclination, WUFI must reconstruct the altitude and azimuth of the sun at the moment of the measurement, so it needs the coordinates of the place where the measurement was performed. If other coordinates are entered, the computed solar positions in the sky will not be consistent with the measured data and the conversion will simply give erroneos results.

(4):
WUFI gives me the water content of the simulated wall in units of kg/m³ or in volume percent. However, I need the result in mass percent. How do I convert the results?

WUFI usually gives the water content as "water density", i.e. how many kg of water are in one m³ of building material.
A result given in volume percent tells you how many m³ of water are in one m³ of building material (expressed as percentage).
A result given in mass percent tells you how many kg of water are in one kg of dry building material (expressed as percentage). Please note that the water content in mass percent may easily exceed 100% if the dry material has low density.

With

m_W	:	mass of the water in the component
r_W	:	density of water (= 1000 kg/m³)
V_W	:	volume of the water in the component
m_C	:	mass of the component
r_C	:	density of the (dry) component
V_C	:	volume of the component

we have

water content as expressed by WUFI:

$$u = m_W / V_C \ [kg/m³]$$

water content expressed in volume percent:

$$u_v = V_W / V_C * 100$$

$$= (m_W / r_W) / V_C * 100$$

$$= (m_W / V_C) / r_W * 100$$

$$= u * 100 / r_W$$

$$= u * 100 / 1000$$

= u / 10

water content expressed in mass percent:

        u_m   = m_W / m_C * 100

                 = m_W / (r_C * V_C) * 100

                 = (m_W / V_C) * (100 / r_C)

                 = u * (100 / r_C)

                 = u / (r_C / 100)

So you get the water content in volume percent if you divide the WUFI result [kg/m³] by 10.
You get the water content in mass percent if you divide the WUFI result by (density of the building component / 100).

(5):
I'm trying to make sense of the WUFI results, but I'm confused. What exactly is 'relative humidity' and what is the relative humidity in a building component referred to?

In air the relative humidity is the ratio of the actual water vapor partial pressure p and the water vapor saturation pressure p_s. Example: If the air temperature is 20 °C (and therefore p_s = 2340 Pa) and the actual vapor pressure is 1872 Pa, then the relative humidity is 1872 Pa / 2340 Pa = 0.8 = 80%.

The condition in a porous building material corresponds to a RH of x % if it has been exposed to air with a RH of x % until equilibrium was reached and no moisture was taken up or given off any more.
The moisture in the material is then in equilibrium with the RH of the air in the pore spaces.
At RHs less than ca. 50% this means that a molecular layer with a thickness of one or a few molecules has been adsorbed at the surfaces of the pores; at higher RHs capillary condensation occurs.

Here is what happens in detail: the usual formulas for the saturation vapor pressure (such as in German standard DIN 4108) are only valid for plane water surfaces. At concavely curved surfaces, where the water molecules are bound stronger, the saturation vapor pressure is reduced; the more so the stronger the curvature of the surface is.

In a partly filled capillary the interface surface between air and water forms a curved meniscus whose curvature is determined by the surface energies involved and in particular by the radius of the capillary. If the air space in such a capillary is filled with air whose partial water vapor pressure is greater than the saturation vapor pressure at the meniscus (whereas the RH in the air is still less than 100%), then the air in the immediate neighborhood of the meniscus is supersaturated and water condenses from the air onto the meniscus, i.e. the capillary fills up.

In a porous material there exists a wide range of pore sizes. In the smallest pores, any menisci may be curved so strongly that in these pores moisture condenses onto the menisci from 50% RH in the pore air upwards. The smallest pores get filled with water, and subsequently larger and larger pores (with smaller curvatures of the menisci) get filled until a pore size is reached where – because of the larger pore size and the smaller curvature of the meniscus – the saturation vapor pressure at the meniscus is equal to the vapor pressure in the pore air. In this way capillary condensation results in an equilibrium between the moisture content and the relative humidity in the pore air, even if this RH is less than 100%. The amount of water needed to fill the pores up to this point depends on the pore structure and the pore size distribution.

The moisture storage function describes the amount of moisture taken up in this manner by the building material if it is exposed to air with a specific RH. Since this relationship between RH and moisture content is largely temperature-independent, the RH is an important and unique parameter describing the moisture content of a material.

(6):
When I do not define a moisture storage function for a material, WUFI uses a default moisture storage function instead. What does this function look like?

WUFI needs a well-defined moisture field for each time step, so it must assign a moisture content even to materials which nominally don't have any appreciable moisture content (e.g. water-repellent mineral wool, air layers etc.).

The default moisture storage function used by WUFI is described by the function

$$w = a / (b - phi) + c$$

> w: water content [kg/m^3]
> phi: relative humidity [-]

Since phi must be 0 for w=0, it follows immediately that

$$c = -a/b$$

The constants a and b are determined as follows:

b is set to 1.0105.

The moisture content at *free* saturation, w_f, corresponds to a relative humidity of 1 (=100%). Since WUFI also needs a unique relationship between moisture content and RH for moisture contents above free saturation, this oversaturation region is assigned RHs greater than 1, up to $phi_{max} = 1.01$. This value phi_{max} is reached when the moisture content reaches *maximum* saturation w_{max} which is determined by the porosity:

$$w_{max} = porosity * 1000 \text{ kg/m}^3$$

Therefore we have

w_{max} = a / (b-phi$_{max}$) − a/b.

Solving for a yields:

 a = w$_{max}$ * b * (b − phi$_{max}$) / phi$_{max}$,

and thus:

w / w$_{max}$ = phi / (b − phi) * (b − phi$_{max}$) / phi$_{max}$.

In particular, for phi=1 we have

w$_f$ / w$_{max}$ = 1 / (b − 1) * (b − phi$_{max}$) / phi$_{max}$ = 0.047.

So this pseudo material has a free saturation of w$_f$ = 0.047 w$_{max}$.
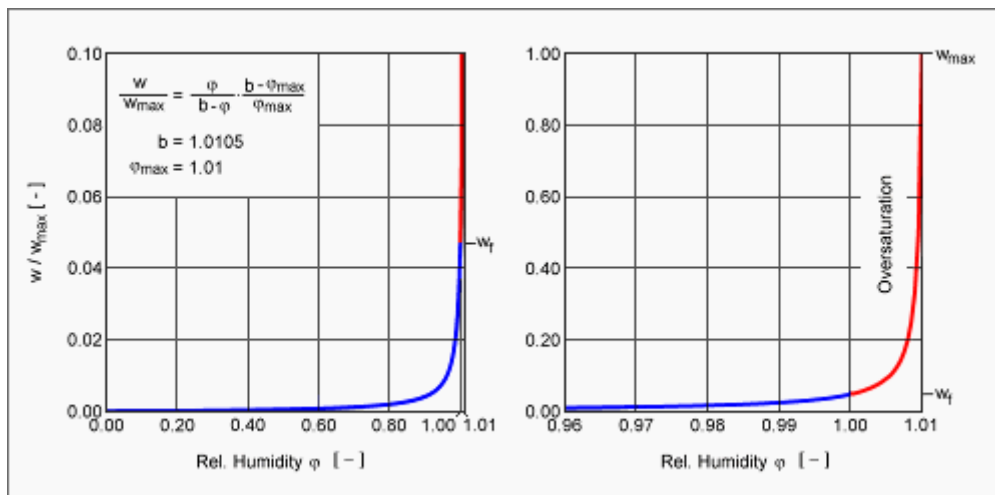
(7):
I did a WUFI calculation with an assembly that includes an air layer. However, I get completely unrealistic water contents for the air layer. What went wrong?

WUFI was developed to simulate the hygrothermal processes in porous building materials. The detailed simulation of heat and moisture transport in air layers (including convection, turbulence etc.) is much more complicated and is outside WUFI's scope. Furthermore, it does not make much sense to try and implement these inherently two- or three-dimensional processes in a one-dimensional simulation program.

Air layers can therefore only approximately be simulated by treating them as a 'porous' material. It is possible to allow for the amplifying effect of convection on heat and moisture transport by employing appropriate effective heat conductivities and vapor diffusion resistance factors.

However, the moisture storage function of an air layer can only very crudely be approximated by the moisture storage function of a porous material. The latter is largely temperature-independent (and implemented as such in WUFI), so that the functional dependence of the moisture content in air on the relative humidity *and*

temperature cannot be reproduced.

Furthermore, the default moisture storage function used by WUFI for materials for which the user has not defined one assumes that capillary condensation will occur in the material already at relative humidities less than 100%, which is not true for an air layer (it has been modeled after the moisture contents of dense mineral wool).

As a result you will get unrealistically large moisture contents for air layers. Note, however, that WUFI uses the *relative humidity* as the driving potential for moisture transport and computes the *water content* as a *secondary* quantity from the resulting relative humidity (using the moisture storage function of the respective material).

So the resulting distribution of *relative humidity* should in general be quite realistic, its temporal behavior will just be damped much more than in reality (the moisture content acts as a 'capacity term' for moisture transport in the same way the heat capacity acts as a capacity term for heat transport). If short-term fluctuations don't play a major role, the general trend in the behavior of the relative humidity should be tolerably realistic.

This also means that quantities that depend on the relative humidity in or near the air layer (e.g. mould growth rates) can be evaluated more realistically than quantities that primarily depend on the moisture content (e.g. heat conductivity, heat capacity).

Please note that the unrealistically large moisture capacity of an air layer may also affect other layers. If you are interested in the moisture distribution in an assembly that contains an air layer, the air may (or may not) take up more moisture than realistic, so that less moisture remains for distribution among the other layers.

You may mitigate these problems by explicitly defining a slightly more realistic moisture storage function for the air layer. To this end, use a linear function like

```
phi:    w:
0       0
1       wf
```

with a low value for w_f (the numerics may not be able to cope with very low values, you'll need to experiment a bit) (*). This avoids the spurious capillary condensation.

Also see the next question for a related problem.

(*) Note, however, that the porosity and thus w_{max} should remain high. If the water content exceeds w_f, WUFI reduces the vapor permeability, in proportion to the excess, to reflect the fact that the pore volume gets increasingly filled with water and thus vapor transport decreases. At $w=w_{max}$ the permeability reaches zero (all pores are filled). For vapor-permeable materials like air layers or mineral wool where moisture transport occurs mainly via vapor transport, w_{max} should therefore remain at a realistic value.

(8):
I tried to perform a WUFI simulation, but the water balance never adds up, regardless whether I make the grid as fine as possible or whether I choose stricter numerical parameters, as suggested in the on-line help. What can I do?

One situation where serious convergence failures tend to occur is a component with a vapor-permeable layer (e.g. air or mineral wool) which has accumulated a lot of moisture (RH ≈ 100%) and which is now exposed to a high temperature gradient (e.g. caused by intense solar radiation). WUFI originally wasn't developed to treat these cases which sometimes prove too demanding for the numerics that are mainly tuned to massive porous materials.
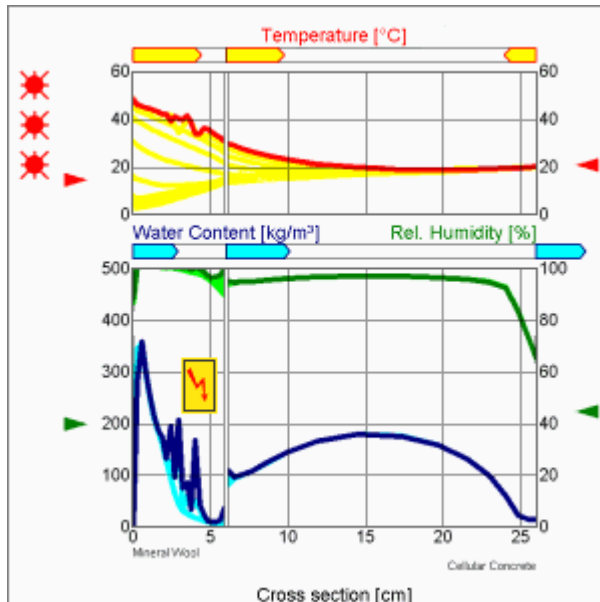
If everything else fails, you may try an alternative moisture storage function. In the material database, the moisture storage functions for materials like air or mineral wool are left undefined, so that WUFI uses an internally defined default moisture storage function (see the preceding two questions).

This moisture storage function assumes that for RHs above ca. 50% capillary condensation occurs which leads to increasingly higher moisture contents until free saturation is reached at 100% RH. This is not really realistic for air layers or hydrophobic mineral wool (it may be more appropriate for non-hydrophobic mineral wool).
Since it seems that the problem is mainly caused by the high water content, reduction of the water content by choosing a different moisture storage function often remedies the problem.
Please note that the *relative humidity* in the material will remain largely unaffected by the specific choice of the m.st.f., as explained above. So if you are interested in the *relative humidity* in the layer, your results will be affected only slightly (but please perform a few test calculations with different choices of the m.st.f. to be sure), and if you are interested in the *moisture content*, you should not rely on the default m.st.f. anyway, but use measured data instead which represent your particular material.

A possible choice for the moisture storage function in these cases is a table like this:

```
phi:    w:
0       0
1       wf
```

Use a low value for w_f (the numerics may not be able to cope with very low values,

you'll need to experiment a bit.) (*).
This linear function is even more realistic than the default function in that it avoids the capillary condensation for RH= 50..100%. The moisture content remains low up to RH=100% (as it should be in air or in hydrophobic insulation materials), and at or above 100% condensation may occur and increase the moisture content beyond w_f and up to w_{max}.

In particular if you are interested in moisture accumulation by condensation in these materials, use such a linear moisture storage function with low w_f. Then you know that any moisture content exceeding w_f must have been caused by condensation. You can then analyse this excess over w_f (test calculations show that this excess is only slightly dependent on the specific choice of w_f).

(*) Note, however, that the porosity and thus w_{max} should remain high. If the water content exceeds w_f, WUFI reduces the vapor permeability, in proportion to the excess, to reflect the fact that the pore volume gets increasingly filled with water and thus vapor transport decreases. At $w=w_{max}$ the permeability reaches zero (all pores are filled). For vapor-permeable materials like air layers or mineral wool where moisture transport occurs mainly via vapor transport, w_{max} should therefore remain at a realistic value.

(9):
How can I get the moisture content at a monitoring position?

WUFI's output includes the temporal behavior of
• temperature and relative humidity at the monitoring positions, and of
• the mean moisture content of each layer.

In order to get the *moisture content* at a *monitoring position*, you can either

• calculate it from the relative humidity prevalent at that monitoring position by means of the moisture storage function, or

• insert a thin 'diagnostic' layer at the position in question which has the same material properties as the surrounding material. WUFI will output curves for the water contents of each layer, including a separate curve for the diagnostic layer. This is also a useful way to get the water content of, say, the outermost 5 cm of a layer.

(10):
I want to examine the effect of driving rain on a painted wall. What liquid transport coefficients D_{ws} do I enter for the paint?

There are no measurements of transport coefficients or, equivalently, water absorption coefficients for paint layers themselves known to us.

What *is* measured sometimes is the water uptake for different paint layers by applying the paint on a standard substrate (such as cellular concrete or lime cement mortar) and measuring the water absorption for this composite material.

So the best thing you can do is probably the following:
Don't use a layer of rendering and a layer of paint; instead, use a layer of the 'hybrid' material for which you already know the combined water uptake from the measurements. Use the D_{ws} from the hybrid water uptake (let it generate by WUFI from the measured water absorption coefficient) and use the D_{ww} and other data from the original rendering.

The vapor diffusion resistance of the paint can then be included in the surface transfer coefficients (as long as it is not markedly moisture-dependent).

Please note some possible problems, though:

- The result of the measurement may (or may not) depend on the substrate material, the details of the application etc. So you should make sure that you are using a water absorption value that has been measured under the same circumstances as the case you consider in your calculations.

- The paint may slowly change its properties when it gets wet (e.g. by swelling). The mean properties over a rain period of two or three hours may be different than the mean properties during a measurement that takes many hours. Again, the measurement should be done close to natural conditions.

(11):
What is the right choice for the rain absorption factor for an unrendered natural sandstone wall? When I use the value of 0.7 suggested by WUFI, then the entire wall gets wet like a sponge. When I reduce the absorption factor to 0.5, the same happens, it just takes longer. What's wrong?

This should not happen, but the rain absorption factor is very likely not to blame. It does not depend on the material of the wall (it depends a bit on its surface structure and, of course, on its tilt). After all, it simply expresses the fact that some of the rain water splashes off when it hits the wall surface and is no longer available for absorption.

Are you sure that the amount of rain is okay? Maybe you created your own *.KLI file and used normal rain instead of the correct driving rain?
Several kinds of sandstone have a very high water absorption (e.g. Rüthener) and may accumulate an inacceptable amount of moisture when exposed to a wet climate such as the Holzkirchen weather. Maybe you used one of those?

(12):
I want to investigate the hygric behavior of ecological insulation materials, such as flax, hemp or reed. However, these materials consist of fibres, whereas WUFI is mainly designed for capillary-active porous materials. What is the best approach?

The difference between fibres and porous mineral materials is in general not really crucial for the transport equations. The fibre materials may tend to have preferred

transport directions, but these cannot be modeled in a one-dimensional calculation anyway.

Determining the liquid transport coefficients, however, may be difficult or even impossible if they change their consistency upon wetting (e.g. by caking).

On the other hand:
As long as your insulation materials don't become so wet that capillary conduction becomes predominant, you can ignore capillary transport and only consider diffusion transport. That is, you leave the liquid transport coefficients undefined and only enter a µ-value. Surface diffusion phenomena may be allowed for by using a moisture-dependent µ-value.

Since you probably only want to assess *whether or not* the insulation becomes wet by rain or condensation, you will mainly be concerned with water contents in the sorption moisture region of the moisture storage function, for which these simplifications should be adequate.
As these materials must be prevented from becoming wetted through anyway, there will be no need to investigate in detail the behavior of an insulation soaked full of water.

(13):
I want to find out how long it takes a wall with construction moisture to dry out. Which initial moisture content should I use?

That depends on a number of individual circumstances such as the amount of production moisture (e.g. in cellular concrete or lime silica bricks), the amount of mixing water (in concrete or mortar), the amount of rain hitting the wall while it was unrendered, the season when construction took place (warm / cold) etc., so no general answer is possible here. The table gives examples for typical initial moisture contents:

Material	Water content [kg/m³]
Fresh concrete:	
free water	175
Concrete, 28 days old (at 70% hydratation):	
bound water	85
dried water	25 … 45
free water	65 … 45
	(sum = 175)
Concrete, 3 to 6 months old (at 90% hydratation):	
bound water	105
dried water	35 … 50
free water	35 … 20
	(sum = 175)
DIN 4108 "thermal protection"	
practical moisture content of concrete	50
Cellular concrete	180 … 220
Clay brick masonry	100 … 150

(14):
How can I simulate a wall whose exterior surface has been treated with a water-repellent agent? Is it correct to set the rain water absorption factor to zero? Do I need to change the sd-value of the exterior surface, even though I use a diffusion-permeable treatment?

The rain water absorption factor must be set to zero if the water absorption is indeed completely stopped by the treatment. If water absorption is only reduced, you must determine the water absorption coefficient for the treated material and replace the part of the wall which corresponds to the penetration depth of the treatment with a layer of the treated material.

If the treatment does not change the diffusion permeability of the material, no sd-value needs to be specified for the exterior surface.
Many treatments do, however, increase the diffusion resistance factor (μ-value) of the material. In these cases, this additional resistance should be allowed for by an appropriate sd-value. Alternatively, and even better, you can replace the part of the wall which corresponds to the penetration depth of the treatment with a new layer that has the same material properties but an appropriately increased μ-value.

Even if the water absorption is negligible (so that adjusting the rain absorption factor instead of the liquid transport coefficients would be sufficient) and vapor diffusion is not hindered by the treatment (so that no μ-value needs to be adjusted), it might nevertheless be preferable to model the treated part of the wall by defining a separate layer whose liquid transport coefficients have been reduced or even set to zero.
This is because the capillary conduction in this layer does not only determine the amount of absorbed rain water; it also influences the wall's drying behavior.
Drying-out proceeds faster if water from the interior of the wall can be conducted to the surface by capillary transport and can evaporate from there. Drying-out is impeded, however, if capillary transport stops a few centimeters behind the surface and moisture can only dry out after crossing this treated layer by vapor diffusion. So this is another mechanism by which water-repellent treatment may reduce the drying potential of a wall, in addition to a possibly increased μ-value.

(15):
WUFI gives me the option to estimate the liquid transport coefficients D_{ws} from the water absorption coefficient. How can I check how good this estimate is?

You can check the estimated D_{ws} or determine an unknown water absorption coefficient from known D_{ws} by simulating a water absorption experiment.

Define an initially dry layer consisting of the material in question, let it rain on the surface (with a higher rain load than the layer can absorb to be sure that no insufficient rain load is limiting the water uptake) and look at the amount of water absorbed after e.g. 100 or 200 hours.

This may be done with a one-line *.KLI-file such as:

[h:	rain:	rad:	t_ext:	RH_ext:	t_int:	RH_int:]
500	1000	0	20	1	20	0

The number of hours entered for the duration of this one-line climate file does not matter since WUFI re-starts reading from the beginning of the climate file if the simulation period extends beyond the end of the climate file.

Set the vapor diffusion thickness of the interior surface to a very high value to prevent vapor transport through that surface.

You should perform a few test calculations in order to find a suitable thickness of the test specimen which assures that the moisture front traverses most of the specimen (in order to make the most efficient use of the numerical grid) but not all of it.
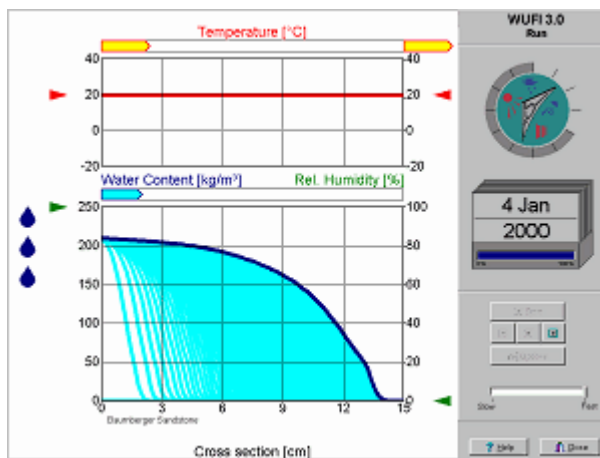
(16):
I want to evaluate the effect of different material parameters on water absorption by simulating a laboratory experiment in which different specimens are exposed to a limited water supply. I created the corresponding KLI file with a spreadsheet program to avoid typing in all those numbers by hand, but WUFI can't read this KLI file.

The reason why WUFI does not accept your spreadsheet file is probably that you did not write it in ASCII format and/or did not write the header lines in the correct format. Please consult the on-line help for details on creating *.KLI files with your own programs.

Also note that if you want to simulate a simple absorption experiment with a specified constant water supply and constant climate conditions it is sufficient to create a *.KLI file which consists of only one single line, for example the line:

[h:	rain:	rad:	t_ext:	RH_ext:	t_int:	RH_int:]
1000	5	0	20	1	20	0.8

means that for 1000 hours after the starting time of the climate file there is a constant rain load of 5 Ltr/m²h.

An alternative would be a single line like

[h:	rain:	rad:	t_ext:	RH_ext:	t_int:	RH_int:]
1	5	0	20	1	20	0.8

which states that for 1 hour after the starting time of the climate file there is a constant rain load of 5 Ltr/m²h. When WUFI reaches the end of a climate file, it starts reading the file anew from the beginning, so you can simulate an experiment which is running for 100 hours (or whatever) and the climate file will automatically be read 100 times over.

The only difference between these two files is that in the latter case WUFI does not accept a calculation time step greater than 1 hour, whereas in the former case you may also choose any convenient time step greater than one hour.

For a simple absorption experiment I usually make sure the climate file contains a rain load large enough so that it does not limit the absorption of the specimen, for example 100 Ltr/m²h, which would not be plausible for real rain.

If you want to have a specified limited supply please don't forget that WUFI reduces the amount of rain it reads from the climate file by the rain absorption factor which allows for the fact that some rain splashes off of the wall on impact and is not available for absorption. This factor should be set to 1 during your experiments.

Furthermore, please note a small subtlety involved in using limited rain supply. Let's assume you have a specimen with a water absorption factor of 3 kg/m²√h and the climate file specifies a rain load of 3 Ltr/m²h. During each time step, WUFI performs a *test* step with an *unlimited* supply and subsequently evaluates the amount of water taken up. If this amount of water is less than the amount supplied in the climate file, then the material is the limiting factor and WUFI accepts the result of this time step and proceeds with the calculation.

However, if the amount taken up is more than the amount supplied, WUFI performs additional iteration steps in which a fictitious 'flow resistance' at the specimen surface is adjusted until the amount taken up matches the amount supplied.

If you are using 1-hour steps in your calculation, and the dry specimen absorbs 3 kg/m² of water in the first step and the climate file supplies 3 kg/m²h, then WUFI accepts the trial step done with unhindered absorption and proceeds with the calculation.

But if you are repeating the same calculation with a time step of half an hour, things are different! Since the water uptake is not linear in time, the specimen will absorb *more* than 1.5 kg/m² in the first half hour, while WUFI compares this with 1.5 kg/m² of rain in the first half hour (assuming the rain is evenly distributed over the hour) and now *limits* the amount absorbed to 1.5 kg/m².

This is usually of no concern with real rain data and real building materials, but it may be beneficial to be aware of these subtleties if performing test calculations with limited rain supply.

(17):
I'm familiar with steady-state water vapor diffusion calculations (in particular, the Glaser method described in German standard DIN 4108). So I knew I had to expect more or less frequent dew conditions in the wall I was simulating. However, when I watched the WUFI film, I could never see the relative humidity reach 100%.

The usual building materials always have some moisture sorption capacity. This

sorption capacity buffers changes in relative humidity inside the wall. If you define boundary conditions which would provoke instant condensation in a Glaser calculation, you may nevertheless not get condensation in a realistic case (such as simulated by WUFI).

That's because a relative humidity of 100% would correspond to a moisture content equal to free saturation of the material in question, and this amount of water must first be transported into the dew region. The diffusion flows *do* transport moisture to the location where dew conditions prevail, but the transported amounts of moisture are generally small, and the RH will only slowly rise from the initial value, say 80%, to 81%, 82% etc. It may take days or weeks until sufficient amounts of water have been transported to the dew region so that finally free saturation (i.e. RH=100%) is reached. Meanwhile, boundary conditions may have changed and there are no dew conditions any more.

The Glaser method, on the other hand, simply assumes that 100% RH are reached instantly, it doesn't consider the necessity to actually move water in order to reach the moisture content that corresponds to 100% RH.

Furthermore, real materials (as opposed to Glaser) usually have some capillary conductivity which tries to dispel any moisture accumulations. This effect actively works against local water build-up, so that 100% RH can't be reached easily.

Of course, you *may* get water accumulation in your building component if conditions are right (or wrong). But this will rarely be accompanied by 100% RH. If you see relative humidity approaching 100% somewhere in your component, it's probably much too late...

(18):
OK, this explains why I didn't see dew conditions *in* the wall. But shouldn't condensation at least happen at the facade on days with high humidity and little sunshine?

The surface of a normal wall in temperate or cool climate regions will always be somewhat warmer than the surrounding air. By day because of solar radiation (even on foggy or overcast days), by night because of heat flow from indoors (exceptions: air-conditioned dwellings or nightly emission, see below).

Since the RH in the air can't be greater than 100% and the RH at the warmer-than-air wall surface will always be less than the RH of the air, you usually can't reach or surpass 100% there.

You'll have free saturation (i.e. 100% RH) at the surface when enough rain is absorbed, but this is not due to dew conditions.

The surface temperature will fall below air temperature when the wall emits more long-wave radiation than it gets back from surrounding surfaces. If it even falls below the dew-point temperature, you will indeed get dew conditions at the surface. This happens routinely during the night, especially during clear nights, when the long-wave emission of the water vapor in the atmosphere is at a minimum.

In these cases you may get repeated and regular wetting of the surface which may lead to dust accumulation or algae growth, especially with exterior insulations whose

surfaces cool down particularly strongly.
Currently, WUFI does not routinely allow for this effect, since the necessary data on atmospheric and terrestrial counterradiation are rarely available. If these data are provided, WUFI can compute nightly emission cooling in principle, but only approximately. Future WUFI versions will have a more sophisticated emission model incorporated.

(19):
I used WUFI to compute the water content in a variety of wall assemblies. In order to evaluate their hygrothermal performance, I now need appropriate criteria, e.g. standards that should not be exceeded.

There are no general criteria which are applicable for every case. Different materials and different applications require different criteria.
Here are some general hints:

• The most important criterion: the moisture must not accumulate over time. Water condensing in the building component must be able to dry out again. If the moisture content in your component keeps increasing – even slowly – you'll run into problems sooner or later.

• The building materials which come into contact with moisture must not be damaged (e.g. by corrosion or mould growth).
  Mineral building materials are usually not at risk.
  Wood should not exceed 20 mass-% of moisture during a prolonged period; otherwise mould growth may result (possible exception: increased moisture while temperatures are low).

German standard DIN 4108-3 adds the following criteria:

• The amount of condensing moisture in roof or wall assemblies must not exceed a total of 1.0 kg/m².
  This is a more or less arbitrary criterion. In order to test it with WUFI, start the calculation with the normal equilibrium moisture (corresponding to 80% RH) and see if the total water content exceeds the starting value by more than 1 kg/m².

• At interfaces between materials that are not capillary-active, no moisture increase exceeding 0.5 kg/m² is permissible.
  This is meant to avoid moisture running or dripping off, which could accumulate elsewhere and cause damage.

• The moisture increase in wood must not exceed 5 mass-%, the moisture increase in materials made of processed wood must not exceed 3 mass-%.
  These are more or less arbitrary numbers.

In addition, special criteria may be applicable in specific cases, for example:
•   Are there any materials which are particularly sensitive to moisture damage?
•   Does increased heat loss by moist insulation exceed any energy conservation requirements?
•   Is the building material at this moisture level sensitive to frost damage?
•   Is there salt in the wall which must be kept from crystallizing or from moving

around?

- Etc.

Even if you don't have clear criteria which fit your case, you may still perform a ranking of your assemblies by comparing them with each other or with a standard case.

(20):
I want to simulate a ventilated curtain wall; how can I do this? I can model the air gap as an air layer in WUFI but it seems these air layers are assumed to be stagnant, which is certainly not the case in my ventilation gap.

If you model the ventilation gap as an air layer in WUFI, it is indeed treated as a *closed* air layer without connection to the exterior air. The effect of inner convection on heat and moisture transport across the air layer is allowed for (as a first approximation) by use of effective heat conductivities and vapor diffusion resistance factors.

The air flow and air exchange phenomena in a *ventilated* air layer cannot be simulated with a one-dimensional program.
If the air exchange is large enough, it *may* be justified to assume exterior air conditions in the air gap. That is, you do not model the curtain facade and the air gap, and you consider the surface of the insulation or the wall itself (as the case may be) as the exterior surface in WUFI's component assembly. Rain must be set to zero (simply by setting the rain absorption factor = 0).
It will be advisable to choose appropriate effective values for the exterior heat transfer resistance and the short-wave solar absorptivity, but this requires calibration by experimental data.

The same problem is encountered in simulations of roofs, either because of a ventilation cavity in the roof or because of the question how to model the covering and the batten space.

The investigations described in [1] used a simplified treatment of a roof. WUFI simulations were carried out to examine the moisture balance in a fully insulated west-facing pitched roof (50° inclination). The covering and the batten space could be omitted from the simulated assembly because measured temperatures in a similar roof on IBP's testing area were available and could be used to determine appropriate effective surface transfer coefficients. The measurements were taken on the waterproofing foil (i.e. directly on the insulation layer) and were compared with the computed temperatures at the outer surface of the modeled insulation layer which sufficed to represent the whole roof for the purpose of a thermal adjustment.
The thermal surface transfer coefficients were adjusted in WUFI until good agreement between measurement and calculation was reached. This was the case with an effective short-wave absorptivity of a=0.6 and an effective heat transfer coefficient of α=19 W/m²K. The effective absorptivity is roughly identical with the real absorptivity (for red roof tiles), while the effective α is slightly higher than the usual standard value of 17 W/m²K. Obviously the covering and the air in the batten space have no major effect on the thermal behavior of the roof, at least in this case. In particular, the amount of heat removed by convection through the ventilated air cavity seems negligible and the entire heat created in the covering by solar radiation is passed on into the underlay.
The question to which extent this isolated result can be generalised could only be

answered by more extensive comparisons with measurements.

[1] H.M. Künzel: Außen dampfdicht, vollgedämmt? – Die rechnerische Simulation gibt Hinweise zu dem Feuchteverhalten außen dampfdichter Steildächer. bauen mit holz 8/98, S. 36-41.

(21):
I calculated the sum of the heat flows through the exterior and the interior surfaces during one year and I noted that the heat flow out of the building component through the exterior surface is much larger than the heat flow into the component through the interior surface. But shouldn't they be nearly equal? How can more heat flow out of the component than into it? No heat can be created in the wall.

The solar radiation incident on the exterior surface is electromagnetic radiation and not heat flow; it is therefore not included in the heat flow data.
However, after absorption it is converted to heat so that there exists indeed a heat source in the wall. Since the heat source is close to the exterior surface, most of the generated heat flows outward through the exterior surface, only a small amount flows inward through the interior surface. This asymmetric heat flow is superimposed on the usual transmission heat flow (which in colder climates alway goes from the indoor side to the outdoor side of the building element).

Please note that in the film display the heat flow arrow at the exterior surface *does* include the solar radiation. Otherwise it would look very strange to see the sun shining on the wall surface but a lot of heat flowing *out of* the wall. This is a concession to the intuitive expectations of the audience.

Also note that there can be a heat source or sink in the wall when water condenses or evaporates. In some cases these latent heat effects can be non-negligible (e.g. drying of a wall wetted by driving rain).

(22):
Are there more recent weather data available? The copy of WUFI I downloaded still has those of 1991.

'Recent' weather data would probably not be very useful to you. It is more important to have weather data which are either known to be typical for a specific location or which repesent defined critical conditions (e.g. for design purposes). We consider 1991 to be a fairly typical year for Holzkirchen. 'Critical' weather data, i.e. one particularly cold year and one particularly warm year, are in preparation and will be made available as two 'Hygrothermal Reference Years'.

(23):
For the numerical solution of the transport equations the component must be divided into a series of grid elements for whose midpoints the resulting temperatures and water contents are computed at each time step, and across

whose element boundaries the heat and moisture fluxes required by the equations are flowing. In order to arrive at correct fluxes across the boundaries, effective conductivities have to be assigned to the boundaries which represent the integral effect of the conductivities between the midpoints of the two elements. The investigations reported in [1] show that the results do in fact depend on the way these effective heat and moisture conductivities are determined from the real conductivities of the two elements: obviously linear interpolation between the neighboring conductivities is preferable within a material layer, and a resistance formulation is more appropriate for boundaries between layers with different materials. How does WUFI treat these element boundary conductivities?

It is obvious that at element boundaries where materials with possibly very different conductivities are in contact with each other a simple average of the conductivities (or resistances) cannot result in a realistic effective conductivity to describe the fluxes between the elements. Take as an example a material with very low resistance which borders on a material with very high resistance. The flux flowing between the midpoints of the two elements is determined by the *sum* of the two successively encountered *resistances*, not by the arithmetical average of the conductivities.
One might suppose now that this physically motivated reasoning also applies to smaller differences between the neighboring elements and that therefore the resistance formulation (i.e. the *harmonic* mean of the conductivities) should always be used within the entire component. However, test calculations during the development of WUFI's numerics showed that this is not the case. Within a material the *arithmetical* mean of the conductivities yielded better results (compared with experimental data), so that WUFI uses harmonic averages at material boundaries and arithmetical averages within a material, in agreement with the cited investigation. The derivation of the resistance formulation assumes equal fluxes in the two element halves, but this need not be the case if transient processes in materials with heat or moisture storage capacities are considered.

[1] Galbraith, G.H. et al.: Evaluation of Discretized Transport Properties for Numerical Modelling of Heat and Moisture Transfer in Building Structures, Journal of Thermal Env. & Bldg. Sci., Vol. 24, Jan. 2001

(24):
I want to perform a hygrothermal simulation of a wall on which every day a shadow is cast for some time by a building on the other side of the street. WUFI does not offer an option to allow for such a shadow, but I could simply use a self-created *.KLI file by converting the measured radiation myself and allowing for the sadow in this process. But, how is the conversion of the radiation data done?

First you need to determine the radiation incident on the surface of your building element from the measured data describing the radiation on a horizontal surface. For this purpose it is necessary to determine the position of the sun in the sky at the time of the measurement.

Position of the Sun:

Let J be the number of the day in the year (1 .. 365 or 366). Then compute the auxiliary quantity x:

```
x = 0.9856° * J - 2.72°
```

and the equation of time `Z` (in minutes):

```
Z = -7.66*sin(x) - 9.87*sin( 2*x + 24.99° + 3.83°*sin(x) ).
```

The equation of time describes the variable difference in time between the actual culmination of the sun and noon. Because of the ellipticity of the Earth's orbit and the obliquity of the Earth's axis the sun wanders with slightly irregular speed across the sky. During the course of the year there are thus times where it reaches culmination earlier than a fictitious sun with constant speed (the so-called 'mean' sun) and times where it reaches culmination later.

The local meridian is the great circle that rises from the horizon due north, passes through the point directly above the observer and crosses the horizon again due south. The instant at which the sun crosses the local meridian on its daily path from east to west is also the instant where its position is due south and where it reaches its daily greatest height.

When the *apparent* sun (i.e. the actually observed sun) crosses the meridian it is 12 noon local apparent solar time (LAT); when the *mean* sun crosses the meridian it is 12 noon local mean time (LMT). The equation of time is therefore the difference between LAT and LMT (Z = LAT − LMT).

Furthermore, since the place where the measurements were taken is usually not located on the reference meridian of the time zone (15° East for the Central European Time Zone, CET), the difference between local mean time and zone time must be allowed for, which is 4 minutes for 1° difference in geographical longitude `L` and one hour for 15° difference. If the measurement was timed in Central European Summer Time CEST, convert to CET first by subtracting one hour (CET = CEST − 1h).

In this way you can now compute the corresponding local apparent time LAT from the known measurement time (in CET):

```
LAT = CET - (15°-L)/(15°/h) + Z/(60 min/h) [h]
```

and thus determine the position of the sun: at 12 noon LAT the sun is exactly on the meridian, before noon it stands at an appropriate distance to the east of the meridian, after noon, an appropriate distance to the west.
The distance between the sun and the meridian is measured by the hour angle:

```
ω = (LAT - 12h) * 15°/h.
```

The hour angle ω is reckoned perpendicular to the meridian; it is negative before noon, zero at noon and positive after noon; it increases steadily by 15° per hour.

The hour angle gives the distance of the sun from the meridian; the declination δ, i.e. the distance of the sun from the celestial equator, then fixes the position of the sun completely. The declination varies between −23°26' at winter solstice, 0° at the equinoxes, and 23°26' at the summer solstice. Since its change during one day is very small, it suffices to compute it once for the day `J` under consideration:

```
sin(δ) = 0.3978 * sin( x - 77.51° + 1.92° * sin(x) ),
cos(δ) = sqrt(1 - sin(δ)^2)
```

where `x` is the auxiliary quantity introduced above.

The last step is the transformation from the coordinate system determined by ω and δ into the more familiar coordinates altitude γ and azimuth ψ (=compass direction). The geographical latitude φ of the measurement location is needed for this.

```
sin(γ) = cos(δ)*cos(ω)*cos(φ)+sin(δ)*sin(φ)
cos(γ) = sqrt(1 - sin(γ)^2)

if cos(γ)=0 then ψ = 0
else begin
        sin(ψ) = cos(δ)*sin(ω)/cos(γ)
        cos(ψ) = (cos(δ)*cos(ω)*sin(φ)-sin(δ)*cos(φ))/cos(γ)
        ψ = atn2(sin(ψ), cos(ψ))
     end
```

This formula uses `atn2(A,B)`, the arctangent function for two arguments `A` and `B`, which is provided by many programming languages, and which gives the arctangent of `A/B` in the correct quadrant. If this function is not available to you, you can use the ordinary arctangent and then explicitly determine the correct quadrant (i.e. you compute ψ=`atn(A/B)`, and in the case B<0 you add 180° if ψ<=0 or subtract 180° if ψ>0. If `B`=0 and `A`<0 then ψ=-90°, if `B`=0 and `A`>0, then ψ=+90°.).
The azimuth ψ is counted from south=0°, positive towards the west and negative towards the east.

Examples for Munich (48.13°N, 11.58°E):

```
                CET        Altitude   Azimuth       Declination
 (J=1)
  1 Jan. 2001 09:00         6.436°    -44.614°      -22.987°
  1 Jan. 2001 12:00        18.836°     -4.209°      -22.977°
  1 Jan. 2001 16:00         3.441°     49.590°      -22.962°
  1 Jan. 2001 16:25         0.434°     54.316°      -22.961°

 (J=79)
 20 Mar. 2001 07:00         6.498°    -82.661°       -0.126°
 20 Mar. 2001 12:21        41.851°     -0.041°       -0.038°
 20 Mar. 2001 16:00        22.726°     62.242°       +0.022°

 (J=172)
 21 Jun. 2001 08:00        34.501°    -87.522°      +23.437°
 21 Jun. 2001 12:00        65.126°     -8.437°      +23.437°
 21 Jun. 2001 18:00        19.771°    103.475°      +23.436°
```

These values were computed with an astronomical ephemeris program. Of course, the simplified method described above cannot reproduce these data exactly, in particular for low altitudes of the sun (1 Jan. 16:25), since it does not allow for atmospheric refraction. On the other hand, the comparison allows you to assess the overall accuracy of this simple method. Your results should agree with these exact positions within a few tenths of a degree. The declinations have been included as well for testing purposes.

Converting the Radiation Data:

We assume that your input data are measured hourly values of the global (`I_glob`) and the diffuse radiation (`I_diff`) on a horizontal surface.

The radiation incident on the measuring or the component surface is split up into a direct and a diffuse component. The direct component is received directly from the sun and is therefore a directed quantity that depends on the position of the sun. The direct radiation vertically incident on a surface which is facing the sun is the direct normal radiation `I_dir_normal`. The direct radiation `I_dir` obliquely incident on a horizontal measuring surface depends on the solar altitude γ:

```
 I_dir = I_dir_normal * sin(γ).
```

Since `I_dir` can be computed as the difference between the measured values of global and diffuse radiation and γ can be determined from the measurement location and time by the method given above, the corresponding direct normal radiation is

```
 I_dir_normal = (I_glob - I_diff) / sin(γ).
```

The angle of incidence η, i.e. the angle that the direct normal radiation makes with the normal to the component surface which is tilted by the angle β and oriented in the direction α, is

```
cos(η) = sin(γ)*cos(β) + cos(γ)*sin(β)*cos(α-ψ)
```

  η: Angle of incidence (vertical=0°)
  γ: Altitude of the sun
  ψ: Azimuth of the sun (south=0°, positive towards west, negative towards east)
  β: Tilt of the component surface (vertical wall=90°)
  α: Azimuth of the normal to the component surface (south=0°, west positive).

The direct radiation incident on the component surface is therefore:

```
 I_dir_in   = I_dir_normal * cos(η)
            = (I_glob - I_diffus) * cos(η) / sin(γ).
```

The diffuse component consists of the radiation scattered by the air ("blue sky") and the clouds which comes from all directions and can approximately be treated as isotropic. Diffuse radiation is measured by blocking the direct radiation with a shadow ring around the solarimeter. The measurement gives `I_diff`, the diffuse radiation incident on the horizontal measuring surface from the entire sky hemisphere. A component surface with arbitrary tilt and orientation receives the same diffuse radiation (since it is isotropic), but for non-horizontal surfaces the fact has to be allowed for that the sky covers a smaller part of its field of view and the total amount of incident diffuse radiation is reduced proportionately (a vertical wall sees sky only in the upper half of its field of view):

```
I_diff_in = I_diff * ( cos(β/2) )^2.
```

Additionally, you may add the global radiation reflected from the ground:

```
I_refl_in = ρ * I_glob * ( sin(β/2) )^2,
```

where ρ is the short-wave albedo of the ground and the reflection is assumed to be isotropic. In the current version, WUFI ignores the reflected component of the radiation.

The total radiation incident on the surface of the building component is the sum of the components:

```
I_in = I_dir_in + I_diff_in + I_refl_in.
```

You may now modify or supplement this conversion method according to your needs. For example, you can allow for shadows by setting the direct radiation to zero at times where the sun is behind the obstacle, and by reducing at all times the diffuse radiation in proportion to the reduction of the field of view caused by the obstacle. On the other hand, at times where the sun illuminates the facing side of the obstacle, it may be necessary to add some reflected radiation.

Hint: if the radiation data to be converted have been averaged over some longer interval (e.g. one hour), please note the following:

It is advisable to compute the solar positions for the middle of the measuring interval, i.e. the averaged data measured between 9h and 10h should be converted using the solar position computed for 9:30h.

If the sun has risen or set during such a measuring intervall (which is easy to check for, using the solar altitude), the solar position must be computed for the middle of the visibility interval, not for the middle of the measuring interval.

Independent of the duration of the measuring interval, radiation data obtained at very low solar altitudes should not be used, since under these circumstances the direct normal radiation must be calculated from very small and unreliable values obtained for the direct radiation at grazing angles of incidence.

Details on these conversion methods can be found in:
VDI 3789 Umweltmeteorologie, Blatt 2: Wechselwirkungen zwischen Atmosphäre und Oberflächen; Berechnung der kurz- und der langwelligen Strahlung.

In addition to data on global and diffuse radiation, the weather file IBP1991.WET included with WUFI contains radiation data obtained with a west-facing solarimeter which you can use to test your conversion routines.

Continue with Conversion Factor Table

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Conversion Factor Table

These are the conversion factors used by WUFI to switch from SI units to IP units and vice versa:

```
Quantity                      SI units   IP units    SI→IP       IP→SI

length                        m          in          1/0.0254    0.0254
length                        cm         in          1/2.54      2.54
length                        mm         in          1/25.4      25.4
length                        m          ft          1/0.3048    0.3048
bulk density                  kg/m³      lb/ft³      1/16.01846  16.01846
porosity                      m³/m³      ft³/ft³     1.0         1.0
temperature                   °C         °F          (**)        (**)
delta-temperature             °C         °F          1.8         1/1.8
spec. heat capacity           J/kgK      Btu/lb°F    1/4.1868E3  4.1868E3
thermal conductivity          W/mK       Btu/h ft°F  0.57779     1/0.57779
therm. cond. supplement       %/m-%      %/m-%       1.0         1.0
thermal resistance            m²K/W      h ft²°F/Btu 5.679       1/5.679
heat transfer coefficient     W/m²K      Btu/h ft²°F 1/5.678263  5.678263
heat flux                     W/m²       Btu/h ft²   1/3.154591  3.154591
relative humidity             -          -           1.0         1.0
relative humidity             %          %           1.0         1.0
sd-value                      m          perm        (***)       (***)
diffusion resistance factor   -          perm in     (****)      (****)
water content                 kg/m³      lb/ft³      1/16.01846  16.01846
water absorption coeff.       kg/m²√s    lb/in²√s    1/703.0696  703.0696(*)
liquid transport coeff.       m²/s       ft²/s       10.764      1/10.764
water balance                 kg/m²      lb/ft²      1/4.882428  4.882428
pressure                      kPa        lbf/in²     1/6.894757  6.894757
rain load                     Ltr/m²=mm  in          1/25.4      25.4
```

(*) = 0.4535924 / 0.0254^2

(**)   t/°F = 9/5 * (t/°C) + 32
        t/°C = 5/9 * (t/°F) - 17.777...

(***)   sd/m = 3.28/(Δ/perm)
        Δ/perm = 3.28/(sd/m)
        Δ: permeance

(****) μ/[-] = 128.8/(Π/(perm in))
        Π/(perm in) = 128.8/(μ/[-])
        Π: permeability

Note that when switching unit systems, the new values need to be truncated to fit the edit fields in the dialogs, so that switching back may result in slight differences from the original values.

Continue with

Go to

Version info

	WUFI Pro	WUFI light	WUFI ORNL/IBP
Assembly:			
manual grid editor	●	-	-
grid data as table	●	-	-
material data user-editable	●	1)	1)
no. of monitoring positions	unlimited	0	2
max no. of layers	120	10	10
Orientation/Inclination/Height:			
Arbitrary inclination	●	0° or 90°	0° or 90°
Numerical input for inclination allowed	●	-	-
possible orientations	8	4	4
predefined building heights can be selected	●	●	●
rain coefficients user-editable	●	-	-
rain load according to ASHRAE 160P	●	-	only predefined params
Surface Transfer Coeffs:			
Values user-editable	●	-	-
explicit radiation balance	●	-	-
Initial conditions:			
"constant" value editable	●	●	●
"in each layer" accessible	●	-	-
"read from file" accessible	●	-	-
"initial temp." editable	●	●	●
Sources and Sinks:			
Number of heat sources	unlimited	0	0
Number of moisture sources	unlimited	0	1 (1% fixed)
Number of air change sources	unlimited	0	0
Climate:			
supplied files	all	dep. on lang.	North-American
user-defined climate files	●	-	-
For left side only selection from map	-	●	●
For right side only sine curves	-	●	●
WTA exterior conditions	●	-	-
sine parameters editable	●	-	-
Calculation:			
numerical options	●	-	-

\# VersionInfo

$ Version info

+ 6030

K version;versions;WUFI Pro;WUFI light;WUFI ORNL/IBP

calculation limited to 2 years	-	●	●
start of calc. user-editable	●	●	●
time step editable	●	-	-
additional profiles	●	-	-

Quick graphs:

quick graph export	●	-	-

Film:

film viewer can also be run after calculation	●	-	-
film export	●	-	-
external film viewer only shows film "example.fid"	-	●	●

General:

options for report	●	-	-
options for result graphs	●	-	-
open project files from earlier versions	●	-	-
switch between unit systems	●	-	●
import measured data	●	-	-
export ASCII results	●	-	-
no. of cases	unlimited	2	2

1) only thickness, typical construction moisture, info text.

Continue with Batch Job

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Batch Job

WUFI can be run from the command line, so that projects can be processed automatically with an appropriate batch file. For example, this allows to run extensive calculations such as parametric studies over the weekend.

Call WUFI with

> WUFI *ProjectFileName* [Options]

The name of the project file to be processed is specified with the parameter *ProjectFileName*. The following options can be used to control WUFI's actions:

-c   Start computing the active case

-C   Start computing all cases

-s   Save the results

-f   Export a film. The exported film file will be given the name %ProjectFileName%_%CaseIndex%.fid; the case name will become the film title.

-v   Export selected courses to an ASCII file. The selection is done with a bit mask (e.g. 0110001) which refers to the list of available courses in the dialog Outputs: ASCII-Export. The number and the sequence of the courses displayed in this list depend on the number of layers and the number of monitoring positions in the project. Examples:
-v010 exports the Solar Radiation (Exterior Climate), **-v0000000000001** exports the Total Water Content (list item #13) if no additional monitoring positions have been defined. The courses produced for any additional monitoring positions would shift the Total Water Content further down in the list .

This option can not be used together with option **-C**.

The name of the exported file will be %ProjectFileName%_%CaseIndex%.asc if no other file name has been specified. To specify a different name for the export file open the dialog Outputs: ASCII-Export, enter the desired file name in the text box "Output file", close the dialog with "OK" and save the project.

The options will only be executed if the project file name has been specified and the option list contains **-c** oder **-C**. The order of the options in the option list is arbitrary; the options may also be written /**c** etc.

[#] BatchJob
[$] Batch Job
[+] 6035
[K] batch job;batch

Version notice: only WUFI Pro can be run from the command line.

Continue with Glossary

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Glossary

assembly

The assembly defines the sequence of layers with their respective thicknesses and material properties that make up the entire →component.
Building up the assembly in the dialog "Assembly / Monitor Positions" is one of the main tasks in setting up a WUFI simulation.

building component

→component

case

A project file may contain several different →projects, so-called cases. This is useful for managing investigations which require a series of calculations that cover the same general subject but are slightly different from each other (e.g. parametric studies). In principle, all the cases in a project are independent, however, and you may save completely different projects in one project file if you wish.

climate

The climate is the description of the boundary conditions that act on the interior and exterior surfaces of the →component. In general, the exterior climate is determined by the weather (and thus described by a collection of weather data), the interior climate is determined by the indoor air conditions. The terms "climate" and "weather" are used indiscriminately in WUFI.
The exterior and interior climates for a WUFI simulation are specified in the "Climate" dialog.

construction

→component

component

The component is the building element that is under investigation in WUFI. It may for example be a complete wall or roof cross-section or part thereof. In most cases it is composed of several layers that consist of different materials.
The layer sequence that defines the makeup of the component is the →assembly.

courses

Courses are one of WUFI's result types. Courses describe the temporal

---

Glossary
$ Glossary
+ 6040
K glossary;assembly;building
component;case;climate;weather;construction;component;courses;film;profiles;proje
ct;WUFI

evolution of certain quantities such as the moisture content in the building component or the heat fluxes through the surfaces. In the "Result Graphs" dialog the courses are displayed as graphical curves. See also "What Do I Get From WUFI?".

The other result types are →profiles and the →film.

film

The film is one of WUFI's result types. The film contains all the profiles of temperature, relative humidity and water content that have been computed during the simulation. These profiles are displayed in rapid succession during the simulation itself and may be viewed again at leisure after the calculation with the film viewer. Viewing this animated sequence of profiles as a 'movie' gives the user a dynamic impression and better understanding of the thermal and hygric transport processes in the component. See also "What Do I Get From WUFI?".

The other result types are →courses and →profiles.

profiles

Profiles are one of WUFI's result types. Profiles show the distribution of certain quantities across the building component at a specified point in time, such as the temperature or the moisture distribution. In the "Result Graphs" dialog the profiles are displayed as graphical curves. See also "What Do I Get From WUFI?".

The other result types are →courses and the →film.

project

The project is the collection of all input data and the calculation results. All of these data are written to the project file *.WUG. Do not forget to re-save the project file after a calculation, otherwise the calculation result will be lost when you close WUFI.

The calculation results in the project file comprise →courses, →profiles and the →film. You may deselect any of these data from being written to the project file in order to reduce the file size.

weather

→climate

WUFI

WUFI (**W**ärme **u**nd **F**euchte **i**nstationär – transient heat and moisture) is a Windows-based program for the hygrothermal (heat and moisture) analysis of building envelope constructions.

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The **approximated** moisture storage function is given by an analytic curve that is made to pass through the moisture contents for 0%, 80% and 100% RH. These moisture contents are known for many materials even if a complete moisture storage function has not been measured: the moisture content at 80% RH is the practical moisture content and the moisture content at 100% RH is the free saturation.

This approximation is useful if it can be expected that the shape of the true moisture storage function is sufficiently similar to the analytic curve, which is not always the case, however.

Example:
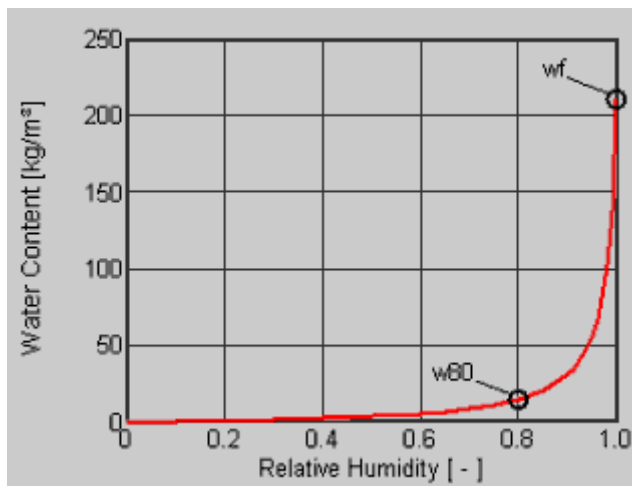
If no detailed data are available on the moisture dependence of certain material data, a table with estimated data for selected moisture contents can be **generated** from appropriate standard material data.
The methods used for these estimates are in some cases based on theoretical assumptions which need not be valid for all materials (i.e., for most materials the estimation yields useful values, for some it does not).

Example: the liquid transport coefficient as measured (left) and as generated from a water absorption coefficient of 0.043 kg/m²√s (right).
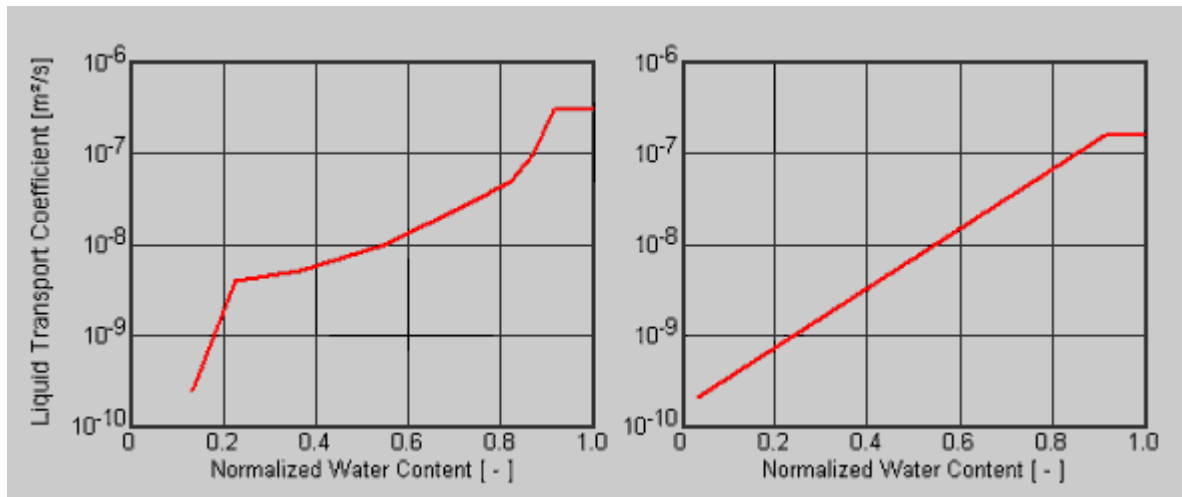
WUFI can generate:
- Liquid transport coefficients (from the A-value and the free saturation)
- Heat conductivity, moisture-dependent (from the heat conductivity dry, the bulk density and the moisture-induced heat conductivity supplement)

Numerous data are entered in WUFI as a **table**. The entries are directly entered in the appropriate field. Use the cursor keys to move between the individual fields. You can create **new** lines and **delete** old ones, **copy** whole lines to a sort of 'clipboard' and **insert** them elsewhere. If there is not enough space to display the entire table, use the scroll bar or the "PageUp", "PageDn" keys to reach other parts of the table.

Example:

Nr.	RH [-]	Water Content [kg/m³]	
1	0,0	0,0	New
2	0,1	8,5	
3	0,3	17,6	Delete
4	0,65	27,5	
5	0,8	35,6	Copy
6	0,9	43,1	
7	0,93	46,5	Insert
Copy 0,8		35,6	