



European Cooperation in the field of Scientific and Technical Research



Building Integration of Solar Thermal Systems – TU1205 – BISTS

Modeling Solar Thermal Systems with DesignBuilder-EnergyPlus

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What is simulation?

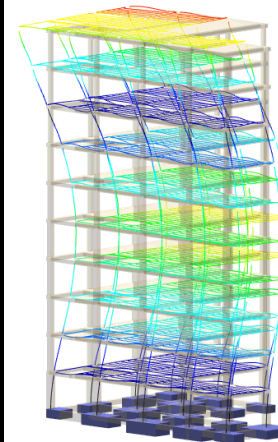
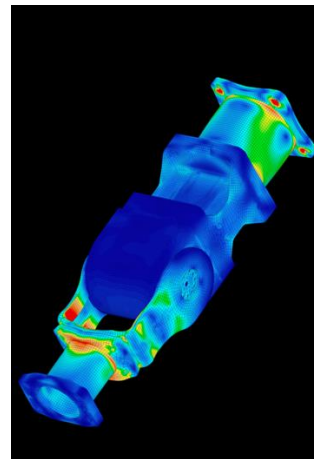
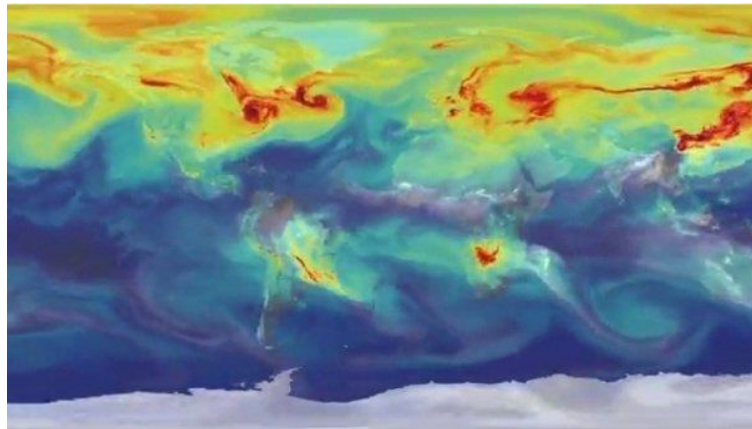
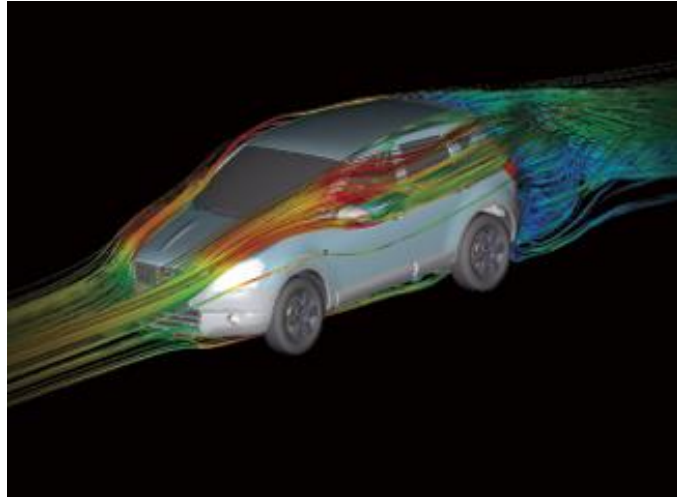
1. The act or process of simulating.
2. Act or object made in **imitation** of something else with intent to **deceive**.
- 3.a. **Representation** of the functioning of **one system** by means of the functioning of another (**simplified**) system.
- 3.b. **Examination** of a **problem** (often not subject to direct experimentation) by means of a **simulation device**.

Based on www.merriam-webster.com



Horse simulation (Wikipedia)

Examples of simulation applications



Product design

Engineering

Weather
prediction

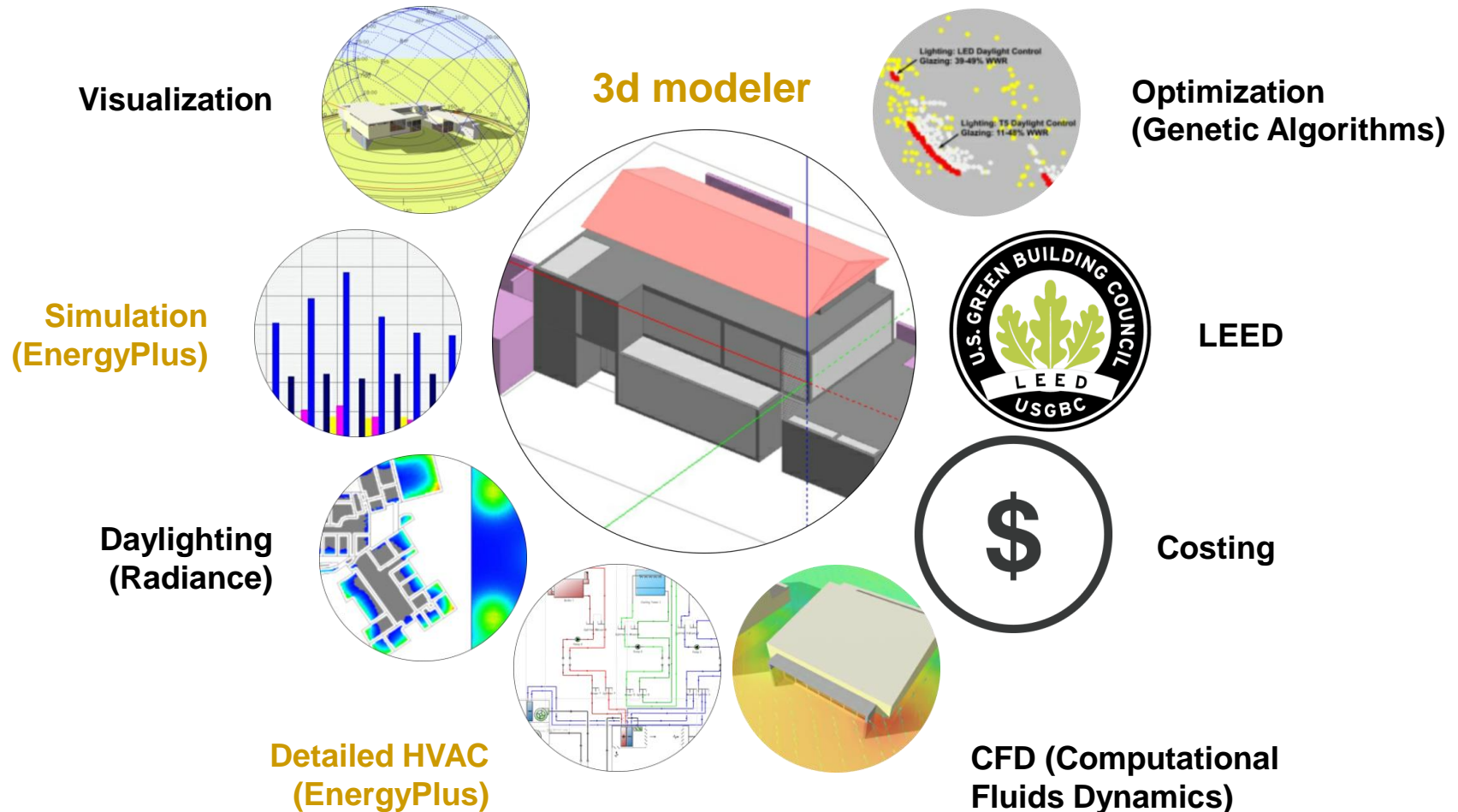
Training and
education

Video games

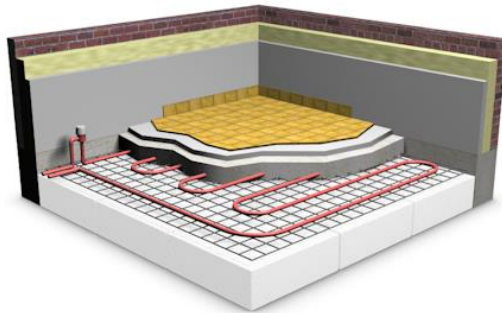
And of course:

**Building and
HVAC design**

DesignBuilder, a modular approach

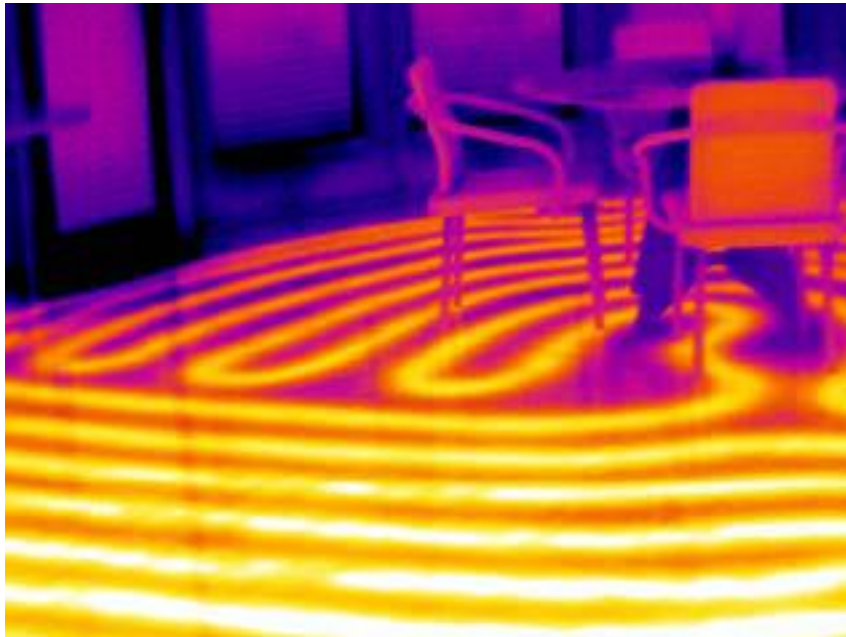


Case study: **STS** applied to a heated floor system



A dwelling in Boise, Idaho, USA
(Lat. **43.57**, Long. **-116.22**)

DesignBuilder-EnergyPlus heated floor model

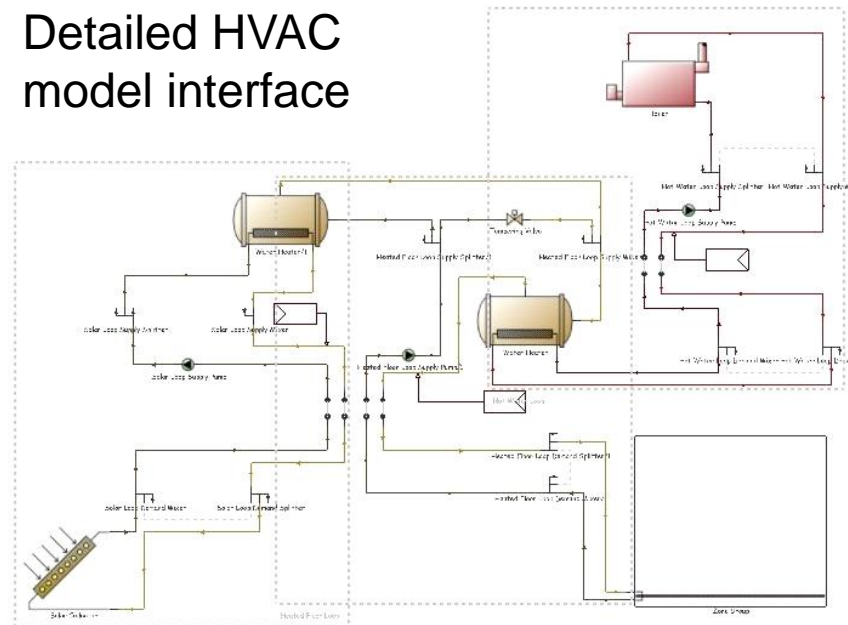


Low temperature radiant systems with **hot water pipes** embedded in **floor constructions**.

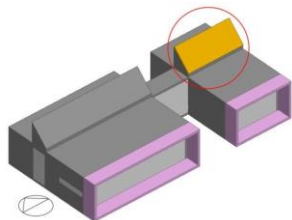
- Large heating surface area and relatively low fluid temperature (40-55 °C).
- Two types of heated floor: **Constant flow** and **Variable flow**. Variable flow heated floor is fully autosizable.
- Heated floors can be connected to hot water loops fed by boiler, Ground Source Heat Pumps and/or **Solar Thermal Systems**.

General modelling approach

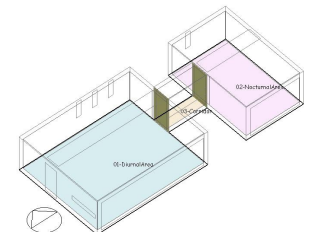
Detailed HVAC model interface



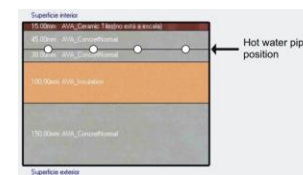
Solar collector surface



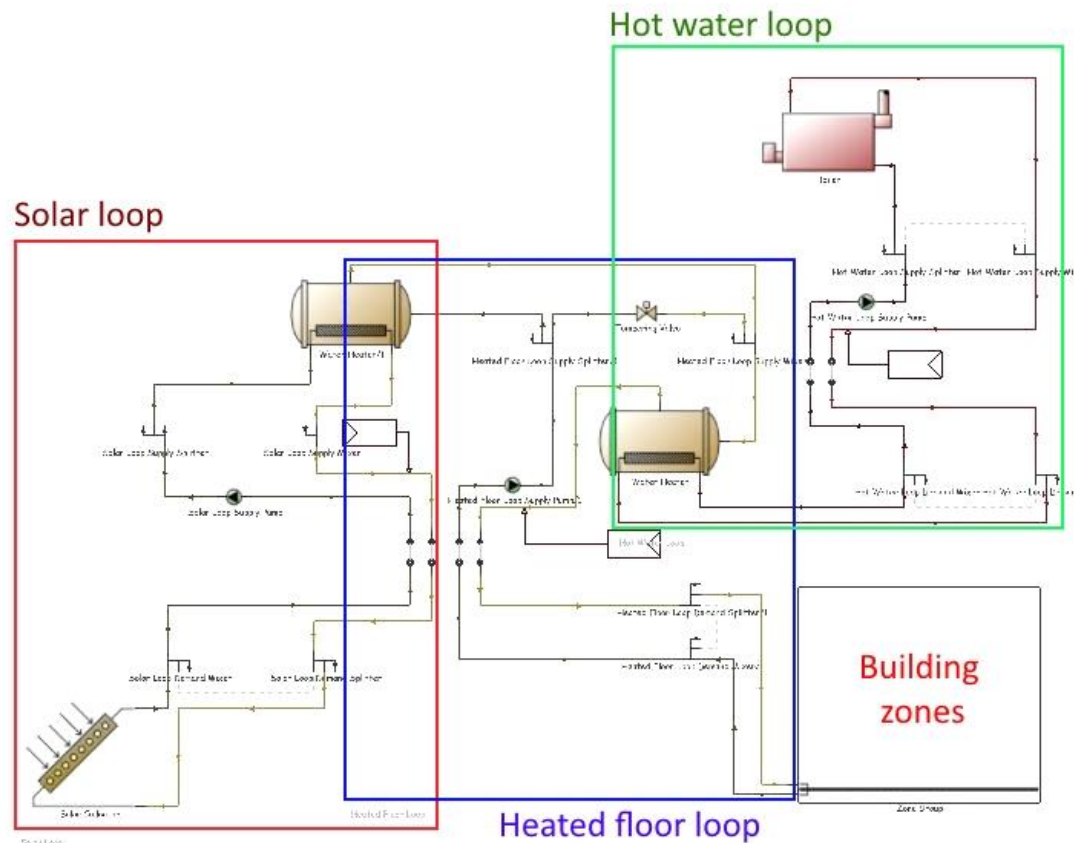
Building thermal zones



Ground floor construction



Detailed HVAC model: general scheme

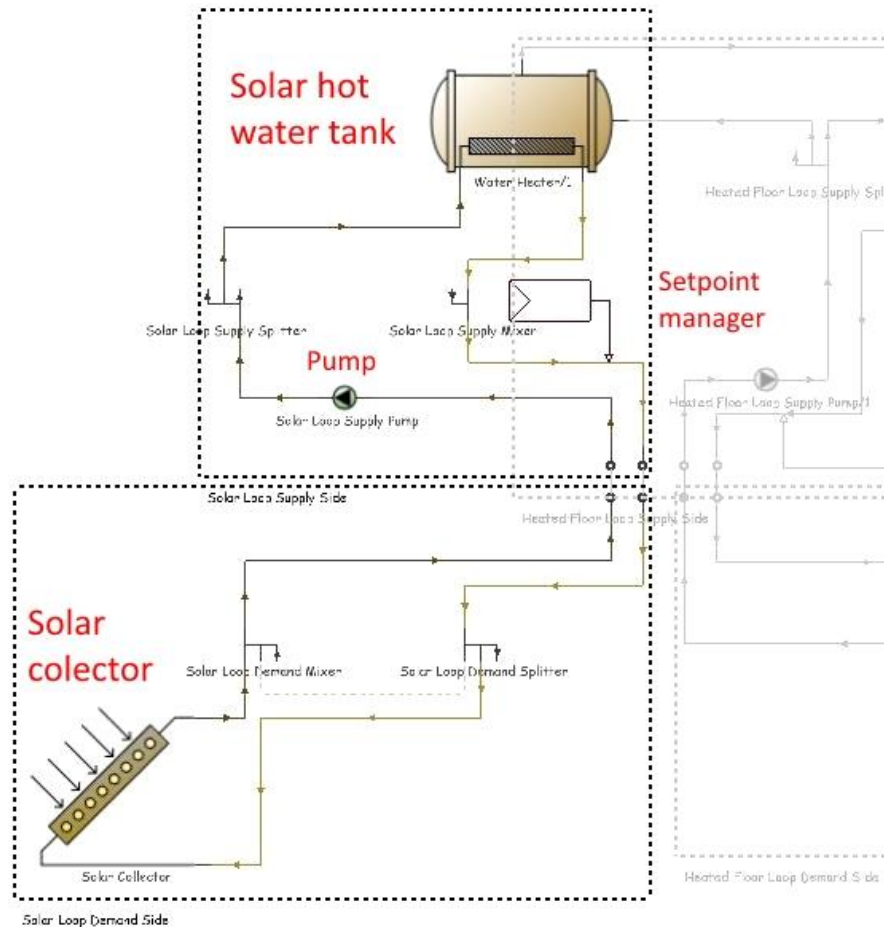


The system consists of three main loops:

- Solar loop
- Heated floor loop
- Hot water loop

The heated floor loop connects the systems with the building zones.

Detailed HVAC model: **solar loop**



Solar loop with storage water tank.

- The solar collector heats the working fluid, which is sent to a heat exchanger into the solar hot water tank.
- The solar water tank heats the water and stores it for later use.

Solar loop data

Edit Plant loop -

Plant loop Data

General Plant Equipment Operation

General

Name Solar Loop

Fluid type 2-EthyleneGlycol

Glycol concentration 0.250

Plant loop volume (m3) Autocalculate

Flow Type

Plant loop flow type 2-Variable flow

Temperature

Maximum loop temperature (°C) 100.00

Minimum loop temperature (°C) 0.00

Flow Rate

Maximum loop flow rate (m3/s) Autosize

Minimum loop flow rate (m3/s) 0.000000

Load distribution scheme 1-Sequential

Plant loop demand calculation scheme 1-SingleSetPoint

Temperature Protection >>

Differential Thermostat >>

Sizing

Design loop exit temperature (°C) 80.00

Model data < Model data < Help Cancel OK

Solar collector data

Edit Solar collector -

Solar collector Data

Solar collector

General

Name: Solar Collector

Maximum flow rate (m3/s): 0.0000500

Solar Collector Surface

Solar collector surface: Solar collector 1

Control

☒ Differential thermostat hot node sensor

Performance

Solar collector performance template: ACR Solar International 10-01

Gross area (reference use only) (m2): 46.298000

Test flow rate (m3/s): 0.000032

Test correlation type: 1-Inlet

Efficiency Equation Coefficients:

Coefficient 1: 0.603000

Coefficient 2 (W/m2-K): -3.8665000

Coefficient 3 (W/m2-K2): 0.0015000

Incident Angle Modifier Coefficients:

Coefficient 1: 1

Coefficient 2: -0.194400

Coefficient 3: -0.018600

Model data <admin> Help Cancel OK

Link to the solar collector surface in the 3d model

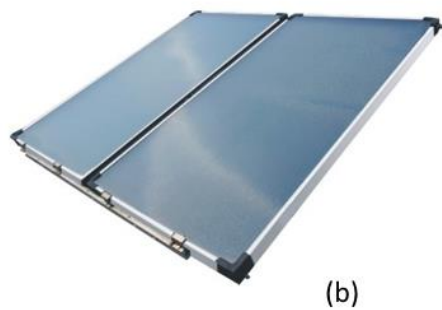
Selection of solar collector type

Solar collector performance data (from template)

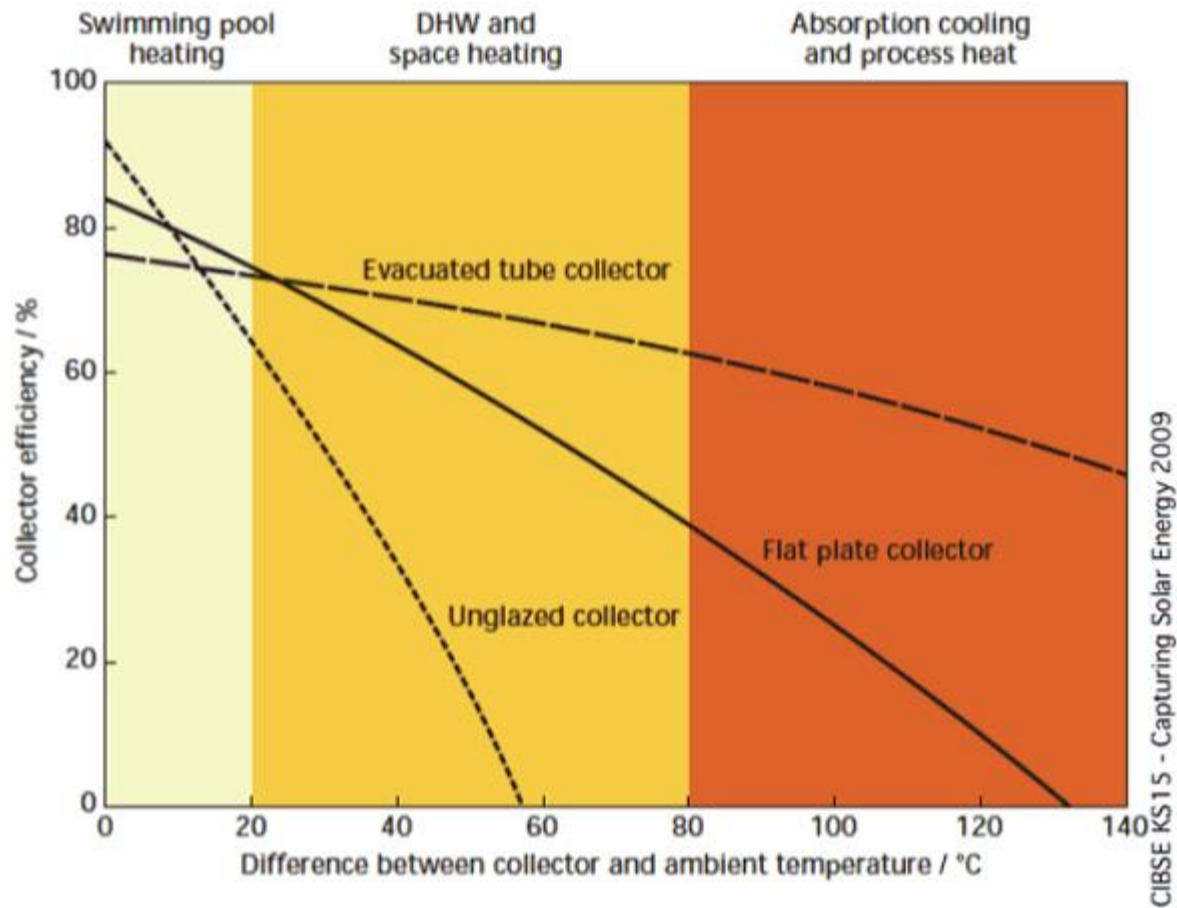
Solar collector object

The **EnergyPlus** solar collector model is based on the equations of the ASHRAE standards, as well as Duffie and Beckman (1991).

- This model applies to **unglazed** (a) and **glazed** (b) flat-plate collectors, as well as banks of **tubular** (c) evacuated collectors.
- The model uses coefficients for the **energy conversion efficiency** and **incident angle modifier**, based on testing methodologies described in ASHRAE Standards 93 and 96.
- **DesignBuilder** offers a dataset of templates containing performance coefficients for near 170 commercial solar collectors (unglazed, glazed, and tubular).



Efficiency and applications of solar collector types



Solar hot water tank data

Edit Water heater -

Water heater Data

Water heater | Sizing

General

Name: Water Heater/1


Tank volume (m3): Autosize

External Heating Plant Connection

☒ External heating plant connection

Indirect water heating recovery time (hr): 1.50


Temperature Settings

 Setpoint temperature schedule: Hot Water flow set point temperatur

Maximum temperature limit (°C): 100.00

Ambient Heat Transfer Settings

Ambient temperature indicator: 1-Schedule

 Ambient temperature schedule: Water heater ambient temperature


Heat Loss Coefficients

On-cycle loss coefficient to ambient temperat...: 0.00

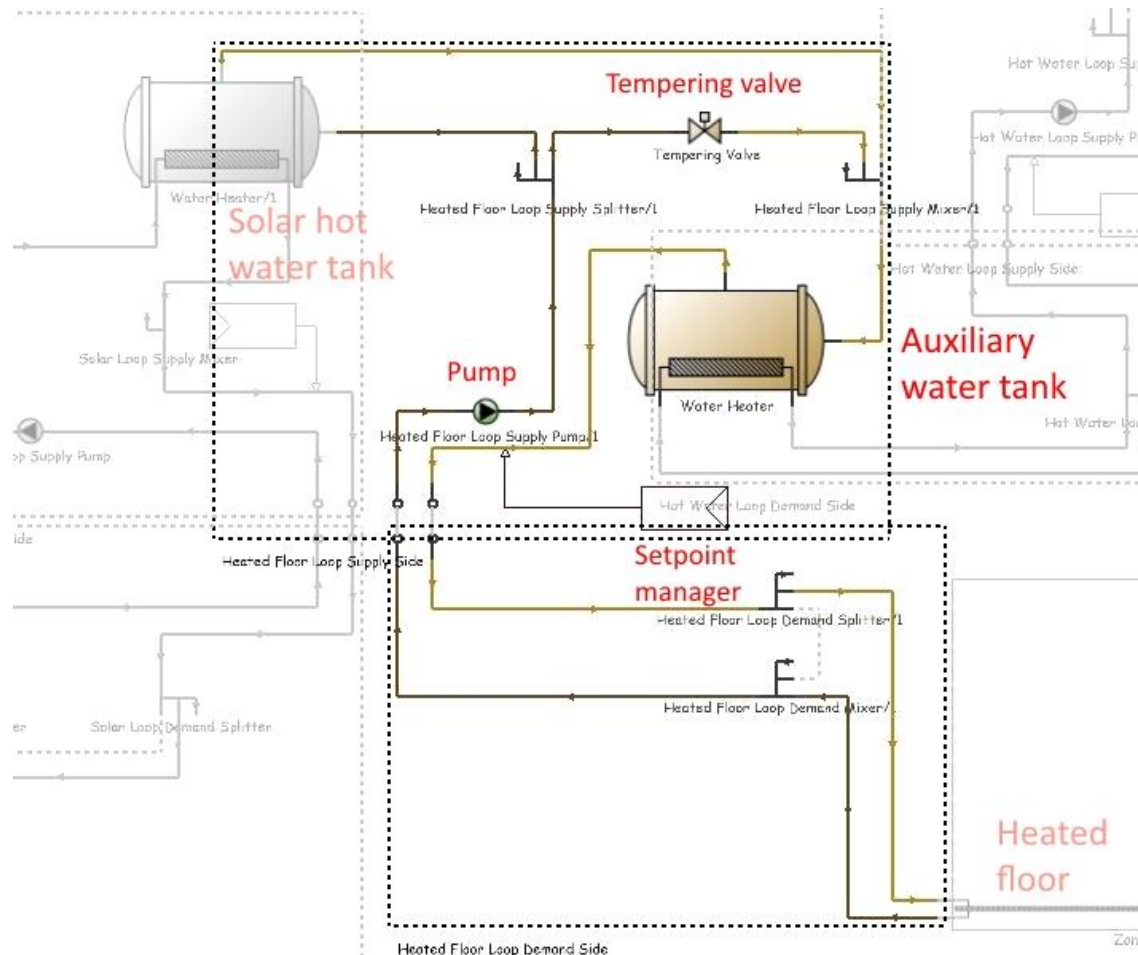
Off-cycle loss coefficient to ambient temperat...: 0.00

Use-Side Settings

Source-Side Settings

 **Model data <admin>** | Help | Cancel | OK

Detailed HVAC model: heated floor loop



The auxiliary water heater provides additional heat if the solar tank water is not hot enough.

- Can be modelled as an instantaneous-tankless water heater, but in this case it is modeled as a standard tank with external heating source.
- The hot water leaving the storage tank can be tempered using a three-way valve (tempering valve) to achieve the target temperature.

Heated floor loop data

Edit Plant loop -

Plant loop Data

General Plant Equipment Operation

General

Name Heated Floor Loop

Fluid type 1-Water

Plant loop volume (m3) Autocalculate

Flow Type

Plant loop flow type 2-Variable flow

Temperature

Maximum loop temperature (°C) 80.00

Minimum loop temperature (°C) 0.00

Flow Rate

Maximum loop flow rate (m3/s) Autosize

Minimum loop flow rate (m3/s) 0.000000

Load distribution scheme 1-Sequential

Plant loop demand calculation scheme 1-SingleSetPoint

Sizing

Design loop exit temperature (°C) 40.00

Loop design temperature difference (d... 10.00

Operation

Availability schedule On

Model data < Help Cancel OK

Auxiliary water tank data

Edit Water heater -

Water heater Data

Water heater | Sizing

General

Name: Water Heater


Tank volume (m3): Autosize

External Heating Plant Connection

☒ External heating plant connection

Indirect water heating recovery time (hr): 1.00


Temperature Settings

 Setpoint temperature schedule: Underfloor heating setpoint tem

Maximum temperature limit (°C): 80.00

Ambient Heat Transfer Settings

Ambient temperature indicator: 1-Schedule

 Ambient temperature schedule: Water heater ambient temperature


Heat Loss Coefficients

On-cycle loss coefficient to ambient temperat...: 0.00

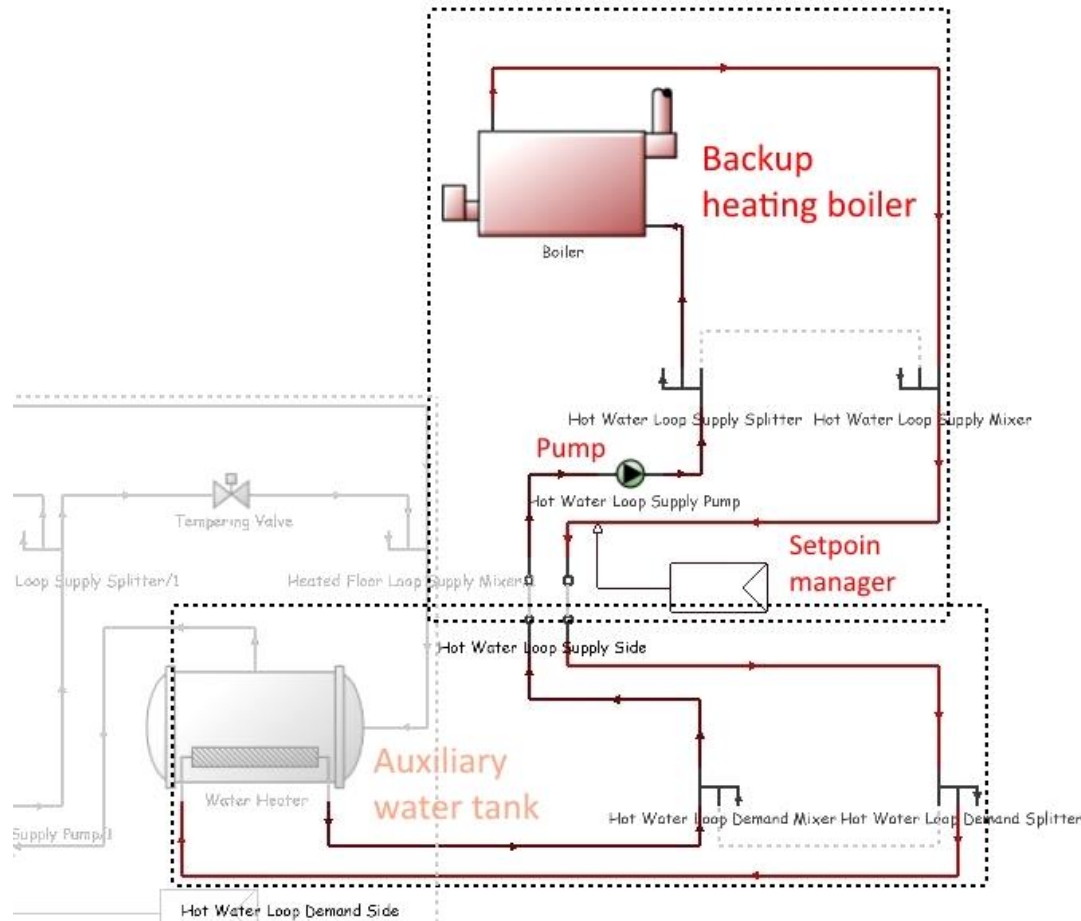
Off-cycle loss coefficient to ambient temperat...: 0.00

Use-Side Settings

Source-Side Settings

 Model data <admin> | Help | Cancel | OK

Detailed HVAC model: hot water loop



The backup heating boiler provides heat to the auxiliary water tank, generating a specific hot water loop.

Hot water loop data

Edit Plant loop -

Plant loop Data

General | Plant Equipment Operation

General

Name: Hot Water Loop

Fluid type: 1-Water

Plant loop volume (m3): Autocalculate

Flow Type

Plant loop flow type: 2-Variable flow

Temperature

Maximum loop temperature (°C): 100.00

Minimum loop temperature (°C): 0.00

Flow Rate

Maximum loop flow rate (m3/s): Autosize

Minimum loop flow rate (m3/s): 0.000000

Load distribution scheme: 1-Sequential

Plant loop demand calculation scheme: 1-SingleSetPoint

Sizing

Design loop exit temperature (°C): 80.00

Loop design temperature difference (d...): 10.00

Operation

Availability schedule: On

Model data < | Help | Cancel | OK

Backup heating boiler data

Edit Hot Water Boiler -

Boiler Data

Hot Water Boiler

General

Name	Boiler
Boiler template	Gas-fired condensing boiler
Fuel type	1-Natural gas
Nominal capacity (W)	Autosize
Boiler flow mode	3-Not modulated
Parasitic electric load (W)	25.000
Sizing factor	1.20

Efficiency

Nominal thermal efficiency	0.890
Normalized boiler efficiency curve	CondensingBoilerEff

Water Outlet

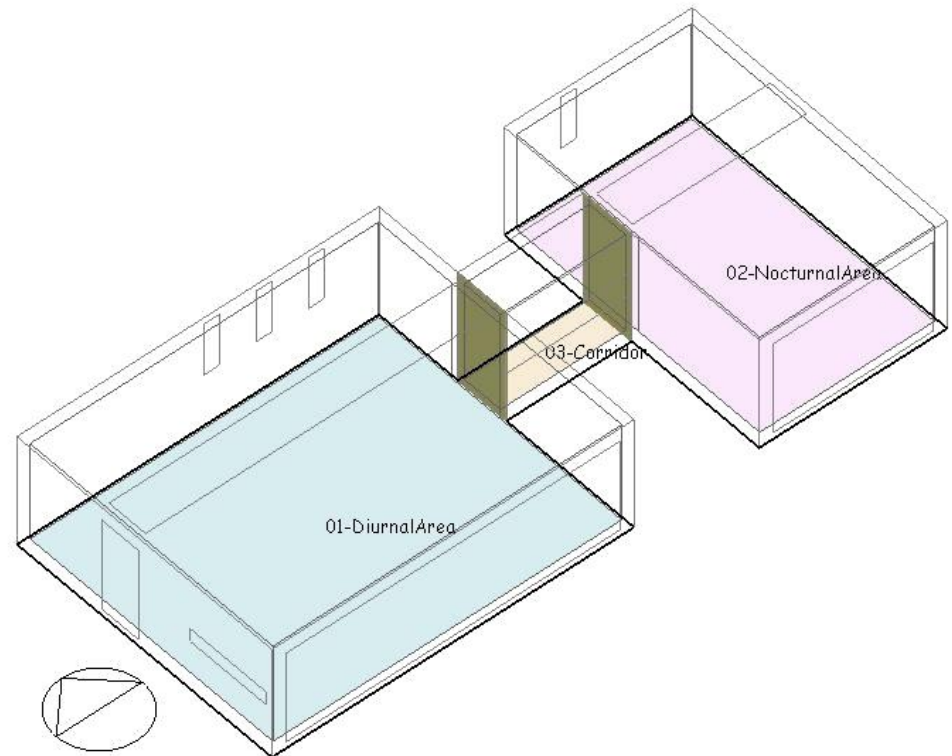
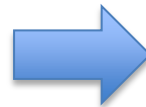
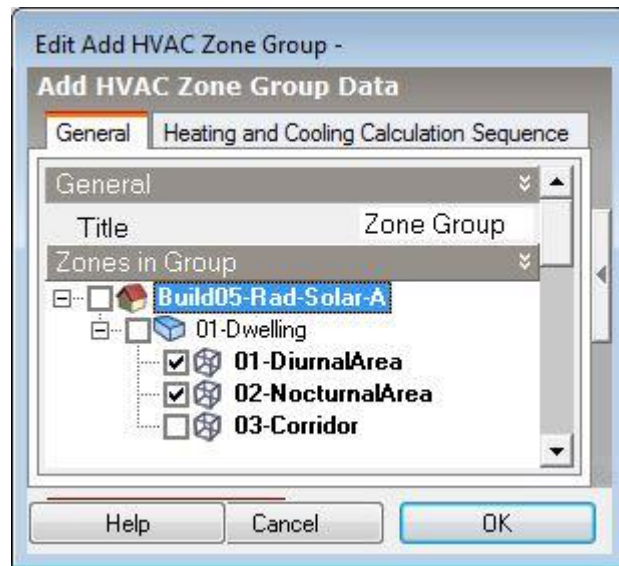
Design water flow rate (m3/s)	Autosize
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Part Load Ratios

Minimum part load ratio	0.000
Maximum part load ratio	1.000
Optimum part load ratio	1.000

Model data <admin> Help Cancel OK

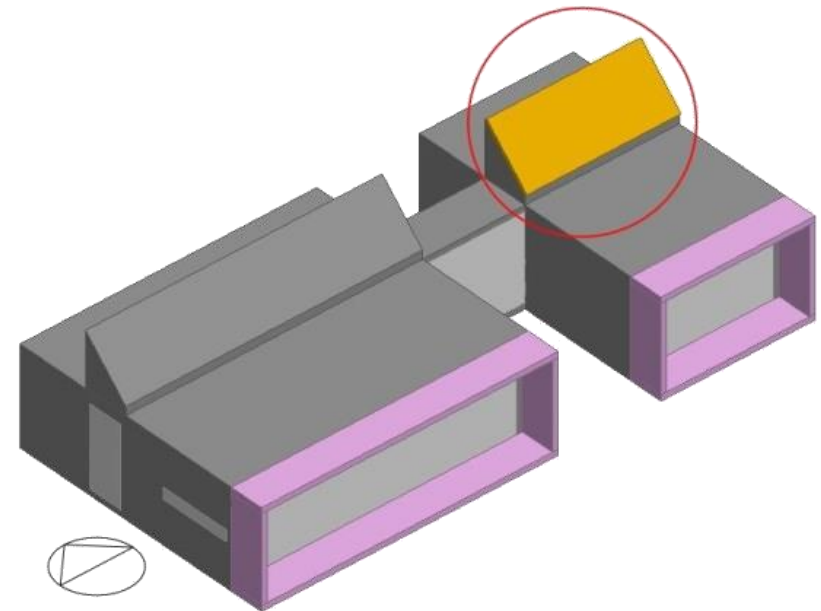
Link to the 3d model: thermal zones



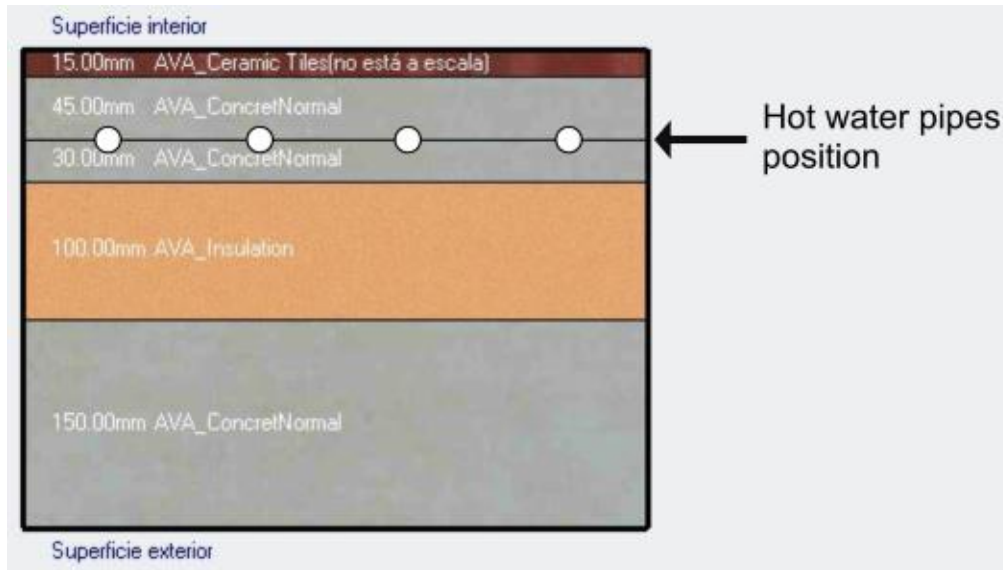
Link to the 3d model: solar collector **surface**

The **solar collector surface** object defines the **gross area**, **position**, **orientation** and **tilt** of the collector. It is included in the detailed solar and shading calculations:

- Incident solar radiation includes **beam** and **diffuse radiation**, as well as radiation reflected from adjacent surfaces.
- **Shading** of the collector by other surfaces, such as nearby buildings.
- Collector surface shading other surfaces (i.e. reducing the incident radiation on the roof).



Link to the 3d model: ground floor constructions



The floor of the zones served by the heated floor system may be defined as an “internal source”.

- It allows to define the position of hot water pipes embedded in the construction.
- It is possible to select from **one-dimensional** or **two-dimensional** heat transfer solution.
- 2-D solution method allows the return water temperature to be accurately calculated.

Considerations about heated floor configuration

Configuration of the heated floor construction has a significant affect on the whole system performance. Some points to take care about:

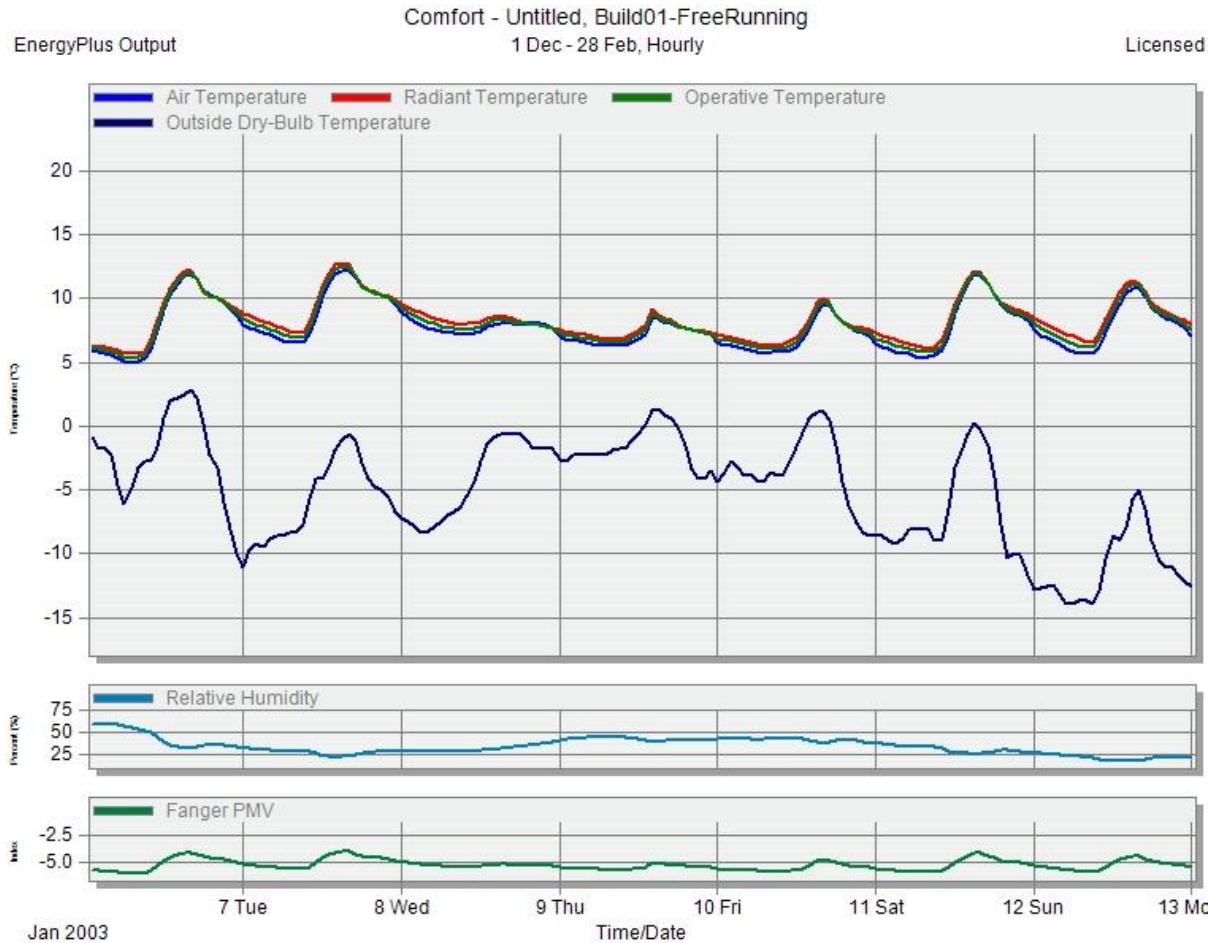
- In order to achieve all its potential, the system requires that heated water pipes are embedded into a **high thermal mass layer**.
- The thermal mass layer should be in contact with the zone.
- The quantity of thermal mass must be carefully calibrated, in order to avoid a excessively **slow response** and high **deviation** from zone setpoint temperature.
- Without good **insulation** below the heated floor source, much of the heat will not find its way into the intended zone.
- If the **floor finishing** has low conductivity (i.e. a thick pile carpet) then the heated floor will struggle to provide adequate heating to the room.

Simulation results

Besides the previously described heated floor with solar thermal system, other options have been simulated for comparison. This is the list of all the simulated options:

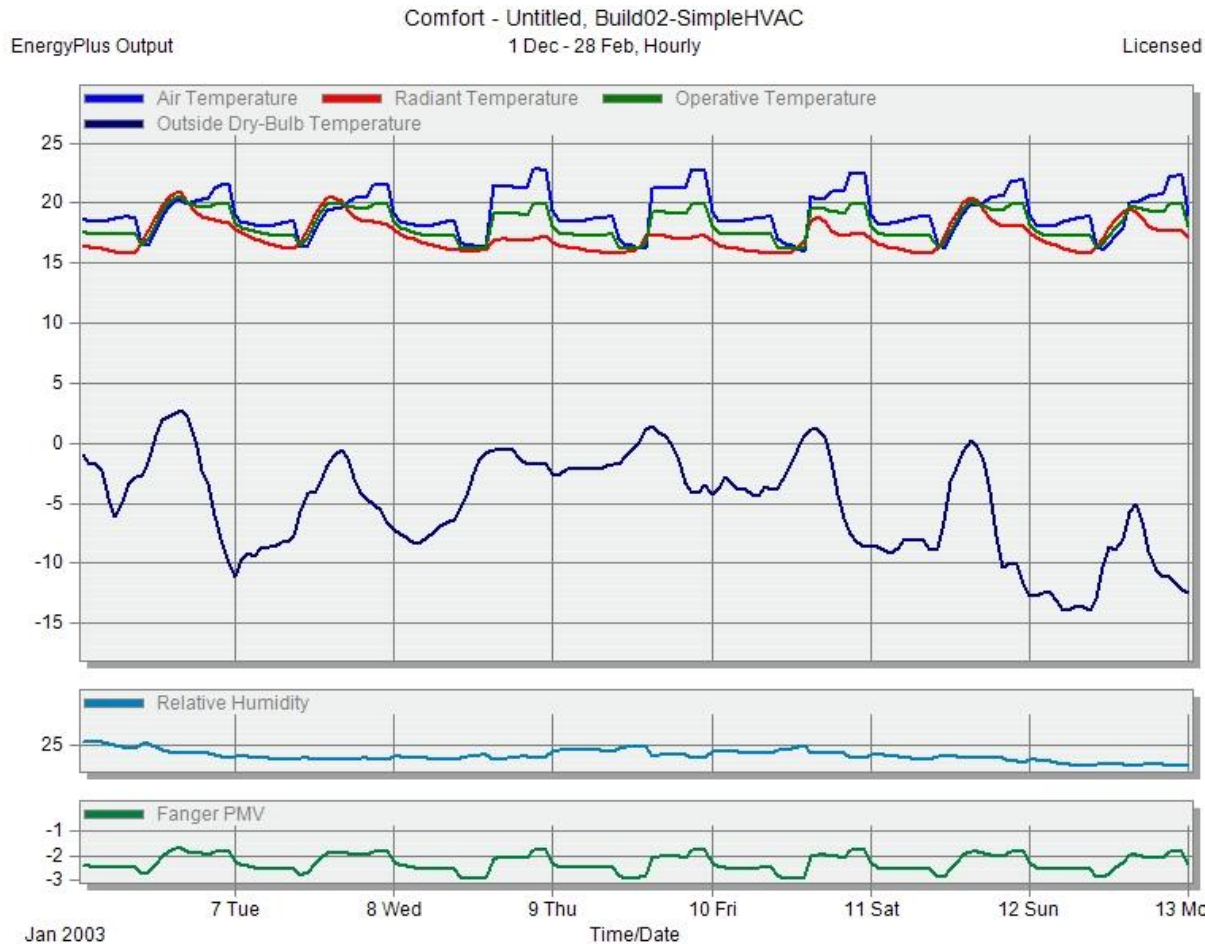
- **Free running building.** No HVAC system.
- **Simple HVAC system** (convective ideal system).
- **Heated floor A:** Without solar thermal system. Boiler and water storage tank.
- **Heated floor B:** Solar thermal system. Glazed flat plate collector, 12.22 m² surface area.
- **Heated floor C:** Solar thermal system. Glazed flat plate collector, 23.53 m² surface area.
- **Heated floor D:** Solar thermal system. Evacuated tubes collector, 23.53 m² surface area.

Simulation results



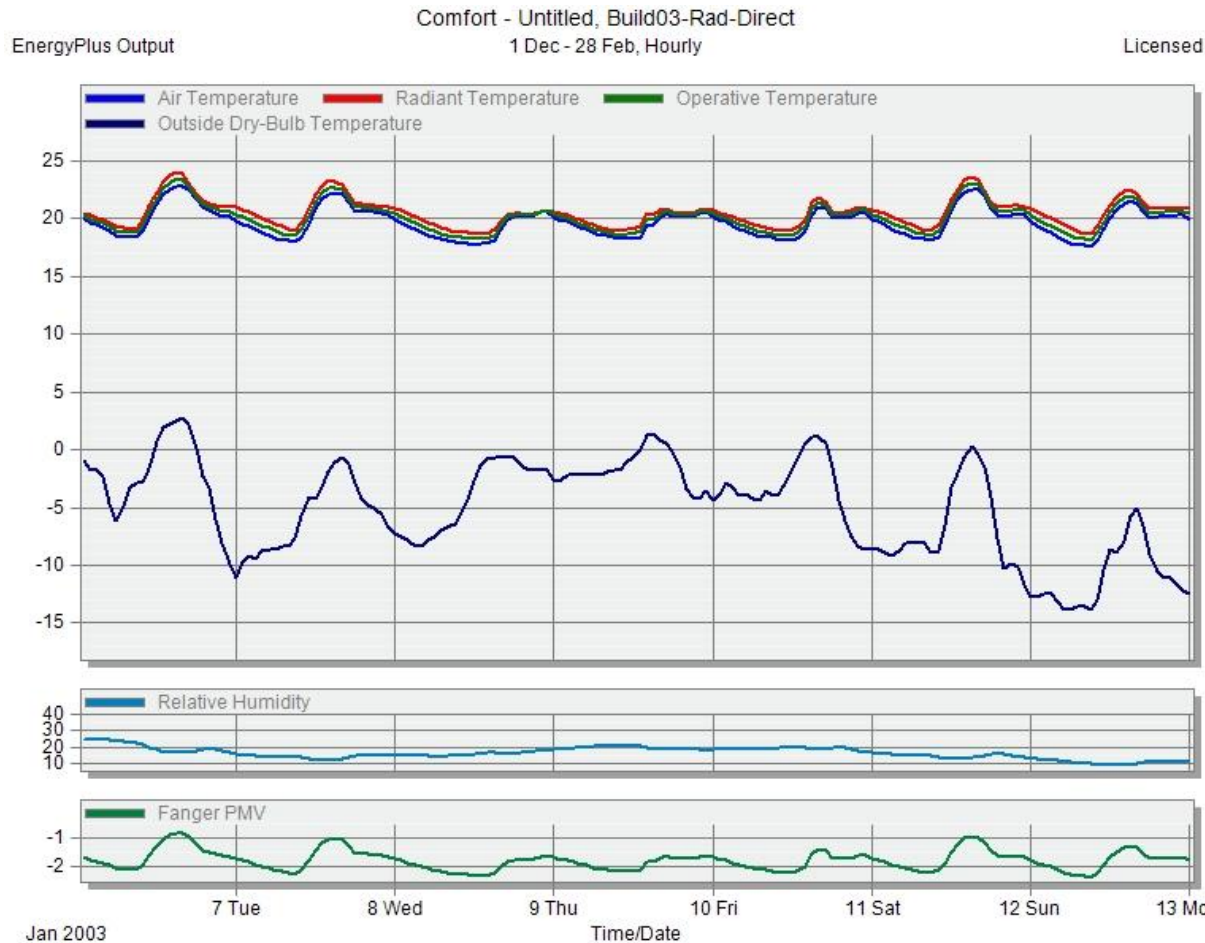
Zone temperatures, free running.

Simulation results



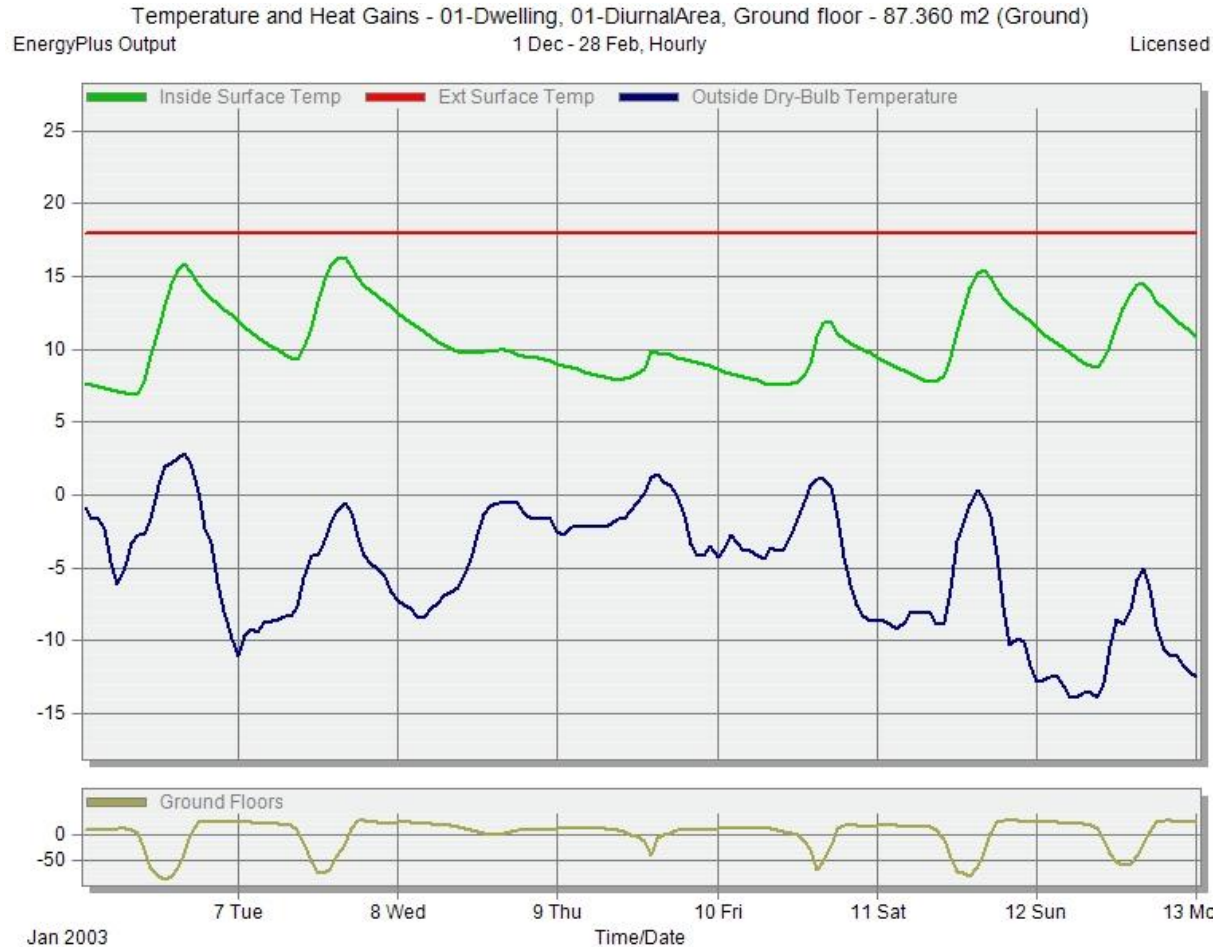
Zone temperatures,
simple HVAC.

Simulation results



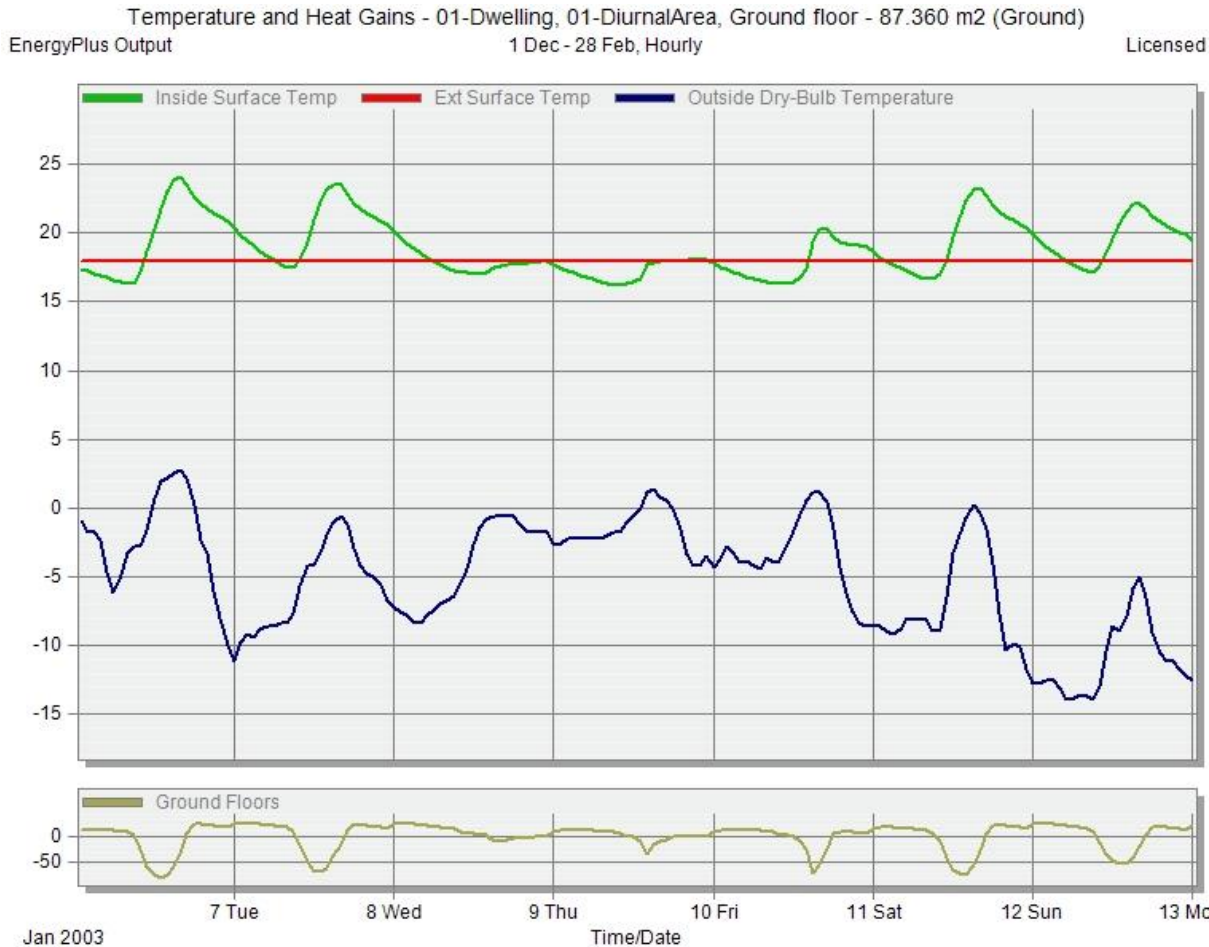
Zone temperatures,
heated floor.

Simulation results



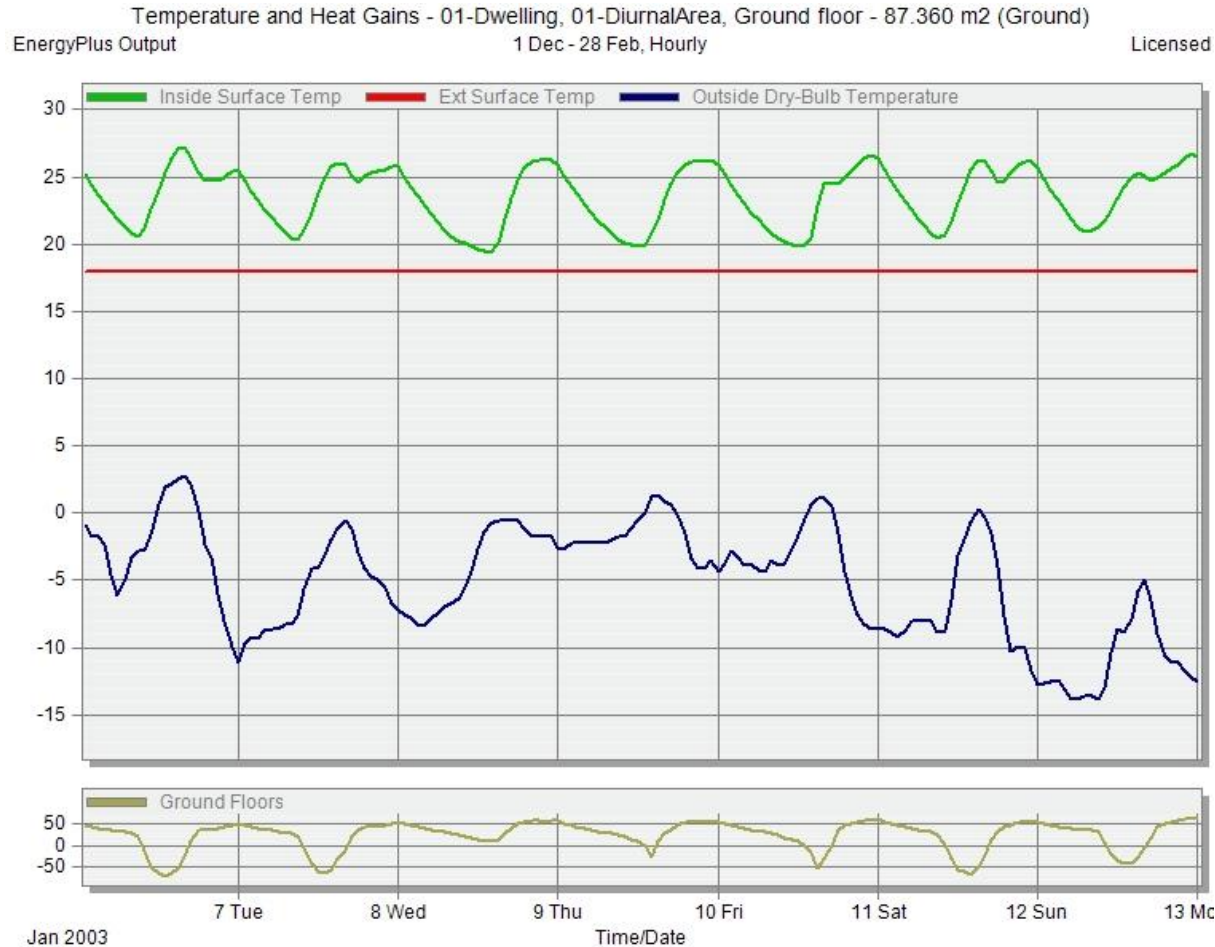
Floor surface temperature, Free running.

Simulation results



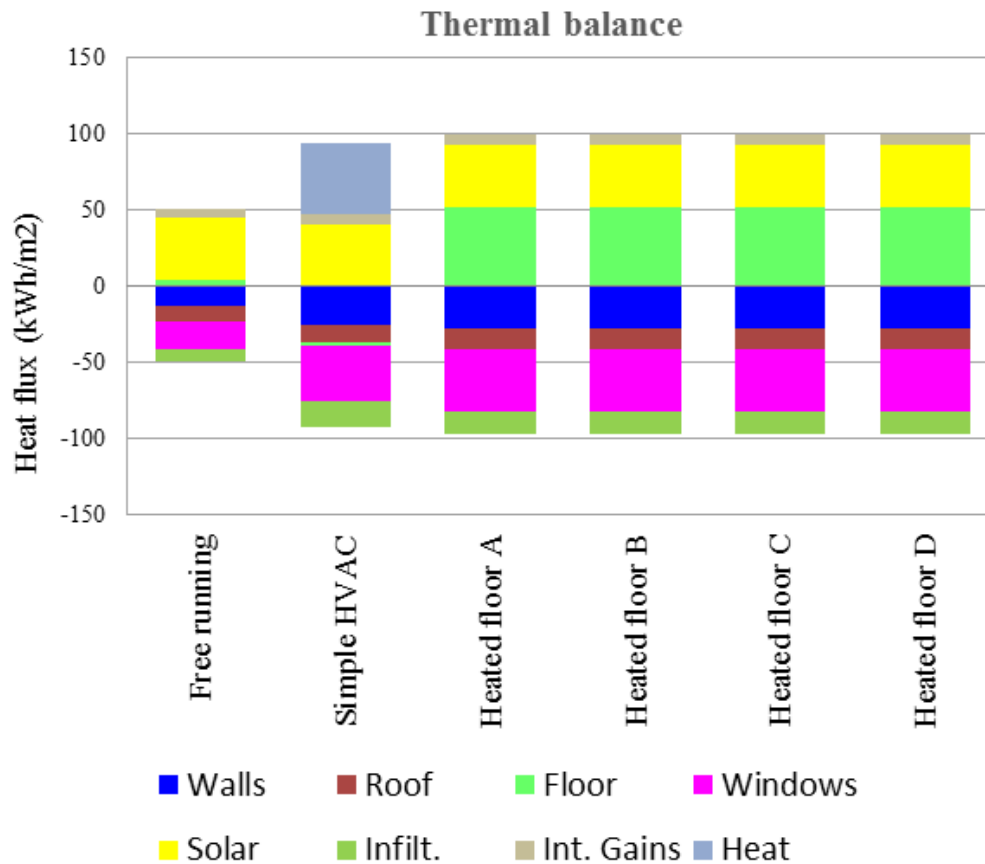
Floor surface temperature, Simple HVAC.

Simulation results



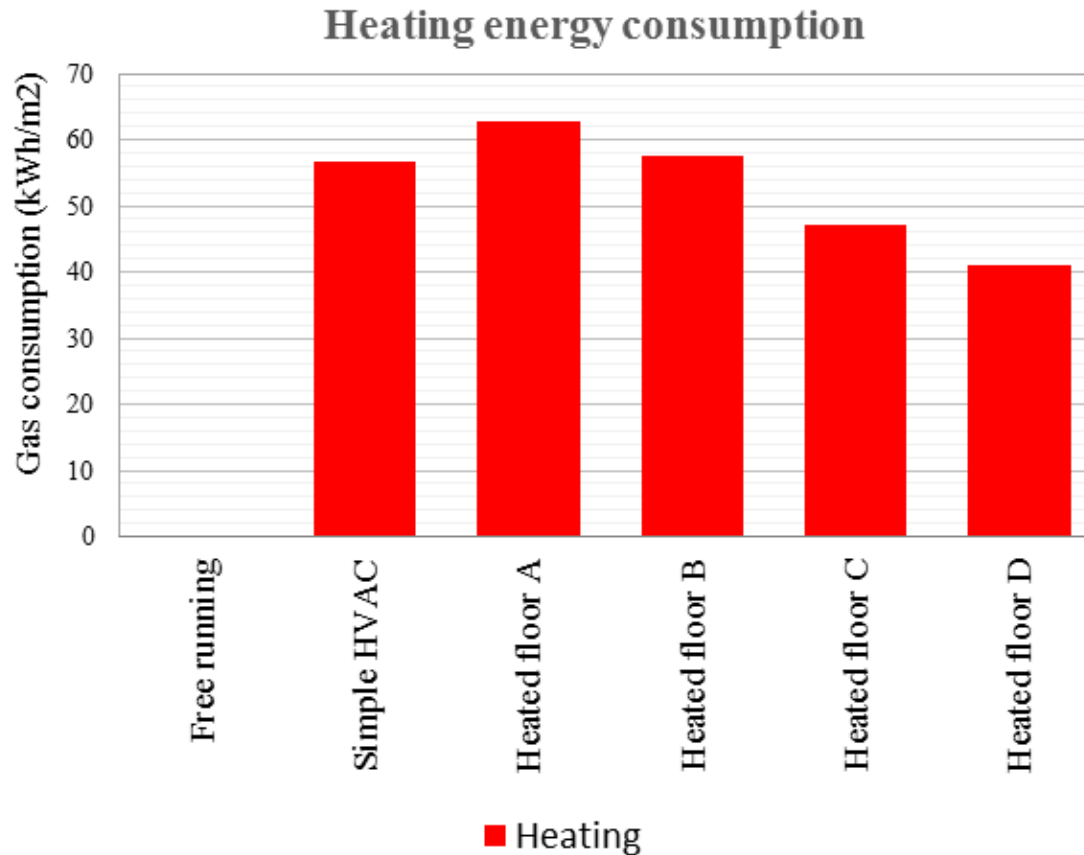
Floor surface temperature, Heated floor.

Simulation results



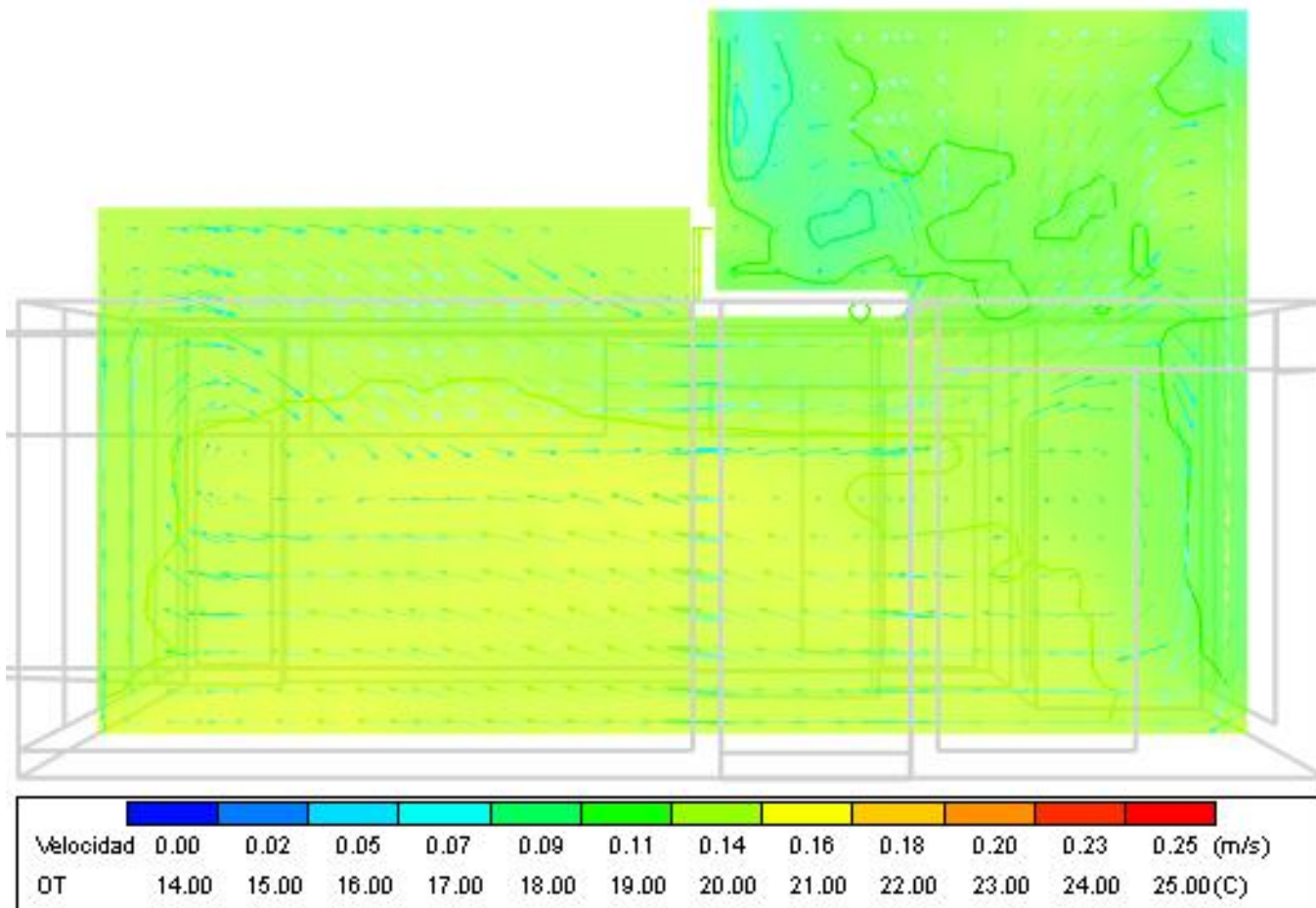
Building thermal balance during the simulation period.

Simulation results

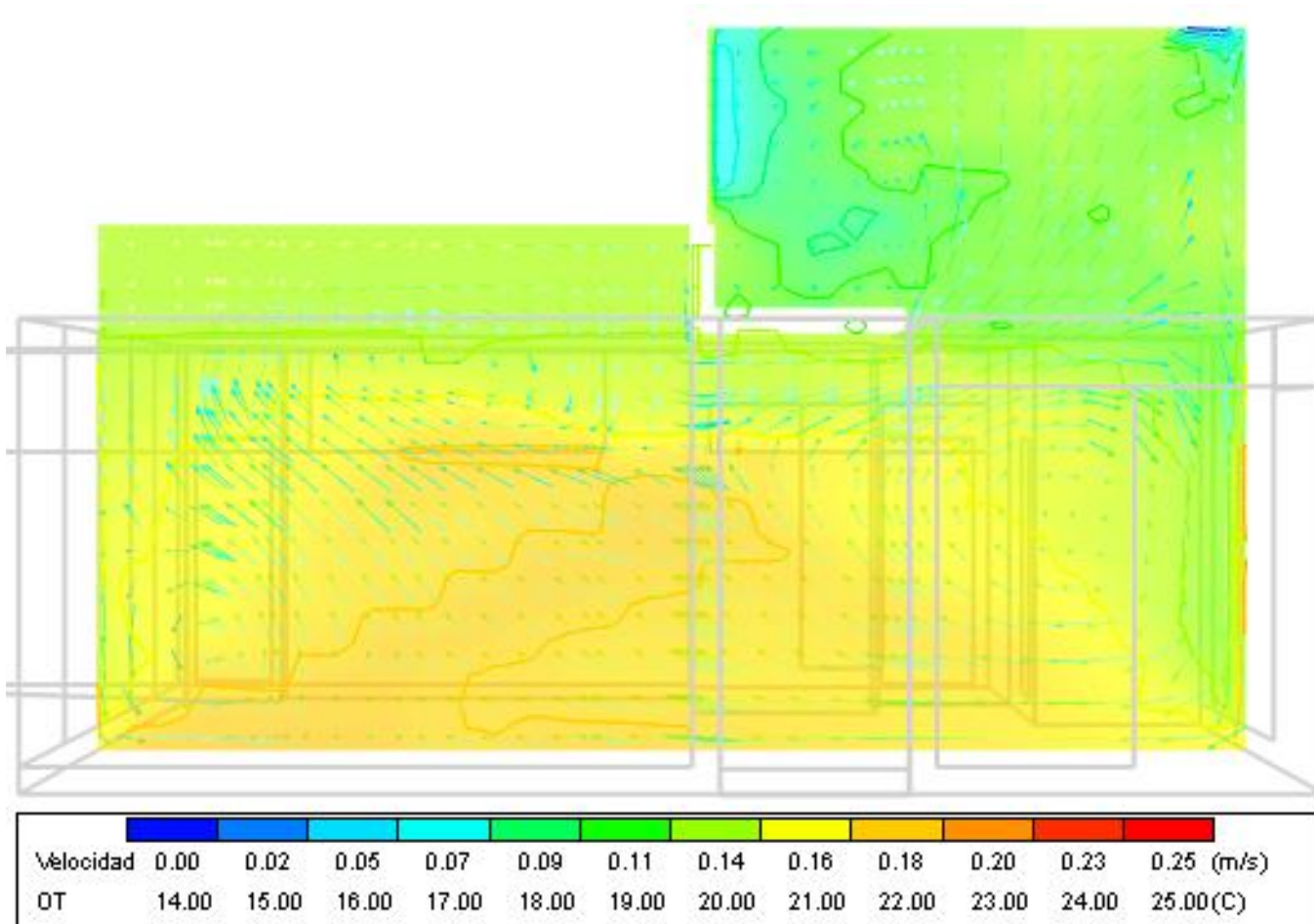


Building heating energy consumption during the simulation period.

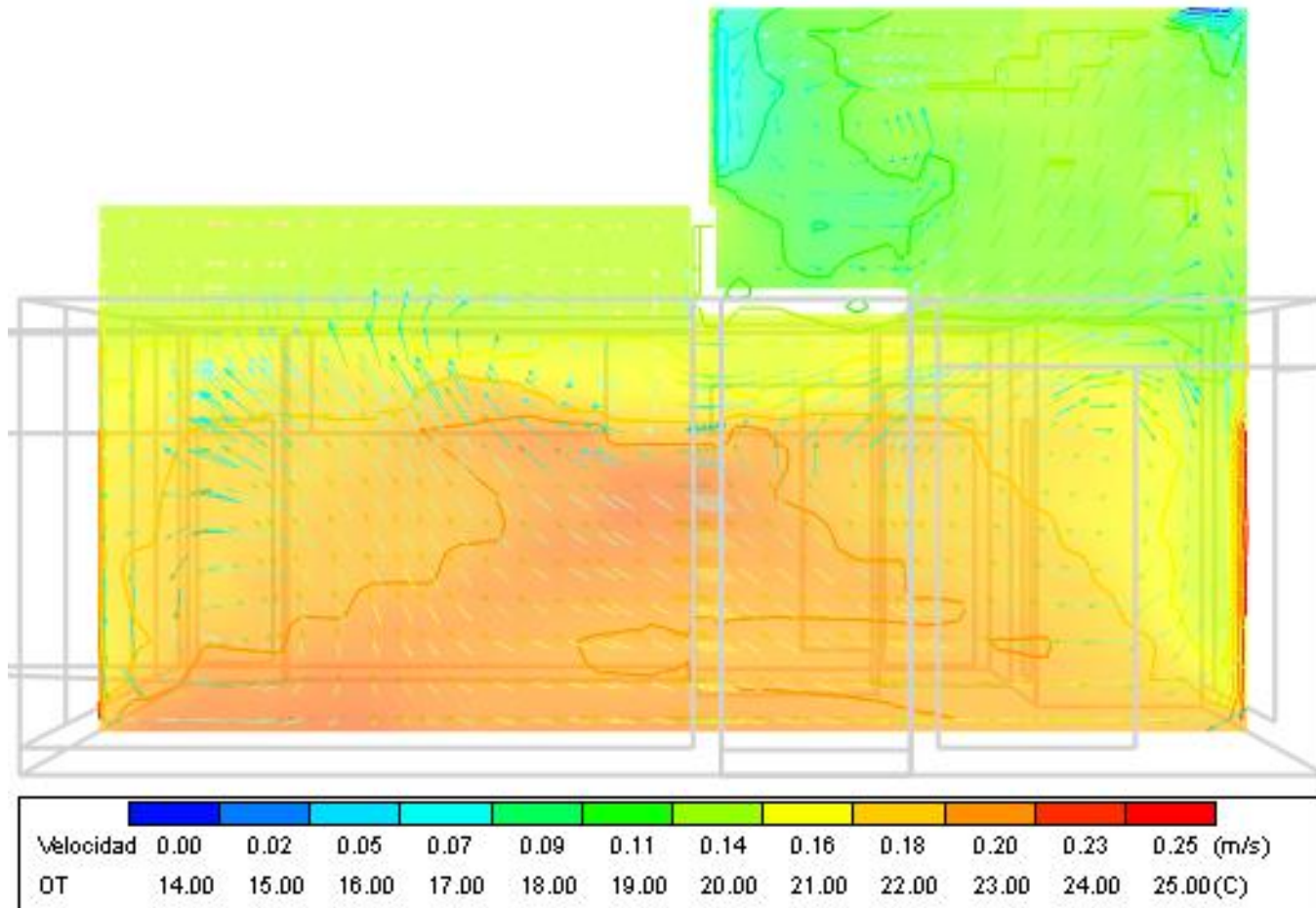
CFD analysis: Floor at 20 °C



CFD analysis: Floor at 25 °C



CFD analysis: Floor at 30 °C



Conclusions

DesignBuilder allows to model, simulate and evaluate solar thermal systems coupled with DWH and/or HVAC systems. Its main advantages are:

- Latest **EnergyPlus** version as simulation engine.
- Relatively **easy configuration** of **detailed HVAC** Systems (user friendly interface).
- Easy and reliable link between **HVAC system** and **3d model**, which allows to explore strategies to optimize both together.

Some limitations:

- Uses performance coefficients to describe solar collectors. It's not possible to model this devices in a very detailed way.
- Just tubular and glazed/unglazed flat plate collectors available at the moment.

Practical session

Download and install the latest **Release** version of DesignBuilder from:

www.designbuilder.co.uk

(You have to register in order to download and use the free 30 day trial license).

Bring your computer with DesignBuilder installed and functioning!



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Thanks for your attention!



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