Thermal Modeling of Buildings I

- This is the first of three lectures concerning themselves with the *thermal modeling of buildings*.
- This first example deals with space heating of a building by means of an active solar system.
- The system is designed after a solar experimental building constructed in Aachen, Germany.
- The example demonstrates hierarchical bond-graph modeling.

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- Active solar space heating
- The solar collector
- The water circulation loop
- The heat storage
Active Solar Space Heating I

- The house has a solar collector on the roof. The collector receives solar radiation.
- Water circulates through the collector in serpentes. It gets heated.
- The hot water is pumped to the heat storage, where it deposits its heat.
- A second water circulation loop picks up the heat, and distributes it to the radiators in the house.

The Solar Collector I

- The solar collector consists of a black metal box covered with a matte glass plate. The collector is oriented toward the sun.
- The solar radiation heats the air inside the collector.
- A water serpentine, placed inside the collector, is heated by the hot air by means of heat conduction (heat exchanger).
The Heat Exchanger

- The heat exchanger is a normal heat conduction element.
- From now on, it will be represented by its own bond-graphic icon, the **HE-element**.
- The entire bond graph of the heat exchanger looks from the outside like any other two-port element.

The Convection Element I

- The (until now highly simplified!) convection element is symbolized here as a directed heat conduction element with a heat capacitor.
- From now on, it will be represented by its own bond-graphic icon, the **1D-element**.
- The capacity is added to allow these elements to be cascaded.
The Convection Element II

- The convection model, as presented on the last slide, is certainly incorrect, as it assumes that the convection is driven by a temperature difference.
- This is evidently not the case. The convection is driven by the pump.
- Using the proposed model, heat flows on both sides of the hot collector down to the cold heat storage element. The heat flows faster when the pump is on.
- This is non-physical, since we know that cold water is pumped up from the storage to the collector on one side, whereas hot water is pumped down from the collector to the storage on the other.
- Yet, for a better model, we are lacking the tools as of now. A better model shall be presented later.

The Heat Exchanger

- The process of heat exchange in the collector is modeled by the water serpentine, which is represented by three cascaded convection elements.
- Each convection element has a heat exchange with the collector box, which is symbolized by the 0-junction at the top.
- The 0-junction is broken into four separate 0-junctions.
- The overall system is a three-port, which shall be represented henceforth by the icon of the Spi-element.
The Heat Loss

- The heat loss element describes the transfer of heat to the environment.
- It takes place conductively (by means of heat conduction), convectively (by air transport of the heated air away from the collector), and radiatively (by means of radiation).
- Here, the proposed convection model is correct, since convection can only take place when heat has already left the collector through heat conduction.

The Solar Collector II

- The solar collector can now be assembled. It consists of the heat exchange process, the heat capacity of the collector, the incoming solar radiation, and the heat loss.
The Water Circulation Loops

- The two water circulation loops consist of cascaded chains of “convection” elements. Since this is a forced flow, this model is most certainly incorrect. A better model shall be presented later.

The Heat Storage Element

- The heat storage element contains the water serpentines of the two water circulation loops, a heat capacity, as well as an electrical backup heater.
Active Solar Space Heating II

- The overall heating system can now be assembled.
- It consists of up to eight levels of hierarchy.

References
