Thermal Modeling of Buildings

- This lecture deals with the model of a space heating system of a building by means of a passive solar system.
- The system is designed after a solar experimental building constructed in Tucson near the airport.
- The model is quite sophisticated. It models not only the physics of radiation through glassed windows, but also the weather patterns of Tucson.

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- Passive solar space heating
- Bond graph of a room
- Floor, windows, and walls
- The Dymola model
- Simulation results

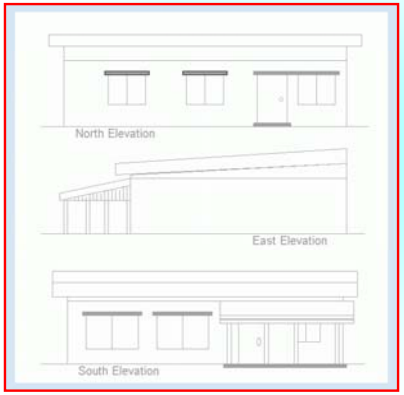
Passive Solar Space Heating I

Southside view with (dismantled) sunspace.

Northside view.

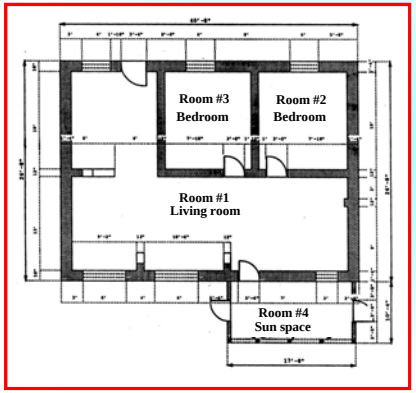
The house is constructed from Adobe brick. The photographs are rather recent. By the time they were taken, the house was no longer being used and had fallen a bit in disarray.

Passive Solar Space Heating II



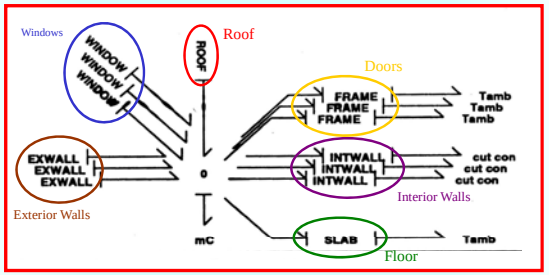
- The experimental solar building is shown here from three sides.
- Solar radiation through the walls, the windows, and the ceiling is to be modeled.
- Losses are also being modeled, including the losses through the slab.

Passive Solar Space Heating III



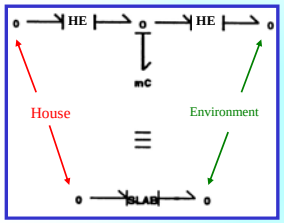
- The house has four rooms to be modeled: a living room, two bed rooms, and a sun space.
- It is assumed that the temperature within each room is constant, which makes it possible to model each room as a single 0-junction.
- ... This is clearly an experimental house, as there is neither a bathroom nor a kitchen.

The Bond Graph of a Room



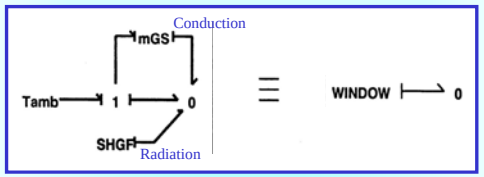
- Every room is modeled in approximately the same fashion. The model shows the heat capacity of the room as well as the interactions with the environment.

The Floor



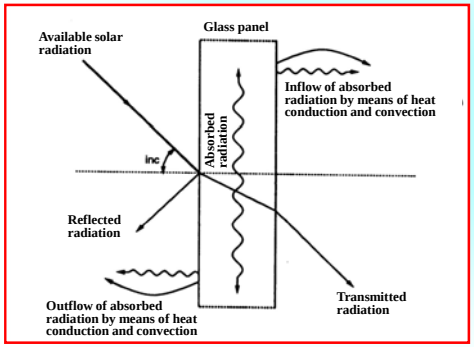
- The floor is modeled like a room.
- It has its own heat capacity (the slab under the house consists of gravel).
- It exchanges heat with the house.
- It also exchanges heat with the environment.
- It is important, not to represent the exchange with the environment as a loss, since during the summer, heat is also entering the building through the slab.

The Windows I



- Heat transport across the windows occurs partly by means of ***heat conduction***, and partly by means of ***radiation***.

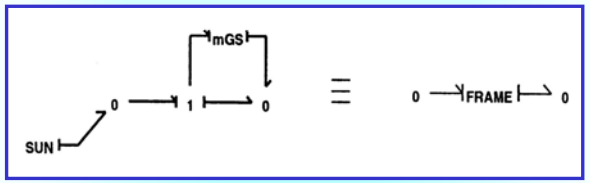
The Windows II



- Modeling the radiation accurately is not easy, since several different phenomena must be considered, and since the radiation is furthermore a function of the day of the year and the time of the day.

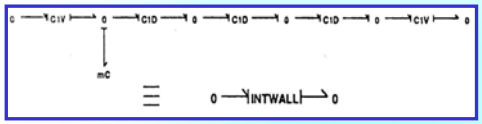
≡ SHGF → 0

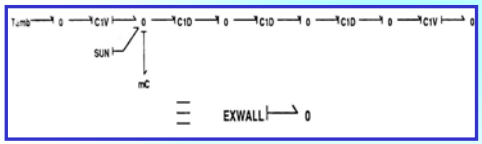
The Doors



- The doors are modeled similarly to the windows, yet there is no glass, and there exists an additional heat conduction through the wood of the door.

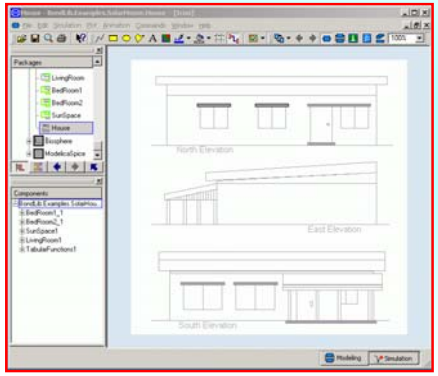
The Walls





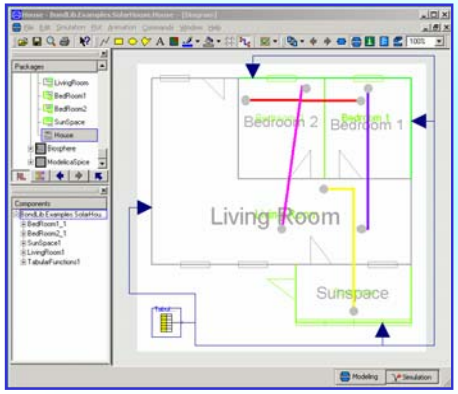
- Each wall is described by three heat conduction elements.
- At the two surfaces, there are additional convection elements modeling the transport of heat in the boundary layer.
- The exterior walls consider in addition the influence of solar radiation.
- In this program, the heat conduction elements ***C1D*** contain on the right side a capacitor, whereas the convection elements ***C1V*** do not contain any capacity.

The *Dymola* Model I



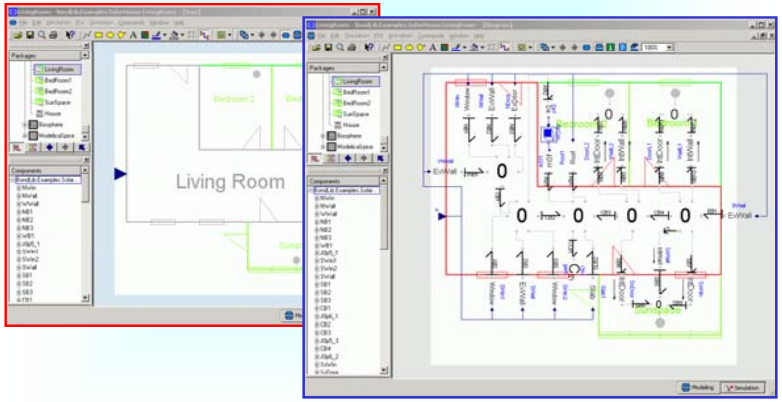
- The overall ***Dymola*** model is shown to the left.
- At least, the picture shown is the top-level icon window of the model.

The *Dymola* Model II

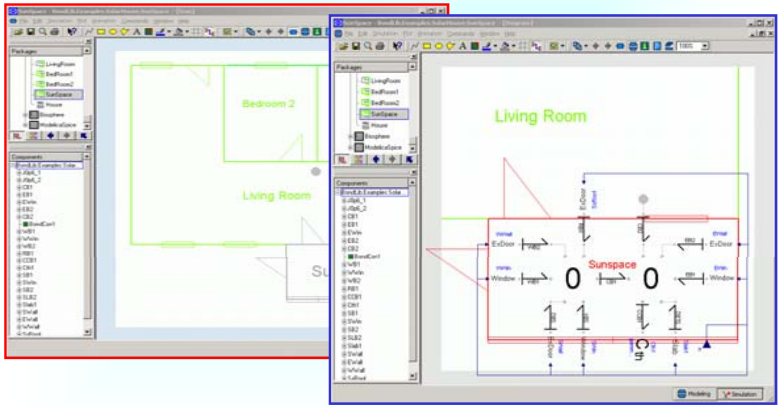


- Shown on the left side is the corresponding top-level diagram window.
- Each of the four rooms is a separate model.
- The four models are overlaid to each other.
- The bond graph connectors are graphically connected, connecting neighboring rooms to each other.

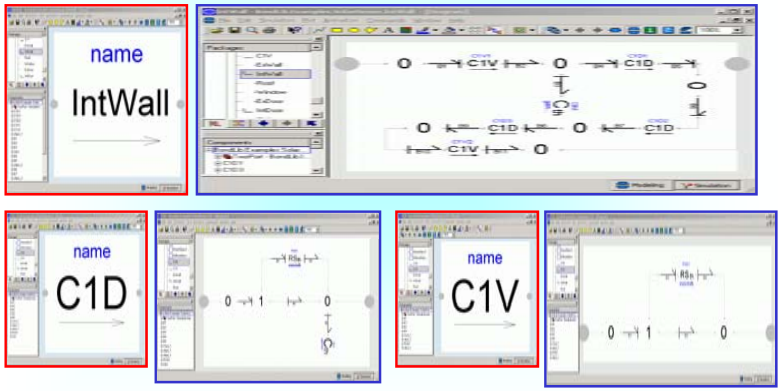
The Living Room



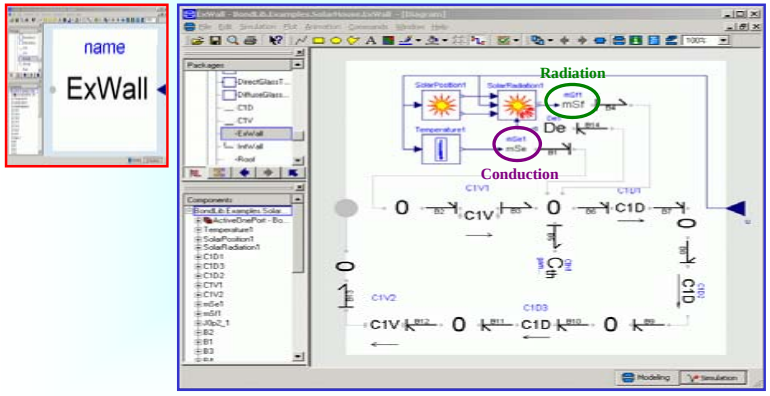
The Sunspace



The Interior Wall



The Exterior Wall



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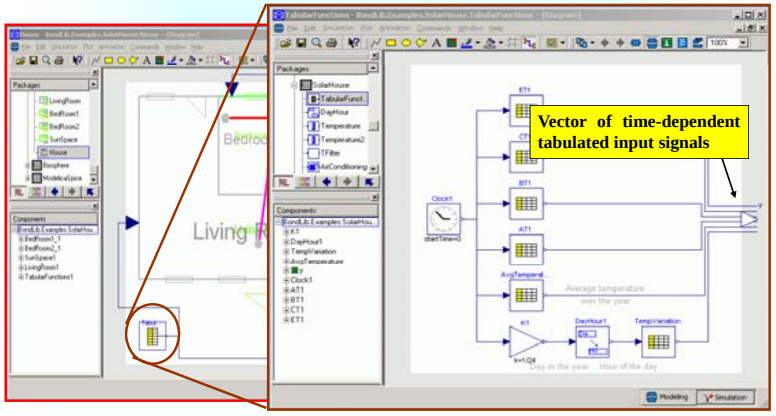
The Tabular Functions



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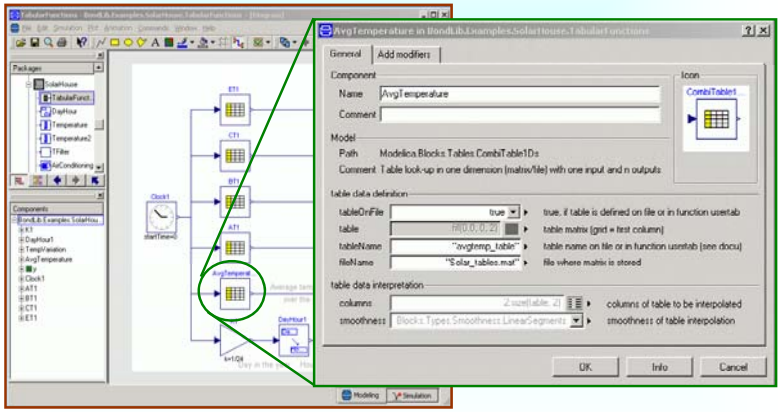
The Tabular Functions II



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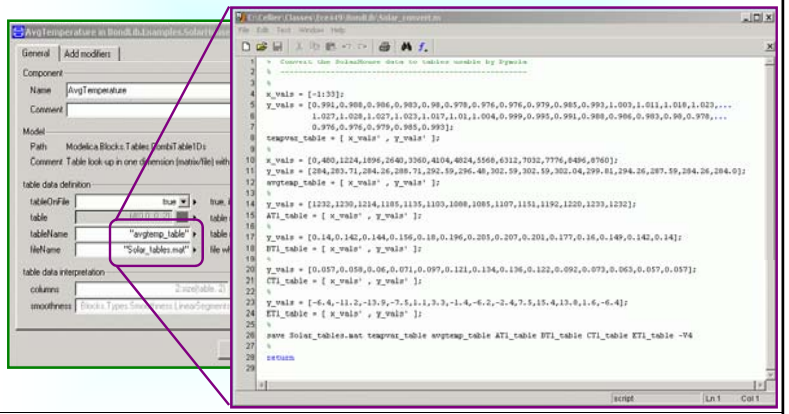
The Tabular Functions III



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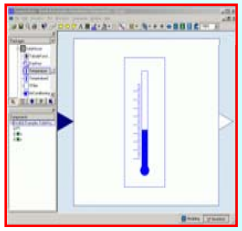
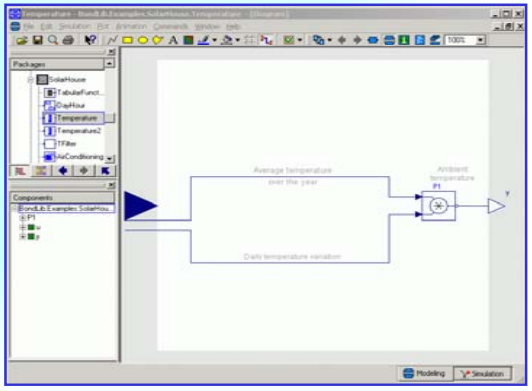
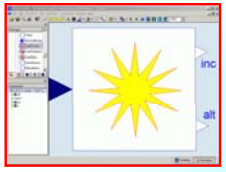
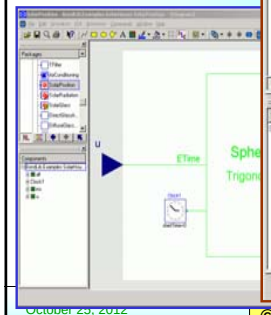
The Temperature

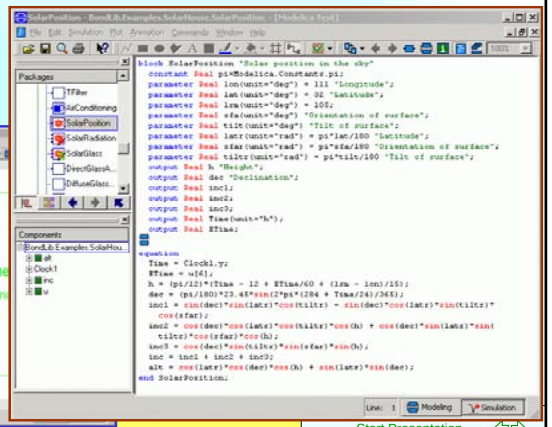




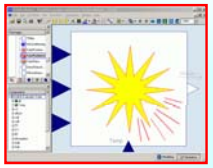
The Solar Position

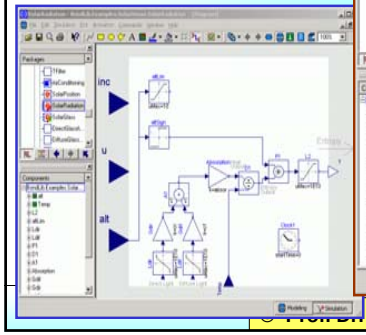


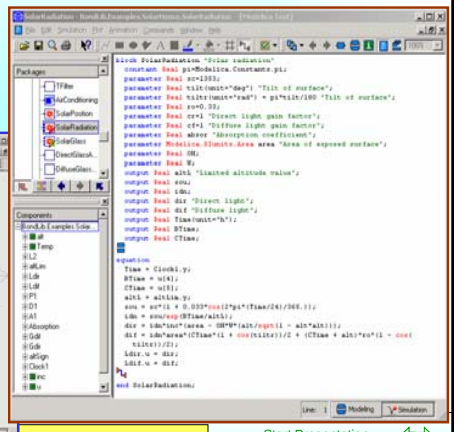




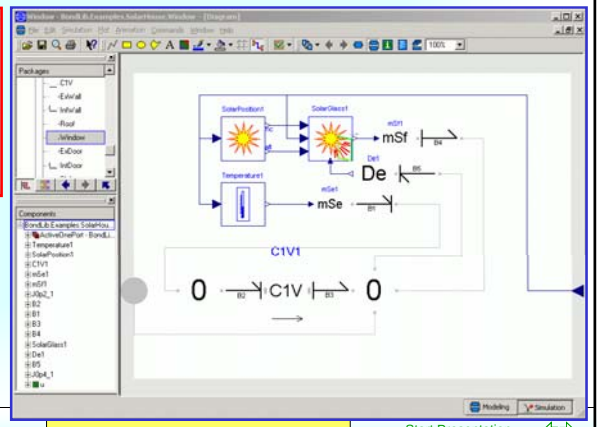
The Solar Radiation



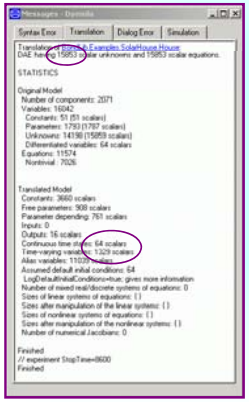


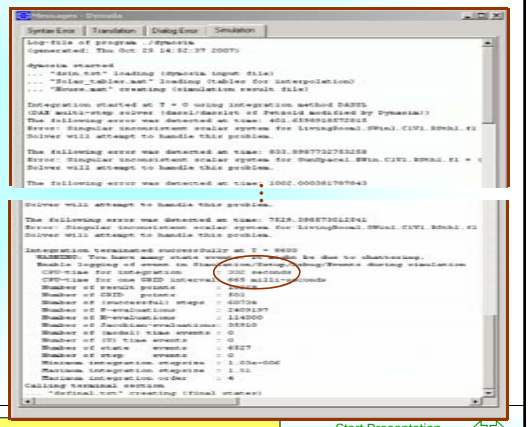


The Window

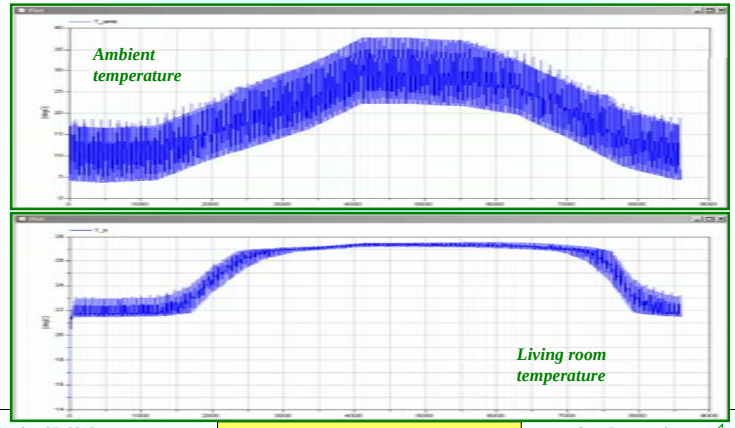


Translation and Simulation Logs

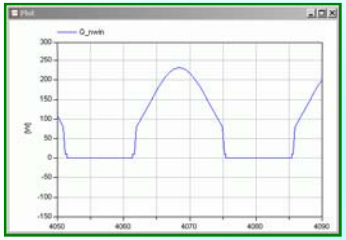




Simulation Results I

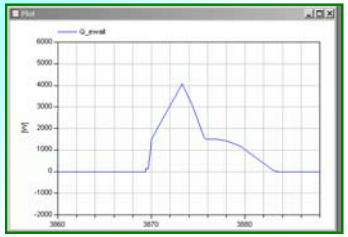


Simulation Results II

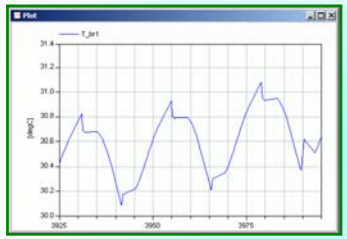


Radiation through North-exposed window

Radiation through East-exposed wall

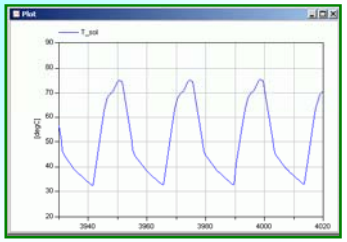


Simulation Results III



Temperature in bedroom #1

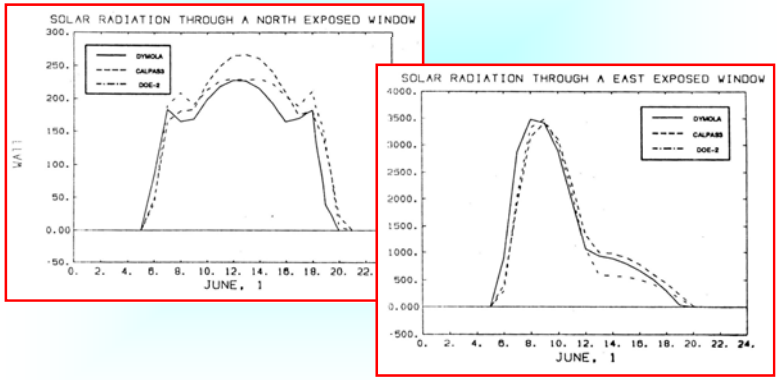
Temperature in sunspace



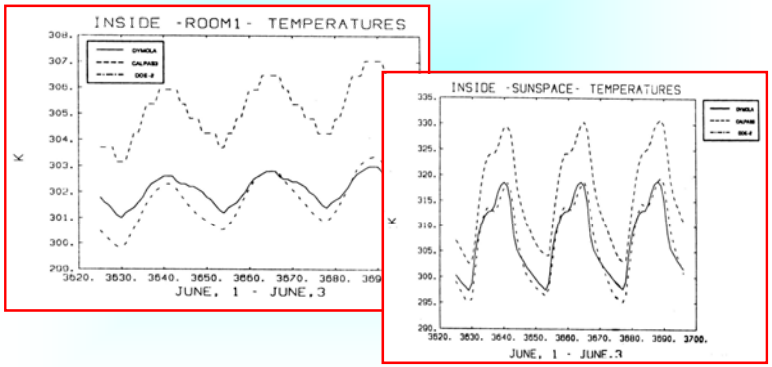
Passive Solar Space Heating III

- The simulation results of three different programs were compared. These programs had been coded in ***Dymola***, ***Calpas 3***, and ***DOE 2***.
- ***Calpas 3*** and ***DOE 2*** are commercial simulation programs specialized for space heating.
- ***Calpas 3*** is a fairly simple Program. It computes rapidly and is easy to use, as it offers only few parameters. However, the results aren't very precise.
- ***DOE 2*** is a much more accurate and rather expensive program. It computes slowly and is not easy to use, as it offers many parameters, for which the user must supply values.

Simulation Results IV



Simulation Results V



Passive Solar Space Heating IV

- ***Dymola*** computes about as accurately as ***DOE 2***. However, the time needed to complete a simulation run is shorter by about a factor of 50 in comparison with ***DOE 2***.
- ***Dymola*** is much more flexible, as the program is not specialized for space heating simulations.
- The model assumptions, on which the simulation results are based, are clearly visible in the case of ***Dymola***. This is not the case for either of the other two programs.

References

- Weiner, M. (1992), *Bond Graph Model of a Passive Solar Heating System*, MS Thesis, Dept. of Electr. & Comp. Engr., University of Arizona, Tucson, AZ.
- Weiner, M., and F.E. Cellier (1993), "Modeling and Simulation of a Solar Energy System by Use of Bond Graphs," *Proc. SCS Intl. Conf. on Bond Graph Modeling*, San Diego, CA, pp.301-306.
- Cellier, F.E. (2007), *The Dymola Bond-Graph Library*, Version 2.3.

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