

## Simulation of solar cooling systems

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### Introduction

To design and optimise thermally driven solar cooling systems, the solar thermal supply with or without storage, the energy conversion by the chiller system and the demand must be closely matched to obtain high solar fractions and thus significant primary energy savings. As there is very limited experience with solar cooling systems and since the cooling loads strongly depend on the internal load and external gain profile of the buildings, simulation tools are essential to avoid oversizing the solar thermal system. During the operation of the solar cooling plants, simulation tools can be very useful to analyse and improve control strategies.

### Simulation tool categories

In general, simulation tools can be classified according to their degree of complexity. The basic of all simulation tools are **algorithmic programming languages** like Fortran or C and/or object-oriented languages like C++, C#, Java etc. Together with an integrated development environment like Eclipse, for instance, these languages provide maximal flexibility in the description and solution of software-based simulations. However, the ability to use a programming language for the purpose of simulating solar cooling systems requires fundamental knowledge in modeling, programming and numerical methods.

**DAE Solver:** Since practically every physical system model uses differential and algebraic equations (DAEs) these must be solved for every time step over the time interval of interest. Several programs exist which release users from having to solve the set of DAEs. Two examples with support for heating and cooling systems are EES (Engineering Equation Solver) developed at the University of Wisconsin and SPARK (Simulation Program Analysis and Research Kernel) developed at the Lawrence Berkley National Laboratory. In the framework of IEA Task 38 (Solar Air-Conditioning and Refrigeration) several components for absorption chiller simulation have been developed for SPARK.

**Graphical programming languages (GPLs)** partly “hide” the formulation of DAEs from the user via a graphical user interface (GUI). Instead of having to formulate the model equations directly these tools provide graphical elements, which can be compiled and interconnected by computer-mouse operations. Two general-purpose examples are MATLAB with the GUI Simulink, both developed by The MathWorks and Modelica developed by the non-profit Modelica Association. For these tools extensions with special-purpose applications like building simulation, heating and cooling systems and so on are available as MATLAB toolboxes, Simulink blocksets or Modelica libraries.

A large number of **special-purpose GPLs** exist, among the first were HP VEE (Hewlett Packard Visual Engineering Environment) by Hewlett Packard and LabVIEW (Laboratory Virtual Instrumentation Engineering Workbench) by National Instruments, both from the sector of data acquisition and instrument control. From the renewable energy sector examples are TRNSYS (Transient System Simulation Tool), originally designed for solar heating and building simulation at the University of Wisconsin, INSEL (Integrated Simulation Environment Language), originally designed for photovoltaic

systems at the University of Oldenburg, and ColSim, primarily designed for the development of controllers in thermal systems at the Fraunhofer Institute for Solar Energy Systems.

Finally, **GUI-based simulation programs** offer convenient solutions for special applications. In this class of programs the simulation model is usually completely hidden behind a window-based interface so that users can modify only the set of model parameters but not the model itself. To mention just a few of such GUI-based simulation programs with ambitions in the solar cooling sector: EnergyPlus can be applied for building simulation, including heating, cooling, lighting, ventilation, other energy flows, and water use. T\*SOL is designed for solar thermal systems and their components, Polysun for solar thermal and photovoltaic systems.

A rather new program named Transol comes from an ambitious project carried out by Aiguasol in collaboration with the French research Centre Scientifique et Technique de Batiment. Transol can calculate a variety of pre-defined configurations of solar thermal systems for hot water, heating, swimming pools, solar cooling, and industrial process heat. The simulation engine behind Transol is TRNSYS, i.e. when the selected configuration is completely parametrised, the values are saved together with a TRNSYS deck file, which is then executed by TRNSYS in the background. The results are returned to the GUI. As the TRNSYS deck is encrypted, it is not possible to see the model structure and which types are used. As there is no description of the physical models used in the Transol systems, there is no way to evaluate the accuracy of the simulation results apart from plausibility checks.

### **Simulation Study: Comparison between thermal and photovoltaic cooling of an office building**

Transol has been used to simulate the annual performance of four different cooling systems at three different locations (Palermo, Madrid, Stuttgart) with the aim to compare the primary energy consumption of the systems as well as their economies. A three-storey office building with a single floor area of 310 square meters taken from IEA Task 25 was chosen. A reference system has been defined with a grid-connected air compressor cooling machine and a cooling storage tank. The photovoltaic cooling system is similar to the reference system with an additional grid-connected PV generator. As Transol only considers sorption technology, these systems have been simulated using the simulation environment INSEL. The scheme for the thermal cooling machine is taken from a predefined Transol configuration as shown in Figure 1.

#### **Problem 1: Weather data**

The first problem in all renewable energy simulations is to get access to irradiance and temperature data in at least hourly resolution for at least one complete year. Several sources for monthly mean values exist, like the European Solar Radiation Atlas (ESRA), for example. However, partly big differences occur between the different sources, which contribute directly to the deviations in the simulation results.

A standard procedure to obtain hourly data is to use the monthly means as input to numerical time series expansion models like the one by Gordon and Reddy and the one by Aguilar and Collares-Pereira. The irradiance data have to be separated into their beam and diffuse fractions via empirical correlations and both fractions have to be converted to the orientation of the PV modules or solar collector absorbers, respectively.

The complete method is implemented in Transol in cooperation with Meteonorm. It is also possible to use Typical Meteorologica Year files (.tm2) in Transol.

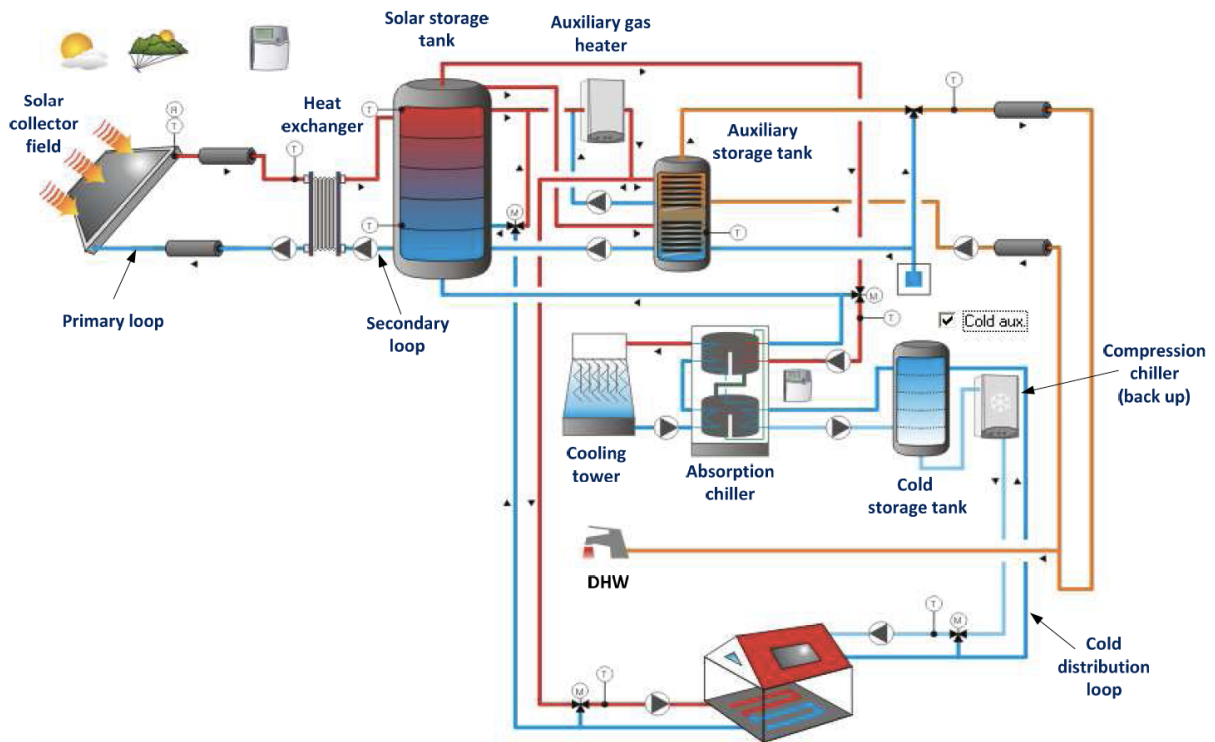


Figure 1: Transol scheme SCH601 for the simulation of a solar thermal collective system for the production of hot water space heating and cooling with external heat exchanger, solar and auxiliary tanks with indirect connection and connections from the boiler direct to the space heating and indirect to domestic hot water supply.

### Problem 2: Heating and cooling load profiles

The Transol software uses the TRSNYS type 56 for the dynamic building simulation. However the parametrisation of the building components is limited, for example it is not possible to select market available windows with low e-coating. The best window is a triple glazed window with clear glass, which has a U-value of  $2.26 \text{ W/m}^2\text{K}$  and a g-value of 0.678. This is a clear limitation of the software, as today's triple glazings can reach U-values as low as  $0.5 \text{ W/m}^2\text{K}$ . A small office building with  $930 \text{ m}^2$  has been used for the case study simulations.

### Problem 3: Simulation of the PV generator and compression chiller

A steady state physical model of compression chillers was developed in INSEL and validated with manufacturer data (see Figure 2). The photovoltaic module parameters were taken from the INSEL database which contains over 5000 commercially available modules.

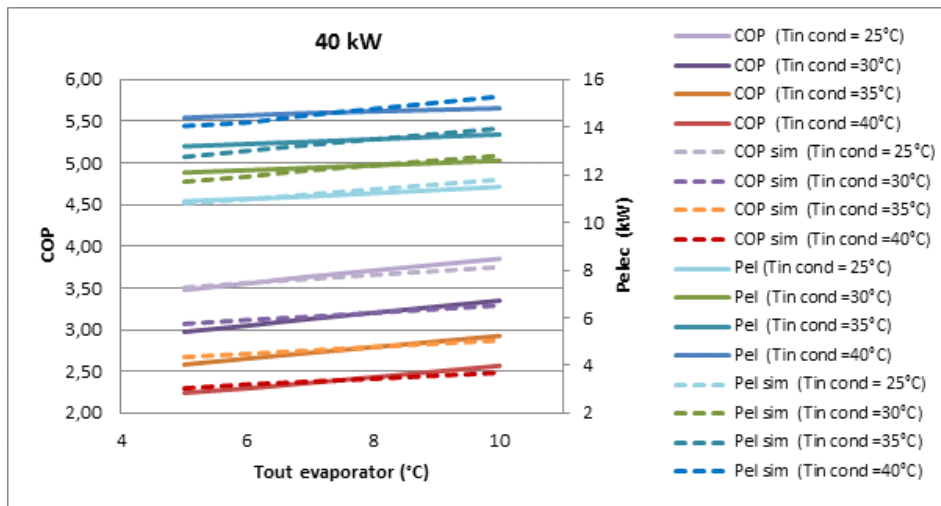


Figure 2: Comparison of measured and simulated coefficient of performance and electrical power for a 40 kW compression chiller.

## Results and discussion

The building load can be considered as reliable, as the TRNSYS type 56 has been extensively validated. The only limitation is the restricted choice of building components and materials.

The annual cooling load duration curve of the building without sun protections in Palermo shows that the maximum cooling load is not related to the total annual cooling energy. For example the maximum cooling load of the building with an average wall U-value of  $0.41 \text{ W/m}^2\text{K}$  is  $50.3 \text{ kW}$  at  $94 \text{ kWh/m}^2\text{a}$  annual cooling energy, whereas the building with a wall U-value of  $1.1 \text{ W/m}^2\text{K}$  has a lower maximum load of  $36.6 \text{ kW}$ , but requires more cooling energy ( $142 \text{ kWh/m}^2\text{a}$ ).

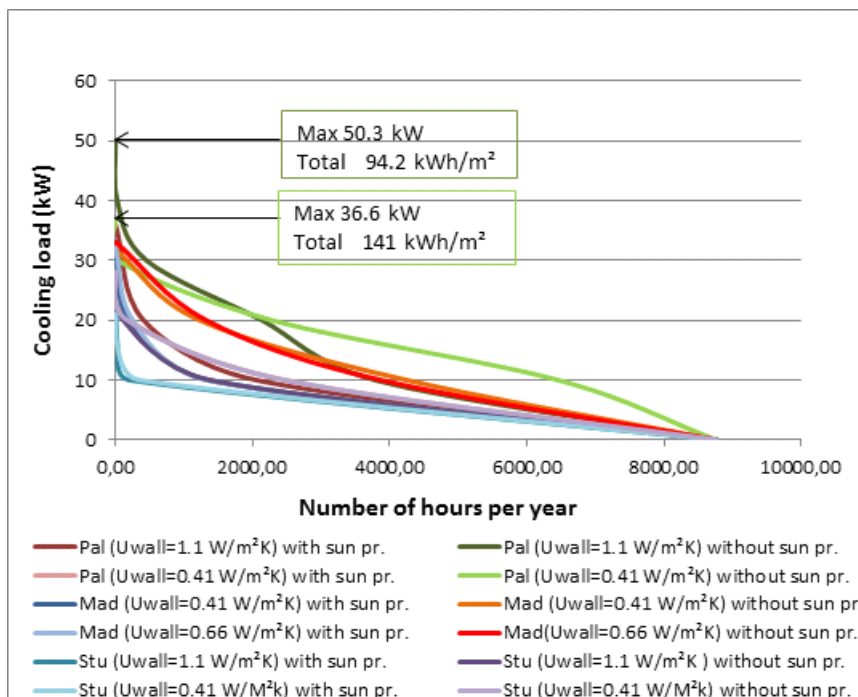


Figure 3: Cooling load curve for the office building in the three locations Palermo (Pal), Madrid (Mad) and Stuttgart (Stu) with and without sun protection and with different U values of the walls.

As the TRNSYS deck is encrypted and there is no detailed description of the component models, it is much more difficult to judge the accuracy of the solar absorption cooling simulation results.

The specific collector energy yield is very low with 120 to 250 kWh/m<sup>2</sup>a in Germany, increasing with annual cooling load. Also the electrical COP's are rather low, which is probably due to rather simple control algorithm. The problem is that sorption cooling systems with low electrical COP's will not save much primary energy when compared to a good compression chiller.

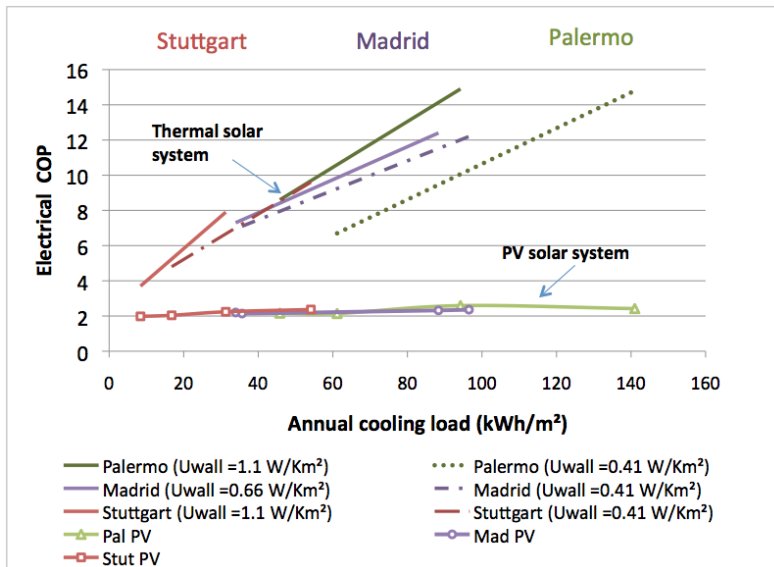


Figure 4: Electrical COP for the absorption cooling and PV electric cooling system for buildings with different insulation standards in different locations.

Only a more flexible simulation tool such as INSEL allows to test more advanced control strategies. A small office building was simulated under German climatic conditions with a very low annual load of 16 kWh/m<sup>2</sup>a. The standard control system gave an electrical COP of 6, which is 3 times higher than the Transol results. Electrical COP's of 11.5 were obtained for a fan speed controlled wet cooling tower and COP's of 13 were reached when geothermal heat exchangers are used for heat rejection.

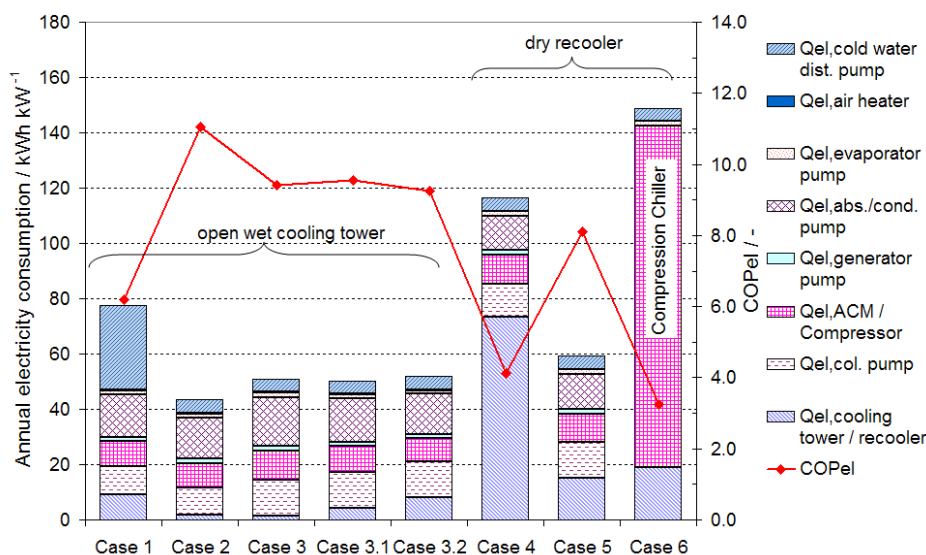


Figure 5: Electrical COP's for different control strategies of a 15 kW absorption chiller system in Germany.

The resulting primary energy ratios show that for good control strategies solar thermal cooling systems can save 50 % of primary energy compared to compression cooling.

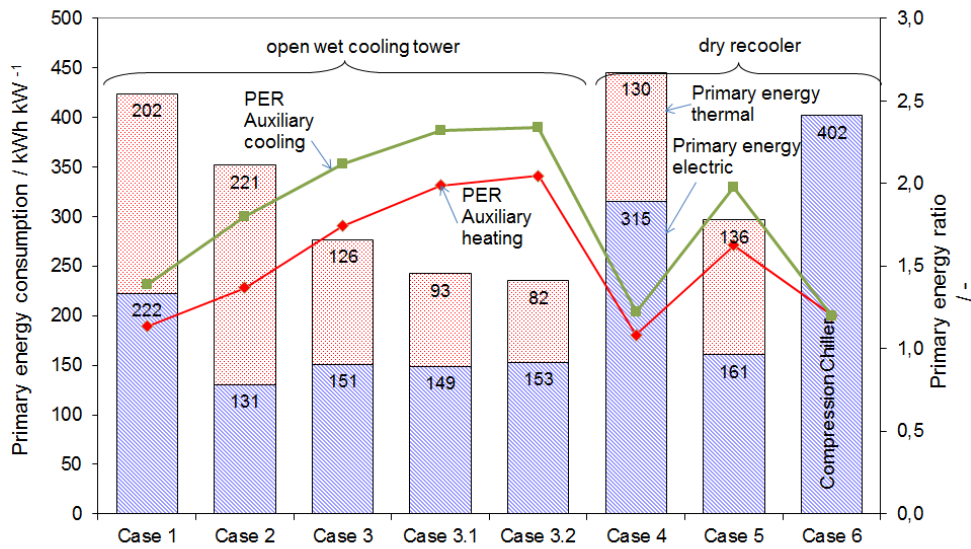


Figure 6: primary energy ratios for different control strategies simulated with the simulation tool INSEL.

In conclusion, at this early stage of development of solar cooling systems it is crucial that simulation tools are capable of optimising all system components including the control, because otherwise photovoltaic compression cooling will not only be more cost effective, but also more efficient in terms of primary energy.