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IMPLEMENTATION OF A MODULAR APPROACH FOR LARGE-SCALE SOLAR THERMAL SYSTEMS IN TRNSYS

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Abstract

This study presents an approach to realise a modular way of building TRNSYS models for typical large-scale solar thermal systems. The time investment required for generating the system model is therefore much smaller, which is useful for e.g. automated failure detection. The model is organised in subsystems that can easily be connected or replaced. Furthermore different options of control strategies have been included in the subsystems and can be specified by setting flags in equation blocks. This is applied to for example the control strategy of the primary pump and of the solar charging strategy. Accordingly, it is possible to quickly build TRNSYS models for a multitude of hydraulically different solar thermal systems with diverse control strategies.

Typical TRNSYS subsystems for large solar thermal systems have been developed and compiled into several complete systems. These are running stably and give plausible results. However, some aspects need to be studied further, e.g. the increase of TRNSYS running time caused by the complexity of the subsystems and the uncertainties of the models.

1. INTRODUCTION

The growing number of large-scale solar thermal systems leads to a demand for intelligent and automatic monitoring approaches. One approach for the detection of failures in components or control is based on a comparison of measured and simulated energy yields. A sophisticated simulation of solar thermal systems is frequently carried out within the simulation environment TRNSYS (Klein, 2006). However, a limiting factor for using TRNSYS for automated failure detection is the large time investment that is required to generate an accurate model for the, often complex, solar thermal systems. Küthe (2008) presents an approach for organising a model in different subsystems that has been applied to a solar combisystem developed within Task 32 of the Solar Heating and Cooling Programme of the International Energy Agency. This study extends and modifies that approach by including options for different control strategies within the subsystems. Furthermore several variants of typical subsystems of large-scale solar thermal systems have been implemented. Therefore, typical large systems can be developed faster and in a simpler way by connecting predefined and verified subsystems. The subsystems should remain flexible, so that individual requirements can be integrated.

Typical large-scale systems were selected based on a market analysis of typical hydraulics of solar thermal systems (>80 m^2) in Central Europe (Dröscher, 2009). The main classification is into systems for domestic hot water, 2-line systems and systems supplying heat to a district heating network. The systems have been divided in so called modules, defining the hydraulics of part of the system, e.g. the solar loop, the storage charging part or the auxiliary heater. These specified modules can be combined to a multitude of solar thermal systems. However, this concept cannot be copied one-to-one to the TRNSYS environment, since also the control strategy plays a large role and often crosses the module boundaries. Therefore, the subsystems and its variants used in this paper differ somewhat from the modules in the previous study.

The next section of the paper describes the concept for the modular way of building TRNSYS decks and gives an overview of the different variants of subsystems implemented. In section 3 TRNSYS models of several real solar thermal systems will shortly be described. In section 4 conclusions will be drawn.

2. METHODOLOGY

Concept

The solar thermal systems are modelled using the Simulation Studio of TRNSYS version 16.1. The Simulation Studio of TRNSYS, a graphical user interface, is used for generating the TRNSYS ASCII input file. The aim is to have a high level of modularity and flexibility for simulating systems. This is achieved by dividing the system into so called subsystems that can easily be connected and replaced. A subsystem is a collection of components that are connected in the common way. These subsystems refer normally to a loop in the solar thermal system, e.g. the solar loop is a subsystem. By generating several variants of the subsystems for one loop, a multitude of systems can be designed.

A critical issue is the connection of the subsystems, so that the compiled model consisting of subsystems will function as desired. This is solved by connecting subsystems via 'Equation' blocks that act as interfaces (Küthe, 2008). Pairs of equations are used for the input and the output of the subsystem, so that variables can be transferred without a visible connection. Therefore, this approach allows to replace complete subsystems. The subsystems are linked to each other for temperature and volume flows. These connections can easily be changed. The functioning of the pairs of equations is shown in the blue boxes in Figure 1. The secondary flow temperature is defined in the inside output equation (Chain_Out_Coll_1) and transferred to the outside output equation (Coll_T_flow=Chain_Out_Coll_1) without being connected. Further variables needed in other loops as where they originate, can 'jump' from the inside output equation box of the original loop, to the inside input equation box of the loop where it is desired. This is illustrated with the red boxes in Figure 1. Ambient temperature is defined in the inside output equation box of the weather loop (Weather_T_Amb) and 'jumps' into the Collector Loop in the input inside equation box of that Loop with the equation (Coll_T_Amb = Weather_T_Amb).

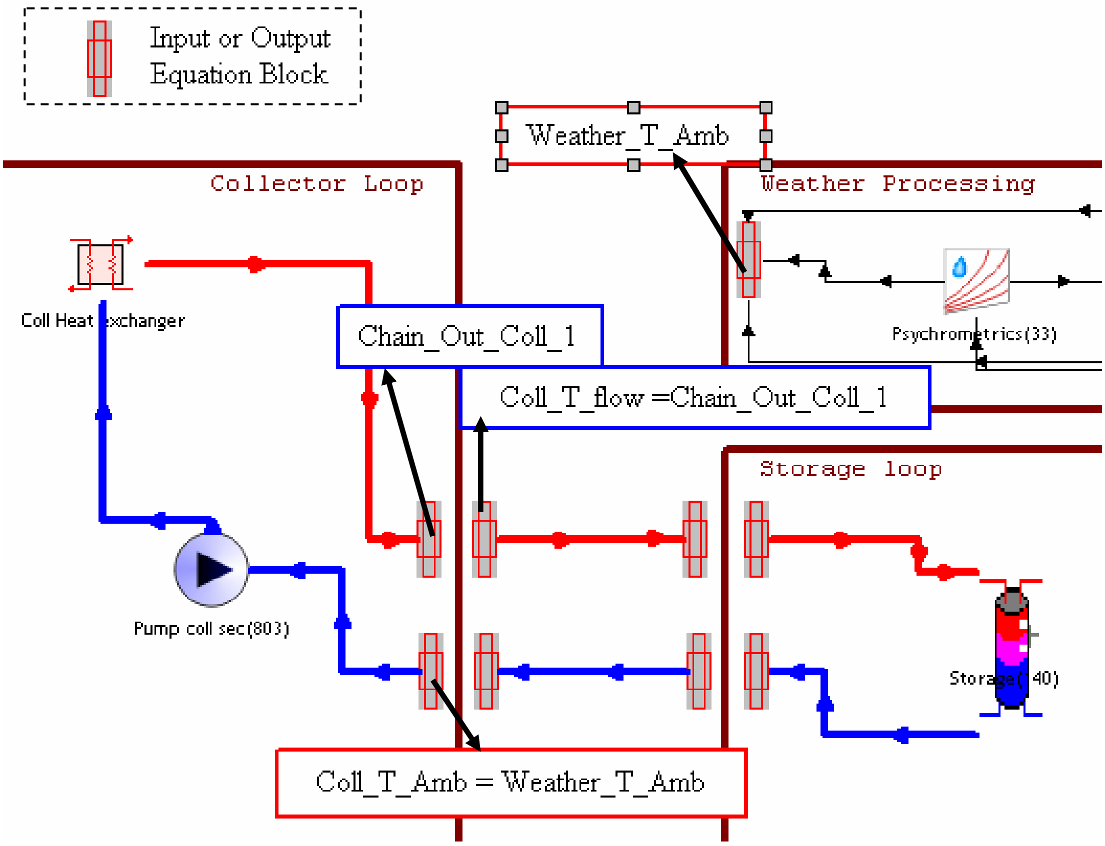

Figure 1. Transfer of variables between subsystems with pairs of equations (blue boxes) or jumping subsystem block (red boxes)

The control strategy can be changed by setting flags, i.e. 1 or 0 in the right equation. This limits the number of subsystems that are necessary. This will be illustrated for the control criterion ‘collector stagnation’, i.e. the pump in the solar loops turns off, if the collector becomes too hot. The flag, as defined in the control equation block, is shown in Figure 2. This and the other relevant equations for collector stagnation in the control equation block are listed in Table 1. The first equation (the flag) indicates if the criterion is applied (1) or not (0) and can easily be changed by the user. This is the only thing the user needs to change. A second equation joins the output of the stagnation controller with the flag. If the criterion is not applied the output of this function is always 1. The last equation determines the pump signal, this depends on control criteria e.g. collector stagnation. The user does not need to change these last two equations.

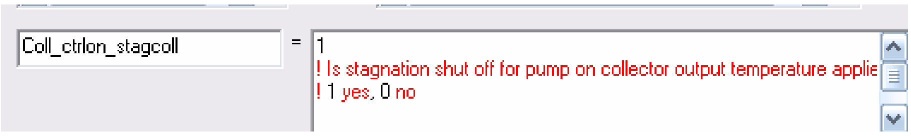

Figure 2. Flag for collector stagnation as defined in equation block

Table 1. Collector stagnation control as defined in the control equation block

Intermediate/output		**Definition**	**Description**
Coll_ctrlon_stagcoll	=	0 or 1 *Set by user, see figure 2*	*Flag* for collector stagnation, criterion is applied (1) or not (0)
Coll_ctrl_stagcoll	=	Coll_ctrlOut_StagColl* Coll_ctrlon_stagcoll+ NOT(Coll_ctrlon_stagcoll)	Control signal for stagnation. This is output of hysteresis controller for stagnation if flag is set to 1, if flag is set to 0, this is always 1.
Coll_ctrl_pumpprim	=	**X*** Coll_ctrl_stagcoll	Pump signal for primary pump is multiplied by stagnation signal

This concept can be used for the control criteria of pumps and valves. In the next subsections the implementation of the flag concept in the solar loop, the storage loop and the domestic hot water loop is described. The parameters of the components are defined in a Parameter Equation block, which is available for each subsystem. The idea is to be able to specify these parameters and flags for control strategies externally and to automatically supply these to the TRNSYS deck before it starts. This has the advantage that systems can be defined in a short time, without having to open several components in the Simulation Studio. However, this is not implemented yet.

Solar loop

The solar loop consists of the collector, pipes, pumps and an heat exchanger. Systems with internal heat exchangers are not considered at this time, since they are not frequently used in large systems. So far, two variants of the solar loops have been defined, one for systems with a store and one for district heating feed in systems. The structure in TRNSYS of Solar Loop 1 is shown in Figure 3. The collector is modelled with the non standard type 832 (Perers, 2002). The other components are modelled with the standard types 5 (heat exchanger), 31 (pipes), 2 (hysteresis controller), 23 (PID controller). The dashed blue line shows the subsystem boundary.

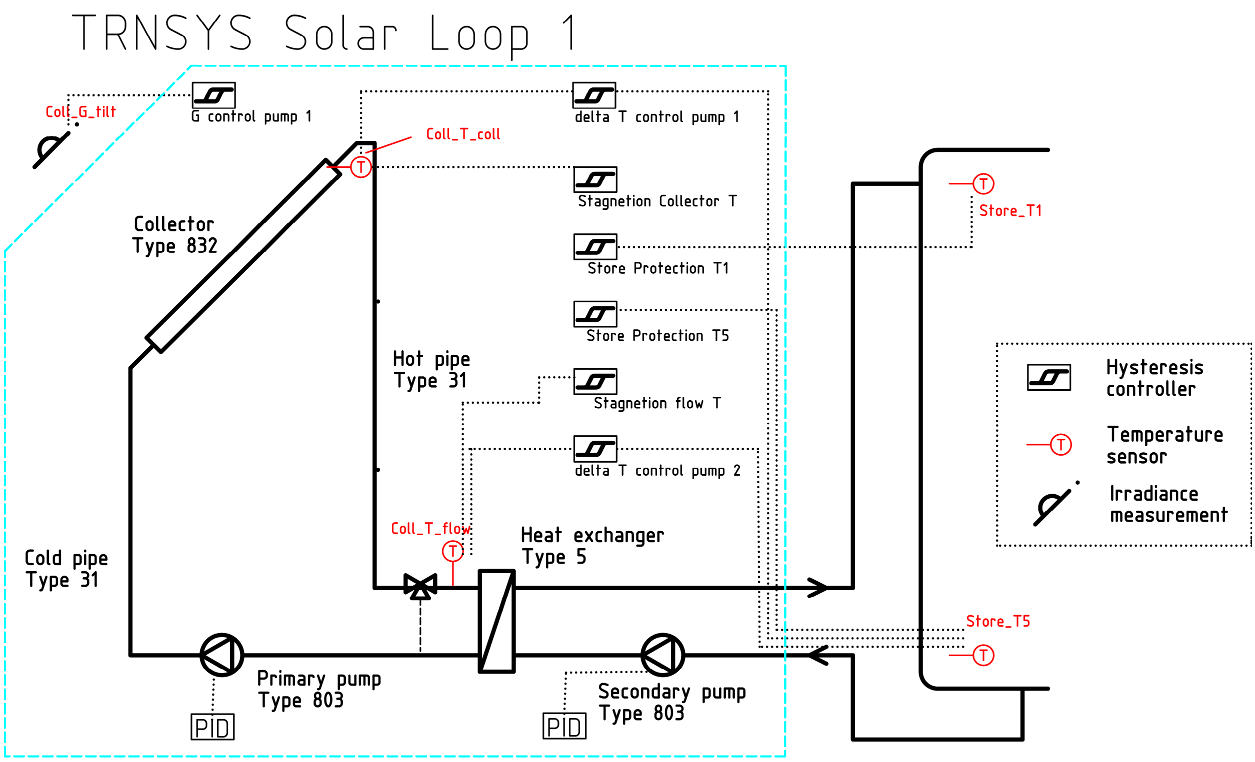

Figure 3. The solar loop variant 1 in TRNSYS with multiple control strategies

Several possible control strategies are shown. By using flags in the control equation block, the user decides on which control mechanisms are used. An example is given for the on/off control of the primary pump in Figure 4. The user chooses the main control scheme; level of irradiance (flag = 0) or temperature difference of collector output and lower storage (flag = 1). This is followed by a decision on which conditions are applied (flag = 1) or not (flag = 0), for: stagnation, store protection, pump lag time, and minimum pump running time. The corresponding component parameters, e.g. collector stagnation temperature, and dead bands are set in the Collector Parameter equation block. A PID controller controls the flow rate in the primary loop, in case of a constant flow the minimum pump speed is set to the maximum pump speed.

The main on/off-control criterion of the secondary pump is based on the temperature difference of the primary flow temperature and the lower store temperature. In combination with stagnation, the criteria store protection, pump lag time and minimum pump running time conditions, determine if the pump is on or off.

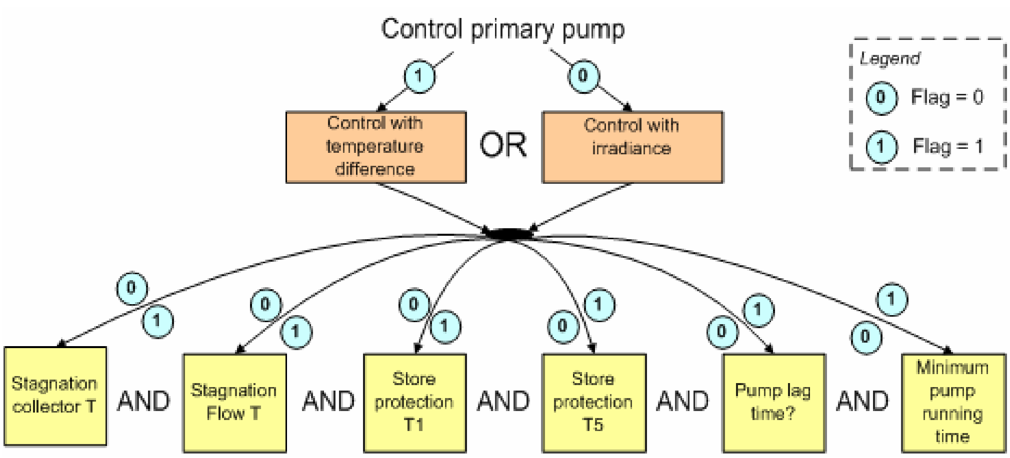

Figure 4. Control scheme of primary pump in solar loop that decides if pump is on or off

Store Loop

The store loop is shown in Figure 5. The store is modelled with Type 340 (Drück, 2006). For the solar charging of the store there is a maximum of three inlets, flags are used to indicate which inlets are used and to determine the control strategy of the valves.

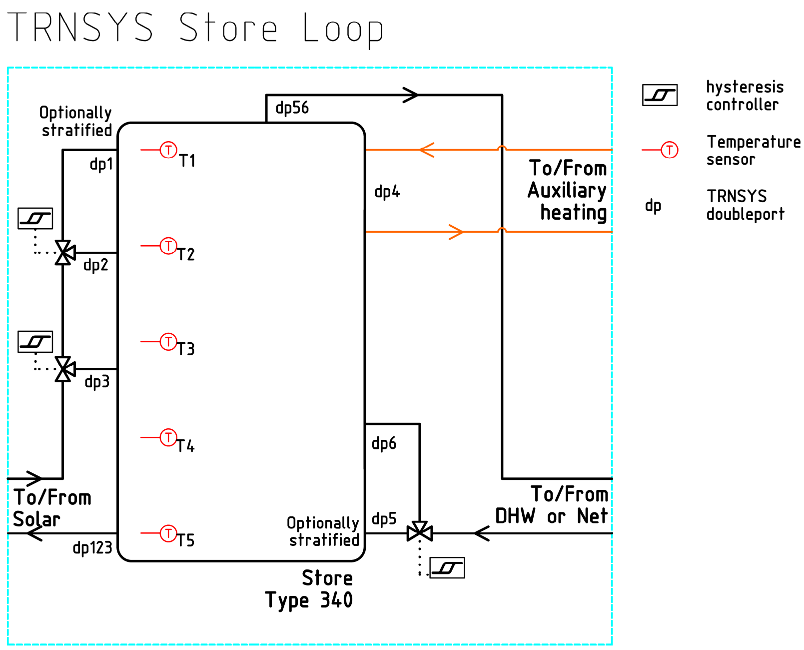

Figure 5. TRNSYS storage loop

A scheme of the control of the solar charging switching valves of the store is presented in Figure 6. The switching valves operate on the output of a hysteresis controller that compares the flow temperature to either the temperature at sensor 1, 2, or 3 in the storage or/and a fixed temperature. Furthermore, the charging of the store can be stratified. An example of a control strategy is indicated by the green lines in Figure 5. The system has one switching valve that is controlled by the temperature of sensor 3 in the store (0.56 relative height) and a fixed temperature of 65 °C. If the solar flow temperature is larger than both T3 and 65 °C, there is an energy flow through doubleport 1, otherwise the valve switches to doubleport 2. Figure 7 shows, for illustration purposes, the functioning of the valve in the example.

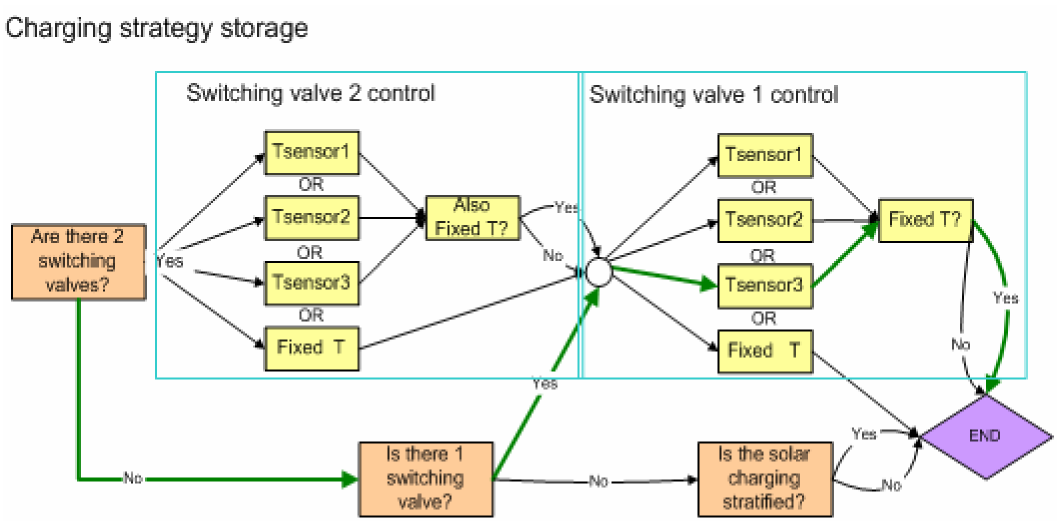

Figure 6. Solar charging options of the storage, including control strategies of the charging valves

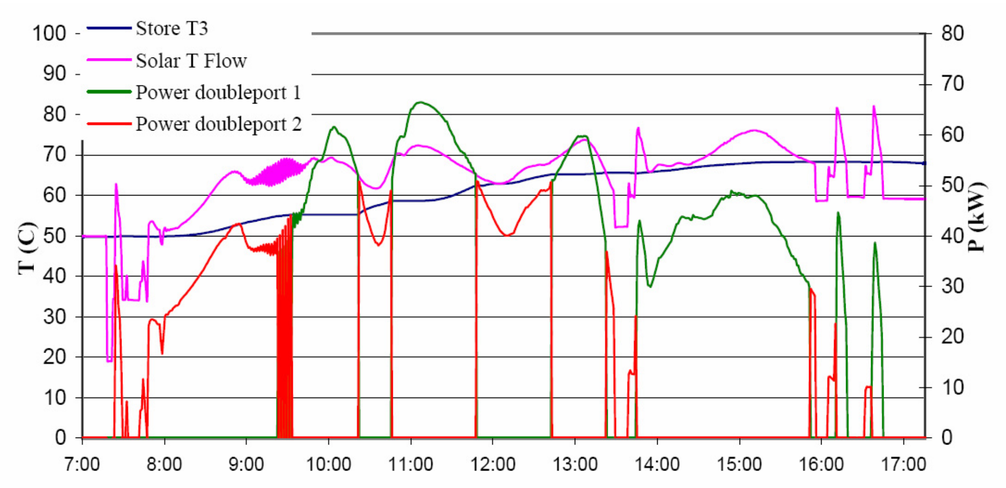

Figure 7. Operation of one switching valve in TRNSYS subsystem store

A similar control scheme is applied for the return flow from the net, with a maximum of two different inlets, or stratified charging. In addition, there is a connection from the buffer store to the auxiliary heating block. Nevertheless, if there is no auxiliary heating attached to the buffer store, the flow can be set to zero.

DHW loop

In Germany large systems with auxiliary heating attached to a stand-by storage tank in the domestic hot water loop are very common, due to the legionella regulations. There are several variants for the domestic hot water loop.
On the left side in Figure 8, a buffer discharging subsystem without pre-heat storage is shown. The drinking water only flows when there is a water demand, and is, when necessary, conventionally heated in a stand-by store. On the right side in Figure 8, the buffer is discharged into solar pre-heat storage and afterwards heated in a standby storage.
Optional in both loops is a mixing valve to limit the buffer flow temperature in the heat exchanger to reduce lime sedimentation. Furthermore, the outlet temperature can be regulated by a mixing valve and there is the option to include circulation. For the variant on the right side the option to heat the pre-heat storage up to 60 °C to comply with regulations to prevent legionella reproduction still needs to be included and is not shown in the graph.
A third option is similar to DHW Loop 1, but with auxiliary heating feeding into the buffer store instead of the DHW store. Furthermore also the control strategy of the heat exchanger between the stores has several options, volume flows can be matched on both sides, or the difference of cold water temperature and return temperature to buffer store can be set (with an different TRNSYS type).
Measured volume (or heat) flows and temperature of the distribution system are necessary as an input for the TRNSYS model.

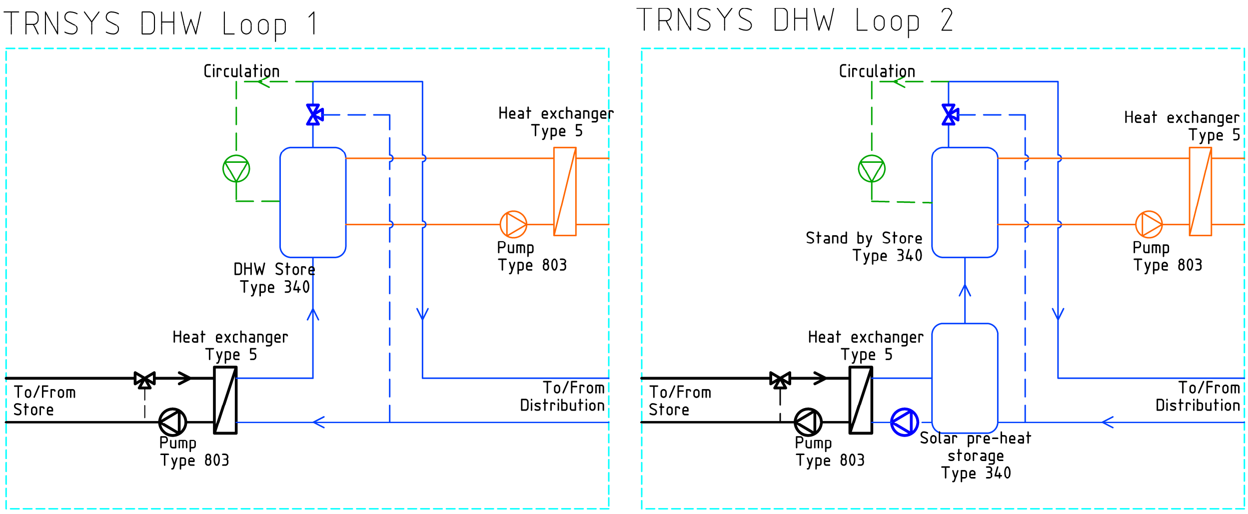

Figure 8. Domestic hot water loop, dashed lines are optional in control

Auxiliary heating loop

There are several options for the auxiliary heating loop. In Droescher (2009) types are described with a heater, with district heating (with or without heat exchanger) and a black box heating that provides a certain temperature are described.

District Heating Net

The loop in the net consists of a pump, and a mixing valve. The necessary inputs are measured volume or heat flows and the return temperature of the net.

Weather

The weather box provides the necessary meteorological information. It can be operated with measured data or with a database. These are two different subsystems.

3. SYSTEM EXAMPLES

Up to now several systems have been compiled and are running with the modularised approach. Two examples will be shown here. Both systems are running stably and give plausible results.
In Figure 9 a sketch of a domestic hot water system without solar pre-heat storage is shown. The primary pump is controlled by irradiance and a store protection criterion, and runs at a constant volume flow. The secondary pump is controlled by the temperature difference between primary flow temperature and the temperature low in the storage. The store has three inlets for solar charging (heights in store not depicted to scale). The switching valves are controlled by the temperature difference of the flow temperature in comparison to the store temperatures at sensors 1, 2 and 3. Also the storage discharging return flow can be diverted by a switching valve to the store. There is a mixing valve that keeps the flow temperature at the discharging heat exchanger at a temperature maximum of 65 °C. The volume flow of the storage discharging loop is matched to the cold water flow. The auxiliary heating is provided by district heating and is attached to a standby store.

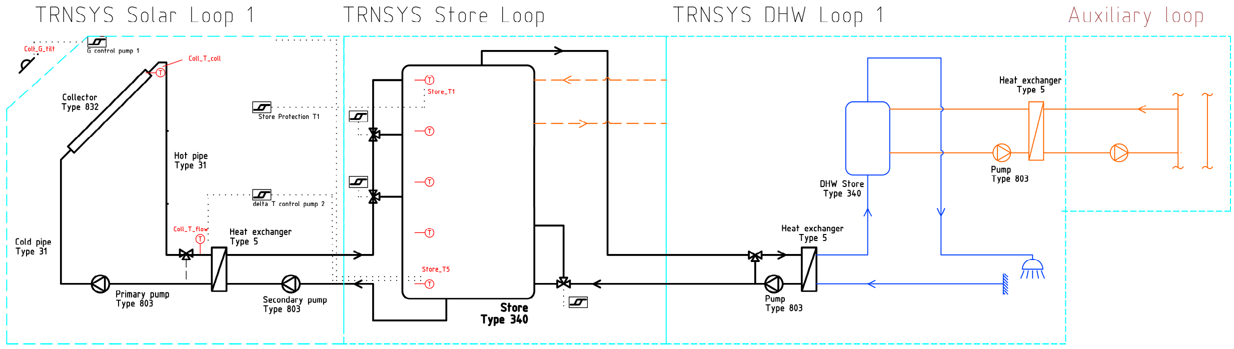

Figure 9. Scheme of simulated domestic hot water system without solar pre-heat storage

In Figure 10 a two line system is depicted. The flows in primary and secondary loop are variable. The primary pump turns on based on a control of the temperature difference. All other criteria for the control of the primary pump in Figure 4 are applied as well. There are two inlets in the store, a switching valve is controlled by the temperature in the store and a fixed temperature. A gas heater heats up part of the buffer storage.

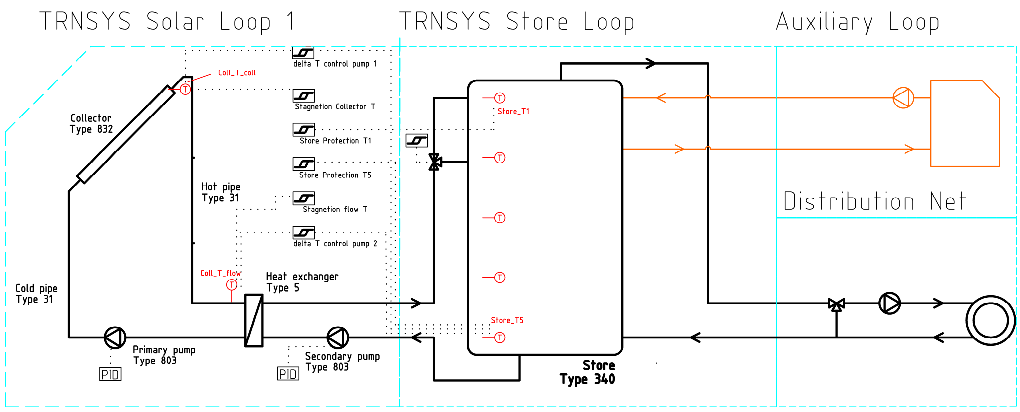

Figure 10. Scheme of simulated two-line system

4. CONCLUSIONS AND DISCUSSION

The methodology of organising TRNSYS models of solar thermal systems in different subsystems has been further developed, amongst others by including several optional control strategies in the subsystems. Furthermore typical subsystems have been generated that can be combined to a multitude of TRNSYS models for large solar thermal systems. A subsystem represents a certain part of the solar thermal system, e.g. the solar loop or the storage. Variants of a subsystem are necessary if the hydraulics differ a lot, e.g. an extra store in the domestic hot water subsystem, or if different TRNSYS types are required. In addition, several control strategies have been integrated into the variants of the subsystems. By setting flags, the user can specify the control strategy. This allows for a large diversity of control strategies and reduces the number of necessary subsystem variants.

The chosen strategy greatly diminishes the time needed for building a simulation model for a large solar thermal system in TRNSYS. The flexibility is maintained since the subsystems can still be altered. However, a disadvantage could be that the complexity of the deck results in a longer running time for a simulation. The precise effect needs to be studied, and the significance of this depends on the application. This project is work in progress. At the moment, the focus lies on the extension of the number of subsystems and the inclusion of a thorough uncertainty analysis. Furthermore a verification of the subsystems, e.g. in comparison to measured real systems is planned. Lastly an ideal balance between quickness of model generation, speed of simulation, flexibility, matter of detail and usability depends on the used application.

5. ACKNOWLEDGEMENTS

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