ADAPTION AND VALIDATION OF A FIN-AND-TUBE HEAT EXCHANGER MODEL FOR TRNSYS USING PRODUCER-SPECIFIC DESIGN SOFTWARE

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ABSTRACT

The investigation of solar heating systems with TRNSYS requires proper numerical models and parameters of the individual components. For standard TRNSYS air-to-water heat-exchanger models heat transfer parameters have to be provided. If these are not known, costly experiments are necessary. The paper describes the verification of a TRNSYS type and the adaptation of parameters for a fin-and-tube air to water heat-exchanger by using accurate output data of producer specific heat exchanger design programs. With the described method, the TRNSYS model can take specific geometries as well as condensation effects on parts of the heat exchanger area into account. The software of the manufacturer was incorporated in the TRNSYS environment without any modification. With this procedure a proper and flexible TRNSYS calculation of a fin-and-tube heat exchanger model with a reasonable accuracy could be achieved avoiding costly measurements.

1. INTRODUCTION

Within the context of a research project in Bishkek (Kyrgyzstan) a conventional fin-and-tube heat exchanger is being investigated. The heat exchanger is used to heat up cold water by using the enthalpy of the ambient air. As fin-and-tube heat exchangers are industrial standard components, they can provide thermal energy at low costs if a high ambient and low water inlet temperature are given. If the water inlet temperature even lies below the dew point temperature condensation occurs on parts or even all over the heat exchange area. Thus, varying flow rates may be applied on both the water and the air side of the heat exchanger.
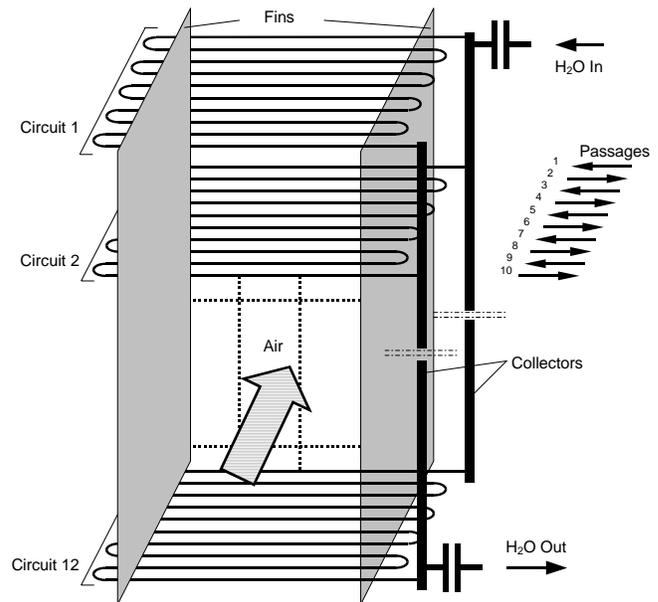

Fig. 1: Basic scheme of a fin-and-tube heat exchanger

In order to achieve a detailed calculation of the geometry a TRNSYS model was used that also considers condensation (Type 1223, cf. Brandemuehl (1993)). The model equation was slightly adapted to the boundary conditions given in the described application. The geometrical data such as fin distance, number of fins per meter, number of circuits, number of tubes per circuit etc. are input data for the TRNSYS model and can be received from the manufacturer whereas the heat transfer parameters (especially the heat transfer coefficient from the air flow to the fins and tubes) are calculated within the model. However, the inaccuracy that still remains in the model equation regarding a special type construction can be minimized by introducing correction factors that have to be identified. One possible

solution for this to compare the model calculations with measured data. If sufficiently accurate data is not accessible, the output temperatures can also be calculated using specific design software that is provided by most manufacturers. These design programs are usually very accurate as the manufacturers have to guarantee the performance of their products, e.g. by certification (cf. http://www.eurovent-certification.com). However, the detailed model equations used in the design software are usually kept secret by the manufacturers so that they can not be implemented in a TRNSYS Type, for instance. Furthermore, the design software only calculates steady-state conditions with a given heat exchanger cooling coil geometry and given thermodynamic input values (such as flow rates, fluid media, temperatures, etc.). If the design software shall be used as a reference to fit an existing TRNSYS model, an interaction between the TRNSYS environment and the design program has to be developed.

2. TRNSYS MODEL

For the calculation of the thermal behaviour of fin-and-tube heat exchangers a lot of models are described in literature. The spectrum ranges from simple equations such as the TRNSYS standard Type 5 (Klein et al. (1998)) to models based on highly complex CFD calculations, e.g. Kaminsky (2002).

For the investigations presented in this paper the main model requirements were the consideration of condensation and bare coil geometry and the availability of an open source code that can easily be modified and integrated into the TRNSYS environment with reasonable computing effort. Therefore, a model was taken that is based on the investigations of Elmahdy (1975) and was modified and published by Brandemuehl (1993) within the scope of the HVAC Secondary Toolkit of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). The Fortran source code can be downloaded from the TRNSYS homepage and is further investigated, cf. Chillar and Liesen (2004). For the calculation Elmahdy and Mitalas (1977) propose to simplify the complex flow conditions due to the distribution of the passes through the heat exchanger coil to a counterflow calculation if the number of passes in one circuit is high enough. Furthermore, heat losses to the environment are neglected and no capacity effects are implemented.

Above the hatched area in Fig. 2 which represents the heat exchange area the (hot) air flow is indicated (flow direction from left to right) whereas the (cold) water flow is printed below. If the dew point temperature is higher than the outer tube temperature, condensation occurs on a part of the heat exchange area (as indicated on the right side of the broken

line in Fig. 2). In the model, the location of the transition is determined before the convective heat exchange in the dry and wet part as well as the condensation gains on the wet part are calculated.
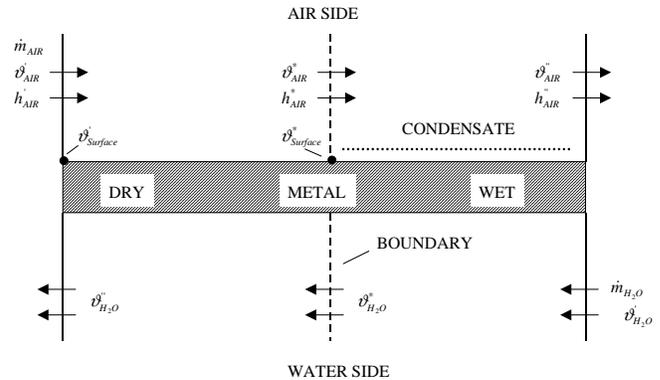

Fig. 2: Schematic diagram of the TRNSYS Type 1223 heat exchanger model
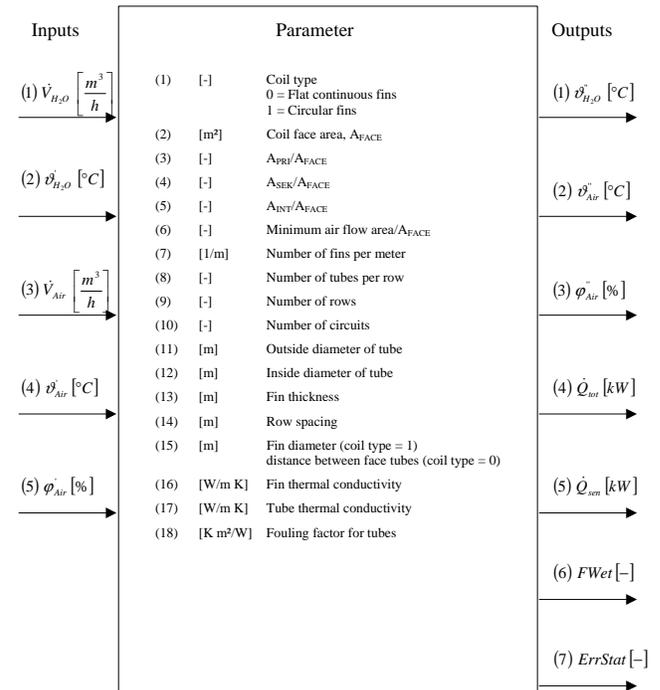

Fig. 3: TRNSYS Type 1223: Input, parameter, output

3. MODEL ADJUSTMENT

Using a producer specific design software (see section 3.1), thermodynamic calculations of a specific fin-and-tube heat exchanger have been carried out. The results are compared to the calculations of the TRNSYS model. To allow a quasi-dynamic calculation with both programs at the same time and with the same input values, an Excel-based control of the producer design software (see section 3.2) and a

TRNSYS-Excel interface have been developed which finally also allows the validation of the TRNSYS model.

3.1 Producer Design Software

The design software used for these investigations is called GPC (Guentner Product Calculator 2004, written and distributed by Hans Guentner GmbH, Germany). The program can either propose appropriate bare coil specifications for needed outlet temperatures or power or calculate the outlet temperatures etc. for a chosen coil with all the geometrical details shown in Fig. 4.
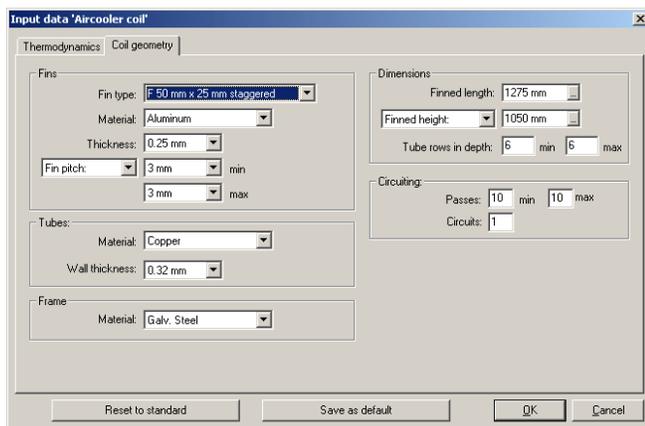

Fig. 4: Input mask "Coil geometry" of the design software GPC (Guentner Product Calculator).

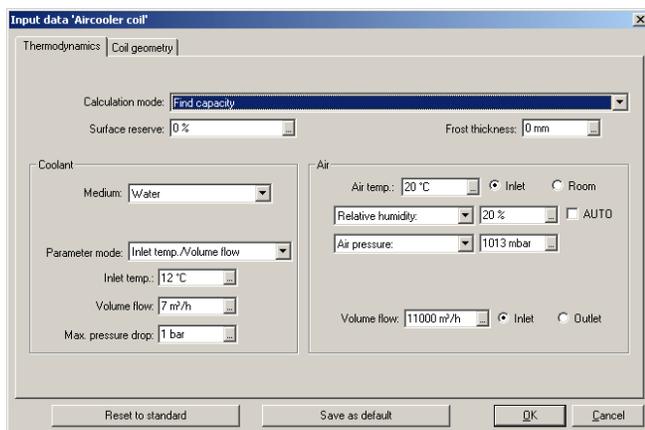For each calculation the user has to provide the thermodynamic inputs by hand, see Fig. 5.

Fig. 5: Input mask "Thermodynamics" of the design software GPC (Guentner Product Calculator).

Beside the missing variables (temperatures, flow rates or thermal output) the program also calculates the relative humidity of the outlet air, the condensate, the heat transfer coefficient and the logarithmic mean temperature difference. On the evidence of the manufacturer the accuracy is in the range of 5 % for dry and 10 % for wet coil conditions (Summerer (2004)). The results of every calculation of a steady-state condition (with given altitude or air pressure, humidity etc.) are filed in a GPC specific data format.

Basically the GPC could also be used as a calculation model instead of a TRNSYS Type. However, as the initialisation of each calculation step needs to call the program in each time step, the modelling of a time interval with changing conditions has a high computational effort. Furthermore, the source code is hidden so that occurring deviations from measurement data can not be analysed and the program is not transferable to products from other manufacturers.

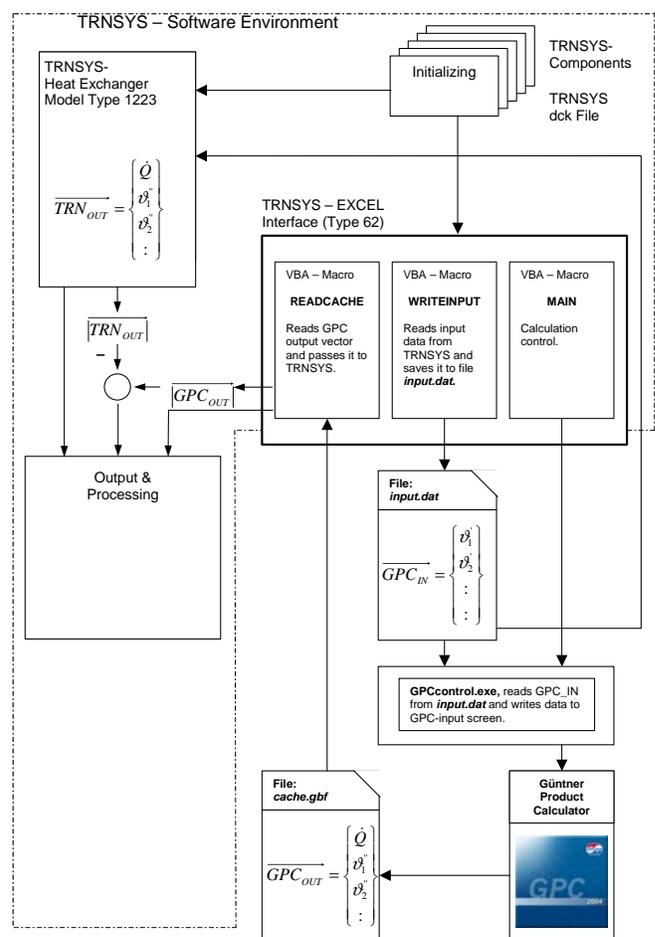## 3.2 Integration into the TRNSYS Environment

Fig. 6: Interaction between TRNSYS, the TRNSYS-Excel interface and the GPC

To calculate the thermal output with both the GPC and the TRNSYS Type 1223 at the same time and to provide the input values for the GPC at each time step automatically, the GPC has been integrated into the TRNSYS environment without any modification.

With TRNSYS Type 62 files can be exchanged with Microsoft Excel. As indicated in Fig. 6 TRNSYS reads the data necessary for the calculations (e.g. from a weather data file) and the initial values. Then, two simultaneous calculations are started, one by using the GPC and one with Type 1223.

For the calculation with the GPC, the initialisation data is transferred to the VBA Macro "WRITEINPUT" which writes the file *input.dat*. The data set (including inlet temperatures, flow rates etc.) for each time step is called the GPC input vector. Then, the file *GPCcontrol.exe* is executed by the control Macro "MAIN". The file *GPCcontrol.exe* is a compiled batch file created with a Windows application control software. By generating *GPCcontrol.exe* in each time step the GPC is started together with a new set of input values from the GPC input vector that are automatically written in the corresponding fields in the input masks. Subsequently the GPC calculates the output data (called GPC output vector) and writes the GPC specific file cache.gbf. The VBA Macro "READCACHE" reads the GPC output vector and directs it to TRNSYS.

The TRNSYS calculation with Type 1223 is carried out with the GPC input vector from the file *input.dat*. A TRNSYS output vector is created. Both output vectors can now be compared and filed for further processing.

3.3 Parameter Fitting

In Type 1223 the calculation of the average film heat transfer coefficient for a dry surface is based on the determination of the overall heat transfer parameter J. Elmahdy (1975) uses the physical heat exchanger dimensions to calculate J as a function of the Reynolds number and two coil specific constants. As the calculation with the Type 1223 model did not match with the results of the GPC satisfactory, this relation has been modified by introducing a correction factor. Using a non-weighted least square approach this correction factor was identified with good results yielding in less than 5% total heat transfer deviation with respect to the values calculated by the manufacturer software.

Based on the dry surface average film heat transfer coefficient the wet surface average film heat transfer coefficient is calculated additionally taking into account a correction term (cf. Elmahdy (1975)) which is a function of the air face velocity. A second correction factor is added and identified using a non-weighted least square approach yielding good results with the calculated total heat transfers by the model. These calculations do not exceed an error of 5% for wet conditions with regard to the reference values.

4. RESULTS

The calculations of the air and water output temperatures of Type 1223 were fitted to the GPC calculations for a 3-day period with typical variations of ambient temperature and relative humidity as shown in Fig. 7. In the application mentioned, the ambient temperature corresponds to the air inlet temperature whereas the water to be heated up has a constant inlet temperature of 12°C. The parameter fitting was carried out at a water flow rate of 5 m³/h and an air flow rate of 9300 m³/h. Fig. 8 shows the total heat flow calculated with the GPC (grey line) and the total heat flow calculations with the TRNSYS model using the correction factors described in section 3.3 (black line). The ambient temperature is plotted on the right axis as well as the relative error which is always lower than 4 %.
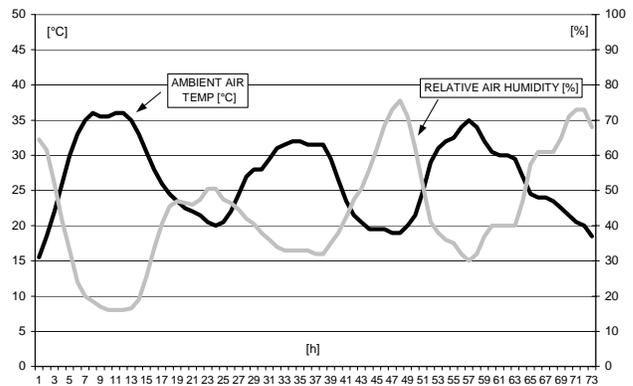
Fig. 7: Ambient temperature and relative humidity for a typical 3-day period in Bishkek (Kyrgyzstan)
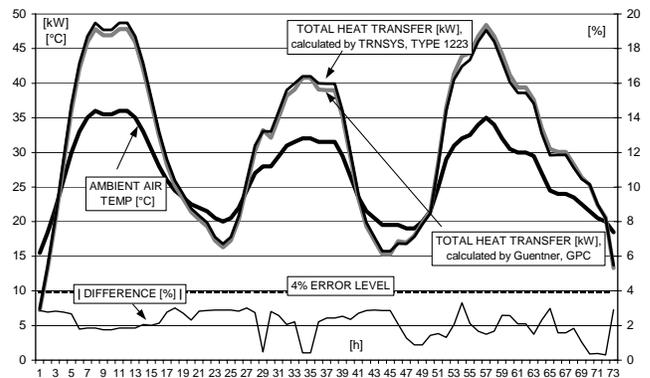
Fig. 8: Total heat flow calculated with TRNSYS Type 1223 and the GPC

Fig. 9 and Fig. 10 show the water and air outlet temperatures, respectively. The difference between the outlet temperatures is plotted on the right axis. As shown in Fig. 9 the correction factor used in the TRNSYS model could be determined leading to a deviation less than 0.3 K in

the calculated water output temperatures for the conditions mentioned above. As in the application the aim was to heat up water this was the main focus of the investigations presented in this paper. The air outlet temperatures calculated with the TRNSYS model differ from the GPC calculations not more than 1 K, cf. Fig. 10.
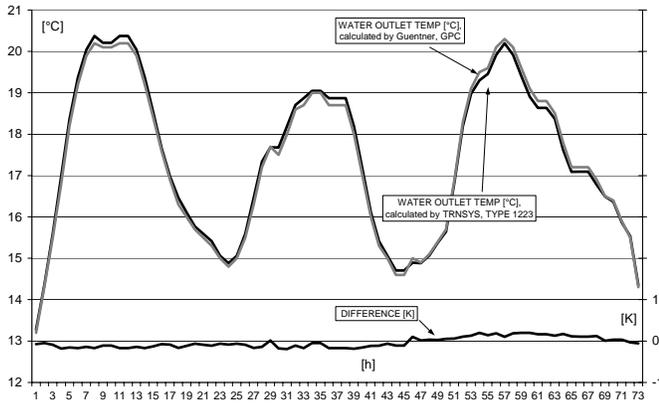

Fig. 9: Water output temperatures calculated with TRNSYS Type 1223 and the GPC
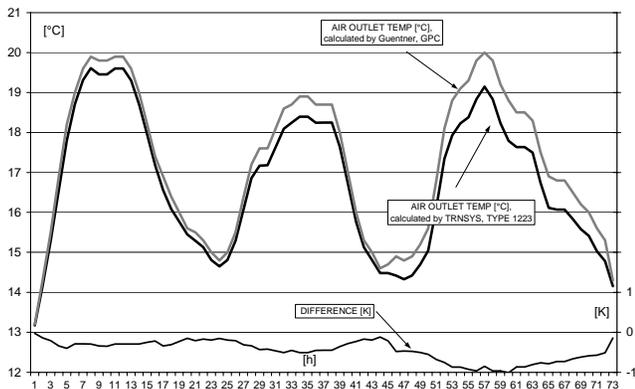

Fig 10: Air outlet temperatures calculated with TRNSYS Type 1223 and the GPC

5. CONCLUSION

A simple model to simulate cooling and dehumidifying coils in order to calculate the outlet temperatures in applications where water is heated up by using warm ambient air has been used in this paper. To avoid the necessity of sufficiently accurate measurement data for the validation of the model, a method is presented to integrate producer specific design software into the TRNSYS environment. By introducing correction factors into the TRNSYS model, the heat transfer parameters could be identified leading to a difference below 0.3 K in the calculated water output temperature compared to the calculation of the producer software. This method can basically be used for different

heat exchanger models if appropriate producer software is available.

6. ACKNOWLEDGMENTS

7. REFERENCES

(1) Brandemuehl, M. J., HVAC 2 Toolkit: A Toolkit for Secondary HVAC System Energy Calculations, ASHRAE 629-RP, Joint Center for Energy Management, University of Colorado, 1993

(2) Elmahdy, A. H., Analytical and experimental multi-row finned tube heat exchanger performance during cooling and dehumidifying processes, dissertation, Ottawa, Canada, 1975

(3) Klein, S. A. et al., TRNSYS 14.2 User's Manual, University of Wisconsin, Solar Energy Laboratory, 1998.

(4) Kaminski, S., Numerische Simulation der luftseitigen Strömungs- und Wärmetransportvorgänge in Lamellenrohr-Wärmeübertragern, dissertation, Technical University Freiberg, 2002

(5) Chillar, R. J, Liesen, R. J., Improvement of the ASHRAE secondary HVAC toolkit simple cooling coil model for simulation, Proceedings of the 1st SimBuild Conference, International Building Performance Simulation Association, 2004.

(6) Elmahdy, A. H., Mitalas, G. P., A simple model for cooling and dehumidifying coils for use in calculating energy requirements for buildings, ASHRAE Transactions No. 2456, pp. 103-107, 1977.

(7) GPC, Guentner Product Calculator, free download version 2004.26, www.guentner.de, 2004.

(8) Summerer, F., personal communication, 2004.