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# COMBITST-PROGRAM MANUAL

CHRIS BALES



HÖGSKOLAN  
Dalarna

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# **COMBITST-PROGRAM MANUAL**

*Chris Bales*

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## Abstract

This manual describes how to operate the test rig for solar combisystems at the Solar Energy Research Center SERC. It describes in detail the computer program running controlling the test rig. This program is called COMBITST and has been developed using C++ within the development environment LabWindows/CVI version 3.1 from National Instruments.

COMBITST can either be run in manual or automatic mode. In manual mode it is possible to control the valves, input temperatures and flows etc directly via special commands in the graphical user interface. In automatic mode, the program reads a control file that defines what the test rig is to perform. This can either be periods of constant inlet temperatures and flows for specific ports using a special command syntax, or it can be emulation or "real" system operation based on weather and load data in the control file. The program can thus perform all tests necessary for store testing and verification according to the preliminary CEN standard, prEN 12977-3, or alternatively it can perform realistic test sequences.

The manual describes the basics of the test rig, the control functions allowed by the program and how to conduct automatic testing. It also describes the structure of the program and the control files that it uses.

## Sammanfattning

Denna manual beskriver hur man använder provanläggningen för solvärmda kombisystem vid Centrum för solenergiforskning SERC. Manualen beskriver i detalj datorprogrammet som styr anläggningen. Programmet heter COMBITST och utvecklades i C++ i en utvecklingsmiljö som heter LabWindows/CVI version 3.1 från National Instruments.

COMBITST kan köras antingen "manuellt" eller i automatläge. När man kör manuellt kan man styra ventiler, inloppstemperaturer, flöden o s v direkt genom kommandon tillgängliga i programmet genom det grafiska användargränssnittet. I automatläge läser programmet en styrdatafil som definierar precis vad som ska utföras av provanläggningen. Det kan t ex vara perioder med konstanta tillloppsförhållanden (temperatur och flöde eller effekt) för anslutningarna, eller det kan vara klimat och lastdata så att realistiska förhållanden kan emuleras. Allt detta sker genom kommandon i styrdatafilen. Programmet kan således användas för att utföra provsekvenser enligt den preliminära CEN-standarden, prEN 12977-3, eller för att utföra tester med realistiska klimat- och lastförhållanden.

Manualen beskriver de grundläggande egenskaperna av provriggen, styrfunktionerna som programmet kan utföra samt hur man kan utföra automatiska testsekvenser. Den beskriver också programmets struktur och datafilerna som används.

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## 1. Introduction

SERCs control and measurement program for solar combisystems is called COMBITST. It has been developed within the development environment LabWindows/CVI version 3.1 from National Instruments. It is an environment allowing general programming in C++ together with a number of built-in libraries for communication with control and measuring devices, analysis tools, user interface and plotting routines. It allows all action to be performed and controlled through a windows based graphical user interface. The program is based to a large extent on the previous measurement program, written before the test rig was rebuilt in 1997.

Combitst can either be run in manual or automatic mode. In manual mode it is possible to control the valves, input temperatures and flows etc directly via special commands in the graphical user interface. In automatic mode, the program reads a control file which defines what the test rig is to perform. This can either be periods of constant inlet temperatures and flows for specific ports using a special command syntax, or it can be emulation or “real” system operation based on weather and load data in the control file. The program can thus perform all tests necessary for store testing and verification according to the preliminary CEN standard, prEN 12977-3.

The following sections describe the basics of the test rig, the control functions allowed by the program, how to conduct automatic testing and the structure of the program and the control files that it uses.

### 1.1. The Real Time Display Window

The real time window shows the values of the various points in the test rig at the current time during measurements. In addition the calculated powers in the four circuits is displayed. Flows are in l/min and powers in kW. Sensors that are not being measured are shown as -999.9. The comment written in the box at upper left will be saved to the data file if written in before measurements are started.

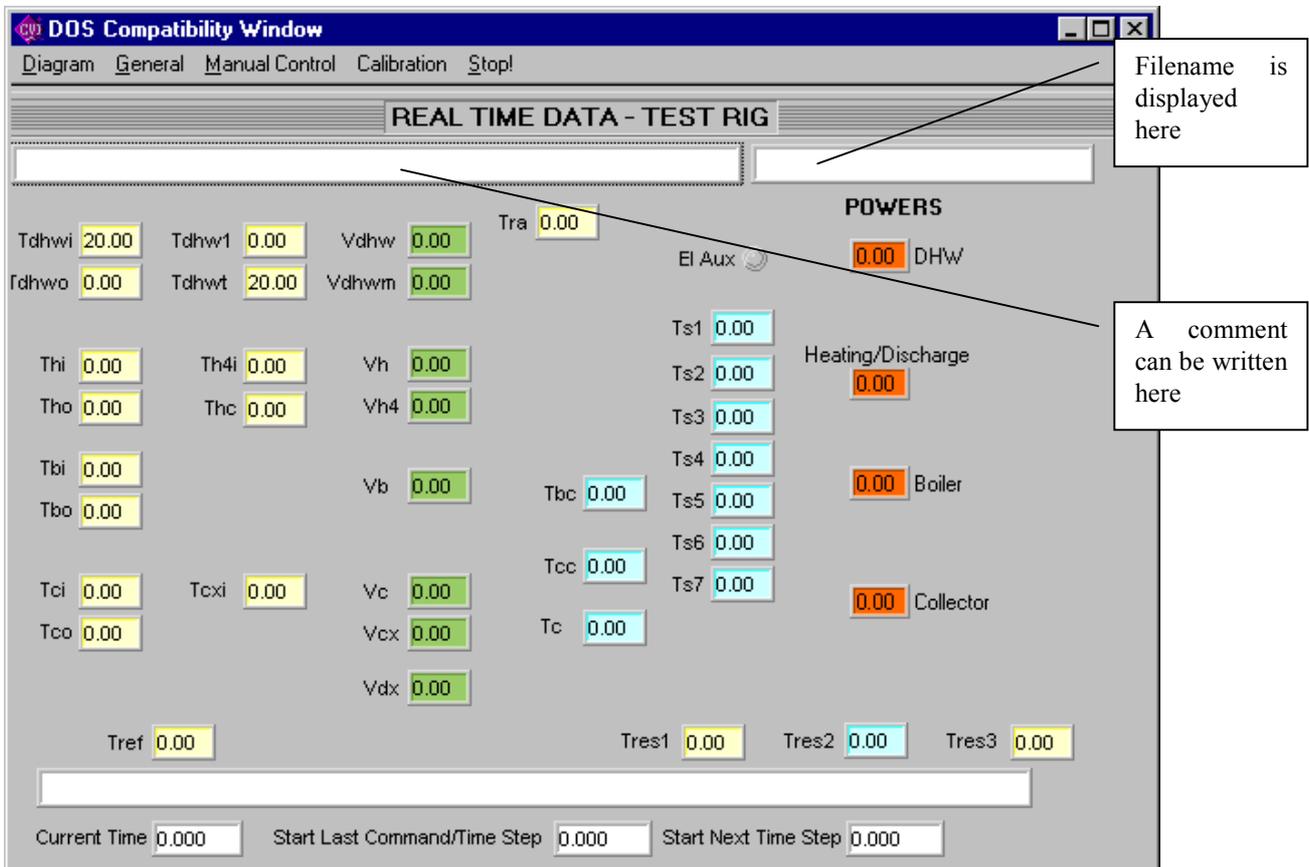


Figure 1.1. Example of the real time display window. The temperatures in the circuits are coloured yellow, the flows green, the temperatures in the store and control temperatures blue and the calculated powers red. Flows in l/min, powers in kW.

## 1.2. Time Diagram

This diagram shows the variation of the values with time. It is possible to vary the time shown, as well the scales for the other axes using the change scales command, see section 5.4. The colours of the various values are defined using the choose colours command, see section 5.3. This command is the only practical way of finding out which trace is for which value.

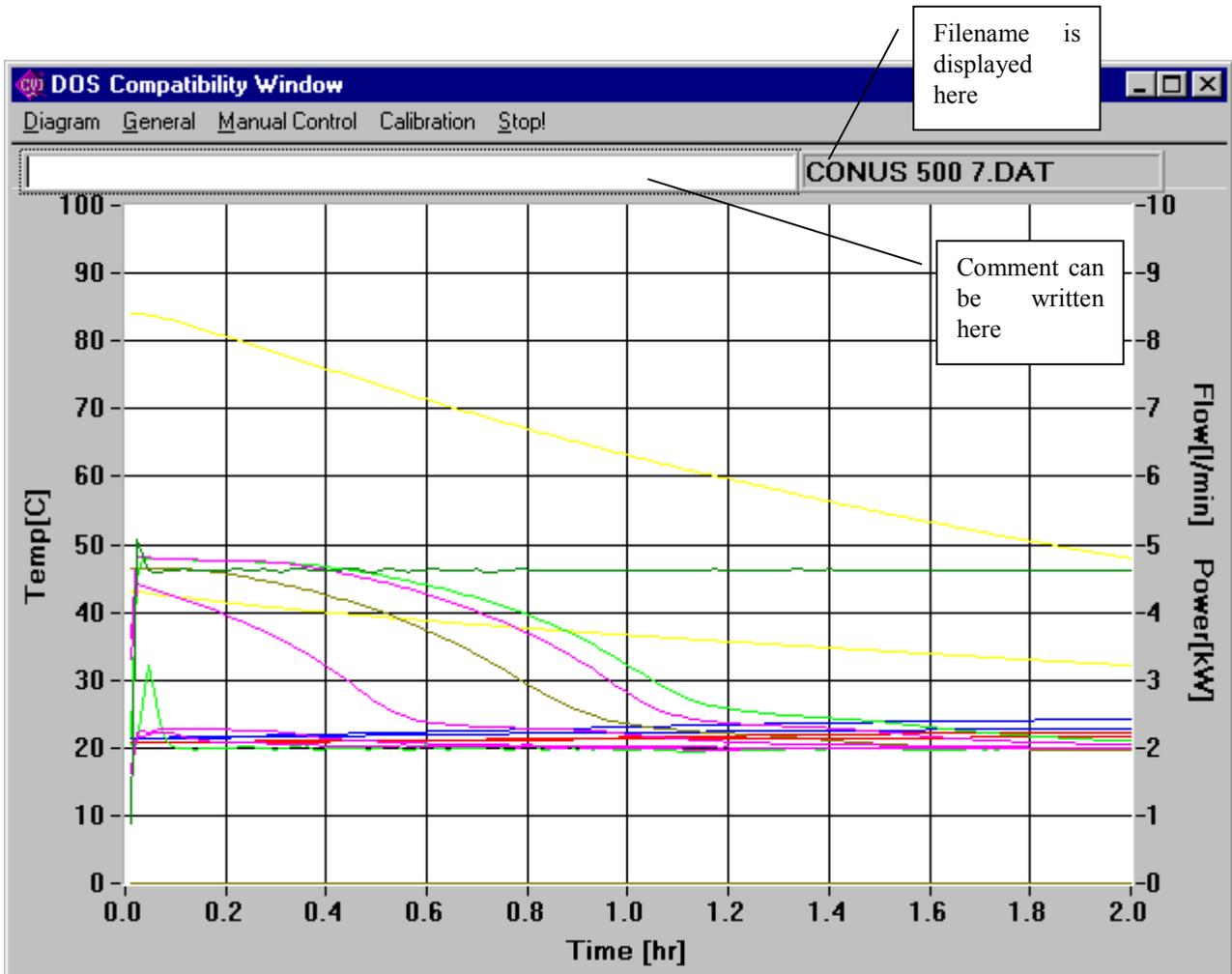


Figure 1.2. Example of a time diagram for the first two hours of a measurement sequence.

## 2. Measurement System

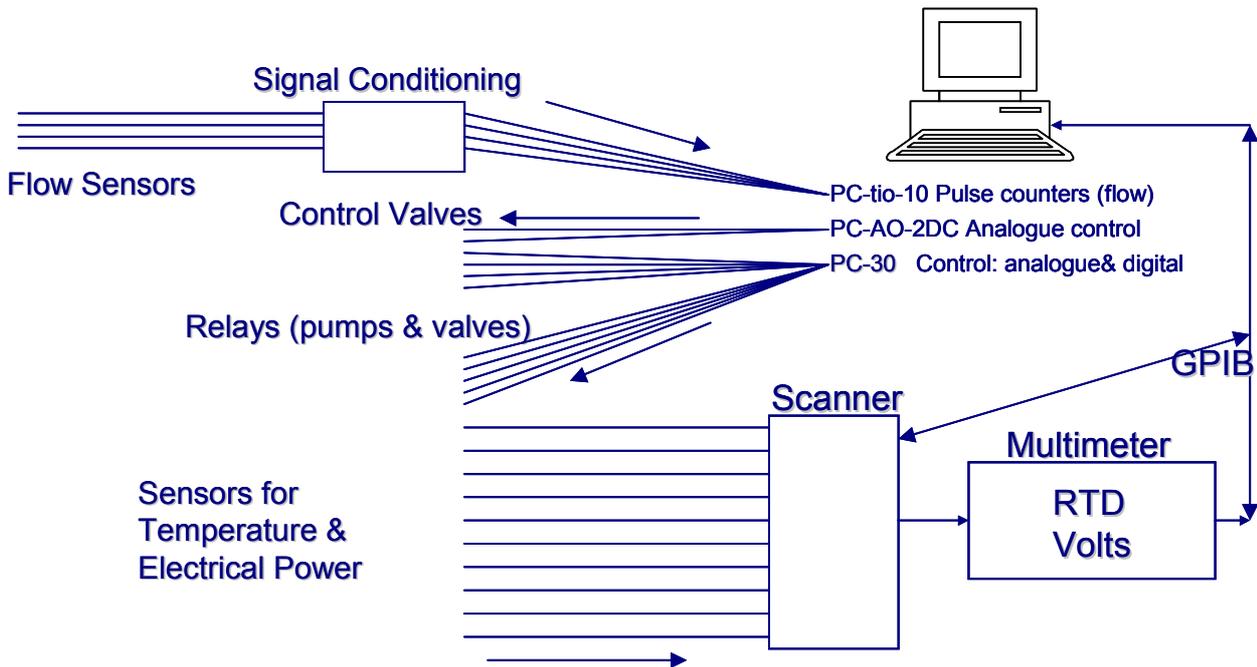


Figure 2.1. Schematic of SERCs solar combisystem test rig.

The basic layout of the test rig is shown in Figure 2.1. All temperatures (in the form of resistance) and electrical powers are measured using a separate Digital MultiMeter. The individual signals are switched using a scanner and both are controlled via a GPIB interface by the measurement program Combitst. In addition there are up to 10 temperatures measured by a separate data logger (Hydra) which is also controlled, and data downloaded by, the measurement program. For flow measurements, inductive flow meters are used. The output signal from these (pulses) go through a signal conditioning card, created specially for the test rig, before being measured on a pulse counter card mounted into the measurement computer, so called PC-card. All control signals, both analogue and digital come from two other PC-cards. The digital output signals go to relays that can switch higher voltages and currents. A summary of this is seen in Table 2.1. The positions of the sensors and the control valves can be seen in the figures of Appendix C.

Table 2.1. List of sensors and control signals.

Measurement Type	Number	Sensor Type	Signal	Measuring Unit	Accuracy
Temperatures in fluid loops	15	PT100	4-wire resistance	Multimeter	$\pm 0.05^\circ\text{C}$
Temperatures in and on store	10	PT100	4-wire resistance	Separate logger Hydra	$\pm 0.1^\circ\text{C}$
Volume flow	7	Inductive	Pulses	PC pulse counting card	$\pm 1.5\%$
Electrical power	1	Meter	Voltage	Multimeter	$\pm 0.7\%$
Electrical energy	1	Meter	Pulse	Separate logger Hydra	$\pm 1.0\%$
Analogue control – valves	5	-	Voltage	PC-card	-
Analogue control – thyristors	1	-	Voltage	PC-card	-

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Digital control – relays	8	-	Voltage	PC-card	-
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### 3. Stages in Running an Automatic Test Sequence

#### 3.1. Initiation . Practical Details

- Check that the boiler tank is heated. Thermostat should be set to maximum for all tests. Check if mixing is necessary.
- Adjust the DHW-flows, different flows is achieved depending on if cold water comes directly or passes through the cold water storage.
- Set the right temperature of the internal electric heater in the test tank.
- Check that correct pump settings are used – refer to separate instructions in the lab.
- Check that all the valves are as they should be, check by testing that you have flow in every circuit.
- Remove air in all pipes check that all pumps are quiet, also check that the pressure are high enough in all circuits (it should be higher than 0.7 bars at 20 °C).
- Measure the glycol concentration and write it in under *general / program control* in combitst (if not already done for this store).
- Check that the solar pumps are connected to the right sockets, and that the valve for cooling is open.
- Adjust the solar flow.
- Check that all the switches in the fuse box and all the valves are as they should be - see section 3.5.
- Make sure that the room temperature controller is working ok (there are three different plugs).
- Check whether the boiler tank mixing pump needs to be on (most CEN tests, except those only having solar circuit tests).

#### 3.2. Running Combitst

- Start the program combitst.
- Choose the sensors to be used under *General/Edit sensors* by typing in Y for all those to be used and N for those not to be used. Note that the sensors Thc and Tc are required by combitst to control the conditioning and collector respectively. They should always be chosen. All chosen sensors have their values saved in the data file.
- Run *General/Program Controls*:
  - Set “Number of samples for stored averages” to 4.
  - Click on OK afterwards.
  - Check that the glycol concentration (refractive index is correct).
  - Fill in the correct storage volume.
- Start measurements (*General/Start Measuring*):
  - choose the control file - this should be in a subdirectory with the tanks name.
  - Open the control file using explorer (Utforskaren) and print out the control file if it is not already printed out.
  - Choose a file name for the data file that is to be created. This should be in a directory with the name the test tank. Use the same name as the control file but with extension .dat. Eg if the control file was EiB.wxd then the file name should be EiB.dat. If there is already a file with that name then add a number, eg. EiB2.dat.
- Write down the file name, the control file and the start of the test (date & time) on the control file printout.
- Check in the printout whether any valves need to be changed during the test and if so when this is likely to occur.

### 3.3. Extra for Verification and .Real Conditions. Tests

- If it is a verification or other “real conditions” test, then turn on the beer cooler and start charging the cold water store at least 6 hours before the test starts and make sure the temperature setting is correct.
- Make sure that the collector circuit is tuned to the correct flow.
- Couple in the tempering valve (if the DHW preparation requires it) and adjust the DHW flows so that they are 5, 10 and 15 l/min.

### 3.4. After The Test is Finished

- Look at the time diagram and compare what has happened with the printout of the control sequence (CEN tests) - check that all has gone as it should, ie flows, inlet temperatures etc are at correct levels with no oscillations. Check also that the flows stop when they should.
- Make an energy balance for the test to check that the test rig is working correctly:
  - Look in the data file and go to the bottom of it.
  - Extract the input and extracted energies to the store during each test sequence and calculate the difference between them. The energies are set to zero after every conditioning. The energies are given in kWh.
  - Estimate the losses during the test and compensate the energy balance of above. The resulting difference, a measure of the inaccuracy of the test rig, should be less than 2% and preferably less than 1%. This is done with an estimate for the heat loss coefficient and the calculated sum of temperature difference during the test (furthest right column in °C.hr). Ualoss is 3 W/K for Solvis and 4 W/K for a slightly worse tank. Losses = Lossdt \* UAloss \* 10<sup>-3</sup> kWh. where Lossdt is taken from the right column in the bottom of the data file.

Note that the heat loss coefficient can be estimated analytically from the test HL using the formula:

$$(UA)_L = \frac{m_s C_p}{time} \cdot \ln \left( \frac{t_{s,start} - t'_a}{t_{s,end} - t'_a} \right)$$

Where  $m_s$  is the effective water mass of the store,  $t_s$  is the average temperature of the store, time in second, and  $t'_a$  is the room ambient temperature. Start and end refer to the start and end of the cooling down (standby) period.

### 3.5. Changes to Valves During Tests

#### 3.5.1. Standard Configuration

The standard connections are:

- Full charge of the tank with boiler, and
- Conditioning of the tank with the space heating circuit.

The comments below show changes from these standard connections.

#### 3.5.2. CD-wb (port heights for wood boiler)

Make sure that the connections from the boiler are connected to the ports used for wood boiler. If in a sequence with other tests, then this should be changed while conditioning is in progress.

#### 3.5.3. CD-ob (port heights for oil/pellets (if ports are available))

Make sure that the connections from the boiler are connected to the ports used for oil boiler. If in a sequence with other tests, then this should be changed while conditioning is in progress.

### 3.5.4. DD-hs (port heights for heating system)

The same applies to other direct discharges (eg, DD-hs2 for port heights for 4-way valve).

- Test phase DD1: conditioning until steady state - **standard ports**
- Test phase DD2: charging of the whole store at constant  $T_{C,i}$  until  $T_{C,o} = 55^{\circ}\text{C}$   
**Change to ports for the heating system during the charging**
- Test phase DD3: discharge through test ports at constant  $T_{D,i}$  until  $T_{D,o} = 30^{\circ}\text{C}$   
**Change to ports for the conditioning AFTER the discharge during a 10 minute standby period (signalled by beep from computer)**
- Test phase DD4: direct discharge of whole store until steady state is reached

### 3.5.5. Verification Sequence

The following stages are in the verification sequence. Remember to start cooling of the DHW cold tank in advance. Check also the adjustment for mixing of hot and cold water into this tank.

- Test phase V1: conditioning until steady state  
**heating circuit for conditioning, boiler circuit to oil boiler ports**
- Test phase V2: charging with electrical auxiliary plus solar, DHW load - day 1  
**Make sure el auxiliary has correct thermostat setting and it and solar heater are switched on**  
**Move heating circuit to heating system ports during this day.**
- Test phase V3: boiler operation plus solar, no el auxiliary, heating and DHW load - Day 2,3  
**Make sure boiler tank is preheated and connected to correct ports on test tank**
- Test phase V4: standby period - 12 hours  
**Move heating circuit to conditioning ports during this day.**
- Test phase V5: direct discharge of whole store until steady state is reached

### 3.5.6. DDS (Direct Discharge with Stratification on Return)

- Test phase DDS1: conditioning until steady state - **standard ports**
- Test phase DDS2: full charge of the whole store at constant  $T_{C,i} = 60^{\circ}\text{C}$  until  $T_{C,o} = 55^{\circ}\text{C}$   
**Change to ports for the heating system during the charging**
- Test phase DDS3: discharge through test ports at constant  $T_{D,i} = 40^{\circ}\text{C}$  until 60% of store discharged
- Test phase DDS4: discharge through test ports at constant  $T_{D,i} = 20^{\circ}\text{C}$  until  $T_{D,o} = 45^{\circ}\text{C}$   
**Change to ports for the conditioning AFTER the discharge during a 10 minute standby period (signalled by beep from computer)**
- Test phase DDS5: direct discharge of whole store until steady state is reached

## 4. Preparation Before Testing a New Store

### 4.1. Test Rig

#### 4.1.1. Temperature Sensors

This is done with Combitst in manual mode. The data file should be saved in data\cal and should be called temperaturecheck\_yymmdd.dat.

For each of the loops (solar, boiler, heating, DHW) connect the inputs directly to the outputs and set to the highest flow to check that the input and output temperatures are the same within 0.02°C. This should be done at 3 temperatures over the range 10-70°C if possible.

- DHW - connect tube to hot water mixed outlet to get higher temperatures.
- Boiler - open 3-way valve to get some hotter water then close again (boiler tank at 80°C)
- Collector - put collector power on for a short time to get correct temperature.
- Heating system - use heat exchanger to get colder temperatures, or the electrical heater to get hotter.

#### 4.1.2. Flow Sensors

- This is done with Combitst in manual mode. The data file should be saved in data\cal and should be called flowcheck\_yymmdd.dat.
- Connect all in series and test at 4 different flow rates: approx. 0.5, 2, 6, 15.
- Still connected in series try 2 flows at higher temperature (40-50°C) to check temperature dependence. If possible do at even higher temperature. NOTE: this does not need to be done for each tank unless it takes less than 2 hours.

### 4.2. Test Sequences & Initial Analysis

- Analyse the store and how it is normally used.
- Decide which ports and heat exchangers will be tested – possible to estimate values?
- Decide where to connect the full charge and conditioning ports.
- Decide whether there are any special features that require non-standard test sequences and define these sequences.
- For unusual features run initial tests manually (or automatically) in order to check whether the store acts as thought.

### 4.3. Test Store

- Check that all the connections are ok and not leaking.
- Test manually all the ports in turn by running Combitst manually. Try constant temperature and flow for boiler and heating circuits, all 3 valves for DHW and 2 different powers for solar.
- Check that the full charge and conditioning ports do not create too much mixing.

## 5. Menus and Commands

Combitst interacts with the user through a number of windows. These are activated by a series of commands from the pull down menus. A list of all the commands are given in Table 2.1. The following sections describe in detail the windows and the affects they have on the program operation.

The shortcut keys are preferable to use as they do not interrupt the operation of the program during measurements.

*Table 5.1. List of menus and their commands. The last column indicates what short cut key combination can be used to activate the commands. The shortcut keys are preferable to use as they do not interrupt the operation of the program during measurements.*

<b>Menu</b>	<b>Command</b>	<b>Shortcut</b>
Diagram	Print	CTRL+P
	Refresh Diagram	F3
	Choose Colours	F7
	Change Scales	F8
	Recall Values	F9
General	Start Measuring	F5
	Load Old Data	F4
	Show Tank	F1
	Show Time Diagram	F2
	Program Controls	
Manual Control	Edit Sensors	
	Set Relays	CTRL+R
	Set Control Valves	CTRL+V
Calibration	Set Powers	CTRL+M
	Start Temperature Point	
	Flow Point	

### 5.1. Diagram/Print (F3)

This command prints the current time diagram out to the default windows printer.

### 5.2. Diagram/Refresh Diagram (F3)

This command updates the time diagram. During the measuring phase the diagram is updated with dots for new points. Once every 5 points the dots are joined together into lines. This command makes the dots into lines immediately.

### 5.3. Diagram/Choose Colours (F7)

This window allows the user to choose which colour to use for each of the values displayed in the real time window. Each value displayed in the real time window has an equivalent colour setting in the same place in this window. To choose the colour for a particular value, click on the box and a list of colours will be displayed. This colour will be used in the time diagram.

#### 5.4. Diagram/Change Scales (F8)

This window allows the user to change the scales for the time diagram. The x-axis (time in hours), the y-axis (temperatures in °C) and the right hand y-axis (powers in kW and flows in l/min) can all be altered by specifying the minimum and maximum values for the axis.

#### 5.5. Diagram/Recall Values (F9)

This command is not fully functioning. In addition the window is in Swedish. Figure 5.1 shows the window. Only a value of -1 is allowed here, and this results in the calculation of the average values for the period shown in the time diagram. If the real time window is shown, then these average values are displayed.



Figure 5.1. Window for recall values. Only a value of -1 works, which results in average values for the period shown in the time diagram'.

#### 5.6. General/Start Measuring (Stop Measuring) (F5)

This command starts the control and measuring functions. Before this is activated however, a new window is displayed asking whether to use an automatic test sequence or not. The answer to this results in the following:

- Automatic Test Sequence. The program asks the user to choose a control data file (with extension .wxd) containing the commands for the test sequence. See section A.2 for details of the commands available. Combitst then reads this file and follows the commands automatically until the commands are finished or the user finishes the test sequence early by pressing F5 again.
- Not Automatic (manual). Measuring is started but no control functions are applied. The user has to manually open valves, start pumps etc in order to activate the test rig. Measuring continues until F5 is pressed.

After this choice is made, the user is then asked to choose a file name for the data file to be created.

#### 5.7. General/Load Old Data (F4)

This command reads in data from existing data files and displays the results on the time diagram. Combitst asks the user which file to read in. There is a limit to how many data points that can be read in of 20000. If this limit is reached then the program stops.

#### 5.8. General/Show Tank (F1)

This command brings up the real time display window, see section 1.1.

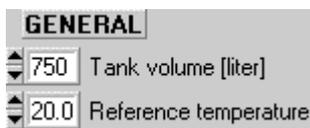
## 5.9. General/Show Time Diagram (F2)

This command brings up the time diagram, see section 1.2

## 5.10. General/Program Controls

This menu controls how the tests are to be performed. It contains general data that does not change very often. More detailed control instructions are handled by the control file (see section A.2) or by manual controls. Here is a list of the controls and their meaning. The values entered here are saved in the file combitst.ini (in directory ..\combitst\control), and are read in when the program is started.

### 5.10.1. Values Affecting All Tests



**GENERAL**  
750 Tank volume [liter]  
20.0 Reference temperature

Volume of tank in liters. Used for calculating flows to and from the tank during full charge and discharge.

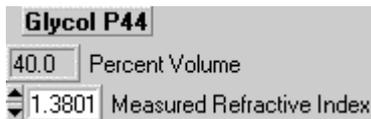
The reference temperature for conditioning the store to. This is normally the same as the test room's temperature of 20°C.



4 **Number of samples in stored averages**

The values stored in the data file will be averaged over this number of samples. One sample takes approximately

9 seconds.



**Glycol P44**  
40.0 Percent Volume  
1.3801 Measured Refractive Index

Value for glycol percentage in solar circuit. Enter the measured refractive index and the percentage is calculated automatically.

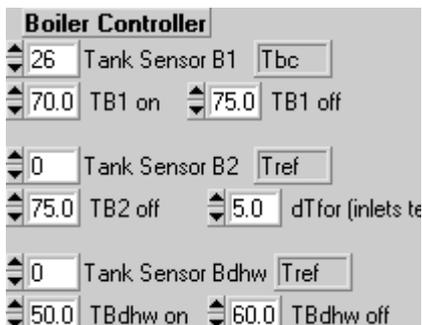
Type of sensors connected to Hydra data logger. This is a simple switch allowing the use of either K-type thermocouples or PT-100 sensors in channels 1-9 of the Hydra logger.

### 5.10.2. Values for Verification "Real Conditions" Tests Only



**Collector Controller**  
10.0 Delta T on  
2.0 Delta T off  
27 Tank Sensor Tcc

Standard control of collector using on/off differential controller. The sensor used for the tank temperature can be chosen with the button at the bottom and the label (in this case Tcc) is displayed on the right. The figure is the number of the sensor in the file sensors.cal.



**Boiler Controller**  
26 Tank Sensor B1 Tbc  
70.0 TB1 on 75.0 TB1 off  
0 Tank Sensor B2 Tref  
75.0 TB2 off 5.0 dT for (inlets te  
0 Tank Sensor Bdhw Tref  
50.0 TBdhw on 60.0 TBdhw off

The boiler can be controlled in several different ways using up to 3 sensors, each of which can be chosen in the same way as for the collector.

#### **On/Off Controller with Hysteresis.**

Use only sensor B1 - the other 2 sensors (TB2 & TBdhw) should be 0 (Tref). TB1 on is the temperature at which a new charge starts, and TB1 off when it stops. Inlet temperature (Tbo) and flow are controlled in the control file for the test.

### Two Sensor Control

This uses TB1 in the upper part of the heated area and TB2 in the lower part to control the boiler. Change the sensor number until you have the correct sensor displayed for TB1 and TB2. A new charge is started when TB1 goes below TB1 on. It stops when TB2 goes above TB2 off. Inlet temperature (Tbo) and flow are controlled in the control file for the test. TB1 off is ignored.

### Three Sensor Control

With this control strategy, two separate areas of the tank are heated to two different temperatures. The upper part is for DHW and the lower for space heating. The upper part is controlled as an on/off controller with hysteresis. Set the correct sensor and the on and off temperatures. The lower part is controlled as for 2 sensor control above, with charges starting when TB1 goes below “TB1 on” and stops when TB2 goes above “TB2 off”. “TB1 off” is ignored. The inlet temperature (Tbo) and flow are normally controlled by the control file for the test, but only one set of values is possible, ie for this lower area the inlet flow and temperature to the store are constant for the whole test sequence. The option below allows a variable inlet temperature (Tbo) dependent on the space heating flow temperature.

### Space Heating Thermostat Coupled to Radiator’s Flow Temperature

If dTfor is non-zero, then the inlet temperature (Tbo) is dependent on the flow (forward) temperature for the radiator circuit. It will be:  $T_{bo} = T_{for} + dT_{for}$ . Tfor is interpolated from hourly values in the control data file. A hysteresis is necessary for this operation. The charge is started when  $TB1 < T_{for} + dT_{for} - 3$  and is stopped when  $TB2 > T_{for} + dT_{for} - 3$ .

### Collector Parameters

Collector Parameters	
10.0	Aperture Area [m2]
0.77	Optical efficiency (n0)
4.26	First Order Loss Coeff (k1) [W/m2.C]
0.02	Second Order Loss Coeff (k2) [W/m2.c2]
0.15	Incidence Angle Modifier (B0)
40.0	Capacitance [kJ/m2.K]

Parameters for the collector. Standard parameters apart from capacitance value. This is for Bengt Perers model and data for this can be got from him.

#### 5.11. General/Edit Sensors

This command opens the file sensors.cal where the calibration constants and channel numbers for each sensor are defined. Values can be changed here and they take effect the next time a new data file is started. See section A.1 f or more details of the contents of this file.

## 5.12. Manual Control/Set Relays (CTRL+R)

This window allows the user to open and shut the solenoid valves and start/stop the pumps.

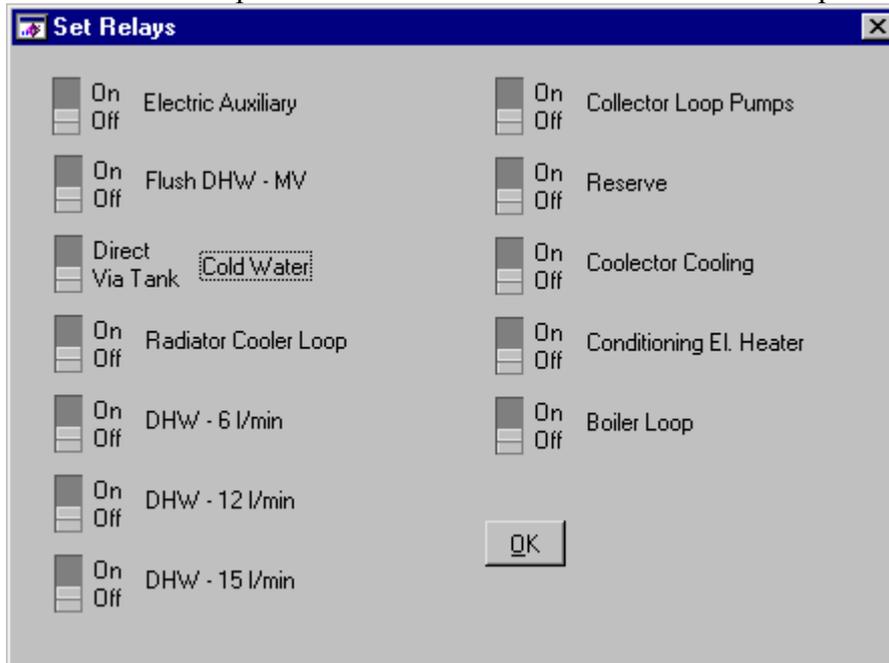


Figure 5.2. Set Relays window.

The following are explanations of the switches in the Set Relays window (see Figure 5.2).

**Electric Auxiliary:** This relay allows the electricity to go to the electric heater in the store. This heater, however, is controlled by its own thermostat and so this switch does not necessarily turn on the heater itself.

**Flush DHW:** This relay opens a solenoid valve to take mains water directly to the drain. This is used to make sure that cold mains water is available and not the water that has been lying in the pipes in the building.

**Cold Water:** This switch controls solenoid valves that control whether the mains cold water goes direct or via the cooling tank.

**Radiator Cooler Loop:** Start/stop the pump in the radiator loop (also known as the conditioning loop).

**DHW – 6,12,15 l/min:** These three relays control solenoid valves to allow hot water discharges of 6, 2 and 15 l/min respectively.

**Collector Loop Pumps:** Start/stop of the collector loop pumps.

**Reserve:** Controls a relay that switch 220V mains electricity to a wall mounted socket in the lab.

**Collector Cooling:** Opens/shuts a solenoid valve for cooling of the emulated collector using mains water via a heat exchanger.

**Conditioning El. Heater:** This controls a relay that switches the output from the 3-phase thyristors between the electrical heater in the conditioning loop (only one phase, switch on) and the electrical heater in the collector loop (3-phase, switch off).

**Boiler Loop:** Start/stop pump in the boiler loop. Controls both the pump for charging the test store.

### 5.13. Manual Control/Set Control Valves (CTRL +V)

This window controls directly the voltage levels of the analogue outputs of the test rig. There are 5 voltage controlled valves, either 2-way or 3-way valves. One controls the thyristors that feed the electrical heater in the collector emulator (or in the conditioning loop).

**CV1** and **CV2** control the temperature ( $T_{bo}$ , 3-way valve) and flow ( $V_b$ , 2-way valve) in the boiler loop.

**CV3** (3-way valve) controls the temperature in the heating system (conditioning) loop for recirculating of water. This is not often used – in fact only when emulating a heating system when the flow is very low.

**CV4** ( $V_h/V_{dx}$ , 2-way valve) controls the flow in the same loop.

**CV5** ( $T_{ho}$ , 2-way valve) that controls the flow of the mains water that cools the conditioning loop via a heat exchanger. This flow control indirectly controls the temperature output of the conditioning loop ( $T_{ho}$ ).

**Collector Voltage:** controls directly the output voltage to the thyristors supplying power to the collector emulator (or heater in the conditioning loop).

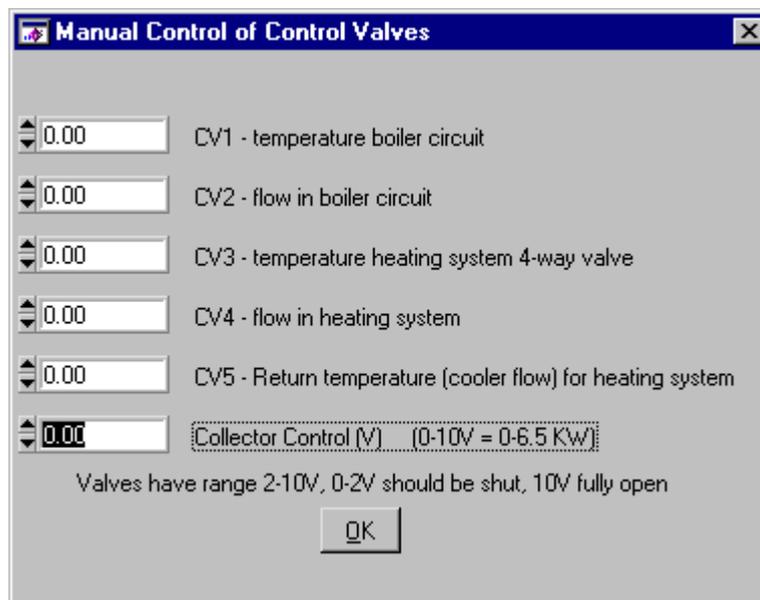


Figure 5.3. Window for analogue outputs (controlling of valves and collector thyristors).

#### 5.14. Manual Control/Set Powers (CTRL+M)

This allows the manual control of flows, temperatures and powers. This only works, though, if the PID control is switched on. Below are explanations of the controls shown in Figure 5.4.

Note that the pumps and solenoid valves required to give flows in the circuits have to be activated manually.

Note that the PID tuning values used are those that are defined in sensors.cal (see section ), and that the values for the PID parameter in the PID tuning control only get changed after one of the tuning values gets changed.

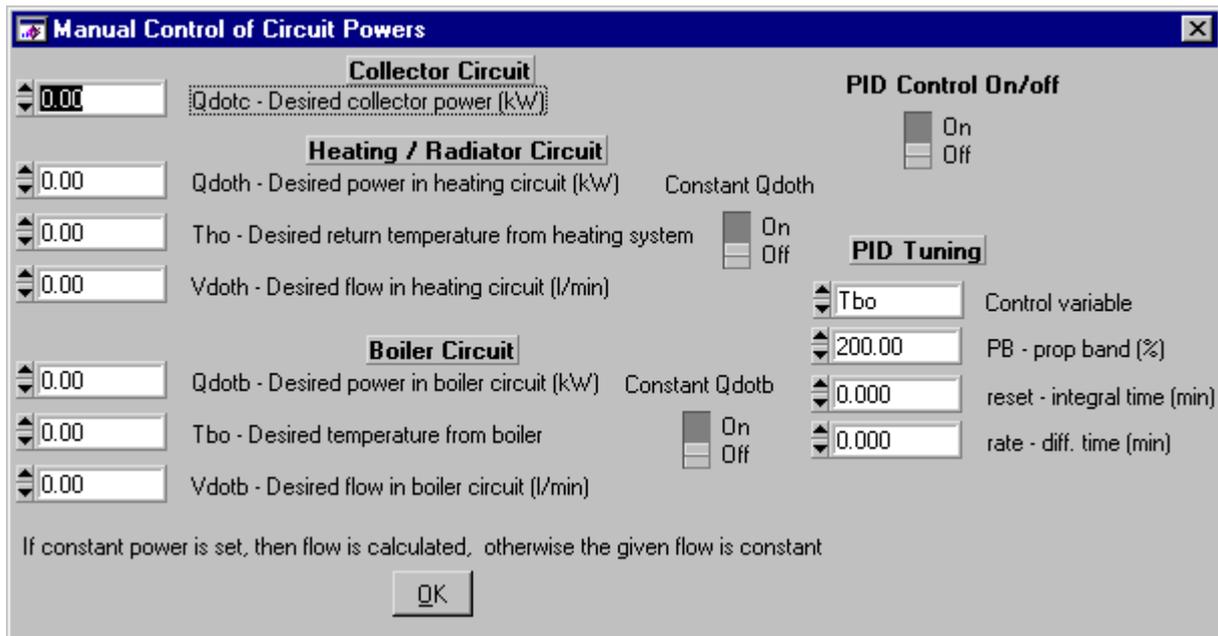


Figure 5.4. Window for manually controlling powers and temperatures in the collector, heating system (conditioning) and boiler loops. It is also possible to manually set the PID control values.

**PID Control On/Off.** This activates or deactivates the PID control routines in the program. If this is off then the other controls for making fixed flow etc will not work. This is off as default at the start of the program.

**Qdotc-** desired collector power (kW). Combitst tries to maintain a constant power in the collector loop.

**Constant Qdoth / Qdotb.** These switches control whether the program tries to maintain constant power (ON) or constant flow (OFF). Constant temperature is the default. Constant temperature is always true. If constant power is chosen, then the flow rate is calculated from the desired power and outlet temperature (values in the relevant control boxes) and the current inlet temperature.

**Qdoth / Qdotb.** This is the desired constant power value. It is only used if the constant Qdoth / Qdotb switch is ON. Combitst tries to maintain this value by varying the flow rate.

**Tho / Tbo.** The desired outlet temperature from the loop. Combitst tries to maintain this at a constant value. Tho is controlled by varying the flow rate (2-way valve) of mains water slowing through the cooling heat exchanger in the loop. Tbo is controlled with a 3-way valve mixing the hot water from the boiler and the water coming from the test store (Tbi).

**Vdoth / Vdotb.** The desired flow rate. This is only used if the Constant Qdoth / Qdotb switch is OFF. Combitst tries to maintain this value together with the desired temperature in the loop. Both flows are controlled with 2-way valves.

**PID Tuning.** The first control box chooses which PID control variable the three tuning values apply to. Each control variable has values for PB, reset and rate. The National Instruments PID control manual should be read before adjusting these values. Read also section 6. Note that the values in these control boxes (PB, reset, rate) are only used for the chosen control variable after one of the three values has been changed.

#### 5.15. Calibration/Start Temperature Point

This command enables relatively easy calibration of the temperature sensors. See section 7 for more details about how to incorporate this command into a calibration routine. This command starts a calibration point. The following activities are performed by this command:

- The correction coefficients for the measured temperature sensors are set to zero.
- A comment is written to the data file that a calibration point is started.
- The time interval for saving data to the file is made short (ie every data point is saved).
- After 15 samples (data points) an average is made of the last ten data points and this is recorded.
- If this command has been activated 4 times, ie four calibration temperatures, new correction coefficients are calculated and the calibration points (temperatures) with and without correction are printed in the data file.

#### 5.16. Calibration/Flow Point

This command enables relatively easy calibration of the temperature sensors. See section 8 for more details about how to incorporate this command into a calibration routine. This command starts a calibration point. The following activities are performed for this command:

- The correction coefficients for the measured flow sensors are set to zero.
- A comment is written to the data file that a calibration point is started.
- The time interval for saving data to the file is made short (ie every data point is saved).
- Combitst makes a signal to show when the calibration period is to start and to end.
- After the end of the calibration point a window (see Figure 5.5) is opened. This displays the flows for the sensors and allows input of the weight of water collected during the calibration period and the temperature of this water. The program then calculates the flow for this measured weight, temperature and time and displays this flow at the bottom of the window. If this value is positive, then the result will be used as a valid datapoint. If it is below zero (input negative weight if the values do not look good) then the point is not valid and will be repeated. The average flows for the point are displayed in this window and also saved in the data file.
- This procedure continues for 15 data points: 3 data points for each of the flows 0.5, 2, 5, 10, 15 l/min. After all fifteen data points new correction coefficients are calculated, and these are printed out in the data file along with the corrected and uncorrected flows for the data points.

The image shows a software window titled "Flow Calibration Results" with a sub-header "CALIBRATION POINT 1". It is divided into two main sections: "Measured Water Values" and "Flows [l/min]".

**Measured Water Values:**

- Measured Weight: 0.000
- Measured Temp: 20.0
- MEASURED FLOW: 0.000

**Flows [l/min]:**

- Vdhw: 0.000
- Vdhwrm: 0.000
- Vh: 0.000
- Vh4: 0.000
- Vb: 0.000
- Vc: 0.000
- Vcx: 0.000

At the bottom, there are "OK" and "Cancel" buttons.

Figure 5.5. Window for inputting the weight of water measured for a flow calibration point.

## 6. Tuning of PID Controllers

See the National Instruments PID Tool Kit manual, pages 1-6 to 1-7 for more details (closed loop).

The basic methodology is to see when the circuit including the PID controller becomes unstable. This occurs when the gain (inverse of proportional band) becomes too large. To do this you have to set the PID controller values manually.

It is not possible to fix one control variable (say flow) using a fixed control voltage and tune the other (say temperature) with a fixed flow. Instead it is best to tune the flow first, as this is easier, and then the temperature afterwards. See section 5.14 for more details about the window that is used for this procedure.

Follow the following procedure:

- Start combitst.
- Set the program to save every data point.
- Start a new file (F5) - not automatic control - and this should be placed in the directory with the same name as the parameter that is to be tuned, eg Tbo. This lies in the directory data\function test.
- Use the command manual/set powers (see section 5.14): choose the relevant parameter to be tuned in the PID tuning area of the window, and set the PID parameters rate and reset to 0.0 and the PB value to the current value in the sensors.cal file).
- Set the desired flow and temperature and the PID control switch to on.
- Write up ALWAYS the date for the test, the file name and then the tuning value, desired flow/temperature and time for each of the changes that you do. This is required later.
- Gradually decrease the PB tuning value. The control variable will get closer to the desired value for each change. Disturb the loop after each change in PB, by change the set value to something else and than go back to the original setting. At some value of PB, the circuit becomes unstable. Continue to adjust the value of PB until the oscillations are just perfectly sustained, neither growing nor decaying over time. This value is called PBU in the PID Tool Kit manual. This is required for calculating the settings for the rate and reset.
- Print out the time diagram for section of the test for the critical PB value, PBU where the oscillations start. Here you have to calculate the period of the oscillations in minutes, called Tu in the PID manual.

- Use the table 1-2 in the PID Tool Kit Manual for calculating PB, reset and rate from P<sub>Bu</sub> and T<sub>u</sub> that you have got from above.
- Put these new values for PB, reset and rate into the control boxes in combitst and do some step changes for the control variable to check that it reacts as it should.
- If everything is ok, then these new values can be put into the sensors.cal file. Make sure that you write up here why the changes were made and the date.

## 7. Calibration of Temperature Sensors

Calibration should be performed at least once per year. If the checks made before testing a new store/system show problems, then a calibration should be done then. The reference sensor should be calibrated once per year together with its multimeter. Look in the calibration file for details of previous calibrations and temperatures chosen. The correction coefficients for the reference sensor have to be converted and put into the file sensors.cal. See the excel sheet Ref\_temp\_cal.xls in the directory \data\cal on the measurement computer.

The following is a description of how to do a calibration of the temperature sensors. It is worthwhile reading the section on making calibration points (section 5.15) before reading the rest of this section.

### 7.1. Setup

- Connect the reference thermometer to its meter (HP3478A - in the optics lab) and connect the meter to the computer via the GPIB cable.
- Make sure that the big calibration box, together with mixer is working ok.
- Start Combitst and mark the sensors that are going to be used for the calibration in the definitions file (sensors.cal). This is done with the menu choice: general/edit sensors. All sensors to be used marked with Y all other sensors marked N. The reference sensor (Tref), first in the list has also to be marked Y. Combitst automatically sets the calibration / correction coefficients to 0.0 for the calibration points, so this does not need to be done here.
- Start measuring using menu choice: general/start measuring, and choose a file name in the directory cal of the form: temp cal 980405.dat. Make sure that the measuring is not stopped until after all measurements are completed.

### 7.2. Calibration Points

There will be four calibration points at roughly: 5, 30, 60 and 90°C. The following notes apply to each of these points - all to be measured in sequence and stored in ONE data file. *Measurements should continue the whole time.*

- Fill the tub with water of roughly the correct temperature and allow the temperature to stabilise. The mixer does not need to be on all the time. Combitst shows what the temperatures are.
- When the temperatures are stable (or decreasing steadily and slowly in the case of 90°C), then make a calibration point by using menu choice: calibration/temperature point. The program automatically averages over 3 minutes to get data for one calibration point. After these three minutes the next point can be prepared by pouring in hotter water.

### 7.3. Check

After the fourth point, the program calculates new calibration/correction coefficients for each of the sensors tested, and uses them while the program is still running. Measure at one or two temperatures other than those used for the calibration data points, in order to check that all the sensors are giving the same temperature within  $\pm 0.02^\circ\text{C}$ .

## 7.4. Implementing New Calibration Values

Once the check is complete you need to copy the new values to the definitions file sensors.cal. From combitst use the menu choice: general/edit sensors to open sensors.cal. Use wordpad to open the data file just created in the calibration procedure. Towards the end of this datafile there is a list of the new calibration coefficients, as well as the uncorrected and corrected (using the new coefficients) data from the four calibration points. Check that these are ok. Copy over the new calibration coefficients to sensors.cal. The format is exactly the same except that in the data file the line starts with ‘ - do not include this when you copy. Once the new values are copied change the calibration date for the sensors just tested to today's date. Save sensors.cal and then save as sensors <today's date>.cal so that there is a unique record of the new values.

## 8. Calibration of Flow Sensors

Calibration should be performed once per year. If the checks made before testing a new store/system show problems, then a calibration should be done then.

The following is a description of how to do a calibration of the flow sensors. It is worthwhile reading the section on making calibration points (section 5.16) before reading the rest of this section.

### 8.1. Setup

- Get a calibrated unit for measuring weight and a suitable bin for up to 50 litres.
- Connect all the flow sensors in series and flush thoroughly to get rid of all air bubbles. The outlet should go to drain via a flexible hose. The bin should be next to it so that it is possible to easily move the hose from the drain to the bin and vice versa.
- Connect loud speakers to the computer and check that they work.
- Start Combitst and choose which sensors are to be used for the calibration procedure by editing the file sensors.cal (command general/edit sensors). All flow sensors and the temperature sensor in the loop with the flows sensors if any. Some temperature sensors should be measured otherwise the program does not work very well - but this can be limited to say the ones for the hot water loop.
- Start measuring using menu choice: general/start measuring, and choose a file name in the directory cal of the form: flowcal980405.dat. Make sure that the measuring is not stopped until after all measurements are completed.

### 8.2. Calibration Points

There will be fifteen calibration points with three points at each of the nominal flows of 0.5, 2, 5, 10 and 15 l/min. The following notes apply to each of these points - all to be measured in sequence and stored in ONE data file. *Measurements should continue the whole time.*

- Adjust the flow to the nominal flow for that data point Combitst shows what the temperatures are.
- Weigh the measuring vessel with no water in it (empty but still wet) and zero the measuring unit.
- Start the command calibration/flow point:
- Go to the hose outlet and await the “start/stop” signal (one minute from starting the command on the computer). This signal consists of 6 beeps. On the sixth beep move the hose from the drain to the bin.

- The program then shows how much time is left until moving the hose again. With 20 seconds left the program gives a warning beep. As for the start the end of the point is given by six beeps. On the sixth beep move the hose from the bin to the drain. It is important that this is done in the same way as at the start of the point.
- Measure the weight of the liquid in the bin and also its temperature. For large volumes and small measuring unit the water may have to be transferred to a smaller bucket and weighed in several parts.
- Write in the weight and temperature measured in the window shown in combitst (see section 5.16 for more details). Check that the measured flow (based on these values) is similar to the flows indicated for the sensors to be calibrated. If it is reasonable (within 2-3% ) press OK. If it is not then it is best to do this data point again. Write in a negative weight and press OK. The program will tell you to redo this point.

### 8.3. Check

After the fifteenth point, the program calculates new calibration/correction coefficients for each of the sensors tested, and uses them while the program is still running. These values get printed out in the data file together with the corrected and uncorrected flows for all sensors for all calibration data points. Measure at two other flows, in order to check that all the sensors are giving the same flow within  $\pm 1.5\%$ .

### 8.4. Implementing New Calibration Values

Once the check is complete you need to copy the new values to the definitions file sensors.cal. From combitst use the menu choice: general/edit sensors to open sensors.cal. Use wordpad to open the data file just created in the calibration procedure. Towards the end of this datafile there is a list of the new calibration coefficients, as well as the uncorrected and corrected (using the new coefficients) data from the four calibration points. Check that these are ok. Copy over the new calibration coefficients to sensors.cal. The format is exactly the same except that in the data file the line starts with ' - do not include this when you copy. Once the new values are copied change the calibration date for the sensors just tested to todays date. Save sensors.cal and then save as sensors <todays date>.cal so that there is a unique record of the new values.

## APPENDIX A: FORMAT OF CONTROL FILES

### A.1 Calibration Data (Sensors.cal)

This file is located in the subdirectory to that of the main program called control. It contains all the data necessary for combitst to use the sensors in the test rig including the correction (calibration) coefficients. In addition the coefficients for control of the PID regulators are included. All lines starting with ‘ are comment lines and are ignored by the program. The file is relatively self explanatory, but the following is worth bearing in mind:

- Whenever changes are made to it, comments should be written in to show what has been done and a copy should be made in the control subdirectory of the form sensorsymmdd.cal where yy, mm, dd are year month and day.
- The total number of different sensors handled by combitst cannot be changed without changing the code of the program.
- The column TYP is not used by combitst, rather it knows when the flow sensors come by counting the number of temperature sensors. The same thing applies for the PID loops.
- Unit and Chan are the unit number and channel of the scanner units. The units are numbered from 0 to 3.

```
' CALIBRATION DATA FOR SENSORS USED IN COMBITST - SENSORS.CAL
' =====
'
'Coefficients are for a quadratic equation which give corrections from a
'standard
'
'T = Tm + k0 + k1*Tm + k2*Tm^2      [øC] (m - calculated value without
correction)
'V = Vm + k0 + k1*Vm + k2*Vm^2      [l/min]
'
'Data for previous calibrations can be found in file: SENYMMDD.CAL
'
'          Calibration coeff.   Y/N
'No  NAME      K0          K1          K2  USED UNIT CHAN TYP  CAL  DATE|
'    TEMPERATURE SENSORS
' reference sensor Tref used only for calibrations
0  Tref      1.8e-02 -1.10e-03  2.22e-06  N   0   0   4 | 980413 |
1  Tdhwi     1.96e-02 -1.41e-03  4.47e-06  Y   0   0   4 | 980409 |
2  Tdhwo     6.43e-02 -1.24e-03  4.22e-06  Y   0   1   4 | 980409 |
3  Tdhw1     8.66e-02 -3.39e-03  2.03e-05  N   0   2   4 | 980409 |
4  Tdhw2     1.58e-01 -2.12e-03  1.02e-05  N   0   3   4 | 980409 |
5  Tci       4.43e-02 -1.29e-03  3.96e-06  Y   0   4   4 | 980409 |
6  Tco       6.96e-02 -1.17e-03  3.93e-06  Y   1   0   4 | 980409 |
7  Tcxi      1.15e-01 -4.35e-02  4.29e-04  N   1   1   4 | 980409 |  Not so
good - use Tdhw1 in future
' Tc changed from Tcxo 980824 to run collector temperature
8  Tc        1.07e-01 -3.56e-03  2.04e-05  Y   1   2   4 | 980409 |
9  Tbi       1.78e-01 -2.91e-03  1.74e-05  Y   1   3   4 | 980409 |
10 Tbo       7.90e-02 -3.55e-03  1.87e-05  Y   1   4   4 | 980409 |
11 Thi       7.00e-02 -3.95e-03  1.82e-05  Y   2   0   4 | 980409 |
12 Tho       5.98e-02 -1.21e-03  3.76e-06  Y   2   1   4 | 980409 |
```

13	Th4i	4.27e-02	-3.70e-03	1.92e-05	N	2	2	4		980409	
14	Thc	8.96e-02	-3.61e-03	1.90e-05	Y	2	3	4		980409	
15	Tra	-1.81e-01	5.85e-03	1.23e-05	Y	2	4	4		980409	Not so good but ok
16	Tres1	0.00e-01	0.00e-03	0.00e-05	N	3	0	4		980409	
17	Tres2	0.00e-01	0.00e-03	0.00e-05	N	3	1	4		980409	
18	Tres3	0.00e-01	0.00e-03	0.00e-05	N	3	2	4		980409	
19	Ts1	-5.13e-01	1.79e-03	-4.65e-05	Y	9	1	4		970317	
20	Ts2	-4.12e-01	1.08e-03	-4.96e-05	Y	9	2	4		970317	
21	Ts3	-5.04e-01	1.99e-03	-2.97e-05	Y	9	3	4		970317	
22	Ts4	-4.71e-01	8.56e-03	-6.83e-05	Y	9	4	4		970317	
23	Ts5	-4.80e-01	5.64e-03	-6.54e-05	Y	9	5	4		970317	
24	Ts6	-5.43e-01	5.06e-03	-5.65e-05	Y	9	6	4		970317	
25	Ts7	-3.33e-01	9.30e-04	-1.80e-05	Y	9	7	4		970317	
26	Tbc	-4.71e-01	-2.86e-03	6.63e-05	Y	9	8	4		980409	Not so good but ok
27	Tcc	-4.02e-01	-5.62e-03	2.83e-05	Y	9	9	4		980409	
'											
' FLOW SENSORS											
1	Vdhw	-4.03e-03	2.43e-03	4.25e-05	Y	10	1	F		980424	
2	Vdhw	8.75e-04	6.88e-03	1.01e-04	N	10	2	F		980424	
3	Vcx	8.12e-03	1.69e-03	-2.10e-04	N	10	3	F		980424	NB unreliable sensor
4	Vh	6.09e-03	-8.91e-03	2.02e-05	Y	10	4	F		980424	
5	Vh4	2.46e-03	-4.96e-03	3.72e-05	N	10	5	F		980424	
6	Vb	6.04e-03	-1.31e-03	-1.49e-04	Y	10	6	F		980424	
7	Vc	-2.84e-03	-5.50e-03	-7.22e-05	Y	10	7	F		980424	
'											
'											
' PID REGULATION LOOPS											
' only the coefficients are used here											
'											
		PB	RESET	RATE							
0	Tc	8.35	0.57	0.1425						980424	
1	Tho	380.0	0.515	0.129						980424	
2	Vdoth	400.0	0.1	0.0						980424	
3	Tbo	150.0	0.78	0.195						980424	
4	Vdotb	600.0	0.15	0.0						980424	
5	Thoel	58.5	0.353	0.088						980424	
' other operating conditions											
6	Vdothm	200.0	0.1	0.0						980424	
7	Vdothl	100.0	0.1	0.0						980424	
8	Thodx	250.0	0.515	0.129						980424	
9	Tboopen	150.0	0.78	0.195						980424	
10	Vbopen	600.0	0.15	0.0						980424	

### A.1.1 Bad Sensors

If a sensor is shown to be bad in a calibration or a check of the sensors before the start of measurements on a tank, then it has to be replaced both physically and in the file sensors.cal. What is important in this case is the following:

- Combitst used the number (No) of the sensor for displaying the values in the correct place on the real time display window. It is therefore important to not change this number for a given measurement point. Ie, the input to the boiler circuit should always have number 9 (and name Tbi). Its sensor number or name could be something different.
- If a new sensor is used then its calibration values get written in the correct line for eg Tbi.
- If a sensor is replaced with another one from somewhere else in the test rig, then the calibration values only shall be copied from the row for this sensor to the row of the sensor being replace.
- Each physical sensor should have its own id – this is not Tbi or Tbo but a separate id number not related to the test rig. Tbi etc are names relevant only for the test rig and the program combitst.

## A.2 Command Definitions for Control Files (\*.wxd)

Below is a list of the commands available via the control file for the program combitst. The commands are in square brackets and, where relevant, example data are given. An explanation is given underneath. All temperatures are relative to the reference temperature Tref unless otherwise stated.

Text to be displayed in the message box on the screen should be on the same line as the main command. These must be in double quotes "example message" – see the first command. If there is any additional information/data for the command then this is found on the line underneath.

For time step data (verification and combitest) there must be one extra set of time step data at the end so that the interpolation has data to "aim" at.

### A.2.1 General Commands

#### **[FULL CHARGE] "Full charge of tank at 60C until Tbi=55C"**

A full charge of the tank using the upper most ports at Tref + 40C (normally 60C) and a flow of (tank volume/2) liter/h, until the whole tank is charge at this temperature (Tbi > Tref + 38). This is equivalent of a Boiler Flow charge.

#### **[FINAL DISCHARGE]**

Final discharge of the store until the outlet temperature (Thi) is within 2 degrees of the reference temperature. Inlet temperature (Tho) is at Tref and the flow rate is (tank volume/2) liter/h.

Uses the uppermost and lowermost connections.

#### **[CONDITIONING]**

Using the same flow rate as for the final discharge, with an inlet temperature (Tho) of Tref, the conditioning is kept up until both Tho and Thi are constant at Tref ±0.05°C for a whole hour. Uses the uppermost and lowermost connections.

#### **[TIME STEP LENGTH]**

##### **1.0**

Length of the time step in hours. An optional command which if used should be at the start of the file. Default value is 1.0. Only required if the time step (for time variable data) is anything other than 1 hour.

#### **[NEW TIME STEP] 20.0 191.0 27.6 67.2 4.00 43.0 30.0**

Ta Ibt Idt Theta Qdoth Tfor Tho

This gives outside air temperature and radiation data necessary for the collector model (Trnsys type 132, the QDT model) as well as data on the space heating load (see below for details). This is used only for the verification and combitest sequences. All commands until the next new time step command will be initiated now (these have to come before this command line). This would apply to commands for e.g. turning on the power to the electrical heater, making a DHW discharge. The values used in the calculations are interpolated linearly over the hour. The last hour has fixed values.

Ta outside ambient temperature [°C]

Ibt	incident beam radiation on collector plane [W/m <sup>2</sup> ]
Idt	incident diffuse radiation on collector plane [W/m <sup>2</sup> ]
Theta	angle of incidence of beam radiation with respect to collector plane [°]
Qdoth	desired heating rate for space heating [kW]
Tfor	flow (forward) temperature in space heating loop [°C] – actual temperature - not relative to Tref
Tho	return temperature in space heating loop [°C] – actual temperature - not relative to Tref

### **[END TIME STEPS]**

Signals the end of the time steps and lets the program go back to normal mode. Must be included after the last time step data.

### **[STANDBY]**

#### **50.0 ON / BEEP**

Standby period with no inputs or outputs to/from the tank. The first data figure controls how many hours of standby there will be, in this case 50 hours. If ON is found on the data line then power is connected to the electric auxiliary in the tank, otherwise it is off. If BEEP is found on the data line then a short sound signal will be emitted after every measurement round during the standby period. This is useful for letting the operator know when a particular sequence is finished and alerting him/her that something requires doing.

### **[PRESSURISED]**

Sets the PID control values suitable for testing a pressurised tank (boiler and heating circuit loops can be affected).

### **[PRESSURELESS]**

Sets the PID control values suitable for testing a pressureless tank (boiler and heating circuit loops can be affected).

## A.2.2 Domestic Hot Water Discharge

### **[DHW TEMPERATURE]**

#### **1 10.0 0.5**

Discharge using DHW discharge valve 1 until the hot water outlet temperature (Tdhwo) is less than 10°C above Tref. The 0.5 is optional and gives a time limit to the discharge of 0.5 hours – without it the discharge can continue indefinitely.

### **[DHW ENERGY]**

#### **1 3.48**

Discharge using valve 1 until 3.48 kWh has been discharged.

### **[DHW FLUSH]**

Flush the DHW inlet using the DHW unit valve for 1 minute. This allows the temperature of the incoming mains water to stabilise before the start of a real discharge.

### **[DHW INTERMITTENT]**

**1 15.0 0.15**

Intermittent DHW discharge through valve 1 until the DHW outlet temperature ( $T_{dhwo}$ ) is  $15^{\circ}\text{C}$  above  $T_{ref}$ . The interval for the intermittent discharge in hours is given last (0.15 in this case). This is the same as the DHW temperature command except that the discharge is done in short bursts.

#### A.2.2 Collector Circuit

### **[SOLAR POWER]**

**5.0 35.0 1.0**

Charging via the collector circuit at constant power of 5.0 kW until the inlet to the collector hardware simulator ( $T_{ci}$ ) is  $35.0$  above  $T_{ref}$ . The third value is optional and specifies the maximum time allowed for the test. If nothing is specified then 10 hours is assumed.

#### A.2.3 Electrical Auxiliary Heater

### **[ELAUX ON]**

Supplies 3-phase power to the tanks electrical auxiliary heater which can then operate using its own thermostat.

### **[ELAUX OFF]**

Turns off the 3-phase power to the tanks electrical auxiliary heater off.

### **[ELAUX ONCE]**

Supplies 3-phase power until after the thermostat turns off the heater for the first time - the power is then turned off and the heater is off. This is required for certain of the CEN tests such as the EiA test.

#### A.2.4 Boiler Circuit

### **[BOILER FLOW]**

**360.0 40.0 35.0 1.0**

Charging the tank using the boiler ports at constant flow of 360 l/hr and constant inlet temperature ( $T_{bo}$ ) of  $40.0^{\circ}\text{C}$  above  $T_{ref}$  until the outlet temperature ( $T_{bi}$ ) is  $35^{\circ}\text{C}$  above  $T_{ref}$ . The fourth value is optional and specifies the maximum time allowed for the test. If nothing is specified then 10 hours is assumed.

### **[BOILER POWER]**

**600.0 20.0 40.0 1.0**

Charging the tank using the boiler ports at constant flow of 600 l/hr and constant power of 20kW until the outlet temperature ( $T_{bi}$ ) is  $40^{\circ}\text{C}$  above  $T_{ref}$ . The fourth value is optional and specifies the maximum time allowed for the test. If nothing is specified then 10 hours is assumed.

**[BOILER WOOD]**

**25.0 60.0 0.15 1.5 0.15**

NOTE! not working yet.

Charging the tank using the boiler ports as a wood fired boiler. A constant inlet temperature of 60°C above Tref is maintained. The power is linearly increased from 0 to 25.0 kW over 0.15 hours. It is held constant at 25.0 kW for 1.5 hours and ramped down to zero over 0.15 hours.

**[BOILER OFF]**

Turns off the boiler until the next command for the boiler. Only necessary after a boiler on command.

**[BOILER ON]**

**420.0 70.0**

Turns the virtual “boiler” on. This will be controlled by the programs own thermostat functions. There are several of these, described in section 5.10. The boiler will charge using a constant flow of 420.0 l/hr and a constant inlet temperature of 70°C

- NOTE. The inlet temperature is the actual temperature and is not relative to Tref.

A.2.5 Heating System Circuit

All the following commands use the ports as connected to the radiator circuit and not the ones for the final discharge / conditioning.

**[HEATING FLOW]**

**300.0 0.0 10.0 1.0**

Discharge using the heating system circuit at constant flow of 300 l/hr and constant inlet temperature (Tho) of 0.0 above Tref until the outlet temperature from the store (Thi) is 10.0 above Tref. The fourth value is optional and specifies the maximum time allowed for the test. If nothing is specified then 10 hours is assumed.

**[HEATING POWER]**

**300.0 3.0 10.0 1.0**

Discharge using the heating system circuit at constant flow of 300 l/hr and constant power of 3.0 kW until the outlet temperature from the store (Thi) is 10.0 above Tref. The fourth value is optional and specifies the maximum time allowed for the test. If nothing is specified then 10 hours is assumed.

## APPENDIX B: Program and Data Structure

### B.1 Introduction . where is everything?

The program is written in Labwindows CVI and the code and program are located in the directories under: C:\CVI401\Programs\combitst and its subdirectories. All data are located in the directory c:\data and its subdirectories.

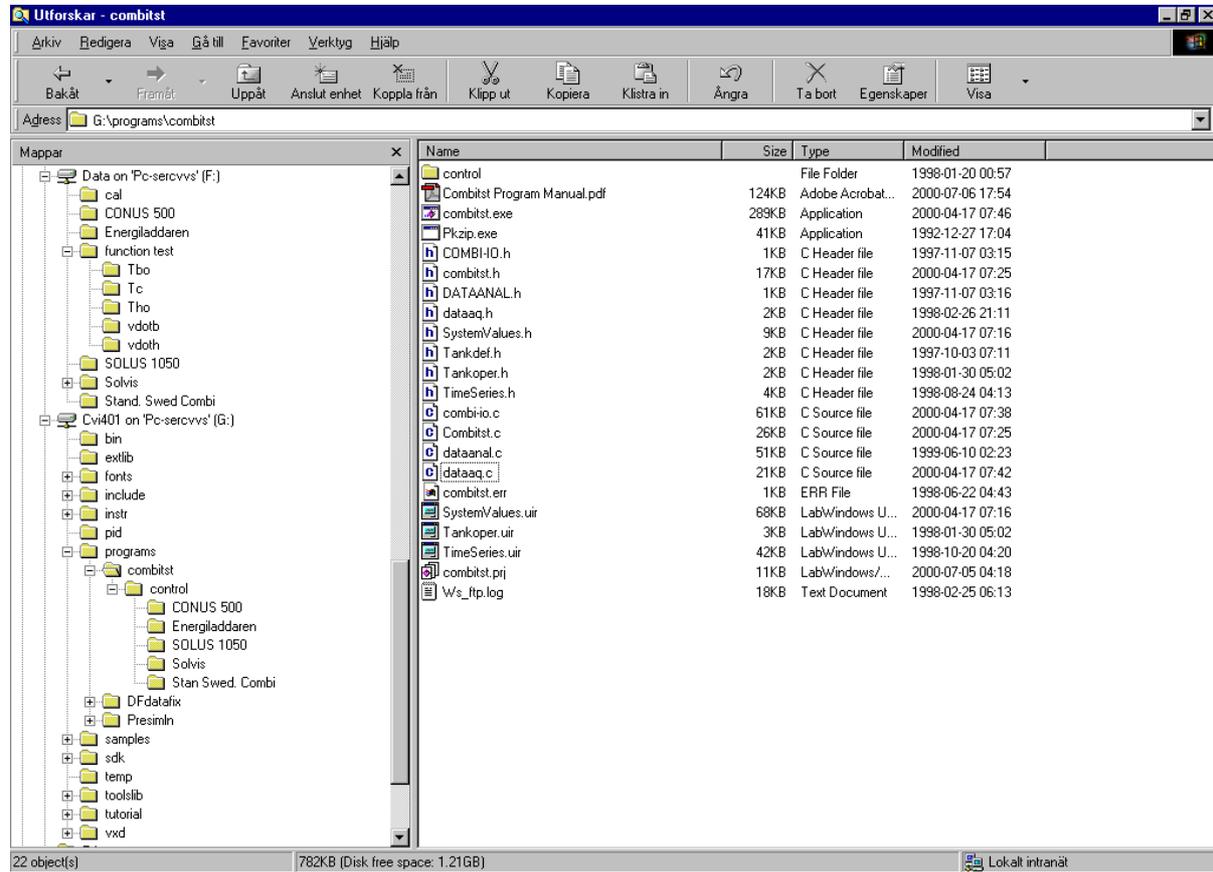


Figure B.1. Directory structure for the program Combitst and the data that is saved by it (as seen when mounted from another computer).

### B.2 Files Read/Written by Combitst

control\sensors.cal

Data file with sensor calibration constants and settings for PID controllers. Details can be found in section A.1.

\*.wxd

These are the control files used to automatically control the program. They can be located in any directory but are preferably in control\ and its subdirectories. See section A.2 for more details.

control\combitst.ini

This contains the current settings for general program control. All the parameters available in the window program controls (see section 5.10) are stored here.

\*.dat

Data files created by the program. These have a header of three lines consisting of:

- program name and version; date; file name, and current glycol concentration.
- comment as written in the comment box in the real time display window (see section 1.1).
- Headers for the columns (the same titles as appear in sensors.cal).

At the end of the file is a copy from the combitst.sum file (see below) of all lines with the same file name. It is thus possible to get data here from more than “one” file if the same file name is used several times with the old file being overwritten.

`\data\combitst.sum`

This file contains summarised data for the data files. Sums of energies are stored here at the start of each new time step – and thus this is only used when automatic test sequences are being run. The energy sums are zeroed after each conditioning command. The following are recorded:

- optional line stating which command has been executed (see section A.2 for details of commands). The data in the line following this comment line shows the energy values after the command has been executed.
- Line containing:
  - Time (from start of 0.0).
  - Integrated powers over time (ie energies) for electrical auxiliary, solar, DHW, heating system (& conditioning & discharge), boiler (& full charge).
  - Electrical energy to auxiliary (from electrical energy meter).
  - Losses in K.hr – this is the integration over time for the average store temperature minus the ambient temperature. In order to get the actual heat losses this needs to be multiplied by the heat loss UA-value for the store.
  - File name.

Note that this file is appended to, ie it keeps growing. The file should be copied periodically and the original reduced to just the header lines.

`combitst.err`

Any errors (principally due to problems reading sensors) are written here. This file also keeps growing.

`\data\currdata.dat`

This is a copy of the current data file being written to. It is copied after every command has been completed (or after a time step). It is created so that the data can be checked from an external computer without disturbing measurements.

`\data\currdata.zip`

This is just a zipped version of `currdata.dat`.

### B.3 ZIP Window

This is created when the zip file of the current data file is created (see above). This window gets removed after every command has been completed and a new one is created. So, at the end of the program there is always one left.

## B.4 Program Modules in Combitst

The project coordination file for the Labwindows CVI environment is called `combitst.prj`. This contains information about which files are used in the program. All the modules are in the main directory for the program. A list is given in Table B.1.

*Table B.1 List of program modules and their contents.*

<b>Module</b>	<b>Contents</b>
<code>combitst.c</code>	Main loop, menus and execution of automatic commands
<code>dataaq.c</code>	Contact to and reading of all sensors
<code>dataanal.c</code>	All calculation work: powers, energies, etc
<code>combi-io.c</code>	Communication to files and the user
<code>combitst.h</code>	Definitions of all global variables used in the program and version history for the whole program.
<code>dataaq.h</code>	not used
<code>dataanal.h</code>	not used
<code>combi-io.h</code>	not used
<code>*.fp</code>	Modules that come with Labwindows and that are used for communicating to instruments or the PID controllers.
<code>timeseries.uir, h</code>	User interface (the windows that are shown in the program) for controlling (diagram menu) and showing the time diagram.
<code>SystemValues.uir, h</code>	User interface (the windows that are shown in the program) for the real time display window and most of the menu commands.

## B.5 Data Structure in Combitst

All global variables and definitions are defined in `combitst.h`. There are no complex structures and this file is well documented internally. There are however, a few things that can be confusing:

- There are 8 flow sensors defined for data but only 7 sensors physically connected. The final one (Vdx) is a virtual sensor that has data in during final discharge or conditioning. Otherwise data from the physical sensor goes to the Vh.

## APPENDIX C: NOMENCLATURE

Table C.1 gives a list of the nomenclature used in the program and here in this manual.

*Table C.1. Nomenclature used in this manual.*

<b>Symbol</b>	<b>Description</b>
<i>General</i>	
DHW	Domestic Hot Water
<i>Subscripts</i>	
i, o	input to, output from a circuit with respect to the circuit, not the store.
h	space heating circuit (discharge, conditioning)
b	boiler circuit (full charge)
c	collector circuit
cx	secondary side of collector heat exchanger
dx	final discharge
dhwm	mixing flow for mixing valve in DHW circuit
elaux	electrical auxiliary in store
ob	oil boiler
wb	wood boiler
<i>Others</i>	
Tbc	temperature in store for boiler controller
Tc	temperature of collector
Tcc	temperature in store for collector controller
Tra	room ambient temperature
Th4i	temperature as input to mixing valve in space heating circuit (from store)
Ts1-7	temperatures in store (7 sensors, 1 being at the top)
Tref	Reference temperature for all tests. This is normally 20°C but could be anything. Most commands have their temperatures related to this temperature. Also used as sensor name for the reference sensor used for calibrations.

## APPENDIX D: Calculation of Density, Heat Capacity & Heat Transfer Rate

Combitst uses specific formulae for calculating the density, heat capacity and heat transfer rate. This is for pure water and mixtures of water and propylene glycol. At present the glycol properties are for the product P44 and for the range 20% to 60% by volume concentration. Below or above this range the calculation treats the fluid as pure water.

Glycol concentration is calculated from the measured refractive index of P44 at 20°C. This value is entered in general\program controls (see section 5.10) and the program automatically calculates the glycol concentration based on formula derived from fitting manufacturing data to a polynomial equation. This concentration is used throughout the program and is recorded in the data file on the first line.

$$\text{GlycPerc} = 19.99472 + 728.8837 \cdot \text{RI1} + 6119.021 \cdot \text{RI1}^2 - 6.2883\text{E}+04 \cdot \text{RI1}^3$$

where:

GlycPerc is the percentage (by volume) concentration of the glycol water mixture, and  
RI1 = Measured refractive index - 1.3563.

In the following equations T refers to the temperature of the fluid.

### D.1 Calculation of Density

Density is calculated in units of kg/l.

#### D.1.1 Water

$$\rho_w = 1.00067 - 0.000073845 \cdot T - 0.000003547 \cdot T^2$$

#### D.1.2 Glycol (P44) / Water Mixture

$$\rho_{\text{glyc}} = 0.001 \cdot (\text{GlycRoCoeffs}[0] + \text{GlycRoCoeffs}[1] \cdot T + \text{GlycRoCoeffs}[2] \cdot T^2)$$

Here the coefficients for this equation have been derived from manufacturers data using curve fitting for a polynomial equation.

$$\text{GlycRoCoeffs}[0] = 988.039639 + 1.98795788 \cdot \text{GlycPerc} - 1.164966\text{E}-2 \cdot \text{GlycPerc}^2$$

$$\text{GlycRoCoeffs}[1] = 0.19219709 - 2.583458\text{e}-2 \cdot \text{GlycPerc} + 2.0381\text{e}-4 \cdot \text{GlycPerc}^2$$

$$\text{GlycRoCoeffs}[2] = -0.523512\text{e}-2 + 1.6088\text{e}-4 \cdot \text{GlycPerc} - 1.5425\text{e}-6 \cdot \text{GlycPerc}^2$$

### D.2 Calculation of Heat Capacity

Heat capacity is calculated in units of kJ/kg.

#### D.2.1 Water

$$\text{Cp}_w = 4.2091 - 0.001328 \cdot T + 0.00001432 \cdot T^2$$

#### D.2.2 Glycol (P44) / Water Mixture

$$\text{Cp}_{\text{glyc}} = \text{GlycCpCoeffs}[0] + \text{GlycCpCoeffs}[1] \cdot T$$

where:

$$\text{GlycCpCoeffs}[0] = 4.263992674 - 1.370543346e-2 \cdot \text{GlycPerc} - 0.71733822e-4 \cdot \text{GlycPerc}^2$$

$$\text{GlycCpCoeffs}[1] = -0.1486013986e-2 + 2.10805861e-4 \cdot \text{GlycPerc} - 1.971362e-6 \cdot \text{GlycPerc}^2$$

### D.3 Calculation of Heat Transfer Rate

This is calculated using a fixed value for the density (at the temperature of the flow sensor) and the integrated value of  $C_p \cdot dT$  over the temperature range from inlet ( $T_1$ ) to outlet ( $T_2$ ). This integration is based on the integral of the equations given in the previous section for the heat capacity.

First the mass flow rate is calculated based on the temperature of the flow sensor.

For water:

$$Q'_w = \text{mdot}_w \cdot (4.2091 \cdot (T_1 - T_2) - 0.5 \cdot 0.001328 \cdot (T_1^2 - T_2^2) + (1/3) \cdot 0.00001432 \cdot (T_1^3 - T_2^3))$$

For water/glycol:

$$Q'_{\text{glyc}} = \text{mdot}_{\text{glyc}} \cdot 0.5 \cdot (\text{CalcHeatCap}(T_1, \text{GP}) + \text{CalcHeatCap}(T_2, \text{GP})) \cdot (T_1 - T_2)$$

where:

$\text{mdot}$  is the mass flow calculated from the volume flow and temperature of the flow sensor using the equations in the previous sections, and

$\text{CalcHeatCap}$  is a routine for calculating the heat capacity of the water glycol mixture based on the temperature and concentration (GP).

#### D.3.1 Estimation of Uncertainty Due to Glycol Properties

Measurement of refractive index	0.0003
Volume concentration (due to uncertainty in refr.ind)	$\pm 0.27\%$ (absolute) <sup>1</sup>
Volume concentration (max error in curve fitting)	$\pm 0.40\%$ (absolute)
Volume concentration (total)	$\pm 0.67\%$ (absolute)
Density (due to uncertainty in vol. conc.)	$\pm 0.04\%$ <sup>1</sup>
Heat Capacity (due to uncertainty in vol. conc.)	$\pm 0.32\%$ <sup>1</sup>
Heat transfer rate (due to uncertainty in vol. conc.)	$\pm 0.25\%$ <sup>1</sup>

<sup>1</sup> Calculated using the propagate uncertainties feature of EES (Engineering Equation Solver).

## APPENDIX E: The Four Test Circuits and Sensor Positions

The following schematics show the four circuits of the test rig and the positions and names of the sensors, pumps and control valves.

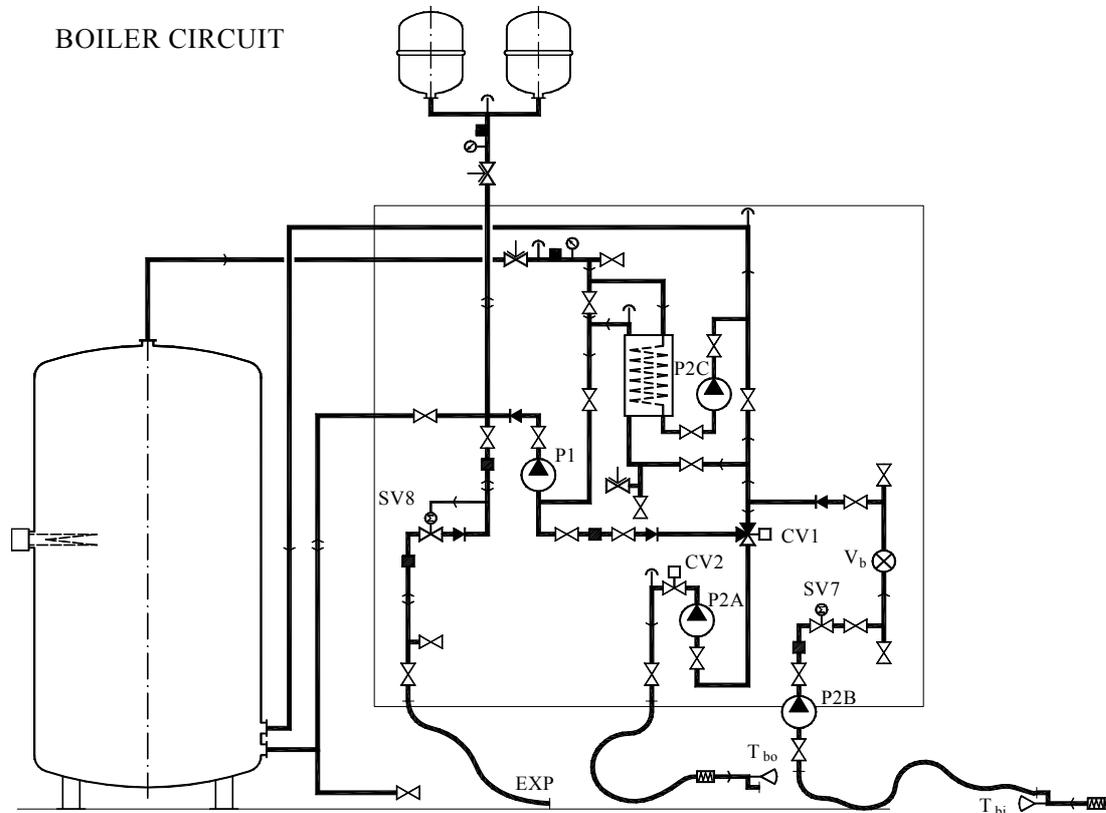


Figure E.1. Schematic of the boiler and full charge circuit.

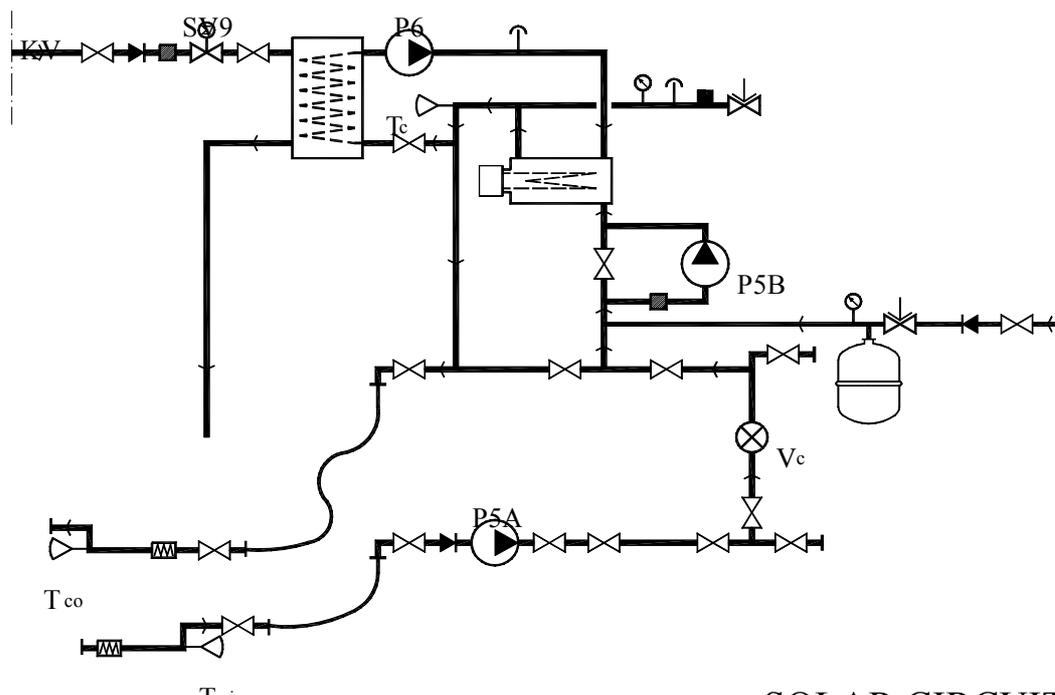


Figure E.2. Schematic of the collector charging circuit.

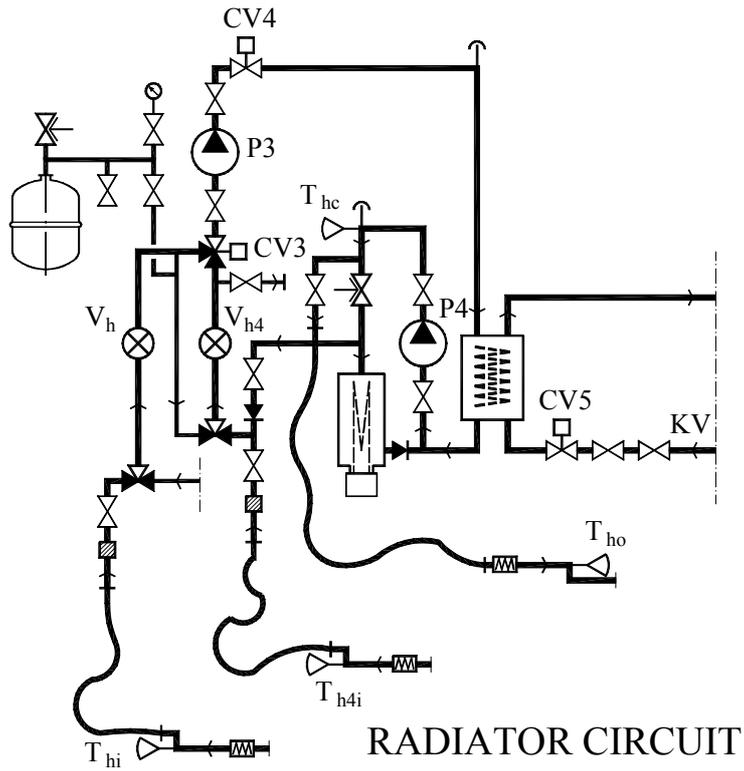


Figure E.3. Schematic of the space heating (discharge, conditioning) circuit.

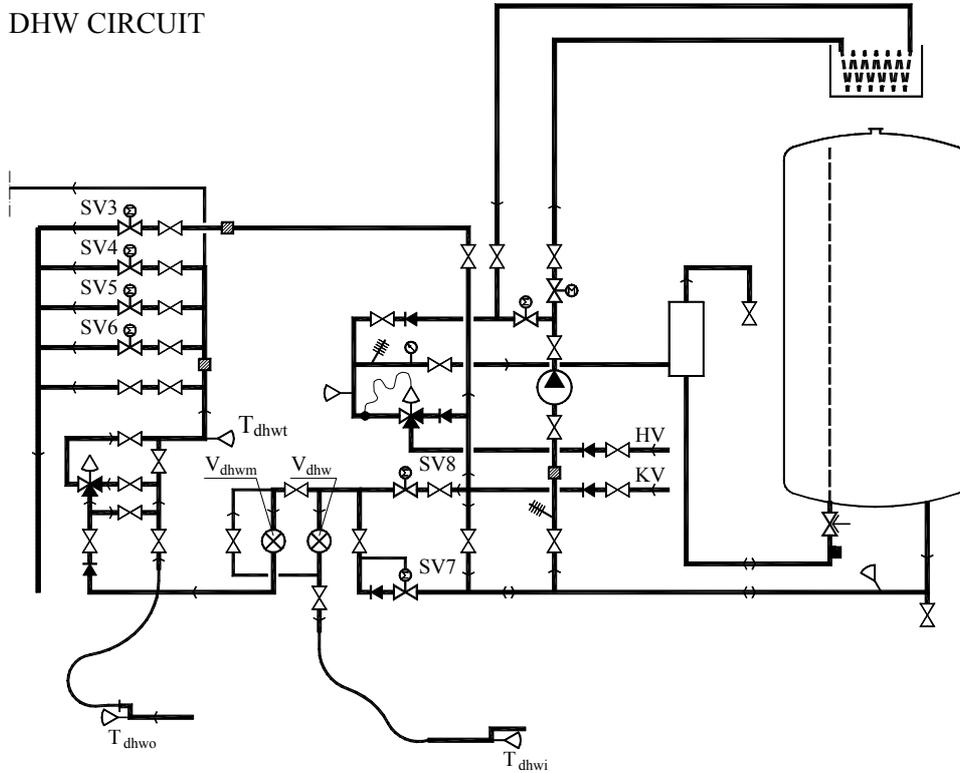


Figure E.4. Schematic of the DHW discharge circuit.