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13. ABSTRACT (Maximum 200 words)

CSA Engineering supported ongoing research involving the rapid addition or removal of heat from human test subjects by providing engineering test and evaluation systems. These systems were intended to provide multiple functions. They allow an independent basis for monitoring effectiveness of the thermal management. They facilitate evaluation of testing on human subjects and precise control of test variables, and accelerate processing of data. Thirdly, they provide a means for evaluating different hand interfaces. Finally, they provide a platform for assessing the role of vasodilation in heat transfer and the sensing and control system to maximize heat transfer for different subjects.
Each test system provides a controllable rate of water flow at a specified temperature through a heat exchanger that contacts the palm of a subject's hand. Mild vacuum pressures can be applied to the human hand to facilitate blood flow. Heat transfer at the heat exchanger is accurately measured and can be monitored in real-time. A provision to subtract quiescent or background heat loss (typically a few Watts) is included, as well as Program and Control Modes allowing for a series of repeatable temperature and flow profiles and the use of arbitrary algorithms to investigate universal vasodilation, respectively.

14. SUBJECT TERMS

RTX, rapid thermal xchange, human thermal control, testing platform

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Enclosure 1

Validation of Systems for Human Thermal Control

Final Report

CSA Report #2007523

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Background and Overview

DARPA has invested substantial funds in the development of technologies for controlling the temperature of the warfighter. In hot environments, and in certain types of protective clothing and equipment, there is value in rapid removal of heat from the warfighter. In certain situation involving cold environments, including underwater ones, there is value in adding heat. One approach developed by Stanford University and others under DARPA funding makes use of heat transfer sites on the palm of the hand to effect temperature control of the human core. This method is based on exploitation of physiology that combines substantial blood flow with heat transferring structures within the hands.

The approach has continued to show promise, but a more systematic evaluation of the effectiveness was needed to determine quantitative performance under different conditions and for different test subjects. Further, an effective validation test system should provide the researchers with the ability to conduct tests with certain variables – set point temperature, fluid flow and others – controlled, not simply monitored.

CSA Engineering supported the research by providing engineering test and evaluation systems. These systems were intended to:

1. Provide an independent basis for monitoring effectiveness of the thermal management.
2. Facilitate evaluation of testing on human subjects and precise control of test variables, and accelerate processing of data.
3. Provide a means for evaluating different hand interfaces.
4. Provide a platform for assessing the role of vasodilation in heat transfer and the sensing and control system to maximize heat transfer for different subjects.

Four systems were assembled and delivered: two were installed at Stanford University and two at the University of New Mexico.

Each system (Figure 1) can deliver between 0 and 3.5 liters per minute of water at temperatures ranging from 2 to 45 C. A new fluid temperature can be set and delivered within tens of seconds. In parallel, each system includes the ability to control air pressure within an attached hand interface, over a partial vacuum range of 0-30 inches of water. This pressure can be controlled with variable duty cycle to allow study of the effects of varying or pulsing differential pressures experienced by the hand. Total heat flow through the system is computed and made available in real time using measurements of differential fluid temperatures in and out of the hand interface and flow rate. Fluid supply temperature, partial vacuum level, and ambient temperature are also recorded. Fifteen additional analog channels are available in each system for supplementary measurements.

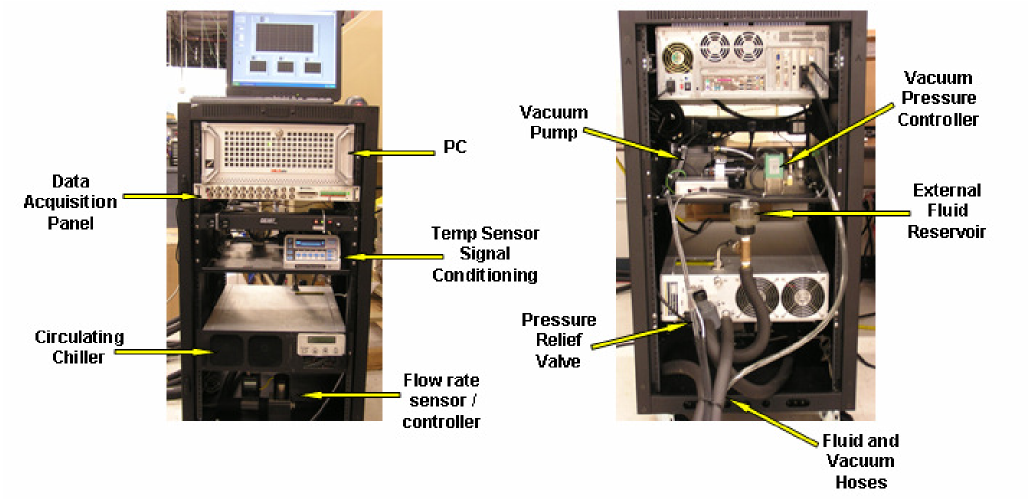


Figure 1: One of four identical laboratory test systems for control and monitoring of fluid flow, temperature, differential pressure, and heat at hand interface

Each test system connects to one hand interface and allows real-time monitoring, adjustment and recording of various parameters. The systems were calibrated prior to delivery, and typical errors in computed heat and power flow are under 4%. A provision to subtract quiescent or background heat loss (typically a few Watts) is included. A Program Mode allows the operator to sequence a series of test points to establish a repeatable temperature and flow profile over time. In Control Mode, the operator can establish arbitrary rules or algorithms to adjust temperature and flow rates based on objectives that may include maximization of heat flow. This feature can be used to investigate universal vasodilation despite differences in the characteristics of particular subjects.

The system design had to be modified to reduce overall bias pressure. The presence of several psi bias pressure caused seals in rigid hand interface units to leak, and rigidized more compliant hand interface units. Finally, the maximum flow of 4 lpm was derated slightly because of a tendency of water filters to clog after extended time. The effort concluded with procurement and delivery of hand interface units to researchers.

Instrumentation

The RTX testing platform is a commanding, monitoring, and logging system to measure the heat transfer from an individual's hands.

The monitored parameters in this system are:

- Flow rate
- Vacuum pressure
- Chilled water supply temperature (T_{supply})
- Ambient temperature ($T_{ambient}$)
- Inlet and outlet temperature at the hand interface (T_{inlet}, T_{outlet})

The parameters which can be commanded are:

- Flow rate setpoint
- Vacuum pressure setpoint
- Vacuum pressure time profile
- Chilled water supply temperature setpoint

The instrumentation dedicated to monitoring (and commanding) these system parameters are detailed in Table 1.

System Parameter	**Instrument**[1]
Flow rate	(1) *Alicat Scientific* LCR flow controller
Vacuum pressure	(1) *Proportion Air* QB3 pressure controller (1) *Gast* miniature oil-less diaphragm vacuum pump (1) *Crydom* solid state relay for controlling ON/OFF state of vacuum pump.
T_{supply}, $T_{ambient}$	(1) *Thermotek* rack mount chiller equipped with auxiliary *RTD Company* 100 Ω platinum RTD for measuring ambient temperature.
T_{inlet}, T_{outlet}	(1) *Automatic Systems Laboratories* F200 thermometer (2) *RTD Company*100 Ω platinum RTDs

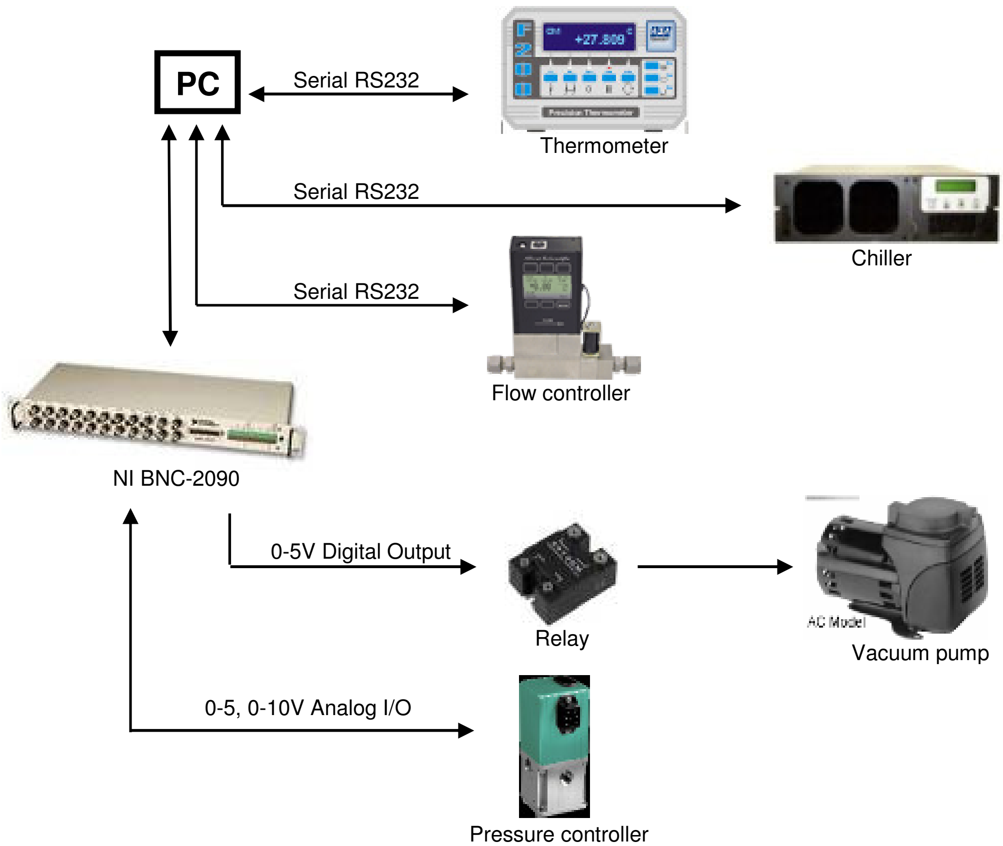
Table 1 - Instrumentation

Instruments which utilize RS232 serial communications (i.e. thermometer, chiller, flow controller) are assigned unique serial COM ports.

Instruments which utilize analog or digital I/O (i.e. pressure controller, relay) are assigned channels in the *National Instruments* BNC-2090 adapter chassis. Digital Output 1 (DO 1) is dedicated to the solid state relay which controls the vacuum pump's ON/OFF state. Analog Output 0 (AO 0) produces the pressure controller's 0-10V control signal, and Analog Input 0 (AI 0) receives the pressure controller's 0-10V response.

[1] Additionally, the following hardware is included in the system:
- (1) *Boldata* rack mount PC equipped with (1) *National Instruments* PCI-6221 DAQ card
- (1) *National Instruments* BNC-2090 (NI BNC-2090) adapter chassis
- (1) *Bay Corportation* water trap

Figure 2 details the communications protocol for instruments under PC control.



Instrument	Connection	Notes
Thermometer	COM 3	9600 baud, no flow control*
Chiller	COM 4	9600 baud, XON/XOFF flow control*
Flow controller	COM 5	19200 baud, no flow control*
Relay	DO 1	
Pressure controller	AO 0 / AI 0	

* 8 data bits, no parity, 1 stop bit, (CR) terminates commands.

Figure 2: Communications protocol for individual instruments.

Software

Overview

The LabVIEW based software application monitors, logs, and commands the parameters of interest in the RTX testing system. Figure 2 is a screenshot of the main page of the application.

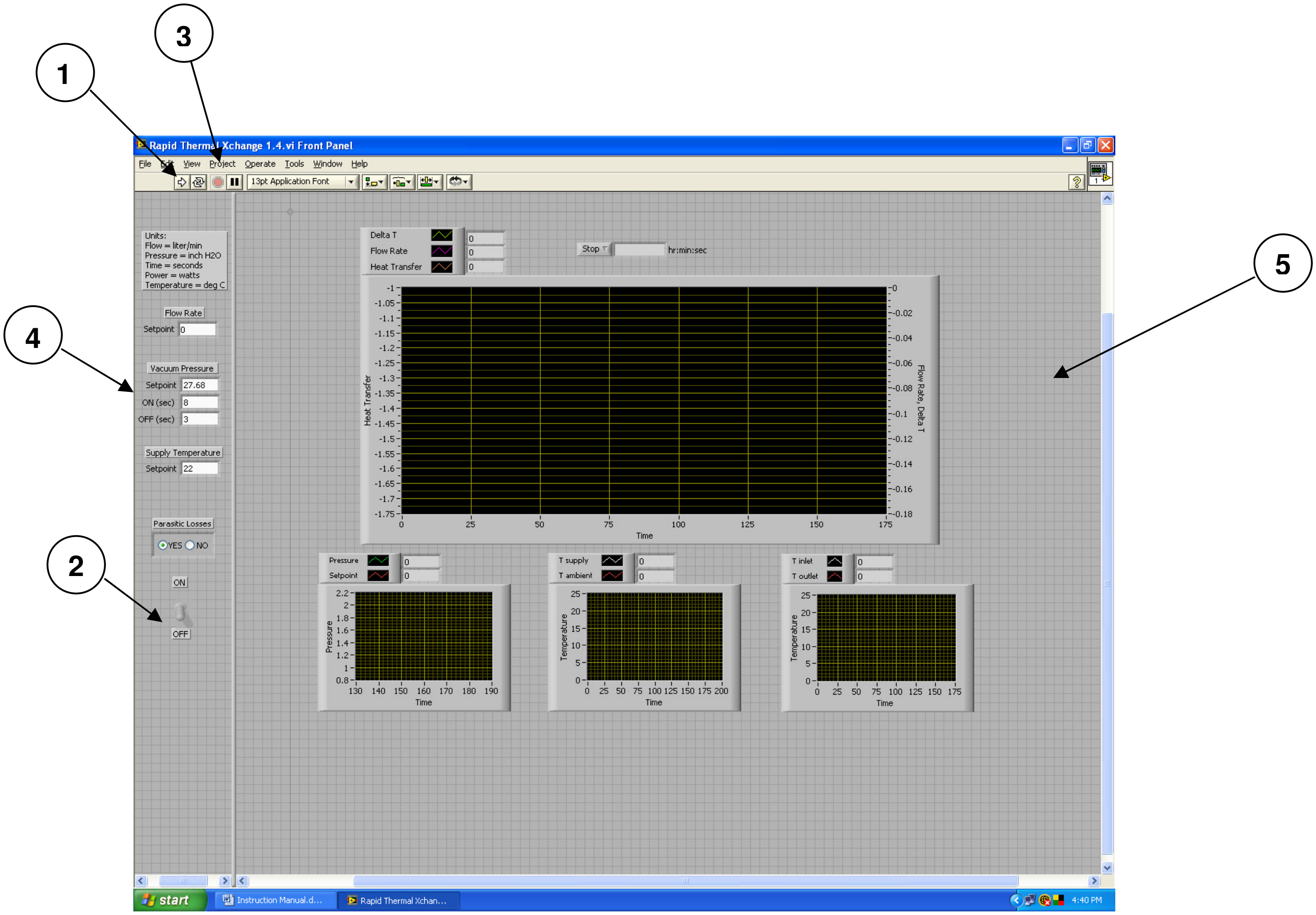
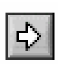


Figure 3: Screenshot of main page of application.

1 **Start Button**
Start the application by pressing this button. The icon will change from  to  indicating the application is in a *running* state.

2 **ON/OFF Switch**
Stop the application safely using the ON/OFF switch. By utilizing the ON/OFF switch to stop the application, the instruments will be stopped safely and restored to their default state. Additionally, the log file will be closed properly and subsequently readable. See the "Terminating" subsection under "Operation".

3 **Abort Button**
This button stops the application immediately. Stopping the application in this manner may leave instruments in an unknown state by not resetting or releasing them properly. Moreover, the log file may not be closed, leaving the log file in an unreadable state. Utilize the Abort button when safely stopping the application is not possible.

4 **Input Pane**
Enter setpoints for the various parameters.

5 **Output Pane**
View real time graphs of the various parameters.

Input Pane
In this pane the user can command setpoints for the following parameters:

- Flow rate
- Vacuum pressure
- Chiller supply temperature

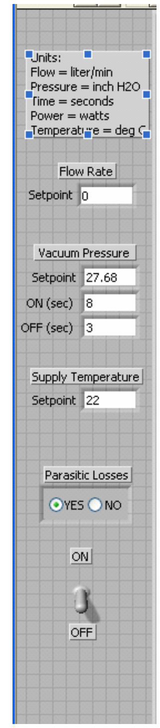


Figure 4: Input Pane

Additionally, vacuum pressure is cycled between atmospheric and its setpoint, subject to a user configurable time profile. The user can specify the duration of time (in seconds) at which pressure is held atmospheric (i.e. “OFF”) or at its vacuum setpoint (i.e. “ON”).

Finally, the user can specify whether or not to correct for parasitic losses[2] in the heat transfer calculation. If the user selects the “YES” radio button, heat transfer will be calculated according to the following formula:

Raw Heat Transfer – Parasitic Losses = Net Heat Transfer

If the user selects “NO” then heat transfer will not be corrected for parasitic losses.

Output Pane
The output pane displays real time information in graphical format. The parameters which are monitored are:

- Delta T (i.e. $T_{outlet} - T_{inlet}$)
- Flow rate
- Heat transfer
- Vacuum pressure
- Vacuum pressure setpoint
- T_{supply}
- $T_{ambient}$
- T_{inlet}
- T_{outlet}

[2] Parasitic losses are predetermined for a matrix of flow rates and inlet temperatures. They must be entered manually into the appropriate fields in the sub VI “Parasitic Losses.vi”

Additionally, a stopwatch is provided which can be utilized under any mode of operation.

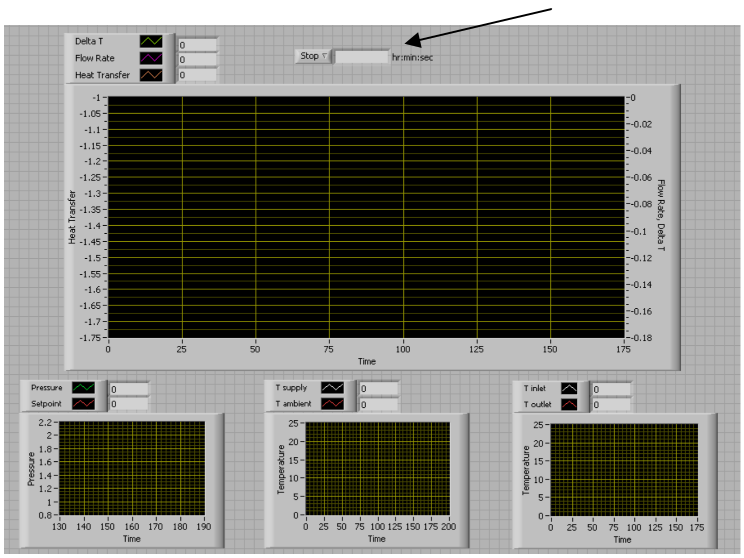


Figure 5: Output pane with stopwatch highlighted

Operation

Initialization

Upon startup, the application will enter an *initialization* phase that establishes communication with the thermometer, flow controller, pressure controller and chiller. If any of the instruments fail to communicate with the PC (e.g. instrument is powered off, serial cable is disconnected) the user is prompted to re-check connectivity and try again or to exit the application.[3] The application will not proceed past the *initialization* phase unless all four instruments can communicate with the PC.

Once communication has been successfully established, the user is prompted to select the mode of operation.

Running

Three modes exist under which to run the application: manual, program or control. The dialog box in figure 6 will display for the user to select which mode in which to operate.

[3] The exception: If the thermometer is not communicating with the PC during *initialization*, the application will terminate and the user must reboot the thermometer. Similarly, if the thermometer loses communication with the PC while *running*, the application will terminate and the user will be prompted to reboot the thermometer. The thermometer will not boot properly unless the application is stopped first. After a successful reboot, the thermometer will display temperature on its front panel. Ensure that temperature is displayed before attempting to restart the application.

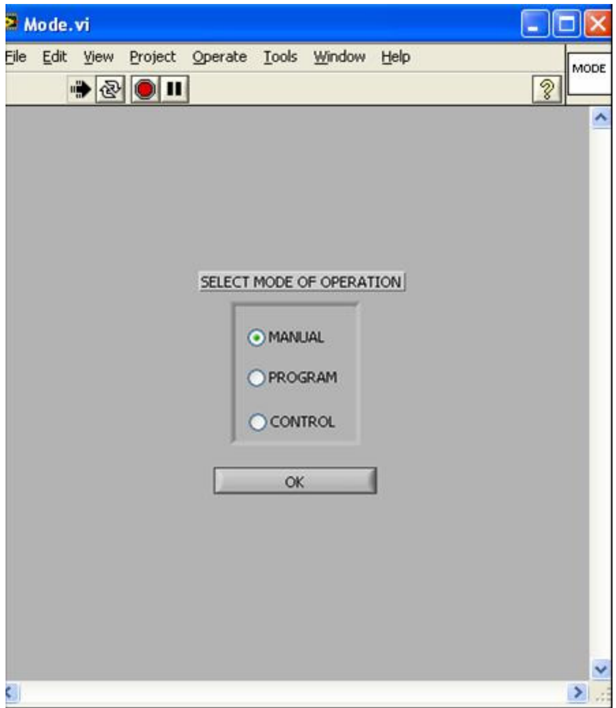


Figure 6: Mode selection

If manual mode is selected, the user can enter or change setpoints manually during the run at any time.

If, however, the user knows *a priori* what setpoints to command and the duration to hold those setpoints, the user can pre-program intervals that will execute in series. In this case, the user should select program mode when prompted which will bring up the following area for user input:

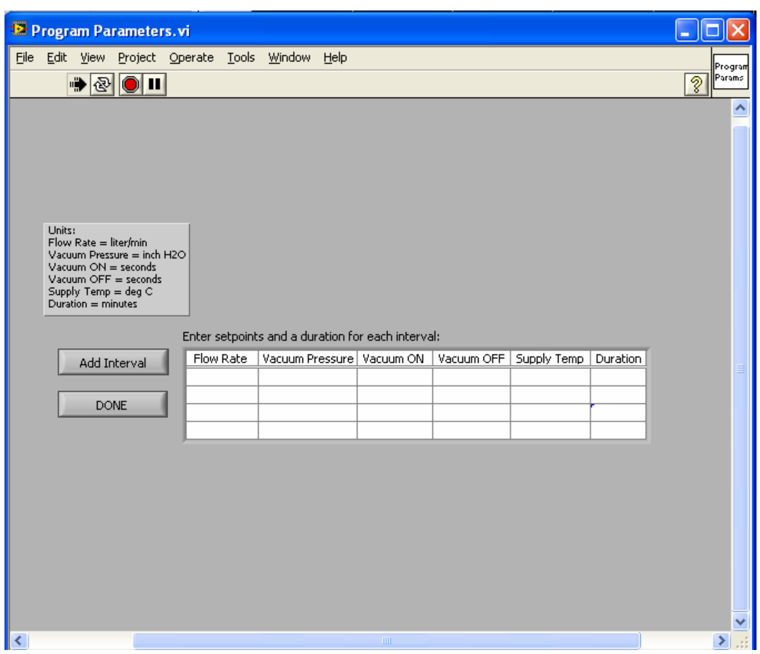


Figure 7: User input of parameters for program mode.

For a given row, the user enters a combination of setpoints and the duration of time to hold those setpoints. Each completed row is an interval in the program. Note that the time duration does not include the transient time elapsed between changes in setpoints. By default, three intervals are provided, however the user may add more intervals by pressing the "Add Interval" button. When finished, the user must press the "Done" button to proceed. After completing all intervals, the application will continue to run utilizing the setpoints from the most recent interval.

The greatest flexibility can be achieved in control mode – wherein the user can introduce logic into their operation. In control mode, a user-written C function is called from LabVIEW which takes in any number of input variables, to manipulate an output variable. For instance, in the example control code delivered with version 1.4, the chilled water supply temperature is varied – automatically – based on the heat transfer rate. One can write any C function (so long as it can be compiled) to manipulate a variable in LabVIEW in real time. Refer to the supplemental documentation "RTX Control Mode Implementation.doc" for details on how to write, compile, and call an external C function from LabVIEW.

In any of the three modes (i.e. manual, program, or control) the user may safely stop the application using the ON/OFF switch at any time.

Terminating

When the user exercises the ON/OFF switch to stop the application a series of steps are taken to safely stop all instruments:

- Flow controller setpoint is reset to zero[4]
- Chiller setpoint is reset to 22ºC
- Vacuum pump is powered off
- Pressure controller valve is opened to atmospheric pressure
- Thermometer is restored to local control[5]

In addition, the user is prompted to save the data to a log file.

Troubleshooting

1.) *According to my graph, flow rate is zero despite my commanding a non-zero setpoint.* Check the front panel of the chiller and make sure that no error messages are shown. If the read-out indicates "Low Coolant Level", add distilled water to the tank. Once water has been added to the tank, press the Run/Standby button twice on the front panel of the chiller. This will clear the warning message, but the current run must be stopped in LabView. Ensure that the flow controller is plugged in and its serial cable

[4] Avoid leaving the flow controller with any non zero setpoint for an extended period of time if no pressure is available to create flow (e.g. the chiller is powered off). The valve will get hot under these circumstances. This is the rationale for resetting the flow controller setpoint to zero in the termination phase of the application.

[5] The F200 thermometer has two modes of control: local and remote. Under local control the F200 thermometer is responsive to the keys on the front panel of the unit. Under remote control, the front panel keys are disabled and the unit is responsive to RS232 serial commands only.

is connected to the PC. Also ensure that the flow controller is configured for serial control by selecting “serial” under the “Input” category in the “Control Set-Up” mode of the flow controller. Additionally, check that the flow controller is closing a loop around flow rather than pressure. Refer to the hardware manual for more details.

2.) *My flow controller reads negative flow.*
   Ensure that “AUTOon/AUTOoff” is activated on the flow controller. “AUTOon/AUTOoff” refers to the standard auto-tare or “auto-zero” feature. It is recommended that the flow controller be left in the default auto-tare ON mode. With this feature, the flow controller automatically tares when it receives a zero set-point for more than two seconds. A zero set point results in the closing of the valve and a known “no flow” condition. This helps to make the flow controller more accurate by periodically removing cumulative errors associated with drift.
3.) *The flow rate will not reach its setpoint.*
   The pump can produce a maximum flow rate of 3.8 lpm, but flow restrictions in the system will reduce the achievable flow rates. A clogged filter is the most likely cause of a flow restriction. Replace the filter located on the inlet of the flow controller.
4.) *The flow oscillates and/or seems to take a long time to reach its setpoint.*
   A clogged filter can make it difficult for the flow controller to maintain a commanded flow rate. Try replacing the filter. Alternatively, the user can manipulate the proportional and derivative terms of the flow controller to achieve the desired response. In general, the proportional term is how fast the controller responds to a change in setpoint, while the derivative term can be thought of as the damping factor. Refer to the hardware manual for more details.
5.) *The log file reads “ERROR” for flow rate.*
   Under normal circumstances, flow rate and flow rate setpoint will be recorded in the log at a rate of 1 Hz. If serial communications are disrupted while the application is in a running state (e.g. flow controller is powered off, or serial cable is unplugged), the user will be continuously notified with a warning dialog. In addition, "ERROR" will be entered into the log to indicate the communications failure and the samples missed due to the error state. If the user elects to stop the application at the warning dialog, the application will immediately abort. If communications are restored, however, the flow controller will resume normal operation and subsequent samples will be valid.
6.) *My Delta T is negative though I know it should be positive.*
   Ensure that temperature probes are connected to the proper channels in the thermometer. If they are reversed there will be a sign reversal.
7.) *According to my graph, T_{inlet} and/or T_{outlet} is zero.*
   When a temperature probe is unplugged, the graph will display zero temperature. Ensure that temperature probes are always connected.
8.) *Vacuum pump does not turn on.*
   The pressure controller, vacuum pump, and relay form the hardware for vacuum pressure control. The relay turns the vacuum pump on and off, while the pressure controller controls the output pressure when the vacuum pump is on. If the vacuum pump does not turn on, check that power has been applied to the vacuum pump and the relay is properly connected. AC power for the vacuum pump is supplied from the electronics box located next to the pump. The relay is also located within this box,

but the AC power should be disconnected before opening the box to avoid the possibility of electric shock. The application will not check whether the vacuum pump and/or relay are properly functioning (neither during *initialization* nor while *running*.) It is up to the user to ensure that the vacuum pump and relay are operational.

9.) *Pressure does not cycle.*
Check communications and power connections to the pressure controller. Communications/power continuity is only verified during the *initialization* phase. The application does not check for communications/power continuity during the *running* phase.

10.) *I cannot command a chilled water supply temperature setpoint lower than 2ºC.*
This is intentional. Do not operate the chiller at temperatures below 2ºC as it can lead to localized freezing in the plumbing lines which can result in damage to instrumentation. Additionally, never run the chiller without fluid in the reservoir.

11.) *The log file reads "ERROR" for supply temperature and ambient temperature.*
If power and/or serial communications to the chiller are interrupted at any time while the application is *running*, the user will be warned once and "ERROR" will be entered into the log for as long as the error state persists. If power and/or serial communications are restored the chiller will resume normal operation and subsequent samples will be valid.

12.) *Supply temperature and ambient temperature have both dropped to zero in my graph.*
Check power and/or serial communications to the chiller.

13.) *I changed the period of execution of the loops and now the data doesn't seem to be displayed correctly on my graphs.*
The periods of the While Loops in the application were selected carefully to accommodate the nuances of each instrument. For instance, the thermometer takes approximately two seconds to sample a single channel. As such, five seconds are allotted to the sampling of both channels on the thermometer which results in a 1/5 Hz overall sampling rate for the thermometer. In general, avoid changing the periods of the while loops in the application.

14.) *The ThermoTek chiller says "Low Coolant Level" even though there is water in the tank.*
If the external tank is filled with water too quickly, air may get trapped in the ThermoTek reservoir, causing it to sense a low coolant level. If this occurs, you can either disconnect the external tank and fill the ThermoTek reservoir directly or wiggle the arm leading to the external tank. You should see bubbles rise to the surface indicating that air is leaving the reservoir and water is entering.

Sensors and Testing Equipment Details

<u>Temperature Sensors</u>

Resistance temperature detectors (RTDs) were selected for coolant temperature measurement for their high accuracy, repeatability, and noise immunity. A single RTD is placed at both the inlet and outlet of the hand interface to effectively capture the temperature difference across the heat exchanger.

Custom platinum RTDs from RTD Company are used in the systems. The custom design allows for the high accuracies (±0.06% @ 0^{o}C) and fast response times (< 1 second time constant). Flow through the sensor housing is unidirectional. Increased errors may result from reversing the flow direction.

A high accuracy RTD signal conditioning unit is also used to minimize any additional errors. The signal conditioning units from Isotech each accept two 4-wire platinum RTDs. The 4-wire arrangement eliminates leadwire resistance effects and shielded cables are used to reduce noise. Calibration parameters for each channel were entered into the signal conditioning units for specific RTD sensors. The sensors should not be connected to different channels without consulting CSA Engineering as this will result in increased measurement errors.

Another RTD is included with each unit to allow the ambient temperature to be measured and logged. A standard accuracy RTD is suitable for this application, and the signal conditioning is performed by an add-on within the circulating chiller.

Flow Meter / Controller

A flow meter / controller unit from Alicat Scientific was chosen for both high accuracy (± 1% of full scale) flow measurement and precision flow control from 0-4 lpm. The flow meter measures the pressure drop across an internal restriction and accounts for variations in fluid viscosity due to temperature and pressure changes. The flow meter does assume that the fluid is pure (distilled) water. Using other fluids will cause errors proportional to the difference in viscosities and could result in damage to the flow meter.

The flow controller uses an internal PID (proportional, integral, derivative) control loop to adjust the position of a proportional control valve. The P and D parameters of the control loop can be adjusted to improve the controller's performance. They have been preset to appropriate values and should not be altered without consulting CSA Engineering. The proportional valve may become hot to the touch during operation. This is normal and is not a sign of controller malfunction.

A 40 micron filter is installed upstream of the flow meter / controller to prevent any contaminants from damaging the device. Bleed ports are located on the unit to allow trapped air to be purged from the system.

Circulating Water Bath

A powerful ThermoTek RC Series solid state re-circulating chiller was selected for the system. The unit includes three thermoelectric heat transfer assemblies capable of reaching temperatures from -10 to 45^{o}C. A small fluid reservoir combined with the high thermal performance of the heat transfer assemblies permits rapid temperature changes of the circulating fluid while still allowing for set-point temperature stability within ±0.1^{o}C.

The chiller is air-cooled and as a result, the chiller requires 6 inches of clearance at the front and rear of the unit for adequate air circulation. The chiller is intended for laboratory use and its performance is dependent on the ambient temperature. A small external reservoir has been provided with each system to avoid frequent refilling of the chillers. If it is desired to quickly change the set-point temperature of the chillers, these external reservoirs should be removed and replaced with a plug provided with each system.

The low temperature rating of the chiller when circulating water is 5^{o}C. ThermoTek's application engineers indicated that this was a conservative limit, but they did not recommend temperatures below 2^{o}C to avoid freezing in the tubes and reductions in cooling rate.

The ThermoTek chiller includes a gear pump capable of producing flow rates up to 3.8 lpm and pressures up to 100 psi. A pressure-maintaining relief valve is used at the outlet of the pump. The relief valve has an adjustable pressure setting from 10 to 150 psi. It was preset to 50 psi to reduce the pump pressure when the flow controller has a low or zero setpoint. This will extend the life of the pump and any excess flow is routed back to the external fluid reservoir. The pressure-maintaining relief valve setting should only be adjusted after consulting with CSA Engineering.

A second relief valve is used just upstream of the inlet temperature sensor. This relief valve is a safety feature that will not allow the pressure at the hand interface to reach excessive levels if a downstream flow restriction forms. This relief valve is set to the minimum pressure (~12 psi) that will still allow a flow rate of 3.8 lpm through the device without popping opening. If the relief pressure is exceeded, water will flow out of the side port of the valve. This flow can be routed to an external reservoir, if desired.

Vacuum Pressure Sensor / Controller

A Proportion Air QB3 pressure regulator is included in the system. The regulator uses two solenoid valves, a pressure sensor, and closed-loop control to produce a commanded vacuum pressure level. The range was set from 0 to -30 in. H_2O. The output of the high accuracy (±0.4% of full scale) pressure sensor is monitored to ensure it tracks the commanded signal.

Vacuum Pump

A Gast diaphragm pump is used to generate vacuum pressure for the system. It can produce flow rates up to 18.7 lpm at atmospheric pressure and can reach a maximum vacuum pressure of 300 in. H_2O gage. The pump's output is controlled by the vacuum pressure controller, and a water trap is placed upstream of the pump and controller to remove any moisture that may be drawn into the fluid lines. A filter/muffler is placed on the exhaust port of the pump to reduce noise.

Electronics Box

A small electronics box is located next to the vacuum pump. It contains junctions that control functionality of the vacuum pressure controller and vacuum pump including a solid-state relay. **The box should not be opened under normal circumstances as the risk of electric shock exists within the box**. If the box is opened, the AC power cord for the pump and AC adapter for the pressure controller should first be unplugged.

Fluid and Vacuum Hoses

Clear polyurethane tubing is used for all liquid and vacuum lines. The tubing has a 0.32 in. inside diameter and a 0.50 in. outside diameter. Instant tube fittings are used for ease of connecting / disconnecting. Elastomer foam rubber insulation (3/8" thick) covers the liquid hoses to reduce heat transfer with the environment.

Computer

Each system includes a computer for the control of all system components and the acquisition and storage of data. The rack-mountable computers come with Intel Pentium D 805 CPUs and two mirrored 250 GB hard drives, so that data will not be lost in the event of a hard drive failure. Each computer includes 1 GB of memory and a DVR for external data storage. LabVIEW Version 8.0 runs the data acquisition and controls tasks, and Microsoft Excel is provided with each machine for data storage and post-processing.

Data Acquisition Card

A National Instruments M-Series multifunction data acquisition card is included in each unit. The card allows for 16 analog inputs (16 bit), 2 analog outputs, and 24 digital I/O. A shielded BNC adapter panel is also included for easy connections to the analog and digital I/O signals. One analog input, one analog output, and one digital I/O are used with the existing hardware, but the remaining connections can be used for additional sensors (thermocouples, etc.) and equipment.

System Start-up and Maintenance

Start-Up

The circulating water bath and fluid lines must first be filled with **distilled water only**. Using other fluids will affect the accuracy of the flow meter and may damage system components. The chiller filling procedure is listed below:

The chiller must be turned off and disconnected from any electrical power source.

1. Slowly pour distilled water into the transparent external tank allowing air to escape from the ThermoTek's internal reservoir.
2. Fill the external tank to the desired level being careful not to overfill the tank. If any water was spilled into or down the back side of the chiller during this

step, the chiller and rear panel must be completely dry before proceeding further.

3. Attach the electrical AC power cord to the chiller and switch the breaker to the ON position. After a short 3-second boot up sequence, the chiller will automatically enter RUN mode and the pump will engage.
4. If the system was dry or the water level was low enough, the pump may pull all of the water out of the reservoir and disengage when the fluid level switch activates the system alarm. If this occurs, the chiller defaults into STANDBY mode with a LOW COOLANT LEVEL alarm and more water must be added. If so, repeat steps 1-3 once.

WARNING: NEVER ADD WATER WHILE THE PUMP IS RUNNING. COOLANT LINES EXPAND WHEN PRESSURIZED AND MAY HOLD MORE COOLANT THAN PERCEIVED. STOPPING THE PUMP OR TURNING THE SYSTEM OFF AFTER AN OVERFILL MAY CAUSE WATER TO EJECT FROM THE RESERVOIR AND CAN CAUSE SERIOUS INJURY OR ELECTRICAL DAMAGE.

5. If after repeating steps 1-3 one time your reservoir still empties and the pump automatically disengages, continue to repeat steps 1-3 until the pump does not disengage on its own. When this occurs, turn off the chiller by switching the breaker to the OFF position or place the system into STANDBY mode by pressing the keypad button "RUN/STANDBY" one time. You may now top off the tank with fluid.
6. Turn the chiller ON once again and allow it to run for at least 5 minutes in order to purge all remaining air from the water lines.

   Note: Failure to purge all air bubbles from the water lines will adversely affect water temperature stability and the thermal performance of the chiller system.

Maintenance

It is recommended that the distilled water is drained and replaced monthly to prevent biological growth. The chiller draining procedure listed below is from the ThermoTek manual:

1. Prepare two tubes, each having one mating connector and one open tube end.
2. Attach the mating connector ends of the tubes to the "Chiller Outlet" and "Chiller Inlet" ports and the open ends into a waste container.
3. Turn the chiller on and allow the pump to eject the water into the container. Note: the pump should stop on its own when the LOW COOLANT LEVEL alarm is triggered. If the alarm does not trigger automatically, power off the chiller.
4. With the waste container located below the chiller, any remaining water should begin to slowly drain out on its own.
5. Allow the chiller to drain for approximately 5 minutes.

6. The chiller is now fully drained and should be refilled with distilled water by following the filling procedure listed above.

A pneumatic air supply may also be used to drain the chiller, if available. Consult ThermoTek manual for instructions.

Consult the ThermoTek manual for long term storage procedures.

It is recommended that the Alicat flow meter / controller be recalibrated at the factory once per year. It is also recommended that the F200 RTD signal conditioner by calibrated once per year. A calibration procedure is listed in the F200 user manual, but it is recommended to have this carried out at the factory.

Measurement Errors

Through careful sensor selection, the testing platforms were designed to minimize the potential errors in the calculation of heat transfer. Assuming a nominal heat transfer rate of 100 Watts, the overall error limits for the measurements are shown in Table 2 for various flow rates. At lower flow levels, the flow rate measurements produce the majority of the overall measurement errors, while the fluid temperature measurements are the major source of errors at higher flow rates. Errors percentages will decrease with higher heat transfer rates and increase with lower heat transfer rates.

Flow Rate (lpm)	Error (%)
1	4.5
2	4.4
3	6.0
4	7.9

Table 2 – Errors limits of the heat transfer rate calculations at various flow rates assuming a nominal heat transfer rate of 100 Watts

Not all heat lost/gained by the fluid is gained/lost by the user. To account for other heat losses to the device itself or the external environment, “no load” parasitic loss tests must be performed, and the results must be subtracted from the overall heat transfer calculations. The parasitic loss tests must closely match each set of test conditions, and CSA Engineering will provide support in designing appropriate tests and procedures. Any errors resulting from these calibration tests will add to the measurement errors listed in Table 2.

Parts List

Temperature Sensors:

- RTD Company part# 10961-1, 100 Ohm platinum RTD, 4-wire, Class A, ±0.06% @0^{o}C, 0.385 Ohm/deg C ±(0.15^{o}C + 0.002*T), stainless steel housing

- RTD Company part# 8964-3, 100 Ohm platinum RTD, 4-wire, Class B, ±0.12% @0°C, 0.385 Ohm/deg C ±(0.30°C + 0.005*T), Teflon cable with strain relief

Temperature Signal Conditioner:

- Isotech part# F200, precision thermometer, ±0.01°C accuracy, 2 channel for platinum 100 Ohm RTDs, RS 232

Flow Meter / Controller:

- Alicat Scientific part# LCR-5LPM-D/10V, 10IN, RANGE:4LPM-HC, 0-4 lpm range, ±1% full scale accuracy, RS-232 serial communications

Water Filter

- McMaster Carr part# 98355K841, pipe fitting style inline filter, ¼" pipe size, 40-micron rating

Circulating Water Bath:

- ThermoTek part# N3A2R1U0K32XMD6XX-0R0RXX, RC Series chiller, 3U height, air chiller, 22" depth, high performance thermoelectric chips, 3 heat transfer assemblies, 2 power supplies, 3.8 lpm gear pump, 6 Delta fans, external RTD sensor, RS-232

Pressure-Maintaining Relief Valve

- McMaster Carr part# 46315K24, PVC adjustable liquid relief valve, pressure-maintaining, 10-150 psi, ¼" NPT female ports

Low Pressure Relief Valve

- McMaster Carr part# 4703K541, extended-life adjustable relief valve, brass body, 0-14 psi, 1/2" NPT ports

Vacuum Pressure Controller:

- Proportion Air part# QB3TFEEN1-S491, electro-pnuematic control valve, 0 to -30 in. H_2O range, < ±0.4% of full scale measurement error

Vacuum Pump

- Gast part# 22D1180-210-1003, oiless diaphragm pump, 115VAC motor, 1.6A, .04kW, 18.7 lpm max, 300 in. H_2O vacuum max

Water Trap

- Bay Corporation part# AFA-2, water trap

Fluid and Vacuum Hoses

- McMaster Carr part# 5648K631, clear polyurethane tubing, 0.32" ID, 0.50" OD

Hose Insulation

- McMaster Carr part# 4463K122, elastomer foam rubber insulation, 3/8" thick, ½" ID

Water Line Quick-Disconnect Fittings

- McMaster Carr part# 51545K76, polypropylene quick-disconnect tube couplings, ¼" coupler plug to ¼" NPT male with shut-off valve

Vacuum Line Quick-Disconnect Fitting

- McMaster Carr part# 51545K23, polypropylene quick-disconnect tube coupling, ¼" coupler socket to ¼" NPT male with shut-off valve

Computer

- Boldata custom server, Intel Pentium D 805, Intel R P965 Chipset, 1GB PC6400 DDR-2, 2 x 250GB SATA drive, 5 integrated SATA 3G controller, NVIDIA GeForceT 6200TC PCIe, Pioneer DVR-111 dual layer, Realtek PICe Gigabit lan controller, 4-port serial DB9 PCI card, Windows XP Professional, Microsoft Office Basic (Word, Excel, Outlook), 3 year standard warranty, 1 year 24/7 on-site service, Microsoft keyboard/MS wheel optical mouse, Advue 19" LCD flat panel

Data Acquisition Software

- National Instruments part# 776671-09, LabVIEW base system for Windows

Data Acquisition Hardware

- National Instruments part# 779066-01, NI PCI-6221, M-Series multifunctional DAQ card, 16 bit, 16 analog inputs, 2 analog outputs, 24 digital I/O, 68 pin
- National Instruments part# 777270-01, BNC-2090 rack mountable BNC adapter, 22 BNC connectors, 28 spring terminal blocks