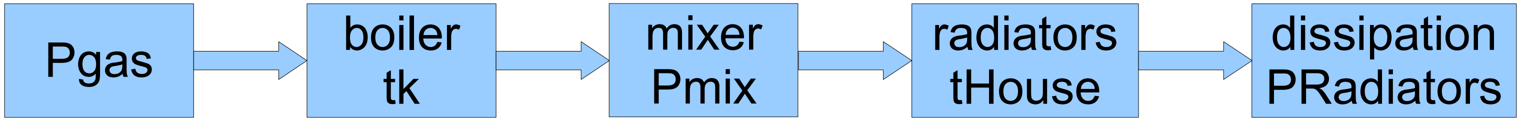
Heat Control System

Energy flow controled heating for buildings



Talk at ESUG 2008
Amsterdam
by Alfred Wullschleger

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Title: Heat Control System
Energy flow controled heating for buildings

Talk at ESUG 2008 Amsterdam
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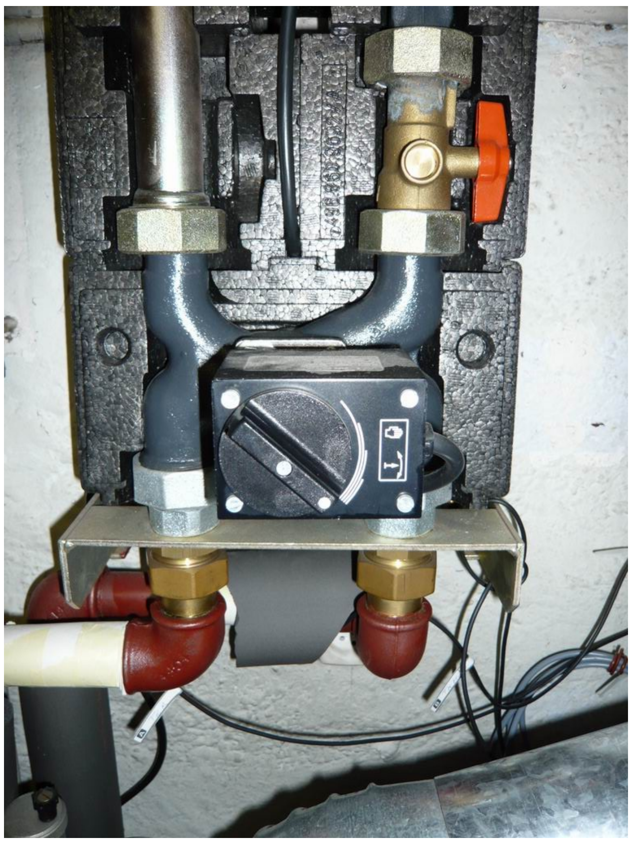
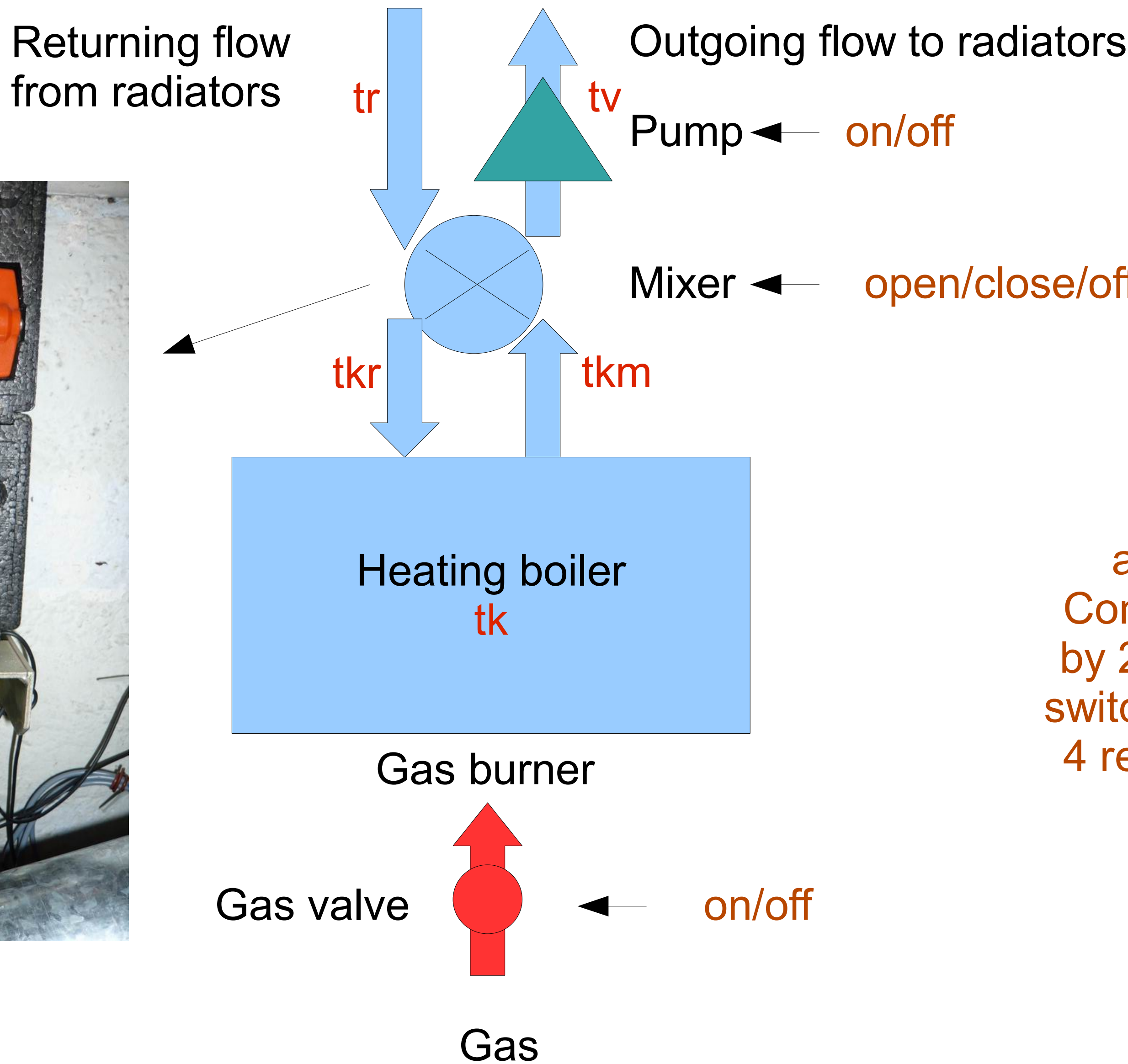
Where to start?

Analyse the heating system that is installed

Central heating boiler





all
Control
by 230V
switching:
4 relays

how to control?

- outgoing temperature tv to radiators is basic for heat flow to the building.
- Typically, 30C <= tv <= 55C
- Important restriction: boiler temperature tk should not be below tkmin = 40C (condensation produces corrosion)
- so, mixer needed!
- Two main actuators: gas valve and mixer position

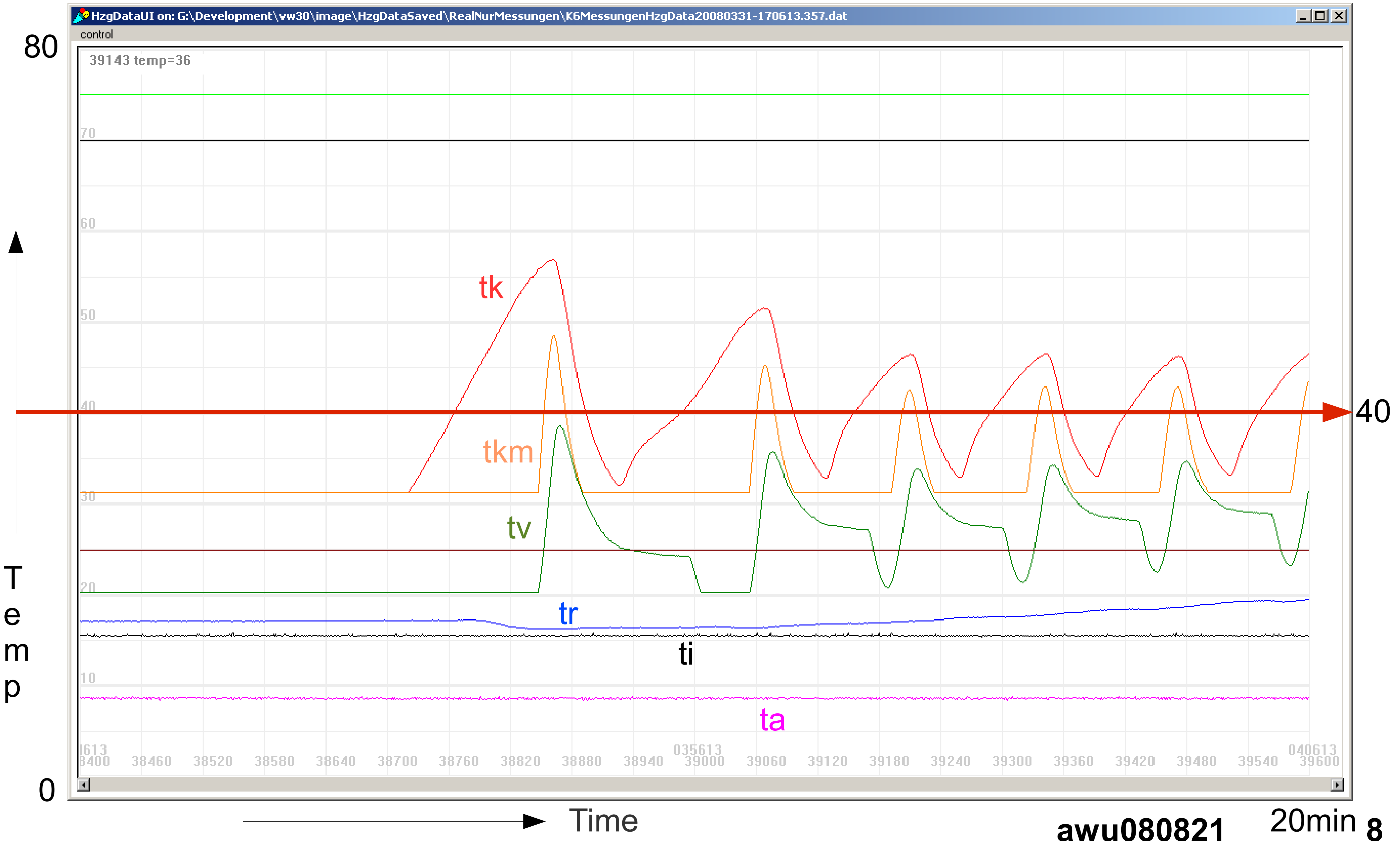
single family house: physical facts

- boiler typically has <10 liters content
- radiators typically have 300 to 500 liters
  - so,
    heat capacity of radiators >> heat capacity boiler
  - requires carefull mixing
- maintain tk > tkmin by mixer angle and by gas power

Control Unit example (CU1)

- commercially built control unit
  - controls boiler temperature by hysterisis:
    - tk varies between tkLower (gas burner starts) and tkUpper (gas burner stops) depending on tv calculated
  - heat flow to radiators is controled by mixer
    - since the mixer is very inert, tk rises very fast: gas valve closes within short time. Then tk drops very fast: after some seconds, tkLower is reached and gas valve starts again

Measured heat up behaviour CU1



awu080821

Properties CU1

- tk swings heavily below 40C during 40 to 50 minutes after cold start
  - condensation + corrosion may result
- the mixer is not efficiently used
  - heat flow is not steady, but burst wise
  - this produces the heavy temperature swings of tk
  - the gas valve is switched on and off far to many times within short periods (each tk-peak represents an on/off-cycle)

The Challenge

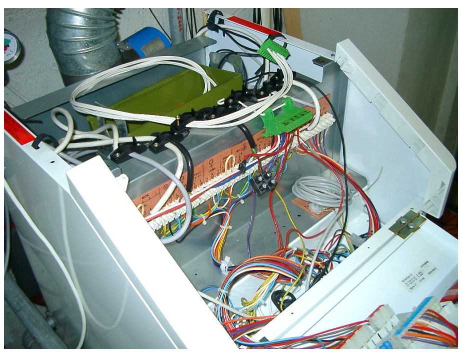
Make a better Control Unit!

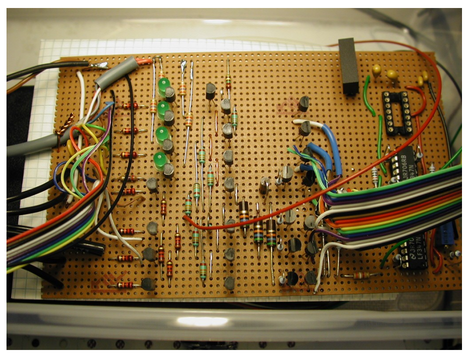
New Control Unit CU2

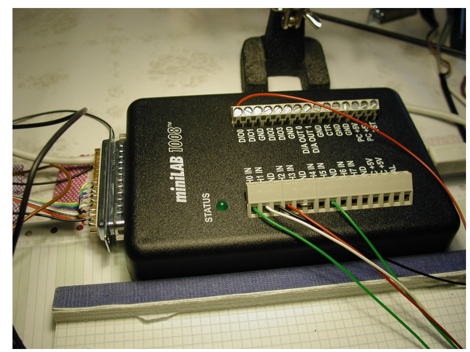
- Require tk > tkmin=40C at all times apart from 3-4 minutes when boiler is starting cold
- Hardware:
  - Standard PC + USB + self constructed interface electronics
- Software:
  - Smalltalk + DLL's
  - Simulator fully independent of hardware
    - in Smalltalk

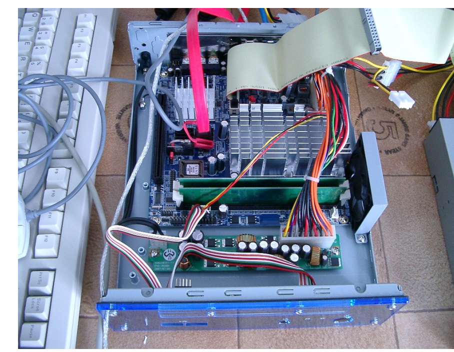
Interface hardware CU2

Heating boiler ⟷ interface electronics, temperature sensors, actuator relays ⟷ Minilab 1008 USB module to PC ⟷ MiniITX PC



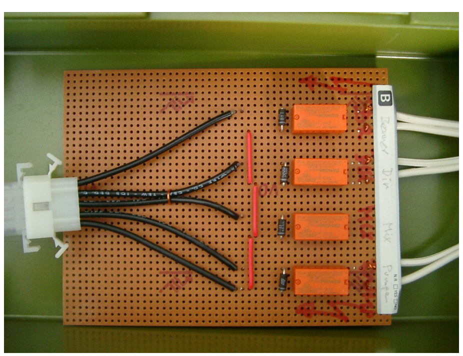




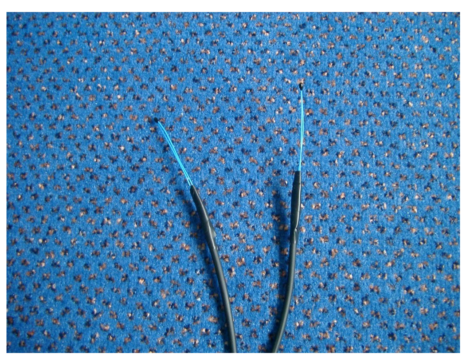


Minilab1008:
8 AD-Channels
28 prog. I/O-Bits
2 DA-Channels

MiniITX used for development and tests will be replaced by board with less energy consumption



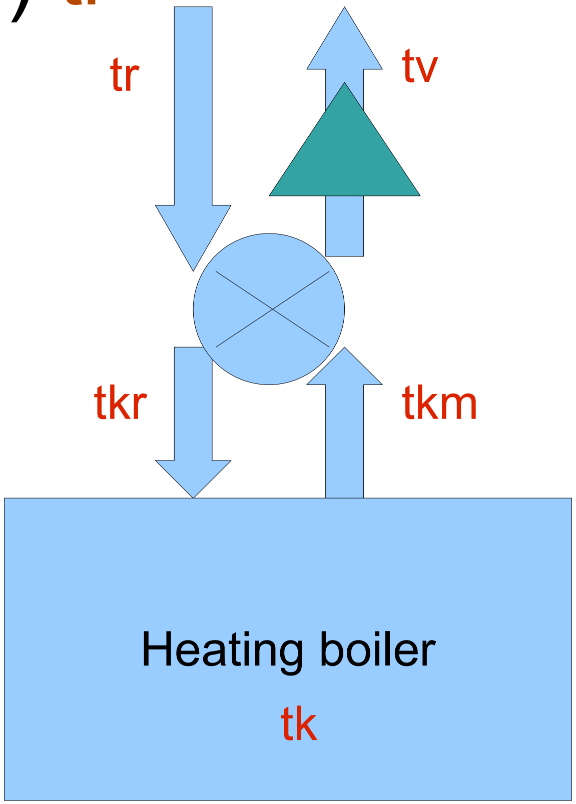
relay board



calibrated temp sensors

Temperature sensors CU2

- Boiler water temp tk
- Outgoing water temp (to radiators) tv
- Return water temp (from radiators) tr
- Outdoor temp ta
- Room temp ti
- Others:
  - boiler to mixer tkm
  - boiler from mixer tkr

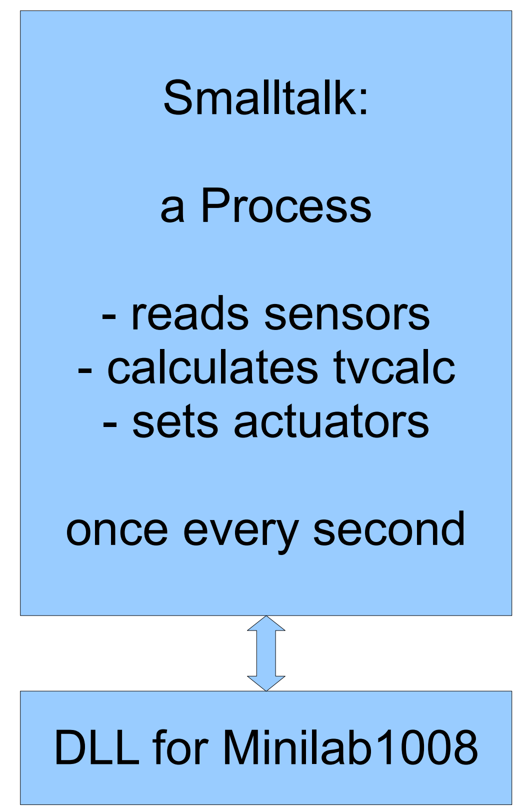


Actuators CU2

- Physical controlling of the heating process is done by relay switching:
  - Gas valve on/off
  - Pump on/off
  - Mixer motion open/close/off
  - 4 relays needed to control the 230V switches
- The software uses temperature sensor information, the heating model and the actuators to run the heating process

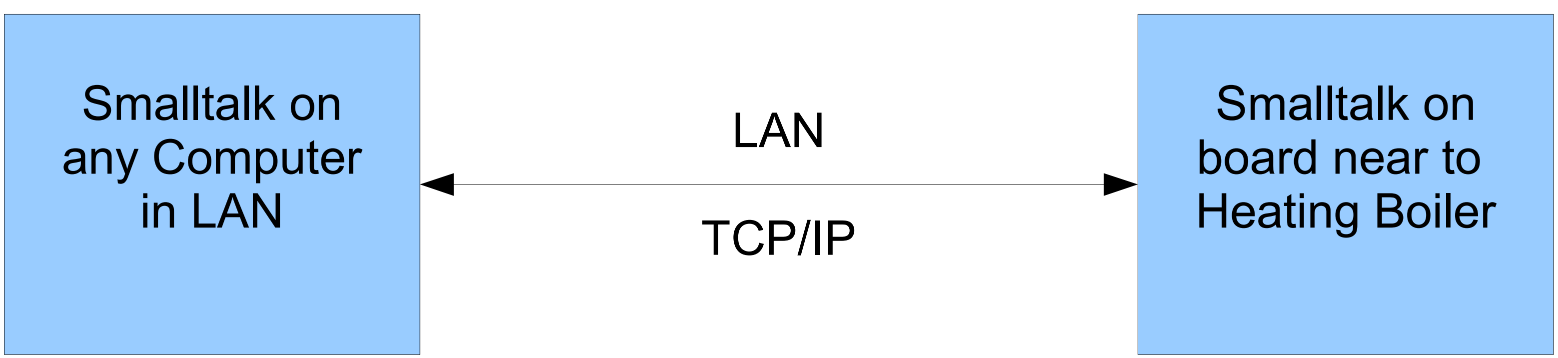
Software

- Interface to hardware via DLL for Minilab1008
  - supplied by manufacturer
- All control done in Smalltalk
- User interface in Smalltalk
- Sockets for remote operation
- Simulation of all hardware
  - uses an energy flow model
  - runs 10 times faster than real system



Local and Remote Software

- Heat Control done on a board near the heating boiler
- User Interface implemented on this board for local use
- Same User Interface also remote avaliable through Socket communication
- can use any computer in LAN to control the system



Heating model

Goal:
smooth running
energy saving
by minimizing mixing entropy

Temperature requirements

- tk > tkmin whenever the boiler is active
- Idea: distinguish 3 phases
  - Early heat up from cold boiler: tk < tkmin
  - Intermediate heat up: tk > tkmin & tv < tvcalc
    (tvcalc = tv as calculated by heating model)
  - Normal running, when tv >= tvcalc
- Keep mixing entropy small:
  - tk should be near to tv, whenever possible
  - not easy for all boiler states and all temperatures tk and tv

Emin: minimal energy needed

- we define
  - Emin = c*mRadiators * (tvcalc - tv)
    - as the minimal energy needed at each moment
    - mRadiators is the mass of the water in the house
    - c = 4.2 kJ/C/kg the specific heat of water
    - tvcalc is the required tv as function of ta
  - Emin < 0: there is an energy reserve in the house

Gas valve control

- When Emin > 0, the gas valve is never closed: this results in heating up phases, where the burner may run for hours without interruption, when needed.
  - During this time, only the mixer controls tk and the flow of energy to the radiators
- When Emin <= 0, the gas valve is controled in a hysterisis fashion:
  - 0 > Emin > EminMaximumReserve
    - EminMaximumReserve ~ -10MJ:
      - chosen for appropriate on/off-intervals for the gas valve

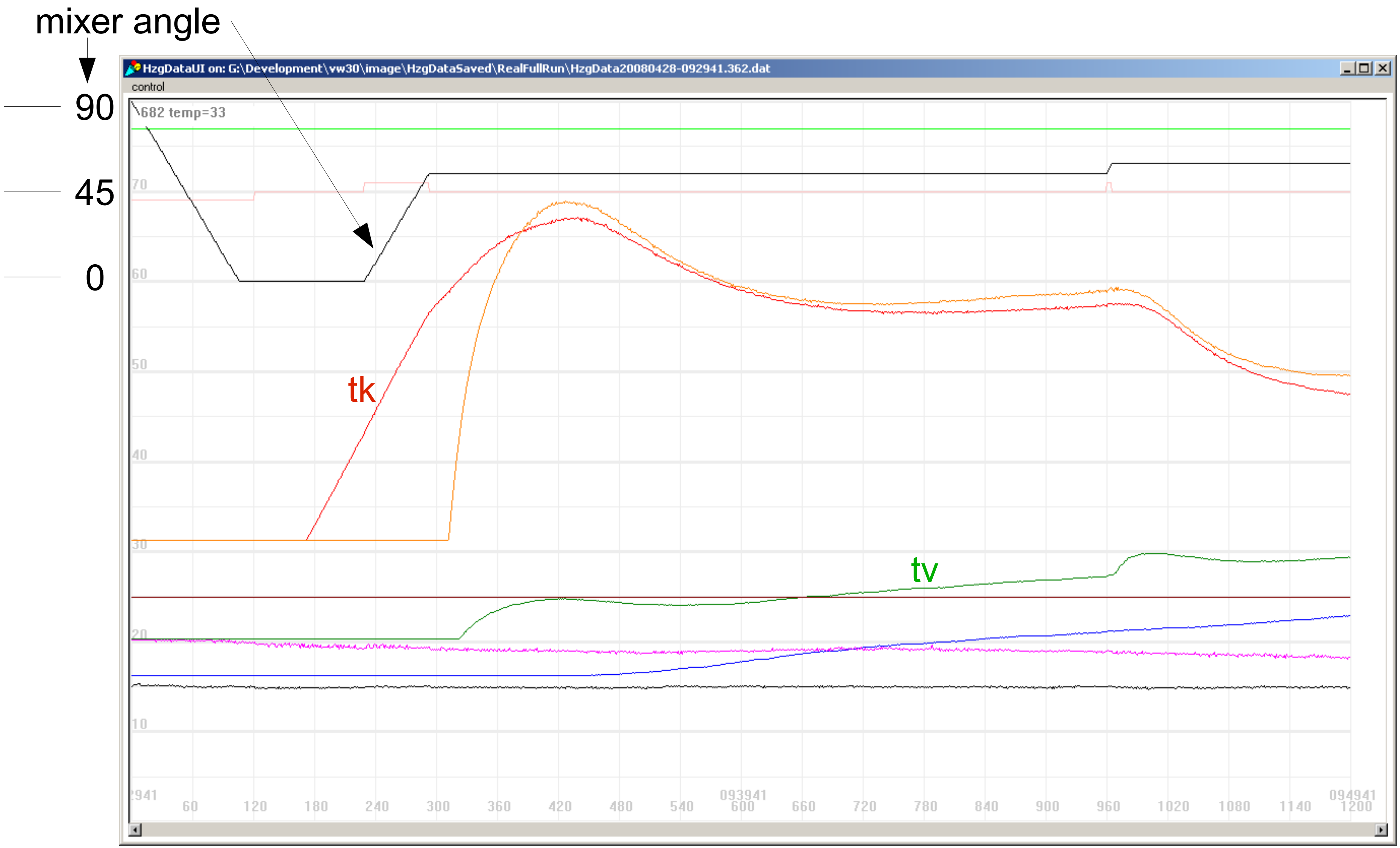
The 3 Phases:

Characteristics and
typical runs

Phase 1: Early heat up (cold boiler)

- Close mixer completely as long as tk < tkmin
  - very fast heat up to tkmin (below 4 minutes)
  - tk > tkmin: start opening mixer
    - build up some energy in boiler, by rising tk > 50-60C
    - control tk by opening mixer step by step to a installation dependent maximum. Gas valve always open!
- Switch to intermediate heat up after 900 seconds

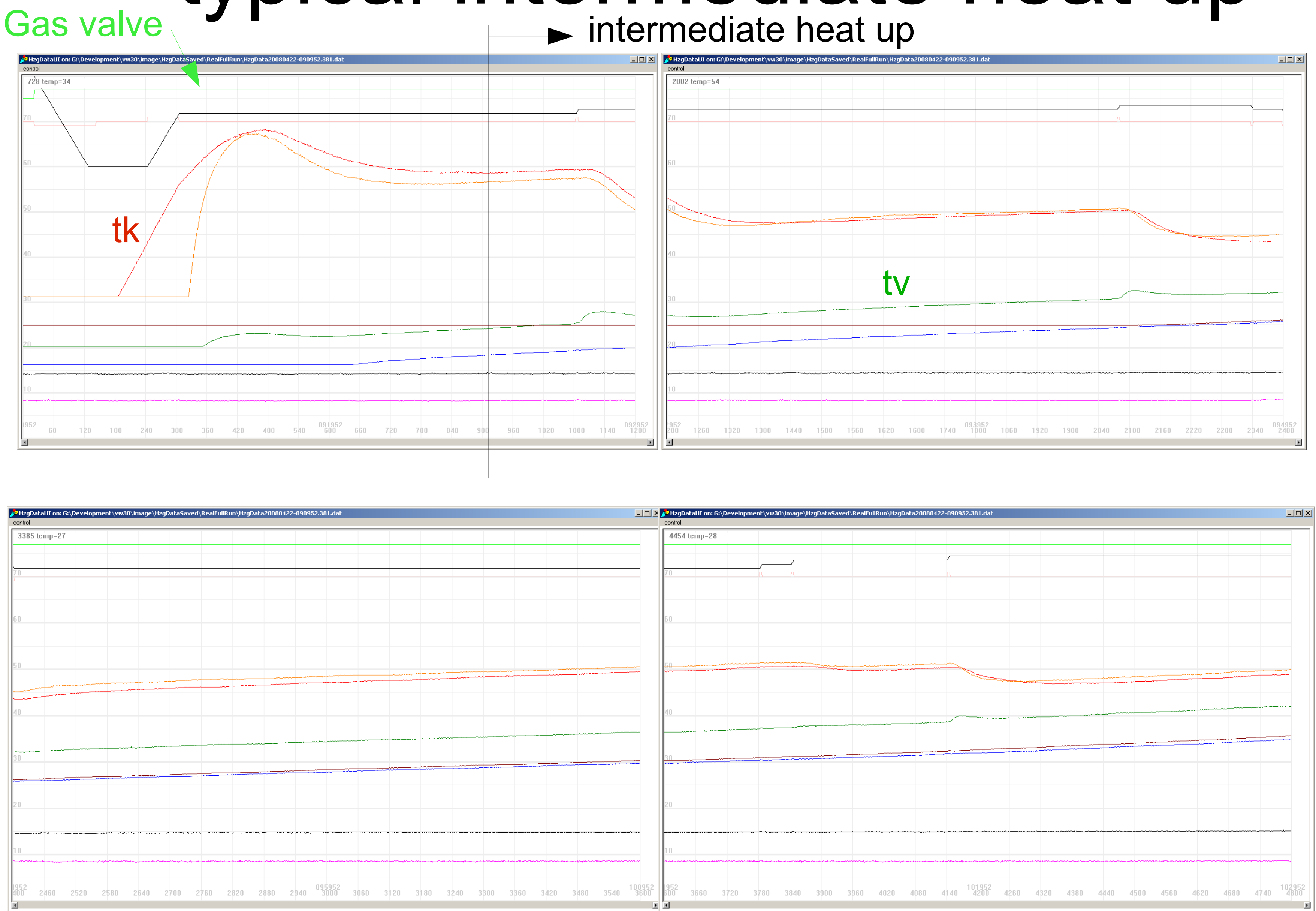
typical cold start heat up



Phase2: Intermediate heat up

- characterized by Emin > 0 (tv < tvcalc)
- Gas valve always open
- heat transfer controled by mixer alone
- mixer is very inert: 106 seconds from 0 to 90 degrees
- mixer moves sparsely by monitoring tk and using time constants. Small changes each time
  - gives very good behavior of heating up

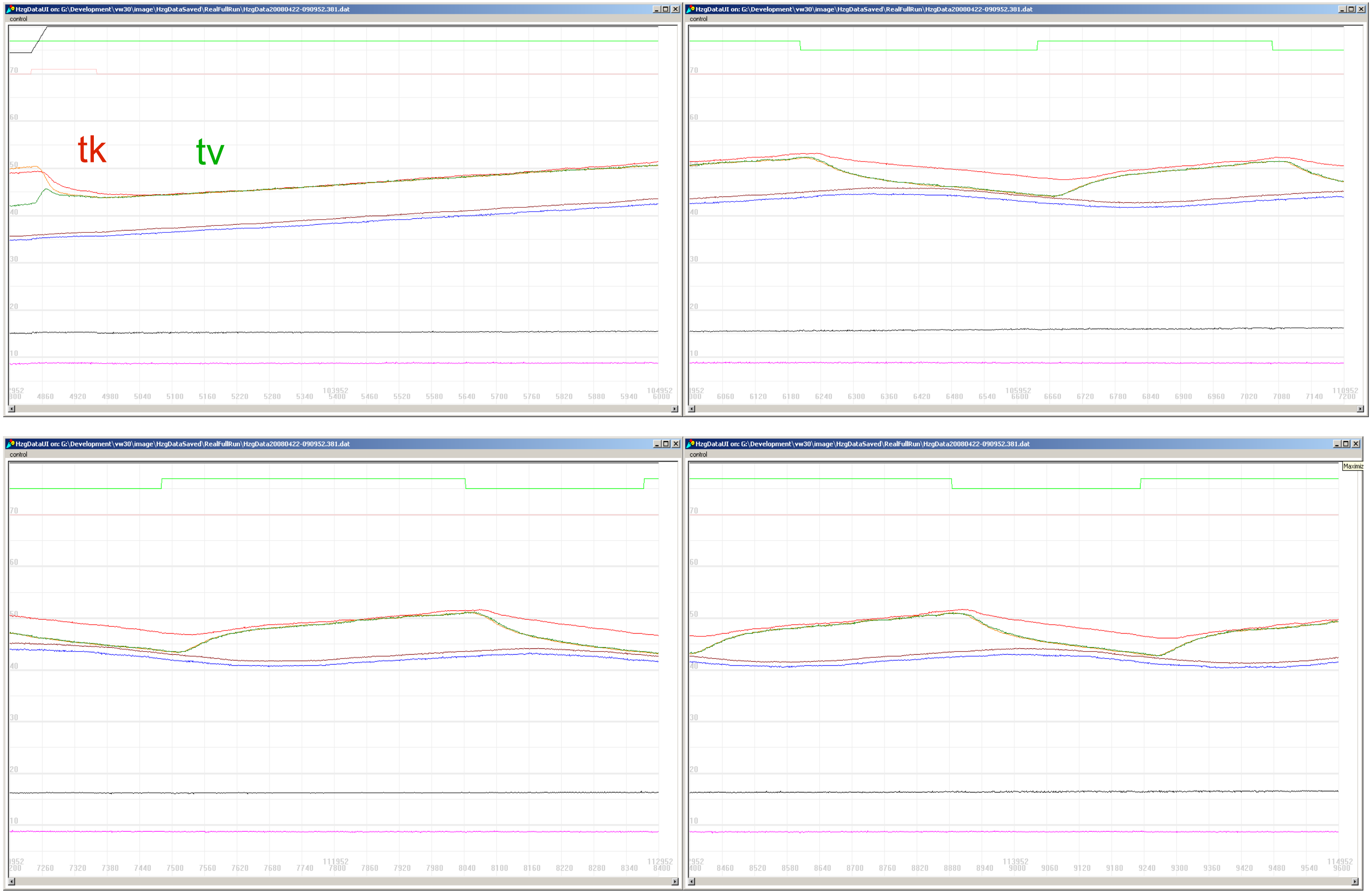
typical intermediate heat up



Phase3: Normal running

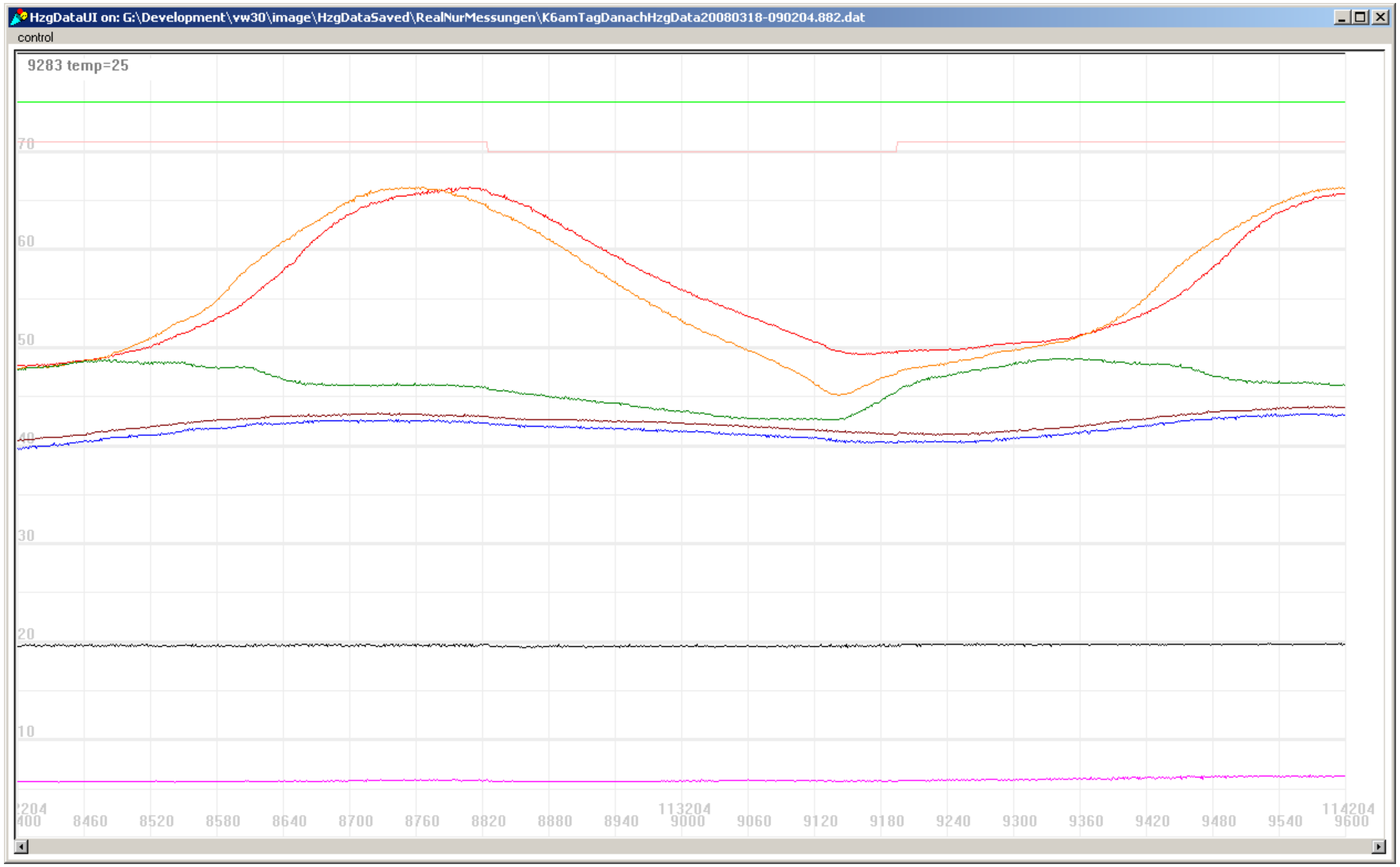
- defined by Emin <=0 (tv >= tvcalc)
- Normal running has two modes:
  - tvcalc < tkmin (Lower mode)
  - tvcalc >= tkmin (Upper mode)
- Upper Mode:
  - since tvcalc >= tkmin, the mixer can be left fully open (90 degrees)
  - no mixer control necessary
  - control simply by gas valve

typical upper mode



note: tk near tv ==> mixing entropy small

compare with CU1



high mixing entropy!
unnecessary mixer motion

Lower Mode

- defined by
  - Emin <=0 (tv >= tvcalc)
  - tvcalc < tkmin
- Problem: when gas valve is off, we have to close the mixer so far, that tkmin is maintained
  - for each cycle we must open and close the mixer
  - more complexity in control
  - try to narrow the range of mixer angles to reduce motion
  - mixing entropy not as small as in Upper Mode

typical lower mode

tk is rising because steel block contains energy
that is heating up the boiler water because of the low mixing angle
that effect helps maintaining tk > tkmin

Simulation

Simulation and real runs
influence one another
for refinement

Simulation

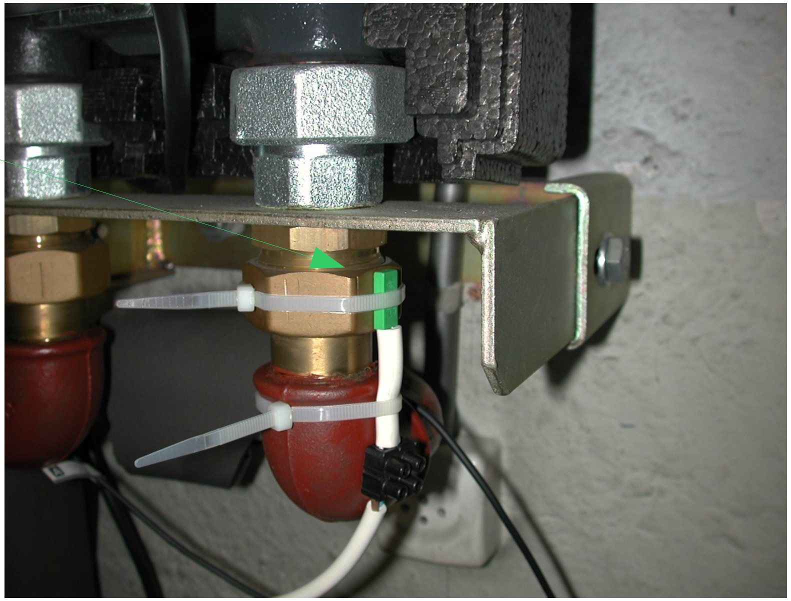
- Implementation of important physical facts
  - One can study the control software without risk
  - Trade Off - Simulation implementation versus real runs
  - but not every problem is efficiently solved by simulation
  - understanding of the physical effects important for good simulation
- Smalltalk helps a lot, to change behaviour during real runs.
  - Refinement of simulation according to results
- Demonstration...

Very Important:

Safety measures

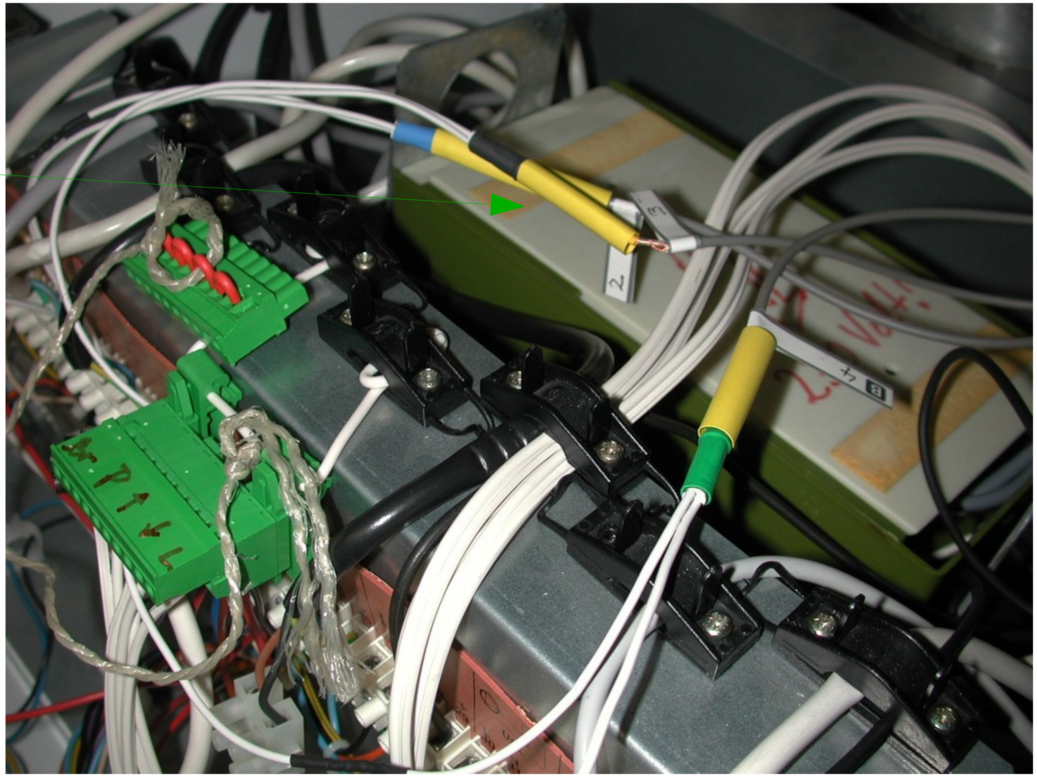
fundamental safety measures

- 1. Avoid steam!
  - guaranteed by a software independent bimetal switch, which turns off the gas valve when tkm >= 80C
  - in addition guaranteed by safety measures in the boiler primary controls (safety temperature limitor, but switches only at 110C)



auxiliary safety measures

- 2. all 230V switches are monitored by self-made optocouplers (including gas valve fault, bimetal switch)
  - so, software can detect problems and react appropriately

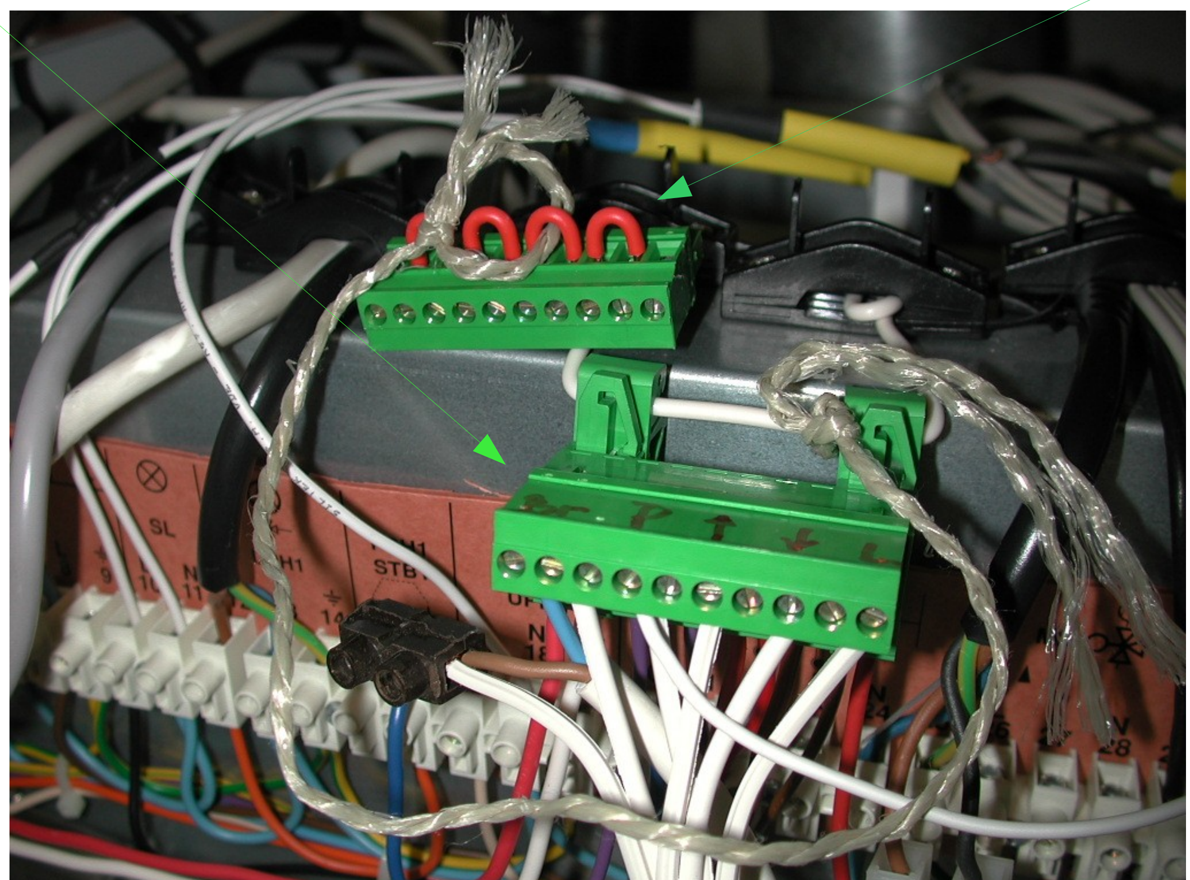


PC and electronics: powerfail safe

- 3. Power fail for MiniITX avoided by Pb-battery supply
  - automatic switching to battery power, when mains goes down
    - critical to avoid hangup of the computer (seeEURO 08)!
  - battery maintenance automatized in software
    - software controled battery switching for test
    - once every 6 month, battery must be decharged and recharged to maintain high lifetime
  - currently under construction

CU2 failure: use CU1

- When CU2 fails, we can simply switch to CU1 by exchanging a 10pole plug with a dummy plug:



Future

- Refinement of control
  - further reduction of tk in heating up
  - better control in lower mode
  - standardisation for parametrisation of the whole heating model
- Reduction of power consumption of the local board (MiniITX uses > 25 Watt input)
- Implement other central heating controls
  - combination with solar heating

Summary

- CU2 much better than CU1
- Smalltalk: wonderfull environment
  - change control behaviour during real run!
  - quick development: this is a constant truth over all my projects in the last 16 years
- Simulation helps to understand problems
- Combination of hardware decisions, electronics and Smalltalk is a lot of fun
- Questions?