Mercedes-Benz model 124 air conditioner (SA code 580) data stream

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July 6, 2024

Contents

1 Disclaimer

The information in this document is provided as is with no warranty of any kind. The information provided is based on reverse engineering efforts which means that its accuracy cannot be guaranteed.

2 What?

This document describes the format of the raw "actual value" data stream provided by some Mercedes-Benz model 124 air conditioning control modules.

So far it is to be figured out if only certain modules from certain manufacturers supply this stream, but it is known that not all of them do. It may have been a diagnostic data experiment with the early digital control units or just for manufacturing stage function check.

The terminology used here may differ from the manufacturer's terminology.

See `https://github.com/the1stArchyx/mb124-ac-decoder` for the latest version of this document.

3 Packet format

A whole packet is made of individual 41 bytes. When capturing data all the way from switch-on, the control module will output 32 bytes of garbage before a consistent data packet is transmitted. The FTDI serial cable used during research may catch one or two bytes of 00 before actual data.

3.1 0x00, 0x02 – temperature setting dial, left and right INPUT

These are signed bytes in range between -56 (0xc8, 14 °C) and +24 (0x18, 30 °C). The actual temperature value in °C can be calculated with the following formula:

```
actual = (raw + 126) / 5
```

The actual value in °F can be calculated with

```
actual_F = (raw + 166) / 2
```

These values indicate the user-requested temperatures from the dial positions on the control unit's operating panel. Due to mechanical reasons the temperature on the dial most likely will not exactly match the internal control unit's value. Otherwise the temperature calculation formula is currently expected to be accurate.

The table below shows also Fahrenheit temperature equivalents on possible US version of the control unit. Be aware that due to the analog approximate nature of this design the values indicated aren't exact when converting between temperature units.

value	°C	°F	printed on dial
-56	14	55	no
-36	18	65	yes
-16	22	75	yes
4	26	85	yes
+24	30	95	no

3.2 0x01, 0x03 – temperature adjustment target, left and right INTERNAL

These are signed bytes that indicate the temperatures the control module is attempting to adjust to. It is biased by multiple factors, like both user-requested temperatures and the outside air temperature. For actual value, see 0x00 above.

3.3 0x04 – timer, self-calibration INTERNAL

Right after switching on ignition this counter counts from 120 (0x78) down to 0 once in about 10 minutes, ie. in 5 second steps. The counter appears to be used for timing some sort of self-calibration. During the calibration time the temperature control may seem erratic.

1. At 120 (10 min. left) — ignition was switched on, counter starts.
2. At 114 (30 s. after, 9 min. 30 s. left) — First self-calibration.
3. At 96 (2 min. after, 8 min. left) — Automatic air recirculation for intense cooling is enabled.
4. At 60 (5 min. after, 5 min. left) — Second self-calibration.
5. At 0 (10 min. after, timer ends) — Third self-calibration.

3.4 0x05, 0x06 – mixing chamber temperature, left and right INPUT

(Note! The actual temperature value here might not be accurate as it's not directly comparable to another temperature value.)

These unsigned bytes range between 0 (10 °C) and 243 (0xf3, 70.75 °C). The actual value in °C can be calculated with the following formula:

```
actual = (raw + 48) / 4
```

The mixing chamber temperature affects the feedback loop for the water valve control.

In some terminology this may be inaccurately called heater core temperature.

3.5 0x07 – interior air temperature INPUT

This signed byte ranges between -128 (0x80, -0.4 °C) and +126 (0x7e, 50.4 °C). The actual value in °C can be obtained with the following formula:

```
actual = (raw + 126) / 5
```

The math formula of interior temperature follows the same formula as the temperature setting dials. This is currently expected to be accurate.

3.6 0x08 – exterior air temperature INPUT

This signed byte ranges between -64 (0xc0, -32 °C) and 126 (0x7e, 63 °C). The formula for the actual value in °C is as follows:

```
actual = raw / 2
```

This formula appears to be accurate.

3.7 0x09, 0x0a – temperature control, left and right INTERNAL

These signed bytes are the differences of dampened interior temperature (see 0x19) and the temperature adjustment targets of the respective sides. The values range between -128 (0x80, -25.6 °C) and +127 (0x7f, +25.4 °C). The actual value in °C can be calculated with the following formula:

```
actual = raw / 5
```

Negative values bias towards heating and positive values towards cooling. The effective range for heating control (see 0x0c) is from -50 (0xce, -10.0 °C) to +23 (0x17, +4.6 °C).

3.8 TODO 0x0b – control bias, exterior air temperature INTERNAL

This signed byte reacts to change of exterior temperature and temperature dial values. The exact math to it is not fully known, yet. What is currently known is that...

1. a change of +1 (0.5 °C) exterior temperature affects the bias by +1. In many cases it has been observed that exterior temperature value 50 (25.0 °C) equals bias value 0.
2. setting the temperature of one side higher than the other causes a negative weighting on the bias value.
3. a change of +2 of the bias affects the adjustment targets by -1 (-0.2 °C). (By observation, the change of the least significant bit of the bias is irrelevant.)

Based on logged data so far the range appears to be from -45 to +34.

As with most other temperature control bias values, negative values bias towards heating and positive values towards cooling.

3.9 0x0c, 0x0d – heater drive, left and right INTERNAL

These unsigned bytes range between 0 and 255 (0xff). They are used to drive the heating control. 0 calls for no heating and 255 for maximum heating. When the target temperature is reached, this value will balance around 80 (0x50).

Change of 1 unit (0.2 °C) of temperature differential control value affects this value directly about 3-4 units (0.75-1.00 °C).

3.10 0x0e, 0x0f – heater feedback reference, left and right INTERNAL

These values slowly follow the values of 0x0c and 0x0d respectively. These values provide the temperature references for the valve control feedback loop. The actual value in °C can be calculated with the following formula:

```
actual = raw / 4
```

3.11 0x10, 0x11 – heating control, left and right INTERNAL

These values follow the values of 0x0c and 0x0d with a dampening. It's not yet clear how these values affect the heating control.

3.12 0x12, 0x13 – water valve feedback bias, left and right INTERNAL

These signed bytes range between -128 (0x80) and +127 (0x7f). Negative values bias towards opening the valve (heating) and positive values bias towards closing the valve (cooling).

It's biased by the heater feedback reference (0x0e, 0x0f) and the mixing chamber temprature (0x05, 0x06).

3.13 0x14, 0x15 – water valve solenoid duty cycle, left and right OUTPUT

These unsigned bytes range between 0 (0%, valve closed) and 255 (0xff, 100%, valve open).

3.14 0x16 – engine coolant temperature INPUT

This signed byte ranges between 5 and 130 (0x82) within its functional range. Within the functional range the raw value is the actual value in °C as is.

Engine coolant temperature is used for prevention of overheating of the engine.

3.15 0x17 – evaporator temperature INPUT

This unsigned byte ranges between 0 (0 °C) and 126 (0x7e, 63 °C). This temperature value controls the air conditioner compressor request line. The actual value in °C is calculated with the following formula:

```
actual = raw / 2
```

The A/C compressor request turns on when this value is 14 (7 °C) or greater, and off when it falls to 10 (5 °C) or below. The compressor request line is routed through the refrigerant pressure switch to the compressor safety cut-out module.

The math formula matches exterior temperature formula and is currently considered accurate.

3.16 0x18 – engine overheat protection status INTERNAL

This byte is bitmapped. Bits 6 and 7 are status indicators and bits 0 to 5 are a counter.

bit	description
7	overheat protection stage 2 active (127-122)
6	overheat protection stage 1 active (122-117)
0-5	counter (<20 = compressor enabled)

During stage 1 the counter counts from 0 to 39 (0x27). Engine overheat protection stage 1 is activated when engine coolant temperature reaches 122. Overheat protection deactivates at engine coolant temperature 117. In stage 1 A/C compressor duty cycle is reduced to 50%, 20 seconds on and 20 seconds off.

During stage 2 the counter value is fixed to 62 (0x3e). Engine overheat protection stage 2 activates at engine coolant temperature 127. The protection mode returns to stage 1 at engine coolant temperature 122. In stage 2 actuation of A/C compressor is inhibited.

3.17 0x19 – interior temperature, dampened INTERNAL

See 0x07. This value follows the interior temperature sensor in a dampened manner. It is used for temperature control to avoid unnecessary abrupt temperature control changes.

3.18 0x1a – user input and intense cooling control BITMASK

3.18.1 0x1a bit 7 – unused

Appears to be static 0.

3.18.2 0x1a bit 6 – intense cooling mode INTERNAL

This bit is set when the control unit operates in intense cooling mode. The switching thresholds from control values 0x09 and 0x0a have been observed to be as follows:

- On when the control values are 17-18 (3.4-3.6 °C) or greater.
- Off when the control values are 10-11 (2.0-2.2 °C) or less.
- During self-calibration intense cooling has been observed to turn off at 2-3 (0.4-0.6 °C). This may be intentional to rapidly cool a car that has been parked in the sun.

The currently available data captures cannot offer less fuzzy thresholds.

1. **TODO** Simulate interior temperature to obtain precise thresholds

3.18.3 0x1a bit 5 – user intervention, temperature adjustment, right INTERNAL

This bit is set when the user is making a temperature adjustment. If the adjustment is larger than three units (0.6 °C), the control unit calculates a timer value for the requested temperature.

3.18.4 0x1a bit 4 - user intervention, mode change INTERNAL

This bit is briefly set when the user has made a mode change. Since the bit is typically set for a very short time, it is most often never seen to change state.

3.18.5 0x1a bit 3 – user intervention, temperature adjustment, left INTERNAL

See 0x1a bit 5.

3.18.6 0x1a bit 2 – button status: reheat INPUT

This bit indicates the status of reheat mode. When this bit is set, the red LED on the button is lit.

When this mode is enabled, the air conditioning compressor is requested whether cooling is needed or not. The primary use for this is to dry the interior air in case the moisture in the air tends to concentrate on the windscreen or other windows.

3.18.7 0x1a bit 1 – button status: economy mode (EC) INPUT

This bit indicates the status of economy mode. When this bit is set, the red LED on the button is lit.

When this mode is enabled, the air conditioning compressor request is inhibited and middle vents are set to bypass heating. Air recirculation is limited to five minutes at a time.

3.18.8 0x1a bit 0 – button status: recirculation INPUT

This bit indicates the status of manually requested interior air recirculation. When this bit is set, the red LED on the button is lit.

The requested recirculation is always 100% and is limited to 20 minutes with A/C enabled or 5 minutes in economy mode.

3.19 0x1b – circulation timer INTERNAL

This (expected to be) unsigned value contains the amount of minutes until air recirculation is automatically switched off to fresh air.

The countdown starts from 20 (0x14) when air conditioning compressor is enabled and 5 when air conditioning is inhibited.

3.20 0x1c – actuator control BITMASK

3.20.1 0x1c bit 7 – water circulation pump OUTPUT

This bit is set when the water circulation pump is running.

In cooling mode, engine coolant over 80 °C, it appears that the circulation pump switches at following thresholds.

- Off when the mid-speed heater drive goes down to 20-22.
- On when either mid-speed heater drive reaches up to 40. (Note: the experimentally calculated reference temperature at slow heater drive value 40 is 10 °C, which is the lowest possible temperature to be measured by the mixing chamber temperature circuit.)

1. **TODO** Simulate various values of engine coolant temperature

   The engine coolant temperature may affect when the circulation pump is switched on and off. Therefore the engine coolant should be simulated at certain fixed values to obtain accurate switching thresholds.

   The heater drive values are easiest to accurately control by simulating the interior temperature.

3.20.2 0x1c bit 6 – unused

Appears to be static 0.

3.20.3 0x1c bit 5 – unused

Appears to be static 0.

3.20.4 0x1c bit 4 – A/C compressor request OUTPUT

This bit is set when the A/C compressor request line is driven. The heater blower must be on for activation and economy mode (EC) must be off.

3.20.5 0x1c bit 3 – air recirculation, 80% OUTPUT

This bit is set when the vacuum valve for 80% air recirculation is driven.

3.20.6 0x1c bit 2 – air recirculation, 100% OUTPUT

This bit is set when the vacuum valve for 100% air recirculation is driven. Bit 3 is always set together with this one.

3.20.7 0x1c bit 1 – radiator blower, stage II OUTPUT

This bit is set when the relay for radiator blower stage II is driven. Radiator blower is switched on at engine coolant temperature sensor value 107 and off at 100.

Radiator blower stage I is controlled by a pressure switch in the high pressure side of the refrigerant circuit.

3.20.8 0x1c bit 0 – temp-control for middle dash vents OUTPUT

This bit is set when the vacuum valve for middle dash vents temperature control flaps is driven.

```
0 = temperature control bypassed
1 = middle vents temperature-controlled
```

When the middle vents are temperature-controlled, they can also be closed to "leak air" state. However, this function is not controlled by this control unit.

3.21 0x1d – temperature control BITMASK

3.21.1 0x1d bit 7 – recirculation enabled for intense cooling INTERNAL

This has been observerd to be set two minutes after switching on ignition.

3.21.2 0x1d bit 6 – self-calibration INTERNAL

When set, the control unit is performing a self calibration. Water circulation pump is switched off during this time.

3.21.3 TODO 0x1d bit 5 – temperature control mode INTERNAL

If left and right control values (0x09 and 0x0a) are roughly the same, the temperature control switches to cooling when the values go above +3 (+0.6 °C) and heating when the values go below -7 (0xf9, -1.4 °C).

It has been observed that with a temperature setting difference of 1.0 °C both control values must go down to -8 before mode is switched to heating.

```
0 = heating
1 = cooling
```

In the heating mode automatic A/C compressor request is inhibited.

3.21.4 TODO 0x1d bit 4 – exterior frosting INTERNAL

This bit is set to 1 when the exterior temperature rises up to 1.0 °C (+2 in raw value). The bit is cleared to 0 when the exterior temperature falls down to -0.5 °C (-1 in raw value).

The names of bit 4 and bit 5 need to be rethought as they are likely direct control bits for automatic A/C function.

3.21.5 0x1d bit 3 - defrost, right INPUT

This bit is set when the temperature control dial is turned all the way to its hot end stop.

3.21.6 0x1d bit 2 - max cooling, right INPUT

This bit is set when the temperature control dial is turned all the way to its cold end stop.

3.21.7 0x1d bit 1 - defrost, left INPUT

See 0x1d bit 3

3.21.8 0x1d bit 0 - max cooling, left INPUT

See 0x1d bit 2

3.22 0x1e, 0x20 – temperature dial value, dampened, left and right INTERNAL

These values follow the values of the temperature setting dials. The stepping speed to reach the value is defined by 0x1f and 0x21 in seconds in a manner that the target value is reached in about 5 minutes.

For minor changes up to 0.6 °C, or 3 raw units, the timer is not used.

For range, see 0x00.

3.23 0x1f, 0x21 – time, temperature dial damping, left and right INTERNAL

When active, these unsigned values range between 4 and 75 (0x4b). They're otherwise 0.

By observation this value is a time in seconds to advance the dampened temperature dial value towards the current user requested value.

The temperature change made must be over 0.6 °C, or 3 in raw value to trigger the timer. By minimum change of 0.8 °C the time value is set to 75 seconds, which results in the target being reached in 4 * 75 = 300 seconds, or five minutes.

3.24 0x22 – static 0x00 SYNC:INTERNAL

This and the following six bytes have been used for data stream synchronisation. The actual meaning of these bytes is mostly unknown but they appear to be static data and therefore useful for easy sync.

3.25 0x23 – static 0x03 SYNC:INTERNAL

3.26 0x24 – static 0x04 SYNC:INTERNAL

3.27 0x25 – static 0x01 SYNC:INTERNAL

3.28 0x26 – static 0x23 SYNC:INTERNAL

Most likely a version number, possibly hardware revision identifier. The number is 35 in base 10.

3.29 0x27 – static 0x02 SYNC:INTERNAL

3.30 0x28 – static 0x3b or 0x3c SYNC:INTERNAL

Most likely a version number, possibly software. 59 (0x3b) has been seen on two cases and 60 (0x3c) was seen on two facelift versions.

4 Serial data electricals

The serial data supplied from socket 7 of the diagnostics connector block is basically 8-N-1 at 4,800 bps with about 30 ms gaps between frames. The only major difference to RS-232 or TTL are the transmission line voltage levels used. See the table below:

	RS-232	TTL	MB AC
mark	-15..-3 V	+5.0 V	+8.0 V
space	+3..+15 V	+0.0 V	+0.8 V

For research purposes the output from the vehicle was converted to TTL by means of a simple circuit of diodes and resistors to use an FTDI TTL-232R-5V "USB to TTL Serial Cable". This is what the initial datalogging and decoder programs written in Python were designed around.

5 Control unit connector pinout

The following pinout table was created by reverse engineering the research platform. This allows further understanding of the limitations of what the control unit can do.

pin	wire colour	IO	description
1	brown green	/O	heating water recirculation pump
2	white green	/O	heating water valve, left (active low to shut)
3	white blue	/O	heating water valve, right (active low to shut)
4	blue green white	/O	A/C compressor request
5	green blue	/O	solenoid valve, air recirculation, 100%
6	green violet	/O	solenoid valve, air recirculation, 80%
7	brown grey	/O	radiator blower stage II
8			n/c (unused input, floats around 5 V)
9	grey yellow	/I	interior air temperature sensor
10	grey black	/I	exterior air temperature sensor
11	grey green	/I	mixing chamber air temperature sensor, left
12	grey red	/I	mixing chamber air temperature sensor, right
13	grey white	/I	post-evaporator air temperature sensor
14	blue grey	/I	engine coolant (heating water) temperature sensor
15	yellow white	IO	diagnostic connector
16	black green white	I	heater blower (>11 V when blower is switched on)
17	black pink	I	15, power supply
18	grey blue	I	58d, instrument panel lights
19	green black	/O	solenoid valve, center vents temperature control
20	brown	c	31, ground
21	brown yellow	c	temperature sensor ground

```
c  = common, ie. a ground reference
/I = input, resistive sensor or switch to ground
/O = output, active low ie. switched to ground when active
```

5.1 Sensor electricals

These tables were obtained by connecting various resistances to temperature sensor inputs. This also allowed calculating values for the pull-up resistors.

These tables serve as an aid to match potentiometer values when building a testing rig for these control units.

5.1.1 Interior air, mixing chamber, and evaporator temperatures – pins 9, 11, 12, 13

mix : Mixing chamber temperature (0x05 and 0x06) – resistance range between 820 Ω and 20 kΩ.

int. : Interior air temperature (0x07) – resistance range between 2.2 kΩ and 46 kΩ.

evap. : Evaporator temperature (0x17) – resistance range between 1.8 kΩ and 34 kΩ.

resistance	voltage	int.	temp	mix	temp	evap.	temp
open	5.03						
45500	4.11	-128	-0.4				
44600	4.11	-127	-0.2				
33560	3.87	-109	3.4			0	0.0
32110	3.84	-106	4.0			1	0.5
21880	3.46	-78	9.6			16	8.0
19610	3.34	-69	11.4	0	12.00	21	10.5
19360	3.32	-68	11.6	1	12.25	21	10.5
14900	3.01	-46	16.0	18	16.50	32	16.0
10050	2.53	-12	22.8	44	23.00	50	25.0
4680	1.61	58	36.8	99	36.75	87	43.5
3244	1.24	94	44.0	128	44.00	105	52.5
2406	0.98	125	50.2	152	50.00	119	59.5
2276	0.94	126	50.4	156	51.00	121	60.5
2153	0.89			160	52.00	123	61.5
1776	0.76			176	56.00	126	63.0
1504	0.66			191	59.75		
998	0.46			226	68.50		
875	0.41			240	72.00		
817	0.38			243	72.75		
shorted	0.00						

Pull-up resistor value is 10 kΩ.

5.1.2 Exterior air temperature – pin 10

Data index 0x08. Sensor resistance ranges between 100 Ω and >70 kΩ. Measurements of resistances over 70 kΩ are flaky at best, and therefore irrelevant. Value of -63 is never seen.

resistance	voltage	value	temp
open	5.04		
87300	4.88	-64	-32.0
75200	4.86	-62	-31.0
69200	4.84	-62	-31.0
66900	4.84	-61	-30.5
47000	4.76	-55	-27.5
32760	4.65	-46	-23.0
21880	4.48	-33	-16.5
14900	4.26	-17	-8.5
10050	3.96	-4	-2.0
4680	3.18	27	13.5
3244	2.73	43	21.5
2703	2.50	51	25.5
2153	2.22	62	31.0
1776	1.98	70	35.0
1504	1.79	78	39.0
998	1.35	92	46.0
817	1.16	97	48.5
676	1.00	102	51.0
117	0.21	125	62.5
95	0.17	126	63.0
shorted	0.00		

Pull-up resistor value is 2.7 kΩ.

5.1.3 Engine coolant temperature – pin 14

Data index 0x16. Resistance range between 158 Ω and 13 kΩ. Value of 6 is never seen.

resistance	voltage	value
open	5.04	
14900	4.83	
12570	4.80	5
11480	4.78	7
10050	4.74	9
4680	4.44	26
3244	4.21	34
2153	3.89	45
1776	3.71	50
1504	3.55	54
998	3.08	66
817	2.84	72
676	2.60	78
457	2.11	90
182	1.12	124
162	1.02	129
158	1.00	130
shorted	0.00	

Pull-up resistor value is likely 560 Ω.

6 Tested vehicles

The following vehicles were equipped with basic "Tempmatic" air conditioning, SA code 580.

- 124.092 – 320 TE (the original research platform, control module part number: 124 830 38 85, Bosch 9 140 010 183)
- 124.191 – E 300 DIESEL (facelift; this was the exception that had 0x3c as the last sync byte instead of 0x3b)
- 124.193 – 300 TD TURBODIESEL / E 300 TURBODIESEL
  - Car #1 was pre-facelift and the last sync byte was 0x3b.
  - Car #2 was facelift and the last sync byte was 0x3c.

6.1 Known not to work

The following vehicle was equipped with fully automatic air conditioning, SA code 581.

- 124.131 – E 300 DIESEL (US version, SA code 494; facelift) – no data stream)

7 Unfinished analysis notes

This section contains notes of observations that aren't necessarily definitive at this point. Some of it may be correct, but much will be incorrect guesses.

[2024-04-23 Tue] A loose control unit (MB 124 830 38 85 / Bosch 9 140 010 183, facelift version, sw 2/60) was acquired for off-car research purposes.

7.1 Temperature reference

[2024-03-21 Thu] It seems to be that a kind of a "zero" reference temperature is likely 25 °C.

7.2 Supply voltage monitoring

The control unit doesn't have any apparent supply voltage monitoring. This was tested with a lab power supply by feeding power into the output contact of fuse #7. The control unit failed to operate when supply voltage was set down to 5.3 volts, and resumed at 6.0 volts.

Observed on the recently acquired control unit: detection of maximum cooling position failed with supply voltage <7.0 volts.

The voltage was required to stay high enough to start the coolant recirculation pump without affecting control unit operation.

In low voltage operation it was possible for the control unit watchdog to fail to reset the microcontroller.

7.3 0x0b – exterior temperature bias

The value appears to bias temperature adjustment targets from actual dial values ~~as well as water valve feedback control~~.

~~For water valve control the bias temperature seems to be `raw / 5`, but it needs to be verified.~~ We shall forget the water valve here for now as it's much too vague.

[2023-07-23 Sun] The following description is partly correct. The bias value is offset one way or the other by the temperature settings at the dials.

The following observation appears to be correct only if both temperature dials are set at the same value! Whether the temperature control is functioning in heating or cooling mode may also skew the values. Self-calibration can also break logic, as two different data captures seem to show offsetting.

For adjustment targets the no bias spot is at -14/-15 (0xf2/0xf3). To calculate the amount to shift from user-requested temperature to adjustment target, use the following formula (// = integer division):

```
adjustment target bias = -1 * (((ext.temp bias + 1) // 2) + 7)
```

If you want the actual temperature difference value in °C, divide the above raw value by 5.

8 Test rig theory

To create a test rig for these control units, partial automation would most likely be useful. With some consideration the two parameters to set manually would be the exterior temperature and the engine coolant temperature. Other temperature values can be derived from those with op-amp integrators controlled by various actuators.

Since the temperature sensors operate as current sinks to ground, they can be simulated with simple NPN transistor circuits that are driven by op-amps in voltage follower configuration, the voltage to follow being the sensor circuit voltage.

Water valve and A/C compressor actuation circuits should be buffered through PNP transistor circuits. The purpose is to isolate the actuation circuits from affecting op-amp circuits. This will also allow proper loading of the actuation circuits if necessary.

```
    [water valve]   [A/C] -->(i)<-- {ext.}
          |                  |       |
          v                  v       |
{ECT} -->(i)<-------------- evap.    |
          |                          |
          v                          |
         mix --->(i)<---------------/
                  |
                  v
                 int.
```

The mixing chamber temperature (`mix` in the diagram above) should be created with an integrator that approaches either engine coolant temperature (`{ECT}`) or evaporator temperature (`evap.`) depending on water valve actuation.

The evaporator temperature should be created by an integrator that approaches exterior temperature (`{ext.}`) or negative infinity depending on A/C compressor actuation (`[A/C]`).

The interior temperature should be created by an integrator that approaches the average of left and right mixing chamber temperatures. This may be biased by the exterior temperature. A possible consideration would be to slow down the integrator when the difference between mixing chamber temperatures and the exterior temperature are large and speed it up when air recirculation is active.