PARTICLE MEASUREMENT PROGRAMME

PMP-IWG

COOLING METHOD

CLAUSE 2 – COOLING METHOD

COOLING METHOD – DEFINITIONS

M1 vehicle category – Vehicles used for the carriage of passengers, comprising no more that 8 seats in addition to the driver's

Nominal Wheel Load (NWL) for M1 vehicle category – Is calculated taking into account the Mass in Running Order (MRO) of the vehicle on which the tested brake (front or rear) is mounted (kg) and the mass corresponding to additional 0.5 passengers (kg)

Suggestion to keep this proposal for the M1 vehicle category OR fully align the definition of the mass with the GTR 15 and define it as MRO (kg) + 25 (kg) + 0.15*MVL (kg)

3.2.5. '*Mass in running order*' means the mass of the vehicle, with its fuel tank(s) filled to at least 90 per cent of its or their capacity/capacities, including the mass of the driver, fuel and liquids, fitted with the standard equipment in accordance with the manufacturer's specifications and, when they are fitted, the mass of the bodywork, the cabin, the coupling and the spare wheel(s) as well as the tools.

3.2.6. '*Mass of the driver*' means a mass rated at 75 kg located at the driver's seating reference point.

3.2.7. '*Maximum vehicle load*' means the technically permissible maximum laden mass minus the mass in running order, 25 kg and the mass of the optional equipment as defined in paragraph 3.2.8.

3.2.8. '*Mass of the optional equipment*' means maximum mass of the combinations of optional equipment which may be fitted to the vehicle in addition to the standard equipment in accordance with the manufacturer's specifications.

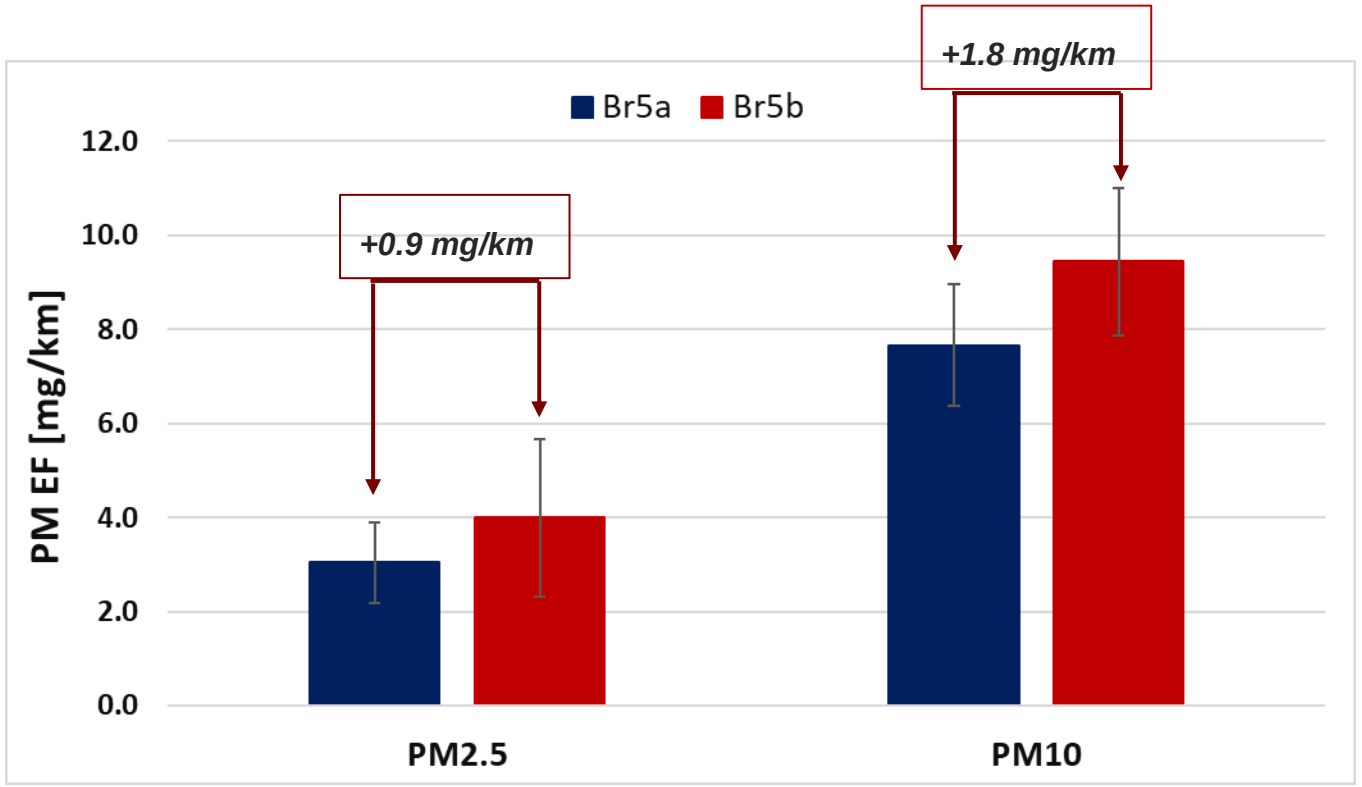
3.2.9. '*Optional equipment*' means all the features not included in the standard equipment which are fitted to a vehicle under the responsibility of the manufacturer, and that can be ordered by the customer.

COOLING METHOD – DEFINITIONS

N1 vehicle category – Vehicles used for the carriage of goods and having a maximum mass not exceeding 3.5t

Nominal Wheel Load (NWL) for N1 vehicle category – Two options were considered at the ILS – Default method as for M1 vehicles and application of 90% of the maximum payload (*Vehicle Test Mass is 2.5t vs. 3.39t*)

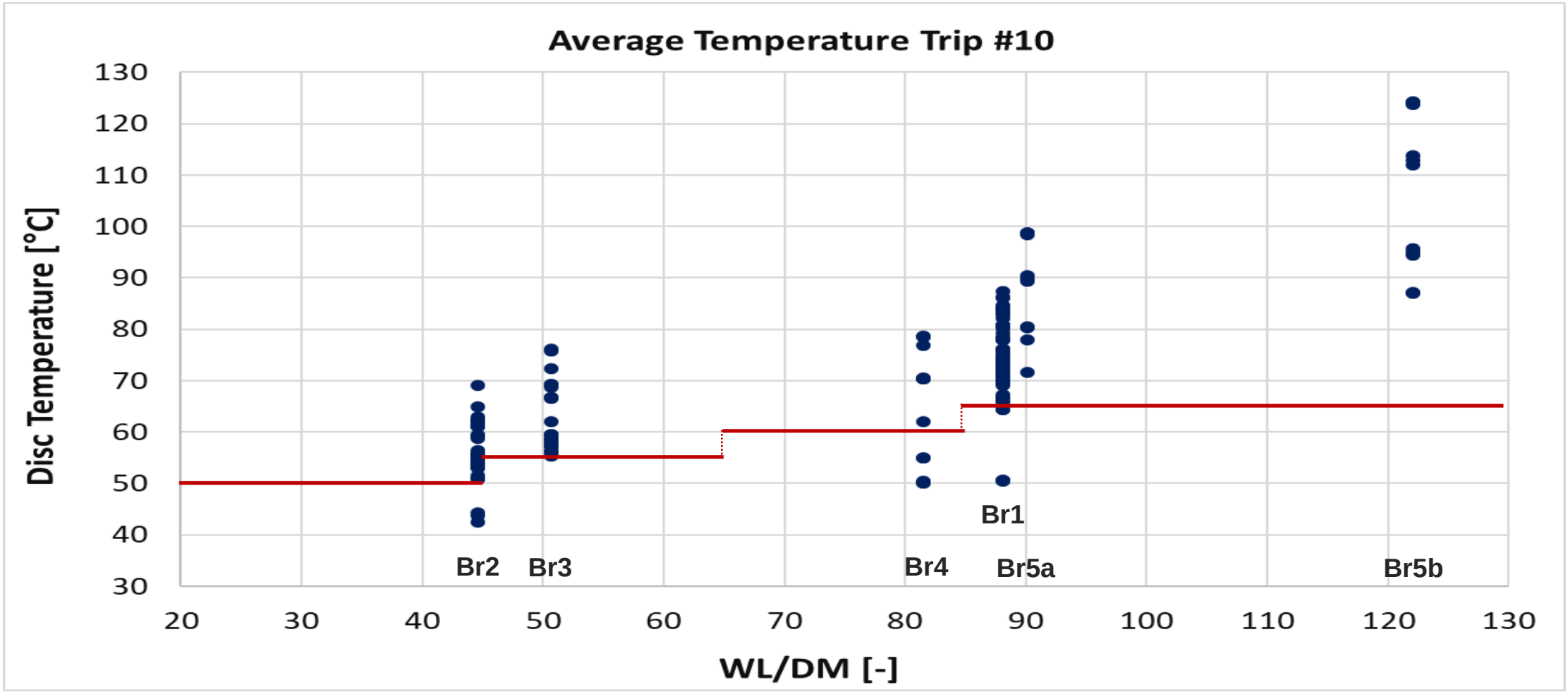
Suggestion to fully align the definition of the testing mass for the N1 vehicle category with the GTR 15 and define it as MRO (kg) + 25 (kg) + 0.28*MVL (kg)



Error bars correspond to the SD of 12 measurements (4 Labs) – Variability of 1SD=17%

COOLING METHOD – AVERAGE TEMPERATURE

Actual cooling adjustment data from ILS not available – ILS data discussed here are for cross-checking purposes and are not 100% comparable to the actual cooling adjustment data



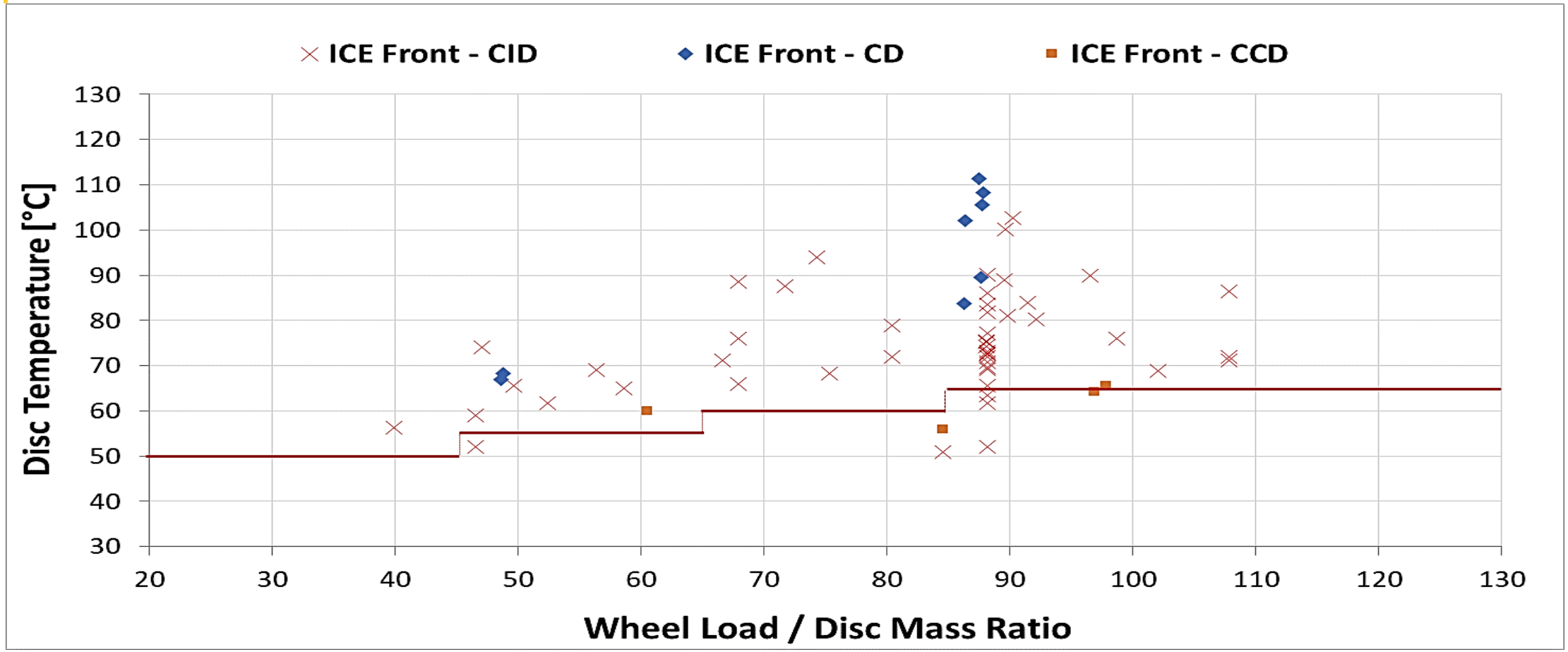
COOLING METHOD – AVERAGE TEMPERATURE

	Br1a	Br1b	Br2	Br3	Br5a
AVERAGE	72.4	76.1	56.2	61.2	87.6
STDEV	8.1	6.1	5.8	5.2	9.7
Variability	11%	8%	10%	8%	11%
MIN VALUE	50.4	64.4	42.5	55.4	71.6
5th Percentile	52.2	65.5	44.1	56.0	74.5
50th Percentile	72.4	75.1	55.3	59.5	89.6
95th Percentile	83.8	86.1	63.4	69.3	98.8
MAX VALUE	84.1	87.4	69.1	69.3	98.9
TARGET	>65	>65	>50	>55	>65

Br1: 93 single data points – 5 "non-compliances" to the minimum target value (5%) – Lab-D (5 non-compliances) – Time-Based files were seriously damaged and Lab does not control the cooling air flow temperature and humidity

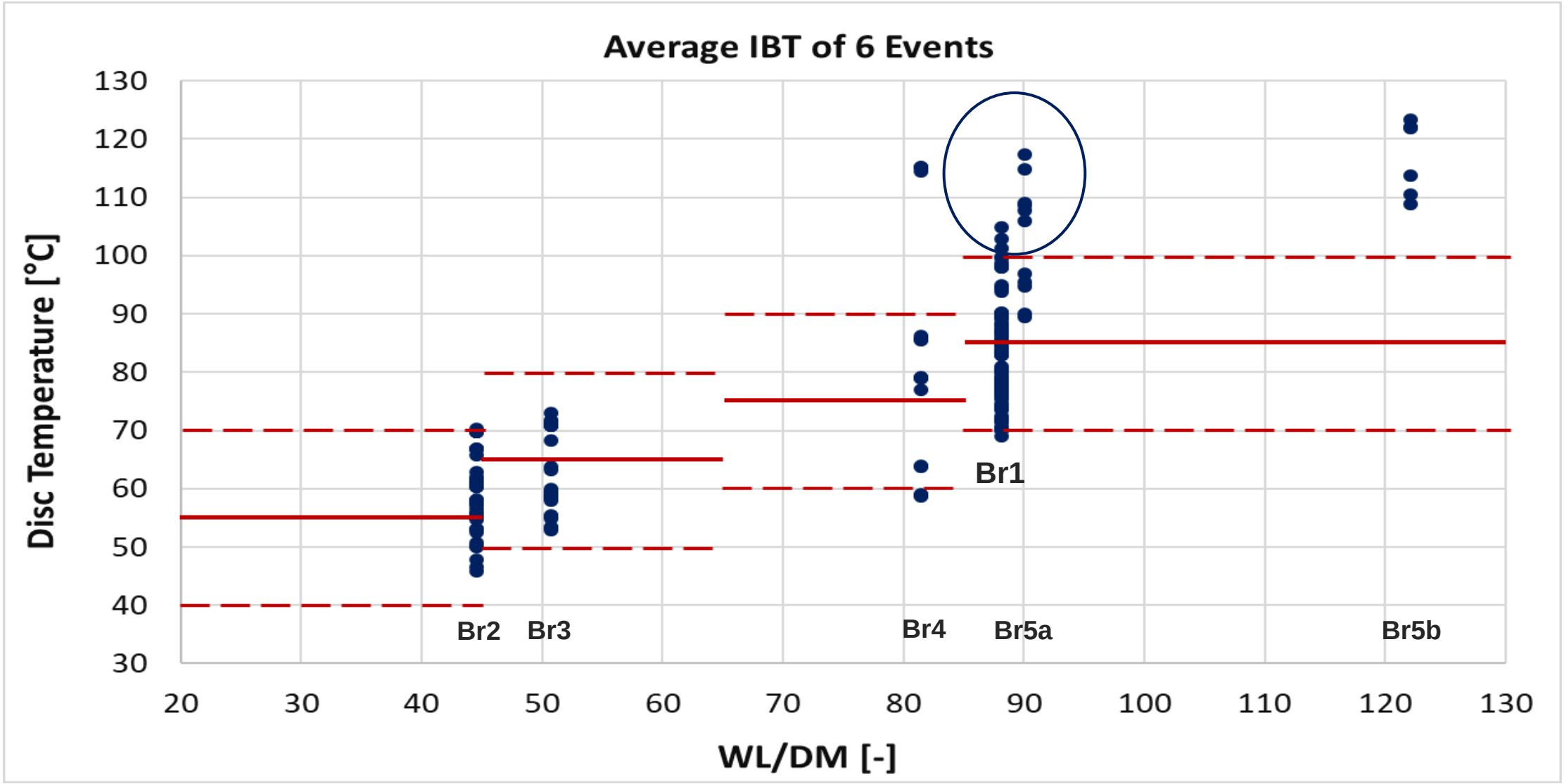
Br2: 40 single data points – 3 "non-compliances" to the minimum target value (7.5%) – Lab-R (3 non-compliances) – Lab-R ran the cycle at constantly 25% lower energy thus resulting in lower temperature regimes

COOLING METHOD – AVERAGE TEMPERATURE



Average Trip #10 temperature has been succesfully applied during the ILS. it ensures that Labs are not running the test much cooler than they should – ***No changes have been applied to the TF2 proposal regarding this criterion***

COOLING METHOD – AVERAGE IBT 5% EVENTS



COOLING METHOD – AVERAGE IBT 5% EVENTS

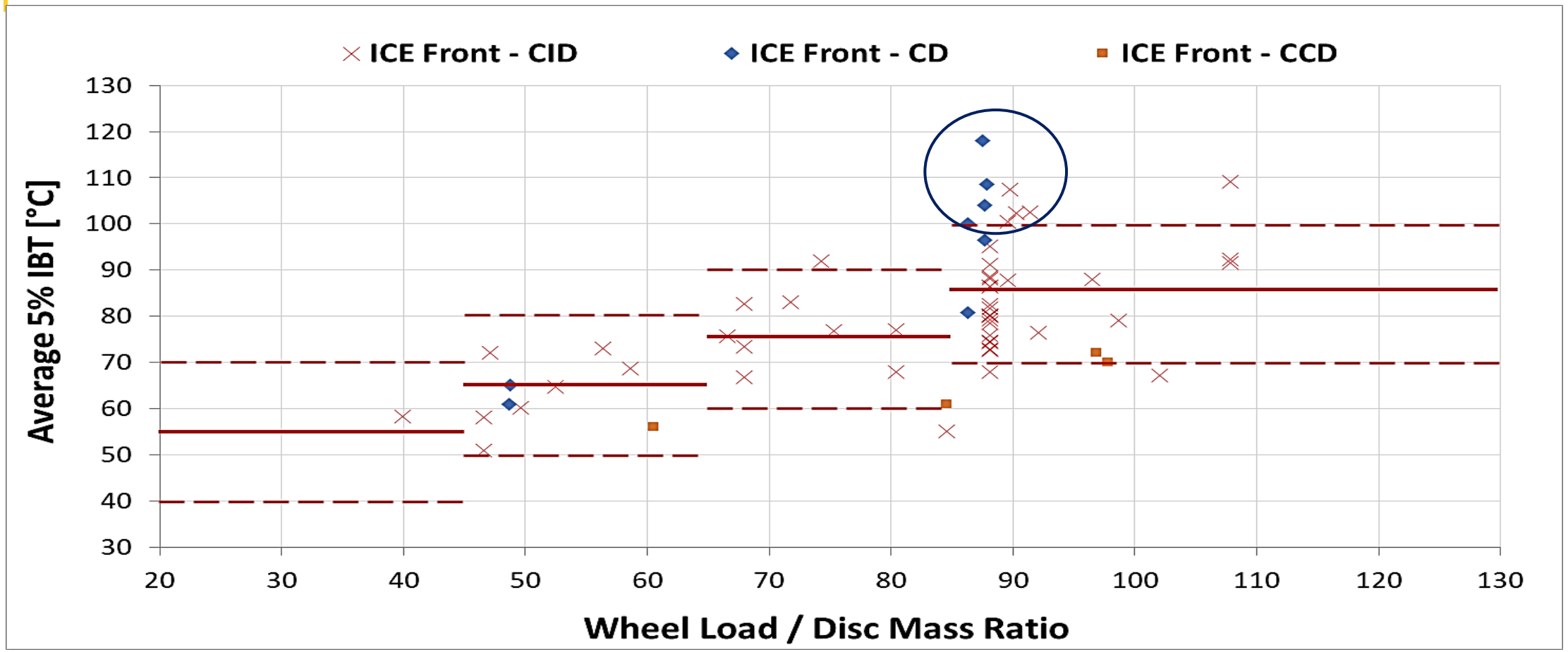
	Br1a	Br1b	Br2	Br3	Br5a
AVERAGE IBT	82.0	84.8	58.7	63.7	102.7
STDEV	8.5	8.9	6.5	7.7	9.8
Variability	10%	10%	11%	12%	10%
MIN VALUE	69.1	70.1	45.9	52.8	89.4
5th Percentile	70.3	71.6	47.8	53.2	89.7
50th Percentile	82.0	83.5	57.9	63.8	106
95th Percentile	98.1	98.8	69.7	71.8	116.1
MAX VALUE	102.8	104.9	70.2	73.0	117.4
TARGET IBT	70-100	70-100	40-70	50-80	70-100

Br1: 108 single data points – 4 "non-compliances" to the target values (4%) – Lab-S (2 non-compliances) and Lab-K (1 non-compliance) are borderline – Could have ran slightly cooler. Lab-R (1 non-compliance) runs the cycle at lower energy thus resulting in lower temperature regimes

Br2: 43 single data points – 1 "non-compliance" to the target values (2%) – Lab-Q (1 non-compliance) runs the cycle at lower energy thus resulting in lower temperature regimes

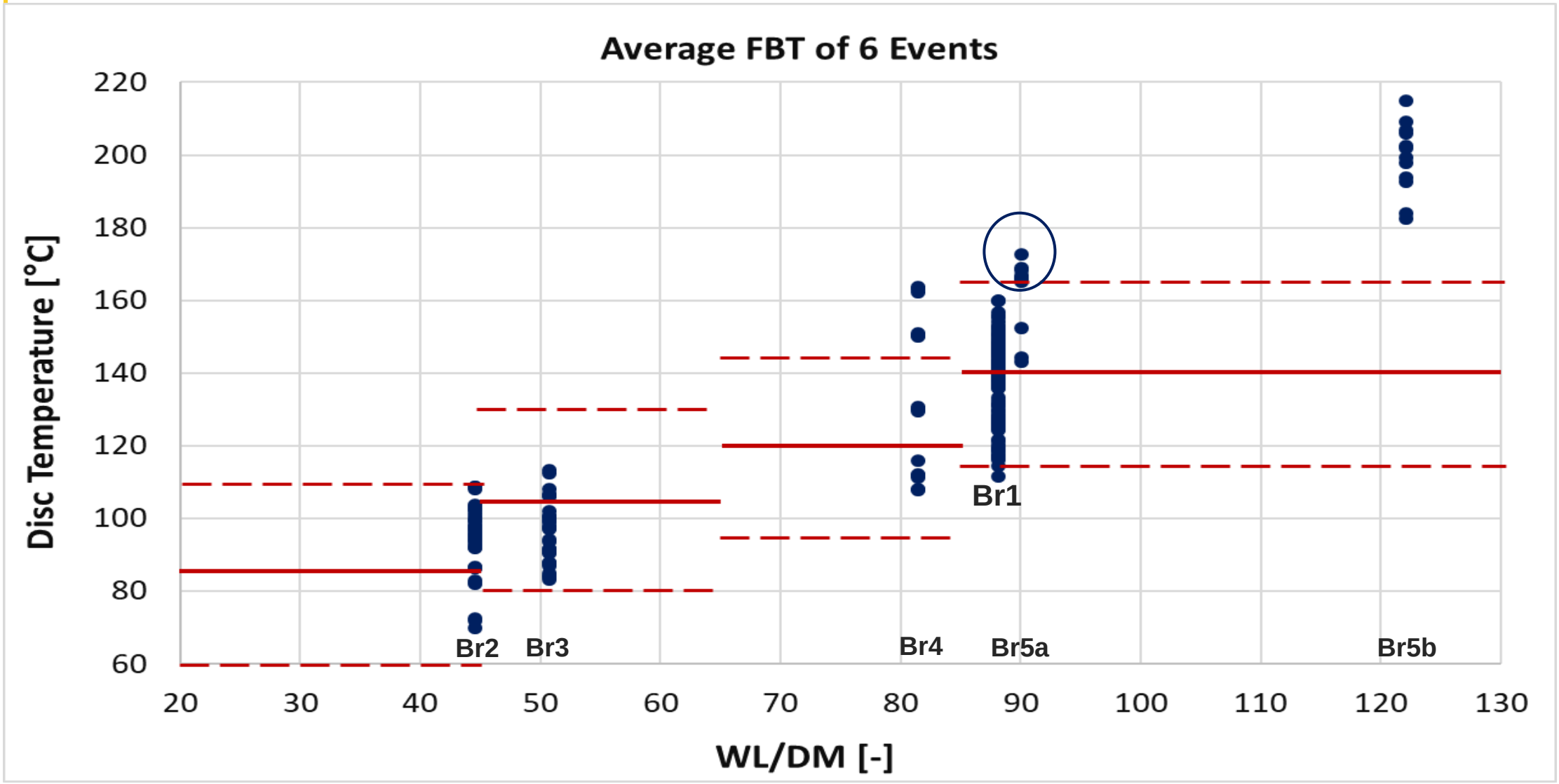
Br5a: 12 single data points – 6 "non-compliances" to the target values (50%) – Labs F (Applied the same flow for all tests) and N run hotter than the upper threshold value (6-17°C) – Lab-M very close to the upper value (95°C)

COOLING METHOD – AVERAGE IBT 5% EVENTS



Average IBT has been generally succesfully applied during the ILS. it ensures that Labs are not running the test neither much cooler nor much hotter than they should – ***There are non-compliances for the maximum threshold IBT for the 4th Group (WL/MD > 85) – This shall be corrected***

COOLING METHOD – AVERAGE FBT 5% EVENTS



COOLING METHOD – AVERAGE FBT 5% EVENTS

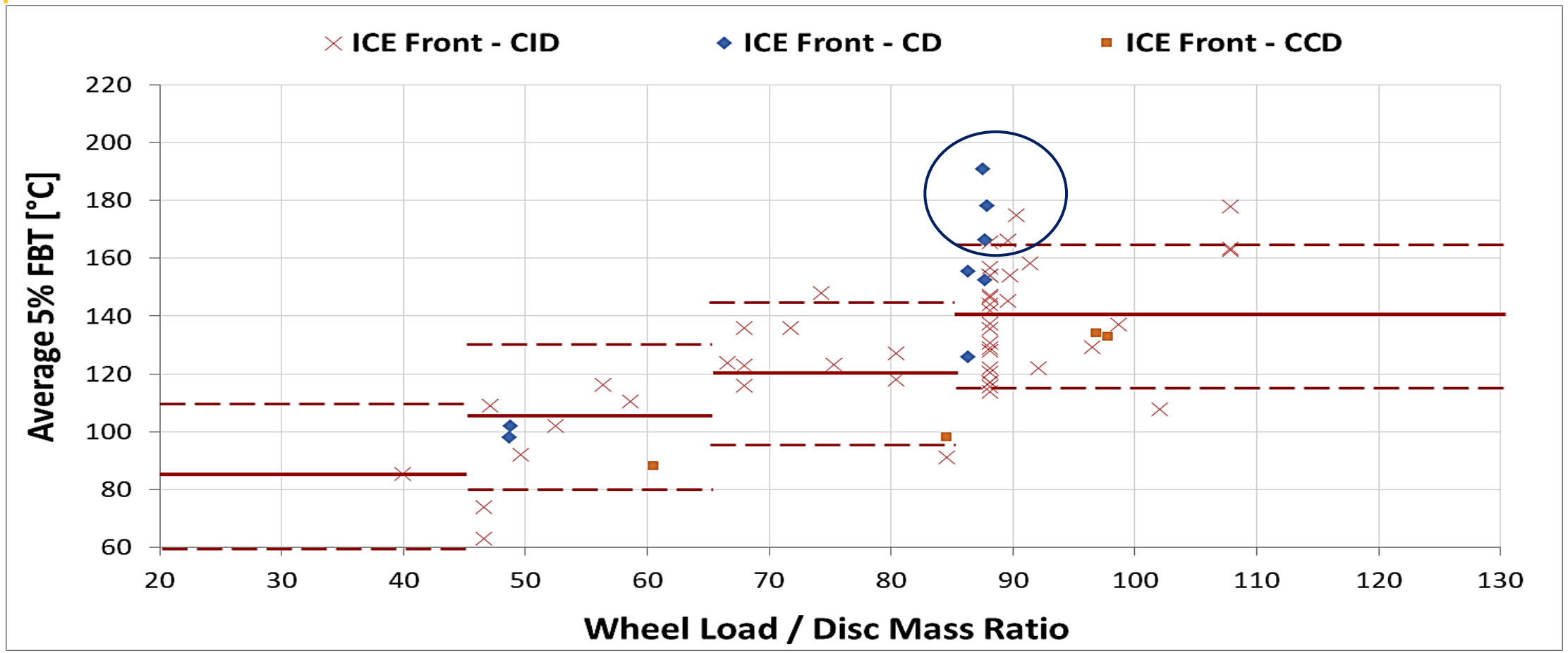
	Br1a	Br1b	Br2	Br3	Br5a
AVERAGE FBT	136.8	136.5	94.9	95.1	161.8
STDEV	12.4	11.8	9.9	9.9	10.2
Variability	9%	9%	10%	10%	6%
MIN VALUE	111.5	117.3	69.8	83.0	143.1
5th Percentile	116.3	118.4	72.3	84.0	143.7
50th Percentile	138.4	138.4	96.0	91.5	165.9
95th Percentile	152.9	155.4	108.5	112.3	170.8
MAX VALUE	159.8	156.7	108.6	113.3	172.6
TARGET FBT	115-165	115-165	60-110	80-130	115-165

Br1: 108 single data points – 2 "non-compliances" to the target values (2%) – Lab-R (2 non-compliances) runs the cycle at lower energy thus resulting in lower temperature regimes

Br2 & Br3: ***73 single data points – 0 "non-compliances" to the target values (0%)***

Br5a: 12 single data points – 8 "non-compliances" to the target values (67%) – Labs F (Applied the same flow for all tests), M, and N run slightly hotter than the upper threshold value (0-8°C)

COOLING METHOD – AVERAGE FBT 5% EVENTS



Average FBT has been generally succesfully applied during the ILS. it ensures that Labs are not running the test neither much cooler nor much hotter than they should – ***There are non-compliances for the maximum threshold FBT for the 4th Group (WL/MD > 85) – This shall be corrected***

COOLING METHOD – OTHER FINDINGS

	Br1a	Br1b
Average Trip #10	72.4	76.1
Maximum Trip #10	84.1	87.4
Average IBT	82.0	84.8
Maximum IBT	102.8	104.9
Average FBT	136.8	136.5
Maximum FBT	159.8	156.7

- ✓ *ILS data demonstrate that NAO and ECE pads have a similar temperature effect on the Ford Focus Disc;*
- ✓ *There seems to be no need to introduce specific provisions for different pad materials taking into account the flexibility of the method*

Cooling Flows	Br1	Br2	Br3	Br4	Br5
Lab-F	491	491	491	491	491
Lab-M	275	275	275	275	750
Lab-N	463	-	685	463	750
WL/DM	**88.1**	**44.6**	**50.7**	**81.5**	**90.1**

- ✓ *A few optimal cooling air flows shall be enough to cover all different groups and the vast majority of the market available WL/DM;*
- ✓ *There is a difference in the behaviour of Br1 and Br5 despite their similar WL/DM.*

COOLING METHOD – POSSIBLE SOLUTIONS

- ✓ ***Remove the upper limit for both IBT and FBT like in case of Average Temperature*** *– Not an optimal solution because Labs could run a test at much lower cooling air setting to artificially get higher temperature values compared to the target ones;*

- ✓ ***Define the target values for each WL/DM using the regression line instead of defined Groups*** *– This would add further complexity and would not solve the problem of these specific brakes since all of them come with a very similar WL/DM ratio as the Ford Focus;*

- ✓ ***Adjust the target IBT and FBT increasing them by 5°C and further relax the maximum allowed deviations by 5°C*** *– This would allow for having the same minimum allowed IBT and FBT while it would be possible to run tests slightly hotter;*

COOLING METHOD – PROPOSAL

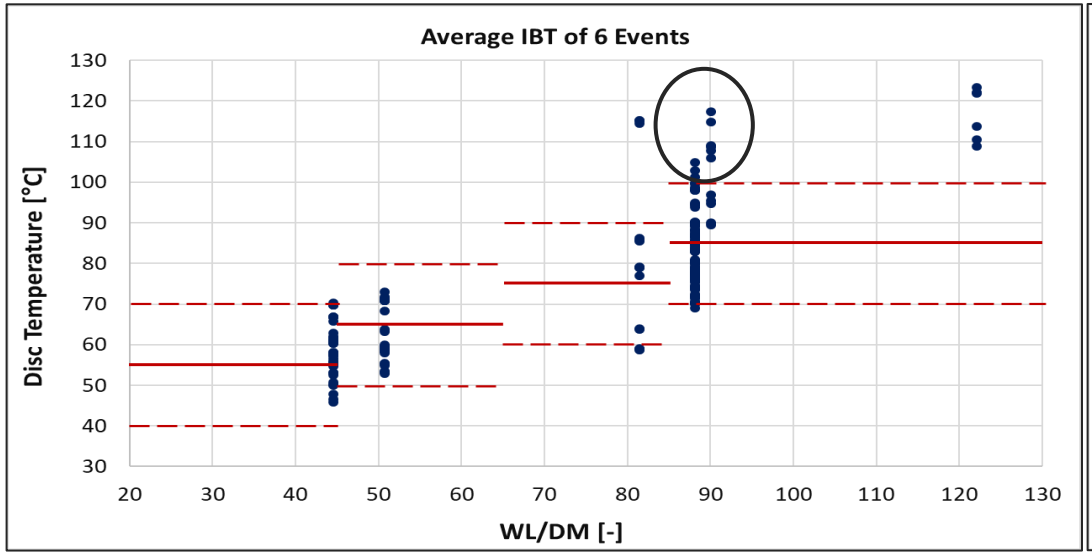
Adjust the target IBT and FBT by increasing them by 5°C – Further relax the minimum and maximum allowed deviations by another 5°C

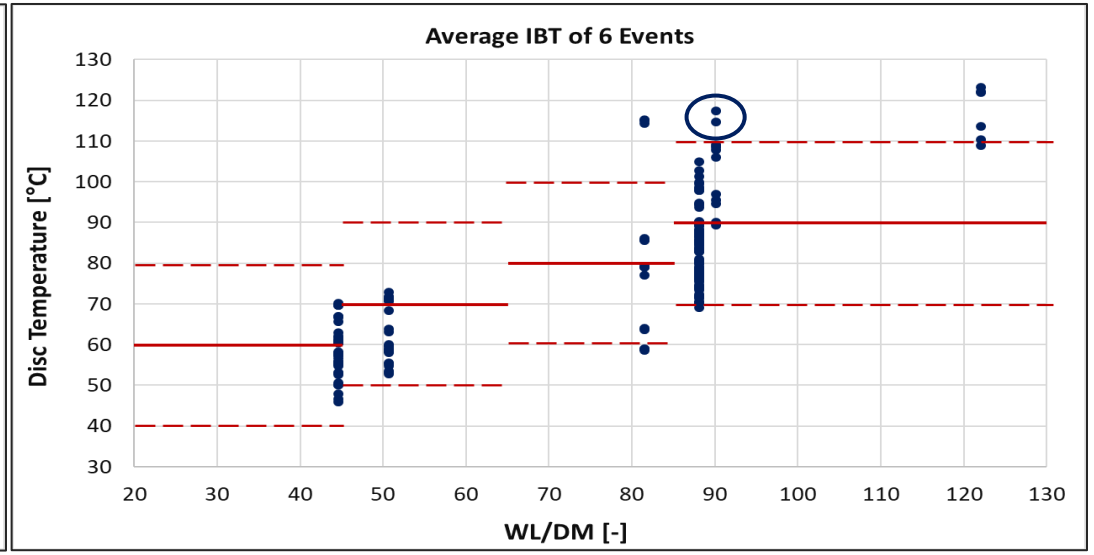
WL/DM	Average [°C]	5% IBT [°C]	5% FBT [°C]
1st Group	>50	55±15	85±25
2nd Group	>55	65±15	105±25
3rd Group	>60	75±15	120±25
4th Group	>65	85±15	140±25

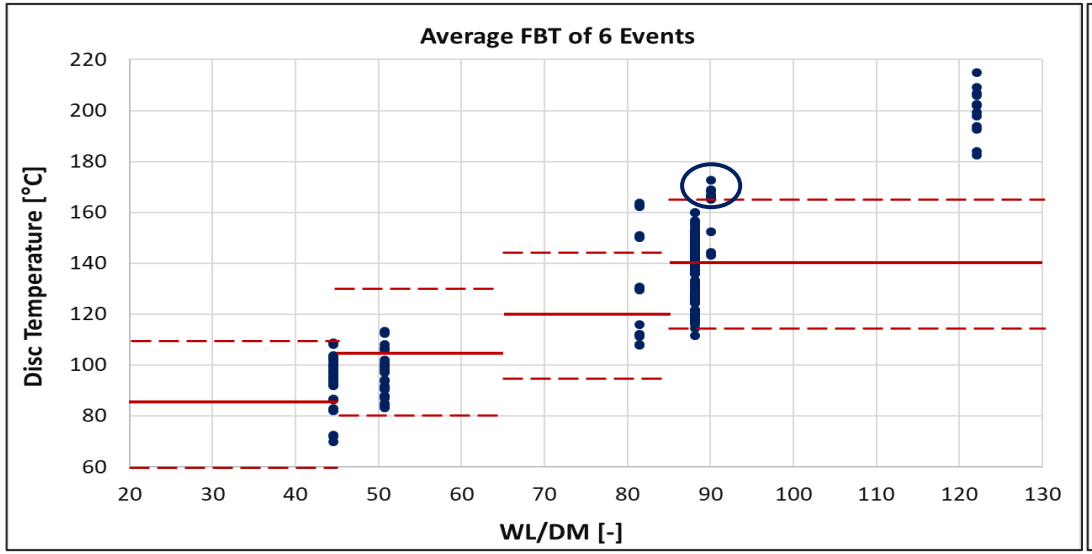
WL/DM	Average [°C]	5% IBT [°C]	5% FBT [°C]
1st Group	>50	60±20	90±30
2nd Group	>55	70±20	110±30
3rd Group	>60	80±20	125±30
4th Group	>65	90±20	145±30

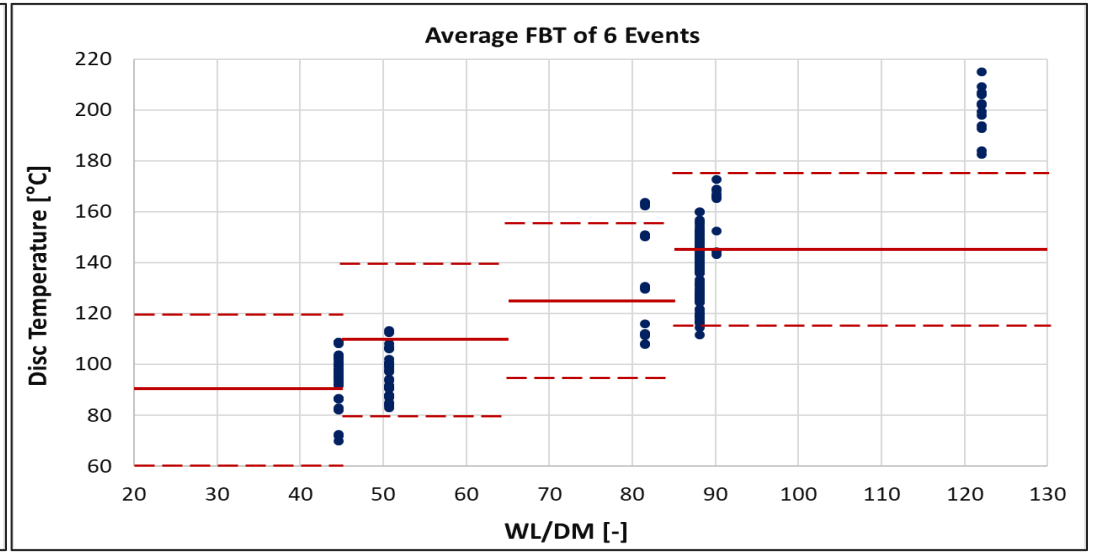
With this proposal the lower IBT and FBT limits remain the same. The higher IBT and FBT limits increase by 10°C. This ensures that the test does not run cooler and at the same time no abuse of possible high temperature regimes is made

COOLING METHOD – PROPOSAL



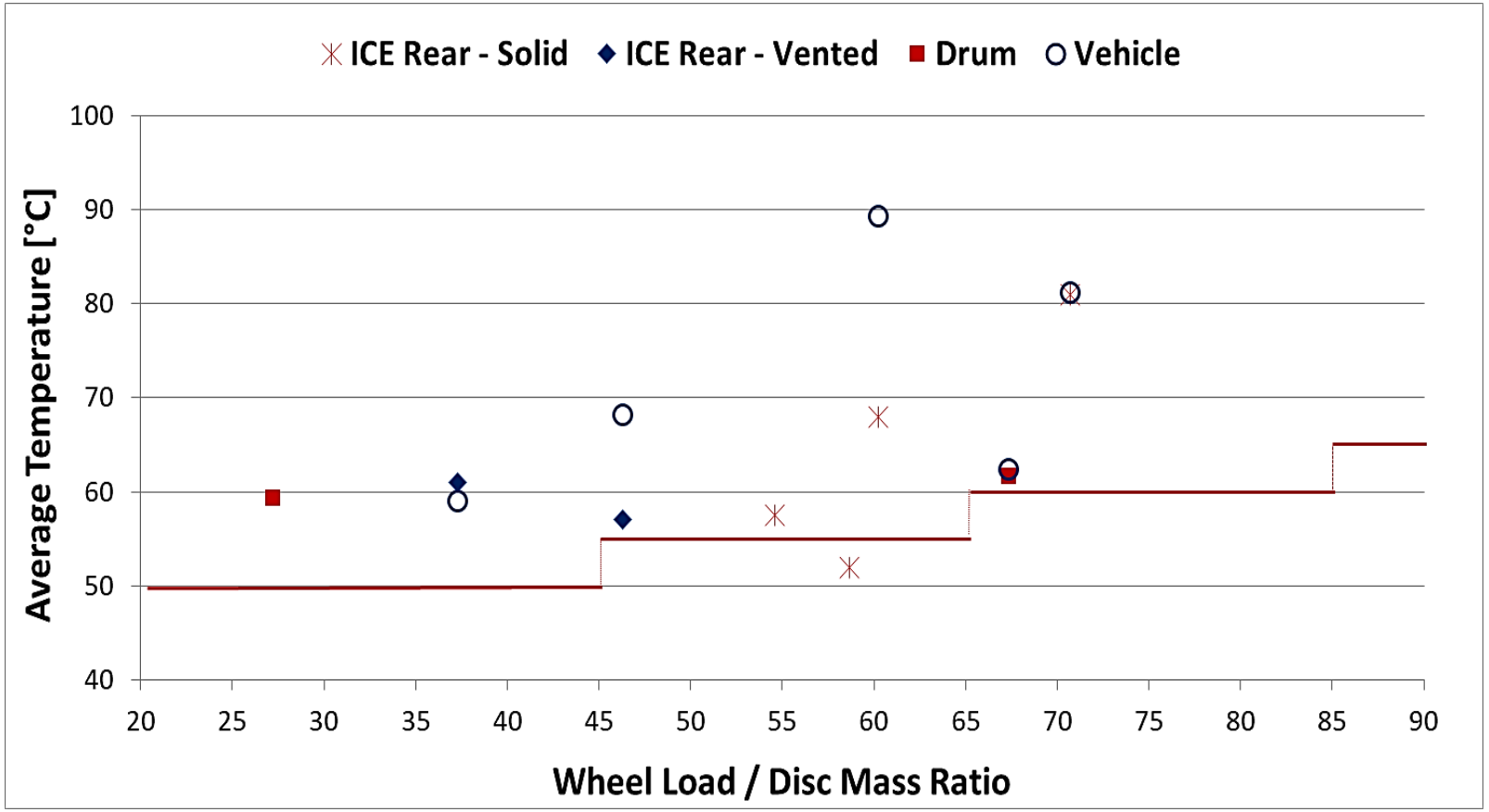






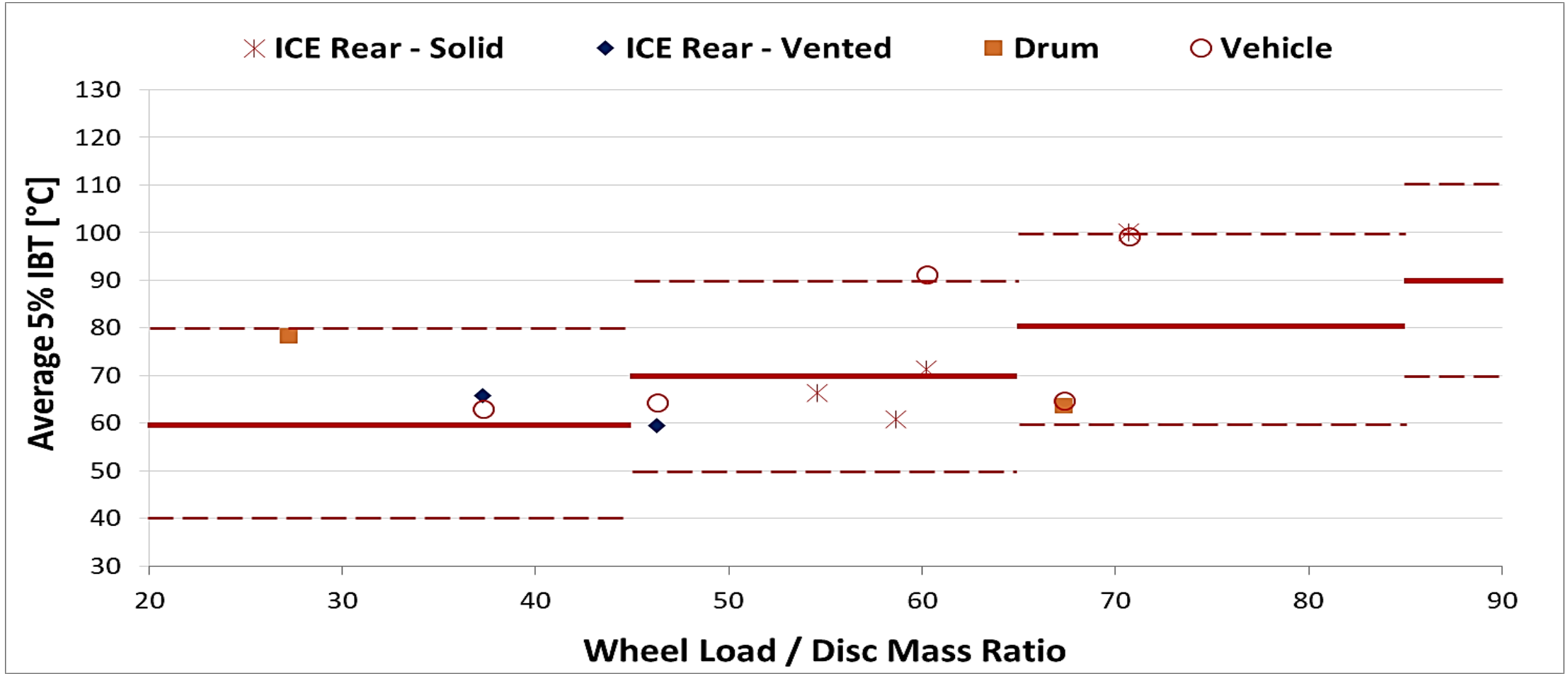
REAR BRAKES – AVERAGE TEMPERATURE

It has been suggested to perform rear brakes emissions testing by applying the cooling air flow obtained for the corresponding front brake application – Data discussed in these slides are for illustration purposes since rear brakes temperatures are not controlled in the protocol



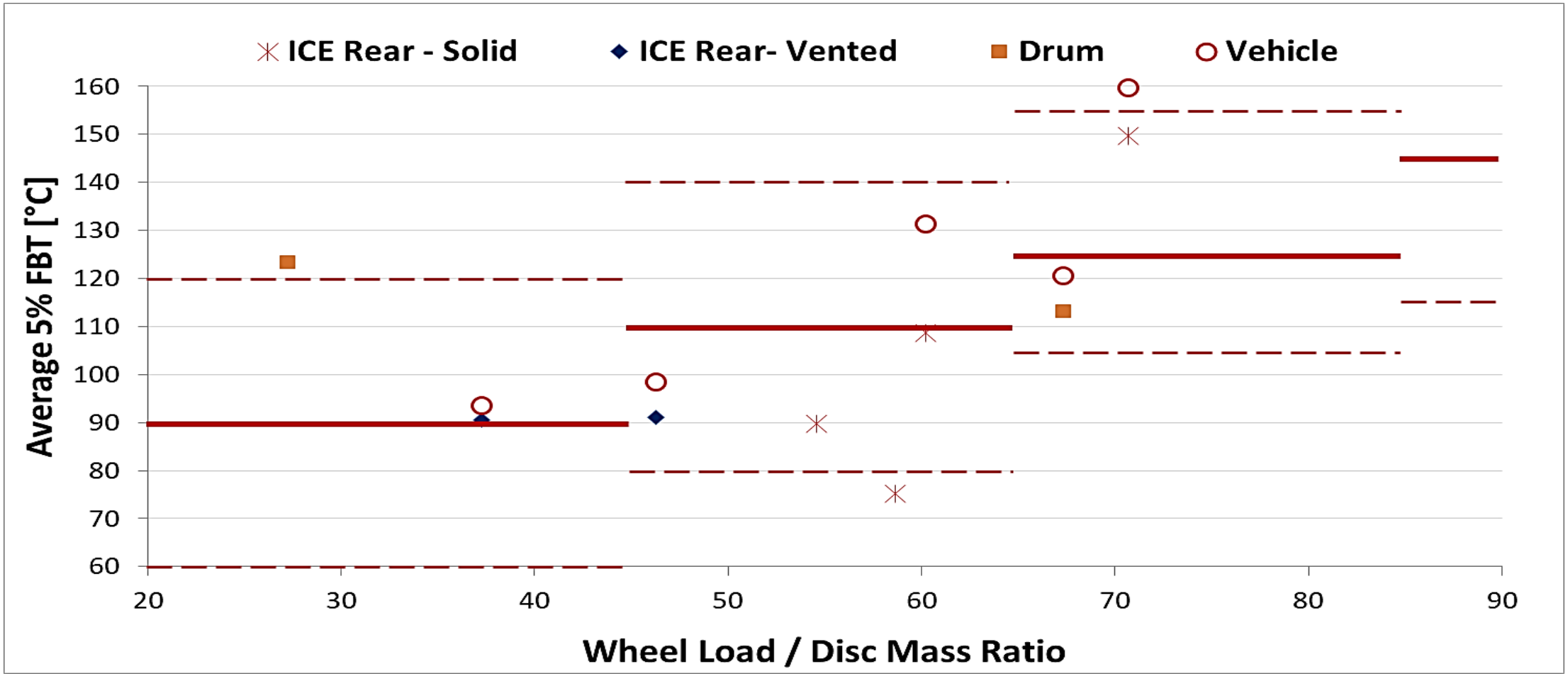
- ✓ *Available vehicle data show that expected rear brake average temp. are within the target values;*
- ✓ *Dyno tests carried out with the front brake flow show good compliance with the target values;*
- ✓ *Lack of more data for vehicle and dyno tests do not allow for more refined target values*

REAR BRAKES – AVERAGE IBT 5% EVENTS



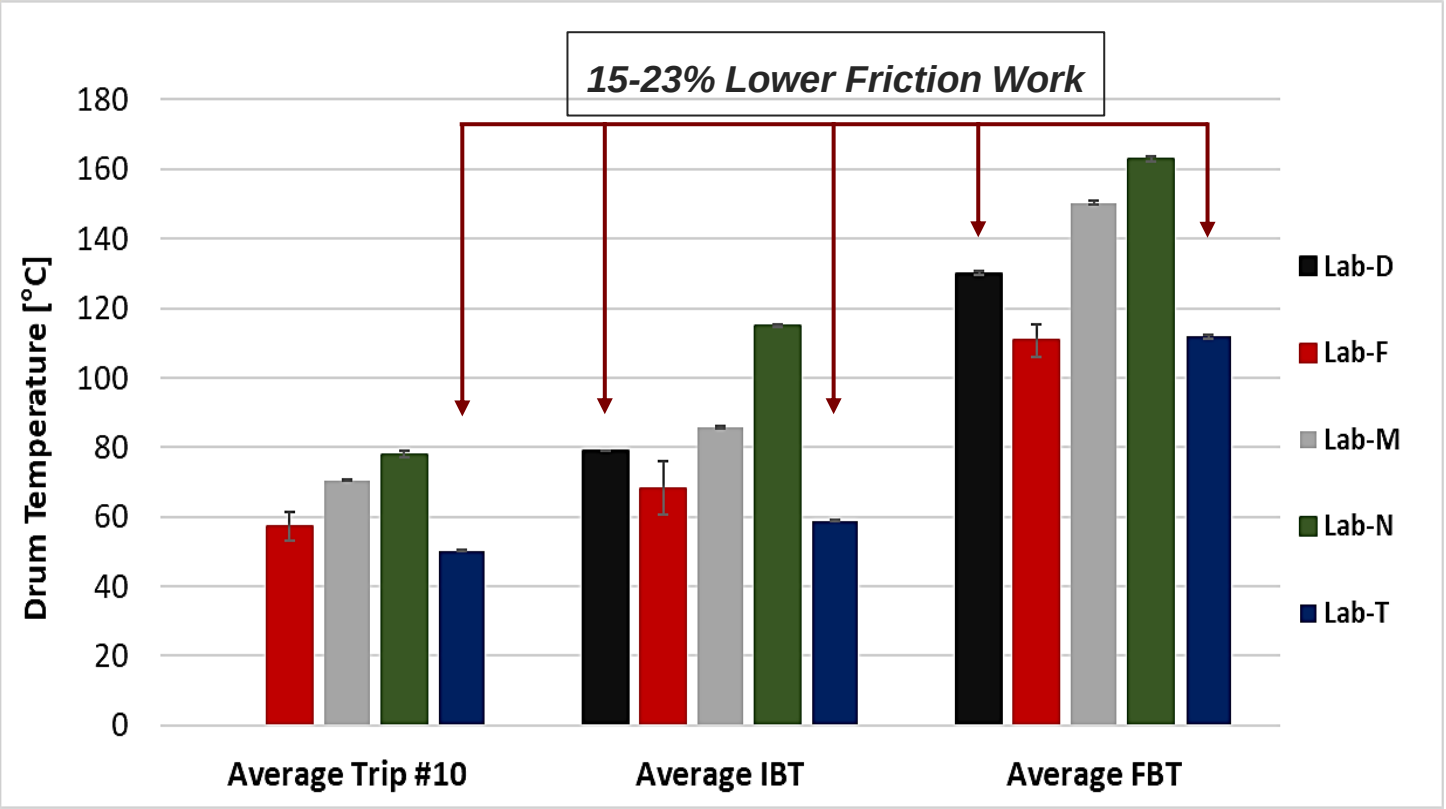
Similar observations as for average temperature – One vehicle data-point is borderline – Available dyno data all within the spec – More refined values are impossible to be derived

REAR BRAKES – AVERAGE FBT 5% EVENTS



Similar observations as for average temperature – One vehicle data-point is outside the spec – More refined values are impossible to be derived

DRUM BRAKE



- ✓ *There are differences in the observed temperatures between the labs;*
- ✓ *Labs D & T ran the cycle at lower energy, whereas Lab D didn't control cooling temperature and humidity;*
- ✓ *Lab N runs at higher temperatures compared to all Labs*
- ✓ *The overall temperature levels are well within the typical temperature regimes of the WLTP-Brake cycle;*

ILS data demonstrate that emission levels are not affected by the observed temperature differences (Average PM_{10} EF <0.7 mg/km and Average PN EF <$2x10^9$ #/km for all Labs)

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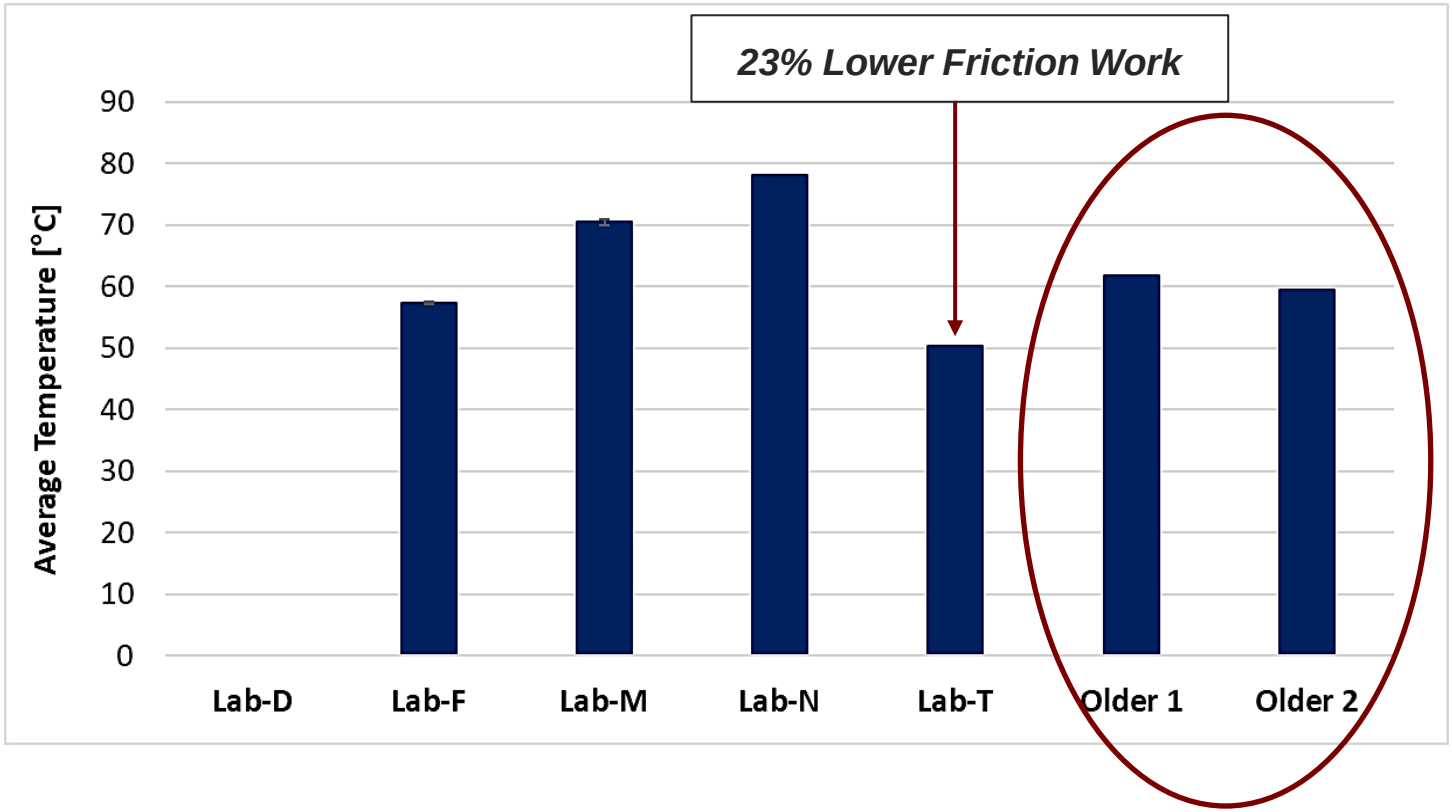
DRUM BRAKE



- ✓ *Older data from the dyno show similar temperature regimes – valid also for IBT and FBT;*
- ✓ *These data were obtained applying the previous version of the cooling adjustment method (non-adjusted temperature targets);*
- ✓ *The overall temperature levels are well within the typical temperature regimes of the WLTP-Brake cycle;*

ILS data did not show that the application of the cooling air flow obtained for the corresponding front brake application has a negative effect on the drum brake's emissions or temperatures – Thus, it is proposed to follow this approach for the cooling adjustment of rear drum brakes

ILS ISSUES LOG – OPEN TOPICS

Excerpt from	Reporting lab & date	Description of the issue	Possible solutions	Issue Closed
Clause 2	Lab-M 22/10/2021	During the application of Trip #10 for cooling adjustment purposes – and while evaluating the temperature traces – there is a need for 1. Careful execution of “automated” routines since very small time differences may lead to significant temperature changes, and 2. Examine if the max temperature is achieved after the stop due to delay in heat flow. In the latest case, it should be defined in the protocol which data should be evaluated: Temperature at the end of the stop or max temperature (also potentially after the stop already finished).	1. Provisions have been introduced in Clause 1 to ensure and crosscheck the correct application of the WLTP-Brake Cycle. Similar provisions are proposed for the correct application of Trip #10 for cooling adjustment purposes. A validation of the cooling adjustment method is proposed (see next issue). 2. The start and end points of all 6 events defining IBT and FBT have been specified via their time, initial and final speed. The maximum temperature of the events might occur during or after the completion of the braking events thus it shall not be confused with the FBT which is clearly defined by its speed set point and the actual time trace.	NO

ILS ISSUES LOG – OPEN TOPICS

Excerpt from	Reporting lab & date	Description of the issue	Possible solutions	Issue Closed
Clause 2	Lab-T 16/11/2021	During the cooling air flow adjustment of Br2, Lab-T noticed a local friction contact between pad and disc (residual braking torque) which had an influence on the temperature profile. For this reason, Lab-T had to ensure a particularly high cooling capacity with the application of increased cooling air-flow. After the adaption of the second Br2 to perform the actual emission tests, Lab-T observed that the temperatures differed significantly compared to those of the cooling adjustment procedure. Did other labs observed a similar effect?	To be checked with other labs if a similar effect was observed for the AUDI or any other tested brake. Two possible solutions: 1) Use the same brake for cooling adjustment and emissions testing without dismounting the hardware for any reason or 2) Crosscheck the average temperature of the 1st bedding test to validate the robustness of the temperatures recorded during trip #10 and thus the correctness of the selected cooling settings. Make sure that the average temperature is higher than the defined limits.	NO

CLAUSE 2.3. – QUALITY CRITERIA

Specifications for checking the correct execution of Trip #10 of the WLTP-Brake cycle for the Cooling air adjustment have been introduced. Three different checks have been specified and are proposed:

- ✓ ***A maximum 3% of speed violations are allowed during the execution of the Trip #10 of the WLTP-Brake Cycle.*** This is in-line with what has been proposed in Clause 1

- ✓ ***Suggestion to introduce a provision for total friction work within ±5% of the nominal value during Trip #10 of the WLTP-Brake Cycle.*** This is necessary to make sure that labs do not run the cooling air adjustment at lower or higher energy

- ✓ ***Validation of the control parameters (1. Average temperature of Trip #10 of the WLTP-Brake cycle, 2. Average IBT of the six selected events, 3. Average FBT of the six selected events) with data from Trip #10 of the 1st bedding cycle***

Thank you

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