The BMW Group's Energy and Environmental Test Centre.
Summary version.

With the new Energy and Environmental Test Centre, the BMW Group's car development process is taking on a new dimension. This comprehensive and future-proof range of test benches ensures that sustainable solutions for the mobility questions of tomorrow are found and can be developed up to the start of production. Above all, however, it changes the development process itself, making it more efficient.

Climatic tests have already been conducted for a long time. Besides the on-road tests and testing grounds, the BMW Group has also had testing facilities for these tasks for over 30 years, including wind tunnels with rain simulation or climatic test chambers.

The newly created thermal wind tunnels and climatic test chambers completely cover the current needs of developmental departments and also address developmental topics of the future, today. This arrangement makes for a unique test setting: the BMW Group's new Energy and Environmental Test Centre (ETC).

Until now, testing and verification of developments under the influence of climatic conditions such as heat, cold, atmospheric pressure, wind and precipitation have only been possible starting at a certain level of development maturity, with completed car prototypes on the road - and often at far away sites. For many of these development subjects, the BMW Group has employed the ETC to perform this verification much more efficiently and productively - and that on-site in Munich. The "in-lab" results are also more precise and easier to reproduce.

Roads of the world in the ETC - many benefits for an efficient development process.

The greatest improvement over the BMW Group's previous test benches is the extreme realism of the ETC test drives. There, it is possible for the first time to produce dynamic test drives under diverse environmental influences within a facility.

"We're bringing the whole world, with all its climate zones, into one building."

(Jürgen Engelmann, Manager of ETC operations)

Thanks to the environmental simulation, the test facility surroundings allow for more exact specification of test parameters than was previously possible on the road. Thus, many of the BMW Group's total vehicle tests can now be moved to the ETC and carried out there more rapidly and efficiently.

For example, tests for thermal management take place in the climatic wind tunnels, with heat as well as cold, up into the highly dynamic driving range. Here, special attention is paid to cooling power, car airflow, brake cooling and heating / air-conditioning performance. The range also includes tests with rain and snowfall. Exhaust emission analyses and altitude driving cycles are performed in one of the two climatic test chambers, while cold starting and defrosting play an important role in the cold test chamber.

The environmental simulation - midsummer in winter.

Starting right away, tests can be conducted with snow, rain, cold, heat and even altitude in the ETC's total of three thermal wind tunnels and two climatic test chambers. This delivers a number of benefits for the entire product development process. Thanks to the environmental simulation at the test facility, it is possible to carry out tests on prototypes for the first time regardless the current time of year, while the testing environment provides for optimum reproducibility. Improved comparability of test results over on-road tests makes for increased quality and considerably more meaningful results. Many of the test drives in hot and cold countries, which involved high CO_2 emissions due to the necessary transport flights, can now take place in the ETC, drastically reducing costs and environmental impact. Process partners must no longer come along on flights or endure long waiting times for results; transfer times are dispensed with. The more streamlined testing calendar means that test cars are much more readily available, allowing them to be better used to their full capacity. The entire development process is becoming significantly more efficient through the ETC.

Testing that closely resembles the customer's reality.

Besides legally required tests, the BMW Group wants to use the new ETC to conduct much more customer-oriented test cycles that reflect customers' day-to-day driving behaviour. This means better design and

verification of car components for maximum functionality and operational reliability with minimum fuel consumption.

The ETC offers diverse possibilities, especially for further development of products in terms of Efficient Dynamics. After all, the success of this strategy lies in the overall combination of measures across the whole car fleet. Even small measures that help eliminate just a tenth of a gram of CO_2 make a significant difference. And these reductions cannot be "experienced", tested and tracked anywhere better than in a state-of-the-art, highly sensitive and precise test facility - the ETC.

This is all especially beneficial for the customer. By an efficient development process, the cars are optimally designed and put into application, consume less fuel and therefore emit less CO_2 - and that without reducing dynamics, safety or comfort. Through the comprehensive testing environment, the best conditions have been achieved for developing innovative technologies and making them usable up to the start of production. In this way, the customer will enjoy the innovative advantage of the BMW Group's cars in the future as well.

The ETC test facilities - all roads of the world under one roof.
With the new Energy and Environmental Test Centre (ETC), the BMW Group possesses more than "just" a testing environment that has instruments and methods efficiently to support the design and verification of components and cars as well as their interactions. This "visionary test setting" accomplishes quite a lot more: Its equipment already covers all future mobility concepts and their testing needs. Altogether, the ETC addresses five comprehensive development and verification topics that mutually complement each other: energy and heat management, thermal operational safety, low-temperature behaviour, operational and functional verification under environmental conditions and the development and functional verification of the air-conditioning / heating.

The ETC has a total of five test cells at its disposal in order to fulfil all these testing requirements. The individual test benches each possess important stand-alone features, but also have similar or identical functions and tasks. This redundancy was planned intentionally in order to ensure a certain flexibility in the use of test facility. Consequently, not every test cell offers

all functions, but overall the test benches cover every relevant requirement.

Three thermal wind tunnels and two climatic test chambers - five individual test rigs in a class of their own.

On the one hand, the ETC consists of three specifically equipped thermal wind tunnels: "thermal wind tunnel", "climatic wind tunnel" and "environmental wind tunnel". These three test cells have a high aerodynamic quality. They help fulfil different requirement of the testing departments and, above all, assist in the development and verification of parts and systems under extreme conditions, such as heat, cold, humidity, solar radiation, rain and snow. In addition, the two climatic test chambers "altitude test chamber" and "cold test chamber" support the design and verification of heating / air-conditioning systems, they allow for emission measurements at high altitudes or in the cold, as well as testing of altitude sensitivity, especially for engines with turbochargers.

Besides wind speed, humidity can be individually adjusted at all five test cells. The test benches differ in their temperature ranges and additional test-specific functions, such as precipitation, altitude or solar radiation - called "subsystems" - because each test cell was designed for special main focal areas. All test benches are equipped with highly modern 4-wheel drive dynamometers. They are responsible for exact simulation of road driving and correct loading of the powertrain.

Besides the test section, each test cell has a separate control room. The test bench is operated and supervised from here. A state-of-the-art test automation system controls all components and monitors hundred of parameters. This allows the measurements from the most frequently conducted tests to be controlled and supervised by just one person.

The thermal wind tunnel – "stay cool".

In the thermal wind tunnel, high car loads are preferred, such as mountain driving with a trailer or high-speed driving over a long period of time in extreme heat. Because even in these borderline situations, the cooling system must be capable of disposing of the engine's waste heat. Since the thermal wind tunnel is especially designed for tests of cooling performance and thermal management, the temperature range of this climatic wind tunnel is from 20 to 45 °C. The blower produces wind speeds of up to 280

km/h. In addition, it has an accessible centre pit with a glass floor, which allows thermographic tests of the underbody, among other things.

The climatic wind tunnel - acceleration like a BMW M5.

Basically identical to the thermal wind tunnel, the climatic wind tunnel also focuses on testing air-conditioning, brake cooling and highly dynamic driving tests. At 250 km/h, the climatic wind tunnel does not reach the thermal wind tunnel's top wind speed, but the fan can accelerate more quickly thanks to especially rigid and lightweight carbon fibre rotor blades - and thus authentically simulate even the air flow conditions of an accelerating BMW M5. Also, the climatic wind tunnel can simulate the sun, which allows for cooling performance with the addition of solar radiation. Moreover, even negative atmospheric temperatures as low as -10 °C can be reproduced for testing and optimising the interplay between interior heating and engine cooling, for example.

The environmental wind tunnel – snow storm in summer.

The design and verification process in car development, however, not only applies to tests in the heat or cold. The objective of the tests is also to ensure operational reliability and road safety under all climatic conditions, even with rain, sun, wind and snow or combinations of these. With the ETC environmental wind tunnel, the BMW Group now has the opportunity to be able to test all environmental factors individually or together in an insulated test facility. In addition to the sun simulation, the environmental wind tunnel thus also has systems for simulating precipitation. More specifically, this means that the test facility technicians can create rain and snow - in varying intensities and with different kinds of snow. Another great feature of the environmental wind tunnel is the flat belt for exposing even motorcycles to certain environmental conditions at the test cell and measuring their influence. The opportunity to test motorcycles at the test facility in this way is new and unique. Overall, a temperature range of minus 20 to plus 55 °C can be simulated in the environmental wind tunnel.

The altitude test chamber - above and beyond.

The altitude test chamber is the "high point" of the ETC: This test cell allows the simulation of test drives at an altitude of up to 4,200 meters above sea level, which corresponds to 620 millibars of air pressure. In other words, the altitude test chamber is a big compression chamber with pre-installed

technology for fuel-consumption measurement. This makes important tests possible on emissions behaviour at high altitudes or in the cold, on engine application and the fuel supply system. Within the altitude test facility it can be summer or winter, since it has a temperature range of minus 30 to plus 45 °C and a solarium. Despite limited space, the chamber test facility was able to be created with the properties of a small wind tunnel.

The cold test chamber - ice age in the ETC.

As the smallest ETC test bench, the cold test chamber especially addresses tests that have to do with extreme cold. The tests in this test cell include cold starting tests and the testing of battery function under extreme conditions, design and functional testing of the heating system and window defrosting or dehumidification. For better traceability of de-icing tests, an image-processing system automatically records how quickly the windows are de-iced by the car's interior heater. The recordings can be used to analyse, compare and evaluate different conduits and design strategies.

Behind the scenes of the test facilities – the ETC's infrastructure.

The ETC requires further infrastructure in order for all tests to be conducted efficiently in the five test cells and each test bench to be put to best use. For this reason, special attention was paid during planning to optimising how the subprocesses are arranged and incorporated, so that the test facilities can be utilised quickly and correctly. Car equipping, preconditioning of cars and the test process itself are seamlessly interwoven; the entire process is considerably quicker and more efficient than ever before.

Altogether, the ETC extends over three floors, with the test cells all on the ground floor, however. With the ETC, a highly compact architecture has been created in which the main movements of the car only take place on one level. Thanks to short routes, the cars can be brought into the test cells more quickly, which, in turn, provides for quicker results. All areas of operation that are test-related, but do not necessarily require immediate proximity to the test benches, are situated on the first floor and basement, and are linked to the test facility level via lifts. While in the basement the cars are brought to the required temperature in the range from minus 40 to plus 55 °C, workshops are located on the first floor for cars that need to undergo even greater modifications for the testing process.

Previously: road test vs. test facility.

On-road test drives are a fundamental and indispensable part of car development and verification. Through the orientation towards subsequent customer demands, the test engineer gains valuable knowledge about the behaviours of individual car components and how they interact. The BMW Group's new Energy and Environmental Test Centre (ETC) brings car development and verification to a new level, because it unifies the benefits of both testing environments, "road" and "testing facility", at the same time as allowing test engineers to carry out reproducible test drives whilst maintaining realism in the precisely operating test facility environment.

In car development and verification, engineers previously had to decide whether they wanted to conduct their tests realistically on the road, but with great discrepancies in test results due to outdoor conditions, or if they wanted do them at a test facility with precision and reproducibility, but limited realism. Many on-road tests are very difficult to reproduce, because by their nature they are always dependent upon unpredictable factors, such as busy traffic, erratic reactions of other drivers, detours or temperature and weather fluctuations. These heterogeneous environmental conditions lead to variances in the test results, which require a great degree of interpretation by the test engineers. For test drives at the test facility, however, it was possible to drive under almost perfectly reproducible conditions and thus compare the results with each other better, but the drives did not completely capture reality.

From the road into the laboratory.

Through the "environmental simulation", i.e. the realistic representation of environmental conditions of road driving at the test facility, a significant part of the hot and cold country test drives can now be moved to the ETC and carried out there considerably more efficiently. The tests used to have to be conducted all over the world, whereas now the ETC test facilities are capable of imitating environmental conditions, such as air temperature, pressure and humidity, as well as precipitation and solar radiation, and measuring their influence. This has an extremely positive effect on the car development process.

"In the ETC, ideal test conditions prevail all year round, practically at the push of a button. For this reason, many tests can now be conducted regardless of season, time of day, outside temperature or precipitation."

(Jürgen Engelmann, Manager of ETC operations)

Drawn-out, costly and CO_2-intensive transfers of test cars to the appropriate hot and cold countries are superfluous and the departments' test calendars are substantially streamlined.

Methodological development - how do we bring the road into the test facility?

The key to successful road testing at the test facility lies in the development of appropriate test methods.

"The test method is, in a way, the 'recipe' for how a road test can be replaced by a test at a test facility. It encompasses all test-related requirements of the engineers and transfers them into the test cell setting."

(Roland Kleemann, ETC Methods and Test Facilities)

In order to achieve realism in the ETC tests, the test method engineers first surveyed their engineer colleagues from the entire development division as to how their particular ideal test facility would look and what environmental parameters are especially important to them. From there, they planned a range of over 150 tests that fulfil all necessary requirements to bring as many tests as possible from the road into the test facility. They also took into account requirements for test conditions in the automotive future, such as special cycles for hybrid, electric or hydrogen-powered cars.

Overall, however, great attention was paid to ensuring that the only tests conducted in the ETC are those that make sense there. Because the ETC can by no means replace road testing. Rather, it replaces those tests that are difficult to perform on the road or until now were only able to be done at high financial cost and expenditure of energy. Tests for subjective driving feel or evaluation of lateral acceleration during cornering, for example, can and should not be simulated in the ETC.

Synthesis and validation.

As soon it was deemed beneficial to substitute one of the tests that previously took place on the road with a test in the ETC, the particular road test was input and all relevant influences recorded. The exact, full, physical description of the test drive, as well as the test-relevant environmental conditions, serve as a basis for transformation into a test cell trial. The recorded data is extracted, unnecessary factors removed and thus a synthetic environmental profile is created. In the course of this synthesis, checks are also carried out regarding the extent to which the route profiles can be condensed. Lengths of the route that have no effect on the result can be "cut out" in order to reach a development or verification objective as quickly as possible. In this way, the same result is achieved within a shorter period of time and valuable resources are saved, since the test facility and car are not in operation unnecessarily long.

Last of all, the method developers, along with the test engineers, check whether the testing process is providing the desired results or must be "tweaked". However, the method development process does not end with the validation. New car concepts and new verification topics require constant new follow-up and further development according to suitable test methods. The tests already implemented are also constantly checked for optimisation potential and linked back to new knowledge from the road test. As an important part of the entire ETC implementation process, validation also contributes to tapping the full potential of the ETC.

Sustainability as a universal principle.

The BMW Group aims to help shape the mobile future. Sustainable actions, in particular, should provide for long-term added value for the company, environment and society, as a fixed design principle of future processes. Sustainability in terms of the BMW Group includes not only ecological aspects, but also the aspects of economy and social responsibility.

The best-known and by far most successful sustainability product strategy by the BMW Group up to now is Efficient Dynamics. With this innovative package of measures, the BMW Group is succeeding in uniting what used to be considered to be conflicting goals: reducing fuel consumption and CO_2 emissions whilst simultaneously increasing driving dynamics and engine performance. Above all, this strategy provides for a significant reduction

in fuel consumption and emissions across the car fleet. The BMW Group's new Energy and Environmental Test Centre (ETC) makes a decisive contribution to the further development of this strategy.

At the same time, the ETC is an example of what can be achieved if attention is paid to conserving resources consistently right from the conception phase. Through intelligent architecture and efficient test facility design, the ETC allows for ecologically sustainable operation. From the start, planning of the testing site placed special emphasis on using as little energy as possible in day-to-day operation. But that was not enough: part of the consumed energy is recovered through active recuperation and made available again. Heat recovery, braking energy recovery and highly effective test facility insulation are only a few examples of the responsible husbanding of resources in the ETC.

Cold on demand - efficient cooling.

The ETC test facilities' cooling system is especially sophisticated. Contrary to the usual method of cooling by a central concentration of media at low-temperature, which must be permanently maintained and demands intense energy consumption, the ETC relies on a cascading cooling concept. In this approach, only as much cooling is provided as is needed at any particular moment. Different stages of the cooling system are activated depending on the test facility's cooling requirements. The permanent cooling rate can be held at a minimum in this way and cooling works very energy-efficiently. In the first stage, "free cooling", only the ambient air of the ETC is used for cooling the test facility; active cooling commences only once lower temperatures are required. Only one of the two cooling modules is activated for "normal cooling". In the event that extremely cold conditions are required, a second cooling unit is switched on. The operational range of this unit lies at this extremely low level of cold.

The ETC's CO_2 lifecycle assessment.

However, it is not just the testing systems that work very efficiently. Thanks to the comprehensive environmental simulation possibilities of the ETC, some of the worldwide test drives can now take place at the test facility. Apart from benefits for the car development process through an integrated testing site that is not dependent on the season of the year, CO_2 emissions can be considerably reduced through test drives in the ETC. Just the omission of

transport to worldwide test locations is more or less equivalent to the energy costs of the ETC. In addition, a number of repeated drives can be omitted that are often necessary during on-road testing, due to insufficiently stable conditions.

Furthermore, repeated tests can be conducted with scientific precision due to the laboratory-like conditions of the ETC. This allows for systematic testing of the influence of individual components at a level of detail that unlocks the potential for further energy savings. If a BMW Efficient Dynamics measure identifies the potential for reducing even just 0.1 gram of CO_2/km and this is applied to all new cars, 80% of the ETC's annual CO_2 emissions would be offset.

Changing working conditions - What does ETC mean for employees?

Working sustainably at the BMW Group also means accepting social responsibility. The restructuring of testing and verification procedures was also accompanied by a change in working conditions. Through the transfer of a number of test drives to the ETC, workloads are changing, travel times and extreme climate conditions are a thing of the past. Besides that, new, valuable positions for technicians have been created who undergo continued training in line with a qualification campaign.

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