The BMW Group's Energy and Environmental Test Centre.
Table of Contents.

1. The new BMW Group's Energy and Environmental Test Centre.
Key facts.

A car must hold out against all climatic conditions. Whether in rain or snow, hot or cold weather, or varying air pressure, all vehicles' systems must function at their best. Rain must not inhibit full braking power, kicked-up snow from vehicles ahead must not adversely affect the engine and heat must not overtax the cooling system. Until now, laborious hot and cold country tests were necessary in order to appropriately design and subsequently test vehicles. Now the BMW Group is bringing the world into its laboratory. All pertinent environmental parameters, such as heat, cold, humidity, atmospheric pressure, precipitation and wind can be simulated in the innovative test facility of the Energy and Environmental Test Centre.

- Five test cells form a unique testing centre: the new Energy and Environmental Test Centre (ETC) is composed of three thermal wind tunnels— the "climatic wind tunnel", the "thermal wind tunnel“ and the "environmental wind tunnel" — and two test chambers — the "altitudealtitude test chamber" and the "cold test chamber".

- All roads and climate zones are under one roof. At the ETC, practically any test can be conducted that used to take place on streets worldwide with cold, heat, sun, rain, snow, air pressure, humidity or wind. Exceptions are driving dynamics tests where vertical forces, lateral dynamics, steering movements and crosswinds are in play.

- The development process becomes more efficient through this unique testing centre. Transport distances and times are reduced and fewer prototypes can be used for more tests. The tests are no longer dependent upon the season of the year and are all conducted together under one roof, which helps results become available to everyone more quickly. In addition, the parameters of the test facility can be adjusted precisely and reproduced as often as desired.

- The question "test facility or test drive" is a thing of the past with the ETC's new possibilities. Before, it was necessary to decide between realistic conditions on the street and reproducibility at a test facility, but the ETC brings together the best of both worlds. Here, a vehicle can drive through all climate zones of the world within eight hours.

- The three thermal wind tunnels are identical, but fulfil different requirements, which allows for maximum flexibility in the testing process. They all have a vertical or "standing" air duct; the fan is about 15 metres above the test section — the plenum.

- The temperature range of the climate wind tunnel ranges from minus 10°C to plus 45°C. A solarium simulates solar radiation. Here, tests are conducted for thermal management, cooling power and climate control, as well as brake cooling. The especially light and rigid rotary blades of the blower also allow for highly dynamic tests, up to a top speed of 250 km/h.

- The thermal wind tunnel also serves to ensure thermal operational security. Here, tests are predominantly conducted on cooling performance and air flow. For this reason, temperatures are restricted to the positive range (20 to 45°C). The highest speed at this test bench is 280 km/h.

- The environmental wind tunnel covers the greatest bandwidth of environmental conditions. Here, temperatures from minus 20°C to plus 55°C are possible. A solarium can also simulate solar radiation. Rain and snow simulation are also included in the test range. For the first time, a motorcycle flat belt allows for motorcycle tests in an environmental test facility.

- Cold starts are tested in a cold chamber, which is also used for the development of optimum heating and air-conditioning systems, and to test defrosting and defogging.

- In the altitude test chamber, a fully-fledged climatic wind tunnel has been completed in an extremely small space, which can also simulate atmospheric pressure. The simulation ranges from beneath sea level, such as Death Valley, to 4,200 metres above it. This is especially relevant for tests on exhaust emissions and engine performance.

- An intelligent infrastructure with short routes contributes to the efficiency of the test setting. Vehicles are no longer brought to temperature in the test bench, but are pre-prepared in so-called "soak rooms". This optimises test facility occupancy and reduces energy consumption, since the soak rooms are smaller and can be cooled more efficiently.

- While planning the ETC, special attention was paid to ecological, sustainable operation. The intelligent conception of the cooling system, good insulation and braking energy recovery in the test facility dynamometers and fans are only a few of the measures that have been implemented.

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

Since the late 1990s, the Efficient Dynamics strategy has defined the long-term orientation of the BMW Group's development work. The objective: sustainable handling of resources through minimisation of vehicles' fuel consumption and CO_2 emissions, without reductions in driving dynamics, performance, safety or comfort, but also optimisation of the development process in accordance with guidelines for sustainability and efficiency. In order to tap full product savings potentials and further reduce fuel consumption, the BMW Group relies on the most modern of working materials and testing equipment in vehicle development and validation. This is because only a comprehensive and future-proof range of test facilities assures that sustainable solutions are found for the mobility questions of tomorrow and can be used right up to the start of production. That's why the BMW Group has decided against comprehensive modernisation of the previous test facilities used for environmental simulation and for the construction of a new and integrated test setting. The newly created climatic wind tunnels and chambers completely cover the current needs of developmental departments and already address developmental topics of the future. This arrangement makes for a unique test setting: the BMW Group's new Energy and Environmental Test Centre (ETC).

"The ETC raises the validation methods of vehicle characteristics in the product creation process to a whole new level."

(Dr. Johannes Liebl, Manager of Efficient Dynamics)

Besides the usual design and vehicle validation tests, the new, self-sufficient test facilities of the ETC incorporate important requirements, especially for performing and advancing essential development work on Efficient Dynamics, intelligent energy management, hybrid drives and emission-free mobility. By employing sensitive high-precision test facility technology, this provides the ETC with accurate and reproducible test results that can hardly be achieved on the street or at a test site. These results contribute to designing vehicles with greater energy efficiency and to "polishing" energy management aspects in detail. The comprehensive, future-oriented equipment of the ETC also supports research of alternative drive concepts. Test cycles that are specially oriented towards the hybridisation of vehicles, such as charging strategies or power balancing have already been integrated into the ETC and are capable of being tested. The technical requirements for the achievement of long-term corporate objectives, such as completely emission-free mobility using electricity or hydrogen, can also be looked into — the test facilities are constructed and conceived for this.

The list of possible tasks at the new test centre runs long. Here, practically all tests can be conducted that used to be conducted on the street with cold, heat, sun, rain, snow, air pressure and wind, except for driving dynamics tests where vertical forces, lateral dynamics, steering movements and crosswinds are in play. The tests that are carried out at the ETC are not supposed to completely replace test drives on the street or at the testing grounds, but to systematically complement them.

For example, tests for thermal operational security take place in the wind tunnels, with heat as well as cold up into the highly dynamic driving range. Here, special attention is paid to cooling performance, vehicle air flow, brake cooling and heating / air-conditioning performance. The range also includes tests with rain and snowfall. Exhaust-emission analyses and high altitude driving cycles are performed in one of the the two climatic test chambers, while cold starting and defrosting play an important role in the other chamber. Precise and reproducible tests allow important product developments to be achieved — besides the conception of optimal energy management throughout the vehicle, the thermal and functional component design and its validation become more exact under laboratory-like conditions, for example. All tests are subject to the BMW Group's standard of making products and product development more efficient and dynamic.

Intelligent energy management continues to bear enormous savings potential.

The exact design of individual vehicle components according to later demands in customer service constitutes an exemplary approach for raising the efficiency of Efficient Dynamics.

"Our standard for ETC is that it provides us with exact and reproducible results as we never could have achieved under on-street conditions. Thus, the developers can design and dimension the parts and components precisely as they are needed in everyday reality."

(Jürgen Engelmann, Manager of ETC operations)

As a result, the systematic use of materials achieved prevents additional weight and thus costs in production, as well as unnecessarily increased fuel consumption and associated CO_2 emissions while driving.

Besides precise component design, vehicles have yet more possibilities for saving fuel and reducing CO_2 emissions that have thus far hardly been taken advantage of, and this is attainable through energy optimisation. Energy management is looking into general possibilities to accumulate, convert, transport, store and use energy efficiently, safely and ecologically. Energy can take on different forms, such as heat, electricity or propulsion. At centre stage of the research is the objective to achieve a high yield of usable energy, i.e. to maximise effectiveness and simultaneously minimise negative accompanying effects on the environment.

Back in 2003, the BMW Group recognised the urgency of tackling in-vehicle energy technology more intensely, and there is still enormous untapped potential for reduction. Even in a very efficiently functioning combustion engine, only about a third of the energy contained in the fuel is transformed into mechanical work for movement. The remaining two thirds are lost as heat that is emitted into the surroundings through the exhaust and cooling systems. If this energy were made usable by the vehicle, fuel consumption and CO_2 emissions could be further decreased. That's why the BMW Group developers have for a long time been researching unexploited possibilities for minimisation of fuel consumption. Examples of this are the use of the engine's and exhaust line's residual heat to generate electricity while driving by means of a thermoelectric generator (TEG) or conditioning vehicle functions for as efficient driving as possible ("intelligent in-vehicle energy management").

From Aschheim to Munich: Close integration for an improved process.

Energy management tests have already been conducted for a long time. Besides the on-street tests and testing grounds, the BMW Group has had testing facilities for these tasks for over 30 years. In the last few decades, the systems in Aschheim (a suburb of Munich) have been modernised several times to meet specific demands, but clearly reached their limits within the last few years. The existing systems were especially incapable of meeting driving dynamics requirements.

That's why in 2005 the BMW Group decided against a further modernisation in Aschheim and to create a new test centre directly in the BMW Group's Research and Innovation Centre (FIZ) network in Munich. The systems in Aschheim are being completely replaced by the ETC testing network after a brief transition phase and many additional tests can be taken from the street into the laboratory, because the commissioning of the ETC brings about numerous benefits that make the testing process faster, more cost-effective and more ecologically friendly in the long term.

The streets of the world hauled into the lab — many benefits for an efficient development process

The ETC's greatest improvement over the BMW Group's previous test facilities is the extreme realism of the tests conducted there. At the ETC, it is for the first time possible to conduct test drives under environmental influences within a facility. In this way, the ETC combines the reality of driving on the street, including airflow, temperature, precipitation, solar radiation, humidity and even altitude with the characteristic properties of a test facility: constant and reproducible test conditions — the basic requirement for optimal comparability of test results. For the first time, environmental effects can be simulated at a test facility almost flawlessly and thus be checked much more precisely than ever before. Apart from vertical forces, lateral dynamics, steering movements and crosswinds, all effects on the vehicle while driving can be reproduced. This makes the BMW Group the leader in realistic environmental simulation at a test facility.

"With the ETC, we're bringing the street into the lab."

(Jürgen Engelmann)

This relocation of test drives into test facilities bears a number of benefits to the entire development process. Short routes, interdisciplinary cooperation, good working conditions, precision and reproducibility, a lack of seasonal dependence and the reduction of the number of prototypes, to name a few.

No matter what time of year: midsummer in winter.

Thanks to extraordinarily realistic environmental simulation, it is now possible for the first time to test the effects of all environmental conditions on the vehicle and its components, regardless of the time of year. Until now, tests had to be irregularly distributed across the year. Most test drives typically took place from November to February and from June to July, since optimal "extreme conditions" prevail in different parts of the world at these times of year. In Southern France, South Africa, Scandinavia or Alaska, tests were carried out under extreme heat or cold as to whether the engine management worked correctly or was compromised by excessively high or low temperatures, for example. Due to the great dependence on outdoor conditions, these tests can normally only take place within a limited time frame, and even then, it's still not certain that optimal testing conditions will prevail.

Conducting test drives worldwide entails laborious planning and high logistics costs. Besides prototypes, supply and workshop vehicles come along for the trip, as well as a complete team of engineers, mechanics and other specialists. This all means costs, complex logistics and, not least, CO_2 emissions through long-distance transport.

"If we want to, we can have midsummer in winter at the ETC — and snow in midsummer."

(Jürgen Engelmann)

At the ETC, climate zones and conditions are available "at the push of a button". This makes dependency on the time of year, test sites and climate conditions a thing of the past for many tests. Tests can be carried out at the time that is best for the development process and under precisely defined conditions, and all that in-house, in the middle of the Research and Innovation Centre in Munich. This not only yields cost benefits, but also means more precise testing results with greater data protection.

"FIZ location advantage"— expertise concentrated in one place.
With the ETC, the BMW Group has a very versatile, broad-ranging test facility directly at the heart of the BMW Group's development network. The BMW Group is thus combining its validation knowledge in one place. If necessary, all developers involved are immediately on the spot and can track the course of the test "live". Laborious travel and transfers are cut. Nearness to the test facility also allows development engineers to be available for other tasks. If they are supervising several projects, they can still attend to their daily business, take part in meetings or continue working at nearby workstations in parallel to the test at the ETC.

The physical proximity is especially beneficial for necessary changes or repairs to test vehicles. Particularly in early development stages, the first prototypes must be continuously technically enhanced, which now and again leads to problems during test driving abroad. At the ETC, it is very simple to remove the vehicle from the test process and repair or convert it at on-site workshops. The necessary resources lie directly at the ETC; the workshops themselves are even integrated into the test centre.

Networking of competencies — synergistic cooperation across disciplines.
The concentration of testing competency in one place helps bring about new zones of development. Test engineers used to go on test drives for several days or weeks with the test vehicle. It wasn't possible to randomly "drop by" a test. In contrast, the test facility reinforces the networking of competencies and thus multidimensional analysis of results.

"In traditional engineering work, measurements responded to questions that you hadn't even posed. This sometimes made it difficult to interpret results. Through networking at the test facility, however, these answers are immediately recognised as such and directly linked to the corresponding question."

(Jürgen Engelmann)

There is an additional appeal to the new test setting in the interplay between vehicle design and validation on the one hand and technology development on the other hand. Due to the fact that different interest groups are united under one roof, engineers obtain a mutual look into the work of their colleagues. In this way, valuable knowledge networking takes place almost by itself, from which all developmental disciplines benefit. Precisely reproducible test cycles, for example, make meaningful test results quickly available, which can immediately be further utilised and incorporated into the development process. This considerably accelerates the validation process.

If several test teams are catered to at the same time, the connection between the test cell automation system and the central control units of the vehicle allows engineers to track how the different test aspects are behaving in real time. And since many interest groups can see the control units at the same time, a complete new depth and breadth of usable results is achieved that mutually compensate each other. Through the differentiated view of results, testing parties can come to new conclusions. Besides that, not only the development engineer, but also the on-site operator can now contribute knowledge about the test facility's behaviour and experiences from similar tests.

Greater availability and improved utilisation of prototypes.
Independence from outdoor conditions, such as time of year, precipitation, and so on, significantly clears up the test calendar. A great advantage of this is that not as many prototypes are necessary for the same number of tests, since the tests no longer have to take place simultaneously. Now, a single prototype can be used for quite a bit more testing; the number of tests per prototype rises. In addition, different departments can keep track of various test interests using a mutual test vehicle. This allows several components to be tested at the same time within one test process. These synergy effects were taken into account while planning the ETC and applied to equipping the individual test facilities. Test sequences are no longer considered vehicle specific, but test specific. The development engineers no longer orient themselves on when the prototype is available, but rather when what test is run and whether their own tests can be carried out with the prototype.

Especially in the early development phase, high utilisation of as few prototypes as possible is very worthwhile, since the first test vehicles are built laboriously by hand and are thus cost-intensive. The prototypes tested at the ETC can also be tested in an early project development phase, when they are not yet suitable for the street.; for example, engine cooling can already be tested, even if certain chassis control systems are not yet fully functional.

"At the ETC, individual characteristics of the later vehicle are already tangible and testable at a very early phase. Our objective is to secure characteristics that yield added value for the customer as early on as possible.

(Dr. Johannes Liebl, Manager of Efficient Dynamics)

Testing that closely resembles the customer's reality.
Another important aspect that the ETC addresses is the minimisation of differences between the test and actual customer demands on vehicles. With the new ETC test centre, the BMW Group would also like to test much more customer-oriented test cycles that reflect actual driving behaviour. On a European and global level, fuel consumption, for example, is measured using standardised fuel consumption cycles (e.g. KV01) that don't necessarily correspond to customer use. This is particularly because the standard depicts a very simplified driving cycle, which doesn't reflect the driving behaviour in detail. Contrary to customer demands, the standard cycle includes, for example, significantly less driving segments that are high in fuel consumption, such as stop-&-go in the city or cold starts. Besides that, any devices that consume electricity, such as lights, radio and air-conditioning are deactivated if possible.

During the customer-oriented tests at the test facility, fuel consumption can be measured "online" at the ETC. Unlike with test drives on the street, measuring devices show test engineers, for the duration of the cycle, how much the vehicle is currently consuming and can thus "track" which load ranges involve more intensive fuel consumption than others. Also, previously unimplemented tests become possible at the ETC. In especially high-load cycles, such as high-speed driving, consumption can for the first time be measured in real time — and that under actual environmental conditions, such as air flow, temperature or altitude.

Modern test environment lowers costs and fuel consumption — spot-on part design.
The ETC bears especially great potential for expanding Efficient Dynamics, because, more the anything else, the sum of many little

individual measures accounts for the success of this strategy across the entire vehicle fleet. Even measures that help save a tenth of a gram of CO_2 make a significant difference. These reductions can't be "realised", tested and tracked anywhere better than in a state-of-the-art, highly sensitive and precise test facility — such as the ETC.

The "street" testing environment has limitations to its accuracy and doesn't always deliver reproducible results. That's why a certain degree of over sizing is calculated into component layout. At the ETC, all components can be designed and validated precisely for their most intense of demands. Using accurate measurement technology, the development engineers determine exactly what loads exists to what part under particular demands. They can come to appropriate conclusions as to how the part must be furnished in order to meet the desired requirements. The positive effect is evident in several places: every part and every gram of material that can be saved reduces costs and CO_2 emissions — in production as well as while driving, since the vehicle consumes less fuel due to less weight. The effect of the spot-on development of parts quickly increases several-fold with the number of components to be developed. And for parts that are electrically powered, the power consumption also changes with the size. Thus the ETC also unlocks new possibilities in vehicle development for the design and validation process and at the same time helps to save on costs.

Process benefits are customer benefits.
Altogether, the link between dynamics, comfort, efficiency and sustainability can be tracked and implemented even better with the ETC. Above all, this means the customer benefits from the ETC and an optimised development process. Efficient operational strategies can be developed and tested here. At the same time, the high quality of test results from the ETC allows the BMW Group's development engineers to gain more knowledge that flows directly into vehicle development. The vehicles are optimally designed and put into application, consume less fuel and therefore emit less CO_2 — and that without reducing dynamics, safety or comfort. The customer receives a well-engineered product within a shorter period of time.

Right now, alternative drive technologies are already being intensely investigated at the ETC. Through the comprehensive testing environment, the best conditions have been achieved for developing innovative technologies and making them usable right up to the start of production. In this way, the customer will enjoy the innovative advantage of the BMW Group's vehicles in the future as well. The products can be even better adapted to the needs of the particular markets. Besides that, faster development allows for greater variety and therefore a greater selection.

Altogether, the BMW Group is making a clear signal with the ETC for the consistent advancement of research and innovation with regard to process efficiency, sustainability and responsible handling of resources. In this effort, the ETC is an important component for the BMW Group for further claiming its innovation leadership and being on the cutting edge of sustainable and resource-friendly mobility.

3. What happens at the ETC? Or: The Weather Maker.

The task of a sustainable test setting is to provide instruments and methods for designing and validating components and efficiently supporting their interplay. The tests conducted at the test facility realistically represent all demands of vehicle life and also cover as many driving scenarios in customer operation as possible. The BMW Group's new Energy and Environmental Test Centre (ETC) also performs a lot more: it is a "visionary test setting" with equipment that already covers all future mobility concepts, and their design and validation requirements.

"The new Energy and Environmental Test Centre is the Swiss army knife of the BMW group for developing new solutions for sustainable mobility. We have everything here that we need for day-to-day validation and can at the same time advance in areas that will be current in five to ten years."

(Peter Hoff, ETC Project Planning)

Through the possibility of simulating environmental influences extremely realistically, cars and motorcycles can be driven for the first time in a test facility at high altitudes, in rain, sun or snow. In this way, operational and functional validation at the test facility takes on an entirely new dimension. Through different driving profiles, the test facility systems simulate conditions of driving in the mountains or on the motorway, for example, to develop economical and efficient operational strategies for vehicles. This is a big relief, especially for such areas as optimisation of engine and transmission applications, but also for hybridisation of vehicles, since tests on the street, which weren't able to be gauged so precisely or at all, can now be carried out in the precisely adjustable environment of the test facility. With exhaust and consumption measurements during different driving cycles, as well as measurements of the behaviour of the engine-transmission combination in the event of sudden changes to load specifications, new optimisation potentials can be identified and unlocked for dynamics, consumption and exhaust composition.

Altogether, the ETC addresses five comprehensive development and validation topics that mutually complement each other. They are energy and heat management, thermal operational safety, low-temperature behaviour, operational and functional validation under environmental conditions, and the development and functional validation of the air-conditioning / heating. Tests that require longer periods of time, such as corrosion, fatigue strength, and durability or mileage tests, however, are not conducted at the ETC.

The ETC test facilities — all the streets of the world under one roof.
The ETC has a total of five test facilities that each possess important unique features, but that also share some similar or identical functions and capabilities. This redundancy was planned intentionally in order to ensure a certain flexibility in the use of test facilities. That means that a test process is not tied to a certain test facility, but rather some tests can be carried out at different test facilities.

"Not every test facility must be able to do everything, but each one must be able to do the right thing. At the ETC, we've accomplished this through intelligent equipment combinations for the tunnels and can now test near to reality and hands-on."

(Peter Hoff)

While implementing the ETC's testing environment, on the one hand maximum coverage of requirements was factored in, in order to be able to work as well as possible. On the other hand, however, costs and energy were supposed to be reduced. At centre stage were all requirements of the departments for simulating and checking particular functions and tasks. But next, not only were all demands fulfilled, but the test setting was realistically tailored to the requirements of the corporate development departments. That means that not every test facility offers all functions, but overall the test facilities cover any environmental simulation that is worth testing.

Three thermal wind tunnels and two climatic test chambers — five individual test benches in a class of their own.
On the one hand, the ETC consists of three specifically equipped wind tunnels: "a thermal wind tunnel", a "climatic wind tunnel" and an "environmental wind tunnel". These three test facilities serve primarily component and system validation under extreme situations, such as heat,

cold, rain and snow. Through the identical conception of the three wind tunnels in size and geometry, it is ensured that test engineers from the various development departments can switch between the tunnels while maintaining the same flow quality, without this negatively affecting test results. Thus, optimal comparability with the greatest possible flexibility is a given for standard tests.

One architectonic feature is the vertical airflow of the wind tunnels. Here, the wind is fed back above the test facility after having left the testing section. There is a fan in this return airflow about fifteen metres above the plenum. In order to achieve circulation that is as realistic as possible, the air is guided through an 8.4 square-metre nozzle when entering the test section and the plenum is appropriately large. This vertical, space-saving arrangement also allows for a process-optimal arrangement of the three test facilities.

Besides the three wind tunnels, the two test chambers, the "altitude test chamber" and the "cold test chamber", support, for example, the design and validation of the heating / air-conditioning systems and allow for emission measurements under high altitude or cold conditions.

Besides the testing area, each test facility has a control room. The test cell is operated and supervised from here. A state-of-the-art test cell automation system controls all components and monitors hundred of parameters. It reports whether the rollers are moving, the fan is turning, at what speed the wind is blowing and whether the cooling machines are running. Without such a system, operation of such a complex test facility would be impossible. The automation system makes it possible to conduct highly dynamic tests with alternating environmental conditions reproducibly, and in detail. During the drive cycle, the technician monitors the course of the test mostly on a computer — and thus has hundreds of recorded values in sight and under control. That means he immediately realises if something has gone awry, and can act accordingly. Intelligent door locking systems and video surveillance of the test facilities contribute to the safety of everyone involved.

In each of these vehicle test facilities, the vehicle is fixed in place and connected to the floor, meaning that it doesn't move forward. In order to still be able to simulate the street in the laboratory, first of all, wind-tunnel technology is put to use, and second of all, four roller drives are installed in the floor of every test facility. These cylindrical rollers have a circumference of up to two metres and simulate moving ground at each of the four wheels. The rollers work like dynamos on a bike and can thus produce various longitudinal dynamics driving situations. For acceleration tests, and uphill or high-speed driving, the roller applies appropriate resistance for the situation and brakes the vehicle. The rollers function as generators and feed the electricity recovered from braking into the BMW power supply.

"The rollers in the test facility are our street — but a street that never ends and that can go uphill and downhill endlessly. If a roller at the test facility is supposed to simulate a drive down the Großglockner High Alpine Road, it more or less pushes the vehicle down the 'mountain' in the same way that grade resistance does so with a car on a real mountain."

(Roland Kleemann, ETC Methods and Test Facilities)

Since driving situations can change very rapidly, the rollers must be able to adapt very quickly. If, for example, emergency braking on a motorway were to be simulated at 100 km/h, the rollers at the ETC can effect an adjustment within 50 milliseconds, which is only half as long as the blink of a human eye. And that with incredible accuracy: The speed synchronisation between the four rollers occurs with a maximum variance of just plus/minus 0.05 km/h. This and the fact that the largest roller drives can yield a maximum output of up to 1.4 megawatts makes them one of the technical highlights at the ETC.

The thermal wind tunnel — Stay "cool".
The thermal wind tunnel is essentially for thermal management and its range of functions are designed accordingly. Here, high vehicle loads are normally driven, such as high-load driving with a trailer or high-speed in extreme heat over a long period of time. The objective here is to simulate and track all tests that establish critical load limits that the customer would drive in "real life". However, mere high-speed driving on the motorway alone isn't especially interesting, but rather the load change: if you drive for a long time on the motorway at maximum load, and get stuck in a traffic jam shortly afterwards, it results in high load on the cooling system, since there is no more headwind supporting the cooling. In this case, cooling capacity drastically drops, but the

hot engine still produces quite a bit of waste heat. In these critical situations, the cooling system must still be capable of disposing of the waste heat.

Since the thermal wind tunnel is especially designed for tests on cooling performance and thermal operational safety, the achievable temperature range is from 20°C to 45°C. The fan produces wind speeds of up to 280 km/h in order to simulate very high-speed drives as well. In addition, it is the only test facility that has an accessible centre pit with a glass floor, which allows thermographic tests of the undercarriage.

The climatic wind tunnel — Acceleration like a BMW M5.
Basically identical to the thermal wind tunnel, the climatic wind tunnel offers a few special features. Besides thermal part validation, it also focuses on testing air-conditioning, brake cooling and high dynamics tests. With wind speeds of up to 250 km/h, the climatic wind tunnel can't match the highest speed of the thermal wind tunnel, but its fan can accelerate more quickly. Through the use of especially rigid and lightweight carbon fibre rotary blades — instead of aluminium blades as in the other chambers — even the acceleration of a BMW M5 can be reproduced in order to validate its cooling behaviour along the Nürburgring, for example.

In addition, the climatic wind channel can simulate the sun. Calibrated at up to 1,200 watts per square metre, 24 high-performance emitters in this test facility provide for real and homogeneous solar radiation. This is particularly advantageous for extended tests on cooling performance. As a special strain to the vehicle cooling system, it is placed in full sunshine and "protected from the wind", after a simulated high-load drive with a heavy trailer. Besides warm atmospheric air and lack of wind, the vehicle is also exposed to a high ground temperature that can be even higher than the air temperature. Here as well, the essential release of waste heat is tested and validated so that no part becomes too hot. To ensure that no more air movement occurs, a shutter closes the nozzle within five seconds. Air vents to the side of and above the jet meanwhile provide for continuous temperature regulation of the test facility.

Besides numerous hot land tests, even negative atmospheric temperatures as low as minus 10° C can be reproduced for testing and optimising the interplay between interior heating and engine cooling, for example. In this wind tunnel, tests are also conducted on air-conditioning design. Conception and validation place particular emphasis on the loads while the engine runs idly, or while standing still, ascending and during stop-and-go cycles, as in city traffic. An important aspect with potential for the future is the interplay between heat management and air conditioning.

The environmental wind tunnel – snow storm in summer.
However, the design and validation process in vehicle development not only applies to tests in the heat or cold. The objective of the tests is also to ensure operational and road safety under all weather conditions — rain, snow, heat or cold, and altitudes. With the "complex environmental simulation", the ETC offers the unique opportunity to expose test vehicles to the most diverse of weather conditions.

The main requirement for a realistic environmental simulation is uniform air flow up to high speeds that also surround the vehicle with a certain flow quality. High air flow quality means that circulation of the vehicle in the test facility is nearly identical to actual circulation when driving on the street. Furthermore, additional factors, such as humidity, temperature, sun, rain and snow must be implemented, which must each exist either constantly or simultaneously in specific combinations and alternations. With the ETC, it is now possible to integrate these requirements into one test bench: the environmental wind tunnel.

"With the environmental wind tunnel, the BMW Group for the first time has the opportunity to be able to test all environmental factors individually or combined in one single test cell. This allows diverse environmental situations to be reproduced true to detail and extremely realistically."

(Christa Hornreich; developed the methods for the thermal test facilities)

Besides the sun simulation, the environmental wind tunnel also has systems for simulating precipitation. Test engineers can create rain and snow — and that in different intensities. Even the composition of the snow can be varied between dry and wet — powdery snow or sleet. The following example demonstrates how laborious snow tests used to be in Alaska or Scandinavia. A particularly critical driving situation in Nordic countries is driving behind a lorry on a snow-covered street. The lorry whips up a cloud of snow through which the cars behind it have to drive. The snow is so fine that it gets caught in the intake system of the engine and can plug up the air filter. In this case, the engine switches off due to lack of air. If these conditions are supposed to be tested, the situation takes hours to set up. Three vehicles and drivers were always required for comparison. All this can now be achieved much more simply and securely: If necessary, the snow gun extends outward and simulates the cloud of snow. No driver is necessary for this test.

Examples of other tests that can take place in the environmental wind tunnel include the testing and optimisation of the windscreen wiper or of the water management concept in the A-pillar for keeping the side window clear of water flowing downwards and the side mirror from being dirtied. Tests can also be carried out on air-conditioning functionality in hot countries or the design of the heating system in cold countries. Brake cooling checks are also conducted here using a special measuring system. Altogether, a temperature range of minus 20°C to plus 55°C can be simulated in the environmental wind tunnel.

Another great feature of the environmental wind tunnel is the flat belt for exposing even motorcycles to certain environmental conditions at the test bench and measuring the effects. The opportunity to test motorcycles in these environmental situations is new and unique. The advantage of the flat belt is its high simulation quality for street driving. As opposed to driving on rollers, not only the drive wheels of the vehicle move, but the entire floor underneath them. This is especially important for motorcycles, because air flow that strongly supports cooling performance is created through rotation of the front wheel. (With motorcycles, the radiator is behind the front wheel.) If the front wheel didn't turn, the test results would be worthless. That's why it is of great importance for validating the cooling system or developing the cooling system's air intake that the entire motorcycle moves in the test facility as though it were driving on the street. What's more, it's even possible to drive the motorcycle "hot" on the flat belt up to certain speeds — meaning with a test driver. In all other cases, the motorcycle is fixed in place and run from the control room.

The altitude test chamber — very high up.

The altitude test chamber is the "highlight" of the ETC. At first sight, it closely resembles the cold test chamber, but, at second glance, a few differences are noticeable. The display panel at the test bench has an additional information field labelled “Altitude”. Another difference is the unusually thick windows with specially reinforced frames and a massive steel door that separates the control room from the test section. The test cell can only be entered via a pressure-tight door. This is necessary, because the facility is used to simulate altitude. The altitude test chamber enables test driving at 4,200 m above sea level, which is equivalent to an absolute pressure of 620 millibars. Up to 400 millibars of pressure difference separate the control room and test section.

"The altitude test chamber can best be compared with a submarine. The pressure conditions and application of force to the outer hull are similar."

(Christa Hornreich)

A large fan evacuates the entire test section, but still manages equalisation between the air that the engine requires for combustion and the exhaust that it produces. Positive pressure can also be produced so that, in Munich, conditions both at sea level and in Alpine passes can be simulated. Among other things, this is important for alignment with previous measurements at the test site in Miramas, Southern France.

But the test facility can do a lot more. In addition to the air pressure, a temperature range of minus 30°C to plus 45°C can be established, the humidity is variable and the test cell has a solar simulation system. This makes complete environmental simulation possible. Practically all climate zones in the world can be simulated here.

Even though this test facility is considerably smaller than the thermal wind tunnels, it possesses the appropriate wind tunnel quality. Thanks to laborious simulations, the BMW Group's test facility designers and aerodynamics experts have succeeded in realising an aerodynamically superior test facility in a very small space. After all, the jet measures two square metres — a novelty for an altitude test chamber — and thus allows for very good air flow at the engine compartment. The collector at the rear also provides for defined outlet flow in the vehicle's rear area and along the undercarriage. The entire airflow is optimally designed to reduce losses and prevent flow separation. Thanks to all these measures, wind speeds of 250 km/h are able to be simulated even at this test rig, with a realistic air flow up to the vehicle's A pillar.

A further unique feature of the test cell is the integrated measurement technology for fuel consumption and emissions. While in other test facilities the measurement equipment is installed in the vehicle, here it is incorporated into the test cell. A modern CVS exhaust measurement system enables measurements that are relevant for vehicle homologation under conditions of altitude, cold and heat. The measurement equipment is suitable for reliably detecting even minimal emissions, as future legislation specifies. Through the expanded speed and temperature range compared to regular exhaust emission test facilities, here devices that reduce fuel consumption can also be tested outside of legal cycles, because Efficient Dynamics incorporates the entire driving range relevant to customers. With all these features, the altitude test chamber is the ideal test facility for engine development.

The altitude test chamber and new the BMW TwinPower Turbo four-cylinder engine.

The altitude test chamber features ideal conditions for helping engineers optimally design and apply engines. The new BMW TwinPower Turbo four-cylinder engine demonstrates this impressively, because in the development of this engine, engineers already relied on test methods that make use of the altitude test chamber. As the first BMW four-cylinder engine with the High Precision Injection direct petrol injection system and VALVETRONIC fully variable valve control, the newly developed engine is setting standards for cost-effectiveness at the highest level of performance. The charging system, in particular, contributes to the extremely direct responses of the new engine because it separates the two conduits of two cylinders from the other two both in the exhaust manifold and the turbocharger itself, according to the TwinScroll principle.

Especially for engines with turbochargers, testing their behaviour at high altitudes is very important, because, for example, the boost pressure of the turbocharger must constantly be adjusted to different altitudes. The higher the vehicle drives, the lower the surrounding air pressure becomes. In order to be able to ensure that the engine maintains optimal torque and performance at high altitude, the control electronics must equalise the very different environmental conditions through intelligent regulation of the boost pressure. In addition, the regulation must ensure that the turbocharger's permissible rpm level is not exceeded due to the higher relative boost pressures that are possible at high altitude. Changes to the boost pressure, as well as the effectiveness of appropriate countermeasures, can be very easily determined and applied in the altitude test chamber. The new BMW TwinPower Turbo four-cylinder engine is optimally adjusted in this area.

Tests on emissions that are relevant to vehicle registration will continue to be conducted at the altitude test chamber. One such test concerns the regulation of emissions via fuel tank ventilation. With increasing altitude, more and more fuel escapes from the tank in the form of gas. These gases, however, must not be released into the environment, but instead fed into the engine and combusted. A special valve controls tank ventilation and its opening rate must be adjusted to the altitude level. With the so-called "Denver cycle", it is then checked in a simulated altitude of 1,620 metres whether the emission limits are maintained for the American market or whether the valve's opening behaviour must be further optimised.

Colorado in Munich.

After basic calibration in the engine test facility, fine adjustment of the drive train normally used to have to be carried out in laborious test drives in places like Colorado. The altitude test chamber now allows the test engineer to carry over his work from calibration to the fine adjustment at the ETC. Test results and methods can be carried over. Important test subjects at the altitude test facility are the application of the turbocharger and adjustment of the vehicle's exhaust aftertreatment, among other things.

The fuel supply system is another important focal point of testing. Just like water starts to boil at lower temperatures at high altitudes, the boiling point of fuel also sinks, meaning that greater amounts of it evaporate higher up. For this reason, the fuel injection must be adjusted. The evaporating fuel is recovered and fed back to the engine. This lowers fuel consumption and protects the environment.

In addition, the on-board diagnostics function (OBS) is applied in this test cell. This is a complex in-vehicle diagnostics system that is active while driving. It monitors all engine and transmission functions and informs the driver immediately when a malfunction occurs. This allows emissions-relevant problems to be identified early on so that they can be quickly eliminated. The system monitors dozens of functions and must work in all driving situations, under all environmental conditions. In the USA, proof of a functioning OBD in the course of a defined driving cycle is part of vehicle homologation.

After successful application of all individual components, a real up-hill drive can be simulated in the altitude test chamber as a final test, with appropriate inclination and increasing altitude, as well as decreasing temperature.

The optimisation of exhaust emissions and fuel consumption is a special area of vehicle development, which extends far beyond engine development and concerns the entire vehicle development. The critical values are specified by law and tightened at regular intervals. In addition, different countries focus on different aspects in their regulations. The development of vehicles that, on the one hand, comply with these regulations and, on the other hand, offer the greatest degree of comfort and dynamics for the customer is an enormous challenge. In this special climatic test chamber, the topic can be investigated in its entirety. The test engineer can perform and evaluate a legally prescribed driving cycle here and a typical BMW cycle as well.

The cold test chamber — ice age at the ETC.

As the smallest ETC test bench, the cold test chamber in particular addresses tests that involve very low temperatures. Since the tests here don't require complete vehicle air flow, the costly routing of air flow is eliminated and the test facility can be built much smaller. The wind produced is only for cooling the engine and thus ensuring that no vehicle components are damaged.

The tests in this test facility include cold starting tests and the testing of battery functionality under extreme conditions, design and functional testing of the heating system, and window defrosting. For this, the vehicle is iced with water at minus 20°. Then the engine is started and the in-vehicle heating set for defrost to make sure that the heating / air-conditioning system de-ices the windscreen within a specified time frame. For better traceability of the de-icing tests, the cold chamber offers the so-called "Automatic Defrost Analysis System". By means of four cameras at the front, both sides of the vehicle and rear, an image-processing system automatically records how quickly the windows are de-iced by the vehicle's interior heating. The recordings can be used to analyse, compare and evaluate different conduits and design strategies. This process was already developed 16 years ago and a modernised version is now being brought into the ETC again. The test is relevant for approval, as well as the proof of fulfilment of country-specific specifications (ECE, USA, Japan type approval, etc.) for defogging of the front and rear windows. This function is subject to certain conditions due to safety reasons: each vehicle must gain a clear window within a certain specified time frame that is legally specified and differs depending on the market. To check adherence to specifications, a device is placed on the driver's seat that uses steam to produce high humidity in the passenger compartment and fogs up the windows. The heating / air-conditioning system's "window dehumidification / ventilation" function now ensures that the windows are clear within the prescribed time frame. The results assist in the development and optimisation of ventilation openings for the passenger compartment.

Preconditioning times used to have to be specially factored into test facility scheduling for tests under extremely cold conditions. These "dead times" are a thing of the past at the ETC; the vehicles are already brought into the test benches preconditioned.

Soak rooms — shock-freezing for vehicles.
A big contribution to the efficient test process is situated in the basement of the ETC — the preconditioning rooms, also called "soak rooms". The thermal preconditioning of vehicles for all test cells takes place in these eight little chambers. Here, the vehicles can be brought to a temperature between minus 40°C and plus 55°C prior to testing, depending on whether a simulation of hot or cold country conditions or even snow tests are to be conducted. Furthermore, the chambers have an electrical socket so that electric cars can be charged during conditioning. A soak room is equipped with an exhaust fume extractor. Here, simple starting tests are carried out. In this way, no test cell has to be occupied for such tests.

The special thing about the concept of the soak rooms is the conscious separation of preparation and execution of tests. In other testing environments, the vehicles have to be brought to temperature over several hours at the test facility. During this drawn-out conditioning, no tests can take place. Thanks to the soak rooms at the ETC, however, parallel preconditioning of vehicles and rapid utilisation of test benches is possible without long waiting or usage times. The test cells are only occupied for the duration of the test, which allows for far more tests within little time and thus far better utilisation of the test facility. If, for example, two vehicles are supposed to be tested under the same conditions, one is brought to the test bench and the other remains in the soak room at temperature. As soon as the first vehicle is done, the second one comes into the test facility at the correct temperature and the tests proceed. At the ETC, transition times for vehicle changing are only about half an hour, as opposed to often several hours in the old testing environment in Aschheim.

The warm soak area is located not far away from the eight soak rooms and offers ten storage spaces. Here, the vehicles are brought to a temperature of 24°C on a large surface for exhaust tests. Especially with these tests, exact temperature regulation and brief occupation of test facilities without a drop in temperature are of great importance.

Short route principle — everything interlocks.
In order to ensure rapid operations, the ETC was built consistently according to the short route principle. It was also carefully ensured that test-ready vehicles can be brought to the test facility as quickly as possible. The vehicles make it from the basement into the test facility level by means of two lifts with special temperature regulation systems and low humidity. The vehicles, which have been cooled to a temperature as low as minus 30°C, would immediately ice up if the humidity in the lift were greater. During upward transport, rotary discs bring the vehicle into position so that it can immediately be moved into the test facility and the test can start. In order to keep transport routes as short as possible for the vehicles, lifts are in place between the test facilities in which preconditioned vehicles are tested.

Behind the scenes of the test benches — the infrastructure of the ETC.

"It was especially important during conception and realisation to make the short distances possible. The ETC is very compact and set up in a very limited space."

(Peter Hoff, ETC Project Planning)

Altogether, the ETC extends over three floors and two intermediate floors, but the test cells are all on one level, the ground floor. An architecture was created in which the main vehicle movements only take place on one level. Thanks to short routes, the vehicles make it to the test facilities more quickly, which, in turn, means swifter results. All areas of operation that are test-related, but do not necessarily require immediate proximity to the test facilities, are situated on the first floor and the basement and are connected to the test facility level via lifts. While in the basement the vehicles are brought to the required temperature in the "soak rooms", workshops are located on the first floor for vehicles that need to undergo even greater modifications for the testing process.

Before a vehicle comes into the test facility, whether its a car or motorcycle, it passes through the Central Space. Here, in the central entry area of the ETC and directly in front of the test facilities, the last modifications take place for test facility operation. Up to seven vehicles can be converted and prepared in parallel. The specification for development departments that vehicles have to be delivered test-ready to the ETC makes for quick cycles.

Firstly the vehicles receive their so-called roller tyres. They keep the test facilities clean and safe, since high load is applied to the tyres on the roller. More precisely, the tyre rolls on the edge of a roller and not on the "flat" street. In addition, the vehicle restraint system, with which the vehicle is later fixed in place, is pre-fitted. Tests with the engine running require a special connection to the exhaust fume extractor, which is also attached in the Central Space. The mechanics wire the vehicles so that the test data can be monitored from the control room. An electronic accelerator pedal is also installed here. It allows the test cell technician to accelerate the vehicle from the control room, because during test operation no one is normally sitting in the car. The computer controls each vehicle precisely according to specifications, in order to ensure reproducibility of conditions and results.

A small room with many functions is just off to the side of the central space. Here, all tasks can be conducted that require an enclosed room for preparation. Test vehicles can be filled up with special fuel types. The room has its own fueling system that not only supplies the vehicle with fuel, but also drains and collects it. Reuse of fuel demonstrates how sustainable and extremely efficient the ETC's testing setup is, down to the smallest detail. Here, winter diesel is available year-round, in order to be able to carry out realistic cold tests even in the summer. Moreover, the multi-functional room has a very effective ventilation system due to strict safety conditions for handling special fuels, which is why it can also be used as a quick-dry chamber for vehicles that are delivered wet.

4. Bringing the street into the lab.

Only through realistic testing can it be determined whether an innovative idea is capable of being realised. It is then determined whether the theory is compliant with real-life demands. That's why test drives have been and remain an indispensable component of vehicle development and validation for the BMW Group. The prototypes cover many millions of miles of test drives at testing sites and on streets round the world. The vehicles must prove themselves during test drives in Alaska and Scandinavia in the cold and snow. Test engineers drive them through rain and wetlands in order to test air-conditioning under tropical conditions or check the effects of low-oxygen mountain air on engine management across Alpine summits or in the Rocky Mountains, and much more. Beyond that, the test vehicles are driven at high speed through the heat of the desert in South Africa and finally through stop-and-go traffic in the lively inner city of Tokyo. And this list goes on.

Test drives provide the BMW Group's development engineers with valuable knowledge on the behaviour of individual components, as well as behaviour of the whole vehicle. But on-street test drives involve a great deal of time and effort on the part of people and vehicles, they don't always take place under optimal conditions, and they normally can't be repeated indefinitely with the desired parameters. With the BMW Group's new Energy and Environmental Test Centre (ETC), this is all changing.

"In the new test facilities, cars experience conditions within a few hours for which they used to have to be sent around the world: Alaska, South Africa, Switzerland..."

(Dr. Johannes Liebl, Manager of Efficient Dynamics)

Many test drives can now take place within the new ETC test facilities. The realistic simulation of environmental conditions, such as heat, cold, altitude or precipitation unlocks completely new testing possibilities at the testing facility. The test drives can be carried out at the ETC within hours or days, regardless of outdoor conditions, such as time of year or day, temperature or precipitation — instead of within several weeks or even months like before. By combining different test facilities in conjunction with the well thought-out test methods of the method engineers, ideal test conditions can be produced at the ETC all year round.

The question used to arise: Test drive or test facility?

Tests on the street deliver meaningful and realistic results for the development and validation of vehicles. However, test drives are significantly more demanding to carry out and also more difficult to analyse than tests at a test facility. In particular, the reproducibility of test conditions presents an enormous challenge on the street. Due to the dependency on external factors, one drive — and one measurement — can barely resemble another. One example: a typical test drive for validating the thermal management consists of ascending a winding mountain road several times with a heavy trailer in midsummer. However, numerous unpredictable factors, such as cyclists, randomly occurring heavy traffic, erratic reactions of other drivers, detours or variances in temperature and weather make it nearly impossible to drive the same route twice in a row under exactly the same conditions — whether with regard to time, speed, ambient temperature or load changes. The results of the two test drives can't be easily compared and their significance must be interpreted by test engineers.

With test drives at a test facility, the test conditions can be optimally reproduced, while measurement and analysis technology records every change to the vehicle. However, in the previous generation of state-of-the-art test facilities, the tests still didn't completely simulate the sum of a drive's demands under actual conditions. The results could still not be directly carried over; interpretation still had to be done.

"We used to always have to face the decision: test at the test facility under adjustable and reproducible parameters — with detriments to realism. Or test on the street under realistic conditions that aren't reproducible. It wasn't possible to have both at the same time. Now it is."

(Roland Kleemann, ETC Methods and Test Facilities)

At the ETC: test drive at the test facility — the best of both worlds.
With the ETC, the BMW Group's development engineers have succeeded in combining the worlds of "street" and "test facility". Through its equipment, the ETC offers significantly enhanced testing possibilities compared to previous test facilities.

"The arrangement of five climatic test cells under one roof provides us with unique test possibilities for our vehicles. All tests can take place within an extremely brief period of time — a vehicle virtually goes around the world within eight hours."

(Roland Kleemann)

For the first time, highly dynamic tests can now be conducted in a climatic test facility. Driving profiles can be simulated at the test facility just like the customer actually drives on the street — with acceleration and braking. With the "environmental simulation", all environmental conditions of street driving are brought into the test facility. The ability to simulate sun, rain, snow, wind, humidity and even altitude unlocks entirely new test worlds — in the truest sense of the word. At the ETC, test drives can take place that were only able to be carried out in South Africa, Tokyo or Alaska, due to the conditions that prevail there. The data from the test facility are reproducible and show very precisely whether parts are fulfilling their function or whether certain functional strategies are actually helping to save fuel.

Many benefits for man, machine and environment.
The new test facility bears many benefits, especially with respect to procedures. A number of test drives in hot and cold countries that are very laborious, expensive and CO_2-intensive can now occur at the ETC regardless of the time of year, which translates into significantly greater cost-effectiveness and environmental compatibility. This makes the overall development process shorter and simpler. The cleaned up test calendar allows for considerably improved utilisation of test facilities, while employing less test vehicles, since they are no longer gone for weeks on test runs. Troublesome transfer times are omitted and test engineers no longer have to fly throughout the world to distant test areas. In addition, the significant post-analysis results are immediately available.

With all efforts to bring the street into the lab, one thing is important to the BMW Group: the ETC is no replacement for test drives on the street, nor is it supposed to be. It's more of an efficient supplement. That's why the BMW Group's engineers take into careful consideration what trials and test drives they conduct at the ETC and which ones on the street; for example, tests for the subjective evaluation of driving qualities, such as comfort, starting behaviour or longitudinal acceleration in curves and along slopes must be done on the street or at the testing grounds, because such factors are only really able to be evaluated there. Especially during on-street driving, new requirements for development engineers arise time and again through adjustment to the "world and perception of the customer".

"There will always be on-street tests, since only then can driving behaviour be tested under true street conditions. The subjective driving feeling of the test driver and test engineers — the so-called "butt-o-meter"—is a measuring device that we don't want to overlook."

(Roland Kleemann)

How do we bring the street into the test facility? - Method development.

To bring the street into the lab, optimally-equipped test facilities are needed, for one thing. However, at least as important are the test methods that allow realistic drives to be carried out at test facilities and thus take full advantage of the ETC's preconditions. The objective is to simulate the environmental conditions of an on-street test drive at the test facility as realistically as possible — to produce the requirements of the test engineers at the test facility through a particular test set-up.

"Only a correctly configured test method can make the test facility into a street."

(Roland Kleemann; worked closely together with the test engineers in method development to bring the "street into the lab")

The procedure for test method development is divided into several phases. After all requirements of the developmental and validation departments have been incorporated, it is decided what tests can be carried out at the ETC and for which of them it makes sense. Once the appropriate tests have been identified, the relevant street data are calibrated and the test facility is "taught" so that a particular driving scenario can run there at the push of a button. Subsequently, the test cycle is validated and verified by the test engineers.

Requirement management — who wants what and why?
In the first step in creating the ETC, the tests that exist in the company were recorded. In a systematic survey of demand, test-method developers asked all potential "test customers" from the company's entire development area — over fifty departments altogether including Motor Sports and Motorcycle — what their test requirements were, what their ideal test stand would look like and what parameters were especially important to them. However, the goal of the survey wasn't to blindly fulfil every need with the ETC. It was more to put together a range of tests that provided for maximisation of substitutability in conjunction with a visionary testing architecture. A test facility environment that meets all necessary requirements for carrying over as many tests as possible from the street to the test facility and at the same time taking into account the prerequisites of automobiles of the future, such as special test cycles for hybrid, electric or hydrogen-powered vehicles.

That's why the departments must also make their requirements plausible and in line with the survey of demand; in other words they must explain why they need what they're requesting. Besides identification of all test issues, it must first and foremost be clarified which of the tests can be carried over to the test facility and for which of them it makes sense. At the ETC, only those tests were put into action that either couldn't be conducted on the street or could be done in the lab better and more cheaply.

A mountain within the test facility.
As soon as the demand was identified and plausible demands were accepted, the BMW Group's experts began developing the correct testing methods for the particular test.

> "The test facility can simulate nearly any load that occurs in nature. The decisive factor is the correct combination of individual parameters. Only then do the measurements exhibit no apparent difference from on-street driving."
>
> (Roland Kleemann)

But there's still a long way to go before a vehicle at the test facility actually exhibits no differences to an outdoor test drive. This is demonstrated, for instance, by the dynamic up-hill drive with a trailer at Mont Ventoux. The test scenario: a test vehicle drives up the difficult mountain road in midsummer with a heavy trailer attached in order to deliberately bring certain vehicle components to the limits of their thermal capacities. Simulating all test-relevant conditions of this drive at the test facility was only one of many challenges for the test-method developers. Not only environmental conditions, such as temperature and solar radiation, have to be simulated, but also the rolling, drag and grade resistance as well as the drive cycle must be correctly produced at the test facility.

A requirement for this is a model in the form of a physical description of the previous on-street test procedure. The test engineers record their street reference tests and note the vehicle, street and environmental conditions during the drive. The drive has a multidimensional character, from the drive over land and motorway, which serve to pre-condition the vehicle, to the actual test drive on the mountain. The measurement equipment makes a recording of the relevant parameters of the vehicle and environment every tenth of a second. This includes constantly changing driving resistance, which consists of tyre friction, air friction, drag and mass inertia. Also, environmental conditions, such as wind, temperature, air pressure, humidity, precipitation and solar radiation — all result-relevant factors that are later simulated and regulated individually at the test facility — are put together as a profile. The sun profile, for example, represents sunshine at each point in time during the test. The individual "partial realities" form the starting point for later substitution of the on-street test at the test facility.

> "We systematically combine data obtained in reality and thus achieve an artificial replacement reality at the test facility. At the end, there's a sort of 'test choreography' and we can simulate a mountain in Southern France at the push of a button."
>
> (Roland Kleemann)

The test facilities at the ETC even allow the simulation of drives with trailers without actually having to pull a trailer in the rear. The increased driving resistance of having a trailer in tow is exerted upon the vehicle's drive train by means of the test cell's dynamometer. A graphical line in the form of a mathematical function demonstrates what resistance much be overcome in order to keep a vehicle consistently at test speed and what forces must be simulated by the test facility's rollers. An example: To maintain a speed of 80 km/h on level ground, a BMW 5 Series Touring requires a constant thrust of 430 newtons to overcome rolling resistance and drag. The same vehicle accompanied by a two-tonne trailer, however, requires a thrust of 1,380 newtons to drive at a constant speed of 80 km/h — in other words, three times as much. The correct, specific values for driving resistance on the drive train of the vehicle to be tested are automatically available at the ETC throughout the entire dynamic test cycle through comprehensive data acquisition. The values are even temperature-adjusted, since the vehicle's air resistance is somewhat greater in the cold than in the heat.

In close cooperation with the test customers, the ETC offers a range of over 150 test drives that can be simulated. They include tests on driving dynamics at the Stelvio Pass, brake tests at the Großglockner or rain tests at high speed. Especially with high-speed driving, the shift to the ETC's test facility environment also contributes to increasing personal safety. Drives in the critical range demand extreme concentration on the part of the test engineers. At the test facility, however, the driver himself sits safely at the control room at high speeds and monitors the test results.

Future test topics were also taken into account in method development. The test-method developers thus work together with the departments on cycles for which there is not yet any data set. The BMW Group's test engineers are performing ground-breaking work particularly in the areas of development and validation of hybrid and electric vehicles.

The synthesis of route profiles — now it's getting efficient.

With the appropriate test methods, it's possible to set up and drive nearly any route profile at the ETC. The test engineer receives a test profile that corresponds precisely to the desired on-street drive. For efficient vehicle development, however, quick achievement of the test and validation objective counts more than anything. The ideal route profile for the intended purpose might not be found among the streets of this world. Here, the second step of method development begins: the synthesis of route profiles. This term encompasses the simplification and condensation of fundamental segments of certain profiles that are important for tests. The original profile serves the engineers as a mere starting point.

"The objective of synthesis is to produce identical vehicle states within a brief period of time. Non-essential parts of a test drive in reality are simply "cut out".

(Roland Kleemann)

Based on real driving, a new profile is supposed to be created that is as simple to describe and reproduce as possible, but at least as meaningful. For this, segments are removed from the test process that don't have any influence on the result, e.g. curves that can only be driven through slowly or any starting time for preconditioning. The condensation of route profiles already provides the results after a shorter period of time and saves on valuable resources, since the test facility is not needlessly in operation.

In addition, the ETC allows the calibrated and synthesised profiles to be linked with each other, i.e. to combine properties of different test routes into a single long-route profile.

"But we're developing replacement profiles here that bring us to the set development objective faster. We can create entirely new test routes that represent a conglomerate of demanding route segments. In this way, we can theoretically start driving in the morning in a Norwegian snow flurry and test the air-conditioning three hours later in stop-and-go traffic in Naples at summer temperatures. In one room, with one car."

(Roland Kleemann)

The synthesis of route profiles is only one part of the path to an optimal testing environment. The test-method developers work on defining uniform specifications for vehicle validation, e.g. loading and traction forces, that should apply depending on the test and model. Such standards ensure the comparability of test results with real on-street tests and allow for efficient and valid validation at the ETC.

From the street into the lab — for real this time.
After data acquisition, method development, synthesis of routes and their implementation into the test facilities, methods are finally validated. The reliability of partial realities simulated at the test facility is put to the test, as well as the consistency of on-street testing results with those of the test facility. Only then can the test facility be used.

The ambitious goal is to run specified tests at the test facility only and to conduct on-street testing only sporadically. In the future, the ETC in Munich will cover 80 percent of all tests in the areas of thermal operational security, energy and heat management and low-temperature operational behaviour, as well as operational and functional validation under various environmental conditions.

Visionary tests — at the ETC, the future is now: Efficient Dynamics — charge balancing.
The relocation of on-street testing to the test facility bears numerous benefits for future developments in line with efficiency research as well. An accurate test facility is an absolute requirement, particularly for the development of energy consumption reduction measures. At the ETC, certain measurements are possible with previously unavailable precision. For

instance, when determining CO_2 emissions, measures can now be identified that provide for a reduction of up to one gram of CO_2/km. What was hidden in the measurement uncertainty of the on-street tests due to exterior influences, and thus couldn't be analysed, can now be clearly demonstrated at the ETC. This is of great significance, particularly for the Efficient Dynamics strategy, since it also and especially builds on the combined effect of numerous smaller measures.

But not only current measures for increasing efficiency and preventing emissions are addressed at the ETC. Test methods for research topics and forms of mobility of the future are also being developed here. An especially important test that is already able to be effectively and precisely simulated at the test facility now is charge balancing of the vehicle battery. Using battery balancing, the influence of different devices that consume electricity can be checked under certain clearly defined conditions. In the near future, this will include the research and development of new operational strategies, such as anticipatory energy management. The vehicle is conditioned such that all its parameters are oriented on optimal efficiency or dynamics. To save energy, the car battery should, for example, not be charged immediately if it falls below a certain voltage, but rather once it makes the most sense, i.e. in case of an ascent or predictable braking, such as at a red light.

The equipment of the test facilities and the synthesised test cycles at the ETC allow for vehicles to be adjusted as best as possible and to completely take advantage of savings potentials. In the long term, with respect to increasing electrification and hybridisation of vehicles, this is becoming especially significant, which is why engineers are already developing special test profiles for electric vehicles. A hybrid simulator provides the energy for the power source and is at the same time equipped with highly sensitive sensors so that engineers can read the current energy demand in real time and make appropriate assumptions regarding energy-consuming parts and their influence. This is unmatched as of yet and a good example of how even developers' future-oriented test requirements are carried over and implemented.

5. Sustainability at the BMW Group — Efficient Dynamics = Efficient Testing.

The BMW Group sets the standard of helping to design the future. Sustainable action, in particular, should provide for long-term added value for the company, environment and society, as a fixed design principle of future processes. This means that the BMW Group's concept for sustainability has many facets. Economically, ecologically and socially, the BMW Group takes on responsibility and has deeply embedded sustainability in its corporate strategy as a fundamental principle.

Particularly in a difficult economic environment, future-oriented growth is a requirement for being able to take advantage of the opportunities that a crisis presents in the long term. That's why growth, an active concept for future development, and access to new technologies and customers, are among the BMW Group's four strategic approaches. For the BMW Group, this means investment in the future, in the truest meaning of the phrase. In this, the company especially concentrates on profitability and long-term value increase, because sustainable business activity is necessary to achieve a breeding ground for sustainable success.

The best-known and by far most successful sustainability product strategy by the BMW Group up to now is Efficient Dynamics. With this strategy and the innovative package of measures already in place, the BMW Group is succeeding in resolving what used to be considered a trade-off: the reduction of fuel consumption and CO2 emissions with a simultaneous rise in driving dynamics and engine performance. Above all, this strategy provides for significant reduction of fuel consumption and emissions across the vehicle fleet. The new Energy and Environmental Test Centre makes a decisive contribution to the further development of this strategy.

Efficient testing – the BMW Group's Energy and Environmental Test Centre.
The fundamental principle of sustainability is applied not only in the Efficient Dynamics product strategy, but also in the efficient design of development processes. An important step in this direction is the BMW

Group's new Energy and Environmental Test Centre (ETC), which reflects all three facets of sustainability through economic, ecological and socially responsible action.

As a new, important process-building block, the ETC reduces the duration of development through centralisation and the fact that it is unaffected by seasonal weather conditions. The intelligently arranged and comprehensive equipment also allows for efficient development of promising mobility concepts for the future. The ETC is a conscious investment in the future of the BMW Group — and thus in the future of mobility.

The ecological balance sheet of the ETC speaks for itself.
Even in the conception of the ETC, project supervisors consistently paid attention to conservative use resources. Through intelligent architecture and efficient test-facility design, the ETC allows for ecologically sustainable operation.

So that nearly all environmental conditions, such as solar radiation, heat, cold, precipitation and even altitude can be realistically simulated using one test facility, large wind and cooling systems are necessary, as well as systems for producing sunshine or precipitation. The concept of the system is oriented for maximum energy efficiency.

This intelligent energy management manifests itself in all parts of the ETC's test facility equipment. During a test drive, for example, the test facility's dynamometers absorb the drive energy of the vehicle and convert it into electricity using an integrated generator. The fuel consumed is thus made usable in the form of electric energy. Active recuperation is also put into use with the test facilities' central fans. In the event of dynamic load changes, for example, the fan is often accelerated in brief sequences and then slowed down again. Through braking energy recovery, as also used in vehicles with BMW Efficient Dynamics, each application of the brakes transforms the braking energy into electricity.

"Each test facility is a little power plant. As soon as a test facility is put into action, not only is energy used, but also regenerated."

(Jürgen Engelmann, Manager of ETC operations)

The test cells are especially well insulated and thus their temperatures can be very efficiently regulated. In addition, rotary and exhaust gas heat exchangers provide for heat recovery from escaping heat of up to 75 percent. To not only to recover heat as well as possible, but also to prevent even using too much of it in the first place, the ETC transformers are intelligently networked. In this way, fewer transformers are necessary, which reduces waste heat through idle losses.

Cold on demand — efficient cooling.
Compared to typical cooling systems, the cooling of ETC test facilities is designed in an especially refined manner. Here, a cascading cooling concept is applied. If a central cold storage unit were used for all temperature ranges, the production and permanent provision of cooling would be especially energy-intensive, because this generates an enormous cold reserve in the form of brine at minus 50°C, which is then accessed whenever necessary. However, its maintenance entails high energy costs, even when no cooling is necessary. At the ETC, this problem is resolved with the principle "Cold on demand". In this manner, only as much cooling is provided as is needed at the moment. Different stages of the cooling system then become active, depending on the test facility's cooling requirements. The permanent cooling rate is held at a minimum and cooling operates very energy efficiently.

"With the cascading cooling system at the ETC, we are meeting the high standard that the BMW Group has set for itself to handle resources responsibly."

(Peter Hoff, ETC Project Planning)

The first level of cascading cooling is called "free cooling" and is permanently active. With it, the ambient air of the ETC is used to cool the test facility. If it is 35°C in the test facility, for example, but only 10°C outside, the colder outdoor air can be used to cool the test facility without high energy costs,
because even a "warm" test facility must constantly be cooled in order to

maintain the required temperature. The temperature begins to rise in the test facility the moment the vehicle is driven under load. Besides the vehicle's waste heat, the fan also emits a portion of its operating energy in the form of frictional heat and, in turn, heats the air of the test cell.

If the free cooling is no longer sufficient or lower temperatures are required, the second level activates, the "normal cold". One of the two cooling modules switches on, depending on needs. Only once low negative temperatures are required is one of the other cooling machines activated, which have operating ranges comprising of low temperatures.

In addition to the cascading of the systems, each test facility has its own cooling circuit. The individual cooling circuits mean altogether less energy consumption, since smaller cooling systems can be put into operation and not always alongside large ones. Only the environmental wind tunnel and climatic wind tunnel share a cooling circuit, since both test cells have to fulfil similar requirements and rarely require intense cooling at the same time. The operators of the ETC pay special attention to this in facility scheduling. The introduction of coincidence factors for two test benches provides for a much better utilisation of cooling systems and allows them to permanently run at an optimal operating point — ten megawatts of energy consumption were able to be eliminated just through this measure.

During planning, the sustainability principle was also applied to the handling of drinking water. At least 80 percent of the water required at the ETC consists of ground water that is specially allocated for industrial use — so-called culvert water. It is used for any process technology, for the hybrid pressure cooling plants on the roof of the building, and in the sanitary facilities. Valuable drinking water is only used in the technical centres and social areas for technical and hygienic reasons.

The ETC's CO_2 balance sheet.
Not only the testing systems work very efficiently. Thanks to the ETC's environmental simulation, a portion of the test drives can now take place at the test facility. Apart from benefits to the vehicle development process of an integrated testing site that isn't affected by seasonal weather conditions, CO_2 can also be considerably reduced through the relocation of test drives into 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-street testing, due to insufficiently stable conditions.

Furthermore, the ETC allows repeated tests to be conducted with scientific precision due to its laboratory-like conditions. This means that the influence of individual components can be systematically checked at a level of detail that unlocks the potential for further energy reduction. New control levers are revealed for reduction potentials through the accuracy of results under laboratory conditions. If a BMW Efficient Dynamics measure identifies the potential for even just 0.1 grams CO_2/km of reduction through the possibilities of the new ETC testing environment, and this was applied to all new vehicles, 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 taking on social responsibility. This is demonstrated by treatment of employees from the testing departments. The commissioning of the ETC is accompanied by a restructuring of the BMW Group's testing and validation processes and also therefore the working conditions of the test engineers.

Through the relocation of many test drives to the ETC, previous work loads are dropped, such as frequent gruelling travel and work under extreme climatic conditions. At the ETC, new, valuable positions have also been created for technicians, who are selected within the BMW Group and provided with advanced training as part of a qualification initiative.

6. Data and facts: the BMW Group's new Energy and Environmental Test Centre.

Construction data	
Construction began	June 2007
Topping out ceremony	June 2008
Wind on in the wind tunnels	January 2010
Employees move-in	December 2009
Total amount of concrete	16,400 m3
Total amount of reinforcing steel	2,900 t
Total façade surface	6,850 m2
Total investment on building, technology and equipment	130 million euros

Building data	
Building length	51 m
Building width	75 m
Building height	22 m
Number of floors	6
Gross floor area	14,840 m2

Thermal wind tunnels	
Floor surface of plenum (length/width)	13.6 x 10 m
Air flow	vertical
Fan diameter	4,750 mm
Max. fan rpm	455-518 rpm
Fan power	1,500-2,060 kW
Max. wind speed	250-280 km/h
Total volume of air duct	3,072 m3

Altitude test facility	
Floor surface of plenum (length/width)	12 x 6 m
Air flow	vertical
Fan diameter	2,240 mm
Fan rpm	1,350 rpm
Fan power	900 kW
Max. wind speed	250 km/h
Total volume of air duct	505 m3

Cold test facility	
Floor surface of plenum (length/width)	10 x 5 m
Air flow	vertical
Fan diameter	1,000 mm
Fan rpm	1,760 rpm
Fan power	110 kW
Max. wind speed	130 km/h

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