# 16
# Automotive applications of smart textiles

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**Abstract:** Smart textiles have become a new topic in vehicle engineering. New applications in the automotive industry seem to have potential and may give access to entirely new system approaches. This chapter presents some of them and focuses especially on the potential of measuring physiological parameters such as heart rate, electrodermal activity and others. Investigations on prototype systems of car seats and steering wheels will be discussed.

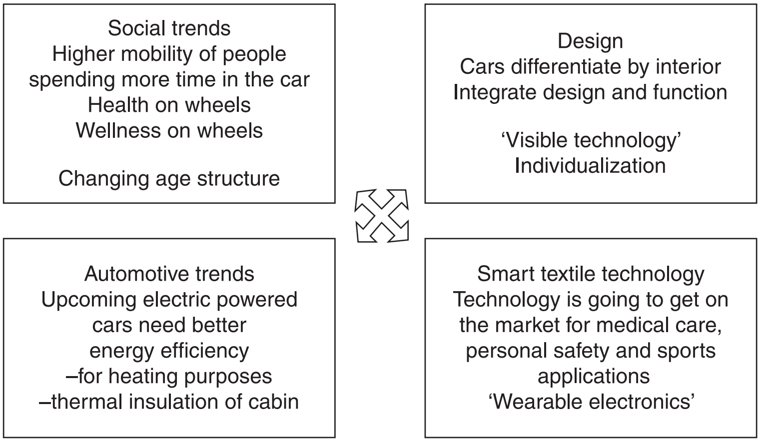
**Key words:** smart textiles, car seats, capacitive coupled electrocardiogram, textile multilayer electrode, vital parameters, sensor steering wheel, INSITEX.

## 16.1 Introduction

Smart textiles have become a new topic in vehicle engineering, although they are not yet being used in mass-produced vehicles. Why is it important for car firms to get involved in this new technology? Cars are products with a long lifecycle. It can take between 25 and 30 years to develop a new car design from the start of research up to its production and the organization of spare parts supply. New technologies are generally not sufficiently reliable to be used immediately in automobiles and so the consumer goods industry is way ahead because of its far shorter production cycle. However, it is precisely this relatively long production cycle that makes it indispensable for the automobile industry to keep in touch with and make use of new technologies. The potential change in consumer attitudes also has to be taken into account.

Futurology analyzes trends in consumer attitudes and markets. One of those researching future trends, M. Horx from the German ‘Zukunftsinstitut’ [1] has, for example, published a list of megatrends [2] comprising individualization, urbanization and behaviour, which he has called ‘the new aging’ (Fig. 16.1).

Some social trends important for the automobile market are individualization and the increase in average age of populations (and therefore customers) in Europe and the US. It is also important to note a change in behaviour amongst younger consumers; they like to have access to a car when they need to be mobile, but they do not need to own the car. It is also clear that the modern consumer is far more conscious of his/her health in all areas of daily life. As the job market requires high mobility, the customer spends more and more time in his/her car. ‘Health on wheels’ and ‘wellness on wheels’ are new areas of research where new applications are needed. Prototypes of smart-textile systems show that there are new




*16.1* Social and technological trends (source: Daimler AG/Manfred Wagner).

opportunities for applications in cars to meet such needs. Sections 16.3 and 16.4 will deal with these applications more closely.

Even the design of car components proves this trend to shape the interiors of the car to our own taste [3]. This is especially apparent for the seats of a car, where mainstream vehicles have followed the example of luxury cars. Smart textiles may enable 'visible design', the combination of functionality and design. Currently in demand are health and protective clothing applications based on smart-textile technology. Some of these products and prototypes will be considered in Section 16.3. Section 16.5 points out that there is at present a mismatch between the requirements of the automotive industry and the state-of-the-art of smart textiles. Qualification standardization is necessary and has already started. The irreversible trend in purely electrically operated cars opens up the appliance of smart textiles in lightweight construction, heat insulation and power efficiency. Some of these appliances with regard to automobiles will be considered in Section 16.6.

## 16.2 The use of textiles in vehicles

Textile elements can be used in both the interior and the exterior (e.g. canvas tops) of cars; however, most of the applications are located in the interior. Typical textile components are seats, seatbelts, fabric covers for roofs, floors, side walls and sometimes parts of the dashboard. The textile surface is responsible for the sensory and aesthetic appearance of the interior and therefore the feeling of quality experienced by the customer. This is especially true where passengers have direct contact with the textile surface, for example with the seat and armrest. The seat is the component with the most contact with the passenger. Fabric-covered seats are widely used in standard models, though they are less common in the luxury car market where customers choose leather-covered seats. More detailed information on automotive textiles in general is available in other research [4].

### 16.2.1 Classification of textile intelligence

The integration of microelectronic devices into textile products has taken place during the last decade. The terms used for these new textile systems are 'intelligent textiles' or 'smart textiles'. Unfortunately, the terms have different meanings for different people. The draft of the new standard CEN/TR 16298 (DIN SPEC 60298):2012-02 *Textiles and textile products – Smart textiles – Definitions, categorisation, applications and standardization needs* includes a classification of textile systems (Table 16.1) [5].

### 16.2.2 Potential applications of smart-textile technology in vehicles

Car interiors are well-suited to the first applications of smart textiles in vehicles. On the one hand, textiles have already been in use for some time in car interiors and research into their handling and testing is available. However, requirements concerning environmental conditions are much lower in this field than in exterior applications. It is common knowledge that applications relating to heating, lighting and sensor functions will have the highest initial potential for car applications. Interior components that can be combined with textile sensors based on smart-textile technology are discussed below. More detail will be presented in Sections 16.3 and 16.4.

*Table 16.1* Classification of textile intelligence

| System | Characteristics | Example |
|---|---|---|
| Textile material | Material made of textile fibres, for use together with another textile or non-textile products or stand-alone | |
| Functional textile material | Textile material modified by structure, treatment or characteristic of the textile fibre | Spacer fabrics, Ag coating |
| Smart-textile material *or* intelligent textile material | Functional textile material which can interact actively with the environment (sensor/actor) | ECG T-shirt |

*Seat*

Seats and steering wheels are the components that are in contact with the driver throughout the driving experience and therefore the seat is one of the most popular components in which to integrate sensors for measuring the driver's condition.

*Seatbelt*

Sensors might be integrated in the seatbelt too; for example, breathing activity can be measured by the deflection of the seatbelt. This is not a major task for textile sensors, because this signal can be taken by the belt retractor. The integration of textile electrocardiography (ECG) sensors into seatbelts is becoming of interest, because the position of the seatbelt is always near the heart. Seatbelts as safety-related components are submitted to a strict test and qualification process, and therefore sensor integration needs intensive coordination in development and production. New extended test methods with safety requirements have to be defined.

*Roof and floor*

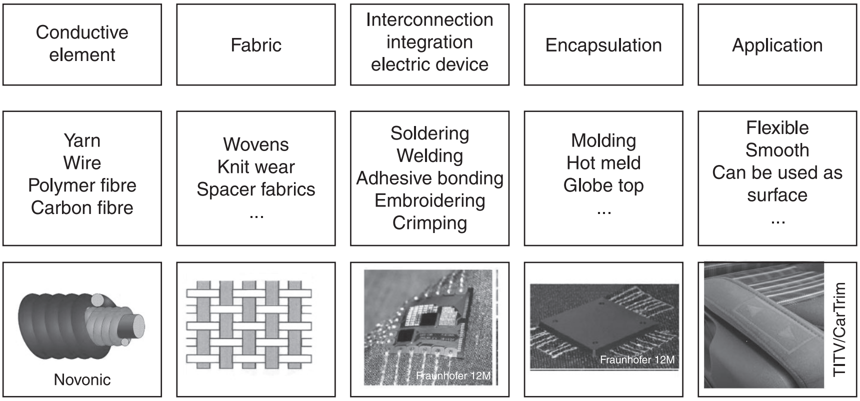
Integration of capacitive matrix structures for recognizing the position of the passengers can be envisaged, as can lighting as a design element and for ambient illumination.

*Steering wheel*

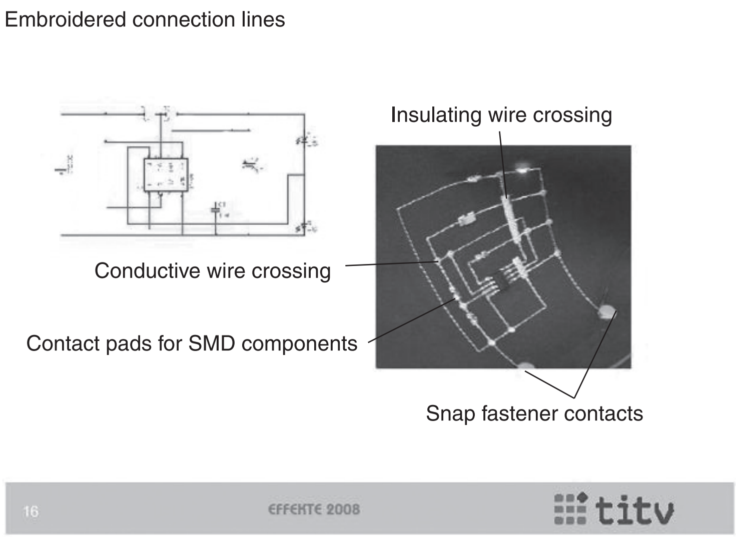
The steering wheel is, along with the seat and the seatbelt, a component that is in contact with the driver all the time. Therefore the steering wheel is also a candidate for integration of sensor functions. Steering wheels usually have a surface of wood, leather or plastic and are therefore not a typically textile component. Conductive yarns in the seams of a leather cover can provide a contact electrode to measure vital parameters [6].

The process flow of making a smart-textile system is shown in Fig. 16.2. Some special components, technologies and processes are necessary. Some of them have to be adapted to vehicle requirements or new developments have to be undertaken.

First, a conductive element is needed. This may be a yarn, as the one shown in Fig. 16.2, which is a multi-filament yarn [7] with a combination of conductive and insulating threads. Making a yarn conductive is usually done by plating it with a conductive layer such as Ag or Cu. A metal wire, a carbon fibre or a special polymer fibre could also be used. The integration of this conductive element in a fabric by a textile process such as, for example, weaving, delivers the base material for the application. Depending on the application, this basic fabric contains an arrangement of parallel conductive elements, a matrix arrangement, or even




*16.2* Smart-textile process (source: Daimler AG, Manfred Wagner with use of pictures of [45], [8], [34]).




*16.3* Textile circuit board [45] (source: TITV).

conductive planes. For producing electrode structures, spacer fabric technology is one of the most popular processes. The next step is connecting electronic devices, for example microsystems, by appropriate interconnection technologies. This may be done by soldering, welding, adhesive bonding or by special textile techniques such as embroidering with conductive yarns or fibres. Through embroidering, a fully textile circuit board can be produced (Fig. 16.3).

Crimping is a new interconnection method in textile technology. A suitable crimping method was developed by Fraunhofer IZM [8] in the INSITEX project [9]. For automotive environments in particular, interconnection technology is one of the most critical topics. As discussed in more detail in Section 16.5, the standard automotive test schedule applies cycled mechanical loads to the textile, and the interconnection must withstand these tests without failing. Reliability and durability over the component's lifetime is an automotive requirement. The typical lifetime requirement is defined as up to 15 years.

Environmental conditions also produce the need to shield the electronic components by encapsulation. Different processes are known from the electronic industry as moulding, hot meld and globe top encapsulation. In addition, the aimed localization of the system in the car may demand some more requirements to the design of the smart-textile component caused by, for example, temperature, vibration or humidity. The requirements and boundary conditions of a defined application are typically detailed in a specification book.

## 16.3 Smart-textile applications and their potential for use in cars

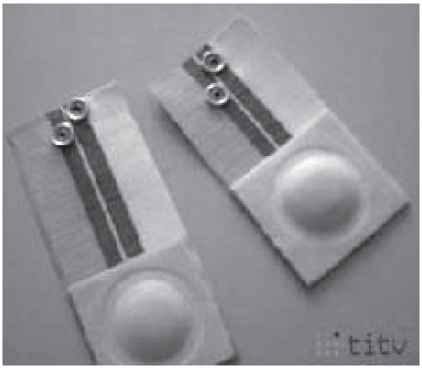
In this section, some developments of smart-textile products, which have the potential to be used in vehicle applications, will be discussed. The chosen selection is the view of the author and makes no claim to be complete.

### 16.3.1 ECG T-shirt and textile electrode

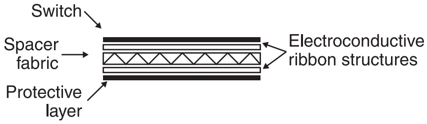
Long-term monitoring of heart disease patients was one motivation to begin the development of textile capacitive electrodes and, in the European project ConText [10], contactless sensors have been developed for the purpose of measuring electromyography EMG and ECG signals. EMG measurement aims to monitor muscle activity for sport and medical applications. The capacitive electrode is connected by a textile conductor path to a miniaturized pre-processing unit, which transmits the data wirelessly to a computer for further processing. The knowledge gained here was a pre-condition of the applications discussed in Section 16.4.

### 16.3.2 Switches and touch pads

Textile switches were first incorporated into jackets and gloves for on/off and volume control, and even keypads have been demonstrated (Fig. 16.4). TITV [45] with partner CarTrim [11] has demonstrated a car seat with textile switches incorporated directly into the seat for motion control, and newer developments use spacer fabrics as the distance layer. Pushing the button connects two electro-conductive ribbon structures.




(a)




(b)

*16.4* (a, b) Textile switches (source: TITV [45]).

Another recent development is a woven two-dimensional (2-D) touchpad sensor and a one-dimensional (1-D) slide sensor using soft capacitor fibres. [12] A special conductive polymer-based capacitor fibre was used to build a fully woven 2-D touchpad sensor and a 1-D slide sensor. Smart phones and notepads have been the motivation to develop the touchpad and build a demonstrator pad of 10 cm by 15 cm. Finger touches or swipes modify the capacitance of the fabric when an alternating current is passed through the fibres. An automotive use of this device should be of high interest and press releases indicate that OEM is interested in the technology [13].

## 16.3.3 Lighting

There are different ways to light textile material, one of which is to combine textile material with incorporated conductive fibres with LEDs. Several R&D institutes have demonstrated the feasibility of this technology [14] and Philips/NL has started a commercial business with lighting textiles for home applications.

The fibre itself can be the light emitting device, as TITV demonstrated with an electroluminescent thread constructed of high conducting ELITEX®-yarns coated with electroluminescent paste. This technology can be used for creating lighting areas or lines. If the lifetime is extended to ten years or more, the use of such fibres for ambient illumination will be of high interest.

In the BMBF project, Texoled [15] researchers tried to boost integration on new levels, whereby the optical fibre itself is the light-emitting device. A stack of layers is deposited on the fibre, which builds an LED structure. The goal is to use this fibre in textile processes such as weaving to form a lighting fabric.

At the Geneva Motor Show in 2012, concept cars with light applications were exhibited [16].

## 16.4 Prototypes of smart-textiles applications in vehicles

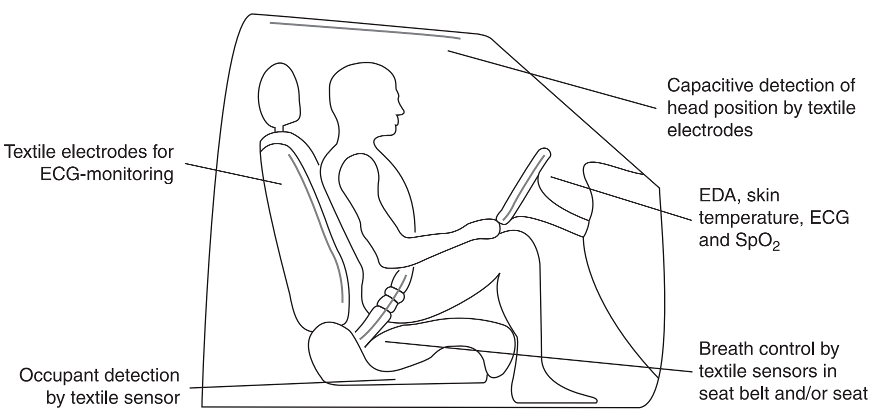
At present there is no smart-textile system in use in car production. The first prototypes of potential vehicle applications are shown in funded research projects [9, 17, 18] or by cooperation of research institutes and OEMs/suppliers [16, 20]. The BMBF [19] funded project INSITEX, 'Active Passenger Safety by Intelligent Textile Applications' [9], as the first project with an OEM participation, developed the vision of an intelligent cabin (Fig. 16.5). INSITEX focused on applications that may enhance passenger safety and can be realized by smart-textile systems.

Its goal was to apply knowledge from other smart-textile businesses, such as sport and medicine, to estimate the driver's condition. By measuring physiological parameters, such as heart rate (HR), electrodermal activity (EDA) [20], and skin temperature and oxygen saturation of the blood ($SpO_2$) [21], it should be possible to estimate attention, drowsiness and/or stress of the driver. Furthermore, the goal was to measure seating position and passenger weight classification according to FMVSS 208 [22] by a textile sensor system.

In Fig. 16.5, possible sensor locations are shown. In principle, all textile elements that are in contact or near the driver/passenger can be equipped with textile sensors. The location of the sensor also depends on the intention of the measurement:

- monitoring of the driver's condition without conscious interaction;
- conscious action of the driver or passenger to use vital signal measurement. This may be for testing health and fitness conditions or controlling another comfort system therewith.

Numerous medical investigations show the relationship between the condition of a subject and physiological parameters, such as electrical brain activity ($\alpha$-signals),




*16.5* Intelligent cabin (source: INSITEX).

HR, HR variability (HRV), EDA [20], skin temperature ($T_{skin}$), oxygen saturation of the blood $SpO_2$ [21] and some other parameters not considered here. Parameters, such as eyelid movement [23], are indicative of drowsiness of the subject, but are much better measured by optical rather than by textile sensors and will therefore not be discussed here.

EEG (electroencephalogram) is the most reliable method to measure drowsiness and $\alpha$-signals, as a measure of brain activity, are directly correlated with drowsiness [24, 25]. The measurement of the electrical activity of the brain by EEG requires electrodes directly attached to the head of the subject to be able to detect these weak signals. Often these sensor arrangements are incorporated into a sensor cap worn by the driver, which is not an object for everyday use when driving a car. However, as test equipment in a driving simulator, it is helpful. It is possible to correlate the test driver's reactions on given traffic situations to the $\alpha$-signals measured in parallel.

ECG [26] is also a well-established measurement method used in clinical as well as in mobile applications. We have to distinguish here between only measuring the HR or the HRV and real clinical applications. Measuring the HR needs only a reliable detection of the R-peak of the QRS signal. This is possible by a 2-electrode arrangement and HRV is the variability of the HR. Time periods between R-peaks can vary, which results in a heart frequency distribution. The width of this distribution is a measure of HRV, which is known as a good measure for stress [27]. Clinical application needs more than two electrodes to characterize the whole QRS complex and can diagnose possible heart diseases from this information.

EDA uses conductive electrodes to measure the EDA of the skin. In practice, this means measuring the conductivity of the skin with contact electrodes, which is mainly influenced by the humidity of the skin. Sweating, for example, changes the skin humidity, and is a physiological process correlated with stress situations [29]. Most lie detectors work on this principle.

$T_{skin}$ can be estimated by all known temperature measuring methods. Temperature is also related to the condition of the person and therefore a patent exists that correlates $T_{skin}$ to the sleepiness of a subject [30]. Nevertheless, the temperature of surfaces in a car interior is heavily influenced by environmental impacts, such as sunshine and other heat sources from car components. Skin temperature measurement in an actual car environment is not as easy as in a laboratory.

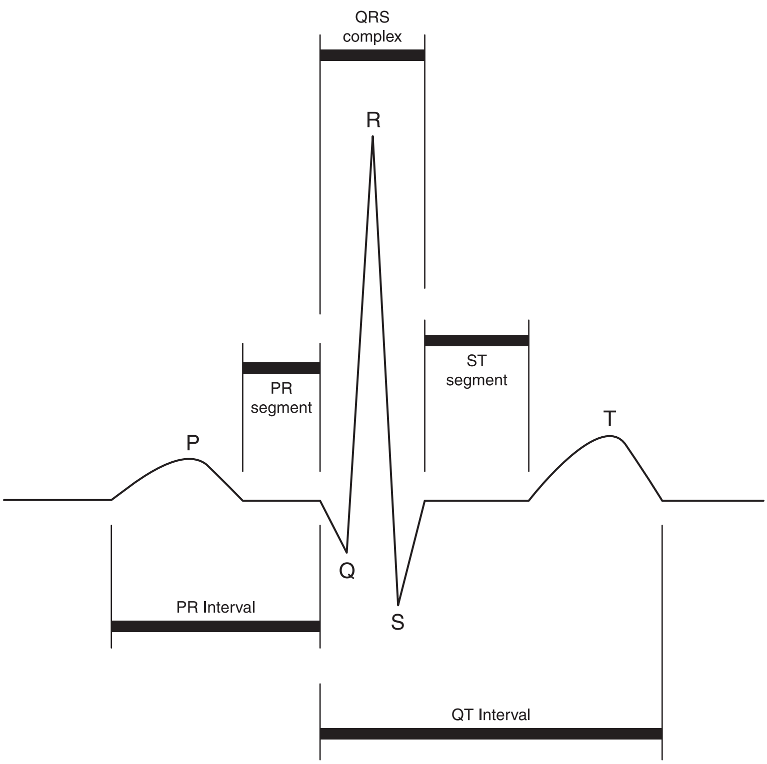
$SpO_2$ is a standard measurement in clinical applications. The signal is typically taken by a finger clamp applied to the person being diagnosed. The saturation of blood with oxygen varies with heart activity. Each time the heart ventricle is pumping blood enriched with oxygen in the lung, the saturation of oxygen is at its maximum. Between the contractions of the heart muscle, the saturation with oxygen decreases. The grade of saturation can be detected by an optical differential measurement. Therefore it is possible to calculate from the $SpO_2$ measurement the pulse, which means the HR of the subject. A runtime measurement, which uses the

R-peak as the start trigger and the arrival of the maximum oxygen saturation at the point of $SpO_2$ measurement as the stop trigger, can additionally provide a value of relative blood pressure.

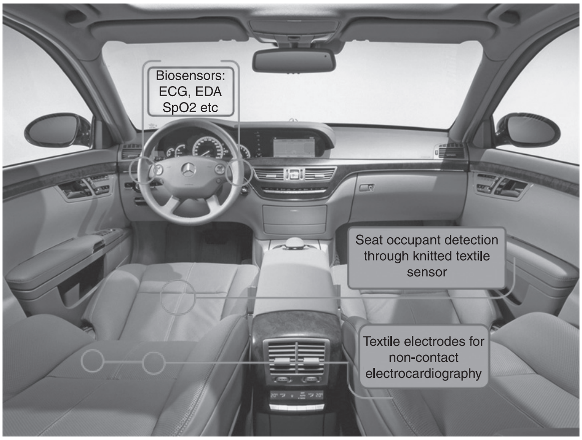
Beyond the measurement of these vital parameters, the measurement of seat occupancy detection (OCS) by textile sensor arrangement was one of the objectives of the INSITEX project. OCS is well-defined by the FMVSS 208 [23] US standard. The weight of a subject must be recognized and different cases such as no load, child, and f05 percentile have to be distinguished. In addition, the detection of the position of the seat occupant is required for different airbag scenarios. Hence the activation of the airbag should be inhibited when the passenger's position is near the dashboard.

Three prototypes have been built in the INSITEX project to demonstrate the potential of textile sensors:

- contactless ECG measurement by capacitive coupled sensors in a car seat (Fig. 16.6);
- steering wheel with vital sensors;
- a textile seat occupancy detection sensor for weight and position recognition.




*16.6* ECG signal with QRS complex [28].




*16.7* Realization of the 'intelligent cabin' vision (Mercedes S-Class) (source: Daimler AG).

Figure 16.7 shows the localization of the prototype systems in a real car environment.

### 16.4.1 ECG-seat with textile electrodes

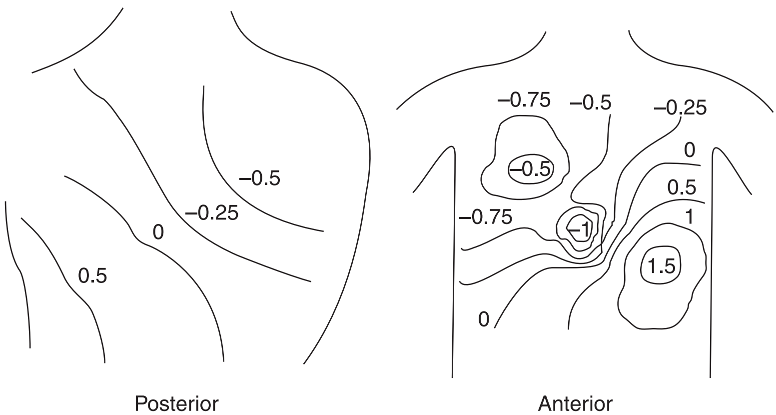
Measuring the ECG of the subject is an approach to monitor the driver's condition and to detect awareness, drowsiness or stress. HR and HRV can be calculated from ECG measurement data. Medical research has found that there is a relationship between HRV, stress and drowsiness [31]. ECG is usually measured by a contact electrode method, coupling the electrodes by gel to the skin of the patient. Contact electrodes are obviously not suitable in a car for daily use and so a contactless ECG measurement method has been established through research projects for long-term monitoring of heart disease patients and persons working with special safety clothes (e.g. firefighters) [32].

INSITEX made the approach to apply a capacitive coupled ECG measurement method to car interiors and implement it in a car seat.

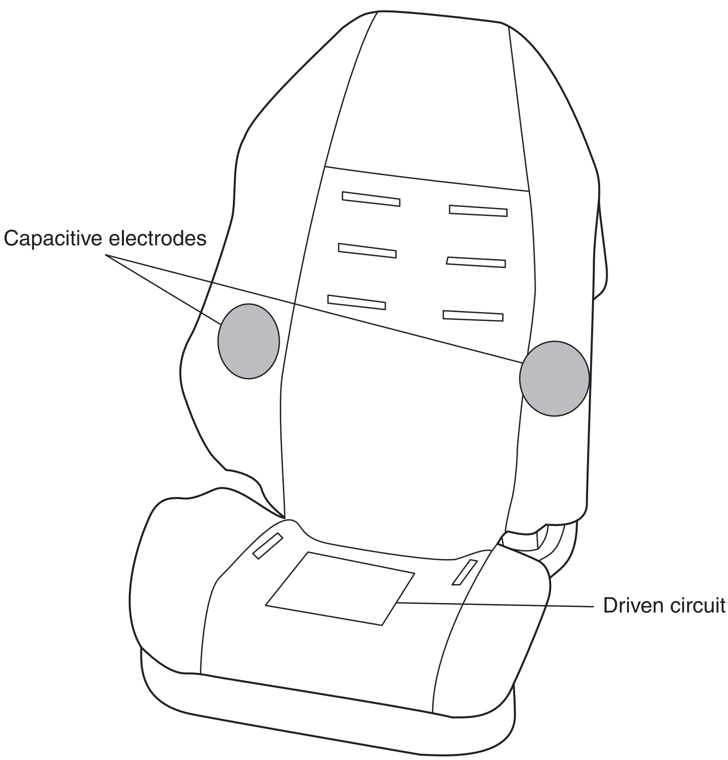
### 16.4.2 Measurement principle

Muscle activity generates an electric potential on the skin. The potential distribution of the electric field generated by the heart activity is shown in Fig. 16.8. The maximum amplitude is more than 2 mV.

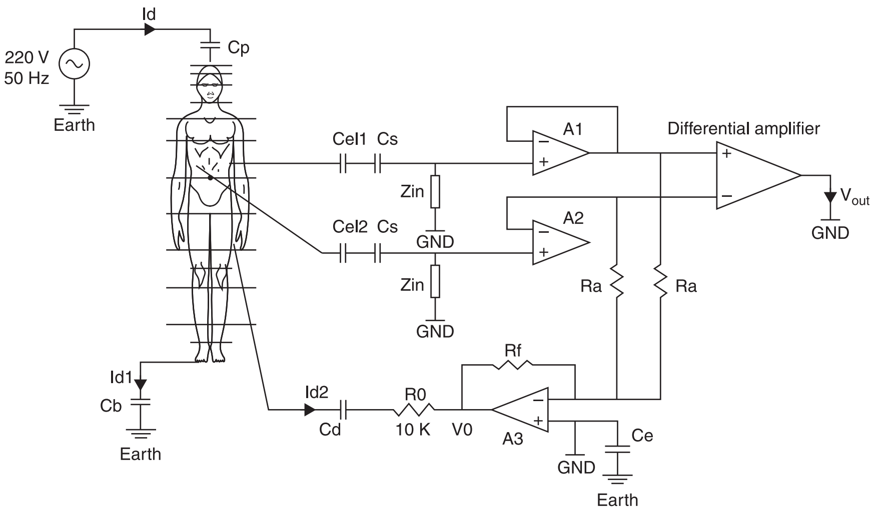
The signal is measured by a differential potential measurement with a two-electrode arrangement. Both capacitive coupled electrodes are integrated into the backrest of the car seat (Fig. 16.9) and a driven circuit method is used to reduce noise.




*16.8* Potential distribution caused by heart activity [46].




*16.9* Positions of electrodes in car seat [33].



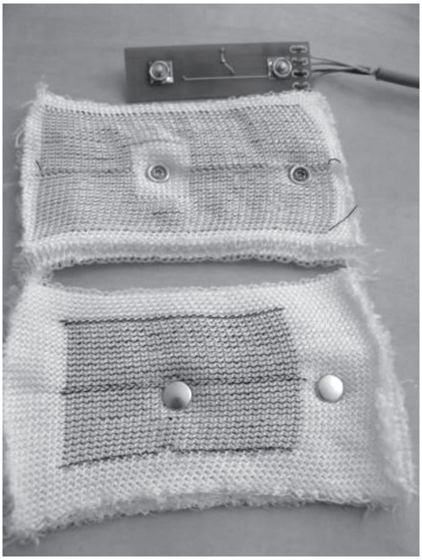

*16.10* ECG measurement set-up [47] (source: INSITEX Bhavin).

Figure 16.10 shows the electrical circuit of the measurement set-up. The electrodes are formed by Cel1 and Cel2, which are similar to parallel plate capacitors. One plate is built by a shielded textile electrode and the other plate is the body surface. The dielectric layer between the plates is given by a textile shielding layer of the textile electrode and the clothes of the subject. The input signal is amplified by a high impedance differential amplifier with |ZQ| of more than 100 GΩ. For noise reduction, a driven seat concept with a third electrode in the seat cushion is used.

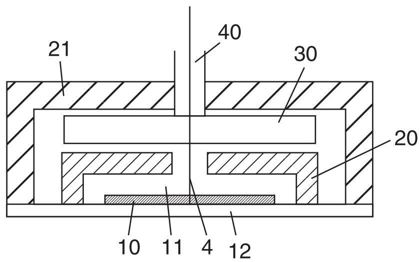
Quality and stability of the ECG signal depends on size, shape and position of the electrode. Despite Fig. 16.8 demonstrating that positioning the electrode near the heart is favourable, Chamadiya [33] found that taking into account robustness against movement artefacts and the differing height of people, a position in the lumbar region is the best compromise. Movement artefacts are caused by the relative movement of the person to the seat.

A key feature in capacitive coupled ECG measuring is the electrode. In INSITEX, the project partners with textile production and development competences [34] developed a multilayer electrode based on spacer fabric technology (Fig. 16.11). The conductive yarn used was e-blocker© [35]. Other textile electrodes with stacked laminated layers are also suitable. The conductive element here is a conductive paste printed to the corresponding layer [36].

The measurement results with textile electrodes are as good as those with metallic electrodes, which is an excellent result, because metallic electrodes are not usable by reason of haptics. Textile electrodes have the advantage of being permeable to air. Sensitivity against humidity is still a problem and is presently



(a)




(b)

*16.11* (a) Prototype of textile multilayer electrode [35] and (b) cross section of multilayer electrode [36] (source: INSITEX (hto), Daimler AG (schematic).

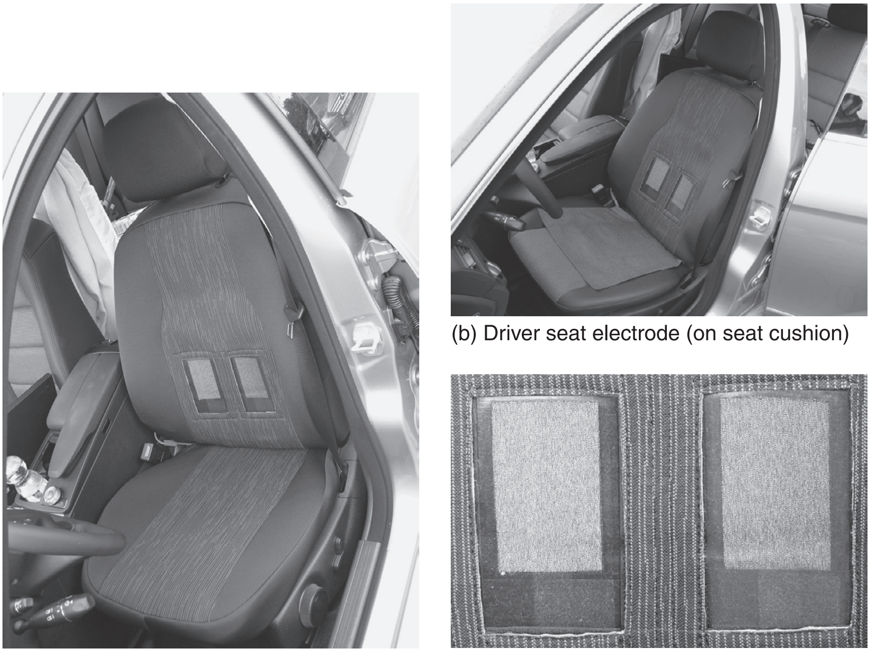
being worked on. A seat cover with textile electrodes has been built and tested on real roads, as well as in the laboratory. Figure 16.12 shows the prototype in a Mercedes C-class.

Tests on roads show a good detectability and stability of the signal. Robustness of the set-up against distortions coming from the car's electronics, such as navigation, mobile phones and servomotors, were astonishingly good for a prototype. Some signals, such as the pwm signal of seat heating with a frequency of 24 Hz, were within the signal window. This distortion can be removed from the measured signal and is therefore no problem.

Driving on highways as well as on city roads has been performed. The most severe problem to be solved regarding signal quality is that of moving artefacts. Movements of the car body, for example on poor roads, or movements of the driver, can be the cause. Electrically this is a displacement of the plates of the capacitor and a resulting peak in the measured signal.

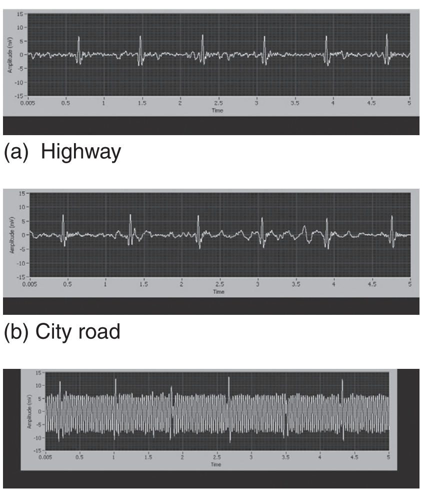
Correction of movement artefacts should be possible by measuring movements of the car body as well as the driver. These signals can then be used to distract them from the distorted ECG signal. Figure 16.13 shows ECG signals measured with the set-up shown in Fig. 16.12 on real roads for different driving situations.

Further investigations with diverse persons and different clothes have been performed. Although the probability of being able to measure ECG is high, the quality varies as for all measurements of physiological parameters. Clothes with



(a) ECG seat cover
(b) Driver seat electrode (on seat cushion)
(c) Textile electrodes

*16.12* (a–c) ECG seat cover. Installed in a Mercedes C-class (source: Daimler AG).



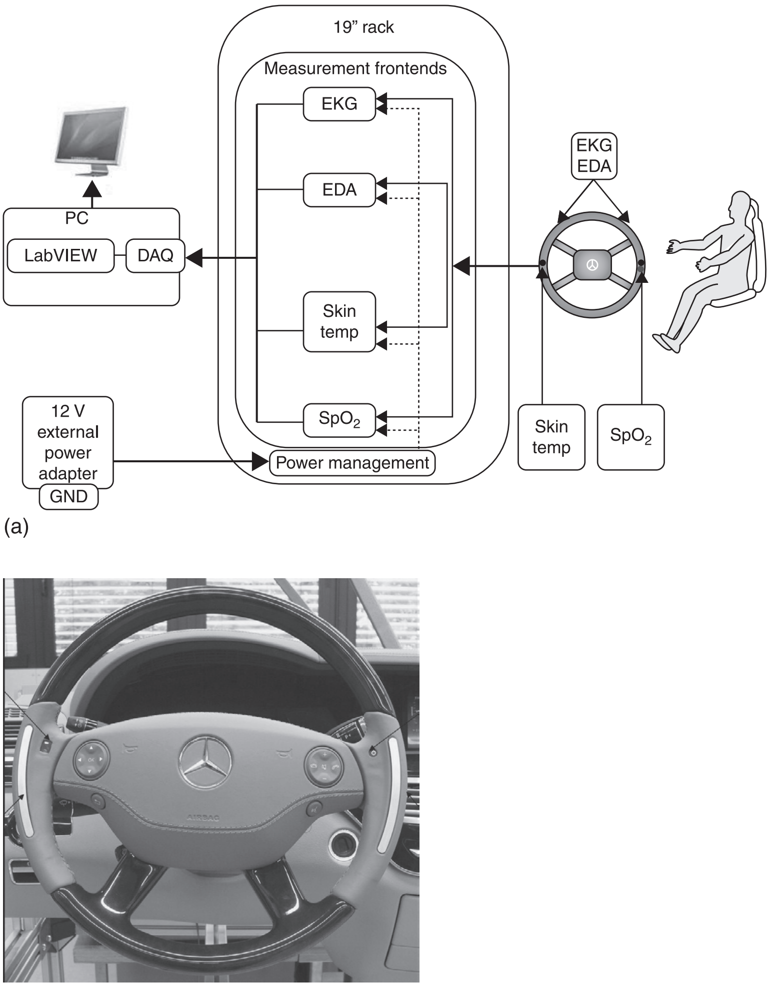
(a) Highway
(b) City road
(c) Distortion by seat heating PWM signal

*16.13* (a–c) ECG measurements on real road [48] (source: Daimler AG).

metallic coatings or surfaces that can be electrostatically charged are problematic for physical reasons.

## 16.4.3 Steering wheel with vital sensors

Another prototype of INSITEX is a steering wheel equipped with different vital signal sensors. The available integrated sensors and the block diagram are shown in Fig. 16.14.




*16.14* (a) Block diagram (source: FZF Karlsruhe Germany) and (b) prototype of steering wheel (Mercedes S-class) with vital signal sensors [49] (source: Daimler AG).

EDA is measured by two electrodes on the front and back side of the steering wheel. A weak constant current is applied and the resulting voltage is measured. The measurement can be taken on both sides of the wheel. Skin temperature is measured by a commercial thermopile. Oxygen saturation uses a commercial sensor with a two-wavelength differential principle.

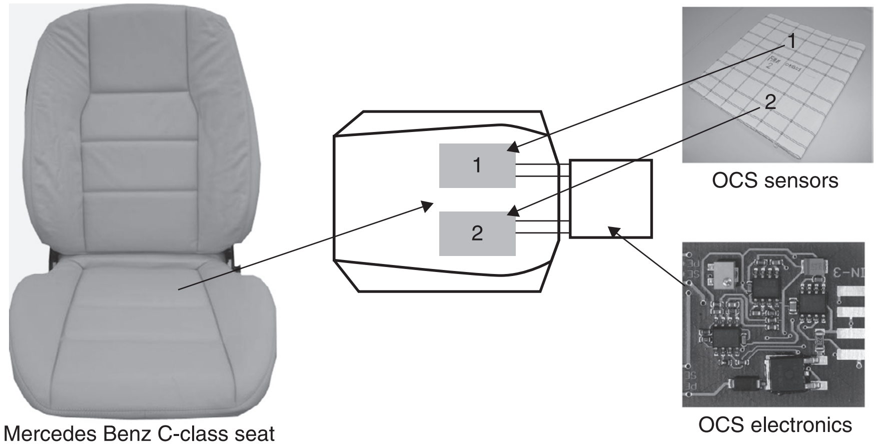
A contact ECG is measured by two electrodes on the left and right side of the steering wheel, when they are contacted by the hands of the driver. By a runtime measurement, as described above, a relative blood pressure value can also be measured. This value can be calibrated for the individual person. This prototype has no textile component but, as mentioned above, it will be possible to build a 'textile' steering wheel [6] (Fig. 16.15). The prototype steering wheel can be used for test drives on test roads.

ECG measurement integrated in a car seat is also shown by other groups. The focus of the Smart Senior project was on disease detection and autonomous failsafe operation of the car [17]. Ford/RWTH Aachen have demonstrated a sensor array in the backrest of the car seat, which selects the best electrode pair for the evaluation of HR [37]. In the published results, they do not use textile sensors. For their experimental set-up, they also found a good detection probability of ECG signal.

### 16.4.4 Occupant detection and classification system with textile sensor

The third prototype built in INSITEX is a textile sensor able to measure weight and position of the passengers on the seat according to FMVSS208. The sensor is

*16.15* Steering wheel mounted in the car and with displayed measurement values (source: Daimler AG).




*16.16* OCS with textile sensor [50] (source: IG bauerhin AG).

working on an inductive principle. By applying a pressure to the sensor, the inductive coupling is changed and a signal is generated. The leading partner for the textile system was IG bauerhin AG. The sensor [38] is based on spacer fabric technology. The special assembly is a development of IG bauerhin AG and patent registered. The use of two sensors in the prototype (Fig. 16.16) allows a rough estimation of the passenger's seat position.

The seat was tested according to automobile test standards and shows very good performance in the environmental and durability tests. Textile solutions for occupant detection and classification have also been the goal of the SeatSen project [18]. The SeatSen approach is based on a textile circuit board assembled with microelectronic devices in a matrix array. A special interconnection technology was developed in the project.

Beyond the above discussed applications of smart textiles for monitoring driver/passenger conditions, a set of other applications are of high interest and many really promising heating and lighting applications have been demonstrated [39], [16]. Textile switches and touchpads were mentioned in Section 16.3.

## 16.5 Key safety and quality requirements

All components used in the automobile industry are subject to a strong qualification process. This is necessary because of the long lifespan of a car and the complexity of its automotive systems. Qualification ensures a high level of quality and safety. Procedure and environmental tests are part of the component specification book. Each OEM has its own procedure, but all are developed from national or international standards and institutions such as IEC, DIN or SAE to name just a few, which are responsible for the standards or the national derivation of international norms.

In particular, environmental tests may be a hurdle for smart-textile systems at the moment. Upper and lower limits of the parameters of temperature, humidity, vibration and mechanical shock are defined in the specification book. The system has to pass these tests over the whole parameter range, otherwise it is not accepted for serial use. EMC qualifications and resistivity against liquids is also part of the test procedure. Seat systems, for example, have to perform the 'Coke' test, which means functions should not be affected when a soft drink is spilled on the seat.

Table 16.2 shows some typical values of the environmental parameters, which depend strongly on the location of the component in the car. Hence, the requirements for cabin electronics are typically lower than for systems located near the combustion engine.

The introduction of new technologies, like smart-textile technology, faces the problem that no appropriate test specifications are available. Sometimes existing norms that cover only a part of the system can be extended to cover the new item. Otherwise a new norm has to be defined. It may also be that the merging of two technologies generates new features that are, for example, safety relevant.

Testing of electronic components is widely covered by the IEC 60068 [40], but there is no textile system considered. Fortunately there is already an initiative for the smart-textile systems of the Standardization Institutes. The draft of the CEN/TR 16298:2011 [5] contains definitions for 'intelligent' and 'smart' systems. These definitions were used in Section 16.2.1. The draft defines furthermore what should be covered by the test norms to be developed. Adequate test norms for specific products, such as textile systems for vital signal measurement or intelligent seat heating, have to be created. This is an important and indispensable requirement, in order to use these systems in serial cars.

*Table 16.2* Typical environmental conditions for car components (depends on system and OEM)

| Parameter | Value |
|---|---|
| Temperature | –40 to 105°C |
| Humidity | Up to 85% |
| Vibration | Depends on location, typically 20 g (RMS) |
| Mechanical shock | Typically 50 g |
| Lifetime | Up to 15 years or 8000 h hours of operation |

## 16.6 The impact of electric vehicles on smart-textiles applications

The fact that resources of fossil fuels are limited has boosted the development of alternative technologies in the last few years. The concept of electrically powered vehicles covers battery electrical cars as well as vehicles powered by a combination of fuel cells and Li-ion accumulators. Hybrid vehicles that use combustion engines with a supporting e-motor and a high voltage battery are considered as the link from the past to the fully alternative powertrain future. Battery capacity nowadays is sufficient to drive 150 to 200 km before recharging is necessary. A typical value for the capacity is approximately 18 kWh [41]. Battery power is not fully available for the powertrain, because all the comfort systems are drawing energy from the battery, so especially when systems for heating in winter or cooling in summer are activated, the range of the car is much shorter than the specified value. The need for energy optimized systems is obvious.

Table 16.3 gives some values of energy consumption of selected systems.

Air conditioning is the comfort system with the highest energy consumption. Heating, headlights and other systems are in the range of 100 to 200 W. The automotive industry discusses three main approaches to increase driving range and save waste energy:

- lightweight construction;
- thermal insulation of the cabin;
- energy efficient design of all components.

Smart textiles can contribute to each of these points and compete with new energy efficient system approaches. Standard solutions are often cost-optimized but not energy-efficient.

*Table 16.3* Energy consumption of car components [43, 44]

| Component | Power [W] | Fuel consumption [l/100 km] |
|---|---|---|
| Headlight, low mode | 110 | 0.15 |
| Electric air conditioning | | up to 2.1 * |
| Seat heating | 100 ** | |
| Steering wheel heating | 50 | |
| Rear-window heater | 150 | 0.12–0.17 |
| 100 kg additional weight | | 0.4 |

*depends strongly on temperature gradient cabin <> outside and car

**depends on car and number of heated seats

### 16.6.1 Lightweight construction

Each kg, which has to be moved, additionally needs additional energy (Table 16.3). Obviously it makes sense to enforce the trend to lightweight construction. Fibre compound materials are the materials of choice here. Textile materials as fabrics are usually not used in vehicle body construction, but new compound materials also use textile fibres. Textile fibres in construction are already in use in the building industry.

The potential of smart-textile systems is the possibility of integrating sensors and actors, for example, in insulating layers. The system weight of heating, cooling and ambient lighting may decrease this way. Spacer fabrics in particular, with their multifunctional properties, and the opportunity to produce different functions in one production flow can succeed here. Another feature of textiles, which should not be underestimated, is the potential to be a design as well as a functional element. Here again is the opportunity to reduce weight if, for example, a surface layer covering the functional layer can be omitted.

### 16.6.2 Thermal insulation of the cabin

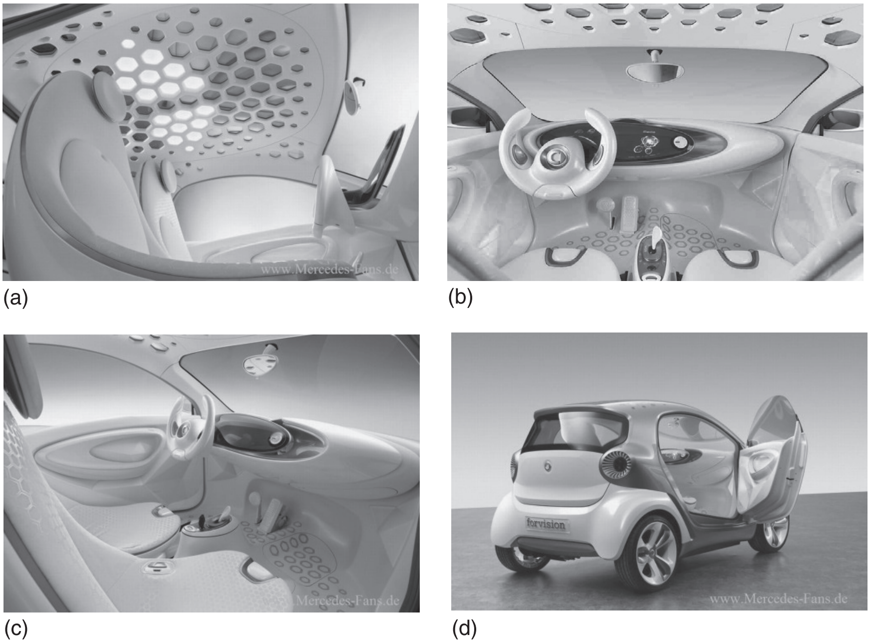
Mass-produced cars on the current market are rarely thermally insulated. Thermal insulation of houses is, meanwhile, a standard, and even a legal restraint. Therefore in seasons when the temperature gradient from the cabin to outside or vice versa is high, a lot of energy is wasted and therefore thermal insulation and heat reflecting outer surfaces will be of great importance in future. The smart for vision concept car (Fig. 16.17), presented at the IAA 2011 in Frankfurt/Main, Germany, demonstrates the potential for using innovative materials in the automotive sector [42] – E-textiles for efficient temperature management; advanced composite materials for weight reduction; super absorbent non-wovens and flexible moulded foam systems for more comfort – the possibilities are endless. In conflict to lightweight construction, thermal insulation increases the weight on first glance but in summary there is a win in efficiency.

Here again combining design and function is an advantage.

### 16.6.3 Energy efficient design of all components

The comfort component with the highest energy consumption is electrical air conditioning, followed by heating (Table 16.3). Established heating applications are seat heating, heating of the steering wheel, panel heating and heating the rear and front windows.

So how could smart-textile heating be used to advantage? The heating of a body from temperature T1 to temperature T2 follows the physical laws of thermodynamics and needs the same energy regardless of the heating method. Obviously the advantage of smart textiles is the special feature to be functional as well as a surface element. In addition, as mentioned above, it can cover design




*16.17* Smart concept car 'for vision' with (a) solar roof, (b) and (c) thermal insulation and (d) heat reflecting paint and window coating

requirements. This means textile heating can be the surface itself or very close to the surface. Therefore no bulk material in the seat has to be heated, which would otherwise cause energy losses. Also the shape of the heating element can easily be adjusted to the body shape of the average passenger, which means no waste heating of non-contacted surface areas. A second way is to make heating 'intelligent' by dividing the heating area into segments and switching off segments where no body contact is detected.

The integration of contact sensors (e.g. capacitive devices) and temperature sensors is possible and needs no additional external wiring. These considerations are also valid for panel heating. If in future light-emitting textile fibres or devices are available, ambient light applications may also have energy saving potential. The growing electro-mobility market offers opportunities for new technologies. Smart textiles stand a good chance by using their very special features to compete successfully with other technologies.

## 16.7 Future trends

Smart-textile technology has left the research lab and found its way into medical-, sportswear- and safety-clothes products. New applications in the automotive industry seem to have potential and may give access to entirely new system approaches. Textile sensors, heating fabrics, lighting devices and other employments of conductive textile materials are under investigation.

The evaluation of new textile sensor systems for driver monitoring and passive safety systems in funded R&D projects (e.g. INSITEX) and other publications demonstrate the feasibility in the actual car environment.

Future car concepts, such as e-drive, will strongly require energy saving and intelligent components, for example for heating purposes. Smart-textile systems have the potential to succeed here if problems related to long-term stability are solved. Fulfilling the automotive requirements is just the challenge.

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