32nd Electric Vehicle Symposium (EVS32)
Lyon , France, May 19 – 22, 2016

Challenge Battery Safety – Solutions with Multifunctional Battery Housings "B:HOUSE"

Jobst Kerspe / TEB Dr. Kerspe ; D-69256 Mauer; kerspe@vakuum-isolierung.de

---

Summary

Requirements for battery housings in e-vehicles are extensive: regulatory requirements; functional requirements; consideration of the installation conditions, transmission of forces and torques into the vehicle structure as well as wishes and demands of the end customer for trouble-free operation under a wide variety of climatic conditions.

Space and weights are scarce resources in electric vehicles; this means lightweight construction and multifunctionality are stringent requirements for all functional units. The *multifunctional battery housing* - the B: HOUSE® in GVI® technology - offers new and highly efficient solutions.

This concept allows effective passive and active thermal management, vibration and crash-proof housing and fixation of the battery cells / modules, fire protection in all directions, EMC safety, environmental protection, lightweight construction – which means resource saving and weight-optimization in one functional unit.

1. Introduction

When designing e-mobiles - and thus the batteries or battery cases - there are some basic requirements that have to be taken into account, both from the technology as well as from various regulations. For example, it is now well known that the usable electrical energy stored in the battery is limited (compared to the energy content of fossil fuels). It is also foreseeable in the short and medium term that this will not change fundamentally.

On the other hand, it should be noted, that in case of damage, a multiple of chemical reaction potential can be released. Furthermore, it should be noted that during charging and discharging of the battery, chemical reactions are more or less dependent on the temperature level - it is not without reason to speak about the "feel-good temperature" of the battery.

What does this mean for the design of the battery or battery case?

a) The enclosure must provide the necessary protection from external mechanical influences (crash, vibration-proof fixation, safe removal of high battery weight forces and transmission of forces and moments in the vehicle structure)

b) Active and passive thermal management to maintain the "battery feel-good temperature" under all possible operating conditions.

c) Protection against external fires as well as active environmental protection – which means encapsulation for every case of an accident (in some cases you will also find the trivialized description "Thermal Event").

d) EMC resistance

e) Space and resource-saving lightweight construction

How to transform these different requirements into a fundamental new concept, will be explained now.

2. The “B:HOUSE®” concept

The basic technology of the B: HOUSE® concept is the GVI® technology, which should be described first.

2.1 The GVI® technology: structure and properties

2.1.1 Types of Vacuum-Insulations and their Possibilities in Design

GVI® stands for *Supported Vacuum Insulation* - we are talking about a highly efficient thermal insulation. In contrast to the well-known "Thermos® vessels"(Fig. 1), however, the insulation gap / vacuum space is firmly "stuffed" with a filling material, which supports the vacuum-tight envelope against the external atmospheric pressure and thus gives a tremendous rigidity and mechanical strength to the insulating element - similar to a honeycomb sandwich element. While the vacuum insulations, known from Thermos® vessels, cannot be pressure-loaded and therefore can only be produced in rotationally symmetric shapes. In contrast GVI® structures can be produced in any desired shape, and the walls, forming the vacuum space, can also be made very thin, which is a basic for heavy-duty lightweight structures.

The fine, microporous structure of the filler is the main reason for a further physical effect: while the insulation in Dewar or Thermos® vessels must be operated in the high vacuum range, the supported vacuum insulation already works in the rough vacuum range - this results in cost advantages and longer lifetimes.

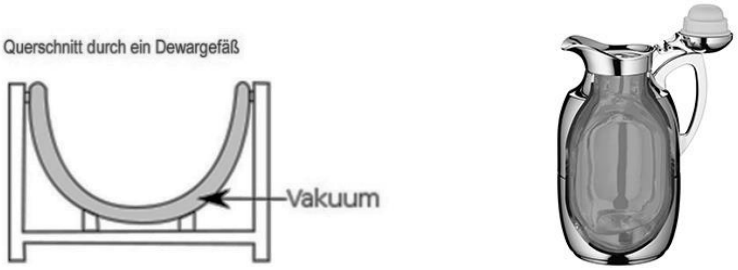

Fig. 1: Dewar vessel (left) and thermos flask® (right; [Alfi])

The basic structure of a GVI® housing is shown in Fig. 2; but also flat, planar elements can be produced, from which complete rooms can be assembled (Fig. 3), which may be interesting for stationary batteries.

A structure according to Fig. 2 is recommended in the B:HOUSE® - this can minimize thermal bridge effects (increased heat flow via metallic elements - in this case the connecting membrane on the open side).

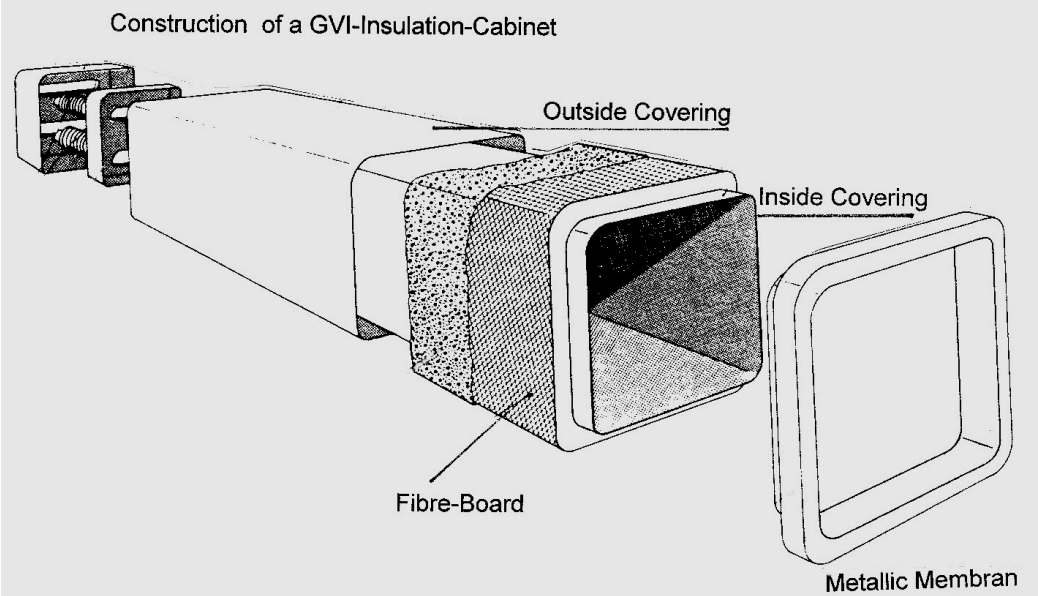

Fig. 2: GVI®-Enclosure

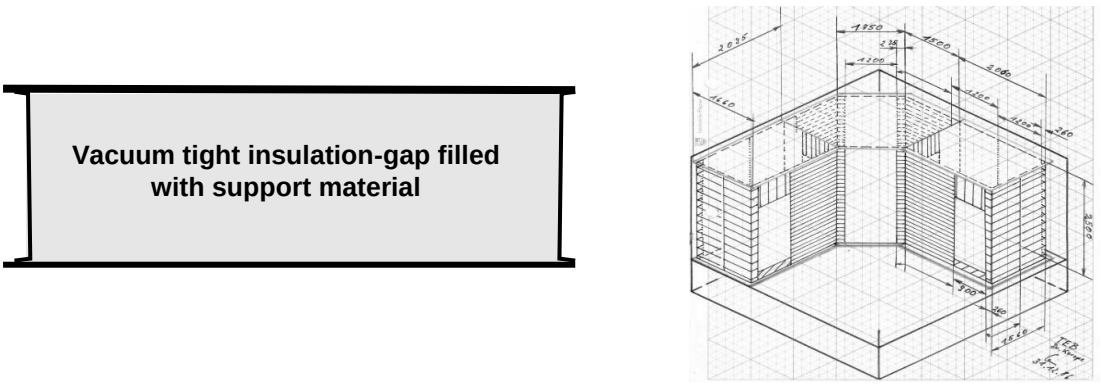

Figure 3: Two-dimensional GVI® element (left) and spatial structure composed of different elements (right)

2.1.2 Physical properties of supported vacuum insulation (GVI®)

a) Thermal Features

Naturally, the outstanding insulating properties of the evacuated insulation should be mentioned here first. Figure 4 shows the specific thermal conductivities of different insulation methods. Compared with conventional (non-evacuated) thermal insulation, the GVI® has an insulation effect, that is up to 30 times better. As a result, evacuated insulation requires a significantly thinner insulation (= less space and less weight!).

The possible application temperatures for GVI® systems are very wide: in the standard version, these insulations can be used from absolute zero to about 500 ° C - with minor modifications, an application even up to > 800 ° C is possible.

Due to the fact, that the insulation layer is completely encapsulated, it never will occur - even at fluctuating temperatures - that moisture will penetrate the insulating layer!

Switchable Insulation (Fig. 5)

A further outstanding feature is, that the insulation effect of the GVI® can be worsened by up to 100 times, by filling up with very small quantities of good heat-conducting gases. This is referred to as ***adjustable or switchable thermal insulation*** (RWD); this effect is exemplified in Figure 5. With appropriate design, this effect is done without pumps, valves or other mechanical actuators and can be cycled as often as desired, so the insulation is in the "optimal" state again at the end of a switching cycle.
It is easy to imagine that for larger GVI®-unit's considerable amounts of energy can be dissipated via the housing surface – provided, that a sufficient temperature difference between the housing internal temperature and the ambient temperature is given! The effect can be helpful to transmit internal (exothermal) heat from the battery to the outside – which means cooling without chiller devices!

b) Mechanical Features

When GVI®-systems are properly designed, evacuation results in rigging of the thin-walled shell material with the filler - the GVI®-structure behaves like a highly rigid sandwich structure.

The supporting effect makes it possible to produce large-area, flat walled elements with thin envelope walls or to support large, heavy units (for example battery blocks) in the insulating layer against the outer vacuum jacket without additional support elements (which would affect thermal bridges!).

The weight loads of a battery are transmitted completely without additional support elements over the insulating layer on the outer supports!
A GVI®-element can withstand forces (preferably pressure), shearing strain and moments, induced into a GVI® housing - but it is important to ensure that this should be via a large area.

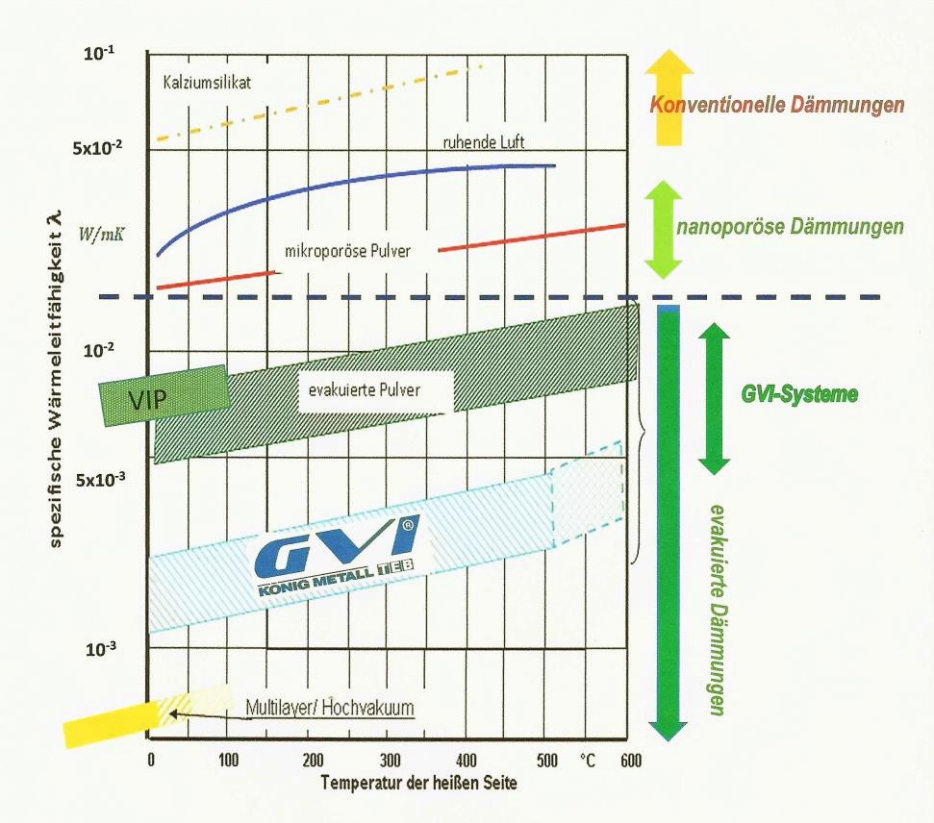

Fig.4: Comparison of different Types of Insulation

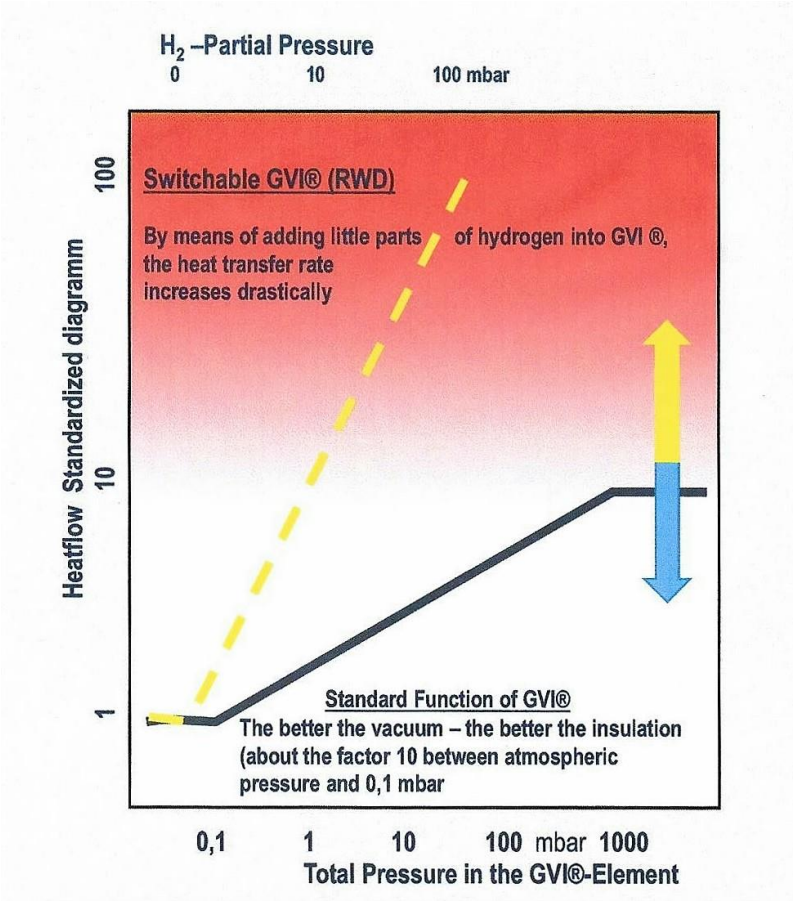

Fig. 5: Switchable Insulation

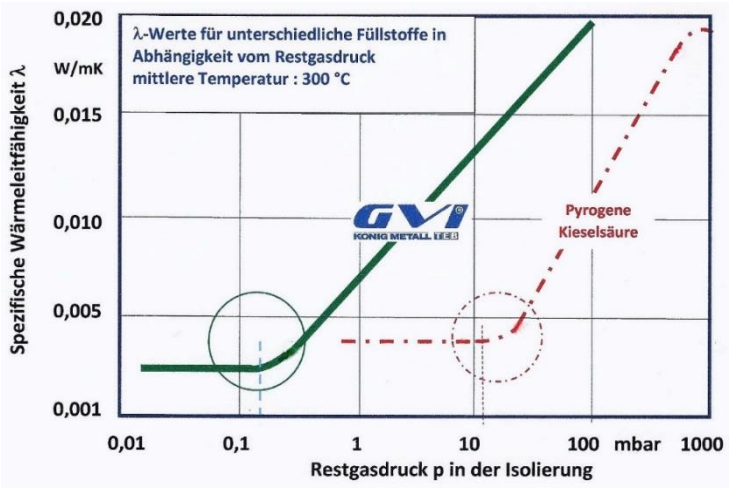

Figure 6: Specific thermal conductivity as a function of the residual gas pressure

c) Vacuum Features

The vacuum characteristics of GVI®-systems act in the range of 0.1 mbar according to Figure 6. Due to the fact, that this vacuum must be maintained over the required life-time of a housing, there are some minimum requirements for the selection of the materials used, their pretreatment and the production technology.

Not least for these reasons, the envelopes of the GVI® structures at König Metall are manufactured almost exclusively from austenitic stainless steel (for example 1.4301) and completely subjected to a helium leak test.

2.2 B: HOUSE®

2.2.1 Multifunctional Structure

The basic idea of the B: HOUSE® is a complete integration of the required functions and properties into the housing.

In a GVI®-housing, numerous functional units can be integrated into this double-walled construction. Not all of these additional functions must be installed in one housing - the respective structure depends on the requirements of the application. Depending on the required thermal properties, the total wall thickness is between 5 mm and 15 mm.

One possible design variant of a fully enclosed battery is shown in Figure 7.

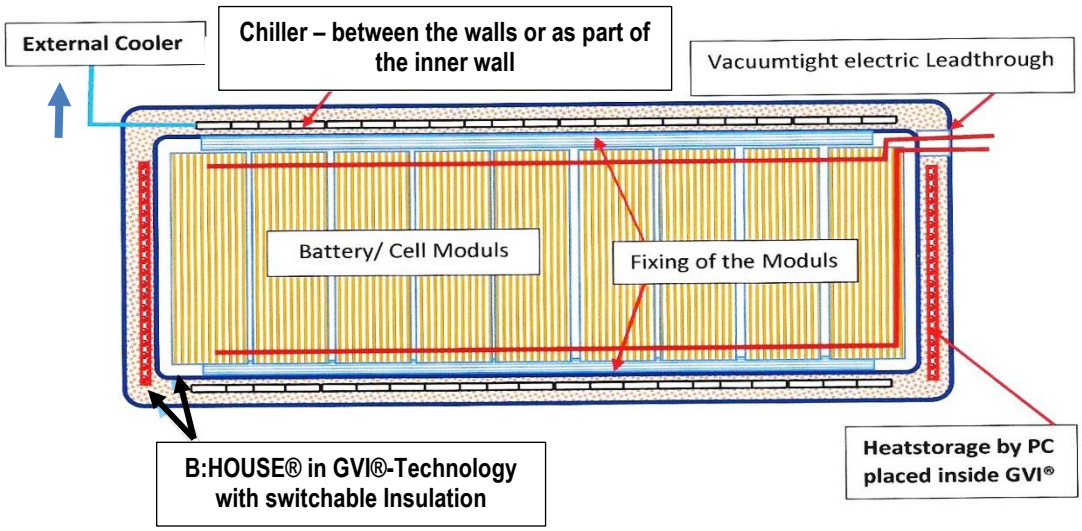

Fig. 7: Principle sketch of the B:HOUSE®Concept

2.2.2 Integrated functions

With the concept of a multifunctional battery housing - B: HOUSE® - a wide variety of basic requirements can be fulfilled within one single unit.

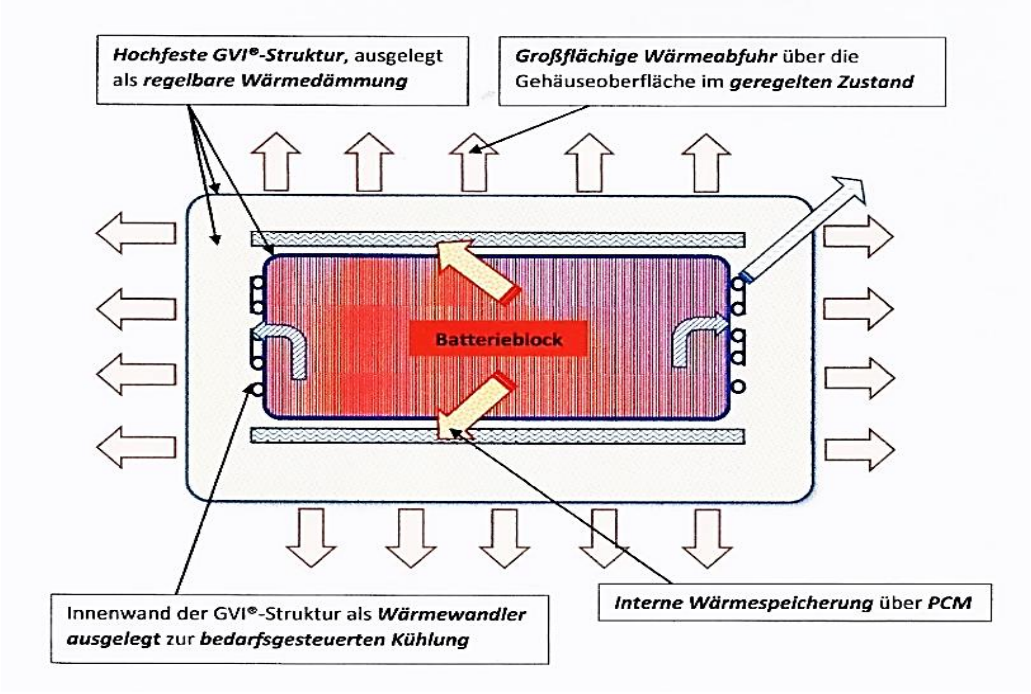

Fig. 8: Possible features of the thermo management in the B:House®-Concepts

- *Passive thermal management:* With the GVI® technology, both, a highly efficient thermal insulation and a regulation of the insulation effect for large-scale heat dissipation is possible. Thus, influences of the ambient climate can be cushioned without additional energy expenditure - therefore we speak of a passive thermal management
- Additional assemblies for *active thermal management* - e.g. cooler or PCM heat storage - can be installed directly in the double-walled housing. For this purpose, for example, one or more of the inner walls may be designed as cooling surfaces, which are linked to a refrigeration unit outside the B: HOUSE®.
- In addition, such a vacuum insulation has excellent *mechanical properties*, so that mechanical loads on the cell can be optimally intercepted (e.g. crash safety - ECE R100 / 2, vibration-proof fixation of the cells).
- With appropriate design, the housing can be installed as *part of the vehicle structure*.
- The housings are *EMC-proof* (closed Faraday cage) without additional components
- The housings protect the cells from *external fire* (ECE R100 / 2) and, with appropriate design, protect the environment even in the case of a "thermal runaway" of individual (or more) cells > delayed spread of such fires to the entire vehicle; no leakage of cell chemistry
- Since all the features mentioned are combined in one housing, resource-saving lightweight construction concepts are possible

3. Examples

3.1 Different designs with the respective advantages and disadvantages

Tube model (Fig. 9) with stopper: Tubular or tunnel-shaped housing in which the battery pack is inserted via rail systems; the open end is insulated and sealed with a plug (conventional insulation or GVI® structure).

Advantages: relatively small thermal bridge zone; battery is relatively easy to open for maintenance; good and easy fixation of the cells / modules possible.

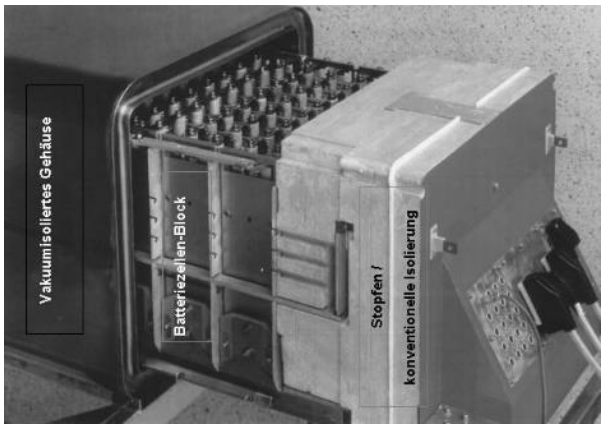

Fig. 9: High-Temperature Battery (NaS) with GVI®-Housing

"Babushka"(Fig.10)

The battery pack is enclosed by 2 half-housings on all sides; with appropriate design of the connection zone, the thermal bridge effects can also be minimized here; the battery pack is also fixed here via rail systems etc. in the housing.

Advantages: almost complete enclosure with GVI® housing with all safety advantages; low thermal bridge effects; very good force and torque transmission in the vehicle structure; good accessibility of the battery in case of revision.

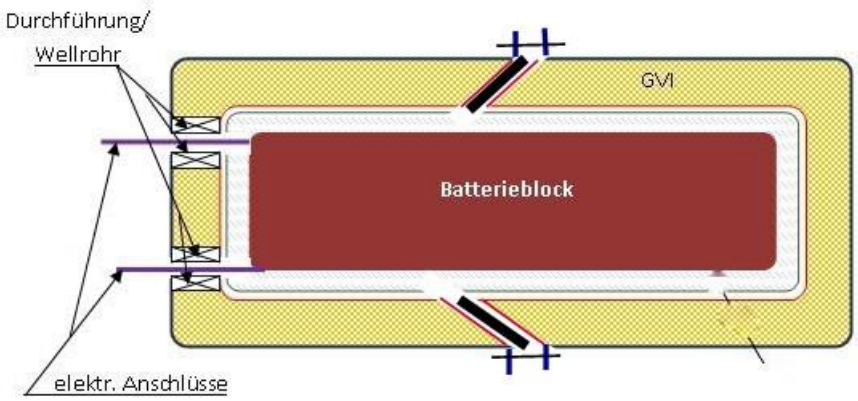

Fig. 10: "Babuschka"-Concept: 2 Envelope-Half shells

Fig. 11: Trough

Trough with lid (Fig. 11)

The battery modules can be installed from above in the trough and fixed with appropriate fasteners.

Advantages: easy handling in battery construction

Disadvantages: strong thermal bridge effects; depending on the size lower rigidity than other types

Complete enclosure

The battery pack is enclosed on all sides by the GVI® structure.

Advantage: maximum safety gain (crash; encapsulation)

Disadvantages: complex handling during maintenance; complex electrical feedthroughs

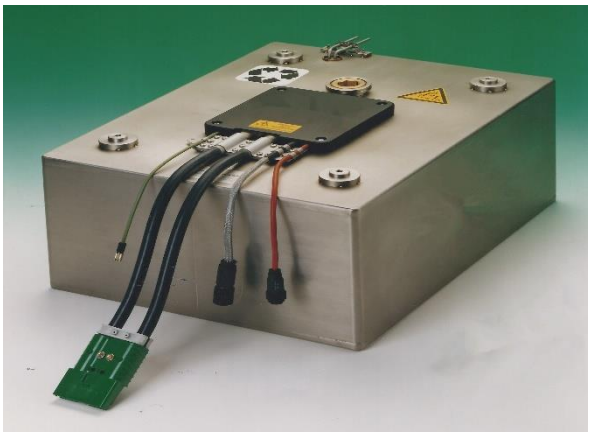

Figure 12: Integral housing of the battery with GVI®

3.2 Example of a Large Truck Housing

3.2.1 Calculation for passive air conditioning

The battery housing (B:HOUSE®) has an approx. 15 mm thick GVI® insulation - open on one side (tube modell). The insulating effect is sufficient to keep the battery pack at operating temperature for more than 12 hours without additional heating! (ambient temperature - 20 °C; starting temperature of the battery 25 °C; temperature after 12 h still 20 °C).

Conversely, of course, even at high ambient temperatures (> 40 ° C) the battery does not unnecessarily absorb heat from the environment - even in this case without additional active cooling.

In the event, that due to exothermic battery reactions, an active cooling is necessary, the GVI® ensures that the introduced cooling power benefits only the battery and not unnecessarily discharged to the environment!

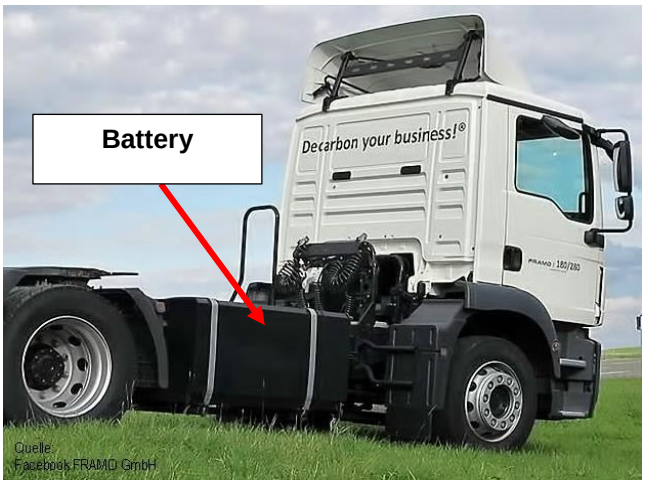

Figure 13: Electric Truck with a Battery mounted to side of the Structure (FRAMO)

3.2.2 Weight ratios / carrying behavior

In the largest version, the housing has the following internal dimensions: approx. 700 x 600 x 1800 mm. The total (double) wall thickness is about 18 mm - of which twice sheet thickness 0.8 mm. This housing weighs about 75 kg empty; the battery weighs about 1000 kg in this case.

The entire battery is fixed to the side rails of the truck via three cantilever arms and straps.

Conclusion: The total weight forces of the battery (in the amount of 1000 kg) are completely supported by the lightweight housing and introduced shockproof in the longitudinal structure of the vehicle.

4. The battery case as part of the vehicle structure – presented in the concept of the ECTT

4.1 The concept of the ECTT (E-City-Thermo-Truck)

The battery housing(s) in GVI® technology forms a sturdy platform, which sits directly on the vehicle's longitudinal frame rails and at the same time serves as a supporting structure for the refrigerated box and forms a firmly connected unit with it. In this way, the space between the vehicle floor and the vehicle longitudinal members, which is necessary for the travel of the wheels, is optimally utilized, without additional components (for example crosswise arranged carrier structures), which otherwise bring only additional weight.

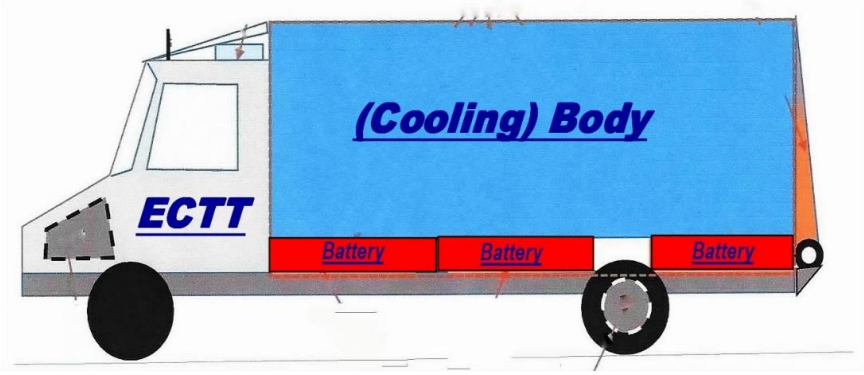

Figure 14: Side view of the ECTT with one unit - consisting of a refrigerated box and the B:HOUSE® units

At the same time, the battery housing formed in GVI® technology represents a highly efficient thermal insulation of the bottom of the case and thus prevents the heat absorption from the heat radiation of the road surface, which is not insignificant in the summer.

Bibliography

Kerspe, J. et al, Vakuumtechnik in der industriellen Praxis, *3. Auflage, expert-Verlag, ISBN 3-8169-2196-5*

Smoluchowski, M., Über Wärmeleitung pulverförmiger Körper, Bericht *II. Intern. Kältekongress, Wien; (1910)*

Fröhlich, D., Earth-Laid Transport Pipes for -162°C to +400°C, *Pipeline Technology Conference 2011, Hannover*

Neumann, H., Thermal Performance of Different Glass Microspheres in Comparison to Perlite between 77 and 300K

Kerspe, J., Vielfältige Eigenschaftsprofile von gestützten Vakuum-Isolierungen – Einsatzmöglichkeiten für das aktive und passive Thermomanagement in Fahrzeugen; 3. VDI-Fachkonferenz „Thermomanagement für elektromotorisch angetriebene PKW“ 5./6.11.2014

Kerspe, J., Passives und aktives Thermomanagement mithilfe von multifunktionalen Batteriegehäusen für die E-Mobilität; 6. VDI-Fachkonferenz „Thermomanagement für elektromotorisch angetriebene PKW“ 14./15.11.2017

Kerspe, J., „Multifunctional Battery-Housings“ and Their Helpful Application for Thermal and Mechanical Tasks; 8. aabc, Feb. März 2018, Mainz

N.N., Elektroautos im arktischen Winter; emove Magazin 01-2014

N.N., Integrierter Brandschutz für Lithium-Ionen-Batterien; VDI Nachrichten 1.8.2014

Stenner, P., VisioM – Leichtfahrzeugkonzept für urbane Elektromobilität; ecartec 2014

Author Dr.-Ing. Jobst Kerspe

Education and degrees

1971 to 1976: TU Clausthal-Zellerfeld; Material sciences and metal forming – engineer degree

1977 to 1981: TU Stuttgart Institut für Umformtechnik; conferral of mechanical engineer

Career

1981 to 1985: installation and managing of the prototype manufacturing at BBC/ABB Heidelberg; Project NaS-high energy battery

Since 1985/86 : Engineering, consulting and development company „TechnologieEntwicklung & Beratung TEB Dr. Kerspe“