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QUalifying and Implementing a user-centric designed and EfficienT electric vehicle

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Publishable Executive Summary

One of the aims of QUIET is to realize a vehicle closures with low weight, good thermal insulation properties, and high stiffness. During the WP3 of QUIET project, development of lightweight glazing, closures (e.g., side doors, trunk lid and engine hood) and seats were targeted all of them with improved thermal properties. The target was weight reduction of 30% in case of glazing, 20% in case of closures and 10% in case of lightweight seat structure besides better thermal properties from viewpoint of demonstrator vehicle energy consumption during heating or cooling of the cabin.

The development process was started with data acquisition and analysis of the current structure estimating possibilities on the field of mass reduction and thermal property optimization. After setting the baseline from the results of the original structures, extensive searching and improving process was carried out using the advantageous tools of material sciences, computer aided design and finite element methods. In every case, a multi-step iteration process was conducted to optimize newly developed structures and to reach best possible outcome. At the end of development, formerly set goals were achieved in weight reduction and in the field of thermal properties, as well.

Lightweight structures were not just designed, in every case they were manufactured as prototypes for implementation on the QUIET project demonstrator vehicle, so the outcome of this work package is not just a new design concept and manufacturing plan but real parts with significant weight reduction and better thermal insulation or lower heat capacity which can be implemented and tested in the last phase of the project.

In all subtask of WP3, possibilities of economic upscale were also calculated. They show what can be the cost using newly developed solutions for not just a prototype vehicle but higher series, as well.

During the first-level assessment of technologies developed in QUIET WP3 for enhanced thermal performance, the realizable and possible weight savings were evaluated regarding the developed new components windshields from Task 3.1, lightweight vehicle components from Task 3.2 and lightweight seats from Task 3.3. The activity was based on simulations to validate the proposed designs against the relevant specifications and standards from Task 1.1.

The possibility of the economic upscale of production was investigated in close cooperation with the assigned partners - besides different manufacturing methods considering different numbers of units. A comprehensive assessment report is prepared about the simulation results and proposed manufacturing methods for each component.

According to the developers, the integration of further sensors into the designed lightweight components (e.g. doors) were not required. The safety sensor topology in the lightweight seats (e.g. to communicate with the airbag system etc.) has been adopted exactly from the original seats structure in order to guarantee undisturbed sensor operation.

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Abbreviations and Nomenclature

Table 1: List of Abbreviations and Nomenclature.

Symbol or Short name	Description
APM	Advanced Pore Morphology
CAD	Computer Aided Design
CF	Carbon Fiber
DoE	Design of Experiment
EPP	Expanded Polypropylene
EV	Electric Vehicle
FEA	Finite Element Analysis
FEM	Finite Element Method or Finite Element Modeling
FMVSS	Federal Motor Vehicle Safety Standards (USA)
HAPM	Hybrid Advanced Pore Morphology
HVAC	Heating, Ventilation and Air Conditioning
HPDC	High Pressure Die Casting
LPDC	Low Pressure Die Casting
NDA	Non-Disclosure Agreement
PA12	Polyamide 12
PC	Polycarbonate
PVB	Polyvinyl butyral
RTM	Resin Transfer Molding
SMC	Sheet Metal Compound
TPU	Thermoplastic Polyurethane
T-RTM	Thermoplastic Resin Transfer Molding
UN/ECE	Economic Commission for Europe of the United Nations
WP	Work Package

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1. Introduction

QUIET aims at developing an improved and energy efficient electric vehicle (EV) with increased driving range under real-world driving conditions. This is achieved by exploiting the synergies of a technology portfolio in the areas of: user centric design with enhanced passenger comfort and safety, lightweight materials with enhanced thermal insulation properties and optimised vehicle energy management.

The developed technologies will be integrated and qualified in a Honda B-segment electric vehicle validator. Among these, a novel refrigerant for cooling, combined with an energy-saving heat pump operation for heating, advanced thermal storages based on phase change materials, power films for infrared radiative heating and materials for enhanced thermal insulation of the cabin will be investigated. Further focus is put on lightweight glazing for windows, as well as light metals like aluminium or magnesium for seat components. Optimized energy management strategies, such as pre-conditioning and zonal cooling/heating the passenger cabin as well as user-centric designed cooling/heating modules will further enhance the thermal performance of the vehicle. WP3 involves developing new lightweight vehicle components with improved thermal performance in order to reduce the entire vehicle weight and to guarantee improved passenger-compartment insulation. For the windshield, different technologies and structures based on innovative approaches will be investigated. Furthermore, vehicle components like lightweight doors will be developed and realised by combining novel materials for enhanced thermal insulation with lightweight composites. Additionally, lightweight materials such as composites will be used for realising closure components for optimising the weight of the reference vehicle. All developed lightweight components (windshield, doors and seats) with improved thermal performance will be ready for integration into the reference vehicle at the end of WP3.

1.1. Description of the deliverable – Goals

This document is to give a comprehensive assessment of the work done in WP3, possible outcomes of further developments and opportunities of economic upscale. This also includes summary of results and calculations.

The goal of this WP was to develop lightweight closures like side doors, trunk lid and engine hood, the windshields and side windows for the closures and seat structures. Further goal is the implementation of the demonstrator closures and seats with improved parts concerning weight and thermal properties. The existing steel design of closures and original design of seats by Honda was the baseline for the improved design. Target was to substitute steel parts with fiber reinforced composite in case of closures, layered glass with pure plastic in case of windows and steel seat frame structure with light metal one. At the end of the development, results of calculations and measurable features of newly developed parts were compared and possibilities of economic upscale were also assessed.

2. Lightweight windshield and side windows (T3.1)

Task 3.1 dealt with the specification and implementation of lightweight glazing with improved thermal performance. Expected weight reduction is about 30% compared to the baseline vehicle. Glazing components of the reference vehicle must be thermally improved by using innovative materials, which feature enhanced thermal insulation capabilities. However, the focus of the glazing improvement was not only on thermal aspects, but also on weight aspects. Thus, the new component must follow lightweight design. In Task 3.1 different potential developers and suppliers for glazing components were explored and the advantages and disadvantages of each supplier was compared. Finally, the supplier who provided the most promising product was assigned and instructed to support the QUIET project as a third party. The intended improvements are expected to lead to lower thermal losses to the ambient environment and to lower weight. After their implementation these factors will have a positive impact on the energy consumption of the overall vehicle, which in turn contributes to increasing the usable driving range.

2.1. Process of development and results

Development process

In T3.1, lightweight glazing components with improved thermal performance were investigated. It started with a research comparing the physical parameters e.g. thermal insulation and weight of standard glazing techniques like laminated safety glass and tempered safety glass with established plastic glazing techniques e.g. polycarbonate (PC), Polyvinyl butyral (PVB) and with high performance aluminosilicate glasses as well.

In total, 16 material and component suppliers were considered and contacted during the exploration phase. During the process it turned out, that only PC has sufficient mechanical and thermal properties besides affordable cost and availability. At the end of research, PC was selected for raw material, COVESTRO as provider of raw material and KIRSCH Kunststofftechnik GmbH as supplier to perform thermoforming, hard- and IR-coating the polymer sheets. As administrative arrangements between the above-mentioned companies and the involved members of the QUIET consortium took longer than expected, the time frame of this subtask was also affected.

Results

Modern thermoplastic glazing techniques can fulfil the requirements for certain lightweight automotive glazing components, while improving thermal performance at the same time. However, some significant disadvantages of plastic glazing shall be pointed. These include cost, low UV stability and low abrasion resistance. The physical drawbacks could be addressed by using hard and IR coating and by using tinted glazing.

Furthermore, safety concerns also should be kept in mind. At the time of the project, polymer materials were not allowed for front windscreens, because polymer window panes cannot be easily cut or destroyed to provide access for first aiders or emergency services in rescue cases. There is no consideration for windscreens made of plastics are provided in the Regulation No 43 of the Economic Commission for Europe of the United Nations (UN/ECE). Therefore, the new glazing material will be applied to side windows, front and rear quarter lights and rear windshield. For these components, weight reductions up to 35% can be managed (Table 2), which exceeds QUIET goals.

Table 2: Weight estimation for glazing

Part	Glass weight [kg]	Weight reduction by material [%]	Weight reduction absolute [kg]	Quantity per vehicle	Estimated weight reduction [kg]
Front side windows	3.7	-40	1.50	2	3.00
Front quarter light	0.8	-31	0.25	2	0.50
Rear side windows	2.5	-38	0.95	2	1.90
Rear quarter light	0.9	-30	0.27	2	0.54
Rear windscreen	3.5	-23	0.81	1	0.81
				SUM	**6.75 (-35 %)**

A comparison of standard glass (i.e. standard windscreen with 2x2.10 mm glass-layers and 0.76 mm PVB interlayer) and modern thermoplastic glazing techniques like PC layer (Table 3), indicates up to 50% less specific weight and 70% less thermal conductivity compared to laminated safety glass. Alternatively, to using polymer materials, weight reductions without significant limitations in mechanical requirements could also be achieved through reducing the glass thickness. Drawbacks of this approach are hereby that thermal isolation and acoustic behaviour would be significantly reduced as well. The same disadvantages are valid when using thin and light hybrid glass compositions (like aluminosilicate glasses). Hence these costly technologies were not considered to be used in project QUIET.

Table 3: Physical parameters of standard glazing, modern thermoplastics and polycarbonate glazing

Properties	Glass	Thermoplastics	PC
Density [kg/m³]	2500	1000-1200	1200
Thermal conductivity [W/(mK)]	0.8	0.2-0.25	0.21

2.2. Goals achieved and economic upscale of production

Goals Achieved

Expected 30% weight reduction was achieved during the development process. Besides, thermal conductivity of the selected PC glazing is about 70% lower, compared to the original laminated safety glass and shows hence better insulation properties. The benefit of better thermal properties of polycarbonate glazing (like better temperature conditions e.g. in hot as well as in cold conditions) was verified by simulations of the thermal vehicle model of the QUIET demonstrator documented in the deliverable D2.2 (Multi-physical entire vehicle model; control units for energy management system). For cooling mode, this simulation indicated, that the cabin temperature could be reduced by approximately 0.5 K compared to the baseline car, when using the same air conditioning power of the baseline vehicle.

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Economic upscale

Looking at raw material costs, polycarbonate (PC) is an expensive polymer material (1.2 to 2 €/kg) compared to standard glazing (0.045 €/kg). Table 4 reflects the cost estimation for standard glazing in large production quantities (> 10000, per year) [6][7].

The listed prices in the last column of Table 4 are a rough estimation derived from production costs of a mass production car and deduced for the standard glazing parts [8]. When upscaling the production of PC glazing, it will be required to achieve similar a cost magnitude as for standard glass. This can be only achieved by assuming a broad introduction and establishment of PC glasses on the car market.

Table 4: Cost estimation for standard glazing

Part	Quantity per year	Estimated costs per vehicle [€]
Front side windows	> 10 000	~ 30
Front quarter light	> 10 000	~ 20
Rear side windows	> 10 000	~ 50
Rear quarter light	> 10 000	~ 30
Rear windscreen	> 10 000	~ 70
	SUM	~ 200

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3. Advanced foam materials (T3.2)

In Task 3.2, design of the basic concepts for lightweight structures with good thermal insulation were provided and suitable polymeric materials (warm or cold curing) as a matrix for the hybrid aluminum-polymeric foam were selected. Design of concepts and the definition of the demonstrator designs were supported with laboratory level feasibility tests.

Numerical simulations were supported with CAD designs providing input data for concerning mechanical attributes of the foam. An evaluation of design concepts and derivation of an optimized solution was performed. Relevant results regarding mechanical and thermal attributes were evaluated and were adapted. Foaming and bonding technology were adopted in the fabrication of sandwich structures complying with the design specifications. During the identification and assessment of the potential improvements, cost benefits were estimated.

3.1. Material development and results

In order to find and select the best suited type of APM material, 3 different variants were investigated:

- Hybrid APM aluminium foam with epoxy binder (HAPM);
- APM aluminium foam with lower PA12 polymer coating thickness (APM1);
- APM aluminium foam with higher PA12 polymer coating thickness (APM2).

Each material variant was characterized regarding mechanical strength and thermal conductivity (Table 5). Further information about the characterization is presented in the deliverable D3.1 (Hybrid foam material and demonstrator seat with weight and thermal improved parts). Based on the conducted investigation, the warm curing APM foams with higher PA12 coating thickness (APM2) foam material was selected for the further work.

Table 5: Properties of developed hybrid foam materials

Material	ρ [g/cm^3]	λ [W/m k]	σ_{COMPR} [MPa]
HAPM	0.65	0.73	8.0
APM1	0.51	0.78	0.7
APM2	0.61	1.09	17.0

Considering producibility, weight, thermal insulation, strength and crashworthiness concerns, APM2 foam was selected to use as core material for side crash beams in the side door constructions because its great ability to absorb e.g. kinetic energy.

The moderate thermal insulation properties did not justify the broad application as insulation material across the entire door panels. As explained in Chapter 4, significant improvements in this matter were achieved by other means.

3.2. Results and economic upscale of production

The foam materials of T3.2 are incorporated into T3.3 so they will be presented and compared to the project goals in that section. Production costs of aluminium-polymer hybrid foam APM were considered based on the assumption that they would be used for the crash beams of the closure set of a car.

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For the prototype manufacturing, APM rods were produced with extremely high cost about 500 €/unit because of the low amount of ordered raw materials and the usage of lab scale equipment. For an amount of 10,000 cars (units), it will be necessary to change the shaping procedure, which leads to reduced processing costs and also reduced costs for the raw materials, e.g. the aluminium powder. For a real mass production of about 1,000,000 cars (units), a price of 10 €/kg seems realistic (Figure 1). If there would be any other targeted area for APM foams e.g. more sandwich structures besides crash beams, this could have further positive effect on the unit price of it.

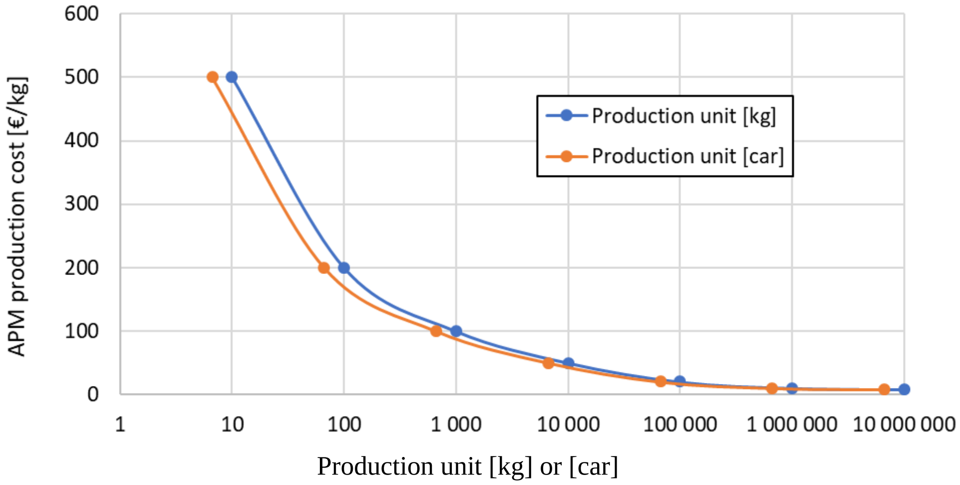

Figure 1: Cost of APM core material production calculated by IFAM

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4. Lightweight composites for vehicle components (T3.3)

In the Task 3.3, suitable composite and sandwich structures were created with optimized composite layer build-up to reach project goals, which are about 20% decrement in weight and significant improvement of its thermal insulation. For this, composite sample specimens were created and measured with different material combinations and layer structures. Based on these, material cards were created and validated according to the measurement results with comparable FEM calculations using ANSYS and ANSYS/Composite Pre-Post software to optimize the construction of lightweight components.

Material properties of the hybrid foam were given as input from Task 3.2, as well as recommendations for the fabrication of sandwich structures. The aim of the activity was to create the ply-book for all lightweight components and to produce the necessary data to support the production partner. Different virtual tests were conducted in this phase according to the relevant regulations including static strength and crashworthiness analyzing the new lightweight components.

Evaluation of design concepts and derivation of an optimized solution were performed complying with the specifications. The final designs were submitted to third party manufacturing partners where fully functional demonstrator parts were created.

4.1. Process of development and results

Development process

Based on the data of the vehicle platform, material properties and CAD data acquisition, an extensive investigation was performed to find the baseline stiffness, strength and crashworthiness of the steel closures using ANSYS and LS-Dyna software.

For input to the composite redesign, composite samples were tested in large spectra of materials and manufacturing processes which allowed to proceed the redesign considering economic upscale. After choosing manufacturing partners for each picked technology, test specimens were produced, and mechanical characterization was carried out on specimens with several reinforcement types.

Material selection is in harmony with manufacturing processes and light weight reduction goals, high strength carbon fibre (CF) reinforced epoxy polymer composites were chosen according to the recommendation of manufacturing partners. This kind of materials assures low weight besides high strength and low thermal conductivity.

Targeted areas for redesign were the skins and panels of closures, because they cover about 80 % of structural mass of closures and about 90 % of heat transfer area counting only the baseline steel components. Furthermore, for these items, evaluation criteria were well defined. Window frames were chosen to be kept in original form because they would not be able to adapt as simple to composite manufacturing as QUIET project needed it according to the budget and time frame. Besides this, most important thing was to be ensured that selected components were suitable for composite manufacturing. During the redesign, using CAE tools for simulation static and crash load cases an optimization process including weight-stiffness and weight-insulation trade-offs aided to find the best possible solutions for new lightweight structures. Based on the mechanical test results of the selected composite materials, a virtual FEA aided composite layer optimization was carried out on the selected sections which helped to find the optimal layer build-up e.g. fibre directions and laminate thickness. The appropriateness of new lightweight components was presented and verified by performed simulations of the vehicle component virtual model documented in the deliverable D3.2 (Lightweight vehicle components (glasses, door, engine hood, trunk lid, etc.).

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Results

Based on the calculated and measured weight data of the new lightweight closures, it can be concluded that the simulations gave correct estimation about the final weight of structures. Besides similar or even better strength and crashworthiness, significant weight reductions were achieved during the development process. In case of structural weight (not including glazing, mechanical parts and bolt-on elements), composite materials were able to achieve weight average reduction of 36% (Table 6). Considering the whole set of non-structural elements, mentioned reduction was slightly decreased to 24% but including new glazing from T3.1 this average was 28% in weight.

Table 6: Measured weight loss of closures

Part	Baseline weight [kg]	Structural weight reduction [%]	Global weight red. [%]	Weight red. with new glazing [%]
Front Side Door	21.43	30.20	21.56	31.23
Rear Side Door	14.12	35.80	22.98	24.89
Engine Hood	3.67	32.80	27.20	N/A
Tailgate	15.53	44.09	22.91	28.13
	AVG	**35.72**	**23.66**	**28.08**

4.2. Goals achieved and economic upscale of production

Goals Achieved

After the virtual optimization process and manufacturing of optimized parts, it can be concluded that for closures the targeted 20% weight reduction has been achieved with a good safety margin in this task.

Thermal properties of newly developed constructions were also calculated, and significant improvement was achieved in this field as well. The thermal conductivity of the used composite material is one order of magnitude lower (~5 W/mK) compared to the originally used steel (~60 W/mK) that resulted an average thermal conductivity decrement of 86 % (Table 7) calculating composite and steel outer surfaces of redesigned closures.

Table 7: Thermal conductivity of developed closures

Part	Composite surface [m^2]	Steel surface [m^2]	Thermal conductivity decrement [%]
Front Side Door	0.74	0.06	84.9
Rear Side Door	0.60	0.08	81.0
Tailgate	0.80	0.00	91.8
		AVG	**85.9**

Calculating thermal inertia from density, thermal conductivity, and specific heat capacity of the original and lightweight material, it means ~80 % reduction of inertia in the targeted structural elements. Calculating with the global structure of the door, it could be up to ~40 % thermal inertia reduction

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Economic upscale

The possibility of economic upscale using different methods for composite closures has been investigated. Different methods are technologically feasible, and the choice depends on the intended production volume and targeted cost of components. Furthermore, different processes could be preferable for different application, the number of units to be produced, and targeted quality, strength, and repetitiveness demands (Table 8). Based on this, for low number of units in small series or prototyping a simple hand lay-up technology can fit, but for a larger number of units a process with higher quality and repetitiveness, a vacuum infusion or resin transfer molding (RTM) can be a better choice.

For composite closures of the QUIET project three different techniques were chosen:

- Hand lay-up (the simplest),
- Vacuum infusion (more complex),
- Prepreg supplemented with vacuum bagging (most complex).

These techniques were good to demonstrate reachable goals in field of lightweight construction of closures and they also fit to the project budget, but mass production cannot be imagined using them.

Table 8: Possible economic upscale using different methods for composite closures* [3][4]

Manufacturing method	Quality, precision, repetitiveness	Tooling Cost	Part per year [unit]*
Hand lay-up (vacuum assisted)	+	$	100-200
Vacuum injection (infusion)	++	$$	300-500
Prepreg + Vacuum bag	+++	$$$	100-200
Prepreg +Autoclave	+++++	$$$$$	100-200
Composite Pressing (SMC)	+++++	$$$	10,000-50,000
RTM	+++++	$$$	1,000-5,000
T-RTM	+++++	$$$$	10,000-50,000

*estimated for a medium size and medium complexity carbon reinforced polymer composite part

For mass production, it is important to face the project costs of feasible processing solutions for automotive applications and make the comparison to the conventional techniques. For automotive applications, more productive processes like composite pressing (Sheet Molding Compound, SMC) or Thermoplastic-Resin Transfer Molding (T-RTM) are feasible solutions in case of higher volumes.

Cost of composite raw materials (Table 9) can be from 1.2 to 3.7 times higher, compared to conventional steel and aluminum. But there is another effect of weight savings due to the density difference which can moderate the cost gap. Embodied energy is also an important factor which shows that in case of glass fiber it can manage lower energy consumption compared to a steel body.

Table 9: Specific cost and other properties of automotive raw materials [5]

Material	Cost [€/kg]	Density [kg/m^3]	Specific strength [kNm/kg]	Embodied energy [MJ/kg]
Steel	0.4 - 0.6	7800	38	45
Aluminum	0.7 - 1.6	2600	130	227
Composite for SMC	1.5 - 1.9	1200	150-400	33-226
Composite for RTM	2.6 - 4.8	1200-1600	150-400	33-226

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The total cost of manufacturing consists of several other factors than material like labor, equipment tooling, overheads and other costs (Figure 2). Considering the whole process, specific cost of composite manufacturing is 2-3 time higher in general compared to steel components.

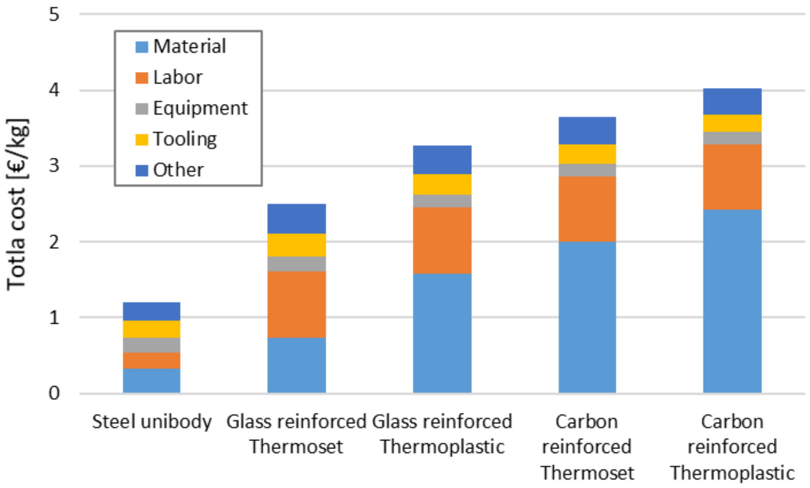

Figure 2: Cost component comparison of various composite RTM and T-RTM in contrast of conventional steel for mass production in high series [4]

For the current project, estimation was made for lightweight closure costs (Figure 3) based on the manufacturing experiences and literature background mentioned above.

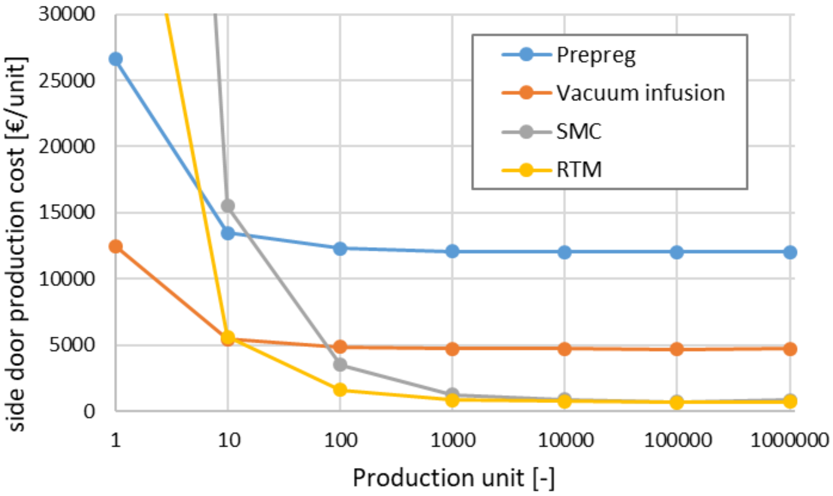

Figure 3: Cost estimation for a side door besides several production techniques.

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5. Lightweight material-based seat components with improved thermal properties (T3.4)

In the Task 3.4 in order to achieve the proposed target of about 10% weight reduction and better thermal properties, the baseline seat structure components were analysed in the actual seat and single parts were selected and the corresponding design space was evaluated and lightweight redesign was made considering strength and producibility aspects.

One of the project goals was to improve the thermal properties of the vehicle. In case of the seats, the aim was to reduce the thermal inertia. As a consequence, the seats will heat up faster in colder seasons, for instance. This goal was not be achieved by simply changing from steel-based alloys to light metals, as the steel has a lower heat capacity. In order to achieve the goal of improved thermal properties, the design of the structure and, even more important, the foam materials had to be optimized, considering the thermal properties.

5.1. Process of development and results

Development process

The first step was an analysis of the technical properties and the baseline seat structure (SotA Honda seat) were performed. The seat was disassembled, and due to the missing CAD data, 3D-Laser scanning of the structural seat parts was performed. As the results of 3D Laser scanning were not a full-featured CAD data, it was not possible to create a FEM model of the original seat. An ABC-weight analysis of the baseline seat showed that around 83 % of the weight are shared by only four parts: Frame seat plate and back complete (50 %), complete rails (21.1 %), foam part backrest (7 %) and foam part seat surface (5.3 %). It was decided to not to modify the complete rails. So, the frame seat plate and back complete was selected for the weight reduction with the goal to reduce the weight from 10 kg to about 8.5 kg (~15 %) through substitution of steel with aluminium alloy structure.

The determined design space was the base for a topology optimisation for the new seat structure. A topology optimisation provided the possibility to reduce the weight and maintain the structural stiffness at the same time. It was also possible to consider the manufacturing techniques during the optimisation to a certain extent. In the next step, a design was derived from the results of the optimisation. The lightweight material selection and the manufacturing technique was determined with a high level of functional integration. In addition, to the structural parts of the seat, the foam material of the seat was also substituted, since there was a high potential for helping to achieve the project targets in terms of weight reduction. After this, the prototype parts were manufactured with low-pressure die casting (LPDC), the front seat was built up, milled EPP foam parts were inserted and the prototype seat structure was assembled for the integration into the Honda validation platform vehicle. For the material of the seat structure, light metals such as aluminium or magnesium alloys were considered and out of them, high-strength aluminium alloys are most suitable for highly stressed structural parts. Several necessary iteration loops in the design phase as well as extended delivery period for mechanical processing by milling allowed to finish the work in the task T3.4 in November 2019.

Results

Design of lightweight structure started with evaluation of corresponding design space to develop concepts with lower weight and enhanced properties which was an aluminium steel lightweight seat. The determined new QUIET aluminium / steel seat structure and the proposed expanded polypropylene (EPP) inserts are enabling an expected total weight reduction of about 16.9 % for the whole seat. The results of the weight analysis for the new QUIET aluminium / steel seat structure showing a weight reduction from approx. 21.4 to below 17.8 kg due to lightweight design.

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The new QUIET metal seat frame mainly consisting of aluminium material. The prototype seat frame consisting of aluminium light metal components assembled together with milled as well as forged components of steel material is depicted. It is worth to note, within the prototype stadium the assembly of back frame was realized by screwing cast aluminium parts and formed sheet metal parts together.

A more sophisticated design of the cast parts would have been too complex in terms of tooling. Anyway, the new seat structure was also designed for serial production. In that case, the backrest consists of two halves and is made entirely of aluminium. The appropriateness of new lightweight seat structure was presented and verified by performed simulations of the seat virtual model documented in the deliverable D3.1 (Hybrid foam material and demonstrator seat with weight and thermal improved parts).

5.2. Goals achieved and economic upscale of production

Goals Achieved

In the proposal, a weight reduction of 10% was mentioned. Due to the substitution of several steel parts by light weight design the proposed weight reduction could be achieved for the first prototype seat allowing an overall weight reduction of 16.68 % (Table 10).

Table 10: Results of new light weight seat structure development

Seat structure	Total weight [kg]	Weight loss [%]
Original Honda FIT EV	21.4	-
Manufactured prototype	19.7	8.0
Serial, developed from prototype	17.8	16.8

Economic upscale

For economic upscale, the analysis of the profitability for several manufacturing techniques over varying seat quantities is an important issue. For the casting parts of the seat structure low-pressure die-casting (LPDC) and high-pressure die-casting (HPDC) manufacturing techniques were investigated over varying cast part quantities. Although those manufacturing technologies cannot be easily compared, the results for the actual cast parts clearly show that HPDC technique is preferable for higher seat structure volumes. Even if the acquisition costs and fixed costs for HPDC plant are higher, the investment amortizes due to significantly shorter cycle times. The productivity depends on the complexity of the cast parts. Assuming for the existing cast components the productivity of HPDC technique is three times higher as LPDC, the cost per casted seat (three cast components per seat in one production step) is lower as soon as more than 20,000 process cycles are performed (Figure 4).

For lower amount of seat structures the LPDC is the process of choice due to lower fixed costs e.g., less maintenance for plant and mould. Here in the calculation a mould of steel permanent mould is considered. With increasing amount of seat structures the HPDC rapidly amortizes due to much lower process cycle times and thus higher productivity.

The thermal properties of the prototype seat structure are considered with the aim to reduce the thermal inertia. For instance, the seats will heat up faster in colder seasons. However, this cannot be obtained by simply changing from steel-based alloys to light metals, as the steel has a lower heat capacity. In order to achieve the goal of improved thermal properties, the design of the structure and, even more important, the foam materials

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must be optimized, considering the thermal properties. For thermal improvements it is proposed to use a grid as support in the back instead of plastic and EPP inserts in the headrest and in the backrest as well.

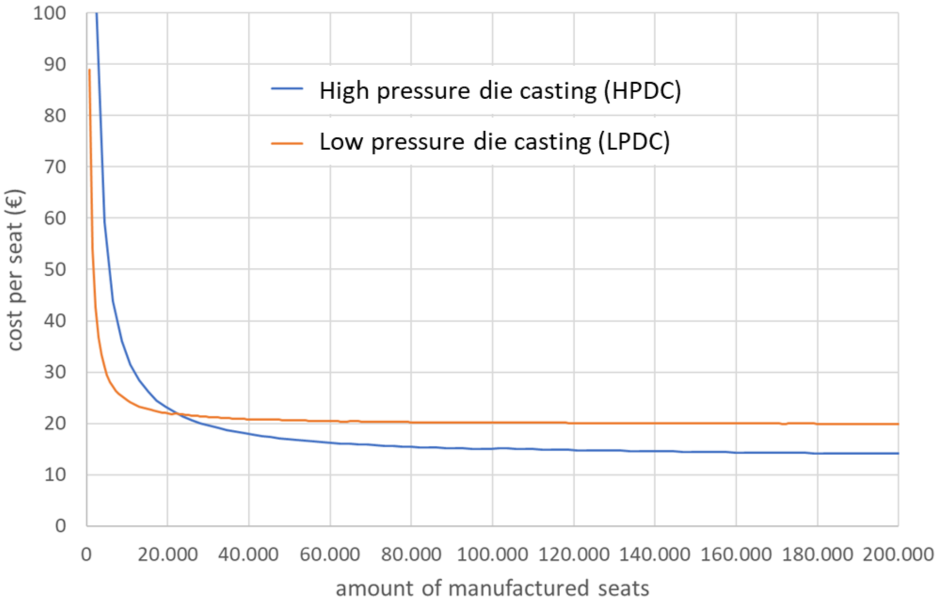

Figure 4: Cost of cast parts per seat vs. amount of seat structures, comparing LPDC (orange line) and HPDC (blue line) technique.

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6. Conclusions

QUIET aims at developing an improved and energy efficient electric vehicle (EV) with increased driving range under real-world driving conditions. This is achieved by exploiting the synergies of a technology portfolio in the areas of: user centric design with enhanced passenger comfort and safety, lightweight materials with enhanced thermal insulation properties, and optimised vehicle energy management.

During the WP3 of QUIET project, development of lightweight glazing, closures (e.g., side doors, trunk lid and engine hood) and seats were targeted all of them with improved thermal properties. The target was weight reduction of 30% in case of glazing, 20% in case of closures and 10% in case of lightweight seat structure besides better thermal properties from viewpoint of demonstrator vehicle energy consumption during heating or cooling of the cabin.

The development process was started with data acquisition and analysis of the current structure estimating possibilities on the field of mass reduction and thermal property optimization. After setting the baseline from the results of the original structures, extensive searching and improving process was carried out using the advantageous tools of material sciences, computer aided design and finite element methods. In every case, a multi-step iteration process was conducted to optimize newly developed structures and to reach best possible outcome. At the end of development, formerly set goals were achieved in weight reduction and in the field of thermal properties, as well.

Lightweight structures were not just designed, in every case they were manufactured as prototypes for implementation on the QUIET project demonstrator vehicle, so the outcome of this work package is not just a new design concept and manufacturing plan but real parts with significant weight reduction and better thermal insulation or lower heat capacity which can be implemented and tested in the last phase of the project.

In all subtask of WP3, possibilities of economic upscale were also calculated. They can show that what can be the cost using newly developed solutions for not just a prototype vehicle but higher series, as well.

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8	**ATT**	ATT advanced thermal technologies GmbH	Austria
9	**ECON**	eCon Engineering Kft.	Hungary
10	**RUB**	Rubitherm Technologies GmbH	Germany
11	**STS**	SeatTec Sitztechnik GmbH	Germany
12	**OBR**	Obrist Engineering GmbH	Austria
13	**JRC**	Joint Research Centre - European Commission	Italy