



# Contents

<b>1. Introduction.....</b>	<b>1</b>
1.1. Introduction to Lithium-Ion Battery Cells.....	5
1.2. State of the Art of Battery Thermal Management.....	8
1.3. Thermal Management Concepts Considered in this Research.....	11
1.4. Goals and Novelty of this Research.....	12
1.5. Structure of this Research.....	14
<b>Methodology</b>	
<b>2. Evaluation Criteria.....</b>	<b>15</b>
2.1. Thermal Performance.....	15
2.2. Hydraulic Work.....	18
2.3. Vehicle Suitability.....	18
2.4. Producibility and Economic Viability .....	19
2.5. Summary .....	24
<b>3. Experimental Method .....</b>	<b>25</b>
3.1. State of the Art .....	25
3.2. Analysis of a Prismatic Cell.....	28
3.3. Design and Validation of the Smart Battery Cell .....	34
3.4. Novelty of the Developed Method.....	37
<b>Analysis</b>	
<b>4. Reference Module for the Experimental Comparison.....</b>	<b>39</b>
4.1. Experimental Setup and Procedure .....	39
4.2. Analysis of the Reference Module .....	43
<b>5. Investigation of Various Cooling Plate Designs.....</b>	<b>48</b>
5.1. Layout and Considered Production Techniques.....	49
5.2. Multifactorial Analysis of Three Cooling Plates.....	56
5.3. Discussion and Design Recommendations.....	66
<b>6. Investigation of Active Spacers.....</b>	<b>69</b>
6.1. Layout and Considered Production Techniques.....	70
6.2. Multifactorial Analysis of Ceramic Spacers.....	72
6.3. Discussion and Design Recommendations.....	80



<b>7. Investigation of Heat Pipe Spacers and Long Heat Pipes.....</b>	<b>82</b>
7.1. Layout and Considered Production Techniques.....	82
7.2. Multifactorial Analysis of Heat-Pipe Spacers.....	87
7.3. Discussion and Design Recommendations.....	94
<b>8. Inter-Concept Comparison.....</b>	<b>97</b>
8.1. Use Case 1: Hot-soak at 40°C.....	97
8.2. Use Case 2: Cold-start at 0°C.....	100
8.3. Multifactorial Analysis Across Both Use Cases.....	102
8.4. Design Recommendations for a High-Performance PHEV.....	106
<hr/>	
<b>9. Conclusion.....</b>	<b>107</b>

—————      **Appendices**      —————

<b>A. References.....</b>	<b>111</b>
<b>B. Abbreviations and References.....</b>	<b>121</b>
<b>C. Details of the Experimental Setup.....</b>	<b>123</b>
<b>D. Numerical Analysis of Cooling Plate Operating Conditions....</b>	<b>126</b>
<b>E. Numerical Analysis of the Ceramic Spacers.....</b>	<b>129</b>