Development of a Thermoelectric Device for an Automotive Zonal HVAC System

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“The range can vary on any given day depending on temperature, terrain, driving conditions and so forth -- especially temperature,” GM Vice Chairman Bob Lutz told reporters this morning at the 2010 Detroit auto show. “Many people don’t understand that. The distance you can go in an electric vehicle varies hugely with the outside temperature, including with the Volt.”

“If on a standard day you see 40 miles with the Volt, on a cold day where it’s right around 32 degrees, you’re going to see 28 or 30 miles,” Lutz said.
Zonal Application Description

- Only condition occupied positions

- Downsize/reduce or eliminate the output of the central system
“Waste” Side Working Fluid

Thermoelectric device constructions for use with 2 working fluids.
## “Waste” Side Working Fluid

<table>
<thead>
<tr>
<th>Air Waste Stream</th>
<th>Liquid Waste Stream</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pros</strong></td>
<td><strong>Cons</strong></td>
</tr>
<tr>
<td>Low weight</td>
<td>Poor heat transfer</td>
</tr>
<tr>
<td>No risk of coolant leaks</td>
<td>Lower power density</td>
</tr>
<tr>
<td>Difficult to vent waste heat</td>
<td>Uses and ejects conditioned air</td>
</tr>
<tr>
<td>Minimizes $\Delta T$ across TE</td>
<td>Low capacity per gram of Tellurium</td>
</tr>
<tr>
<td><strong>Pros</strong></td>
<td><strong>Cons</strong></td>
</tr>
<tr>
<td>Good heat transfer</td>
<td>Added weight</td>
</tr>
<tr>
<td>High power density</td>
<td>Routing liquid lines in cabin (leaks)</td>
</tr>
<tr>
<td>Removes heat from Interior</td>
<td>Requires an additional radiator</td>
</tr>
<tr>
<td><strong>Pros</strong></td>
<td><strong>Cons</strong></td>
</tr>
<tr>
<td>Capacity per gram of Tellurium</td>
<td>Waste side temp tied to ambient</td>
</tr>
<tr>
<td>Minimal noise – Lower airflows</td>
<td>Added coolant controls</td>
</tr>
<tr>
<td>Waste heat scavenging</td>
<td>Added coolant controls</td>
</tr>
</tbody>
</table>
2 Devices were modeled, both having the same volume and using the exact same thermoelectric engines.

Air-to-Air Device designed to have the Waste side flow = 2 x Main flow to improve performance. This requires 3x the airflow rate of the L/A device. (This increased airflow has a significant impact on blower power, package & noise.)

Liquid-to-Air device assumed a conservative flow rate of ~2 L/min
**Air vs. Liquid Performance Comparison**

Main & Waste Inlet Temperatures 30 °C

**Diagram Description**

- The graph shows the performance comparison between Air-Air and Air-Liquid systems.
- The x-axis represents Input Power (W), while the y-axis represents |ΔT_{air}| (°C).
- The blue line represents the Air-Air system, and the red line represents the Air-Liquid system.
- At a certain point, the Air-Liquid system achieves a significantly lower |ΔT| compared to the Air-Air system, indicating a better performance.
- The design target is marked on the graph, showing the ideal performance point.

**Additional Note**

- A/A limited Qc results in significantly lower ΔT.
Air vs. Liquid Performance Comparison

Main & Waste Inlet Temperatures 30°C

Design Target
Device Optimization

Design Methodology:
- Optimize at the device and component level
- Major components are:
  - Liquid HEX, Air Fin, Dielectric Systems and Thermoelectric Engine

Performance “Walk”

Baseline w/ Extruded HEX
Custom Liquid HEX
Custom Liquid HEX #2
Optimize Pellet (A/L)
Increase Shunt Thickness
With 50/50 EGW
Increase Air Fin Depth 20%

COP
TE Engine & Air Fin

- Select number of elements and airflow depth
TE Engine & Air Fin

- Select number of elements and airflow depth

![Graph showing the relationship between input power and absolute temperature difference (C) for different airflow lengths (40mm to 90mm).]
Goals:

- Maximize heat transfer efficiency
- Minimize coolant pressure drop
- Control flatness
- Manufacturing feasibility – utilize current production processes
Liquid Heat Exchanger

Static Pressure Profile-
Liquid Heat Exchanger

Total Pressure Profile-
Liquid Heat Exchanger

Velocity Profile:
Thermoelectric Engine

- Select pellet side length
  - Optimize for performance
  - Material usage
  - Thermal stress management

![Chart compares performance of elements with various A/L ratios. (Purple Selected)](chart.png)
Thermoelectric Engine

- Select pellet side length
Thermoelectric Engine

- Select pellet thickness
  - Optimize for performance
  - Manufacturing process capability
  - Material usage
  - Thermal stress management

![Graph showing COP against TE Thickness](chart.png)
Phase 2 Device

- Thermal Isolation
- Steel Clamp plate
- TE Engines
- Aluminum Air Fins
- Liquid HEX
Status

Where Are We?

- Testing Phase 2 Devices
  - Evaluating various air fin derivatives
- Start durability testing of Phase 2 device.
- Preparing Phase 3 device refinements for the design and manufacturing process. Scheduled for delivery 3rd Qtr 2012.
- Prepare a detailed cost analysis of the devices and system components. 4th Qtr 2012.
Summary

Conclusions:

- Phase 2 Device has been tested at a wide range of Input Powers from 100 to 700 W.
- Design is scalable to customer requirements
- Heavy focus on production feasibility.
- Durability – Phase 1 part survived 150,000 cycles
- Available for alternative applications:
  - Battery thermal management
  - Electronics cooling
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