# Projects in WP2: Air Conditioning, Chilling and Freezing

<table>
<thead>
<tr>
<th>WP2.1</th>
<th>Retail chilling and freezing</th>
<th>Wave</th>
<th>Team</th>
<th>Start month</th>
<th>End month</th>
</tr>
</thead>
<tbody>
<tr>
<td>WP2.2</td>
<td>Retail chilling and freezing</td>
<td>2</td>
<td>JE, AF, EH, GM (LSBU)</td>
<td>15</td>
<td>24</td>
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<tr>
<td>WP2.3</td>
<td>Data centres</td>
<td>1</td>
<td>GD, GM (LSBU)</td>
<td>6</td>
<td>24-48</td>
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<td>WP2.4</td>
<td>Refrigerated transport</td>
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<td>GD, JE, CF, GM (LSBU)</td>
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<td>36</td>
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<tr>
<td>WP2.5</td>
<td>Integration – cooling, heating, storage</td>
<td>1/2</td>
<td>AR, IC, MM, GM (LSBU)</td>
<td>6</td>
<td>42</td>
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</tbody>
</table>
WP 2.1 Retail chilling and freezing [1st Wave, Graeme Maidment, LSBU]

Rationale:
- UK Supermarkets are large energy users/carbon producers & consume 3% of UK energy and 7.3 MT CO$_2$.
- At least 40% of energy is used directly for cooling, mainly refrigerated display cabinets (RDCs).
- A further 25% is used for heating, of which 1/3 offsets cooling losses from RDCs.

Carbon Reduction Potential: 4.8MT CO$_2$ pa UK. Investigations consider cradle to grave, remanufacture/recycling, reducing embodied carbon impact.

Pathway to impact: with Asda, Sainsbury's, The Coop and Bond Retail Display and will consider form and ergonomics, user requirements, readiness, etc.
WP2.1.1 Technologies initially investigated and sifted

Road map

WP2.1.2 Technologies investigated experimentally and a physical proof of concept prototype developed

WP2.1.3 Non technical barriers preventing uptake of new technologies assessed

WP2.1.4 Trial of the prototype in-store with ASDA
WP 2.1 Retail chilling and freezing

- WP2.1.1 – Technologies will be initially investigated and sifted
- WP2.1.2 – In parallel with WP2.1 technologies will be investigated experimentally and a physical proof of concept and a prototype will be developed
- WP2.1.3 – Non technical barriers preventing uptake of new technologies, such as customer reaction, implementation, cost-benefit models, end user (supermarket) incentives will be assessed
- WP2.1.4 – The final part of this work package will involve a trial of the prototype in-store with ASDA
WP 2.1 Retail chilling and freezing

- WP2.1.1 – Technologies will be initially investigated and sifted
- WP2.1.3 – Non technical barriers preventing uptake of new technologies, such as customer reaction, implementation, cost-benefit models, end user (supermarket) incentives will be assessed
- Update of retail road map to identify best technologies
  - Retrofit (technologies that can be fitted in situ to a cabinet)
  - Refit (technologies that can be applied when refitting store)
  - Future technologies (technologies available in the future)
Retrofit

- Refrigerants
- Floating head pressure
- LED lights
- EC Evaporator fan motors
- EC Condenser fans motors
- Suction pressure control
- Doors on cabinets
- Store dehumidification
- Anti-sweat heater controls
- Better cabinet loading
- Short air curtains
- Back panel flow
- Occupancy sensors and controls for cabinet lighting
- Strip curtains
- Night blinds
- Liquid pressure amplification
- Risers or weir plates
- Defrost controls
- Store lighting
- Radiant heat reflectors
- Store temperature control
- Cabinet temperature control
- Training
- Cleaning and maintenance
- Re-commissioning
- Covers
- Loading – duration and temperature

Completed

Covers
Refit and future

- Cabinet selection
- Secondary systems
- Water loop systems
- CO2 refrigeration technology
- Borehole condensing
- Dynamic demand
- Ground source
- Pipe insulation/rifling/reduced pressure drops
- Anti-fogging glass
- Optimisation of cabinet air flow
- Evaporative condensers
- High-efficiency evaporators and condensers
- Refrigeration system contamination
- SLHE
- Nanoparticles
- Heat pipes and spot cooling
- Anti-frost evaporators
- Fans
- Economisers

- Electronic expansion valves
- Reflective packaging
- Insulation e.g. VIPs
- Off-cycle losses
- Cabinet location
- Desuperheating/heat recovery
- Variable speed drives (integral)
- Internet shopping
- Supermarket cold store
- Vending cabinet concepts
- Polygeneration
- Adsorption
- Absorption
- Novel building fabric
- High-efficiency compressors
- Centralised air distribution
- Store light (natural)
Baseline store (Asda W-S-M) for model

<table>
<thead>
<tr>
<th>Service</th>
<th>TOTAL kW</th>
<th>% of store main</th>
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<tbody>
<tr>
<td>Refrigeration</td>
<td>158.9</td>
<td>39.73%</td>
</tr>
<tr>
<td>HVAC</td>
<td>48.9</td>
<td>12.23%</td>
</tr>
<tr>
<td>Lighting</td>
<td>85.8</td>
<td>21.45%</td>
</tr>
<tr>
<td>Food Prep</td>
<td>63.2</td>
<td>15.80%</td>
</tr>
<tr>
<td>Small Lighting &amp; Power</td>
<td>0.0</td>
<td>0.00%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>89.21%</strong></td>
</tr>
</tbody>
</table>

- Currently working to identify missing 10% energy!
- Currently matching cabinets to refrigeration power
- Need detailed info on HVAC, lighting and food prep
WP2.1.2 – In parallel with WP2.1 technologies will be investigated experimentally and a physical proof of concept and a prototype will be developed.

Roadmap used to identify the technologies that have the best potential for improvement:

- Probably multi-deck chilled cabinet
- Only commercially available technologies
- Some technologies will not be suitable for a multi-deck or compatible
Likely current technology candidates:

Cabinet:
1. Doors
2. LED lights
3. ECM fan motors
4. Occupancy sensors
5. SLHE
6. Anti frost evaporator
7. Insulation

Refrigeration system:
1. Floating head pressure
2. Changing refrigerant
3. Suction pressure control
4. ECM condenser fans
5. LPA
6. Evaporative condensers
Savings from cabinet modifications for supermarket calculated

Before/after applied to standard ASDA store model

Selected technologies incorporated

Cabinet re-tested

Cabinet sourced and tested

Overall savings for whole system calculated

Savings from refrigeration system modifications for supermarket calculated

Savings from changes to refrigeration system calculated using validated model

Compared using refrigeration system models

Measurements of heat extracted in ASDA store

1

2
WP2.2  Retail chilling and freezing [Potential 2\textsuperscript{nd} Wave project, Graeme Maidment, LSBU]

*Rationale:* WP2.1 will be extended into a 2\textsuperscript{nd} Wave project investigating more fundamental concepts of retail display and their applicability in the longer term.

*Challenge:* to challenge the concept of the retail display cabinet, specifically from a fundamental aesthetic, ergonomic and energy use perspectives.

*Objectives/ Deliverables:* To deliver a new concept in RDC that has 1/10 of the existing energy consumption

*Carbon Impact potential:* 12 million tonnes of carbon in energy alone

*Pathway to impact:* as for WP2.1
WP 2.3  Data centres [1st Wave and 2nd wave, Graeme Maidment, LSBU]

*Rationale*: Cooling of data centres with integrated free cooling, evaporative cooling and energy stores, to deliver effective low cost cooling with minimum PUE.

*Challenge/Objectives/ Deliverables*: To develop integrated solutions utilising free cooling and energy storage and avoid the need for mechanical cooling.

*Carbon Impact potential*: Data centres use 7.9 TWh of UK electricity and this is expected to double by 2020. Cooling can use 50% and we can massively reduce their footprint with integrated free and low energy solutions.

*Pathway to impact*: By working with data centres, solutions can be trialled and implemented. The Green Grid will provide the dissemination route.
**WP2.3 Data centre cooling project**

- Identify and evaluate technologies that can improve data centre cooling efficiency reducing energy use and carbon emissions

- Create a roadmap for the adoption of improved cooling technologies in data centres

- Select a few technologies for detailed study e.g. direct two phase liquid cooling of server racks

- Devise programme for detailed study

- Carry out study

- Produce report and recommendations for future use
Data centre cooling approaches

**Air based**

**Advantages** – Conventional. Effective. Fans, air conditioners and chillers. Electrical compatible. New: free cooling and evaporative cooling, higher operating temperatures

**Disadvantages** – Low heat carrying capacity, large volumes, costly equipment, inefficient

**Water based**

**Advantages** – High heat capacity, pumped, small volumes, efficient, low energy input

**Disadvantages** – Incompatible with electronics, only recently used in data centres

**Refrigerant based**

**Advantages** – Electronics compatible, high heat carrying capacity, particularly 2-phase. Pumped system – low energy input

**Disadvantages** – not much experience of use in data centres
Energy flows in data centres

- Typical air-cooled data centre configuration

- Main aim of conventional data centre cooling is to remove heat from vicinity of microprocessors and reject to outside ambient air

Energy (electrical and mechanical) inputs, heat outflows and typical temperatures

Total energy input $\dot{E}_{TOT} = \dot{E}_{IT} + \dot{E}_{L} + \dot{W}_{F} + \dot{W}_{F} + \dot{W}_{C}$

Total heat energy output $= \dot{Q}_{4}$

Power Usage Effectiveness PUE $= \frac{\dot{E}_{TOT}}{\dot{E}_{IT}}$

Exergy.....
## Comparison/evaluation of cooling technologies

| Cooling medium | Cooling Technology | Energy saving (%) | PUE | Energy destroyed | Cost saving (%) | CO₂ saving (%) | Reliability (L/M/H) | Barriers to uptake (L/M/H) | Availability to purchase (L/M/H) | Limits to commercial maturity (L/M/H) | Ease of use and installation (L/M/H) | Technology independence (L/M/H) | Maintainability (L/M/H) | Legislative issues (L/M/H) | PUE | Scopes | Qualification |
|----------------|-------------------|-------------------|-----|------------------|----------------|---------------|-------------------|-------------------------|--------------------------------|------------------------------------|--------------------------------|----------------|--------------------|------------|--------|----------------|
| Air            | Inverter driven screw compressor for air cooled chiller | 30%-50% | 1.55-1.77 | H | L | H | L | H | H | H | H | L | R | Energy saving c.f. compared with non-inverter chiller |
|                | EC fans for condensers | 45% | 1.61 | L | L | L | L | L | L | L | L | L | L | L | Energy saving c.f. that for traditional condenser fans |
|                | Fanwall technology | Low | High | L | L | L | L | L | L | L | L | L | L | L | TCO cost saving on total purchase price and running c.f. traditional steam humidifier |
|                | Humidification e.g. high pressure atomisation or ultrasonic low energy humidifier | 93-99% | 60% | L | L | L | L | L | L | L | L | L | L | L | |
|                | Direct fresh air-free cooling | 82% | 1.2 | 26% | L | L | L | L | L | L | L | L | L | L | |
|                | Indirect free cooling | 14-55% | 1.95 - 1.5 | L | L | L | L | L | L | L | L | L | L | L | |
|                | Indirect air-to-air free cooling using thermal wheel or plate heat exchangers | 96.8% | 1.035 | L | L | L | L | L | L | L | L | L | L | L | PUE achieved depends on the level of redundancy, ambient temperature and operating conditions required |
|                | Direct evaporative cooling (computer room evaporative cooler - CREC) | > 90.9% | < 1.1 | L | L | L | L | L | L | L | L | L | L | L | PUE indicated is for a N+1 system (Typical PUE 2.1) |
|                | Cooling tower and water cooled chillers | 95.9% | 1.045 | L | L | L | L | L | L | L | L | L | L | L | PUE achievable |
|                | Use of borehole at 14°C with water cooled chillers | 97.2% | 1.03 | L | L | L | L | L | L | L | L | L | L | L | PUE achievable |
|                | Use of river and sea water with water cooled chillers | v. low | rapid ROI | L | L | L | L | L | L | L | L | L | L | L | |
|                | Indirect evaporative modular cooling system (Oasis) | 75% | < 1.1 | 67% | L | L | L | L | L | L | L | L | L | L | Energy saving c.f. that for a traditional data centre |
## Comparison/evaluation of cooling technologies

<table>
<thead>
<tr>
<th>Cooling medium</th>
<th>Cooling Technology</th>
<th>Energy saving (%)</th>
<th>PUE</th>
<th>Exergy destroyed</th>
<th>Cost saving c.(%)</th>
<th>CO₂ saving (%)</th>
<th>ROI</th>
<th>Barriers to uptake</th>
<th>Availability to purchase</th>
<th>Energy saving c.f. that for a traditional data centre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>Direct on-chip water cooling</td>
<td>80%</td>
<td>1.14</td>
<td>ROI &lt; 1 year</td>
<td>80%</td>
<td>1.14</td>
<td>ROI &lt; 1 year</td>
<td>80%</td>
<td>1.14</td>
<td>ROI &lt; 1 year</td>
</tr>
<tr>
<td>Water</td>
<td>In-row cooling</td>
<td>25%</td>
<td>1.82</td>
<td>14%</td>
<td>25%</td>
<td>1.82</td>
<td>14%</td>
<td>25%</td>
<td>1.82</td>
<td>14%</td>
</tr>
<tr>
<td>Water</td>
<td>Recirculating rack cooling</td>
<td>25%</td>
<td>1.82</td>
<td>7%</td>
<td>25%</td>
<td>1.82</td>
<td>7%</td>
<td>25%</td>
<td>1.82</td>
<td>7%</td>
</tr>
<tr>
<td>Water</td>
<td>Rear door water cooled heat exchanger</td>
<td>80%</td>
<td>1.22</td>
<td>50%</td>
<td>80%</td>
<td>1.22</td>
<td>50%</td>
<td>80%</td>
<td>1.22</td>
<td>50%</td>
</tr>
<tr>
<td>Dielectric liquid</td>
<td>Immersion cooling of whole server board in dielectric liquid</td>
<td>97.2</td>
<td>1.03</td>
<td>7%</td>
<td>97.2</td>
<td>1.03</td>
<td>7%</td>
<td>97.2</td>
<td>1.03</td>
<td>7%</td>
</tr>
<tr>
<td>Refrigerant</td>
<td>2-phase on-chip cooling - pumped</td>
<td>97.2</td>
<td>1.03</td>
<td>7%</td>
<td>97.2</td>
<td>1.03</td>
<td>7%</td>
<td>97.2</td>
<td>1.03</td>
<td>7%</td>
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<tr>
<td>Refrigerant</td>
<td>2-phase on-chip cooling - vapour compression</td>
<td>97.2</td>
<td>1.03</td>
<td>7%</td>
<td>97.2</td>
<td>1.03</td>
<td>7%</td>
<td>97.2</td>
<td>1.03</td>
<td>7%</td>
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**WP2.3 Data centre cooling project - timescales**

<table>
<thead>
<tr>
<th>Activities</th>
<th>Duration</th>
<th>Milestones</th>
</tr>
</thead>
</table>
| Detailed study of selected technologies          | May 2014 - July 2016| Interim report – November 2014
|                                                 |                     | Interim report – May 2015
|                                                 |                     | Interim report – November 2015
|                                                 |                     | Final report - July 2016
|                                                 |                     | Recommendations – July 2016                     |
WP2.4 – Refrigerated Road Transport (RRT) – carbon saving

• Refrigerated road transport in UK is responsible for 2.7 million tonnes of CO$_2$ pa due to engines alone

• Refrigerant leakage from transport systems is high due to the harsh conditions experienced

• Environmental impact of refrigerant leakage in transport systems is up to 40% that of vehicle emissions

• Transport refrigeration currently exempted from F-gas regs, but expected to be included in new FGas2 regs

• Potential for large reductions in refrigerant leakage in transport systems and substantial carbon savings
Research Objectives/ Deliverables:

1. Review industry, examine different types of designs and technologies

2. Analyse existing maintenance and leakage records to:
   a) Identify problematic components/ sources of refrigerant leakage
   b) Determine generic solutions for leak tight systems

3. Identify RRT samples and collect actual data using appropriate instrumentation and controls (IC)

4. Develop a predictive model to simulate different scenarios of RRT systems;
   a) Determine relative operational costs of units
   b) Estimate respective direct and indirect carbon emissions
   c) Evaluate the effectiveness of various designs – proportion of chilled vs. frozen

5. Validate and optimise model

Food Transport –

Review of Indirect Emissions
♦ Food transport accounts for 25% of all HGV vehicle kilometres in the UK
(It is estimated that a 1/3 are refrigerated)

♦ Food transport produced 19 million tonnes of carbon dioxide,
of which 10 million tonnes were emitted in the UK (almost all from road transport emissions from truck engine),
  = 1.8% of the total annual UK CO₂ emissions, and
  = 8.7% of the total emissions of the UK road sector.
Based on Defra, The Validity of Food Miles as an Indicator of Sustainable Development: Final Report, ED50254, Issue 7, 2005

Review of Direct Emissions
♦ In 2010, refrigerated road transport
  • Total world fleet est. at 4,000,000 vehicles
  • Refrigerant bank est. at 19,400 t
  • Refrigerant emissions est. at 2,460 t/year

Based on Montreal Protocol on Substances that Deplete the Ozone Layer UNEP 2010 TOC Refrigeration, A/C and Heat Pumps Assessment Report

♦ Annual leakage reported for RRT is approx. 20-25% of the refrigerant charge
  — IPCC/TEAP 2005, Special Report: Safeguarding the Ozone Layer and the Global Climate System. Chapter 4
**Proposed project plan flow chart**

- Prelim Study & Data Analysis I
- Data Collection & Analysis
- Develop Model
- Validate & Optimize Model
- Report for Transport Industry
- PhD Thesis
## Project Milestones

<table>
<thead>
<tr>
<th>W.P.</th>
<th>Activities</th>
<th>Duration</th>
<th>Milestones</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.4.2</td>
<td>Plan Project Research</td>
<td>Nov 2013 - Oct 2014</td>
<td>• LSBU Report – April 2014</td>
</tr>
<tr>
<td>2.4.3</td>
<td>Prelim Study &amp; Data Analysis</td>
<td>Jan 2014- Apr 2014</td>
<td></td>
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</tbody>
</table>
| 2.4.4| Data Collection                   | May 2014 – July 2015 | • Interim Report – Jun 2014  
• LSBU Report – Oct 2014 |
• LSBU Report – April 2015 |
| 2.4.6| Develop Model                     | Aug 2015- Jan 2016 | • LSBU Report – Sept 2015  
• Demonstrate Model – Dec 2015 |
| 2.4.7| Validate & Optimize Model         | Jan 2016 – May 2016 | • Interim Report – Mar 2016  
• Completed Model – May 2016 |
• Viva – Nov 2016 |

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**Next immediate steps**

- Discuss project with prospective retailers and explore possibilities of active involvement in measurement of RRT performance
- Understand maintenance routine conducted by a RRT service engineer to include common types of faults and fault repair procedures
- Review existing models applied to analysis of RRT units
## Transport refrigeration project - timescales

<table>
<thead>
<tr>
<th>Activities</th>
<th>Duration</th>
<th>Milestones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collection of refrigerant leakage data and analysis</td>
<td>Oct 2013- Jan 2015</td>
<td>Interim report Jan 2014</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Final report Jan 2015</td>
</tr>
<tr>
<td>transport refrigeration systems, validation and</td>
<td></td>
<td>Final report Aug 2016</td>
</tr>
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<td>optimisation</td>
<td></td>
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<tr>
<td>refrigeration industry</td>
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</tbody>
</table>
Work Package 2.5

Integrated cooling, heating and storage

Research student: A. Revesz

Supervisors: I. Chaer, G. Maidment, J. Thompson, M. Mavroulidou
Overall project aim

Investigate the thermal interaction of ground heat exchangers with the London Underground network.
Deliverables

- List of parameters which influences the thermal interaction between the two schemes.
- Develop a model that will
  - Determine the regions of interactions.
  - Quantify the scale of the interactions.

Potential use of the outcomes

- The outcomes may enable...
  - To inform decision makers about the interaction of GSHPs with the LU network.
  - The formation of potential policy.
  - Various design options to be considered that may enhance efficiency of heat pumps.
  - To provide detailed data for stakeholders who have an interest in utilising the waste heat from the tunnel environment.
Key progress to date

Time plan development

• Overall schedule to carry out the project has been set by listing a number of different stages with a given time frame. The project currently under the background research stage.

Background research

• Subject areas required to investigate were listed and exploration of topics has started.

Induction with London Underground

• In order to familiarize with the underground railway environment and the engineering challenges involved, industrial induction with London Underground has been agreed, which is currently under progress.
Immediate next steps

Following the induction with London Underground, summarize the...

- Cooling challenges of the London Underground railway environment.
- Methods implemented to overcome of those challenges.
- Thermal behaviour of the different deep level tube lines and quantify the reasons if there are different behaviours.
- Data available from London Underground that support the research.

Investigate parameters that influence and equations that govern the heat transfers between the tunnels and ground heat exchangers.

Evaluate appropriate simulation software models.

Investigate and select GSHP case studies close to LU tunnel network.