A fully integrated understanding of household refrigerator energy consumption during normal use in the home

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Energy Efficient Strategies

Overview

- Examines key drivers of refrigerator energy
- Documents a new approach to disaggregate refrigerator energy field data into key components: temperature, defrost and user interactions
- Examines measured total energy consumption for a wide range of products in the field
- Illustrates that energy efficiency is the most important product attribute, with room temperature also a major factor
- Concludes that defrost energy and user interactions are significant, but generally small, components of normal use

Global Context

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- Around 150 million household style refrigerators are made and sold every year globally
- Global stock is around 1.8 billion appliances
- These appliances are responsible for up to 6% of global electricity consumption
- They are the most regulated product globally for energy efficiency (75 countries, ~200 programs)
- Until this research, we knew little about the key drivers of energy consumption and how much energy they are likely to use in the home

Drivers of refrigerator energy

- Refrigerator energy data in the field is incredibly difficult to analyse
  - need high quality energy data (1 min intervals)
  - room temperature data
  - long periods of time
  - detailed method to split into components
- Many researchers have examined a range of obvious factors, such as ambient temperature, humidity, door openings and the insertion of food loads to be cooled
- Most conclude that ambient temperature is the most important factor, but this was poorly quantified

Background to the Study

- High quality energy and temperature data collected in 273 homes, 320 appliances
- Ended up with 260 energy data sets – distilled down to 235 usable appliances with full data
- Most appliances measured for 6 to 9 months
- Total of 66,000 appliance-days of 1 min data (95m records), >55,000 defrost events
- Database (80 GB) and analysis software to process
- Data collection and analysis was by Lloyd Harrington as part of his PhD at the University of Melbourne

Data collection and analysis

- Appliances were monitored in situ during normal use with energy measurements each minute for long periods
- Room temperature was also measured
- Data was broken into compressor cycles using interpolation to estimate each compressor start time (adapted best practice lab techniques)
- Defrost heater operation (where present) was separately identified and analysed
- Refrigerator energy was separated into four separate components (see next slide)

Components of refrigerator energy

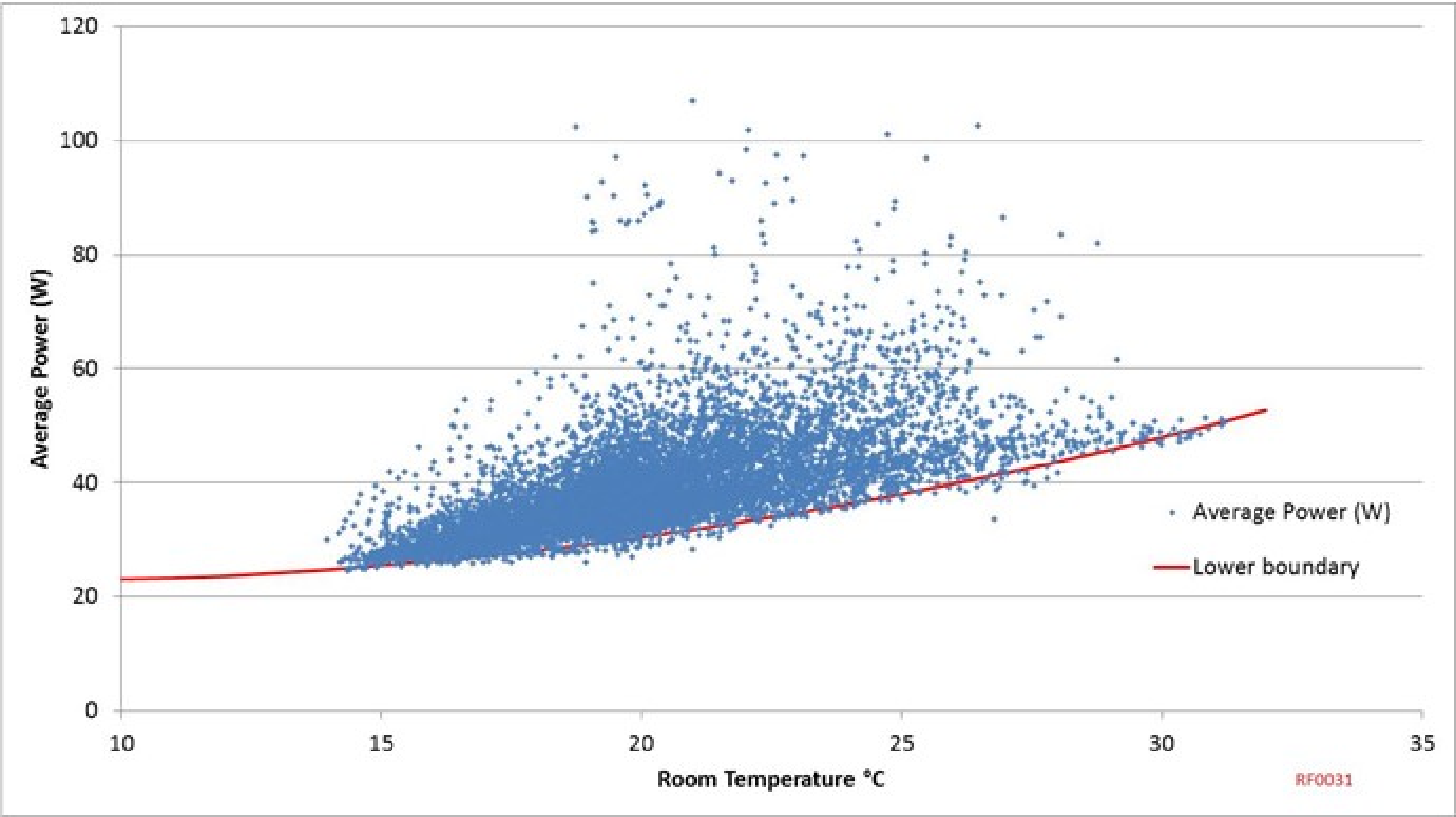
Refrigerator energy consumption can be broken into four main elements

1. Energy consumption driven by room temperature
2. Energy consumption required for defrosting without user interactions
3. Additional energy consumption for defrosting arising from user interactions
4. Energy consumption induced by user interactions such as dooring openings and food loads

Method – temperature driven

- Analysis of data in each house focused on energy consumption and ambient temperature for each appliance across the monitoring period
- This allowed a function of temperature versus average power for each appliance to be developed
- This quantifies the temperature driven component of energy consumption during normal use
- It was found that most Australian houses have significant changes in indoor temperature through the seasons and even during the day

Room temperature impact on energy
each point is a compressor cycle



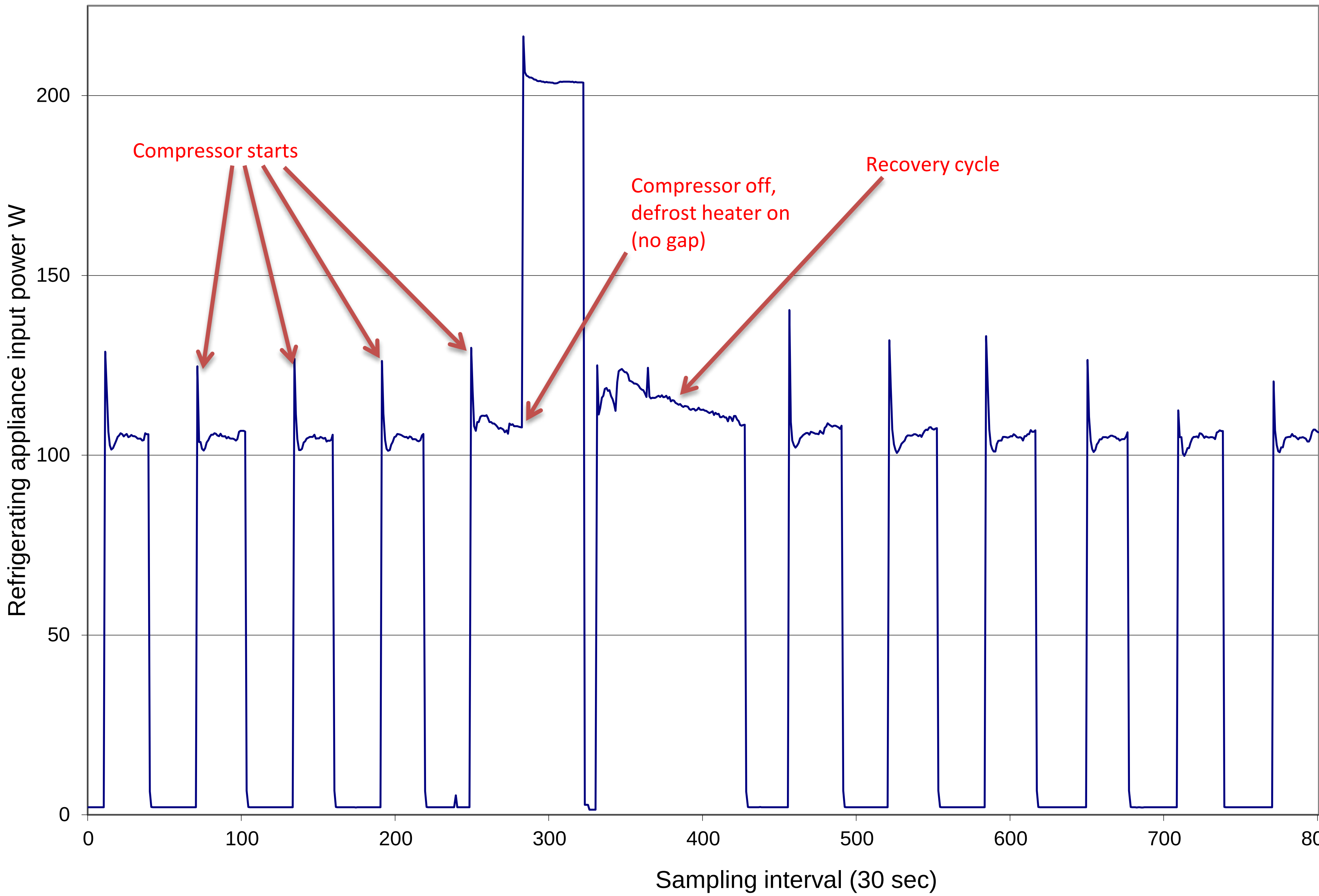
Temperature data - interpretation

- Each dot represents a separate compressor cycle
- The fitted red line below the cloud of data (lower boundary) represents the response of the appliance to changes in ambient temperature WITHOUT ANY USER INTERACTION
- This provides a generic function of room temperature versus power for the specific appliance as installed (for the given control setting)
- The difference between each point and the red line represents the additional energy induced by user interaction (or in some cases defrost related energy, which is separately examined)

Defrosting

- A large proportion of refrigerator-freezers now use automatic defrost systems
- In forced air systems, air passes over the evaporator and frost can accumulate
- This has to be periodically removed with a defrost cycle – the compressor stops, a heater in the evaporator is turned on to melt frost and ice which is drained outside the appliance
- Typically the heater is turned off once the evaporator surface temperature reaches a defined limit (~+8°C) indicating all frost is melted
- The recovery cycle cools the refrigerator components down again and compensates for compressor off time

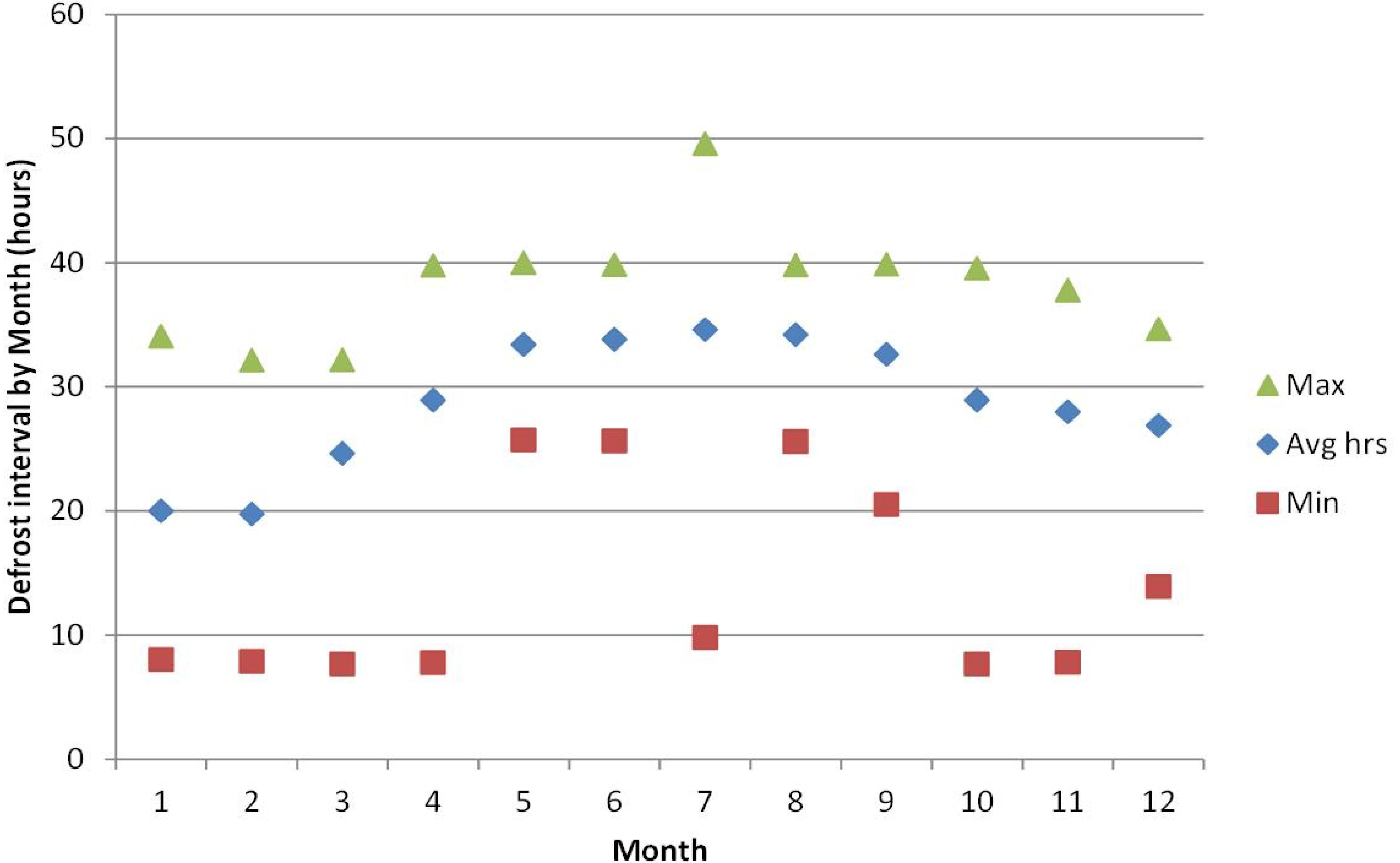
Defrosting in the laboratory



Method – defrosting

- The defrost heater power is generally very different to the compressor, allowing these events to be separated
- The type of defrost control was determined (variable or run-time controller) from defrost interval observed
- This allowed defrost energy to be split into a base energy consumption (no user interaction) and additional defrost energy driven user interactions
- Energy for each defrost is fairly constant – defrost interval is the main parameter that varies during use
- Run-time controllers had shorter defrost intervals and had a low share of user driven defrost energy
- Variable controllers had longer defrost intervals and about half the energy was user driven

Defrost intervals in a house



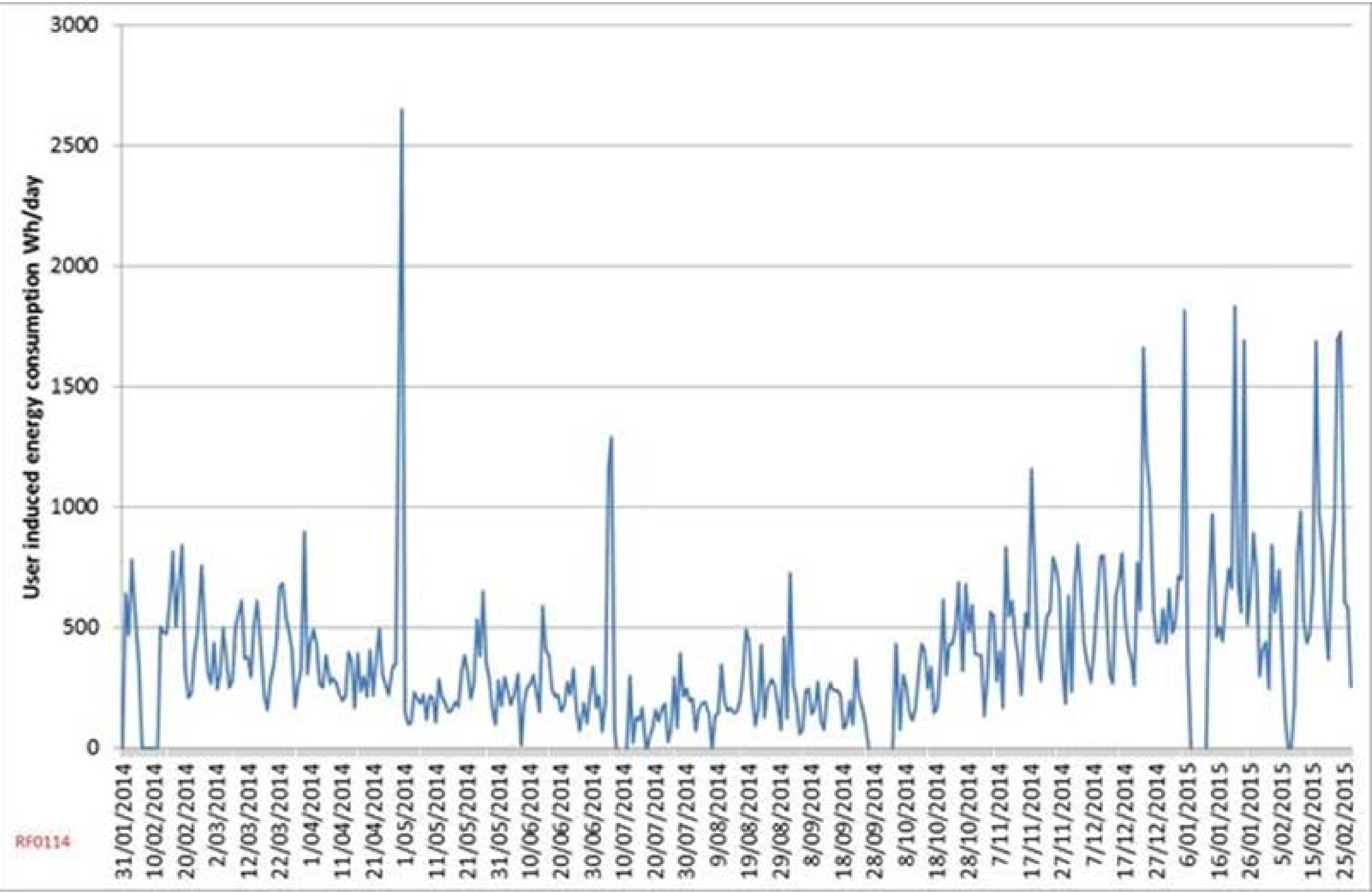
Defrost data - interpretation

- The defrost interval is dictated by the defrost controller
- Run-time controllers are highly predicable
- Variable controllers use a range of parameters like door openings, run-time and defrost heater ON time during defrost to predict when to next defrost
- Most variable defrost algorithms are proprietary
- Defrost energy can be split into heater energy (visible) and recovery energy (less visible - usually mixed in with steady state and usage)
- New technique allows recovery energy to be estimated by examining hundreds of defrosts in-situ

Method – user interactions

- For each compressor cycle, user interaction can be estimated from the actual power minus the power expected at the ambient temperature with no user interactions ("lower boundary")
- As would be expected, user induced energy is highly variable from day to day
- User induced energy tends to be seasonal
- Some random low periods (when absent) plus high use events (parties, festivities)

User induced energy for 1 year



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User interactions - interpretation

- Monthly values were found to be more stable and usable – typically summer is 2-3 times winter
- Important to note that this user induced energy is NOT the total heat load the appliance has to remove
- Need to estimate operating system COP in order to calculate sensible and latent heat loads from user interactions, which is ultimately more useful

User induced energy for 1 year

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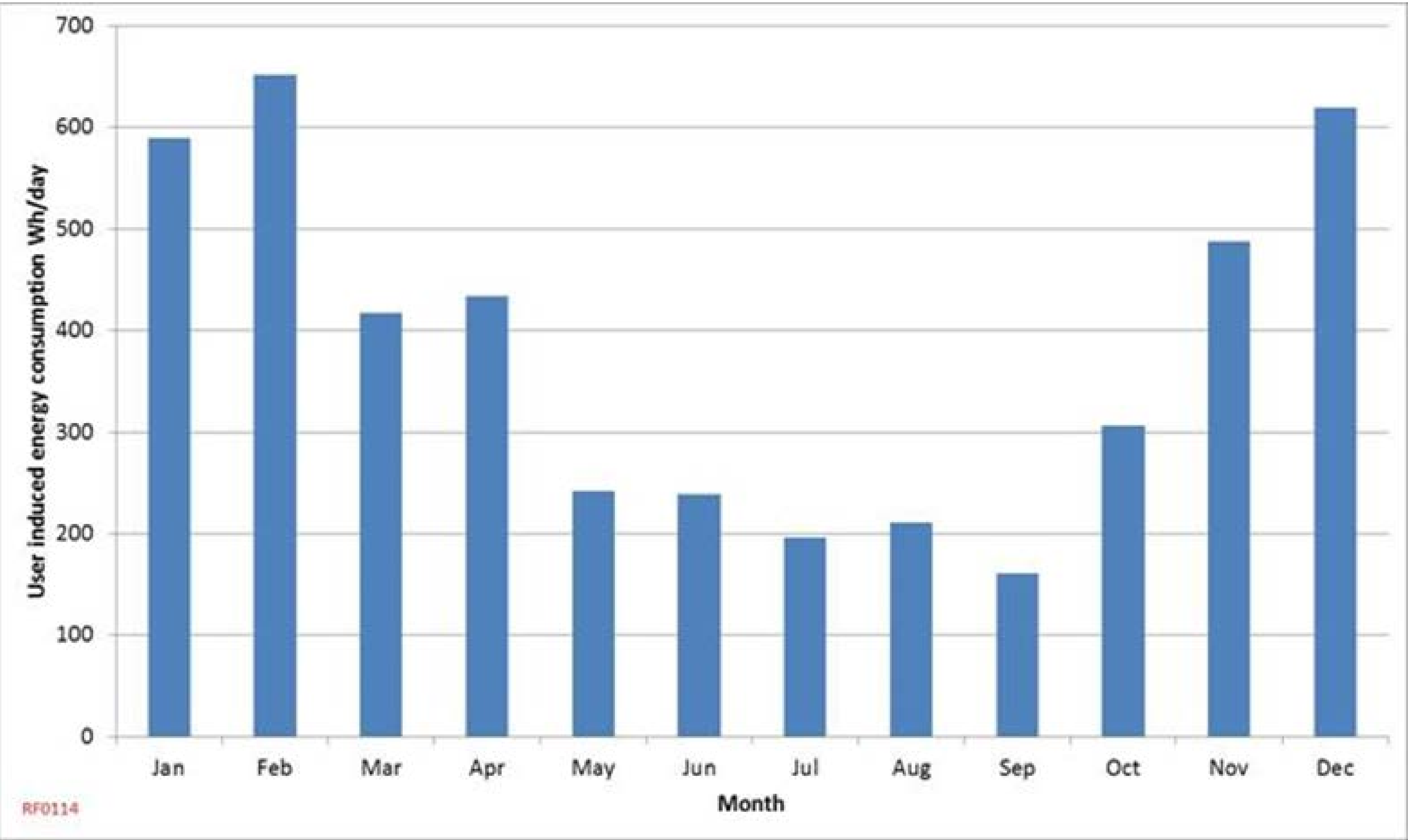
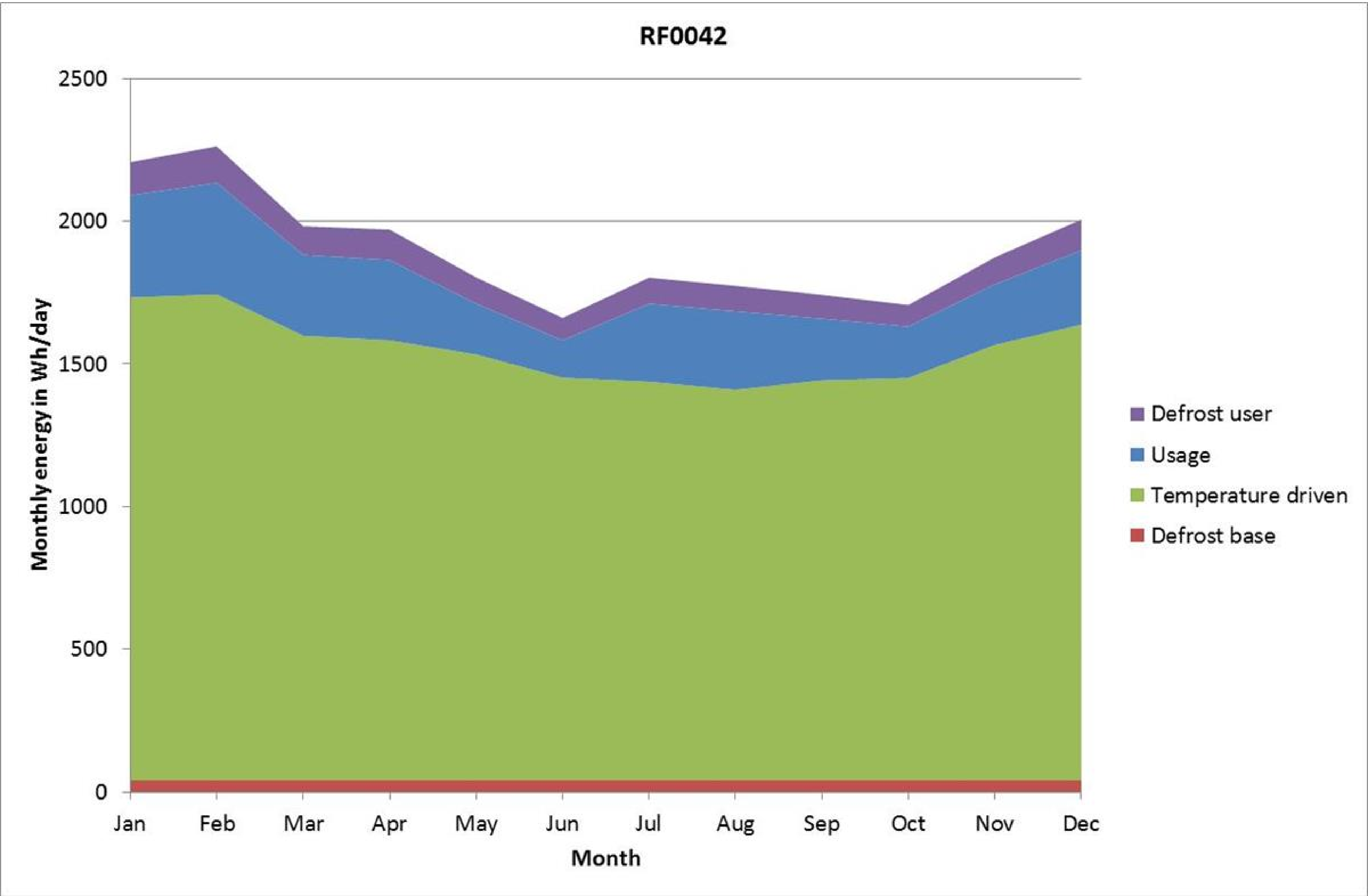


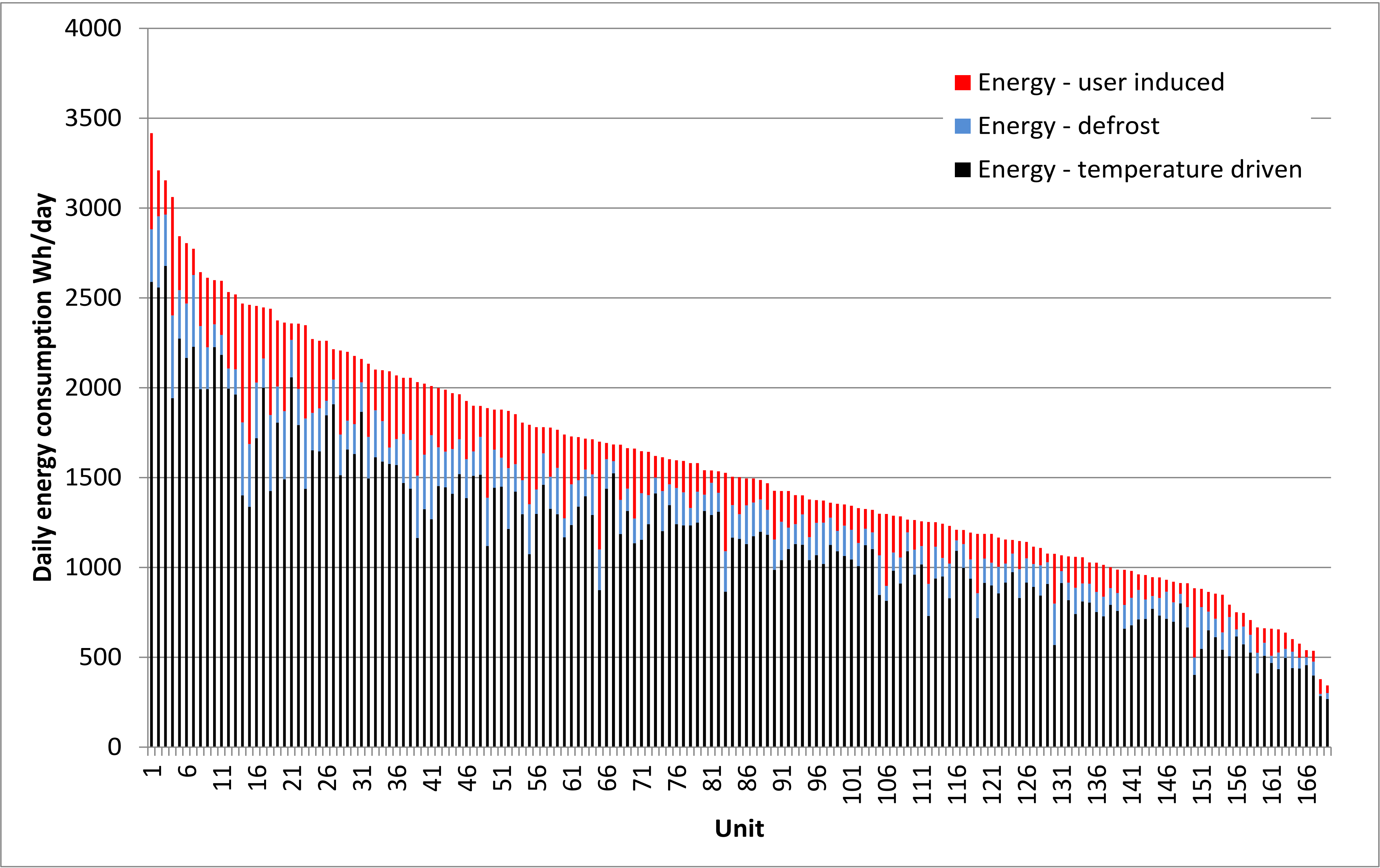
Total energy consumption

- Analysis gave a breakdown of energy into components for all sites measured
- This provides great insights into how users interact with their refrigerators and the key energy consumption drivers
- This can be done day by day (which is visually quite noisy) or monthly or annually.
- Monthly breakdown for one site is shown then annual breakdown for all sites with a main refrigerator

Components of refrigerator energy - monthly



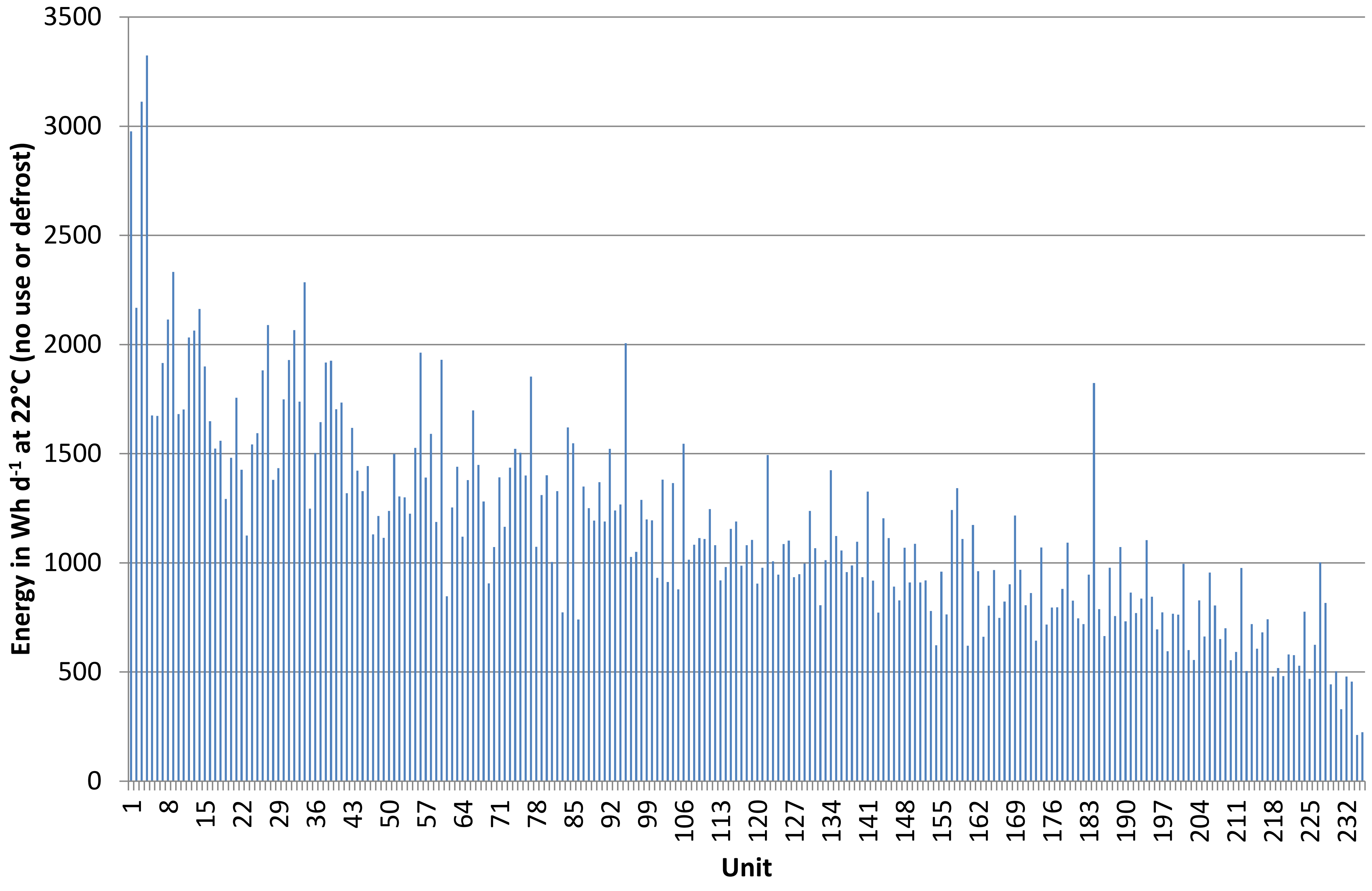
Components of refrigerator energy – daily 170 main refrigerating appliances (all climates)



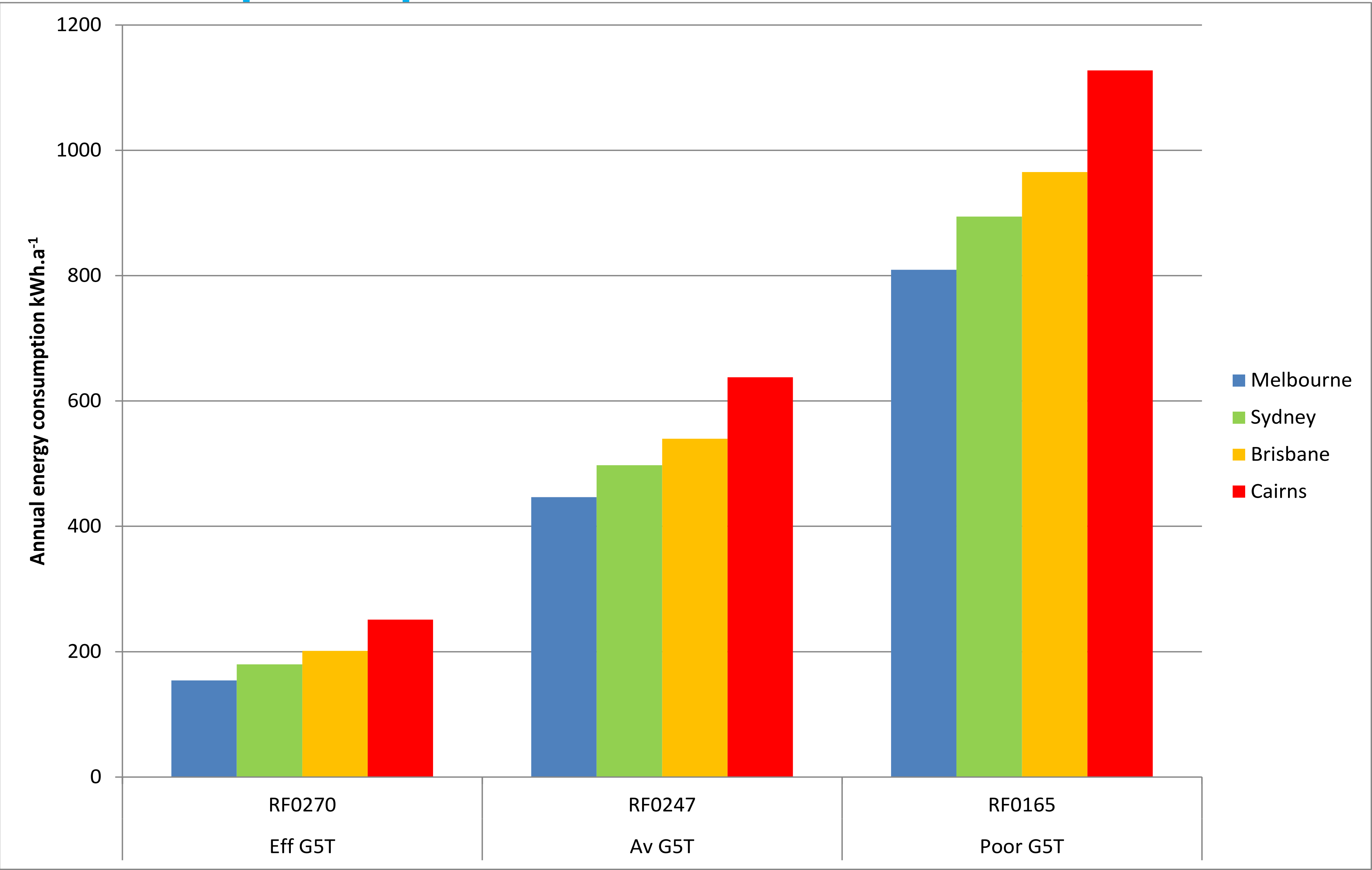
Total energy - interpretation

- User interactions are a modest share of total energy for most sites – typically 15% for a main refrigerator, up to 40% for large households
- Defrost energy is usually small (~10%) but can scale with usage to some extent
- Ratio of lowest energy refrigerator to the highest energy is a factor of 8 – this wide distribution was also found in large studies in Sweden and the UK
- While climate has some impact, a similar distribution is apparent even where energy data is corrected for an ambient temperature of 22°C with no defrost energy or usage (next slide)

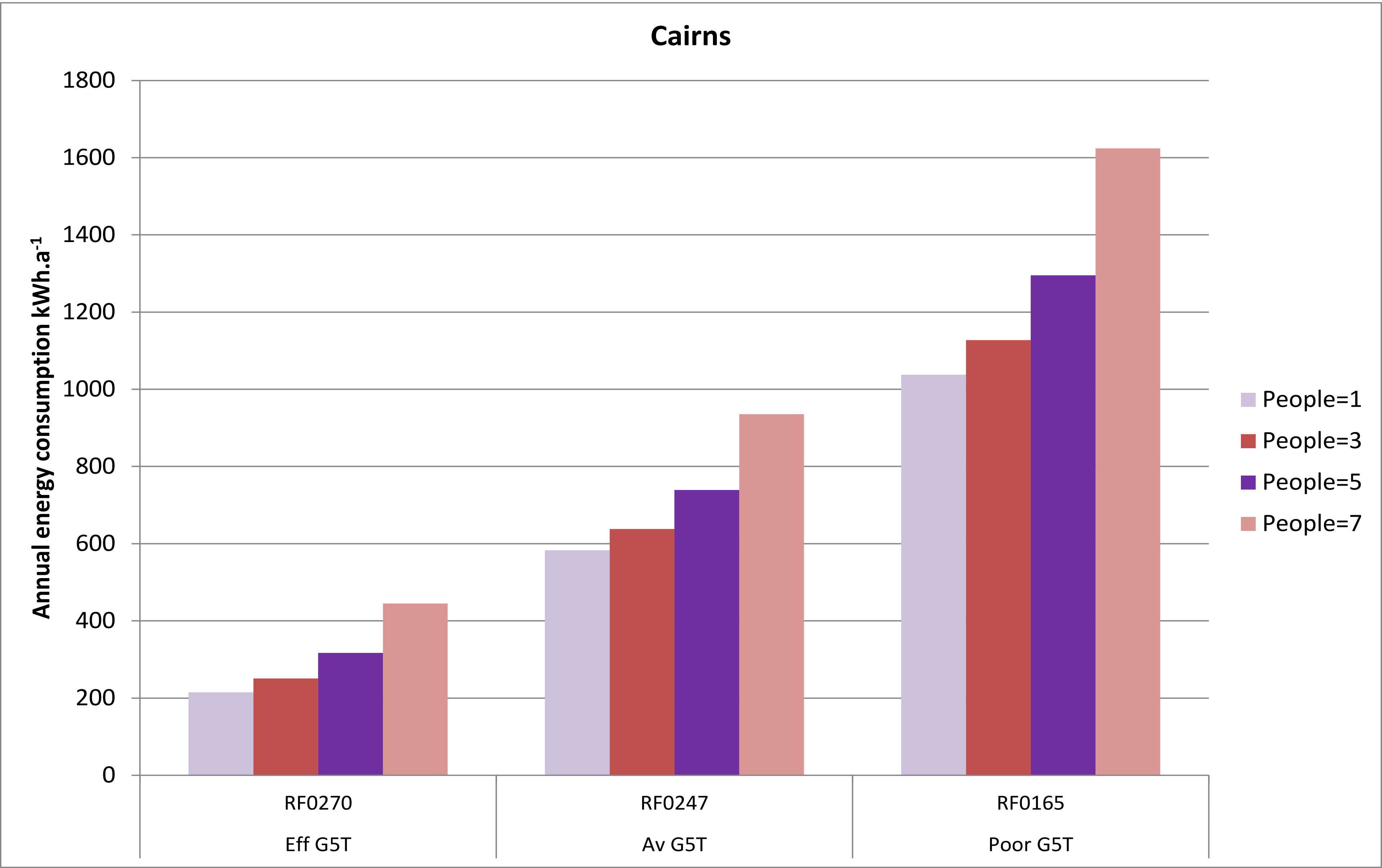
Components of refrigerator energy – daily 170 main appliances at 22°C (no use or defrost)



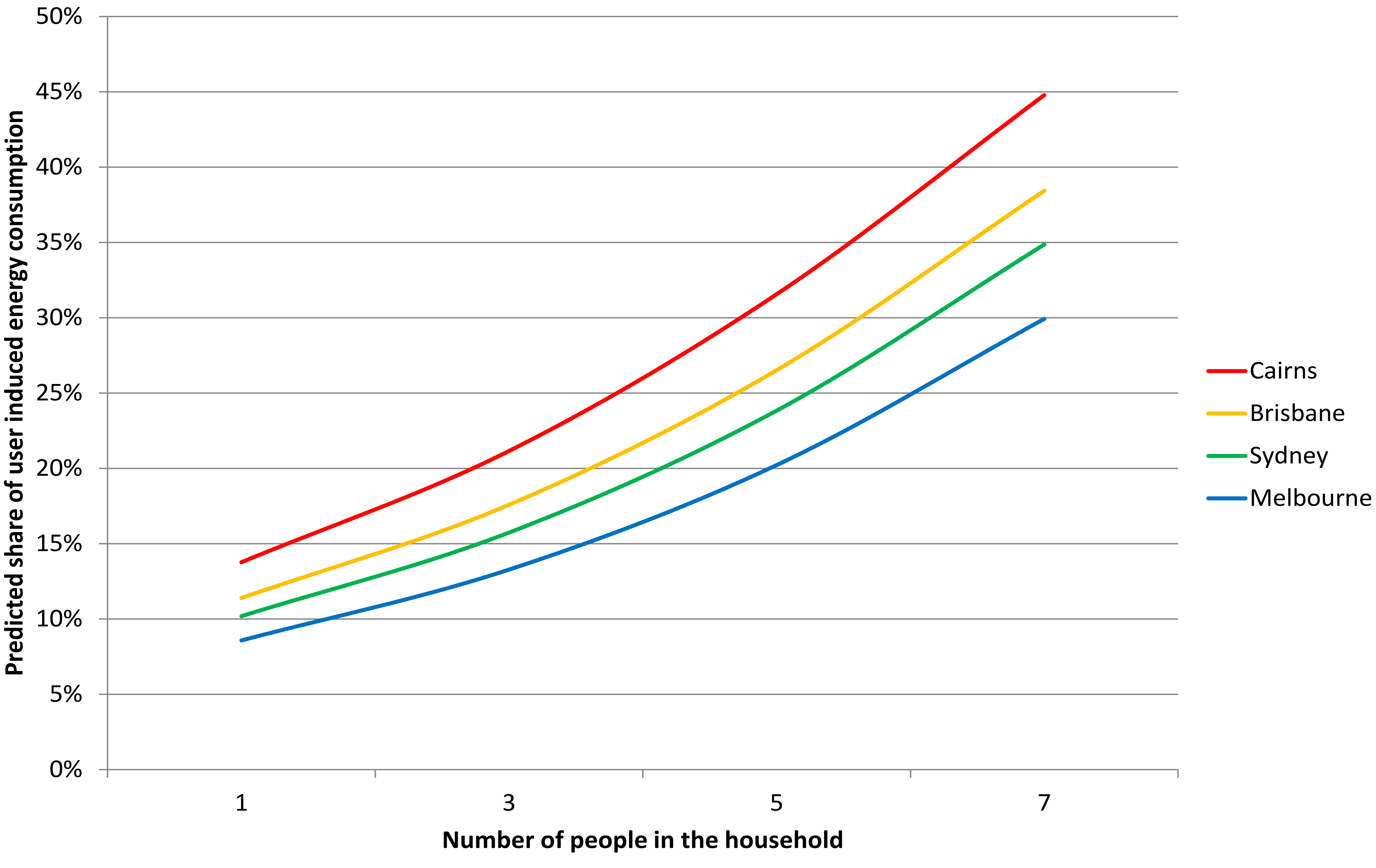
Comparison of an efficient, average and poor product in 4 climate zones



Comparison of an efficient, average and poor product across usage levels (Sydney)



Comparison of modelled impact of household size by climate



Conclusions

- The energy consumed by refrigerators in the home is strongly affected by room temperature (as expected) and this is the single most important factor in predicting energy use in the home
- User interactions typically make up about 15% of total energy consumption, but this varies from a few % (separate freezers and secondary refrigerators) to as much as 45% for large households
- Hotter climates increase the overall share of user impacts to a small extent for a given household size
- Defrosting behaviour in the field for variable defrost systems is difficult to predict from laboratory data (run-time controllers are predictable), defrost energy (per defrost) in the field tends to be higher than measured in the lab

Conclusions

- This research has allowed the key factors that drive energy consumption of refrigerators during use to be quantified
- Field data and analysis has demonstrated that ENERGY EFFICIENCY has a massive impact on energy consumption during use: this attribute is the single most important characteristic in terms of energy: it is dictated by the product design when new
- Once a product is selected and installed, changes in usage/behaviour only have a modest impact on energy
- The new IEC test procedure IEC62552-3 measures all of the key energy parameters required to model and accurately estimate energy during use across all climates and usage levels
- This research gives policy makers the tools required to drive refrigerator efficiency to new levels to reduce global emissions

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Thank you for your attention

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