from room to regional scales

developing a coupled energy demand & urban climate model

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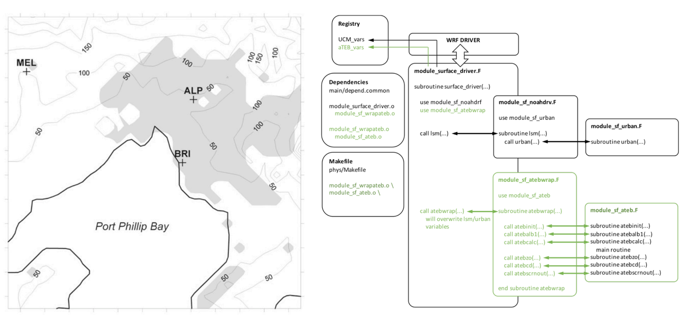
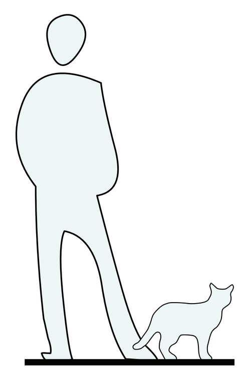
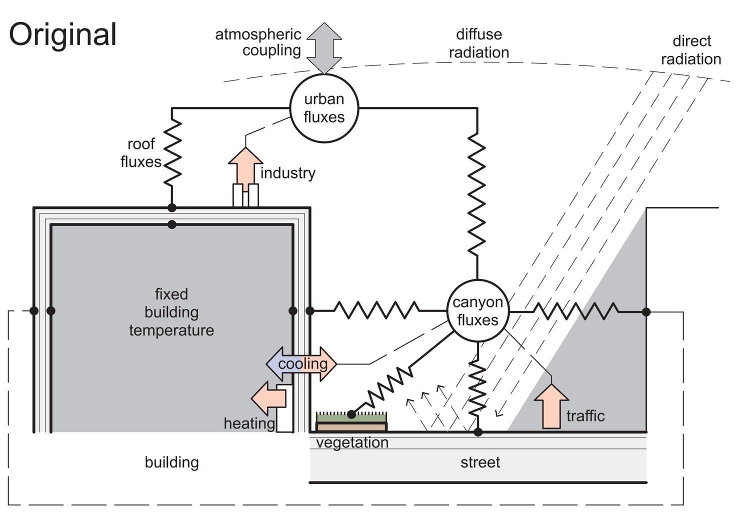


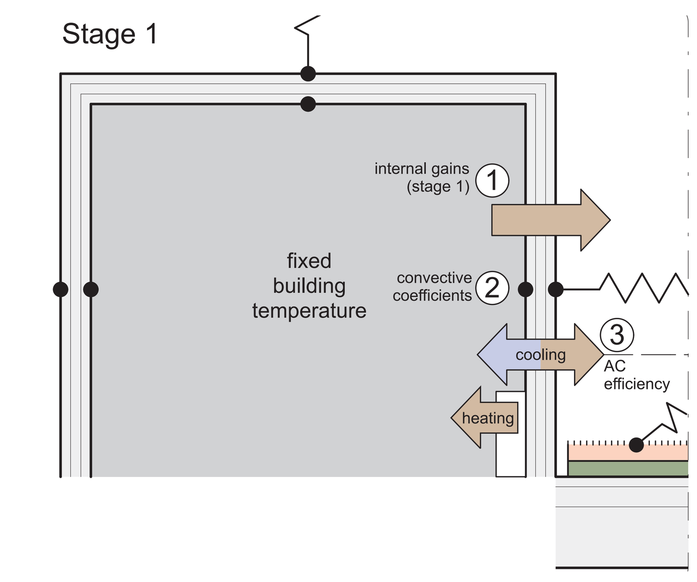
Finding methods to efficiently represent environmental processes over different scales in heterogenous landscapes is a significant modelling challenge. Urban environments are particularly interesting because boundary layer dynamics are impacted by the behaviour of people. We have developed an integrated building energy model and urban land surface model which is able to predict the intraday and seasonal energy demand of buildings at the neighbourhood scale, responding to atmospheric forcing and human activity. We combine a physics based model representing the most important internal and external thermodynamic processes with a statistical model representing an ensemble of human behaviours affecting energy use over the diurnal cycle.



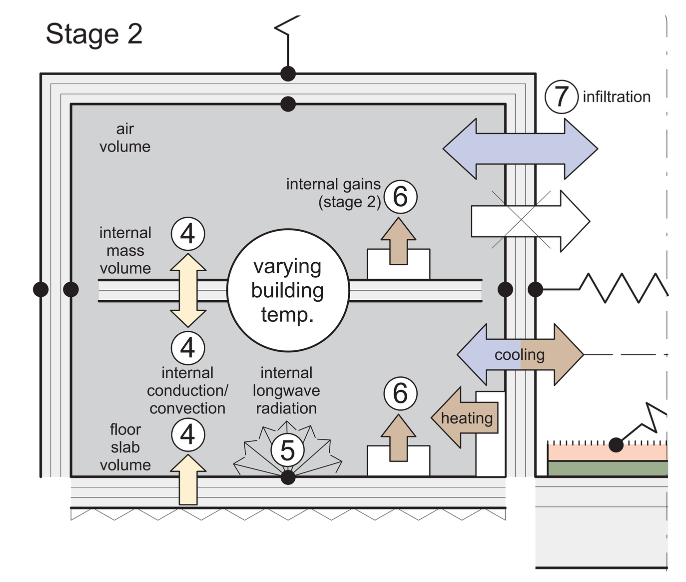
regional weather/climate model + external urban physics (Original model)



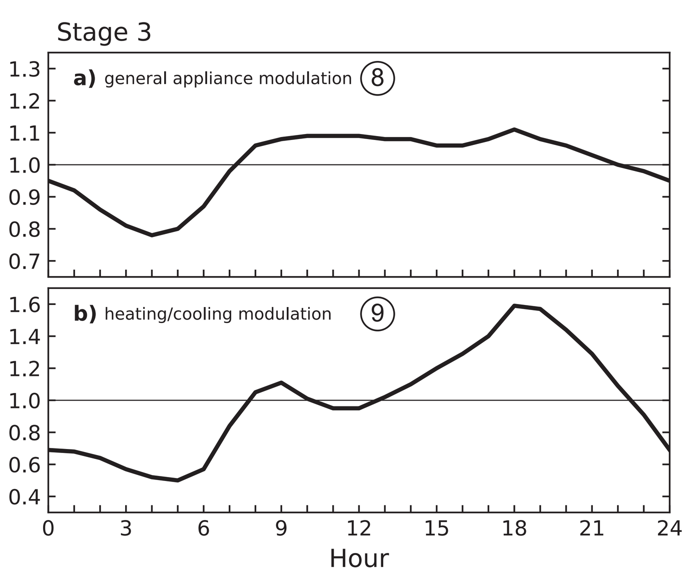
+ building electricity use & AC (Stage 1)



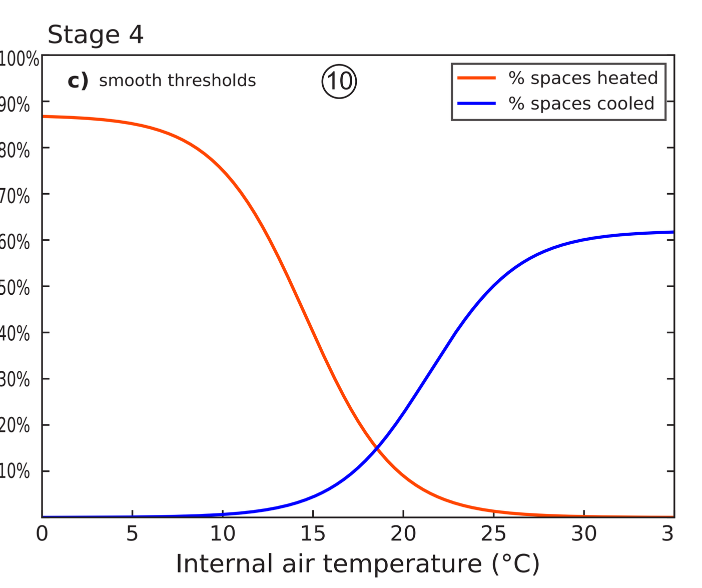
+ internal building physics (Stage 2)



+ time-dependent behaviour (Stage 3)



+ temp.-dependent behaviour (Stage 4)



Development:

We start with the aTEB urban climate model by Thatcher and Hurley (2012), which was developed to simulate urban land/atmosphere energy fluxes for regional climate modelling in Australia. At the grid scale, aTEB takes an efficient street-canyon approach, representing the density, geometry, materials, and vegatation typical of a neighbourhood. Heating and cooling energy demand is equal to the energy required to maintain a fixed internal air temperature, assuming heat loss and gain via conduction through the building envelope only. This method is efficient as internal processes are not represented but has significant limitations for predicting building energy use intensity. Limitations are addressed incrementally in Stage 1-4.

Stage 1 retains the original model framework of a fixed internal temperature, but adds:

1. **Internal gains:** electrical appliances emit waste heat inside buildings. The amount of electricity used can be estimated based on a nominal value per square metre per floor, with high density suburbs and taller buildings having a higher overal energy use intensity.
2. **Dynamic convective heat transfer:** Heat transfer rates between internal surfaces and the air volume depend on whether convection is suppressed or enhanced. Convective transfer rates are now dynamically dependent on surface orientation, skin and air temperature.
3. **Air conditioning efficiency:** The electricity used by air-conditioners to pump heat outside depends on the air temperatures of the hot and cool resovours. This is now estimated using ideal Carnot efficiency and a fixed factor to bring efficiency back to real-world values.

Stage 2 adds internal air, floor and other internal material volumes, a varying internal air temperature, as well as some important heat transfer processes, including:

4. **Conduction:** Conduction through multi-layer wall, roof, slab and internal mass volumes is now calculated via a new, fully implicit 'interface' conduction paramaterisation (Lipson et al., 2017), which has been shown to be more accurate and efficient for urban materials at relevant temporal and spatial scales compared with a conduction scheme most commonly used in urban, soil and snow surface models.
5. **Longwave radiation:** Longwave radiation exchange is calculated with infinite internal reflections, and is dependent on room geometry and surface emissivity. The method uses pre-calculated, time-invariant reflection factors which are applied to surface temperatures at each timestep, and so is computationally efficient.
6. **Internal gains:** Per Stage 1, but waste heat is released internally.
7. **Infiltration:** Infiltration is the unintended exchange of air between inside and out, and is typically responsible for 25-50% of heating and cooling energy demand. We represent infiltration dynamically, with a fixed value representing the air-tighness fo the building and a paramaterisation for air pressure differences caused by wind on the facade and the buoyancy driven 'stack effect'.

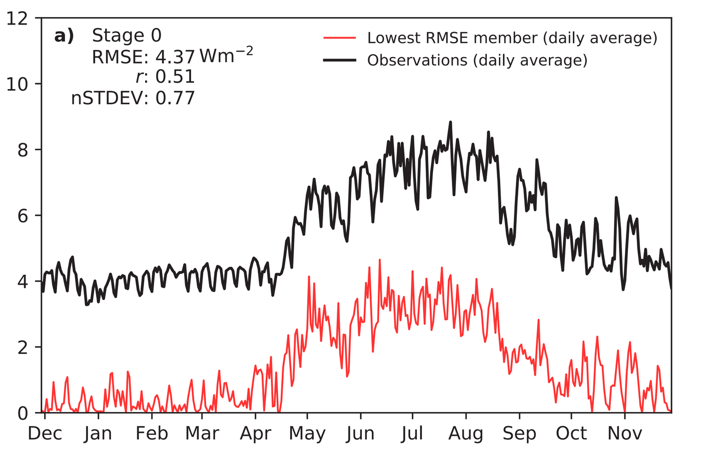
Stage 3 introduces a representation of human behaviour over the diurnal cycle based on a statistical model developed to predict electricity use for the Australian National Electricity Market (Thatcher, 2007). Two modulation terms are calculated which represent behaviour over diurnal cycle, based on four years of demand data for all customers in Queensland, New South Wales, Victoria and South Australia. Modulation improves the model because energy use intensity changes significantly depending on when buildings are occupied and the activities of occupants. The two terms are:

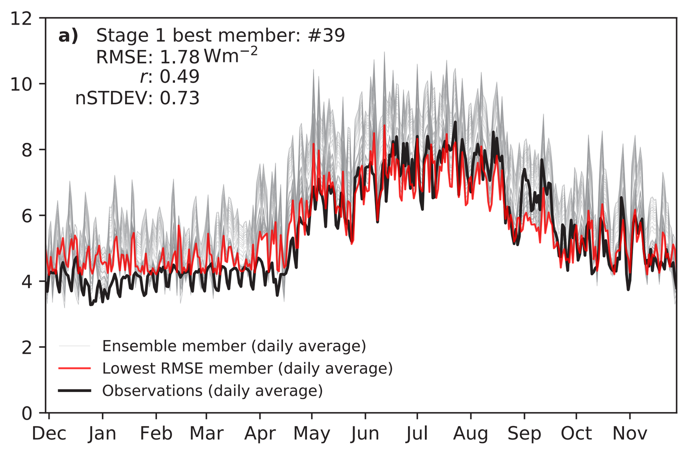
8. **General appliance modulation:** This is the climate independent base level of electricity use throughout the day. We use it to modulate internal gains. It is generally constant during working hours, but drops considerably at night while most people sleep.
9. **Heating/cooling modulation:** This describes the relative number of heating and cooling appliances in use at different times of the day. This is necassary because people control temperature more or less closely at different times of the day. For example when people wake up, or arrive home from work, they tend to turn on their heating or cooling devices. This is captured in the double peak in the figure above. At night while people sleep, temperature is not controlled as tightly.

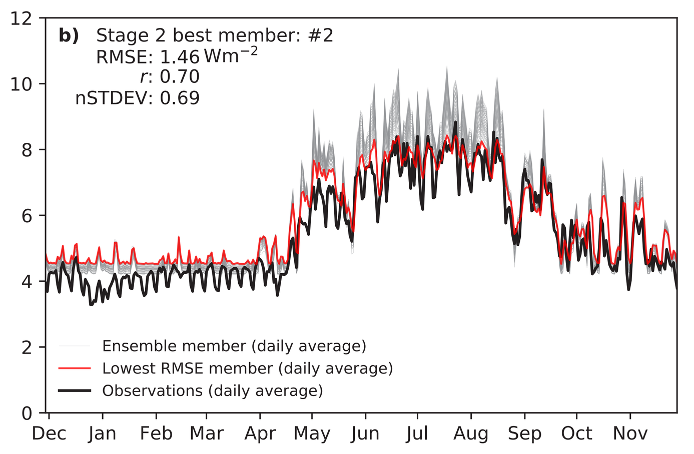
Stage 4 replaces the previously fixed heating and cooling comfort temperature points with a smooth transition, acknowledging that within a model gridpoint, there will be a range of people who perceive 'comfort' temperature differently.

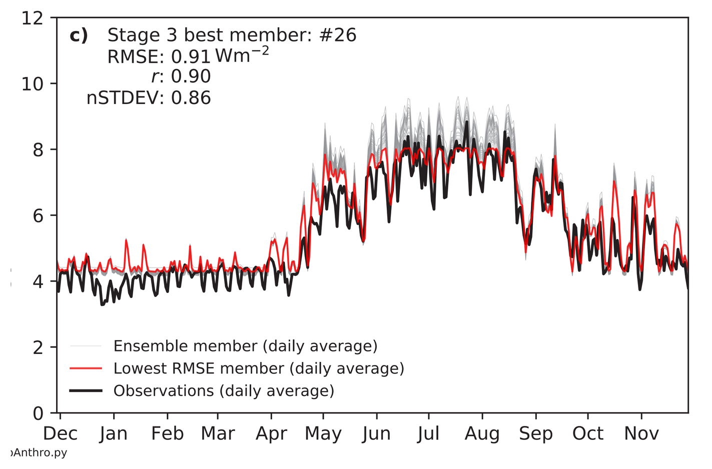
10. **Smooth heating and cooling thresholds:** A set of internal air temperature dependent functions which control the percentage of heating and cooling devices which are in use. This results in the possibility that at certain temperatures, some spaces are being heated while others spaces are being cooled, which is borne out by observation. It also allows a simple representation of maximum proportion of spaces that are either heated or cooled. In the figure above, 87% of spaces are able to be heated in very cold conditions, while only 62% of spaces have access to air conditioning in very hot conditions.

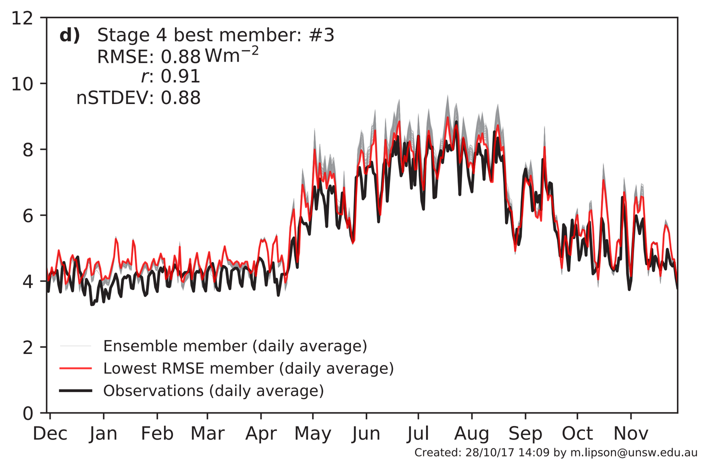
With developments up to Stage 4, the model can predict energy use intensity over a year with a normalised mean absolute error (MAE) of 13%. This compares favourably with other models developed to predict neighbourhood scale energy use intensity.





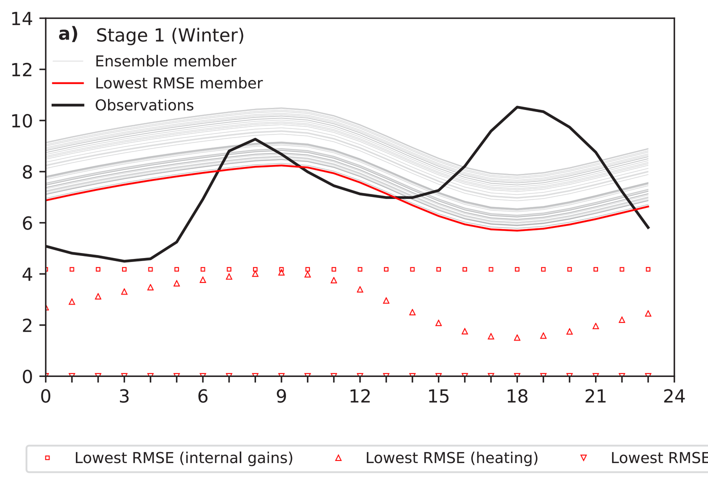


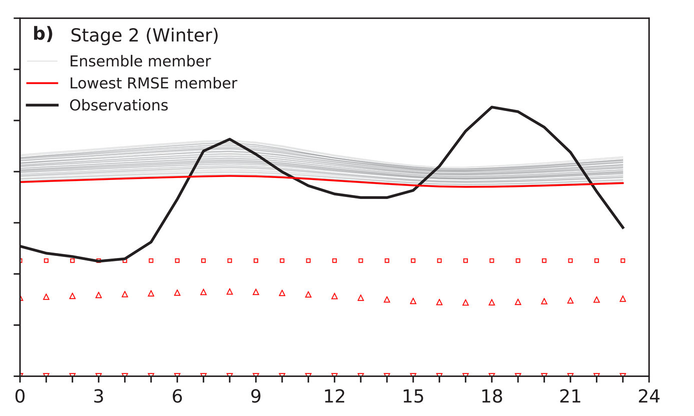


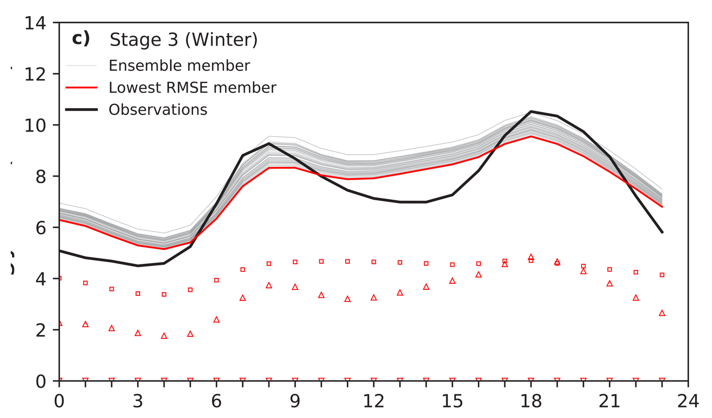


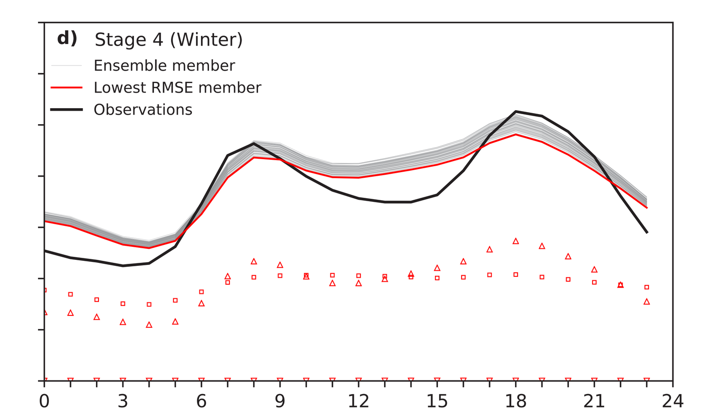
Top row: Comparing observed and simulated building energy use intensity (W m^{-2}) at different stages of development for the suburban neighbourhood of Preston, Melbourne: Dec 2003 - Dec 2004.

Bottom row: Comparing average Winter intraday building energy use intensity (W m^{-2}) at Preston, Melbourne.









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