Characterising the Uncertainty of a Fixed COP Calculation

David Ferrari[1], Rebecca Powles, Marco Salinas[2]

[1]*MOMENT, Melbourne, Australia*
[2]*Hubble, Adelaide, Australia*
Corresponding author: *david.ferrari@moment.energy*

Background and Aim

Electrification provides a range of social and environmental benefits, including enabling the use of renewable electricity in applications that previously relied upon greenhouse emitting fossil fuels. Governments across Australia have created policies and set targets to increase the rate of electrification.

In many cases, consumers are switching from gas- to refrigerant-based appliances. It is important to understand the impacts of this change on electricity demand, as a widespread shift will bring significant consequences for the electricity supply and distribution systems.

While the performance of gas-burning appliances such as space heaters does not vary significantly in response to environmental conditions, refrigerant-based HVAC systems will operate at a higher or lower Coefficient of Performance (COP) depending on the ambient temperature and humidity.

For analysts, this can create a challenging problem. In cases where a building's heating and cooling requirements can be estimated from simulation, the annual energy demands of a gas-based space heating system could be estimated in direct proportion to the heat demand.

However, for refrigerant-based heating and cooling, an accurate assessment of annual electricity demand requires a dynamic calculation of COP from the hourly conditions (temperature and humidity) combined with the thermal load data arising from the simulation. Previous work has suggested applying a fixed Seasonal COP (SCOP, for heating) and/or Seasonal Energy Efficiency Ratio (SEER, for cooling) (Schibuola,2000).

In this paper, the authors propose to characterise the uncertainty of a calculation of the electricity consumption attributed to a residential air-to-air heat pump used for heating and cooling. In an approach similar to (Ertesvåg,2011), we compare results of a fixed calculation of the COP to those arising from a dynamic calculation of COP from the hourly ambient conditions and thermal loads. Ambient conditions for both building and HVAC calculations use the reference meteorological year climate data from the Nationwide House Energy Rating Scheme (NatHERS,2022), and thermal loads were derived from simulations using the CSIRO's CHENATH engine.

Approach

Three dwellings were modelled using the CSIRO CHENATH calculation engine which underpins NatHERS. The designs were selected to represent a broadly 'typical' load profile, along with two extremes which skew the load towards the morning or afternoon respectively due to their window (solar load) orientation.

The set of dwellings consisted of NatHERS reference[1] building 100 (4-bedroom single level brick veneer concrete slab on ground) with default (north) orientation, and two versions of reference building 620 (2-bedroom 5th floor apartment, with another apartment above) in east-facing and west-facing orientations. The building geometry is outlined in Figure 1 and Figure 2. The building

[1] References are to the NatHERS test dwelling design numbers a specified in NatHERS (2022).

100 model used default window coverings (holland blinds internally, no outdoor covering) and the two versions of building 620 had no window coverings.

Figure 1: NatHERS reference 100 – 4-bedroom single level brick veneer CSOG

Figure 2: NatHERS reference 620 – 2-bedroom 5th floor apartment

The dwellings were modelled in 8 NatHERS locations across Australia, selected as broadly representative of each of the National Construction Code (NCC) climate zones as outlined in Table 1. Each dwelling was modelled at two- and seven-star performance levels in each location.

Table 1: Locations to be modelled

NCC Zone	Site	NatHERS location number
1	Darwin	1
2	Brisbane	10
3	Alice Springs	6
4	Mildura	27
5	Sydney	17
6	Melbourne	21
7	Canberra	24
8	Thredbo	69

Results were then processed as outlined in Steps 1-4 below:

- *Step 1:*

  Using a model developed by the American Society of Refrigeration, Heating and Air-Conditioning Engineers (ASHRAE, 2021), a fully dynamic COP calculation was applied to derive the hourly heating, cooling and temperature results to accurately estimate the performance of the HVAC system in each scenario.

  Buildings 620-west and 620-east are intended to produce extremities in the skew of heating and cooling demand towards the afternoons or mornings, thus providing an indication of extreme high and low average COP values across the annual profile.

- *Step 2*

  For each location, the COP results from for reference building 100 were used to calculate the average or Seasonal Energy Efficiency Ratio $SEER_{cz}$ (for cooling) and Seasonal Coefficient of Performance $SCOP_{cz}$ (for heating), where:

  $$SEER_{CZ} = \frac{total\ annual\ cooling\ energy\ demand}{total\ annual\ cooling\ electricity\ demand} \quad \text{(Equation 1)}$$

  $$SCOP_{CZ} = \frac{total\ annual\ heating\ energy\ demand}{total\ annual\ heating\ electricity\ demand} \quad \text{(Equation 2)}$$

  with all values in Equations 1 and 2 being drawn from building 100 results.

- *Step 3*

  For each location, the heating and cooling consumption results for the two variations of reference building 620 were multiplied by $SEER_{cz}$ and $SCOP_{cz}$ to produce an estimate of HVAC system electricity consumption.

- *Step 4*

  The difference between the heating and cooling electricity consumption calculated for the two versions of reference dwelling 620 at Step 1 and Step 3 was used to quantify the error introduced by applying the fixed COP values of $SEER_{cz}$ and $SCOP_{cz}$ as compared to the fully dynamic COP calculation. i.e. for each building

  $$cooling\ electricity\ demand = cooling\ energy\ demand\ \times\ SEER_{CZ} + \partial_C \quad \text{(Equation 3)}$$

  $$heating\ electricity\ demand = heeating\ energy\ demand\ \times\ SCOP_{CZ} + \partial_H \quad \text{(Equation 4)}$$

  Where the values $SEER_{cz}$ and $SCOP_{cz}$ are the results of Equations 1 and 2, and the values ∂_C and ∂_H are the errors arising from the calculations.

Presentation of Results

The full range of permutations will produce a set of 48 simulations across:

- Three dwelling designs
- Two performance levels
- Eight climate zones (locations)

Results for each simulation will consist of:

- Annual cooling energy demand (kW)
- Annual heating energy demand (kW)

- Cooling electricity demand (kW)
- Heating electricity demand (kW)

Results for each location will consist of:

- Building 100 SEER and SCOP
- Building 620-west SEER and SCOP
- Building 620-east SEER and SCOP
- Climate zone-specific average $SEER_{cz}$ and $SCOP_{cz}$
- Building 620-west SEER error (∂_C) and SCOP error (∂_H)
- Building 620-east SEER error (∂_C) and SCOP error (∂_H)

The final results of ∂_C and ∂_H will be used to evaluate whether climate-zone specific averages $SEER_{cz}$ and $SCOP_{cz}$ can be meaningfully used to estimate annual electricity demand in direct proportion to the annual heating and cooling demand.

References

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