# Heat Pump Water Heaters: Path to Harmonisation of Test Standards

# Session 4: Energy performance modelling

Waide Strategic Efficiency

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# Objectives

- To setup a model to compute heat pump water-heater COP values from a limited set of test data
- Model requirements
  - Can be used for any of the existing test standards
  - Flexibility to account for the effects of:
    - different configurations (split, unitary, coil types)
    - tank location and volume
    - different draw-off patterns
  - Simplicity, i.e. only requiring input parameters available from: technical product documentation, measured and reported data in test standards, and by observation
  - Accuracy

# Possible path to harmonisation

- Tester does 2 (or 3?) heat-up tests, no draw-off
  - Probably 7DB/6WB and 20DB/19WB for all
  - Another at colder or warmer, depending on class
- Static heat loss or cool-down test (for model)
- Computer simulation (using public data)
  - AS/NZS already uses TRNSYS simulation
- One draw-off routine to validate – if OK, accept
- Frosting test may have to be separate

# Spreadsheet model: principle

- The HPWH is considered as a black-box where the inputs are temperature conditions and the outputs are performances (COP, heating capacity)

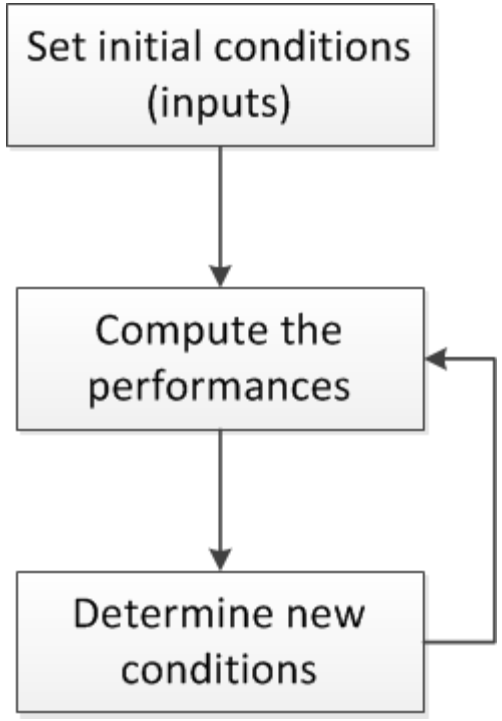
$$COP, HC = f(inputs)$$

- Principle of simulation algorithm:

STEP 0
Input from test standard

STEP 1
COP,HC = f(inputs at t)

STEP 2
Energy balance




Loop until end of the test
For instance for heat up test, Tt = Tset point

# Spreadsheet model - Morrison *et al.*,2004

## Model

- The coeff. are determined by regression using physical test data

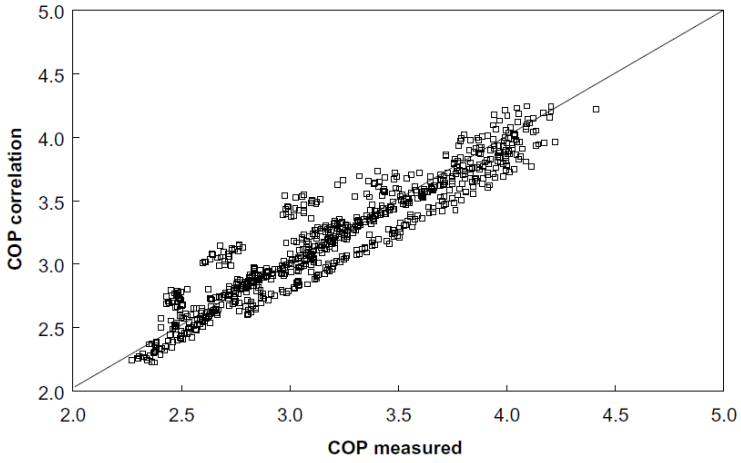
$$COP = \left[ a_1 + a_2 \left( T_t - T_a \right) \right] \left[ 1 - a_3 \frac{T_a - T_w}{T_a - T_d} \right]$$

*t: tank; a: (dry) air; w: wet bulb; d: dew point*

*(the tank temperature $T_t$ is not specifically defined in the paper)*

## Validation

- 2 HPs tested: one with wrap-around condenser coil and the other with external condenser.
- Test procedure: in different ambient conditions, without draw-off (warm-up test only)
- The model gives an average error of 4 % (max. error of about 15 %) (warm-up test only)



# AS/NZS 5125 & 4234

## Product Model AS/NZS 5125

- The coeff. are determined by regression using physical test data

$$COP = \left[ a_1 + a_2 \left( T_t - T_a \right) + a_3 \left( T_t - T_a \right)^2 + a_4 (T_w - T_d) \right]$$

*t: tank; a: (dry) air; w: wet bulb; d: dew point*

*(the tank temperature $T_t$ is not specifically defined in the paper)*

## Validation

- Model tested for 10 products including wrap-around condenser coil, internal and external condenser models.
- The model gives an average error of 3 % (warm-up test only)
- Accuracy of annual performance depends on knowledge of heat pump and booster control settings

**Annual Performance Model AS/NZS 4234**

- Annual performance determined by TRNSYS model for the desired load pattern and weather data

# Spreadsheet model - EnergyPlus

## Model

- To compute COP or electricty consumption (EC), the EnergyPlus software uses the following model (EnergyPlus, 2012):

$$COP, EC = c_1 + c_2 T + c_3 T^2 + c_4 T_t + c_5 T_t^2 + c_6 T T_t$$

where $T_t$ is tank average temperature, T is either dry air temperature or wet bulb temperature

- The coeff. can be determined by regression using physical test data
- Stand-by losses are calculated from UA coefficient

## Validation

- 1 HP tested: wrap-around tank type
- Test procedure: draw-off cycles in different ambient conditions
- The model gives an error of 18 % in energy consumption during a draw-off cycle, but the accuracy is better in the heating-up phase (Hudon *et al.*, 2012)

# How to improve spreadsheet model accuracy?

## Sources of error

- Tank stratification :
  → average tank temperature
  ≠ temperature around the condenser

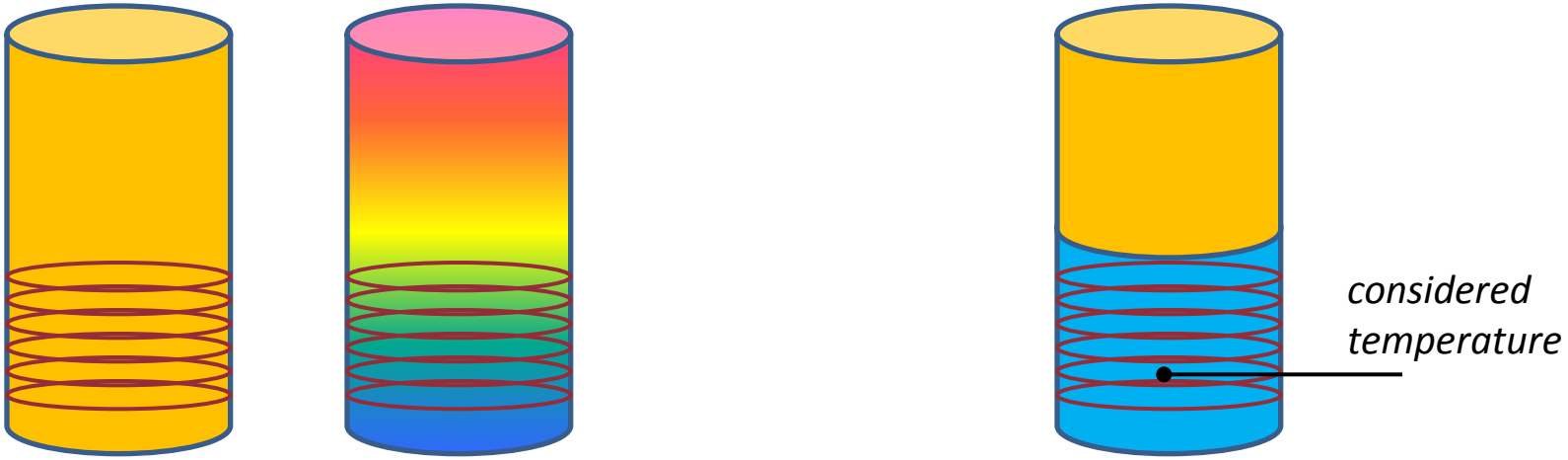
- Draw-offs increase the effect of the tank stratification

## Potential solutions

- The model should be based on the water temperature at the condenser (not tank average):
  -> 2 zones to be considered
  - > Main issue: step 2 (energy balance)

- The model should take into account the inlet water flow rate and temperature

*2 mixed water columns*



# The impact of the control strategy

- The control strategy has an important impact on the performance
- In the spreadsheet models, performance is supposed to only be dependent on the input parameters
- Which introduces the following sources of error:
  - the control strategy may be dependent on the draw-off patterns and hence change with them
  - it depends on the evolution (values and derivatives) of the operating conditions
  - it depends also on the operating mode
  - $T_t$ used in the models is not the exact temperature that is sensed by the heat pump control

# A more complex approach

- Model:
  - based on a HPWH model with a stratified tank in the library TESS (TRNSYS)
  - the model inputs are $T_t$ ,$T_a$ and draw-off pattern
  - other parameters are determined via technical data and by regression from test data
  - control strategy is included
- Validation:
  - 1 HPWH tested: wrap around tank type
  - Test procedure: tests in different temperature conditions with draw-off cycles
  - Results:  the model has an error of only 2 % (Hudon *et. al.*, 2012)
- Limitations
  - it requires inputs derived from tests conducted under a full range of conditions (not necessarily standardised test conditions)
  - it is not always possible to find out the required control logic details from manufacturer information or tests
  - it does not take frost-defrost cycles into account
  - experience with TRNSYS is necessary to use the model (compared with Excel …)

# Conclusion on possible modelling options

- Spreadsheet models
  - a spreadsheet model seems to be sufficient for the heating-up phase, but it is necessary to verify the model using different HPWHs e.g. using the KTL test data
  - There is a risk this approach may not be suitable for HPWHs with sophisticated control strategies, because it cannot *a priori* address the control logic. But the risk is limited for heating-up test in isolation.
  - It might be possible to refine the model by introducing additional variables in order to better take into account tank stratification and to model the draw off cycles. For draw-off cycles, the feasibility will depend even more on control.
- Detailed models:
  - Were a more detailed model to be developed it would be necessary to develop at least one model type by product archetype, but would not necessarily solve the control issue as it is difficult to identify, it also requires the necessity to use a complex simulation tool – e.g. TRNSYS

# References


- Hudon, K., Sparn, B., Christensen, D., & Maguire, J. (2012). Heat pump water heater technology assessment based on laboratory research and energy simulation models. *ASHRAE Winter Conference.* Chicago.
- Morrison, G., Anderson, T., & Behnia, M. (2004). Seasonal performance rating of heat pump water heaters. *Solar Energy 76* , 147-152.
- EnergyPlus. (2012). Documentation, Engineering Reference