AIR CONDITIONER PERFORMANCE RATING

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1. INTRODUCTION

Testing of air conditioners under controlled operating conditions is defined in International Standards ISO5151:1994 *Non-ducted air conditioners and heat pumps - testing and rating for performance and* ISO13253:1995 D*ucted air conditioners and heat pumps - testing and rating for performance* . Direct assessment of the performance of air conditioner appliances requires access to large capacity calorimeter or psychrometric loop test facilities. Australian standard AS3823.3 has been developed as an alternative to physical testing, based on simplified measurements and a simulation model of air conditioner performance. The simulation model used is the ORNL Mark V (1997) program with additional requirements that make the results product specific. In all cases test results obtained by physical testing using the procedures defined in AS/NZS3823.1.1 or AS/NZS3823.1.2 (Australian adoption of ISO5151 & ISO13253) take precedence over the results obtained using performance simulation methods. If the simulation methods are not considered applicable to a particular appliance then that appliance can be assessed under AS/NZS3823.1.1 or AS/NZS3823.1.2.

The purpose AS3823.3 is to provide a low cost method of assessing air conditioner performance and also to provide a tool for assessing design modifications for appliances that fail the Minimum Energy Performance standards set in AS/NZS3823.2. This paper describes the HPRATE (2004) simulation model that has been adopted for assessing Minimum Energy Performance Standards (MEPS) for split unit air conditioners in Australia and presents the results of validation tests of the procedure.

2. PERFORMANCE ASSESSMENT PROCEDURES FOR AIR CONDITIONERS

Introduction of MEPS for air conditioners requires the development of an agreed basis for determining the cooling and heating capacity, and the Energy Efficiency Ratio (EER - cooling) and coefficient of performance (COP - heating) of products. Two approaches are:

- Determining capacity and EER at one standardised test condition for cooling and capacity and COP one condition for heating.
- Assess comparative energy use from multi-point testing of products and a model of system part load performance.

The alternative approaches that were considered for the Australian MEPS program were

- Measurement of performance at a standardised operating condition.
- Simulation of performance at a standardised operating condition.
- Calculation of energy-use based on measured or simulated performance at two or more standardised test conditions and an algorithm to relate energy use to the performance at standardised test conditions.
- Modelling energy-use using measured or simulated performance at two or more test conditions combined with a reference application in which climatic conditions, building thermal performance and operating regime are specified. This would account for part-load performance and design sizing.

2.1 Climatic dependent rating

Australian standards AS3823.1.1 and AS3823.2 define test conditions for rating products for cool, moderate and hot climates. The outdoor dry bulb temperatures for cooling capacity and EER rating are 27°C, 35°C and 46°C respectively. Testing under conditions appropriate to the intended sales region of products would provide the most relevant labelling information for the purchaser, however, this would introduce additional costs due to the need to test each product at three rating conditions.

2.2 Seasonal energy consumption rating

Seasonal performance rating based on testing at two or more standardised conditions and an algorithm relating seasonal performance to the test point results is the procedure adopted in the USA for MEPS and labelling purposes. Products are tested for capacity under high-duty cooling conditions (Test A) and seasonal performance is determined from an additional 1 or 3 tests under typical operating conditions (Test B or Tests B, C and D).

Test A = indoor 27°C DB/19.5°C WB, outdoor 35°C DB (High capacity cooling rating)

Test B = indoor 27°C DB/19.5°C WB, outdoor 28°C DB
Test C = indoor 27°C DB/14°C WB, outdoor 28°C DB
Test D = indoor 27°C DB/14°C WB, outdoor 28°C DB - cyclic test
} Seasonal rating data

The seasonal energy efficiency ratio (SEER) is given by

$$SEER = EER_{Test\ B} * \text{Part Load Factor}$$

The manufacturer may elect to use a Part Load Factor of 0.875 or have the product tested at two additional operating conditions (Tests C and D) and determine the Part Load Factor from

$$\text{Part Load Factor} = 1 - 0.5 * \text{Degradation Factor}$$

where

$$\text{Degradation Factor} = \frac{\left(1 - \frac{EER_{Test\,D}}{EER_{Test\,C}}\right)}{\left(1 - \frac{Capacity_{Test\,D}}{0.5*Capacity_{Test\,C}}\right)}$$

The default condition for the Part Load Factor of 0.875 is a very conservative value, hence in the USA most manufacturers elect to have their products tested at the two additional conditions (C and D) in order to obtain a higher rating. Rating of products for capacity and seasonal energy efficiency ratio under the USA program is expensive as tests are required for a minimum of two operating conditions and most manufacturers elect to have their products rated at four test conditions in order to achieve the highest possible seasonal rating.

2.3 **Seasonal energy consumption simulation**

Seasonal performance rating based on multi-point performance testing (or simulation) and a model of a reference building and climatic conditions would provide the most representative measure of annual product performance. Such a procedure requires specification of the thermal characteristics of a representative building and modelling of transient cooling (and heating) loads for the location

considered. This procedure was used to quantify the impact of a MEPS program for air conditioners in Australia but was not recommended for use as the product rating tool or in the MEPS program as it is unnecessarily complicated as a ranking tool for setting minimum performance requirements.

Performance rating at a standardised test condition is the simplest and cheapest means of determining product performance.

3. INTERNATIONAL STANDARDS FOR RATING AIR CONDITIONERS.

The international standards for airconditioner rating are

ISO5151 1994 Non-ducted airconditioners and heat pumps – testing and rating for performance.

ISO13253 1995 Ducted airconditioners and air to air heat pumps – testing and rating for performance.

The International Standard ISO 5151 is currently under revision by ISO/TC86/SC6. The test conditions for cooling capacity rating are being retained, however, the test procedures are being modified and the accuracy of all aspects of the tests are being quantified. In the revised standard test conditions for heating rating are being specified whereas previously the manufacturer was able to specify the conditions for some heating tests. The objective of the revision of ISO 5151 is to integrate ISO5151 (non ducted) and ISO13253 (ducted) into a unified standard for rating all air conditioner configurations.

4. AUSTRALIAN STANDARDS FOR AIR CONDITIONER RATING

The Australian standards for rating, energy labeling and MEPS requirements for air conditioners are

AS3823 Performance of Household Electrical Appliances - Room air conditioners.

Part 1.1:1998 Non-ducted air conditioners and heat pumps - Testing and rating for performance.

Part 1.2:2001 Ducted air conditioners and heat pumps - Testing and rating for performance.

Part 2:2001 Energy labelling and minimum energy performance standard (MEPS) requirements.

Part 3:2001 Calculation of performance for minimum energy performance standard (MEPS) requirements

The performance test standard AS3823 was developed from International Standards ISO5151:1994 and ISO13253:1995 with minor variations and additional requirements in parts 2 and 3. Australian standard AS3823.1.1 specifies test conditions for cool, moderate and hot climates (27°C, 35°C and 46°C outdoor dry bulb temperature for cooling capacity rating). Given the significant difference in climatic conditions between coastal and inland Australia products should ideally be rated under conditions appropriate to the intended sales region. Adoption of a rating scheme for

two or more climatic conditions as in the USA would improve purchaser information, however, it would significantly increase the cost of testing for products designed for hot inland conditions. Information on location based performance could be provided through other product performance publications rather than through a multi-level MEPS requirements.
The energy labelling standard requires that manufacturers certify that their product is suitable for operation under maximum cooling conditions specified in AS3823.1.1, however, the performance under the maximum cooling conditions does not have to be independently quantified.

The energy labelling standard AS3823.2 specifies a simple comparative energy use model and energy labelling requirements for single phase non-ducted room air conditioners. The comparative energy use model is based on 500 hours operation at the standard performance rating condition.

5. SIMULATION OF AIR CONDITIONER PERFORMANCE

5.1 ORNL Heat Pump Model

The ORNL heat pump simulation program is a public domain software (ORNL Mark V 1997) developed to predict the steady-state performance of vapour compression, electrically driven air-to-air heat pumps in both heating and cooling modes. The model is based on underlying physical principles and generalised correlations in order to make the program applicable to a wide range of equipment configurations. The basic model does not incorporate empirical correlations derived for particular products. A first principles thermodynamic model of the heat transfer processes in coils and analysis of the refrigerant states around the circuit are combined with psychometric analysis of the air side of the coils to determining the operating state to provide an assessment of the performance of the equipment.

“Transient (cyclic or frosting/defrosting) effects are not considered. The program has physically based heat transfer models for single and two phase refrigerant regions of fin –and-tube air to refrigerant heat exchangers. Simple parallel refrigerant circuiting is assumed. Air-side dehumidification and evaporator sensible heat rations are calculated.
In the Mark V program the following refrigerants can be modelled, CFC’s R12, R114 and R502, HCFC’s R22, R123 and R124, single component HFC’s R134a, R32, R125, R143a and R152a and azeotropic or near azeotropic refrigerants R410a, R507 and R404a and one hydrocarbon R290 (propane) . The thermodynamic properties are modelled with either the Martin-Hou or Downing equation-of-state representations.

Additions currently underway include modelling of refrigerant glide in the two phase region for R407C and more detailed coil circuiting including cross-parallel and cross-counter flow circuiting” (Rice 1997).

The ORNL Heat Pump Design Model allows the user to specify:

Appliance Operating Conditions

- the desired indoor and outdoor air temperatures and relative humidifies,
- the arrangement of the compressor and fans in the air flow stream, i.e., up or downstream of the heat exchangers.

Compressor Characteristics

- a map-based model for available equipment or direct entry of 6 or 10 coefficient ARI curve fits to measured compressor performance.

Refrigerant Flow Control Devices
- capillary tube, thermostatic expansion valve (TXV), or a short-tube orifice, or
- specified values of refrigerant subcooling at the condenser exit and superheat at the compressor suction.

Fin-and-Tube Heat Exchanger Parameters
- tube size, spacing, and number of rows, and number of parallel circuits,
- fin pitch, thickness, and thermal conductivity; type of fins (smooth, wavy, or louvred),
- air flow rates;

Refrigerants
- 17 alternative refrigerants, including propane.
- other refrigerants can be included by adding the appropriate thermodynamic constants.

Refrigerant Lines
- lengths and diameters of interconnecting pipes,
- pipe specifications independent of heating or cooling mode,
- heat losses from suction, discharge, and liquid lines.

Program Outputs
- capacity and EER or COP,
- sensible to total heat transfer ratio,
- outlet dry- and wet-bulb temperatures,
- air- and refrigerant-side pressure drops,
- overall isentropic and volumetric compressor efficiencies,
- heat exchanger effectiveness and UA values in different phase zones.
- sizing of flow control devices for specified operating conditions

Limitations
- The model assumes simplified heat exchanger circuitry, equal parallel circuits in cross flow; the model does not account for heat exchanger flow splits and confluences.
- Requires measured compressor characteristics for accurate modelling. An efficiency-loss compressor model is also available for preliminary design evaluations.
- Capillary tube modelling is based on curve fits of ASHRAE flow factor charts rather than a first principles thermodynamic analysis of flow.
- Real flow effects such as friction pressure drop in refrigerant components are modelled using user adjusted scaling factors as accurate absolute calculations of pressure drop are not possible.
- Inputs and outputs are in English units.

5.2 Australian MEPS performance rating software

Due to the high cost of testing the large number of air conditioners available in Australia a simulation based performance assessment method was adopted AS3823.3:2001. The procedure set out in AS3823.3 uses a mathematical model to assess the performance of air conditioners; hence the application of the procedure is restricted by the availability of suitable mathematical models. The performance assessment procedure is based on measured refrigerant circuit operating conditions (subcooling and superheating) and measured refrigerant circuit pressure drops. If these measurements are not available then specified default conditions are required to be used in the analysis. These default conditions result in a conservative evaluation of performance. The accuracy of the simulation models accepted under this Standard must have been demonstrated by

comparison with measured performance to have an accuracy equivalent to the appliance test standards AS3823.1.1 and AS/NZS3823.1.2.

Simulation models that can be used for rating products under this Standard must include the following features.

- Compressor performance determined from measured capacity and power consumption (ASHRAE23:1993).
- Correction of compressor performance characteristics to account for differences between the operational superheat condition and the superheat condition applying during the compressor performance tests.
- Measured pressure drop along the high and low pressure sides of the refrigerant circuit when the equipment is operating under rating point conditions.
- Measured superheat and subcooling temperatures when the equipment is operating under rating point conditions.
- Detailed modelling of the superheat, two phase and subcooled refrigerant sections of both the evaporator and the condenser.
- Evaluation of refrigerant properties at the local temperature and pressure conditions at each point around the refrigerant circuit.
- Detailed psychrometric analysis of the state of the moist air passing over the evaporator, including analysis of the condensation rate on the coil.

These requirements can be satisfied by matching the adjustable factors in the ORNL model to the measured operating state of the appliance or conservative default conditions can be accepted in place of the product specific measurements. The modeling requirements of AS3823.3 have been implemented in the HPRATE software package. HPRATE V5 is a graphical interface to the ORNL (1997) MarkV heat pump model that incorporates measured of default appliance operating characteristics so that the results of the simulation are product specific (or a conservative estimate if measurements are not available) and not generic results as in the case with the flexible ORNL code.

The features of the ORNL Mark V model adopted in HPRATE V5 allows the user to specify:

System operating conditions	Indoor and outdoor air wet and dry bulb temperatures, arrangement of the compressor and fans in the air flow stream.
Compressor characteristics	Measured capacity and power input in the form of a compressor map.
Refrigerant flow control	Specified refrigerant sub-cooling at the condenser exit and superheat at compressor suction; either product specific measurements or conservative defaults.
Fin and tube heat exchangers	Tube size, spacing, number of rows and parallel circuits, fin pitch, thickness, material and type, smooth, wavy or louvered, air flow rates. Heat transfer correlations for grooved and cross-hatch tubes are included.
Refrigerants	R114 R12 R123 R124 R125

	R134a	
	R143a	
	R143a/R125 (50/50)	(R507, AZ50)
	R143a/R125 (55/45)	
	R143a/R125/R134a (52/44/4)	
	R152a	
	R22	
	R290	(Propane)
	R32	
	R32/R125 (50/50)	(R410A, AZ20)
	R32/R125 (60/40)	
	R502	
Refrigerant lines	Lengths and diameters of interconnecting pipes, heat losses from suction, discharge and liquid lines.	
Refrigerant pressure drops	Measured pressure drops in pipes and coils (if available) or conservative default conditions.	
HPRATE Outputs	Capacity and EER or COP Compressor power consumption Output dry and wet bulb air temperatures Refrigerant states throughout the cycle. Sensible and latent cooling capacities	

The main restriction in the current model is that it is assumed that the system is correctly charged for the specified operating conditions. This is a satisfactory model for systems having a suction line accumulator which can store excess refrigerant and maintain a low compressor inlet superheat. For charge sensitive systems, the performance for a given refrigerant charge cannot be accurately modelled for different operating conditions unless the level of compressor inlet superheat is known for each operating point.

6. ASSESSMENT OF SIMULATION PROGRAM ACCURACY

The HPRATE model was used to predict the performance of a total of 13 system cooling tests. The system configurations evaluated in the tests included:

- Plain bore coil tubing.
- Grooved bore coil tubing.
- Wavy fins on both coils.
- Louvered fins on both coils
- Six air-on test conditions for cooling.
- Reduced airflow over the outdoor coil.
- Blocked out door coil to simulate damaged finning.

The inputs to the simulation were the physical dimensions of the coils and plumbing, coil airflow rates and the compressor capacity and power test maps and measured pressure drop on the high and low pressure sides of the refrigerant circuit. The test conditions used in the 13 tests are summarised in Table 1 and the test results are summarised in Table 2. Comparison of measured and simulated EER, power consumption and cooling capacity are given in Figures 1-3.

Table 1: System configurations evaluated

Test No.	Operating condition	Indoor air dry bulb °C	Indoor air wet bulb °C	Outdoor air dry bulb °C	Outdoor air wet bulb °C
Louvred fins and grooved tubes					
1	A	27	19	35	24
2	B	29	19.5	46	30.5
3	L	27	19	25	18
Wavy fins and grooved tubes					
4	A	27	19	35	24
5	B	29	19.5	46	30.5
6	L	27	19	25	18
7	A*	27	19	35	24
8	Sp*	24	17	35	24
9	Sp**	24	17	30	20
10	Sp***	24	17	25	19
Wavy fins and plain tubes					
11	A	27	19	35	24
12	L	27	19	25	18
13	A***	27	19	35	24

	Operating conditions	
A,B,L	Standard test conditions	Cooling with full air flow on coils
A*	Condition A	Cooling with 20% of condenser blocked
A***	Condition A	Cooling with 50% outdoor fan power
Sp*, Sp**, Sp***		Special conditions

Table 2: Comparison of measured and predicted performance

Test No.	Operating condition	Power consumption kW Measured	Power consumption kW Simulated	Capacity kW Measured	Capacity kW Simulated	EER Measured	EER Simulated
Louvred fins and grooved tubes							
1	A	5.4	5.40	14.5	14.41	2.70	2.67
2	B	6.4	6.44	12.9	13.37	2.03	2.08
3	L	4.5	4.67	15.3	15.50	3.36	3.30
Wavy fins and grooved tubes							
4	A	5.4	5.30	14.4	14.13	2.67	2.65
5	B	6.3	6.27	12.7	13.15	2.00	2.10
6	L	4.6	4.61	15.8	15.40	3.40	3.34
7	A*	5.5	5.64	13.8	13.68	2.50	2.42
8	Sp*	5.2	5.25	13.0	12.91	2.50	2.46
9	Sp**	4.8	4.79	13.5	13.65	2.83	2.85
10	Sp***	4.4	4.45	13.5	14.04	3.05	3.15
Wavy fins and plain tubes							
11	A	5.4	5.41	12.8	13.22	2.40	2.44
12	L	4.6	4.64	14.4	14.55	3.13	3.14
13	A**	5.5	5.36	12.5	13.14	2.30	2.46

Operating conditions

A,B,L	Standard test conditions	Cooling with full air flow on coils
A*	Condition A	Cooling with 20% of condenser blocked
A**	Condition A	Cooling with 50% outdoor fan power
Sp*, Sp**, Sp***		Special conditions

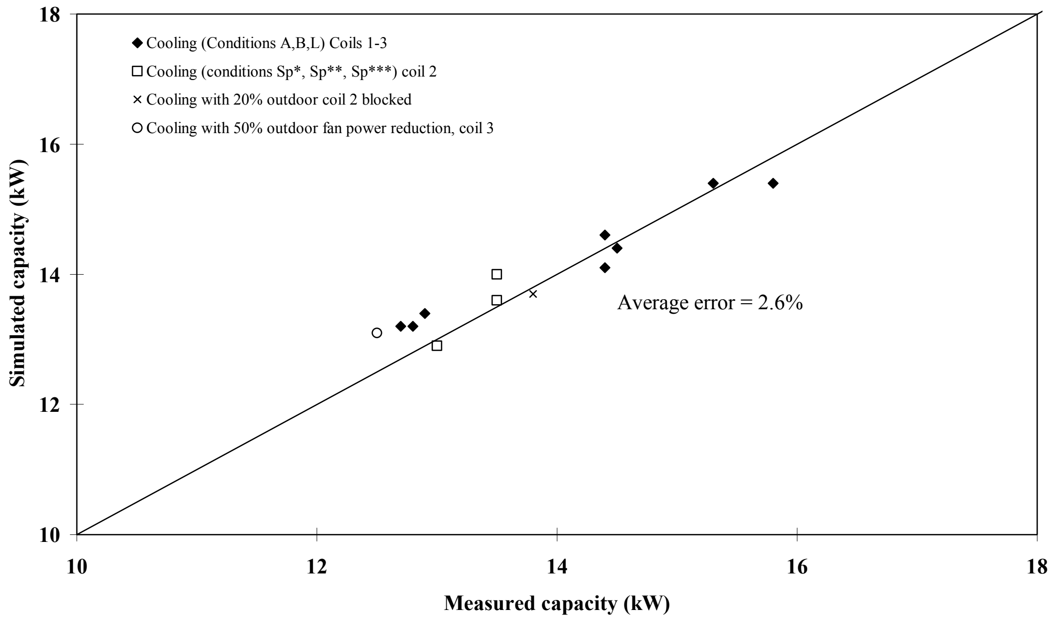

Figure 1. Comparison of measured and simulated cooling capacity

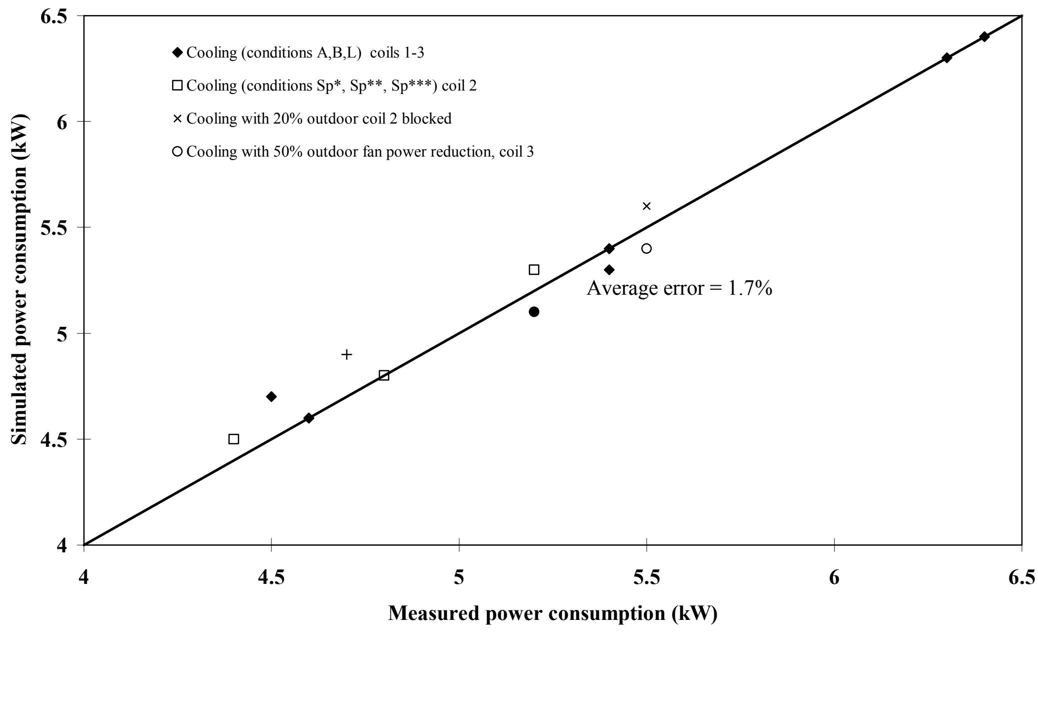

Figure 2. Comparison of measured and simulated power consumption

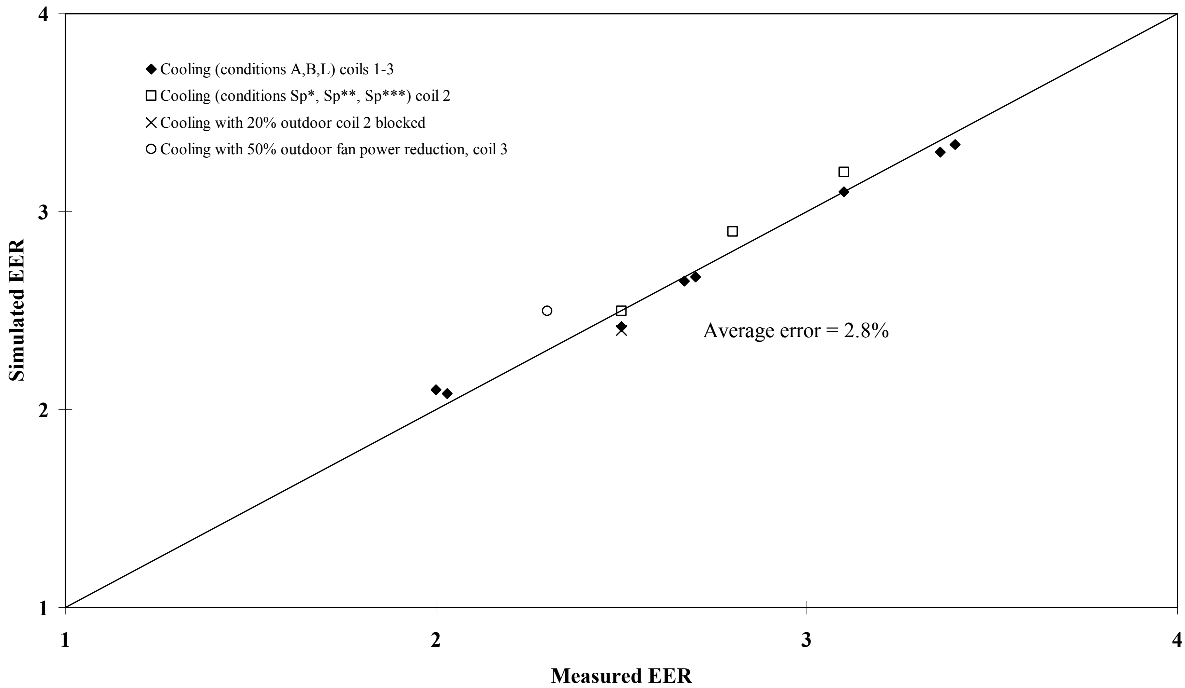

Figure 3. Comparison of measured and simulated Energy Efficiency ratio (EER).

6.1 Cooling Capacity Predictions

The comparisons of measured and predicted cooling capacity are shown in Figure 1. For normal system configuration (no coil blockage) the HPRATE simulations showed a maximum deviation of 3.6%. When abnormal airflow conditions over the outdoor coil were assessed the model over predicted the cooling capacity by 5.1% (test 13). The over prediction is most likely due to non-uniform airflow across the coil as a result of off-design operation of the fan. The simulation model assumes uniform airflow over the coil while in practice at off-design conditions the capacity may be reduced due to changes in coil airflow distribution.

The cooling tests demonstrate that the HPRATE model gives a reliable prediction of capacity (maximum error for cooling 3.5%, average error for cooling = 2.3%). The capacity predictions were biased towards an over estimate of capacity. This is expected as the model assumes a good design e.g. even flow distribution between coil circuits and uniform airflow over the coils.

6.2 Power Consumption Predictions

Comparison of measured and predicted power consumption are shown in Figure 2. The average deviation between measured and predicted power consumption was 1.7% and the maximum deviation was 3.8%.

6.3 EER Predictions

Comparisons of measured and predicted Energy Efficiency Ratio (EER) are shown in Figure 3. The average deviation between measured and predicted EER was 2.8% with maximum deviation of 5% for the blocked coil case.

7. CONCLUSIONS

The HPRATE/ORNL software tool developed for air conditioner rating has been found to provide reliable product-specific performance results if the refrigerant circuit pressure drops and product superheat and subcooling operating states are known. Implementation of Australian minimum energy performance requirements for product-specific EER ratings has been based on the restricted features of the ORNL software that are accessible via the HPRATE interface or the conservative product operating conditions set in the HPRATE model. This approach has allowed rapid introduction of MEPS requirements for a market of many hundreds of products without the high cost and delays associated with caloriometer measurements. Caloriometer measurements are still an essential part of such a MEPS scheme in order to ensure the integrity of the simulation results through check testing. The simulation approach to product performance rating has been readily adopted as it facilitates the rapid changes in the market place product mix that result from minimum energy performance requirements.

8. REFERENCES

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