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Provision of a Green Loans Feedback Mechanism - Sustainability Advisor

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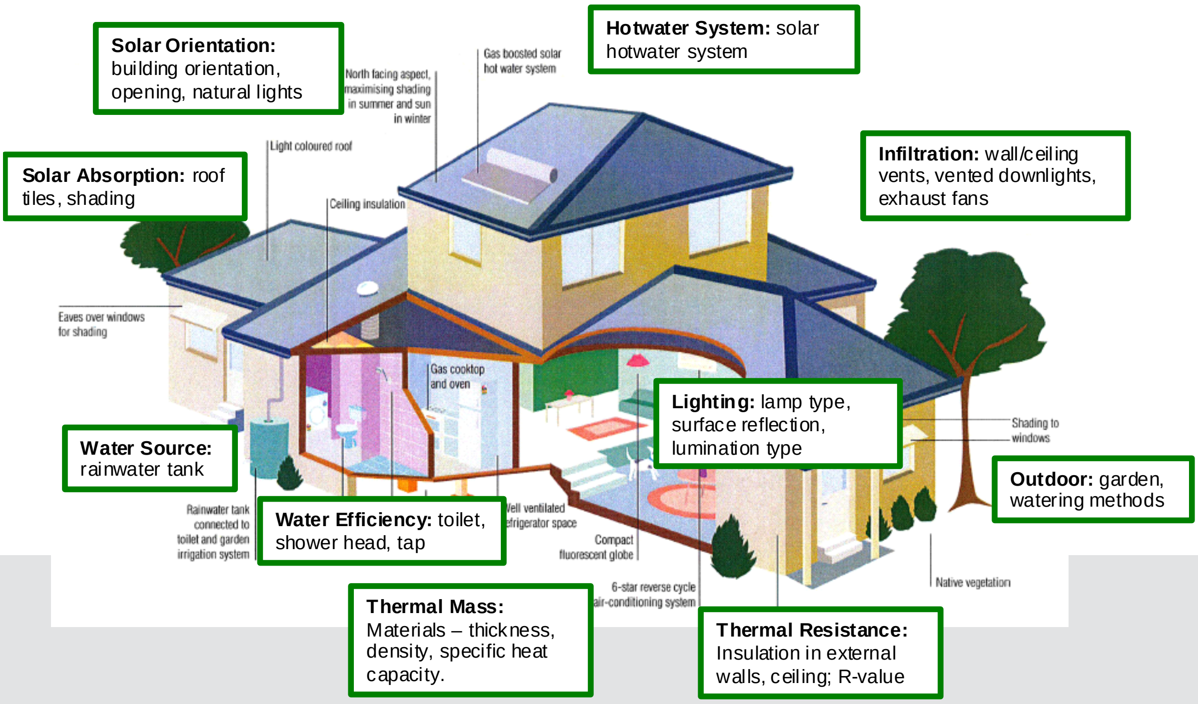

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Summary

AccuRate is being upgraded to a more integrated building sustainability assessment tool through the implementation of sustainability modules which include lighting, hot-water, water usage, heating, cooling, peak load and green modules. In order to facilitate expert advice on improving building sustainability performance, the Green Loans Program requested a feedback mechanism be developed within the AccuRate sustainability tool to provide advice on the most appropriate actions for sustainability improvement.

This research project developed a Sustainability Advisor module to provide a feedback mechanism for the assessment process. The new module was tailored to the AccuRate assessment outputs, enabling automatic diagnosis of building design problems and providing recommendations on actions. Within the Sustainability Advisor, key performance criteria have been defined and benchmarks from best practice incorporated to support an automated reasoning process. A knowledge base was developed by engaging with domain experts to provide reliable knowledge and design options which will assist house owners in improving the sustainability performance of their homes.

The Feedback Mechanism requires data exchange between AccuRate and the Sustainability Advisor to streamline the building design, sustainability assessment and feedback process. A common data model was developed using XML and Eclipse Modelling Framework (EMF) to support data sharing and interoperability between AccuRate and the Sustainability Advisor.

The internal test of the Sustainability Advisor was conducted using example building designs which failed to satisfy proposed sustainability requirements. The results show that the Sustainability Advisor is a very suitable method to implement this important feedback component to the AccuRate sustainability tool.

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1. INTRODUCTION

The Australian Government in its 2008/2009 Federal Budget announced the provision of $300 million for Green Loans to assist families to install solar, water and energy efficient products (Department of the Environment, Water, Heritage and the Arts, 2009). Before a Green Loan will be available to a household, a detailed sustainability assessment will be conducted by a recognised expert to determine the most appropriate actions to improve the environmental performance of that property.

CSIRO proposes to research and develop a Sustainability Advisor module in the AccuRate Sustainability tool to support the requested Green Loans feedback mechanism.

1.1 Project Objectives and Scope

The Sustainable Advisor is intended be a rule-based system capable of providing expert advice to the assessors in their preparation of the list of actionable recommendations for either renovating an existing home or improving the design of a new home. The Sustainable Advisor will perform a diagnosis on the household based on assessments results on thermal performance, energy and water consumption from the AccuRate sustainability tool and against pre-defined evaluation benchmarks from best practice. A knowledge base will be developed by engaging with the domain experts and key stakeholders, including the Green Loans Program (GLP) and the Association of Building Sustainability Assessors (ABSA).

1.2 Project Deliverables

The project deliverables included:

- A Sustainability Advisor module in the AccuRate sustainability tool to support the requested Green Loans feedback mechanism. The Sustainability Advisor module performs an automated house sustainability diagnosis based on the assessment results and against pre-defined evaluation benchmarks. In addition, a knowledge base was developed to support recommendations.
- A User Guide document for the Sustainability Advisor module, including instructions to assessors and home owners on how to use the Sustainability Advisor.
- A final report clearly describing the research conducted and project outcomes.

2. BACKGROUND

2.1 AccuRate Sustainability Tool

The introduction of the Nationwide House Energy Rating Scheme (NatHERS) saw the development of an energy rating tool called AccuRate by CSIRO researchers (Delsante, 2005; AccuRate, 2007). The tool first used in Australia in the early 1990s provides assessment on the heating and cooling efficiency of simple or complex residential building design. The tool has been used to rate dwellings for more than 10 years.

AccuRate today as shown in Figure 1 is undergoing a significant upgrade to become a sustainability assessment tool by implementing sustainable assessment modules for lighting, hot-water, heating, cooling, water usage, peak load, green modules and so on.

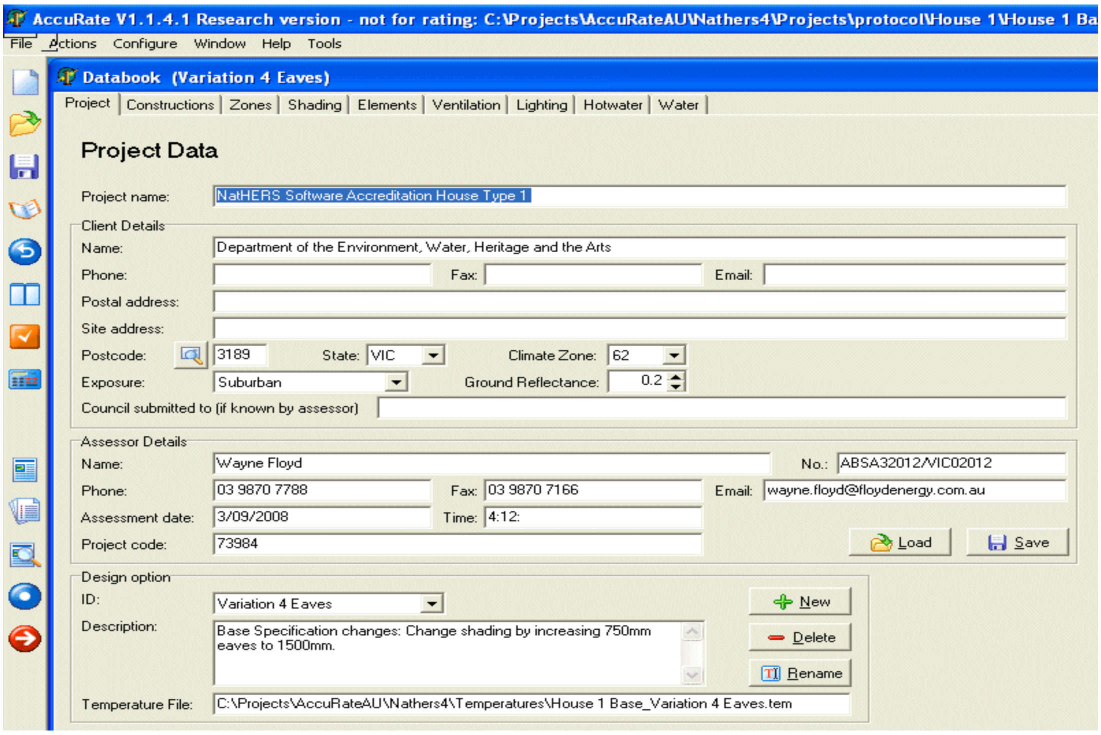


Figure 1 AccuRate Sustainability Tool

2.2 Sustainability Advisor Module

The Sustainability Advisor module is a proof of concept tool that aims to demonstrate how the automated diagnosis and feedback can assist home owners in improving the sustainability performance of their house.

The diagnosis performed on the house design is based on performance criteria tailored to the AccuRate assessment and domain knowledge from domain experts. It is implemented using the Decision Table algorithms.

As an example of a scenario handled by the Sustainability Advisor - if the assessment result from AccuRate indicates the building has failed to meet a minimal requirement of energy performance, the diagnosis will automatically check the house design against energy performance criteria, including thermal resistance, thermal mass, infiltration, solar absorption and energy efficiency systems. For example, if insulation is not found in the roof, the Sustainability Advisor proceeds to make a recommendation that bulk insulation be installed in the roof. A complete list of the recommendations will be reported back to the assessor and/or home owners at the end of the diagnosis.

The key features of the Sustainability Advisor in providing assistance to the household sustainability assessors include:

- An automated process to make a diagnosis and recommendation.
- Providing recommendations from the design point of view, based on existing houses or new houses.
- Providing reliable expert knowledge for recommendations.

A schematic diagram showing an overview of the Sustainability Advisor module is given in Figure 2.

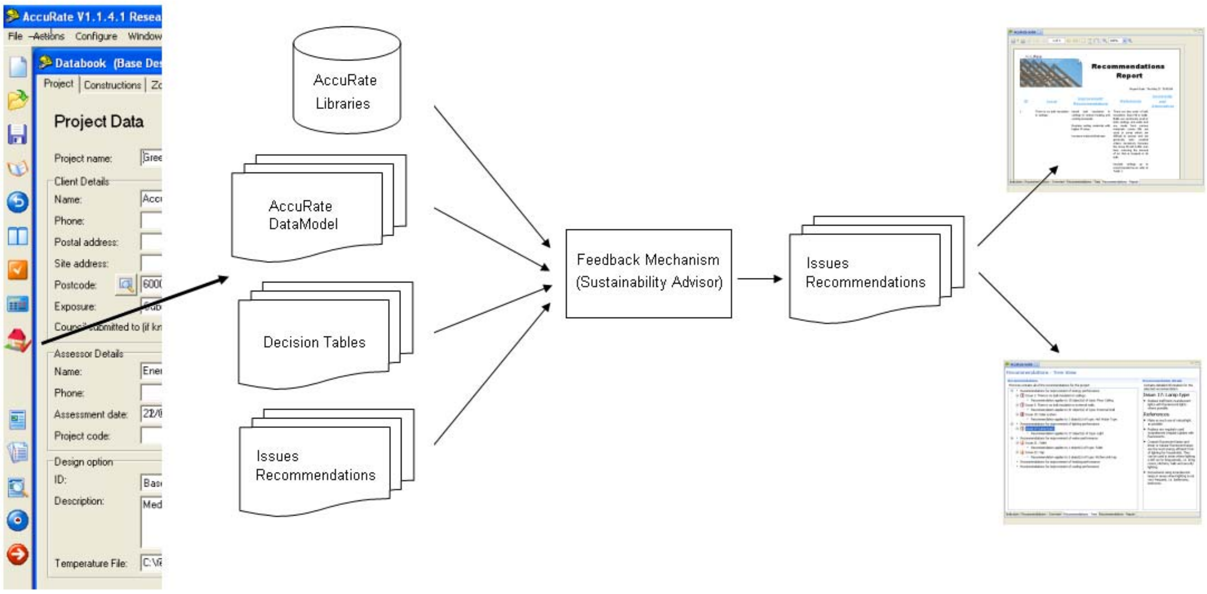


Figure 2 A schematic diagram of the Sustainability Advisor module

3. SUSTAINABILITY ADVISOR

The development of the Sustainability Advisor comprises of the following major components:

- Key performance criteria tailored to the AccuRate assessment.
- Key influential factors and design choices linking to sustainability performance.
- Domain knowledge in support of performance assessment.
- Decision Table algorithms to support automated reasoning about design problems.
- Recommendations for improving building sustainability performance.

A list of key performance criteria is required to drive the logic and reasoning behind the recommendations given by the Sustainability Advisor. The key performance criteria were defined according to the AccuRate assessment models. This will enable the recommendations to be tailored to the AccuRate assessment results.

An understanding of the main influential factors is crucial in achieving sustainability performance target, and in supporting decision making from different design choices. Section 3.2 will analyse the main factors which will influence building energy performance, including thermal resistance, thermal mass, glazing, infiltration and lighting.

Domain knowledge plays a key role for building sustainability assessment, automatic diagnosis and recommendations for actions. Section 3.3 will describe the domain knowledge employed in the Sustainability Advisor whilst the Design Table algorithms which encode reasoning rules for automatic diagnosis will be demonstrated in Section 3.4.

3.1 Sustainability Performance Hierarchy

Performance criteria in hierarchy represent performance requirements or benchmarks at the different levels. In the Sustainability Advisor, we define a building sustainability performance hierarchy in order to provide a decision tree and an orderly sequence of how design problems can be tackled.

Figure 3 illustrates the building sustainability performance hierarchy, tailored to the AccuRate assessment models, which enables an automated diagnosis. The diagnosis traverses each level of the tree hierarchy starting from the root and moving down each branch until a leaf node is encountered. It then backtracks to a level where there is a sibling branch and the process is repeated again. Since the diagnosis that needs to be performed at each node level consists of multiple conditions and actions, Decision Table algorithms have been employed to model the complicated logic.

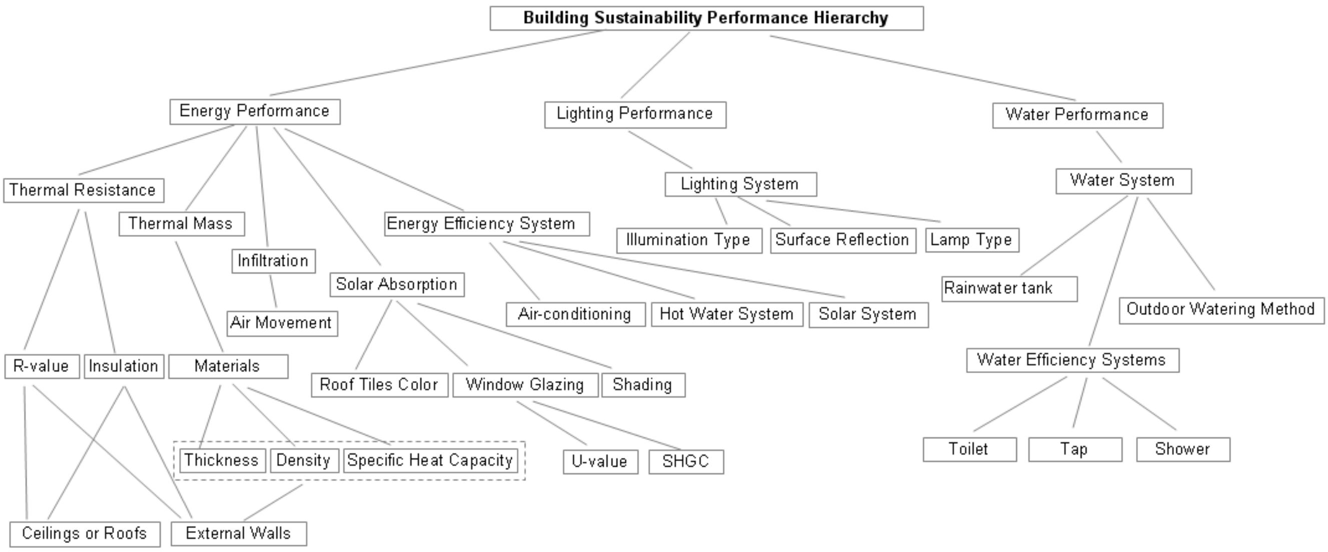


Figure 3 Illustration of building sustainability performance hierarchy

3.1.1 Building Energy Performance

There are three key components in the building sustainability performance hierarchy, which are energy performance, lighting performance and water performance.

Under the energy performance node (Figure 3), thermal resistance, thermal mass, infiltration, solar absorption and energy efficiency systems are the key factors. These factors (except energy efficiency systems) are the major contributors to the building envelope thermal performance which is the key driver of heating and cooling loads.

The next level nodes involve insulation, materials, air movement, glazing, shading and so on. According to the ABSA household sustainability assessor trainer guide (ABSA, 2009), these factors will affect building thermal performance.

There are a number of energy efficiency systems in a household. The Sustainability Advisor considers major energy efficiency systems such as hot-water system.

3.1.2 Lighting Systems

Lighting is also a significant part which will affect energy use. Illumination type, lamp type and surface reflection are identified as the key factors in the building sustainability performance hierarchy (Figure 3). Efficient illumination design, such as direct illumination, and efficient lamp type will increase lighting efficiency and lower energy use.

3.1.3 Water Systems

Water efficiency systems, outdoor watering methods and rainwater tank are identified as the key factors that will affect building water performance (Figure 3). Not all water efficiency systems in a household have ratings. Therefore, the Sustainability Advisor considers the toilet, tap and shower which have been rated by the Water Efficiency Labelling and Standards Schema (WELS, 2008).

3.2 Key Influential Factors and Design Choices

Heating and cooling requirements are the major factors which influence building energy performance. According to the Your Home Technical Manual (Your Home Technical Manual, 2008), 38 percent of day-to-day energy use in an average Australian household goes into heating and cooling, Figure 4.

Residential building design can take advantage of the natural climate such as the sun and wind to provide heating, cooling, ventilation and lighting in order to maintain thermal comfort. Passive design is encouraged, which is design that does not require much mechanical heating or cooling (Level, 2009).

In the Sustainable Advisor, we consider key passive design features including good thermal insulation, choices of building materials, window glazing, infiltration, ventilation and shading.

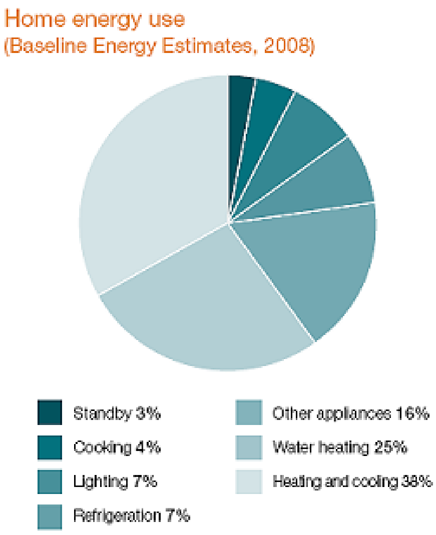


Figure 4 Energy use of an average Australian household (source: Your Home Technical Manual, 2008)

3.2.1 Insulation

Insulation is an effective way to improve energy efficiency of a home and can save 45-55% of the heating and cooling energy. Table 1 shows the potential savings on heating and cooling energy while insulation is installed (source: Sustainability Victoria, 2008).

EXTENT OF INSULATION	HEATING	COOLING	HEATING AND COOLING
Ceiling only (added R2.5)	15–25%	30–45%	20–30%
Ceiling (added R2.5) and walls (added R1.0)	40–50%	40–55%	40–50%
Ceiling (added R2.5), walls (added R1.0) and floor (added R1.0)	45–55%	35–50%	45–55%

Table 1: Typical energy savings due to insulation (source: Sustainability Victoria, 2008)

3.2.2 Building Materials

Density, thickness and specific capacity of building materials will affect thermal mass performance. The Sustainable Energy Thermal Mass Fact Sheet from Sustainability Victoria shows that use of heavyweight construction materials with high thermal mass, such as concrete slab on ground and insulated brick cavity walls, can reduce total heating and cooling energy requirements.

3.2.3 Window Glazing

The type of frame has an impact on the thermal performance of the glazing units. Frame colour normally has lesser impact.

The glazing system U-value and the Solar Heat Gain Coefficient (SHGC) are the two key indicators of window energy performance. The U-value indicates how much heat will be lost through a window whilst the SHGC measures the amount of solar energy that pass through the window into the interior.

Solar heat gain is good in the winter, whilst it reduces the load for the building's heating requirement. In the summer, however, added solar heat increases the cooling load. Therefore, windows for colder climates should have higher SHGC, whilst warmer climates should have lower SHGC.

3.2.4 Air Infiltration

Air infiltration increases the need for additional heating in winter and cooling in summer. For example, heat loss and gain may occur by infiltration through cracks in the window assembly. The lower the air infiltration, the less air will pass through the cracks, and thus improving energy efficiency. It is important to fix the uncontrolled air leakage in buildings, such as the leakage at structural gaps, window and door openings, exhaust fans and vented downlights. The Energy Audit Tool of the Australian Greenhouse Office states that reducing infiltration and installing controllable ventilation systems in a building can save up to 20% on heating and cooling costs.

3.3 Domain Knowledge

This section describes the domain knowledge used for encoding the reasoning rules in the Sustainability Advisor.

3.3.1 Climate zones

The Building Code of Australia (ABCB, 2009) criteria for testing of thermal resistance and glazing solar absorption are climate zone dependent.

The Building Code of Australia (BCA) climate zones are structured into eight different climate zones, based on climatic data with the adjustments made for local government boundaries, Figure 5. The BCA climate zones are used in the Sustainability Advisor.

AccuRate uses the Nationwide House Energy Rating Schema (NatHERS) climate zones. In NatHERS, Australia is divided into many regions of similar climate, namely, regions where local climate conditions are unlikely to require significant house design difference. Figure 6 shows the map of the sixty nine different climate zones used in AccuRate.

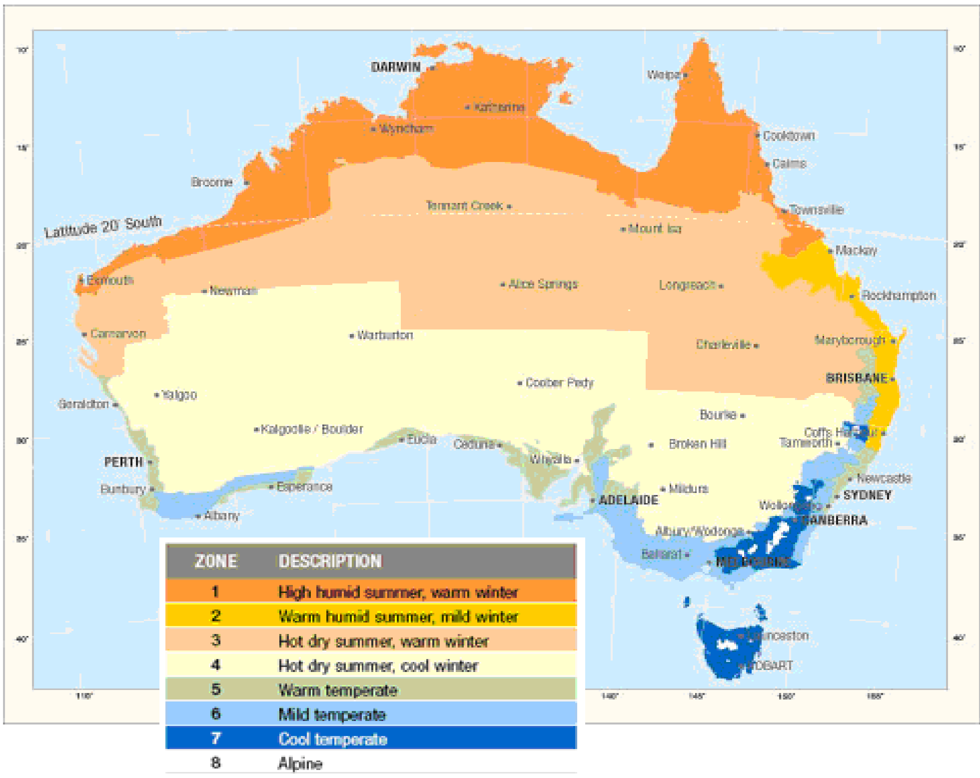


Figure 5 Building Code of Australia climate zones used in the Sustainability Advisor (source: ABCB, 2009)

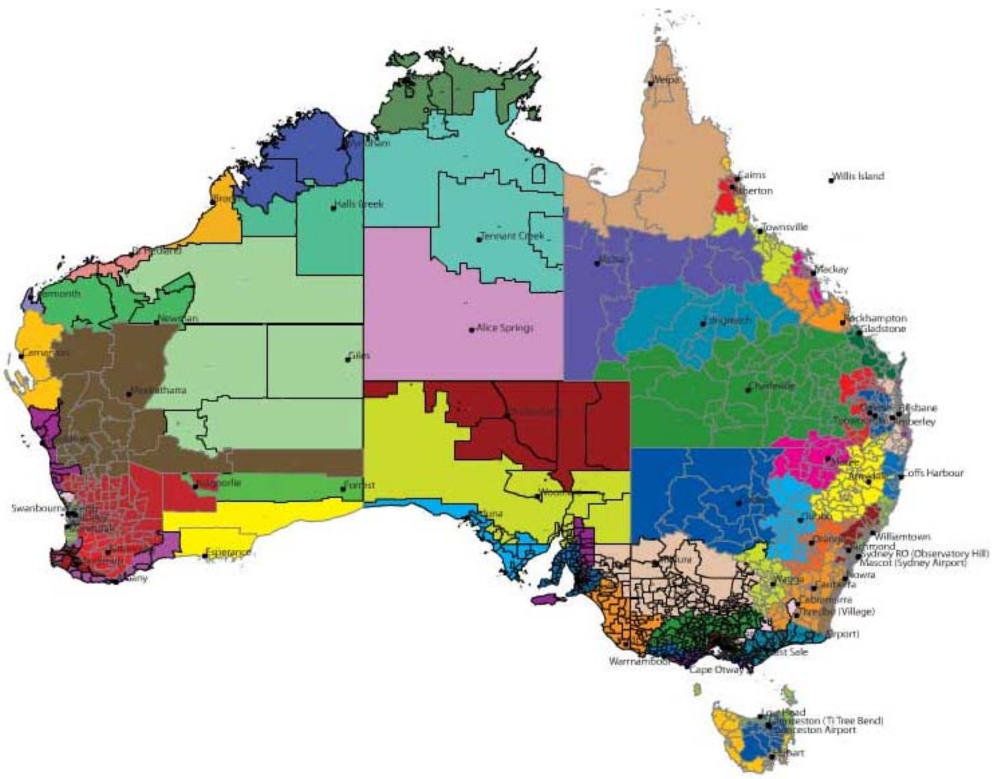


Figure 6 NatHERS climate zones used in AccuRate (source: NatHERS, 2008)

The relationship between the BCA climate zones used in the Sustainability Advisor and the NatHERS climate zones used in AccuRate are given in Table 2.

BCA climate zones	AccuRate climate zones
1	1,2,5,29,30,31,32,33,34
2	7,9,10,11,35,36
3	3,4,6,19,37,38,39,40
4	8,20,27,41,42,43,44,45,46,47,48,49
5	12,13,15,16,17,50,51,52,53,54,55,56
6	18,21,22,28,57,58,59,60,61,62,63,64
7	14,23,24,26,65,66,67,68
8	25,69

Table 2: The relationships between BCA climate zones and AccuRate climate zones

3.3.2 Building Class

The Building Code of Australia classifies buildings into Class according to use of the building to ensure the appropriate BCA provisions are applied to a particular building.

Building Class 1, 2 and 10 are applicable in AccuRate. The definitions for these building classes are presented as follows (National Timber Development Council, 2000 and 2001).

A Class 1 building means one or more buildings which in association constitute:
Class 1a - a single dwelling being -

- *a detached house; or*
- *one of a group of two or more attached dwellings, each being a building, separated by a fire-resisting wall, including a row house, terrace house, town house or villa unit; or*

Class 1b - a boarding house, guest house, hostel or the like

- *with a total area of all floors not exceeding 300m² measured over the enclosing walls of the Class 1b; and*
- *in which not more than 12 persons would ordinarily be resident,*

which is not located above or below another dwelling or another class of building other than a private garage.

A Class 2 means a building containing two or more sole-occupancy units each being a separate dwelling.

Class 10: a non-habitable building or structure -

- *Class 10a - a non-habitable building being a private garage, carport, shed or the like; or*
- *Class 10b - a structure being a fence, mast, antenna, retaining wall or free standing wall, swimming pool or the like.*

The Sustainability Advisor needs to determine the classification of a building prior to providing recommendations. The following examples present the algorithms how to identity Class 1, 2 and 10 buildings.

Determining Class 2 Building requires knowledge of:

a. *the zone adjacent to the zone in question and*
b. *the zone below or above to the zone in question.*

To do this, one need to look at the internal wall of the zone in question for criteria *a* and the floor or ceiling for criteria *b*. If the zone for *a* or for *b* happens to be the neighbours then the building is a Class 2 building.

Figure 7 illustrates an example of an internal wall. If the *adjacent zone* of the internal wall of a zone, e.g. bedroom, is of zone type *Neighbour*, then the building is a *horizontal* row of units (villa) and thus falls into the classification of Building Class 2.

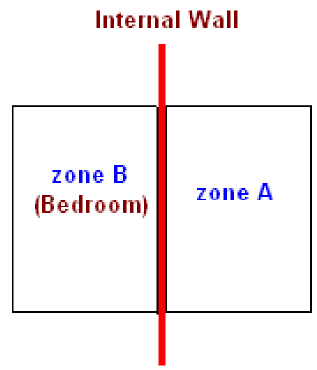


Figure 7 Internal wall adjacent to two zones

Figure 8 illustrates examples of ceiling and floor. If the zone (e.g. zone A in Figure 8) above-the-ceiling or below-the-floor of the zone in question, (e.g. zone B (lounge) in Figure 8) is of zone type *Neighbour*, then the building is a *vertical* column of units (apartment) and thus falls into the classification of Building Class 2.

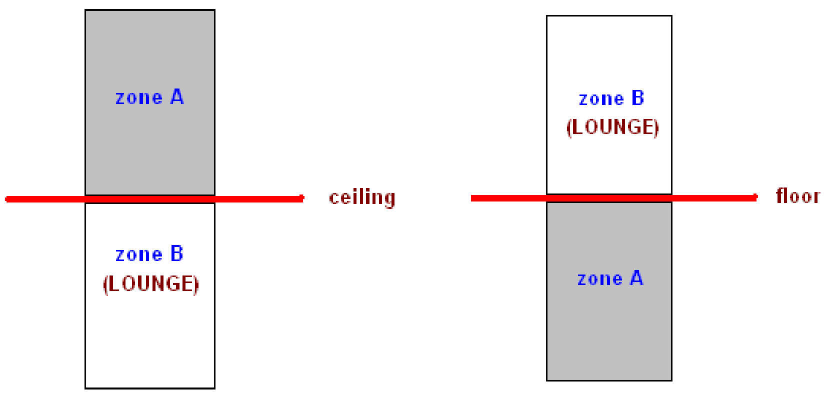


Figure 8 Ceiling-above or floor-below between two zones on top of each other

The negation for Building Class 2 determines the building is a Class 1 or 10 building. The differentiation of whether the building is a Class 1 or 10 has no significance in determining the minimum R-value to be used for measurement of thermal resistance.

3.3.3 Thermal Resistance R-value

The thermal resistance performance of building material for insulation is represented by its R-value. Table 3, Table 4 and Table 5 present the minimum total R-value requirements from BCA. The R-value which is calculated in AccuRate includes the R-value for thermal bridging materials. Therefore, the values provided from BCA have to be multiplied by the relevant adjustment factors given in Table 9 before these values can be used in the Sustainability Advisor.

	Minimum Total R-value	
BCA climate zones	**Class 1 & Class 10**	**Class 2 to Class 9**
1	2.7	2.2
2	2.85[1]	2.35[2]
3	2.7	2.2
4	3.5	3.0
5	3.2	2.7
6	3.7	3.2
7	4.3	3.8
8	4.8	4.3

Table 3: Minimum Total R-value for roof or ceiling

	Minimum Total R-value	
BCA climate zones	**Class 1 & Class 10**	**Class 2 to Class 9**
1	1.9	1.4
2	1.9	1.4
3	1.9	1.4
4	1.9	1.7
5	1.9	1.4
6	2.2	1.7
7	2.4	1.9
8	3.3	2.8

Table 4: Minimum Total R-value for external wall

	Minimum Total R-value		
BCA climate zones	**Class 1 & Class 10**		**Class 2 to Class 9**
	Enclosed	**Unenclosed**	
1			
2			
3			
4	1	2	
5			
6	1	2	1
7	1.5	2.5	1
8	2.0	3	2.5

Table 5: Minimum Total R-value for floor - suspended floor

[1] domain expert estimation
[2] average of below & above altitude

Figure 9 illustrates the process of diagnosing the R-value in the roof or ceiling, external wall and floor constructions and making recommendations in the Sustainability Advisor.

Of the three construction types: roof, wall and floor, installation of insulation in roof cavities is the simplest. If the floor construction is found to have no or insufficient insulation, the recommendation to add insulation depends on whether there is sufficient access to the subfloor. The minimum clearance requirement[3] is 500mm from ground to joist or 600mm from ground to floor. Wall insulation is recommended only if the wall cladding needs replacement or the wall is renovated.

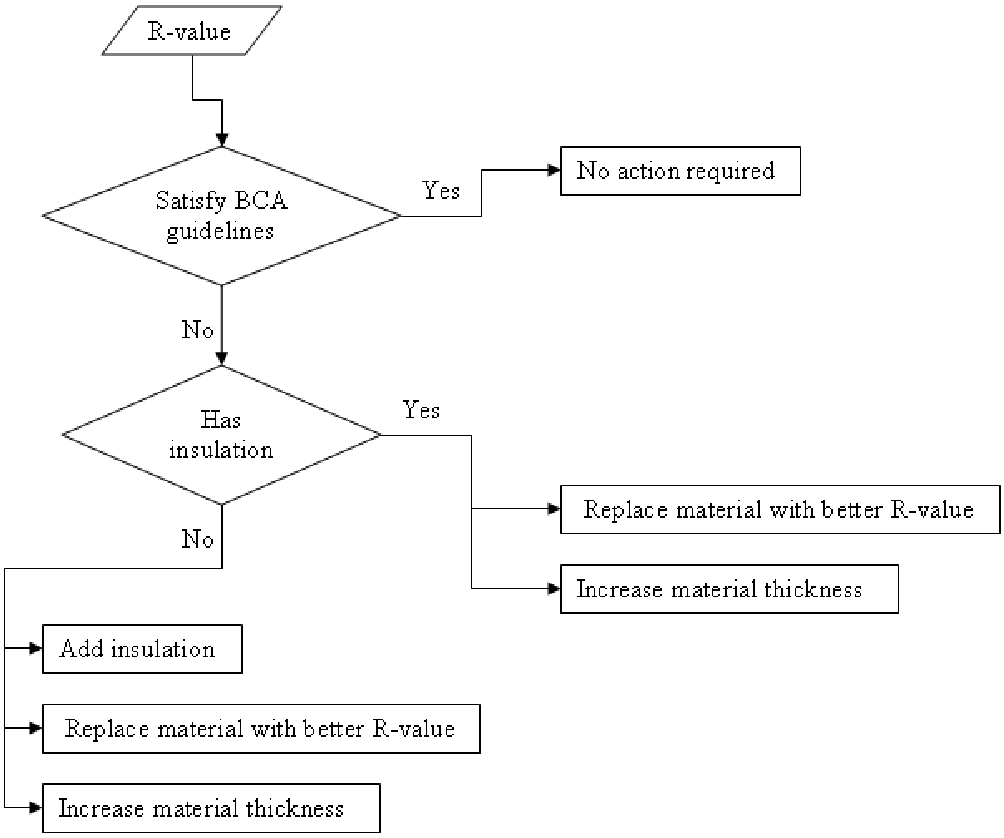


Figure 9 Flowchart for diagnosing R-value

3.3.4 Thermal Mass

Thermal mass performance describes the ability of building materials to absorb heat, store it, and release it at a later time. Unlike R-value for thermal resistance performance, no explicit minimum performance criteria for thermal mass are provided by BCA. Table 6 presents the recommended minimum thermal mass for each of the climate zones for wall and floor construction, suggested by CSIRO domain experts.

The formula for calculating thermal mass of a construction is as given below.

[3] feedback from ABSA trainer

If the material library has information on Density & Specific Heat Capacity for the material in question then calculate as follow:

$$ThermalMass \quad = \quad Thickness * Density * SpecificHeatCapacity$$

Where

Thickness	-	*user specified*
Density	-	*material library*
SpecificHeatCapacity	-	*material library*

If there is no information on Density & Specific Heat Capacity in the material library for the material in question then calculate as follow:

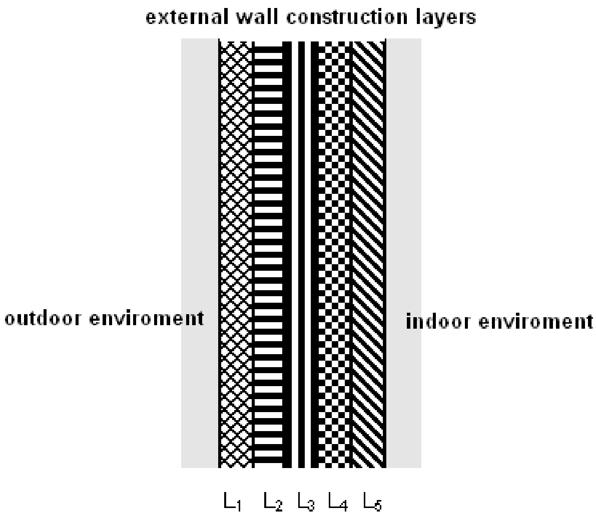
$$ThermalMass \quad = \quad Thickness * Capacitance$$

Where

Thickness	-	*user specified*
Capacitance	-	*material library*

The Sustainability Advisor will diagnose whether there is an insulation layer or not, and then check the thermal mass against minimum performance requirement in associated BCA climate zone. Details are illustrated as follows.

If there is no bulk insulation layer, check the sum of the thermal mass of the construction. Figure 10 illustrates thermal mass calculation of the external wall construction without bulk insulation layer.

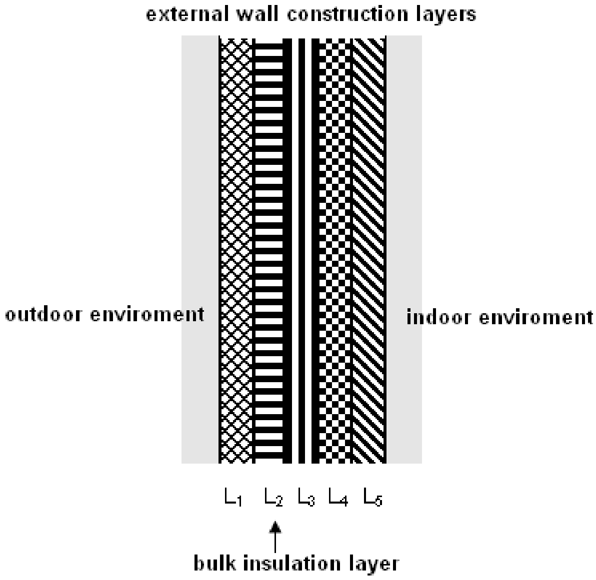


$$TM \quad = \quad \sum_{i=1}^{n} TM_{ConstructionLayer_i}$$

Where	n	- total number of construction layers
	i	- layer of interest
	$TM_{ConstructionLayer_i}$	- calculated thermal mass of i^{th} layer

Figure 10 External wall construction without insulation

If there is a bulk insulation layer, check the sum of the thermal mass of the construction layers between the insulation layer and the indoor environment. Figure 11 illustrates thermal mass calculation of the external wall construction with bulk insulation layer.



$$TM = \sum_{i=k+1}^{n} TM_{ConstructionLayer_i}$$

Where k - bulk insulation layer
n - total number of construction layers
i - layer of interest
$TM_{ConstructionLayer_i}$ - calculated thermal mass of i^{th} layer

Figure 11 External wall construction with insulation

The criterion of 8 × 10^4 J/m² °C was suggested for thermal mass for wall and floor for all BCA climate zones. It is equivalent to half of a generic extruded clay brick (typical density) construction.

3.3.5 Solar Absorption

The amount of solar energy that passes into a material relies on the colour no matter what material is used. Dark materials have a higher solar absorptance and hence will absorb more solar energy.

Solar absorption in glazing is defined by the conductance (U-value) and the Solar Heat Gain Coefficient (SHGC). Different climate zones will have different U-value and SGHC requirements.

The aggregate conductance and aggregate solar heat gain of glazing (such as window or roof window) in the building is calculated by adding the U-value and the SHGC of each glazing element according to the formula given below:

For conductance:

$$Aggregate\,Uvalue = \sum_{i=1}^{n} A_i * U_i$$

Where

A_i = Area of i^{th} glazing element

U_i = U-value of i^{th} glazing element.

For solar heat gain:

$$Aggregate\ SHGC = \sum_{i=1}^{n} A_i * SHGC_i * E_{cz_{orientation}}$$

Where

A_i = Area of i^{th} glazing element

$SHGC_i$ = SHGC of i^{th} glazing element.

$E_{CZ\ orientation}$ = Solar exposure factor for climate zone climate & orientation

cz $\in$ (climate zone 1,…, climate zone 8)

orientation $\in$ (N,NE,E,SE,S,SW,W,NW)

The solar exposure factor for projection-height (P/H) ratio of 0.5 is given in Table 6.

	Orientation								
BCA climate zones	**P/H**	**N**	**NE**	**E**	**SE**	**S**	**SW**	**W**	**NW**
1	0.5	0.27	0.41	0.72	0.64	0.38	0.67	0.75	0.42
2	0.5	0.36	0.5	0.67	0.55	0.37	0.61	0.75	0.53
3	0.5	0.3	0.49	0.81	0.65	0.35	0.64	0.77	0.5
4	0.5	0.29	0.58	0.83	0.61	0.31	0.58	0.79	0.53
5	0.5	0.37	0.52	0.65	0.52	0.36	0.56	0.73	0.55
6	0.5	0.33	0.51	0.66	0.49	0.33	0.63	0.83	0.6
7	0.5	0.36	0.58	0.71	0.54	0.35	0.51	0.69	0.57
8	0.5	0.36	0.53	0.67	0.53	0.36	0.56	0.73	0.56

Table 6: Solar exposure factor

The aggregate conductance and aggregate solar heat gain of glazing in the building must not exceed the allowances obtained by multiplying the floor area of the building by the conductance (U-value) and Solar Heat Gain Coefficient (SHGC) given in Table 7 for a climate zone.

For conductance:

$$Aggregate\,Uvalue \quad \leq \quad FloorArea * U_{cz}$$

For solar heat gain:

$$Aggregate\ SHGC \quad \leq \quad FloorArea * SHGC_{cz}$$

BCA climate zones	U-value U_{cz}	SHGC $SHGC_{cz}$
1	2.4	0.09
2	2.5	0.15
3	1.6	0.1
4	1.2	0.13
5	1.9	0.14
6	1.4	0.19
7	1.2	0.22
8	0.7	0.32

Table 7: U-value and SHGC for each climate zone

Roof colour affects the temperature in the roofspace and inside the dwelling (SteelSelect, 2009, Australbrick, 2009). Insulated roof and/or ceiling are no exception. Roof colours are defined by the solar absorptance which measures the amount of heat transferred through the roof. Light colour roof reflects more heat and helps to keep the roofspace and dwelling cooler on hot days. The colour range of roof with the associated solar absorptance is given in Table 8 (BASIX 2009).

Colour	Solar Absorption
Light	< 0.475
Medium	0.475 – 0.7
Dark	> 0.7

Table 8: Solar absorption of roof colour (source: BASIX, 2009)

The minimum performance requirement for roof is presented as follow.

$$SolarAbsorption_{roof} \quad \leq \quad SolarAbsorption_{Dark}$$

The values (R-value, Thermal mass, U-value and SHGC) derived from BCA are modified for use in the Sustainability Advisor by multiplying with an adjustment factor as given in Table 9.

	Adjustment Factors (%)			
	Roof / Ceiling	**External Wall**	**Floor**	**Window / Roof window**
R-value	85	85	85	
Thermal mass		100	100	
U-value & SHGC				100

Table 9: Adjustment factors (%) for BCA criteria

3.3.6 Water Consumption

The information of water consumption in Australia is presented in Table 10 (source: Kenway et al, 2008). The figures are water consumption in gigalitres (GL) by major cities in Australia for period 2006/07.

Cities	**Sydney**	**Melbourne**	**Perth**	**Brisbane**	**Gold Coast**	**Adelaide**
Population served	4,300,000	3,621,000	1,538,000	1,006,000	492,000	1,095,000
Water supplied (GL)						
Total	507	412	235	113	65	159
Residential water	315	257	170	61	40	112
Indoor water use (%)	65	84	53	–	–	–
Wastewater collected (GL)	508	296	119	86	47	89

Table 10: Urban water usage in Australia (source: Kenway et al, 2008)

Table 11 presents the typical household water usage modelled in the House Water Expert software tool (Grant et al, 2004). The figures are based on the 2000-01 ABS data covering indoor and outdoor water usage estimates for every state and territory in Australia. The figures have typical range varying by ±15% from the ABS estimates and depend on two factors, namely, location (climate) and household numbers.

	Indoor (kL/capita/yr)		**Outdoor (kL/hh[4]/yr)**	
State	**Lower**	**Upper**	**Lower**	**Upper**
NSW	65	90	55	70
VIC	55	75	75	100
Qld	60	80	145	195
SA	50	70	120	160
WA	55	75	135	180
Tas	70	95	85	115
NT	90	120	264	350
ACT	45	60	140	190

Table 11: Household water usage in HWE (source: Grant et al, 2004)

Table 12 presents the data on water use by Australian households sourced from the 2004-05 ABS water account for households (Australia Bureau of Statistics, 2006; Australian Government National Water Commission, 2007).

[4] kilolitres per household per year

2004-05	Household (GL)	Household per household (kL)	Household per capita (kL)
Australia	2108	268	103
NSW	573	219	84
VIC	405	209	81
QLD	493	323	124
SA	144	244	94
WA	362	468	180
TAS	69	372	143
NT	31	399	153
ACT	31	248	95

Table 12: Household water usage in the ABS 2004-2005 survey

The Water Efficiency Labelling and Standards Schema (WELS, 2008) labels a range of products for water efficiency, including toilet, tap and showers. The approach taken in the Sustainability Advisor is to set up benchmarks in support of performance measures of water efficiency. An example of the benchmarks for toilet, tap and shower is presented in Table 13.

Water Efficiency System	Benchmarks[5]
Toilet	4 star
Tap star	4 star
Shower	3 star

Table 13: Example of minimum requirement by respective water efficiency system

3.3.7 Outdoor Watering Methods

Outdoor watering methods are linked to frequency of watering and the duration or the number of buckets used. There are two ways to set up the benchmark for recommendations: (1) water use per week; and (2) most water efficient methods. In the Sustainability Advisor, the second approach is taken. The steps involved in the analysis are described below.

Checking the method of watering that has been applied is the first step in the diagnosis. Table 14 lists the watering methods implemented in AccuRate. The associated application rate of each watering method is also given in Table 14.

[5] domain expert recommendation

Method of watering	Rate
Do not water	0
By Hand – Bucket or watering can	10 L/bucket
By Hand - Hose	20 L/min
By Sprinkler - Hose Connections	15 L/min
By Sprinkler - Fixed Connections	30 L/min
By Drip Irrigation	5 L/min
By Micro-spray Irrigation	10 L/min

Table 14: Garden/Lawn application rate (source: Grant et al, 2004)

Having determined the method of watering, the next step is to make recommendation if a better approach is to be applicable. For example,

If the method of watering is hand watering methods or drip irrigation methods, then the diagnosis terminates since these two methods of watering are considered to be efficient methods.

If manual sprinklers are installed, then the recommendation is to install garden tap timers to the water system.

If automatic sprinklers are installed and since these systems often use much more water than other watering methods, then the recommendation is to change to other efficient methods such as hand watering methods or drip irrigation methods.

3.4 Automated Diagnosis of Design Problems

The Sustainability Advisor provides a diagnosis function that will automatically address the design problems and provide recommendations which will assist households in improving energy, lighting and water performance of their houses.

The assessment result from AccuRate will provide a starting point. The factors that may have contributed to the high energy or water usage are analysed through the key sustainability performance hierarchy described in Section 3.1.

The most appropriate recommendations to help rectify the problem will be issued to the household. Some of the recommendations may just be a straight forward replacement of material with another, while others may be advice that has a significant impact on the existing behaviour of the household.

3.4.1 Decision Table Algorithms

The Decision Table algorithms are developed to reason about building design problems against sustainability performance target and provide recommendations to house owners.

Decision Table (Decision Table, 2009; Kirk, 1965; Wilde, 2002) represent decision logic in a tabular form. Decision Table associates conditions with actions to provide a neat and compact way to model complicated logic. Using Decision Table to model a problem offers several advantages: the logic is stated precisely and compactly; complex situations are easy to understand; relationships between variables are clear; and programming is simple.

In the Sustainability Advisor, key performance criteria are the combination of multiple conditions. These multiple conditions are encoded using the Decision Table algorithms to enable complicated diagnostic logic and actions.

Decision Table varies in the way that condition alternatives and action entries are represented. Condition alternatives can be represented using simple true or false value or numbers. Some have even used fuzzy logic or probabilistic representation for condition alternatives (Wets et al, 1996; Ziarko, 1999). Action entries can simply represent whether or not an action is performed, or the ordering of actions to be performed in a more advanced Decision Table.

The Decision Table structure used in the Sustainability Advisor is shown in Table 15. It has two parts: the top part contains the conditions and the bottom part contains the action rules.

Conditions	Condition Alternatives
Actions	Action Entries

Table 15: Structure of the Decision Table

Table 16 shows a decision table used in the Sustainability Advisor. It shows how the action of diagnosis is determined against the minimal performance requirement of energy use, heating and cooling performance. Other decision tables in the Sustainability Advisor are presented in Appendix A.

Figure 12 presents an implementation flow chart for energy performance diagnosis that is supported by a set of decision tables. The diagnosis will identify whether the building is a new building design or an existing building and decide what actions and recommendations to provide. If the building performance doesn't satisfy the minimal requirement and no design problems are found, the software will advise home owners to discuss with experts.

1a – Check Energy Performance									
		Rules							
Conditions	Outcome of total energy star rating >= minimal requirement	Y	Y	Y	Y	N	N	N	N
	Outcome of heating star rating >= minimal requirement	Y	Y	N	N	Y	Y	N	N
	Outcome of cooling star rating >= minimal requirement	Y	N	Y	N	Y	N	Y	N
Actions	Action 2a: Check thermal resistance (insulation)		X	X	X		X	X	X
	Action 2b: Check thermal mass (building materials)		X	X	X		X	X	X
	Action 2c: Check Infiltration		X	X	X		X	X	X
	Action 2d: Check solar orientation		X	X	X		X	X	X
	Action 2e: Check solar absorption		X	X	X		X	X	X
	Action 2f: Check energy efficiency systems					X	X	X	X

Table 16: Energy performance check (where 'Y' denotes yes, 'N' denotes no, and 'X' denotes action)

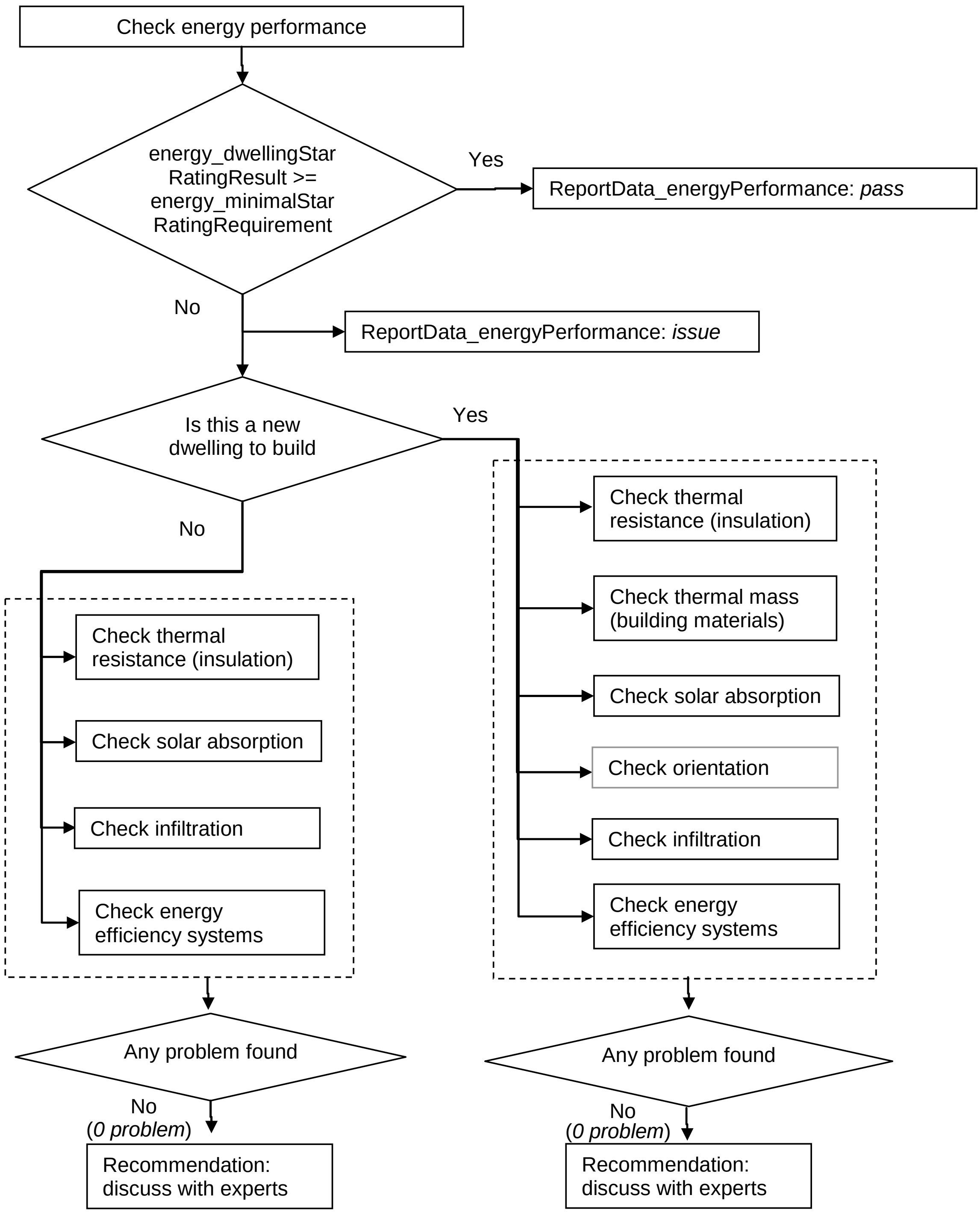


Figure 12 An implementation flow chat for energy performance diagnosis

3.5 Recommendations for Sustainability Improvement

The Sustainability Advisor will provide a report to house owners on what design issues are found and how sustainability performance can be improved if the building fails to satisfy the minimum requirements. The recommendations in the Sustainability Advisor incorporate: (1) recommendations corresponding to the specific issues found; and (2) references that will provide associated information which may not have been included in the existing AccuRate assessment. A priority ranking of the recommendations is provided to house owners.

Table 17 presents an example of building design issues associated with thermal resistance and thermal mass, as well as the recommendations and reference information on how to improve them. Table 18 and Table 19 present detailed insulation recommendation referred to within Table 17.

A screenshot of the Recommendation-Overview screen in the Sustainability Advisor is presented in Figure 13. On the left panel, it lists all building design issues found and a priority ranking of options suggested to house owners. Once an issue is selected, detailed recommendations and reference information will be displayed on the right panel. It will help house owners to make design choices in order to meet the sustainability performance target.

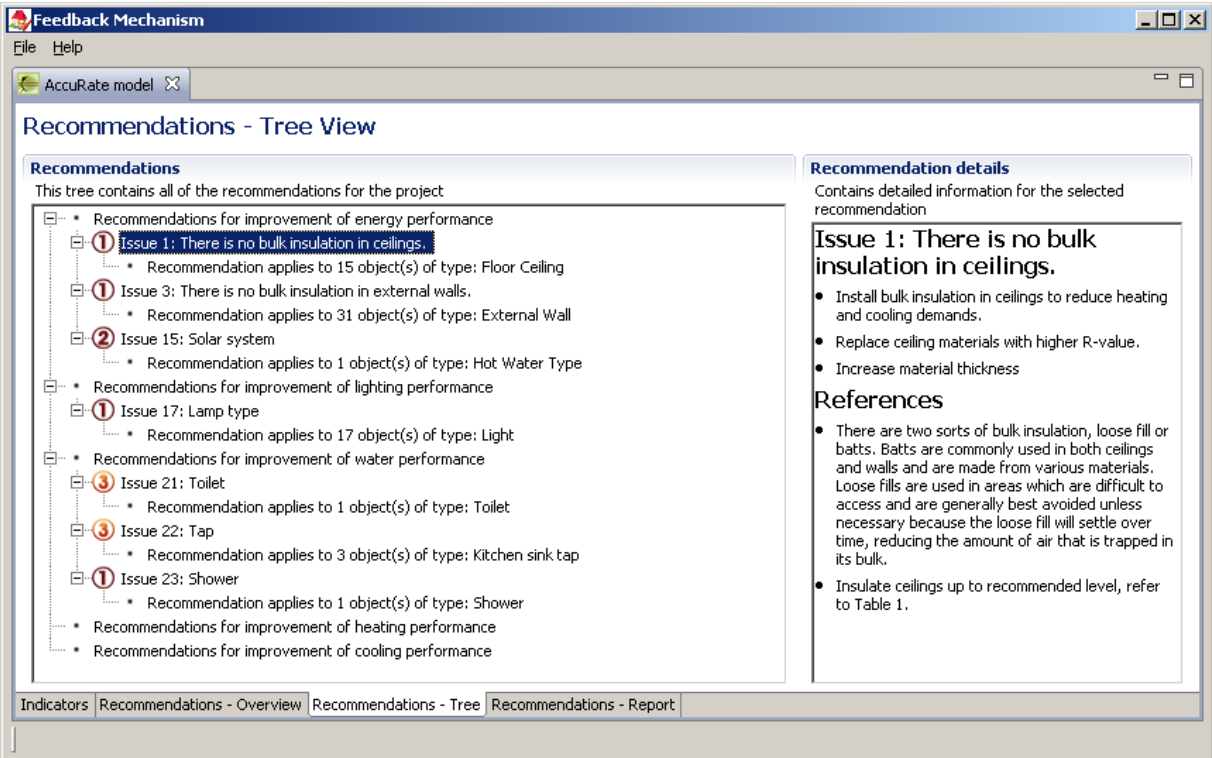


Figure 13 A screenshot of the recommendation page in the Sustainability Advisor

Index	Improvement Area	Issue Found	Recommendation for Improvement		Reference	Priority Ranking
1	Thermal resistance	There is no bulk insulation in ceilings.	*New dwelling*	Install bulk insulation in ceilings to reduce heating and cooling demands. Replace ceiling materials with higher R-value. Increase material thickness	There are two sorts of bulk insulation, loose fill or batts. Batts are commonly used in both ceilings and walls and are made from various materials. Loose fills are used in areas which are difficult to access and are generally best avoided unless necessary because the loose fill will settle over time, reducing the amount of air that is trapped in its bulk. Insulate ceilings up to recommended level, refer to Table 18	Priority for thermal improvement: **1**
			Existing dwelling	Install bulk insulation in ceilings to reduce heating and cooling demands.		
2	Thermal resistance	The R-value of insulation in ceilings does not satisfy the BCA minimum R-value requirement.	*New dwelling*	Replace insulation materials in ceilings with suitable R-value for the climate zone. The property climate zone is: *value* The R-value of ceiling insulation materials of the property is recommended to be greater than: *value* Increase thickness of ceiling materials.	In general, the higher the R -value, the better the thermal performance. In Australia, R ratings tend to fall between 'R 0' (no thermal performance) and 'R 5' (high thermal performance). 'Up' R values refer to resistance to heat flow upwards. 'Down' R values refer to resistance to heat flow downwards. Reference for roof insulation values is in Table 18.	Priority for thermal improvement: **2**
			Existing dwelling	Install bulk insulation with higher R-value in ceilings suitable for the climate zone. The property climate zone is: *value* The R-value of ceiling insulation materials of the property is recommended to be greater than: *value*		
3	Thermal resistance	There is no bulk insulation in external walls.	*New dwelling*	Install bulk insulation in external walls to reduce heat transfer. Replace external wall materials with higher R-value. Increase external wall material thickness.	There are two sorts of bulk insulation, loose fill or batts. Batts are commonly used in both ceilings and walls and are made from various materials. Loose fills are used in areas which are difficult to access and are generally best avoided unless necessary because the loose fill will settle over time, reducing the amount of air that is trapped in its bulk. Insulate external walls up to recommended level, refer to Table 19.	Priority for thermal improvement: **1**
			Existing dwelling	Install bulk insulation in external walls to reduce heat transfer.		

4	Thermal resistance	The R-value of insulation in external walls does not satisfy the BCA minimum R-value requirement.	*New dwelling*	Replace insulation materials in external walls with suitable R-value suitable for the climate zone. The property climate zone is: *value* The R-value of external wall insulation of the property is recommended to be greater than: *value* Increase thickness of external wall materials.	The higher the R rating is the better the thermal performance. In Australia, R ratings tend to fall between 'R 0' (no thermal performance) and 'R 5' (high thermal performance). 'Up' R values refer to resistance to heat flow upwards. 'Down' R values refer to resistance to heat flow downwards. Reference for wall insulation values is in Table 19.	Priority for thermal improvement: **2**
			Existing dwelling	Install bulk insulation with better R-value in external walls suitable to the climate zone. The property climate zone is: *value* The R-value of external wall insulation of the property is recommended to be greater than: *value*		
5	Thermal mass	The thermal mass of external wall materials does not satisfy the minimum thermal mass requirement	*New dwelling*	Improve the external wall construction thermal mass: 1 Increase thickness of external wall materials. 2. Replace external wall construction with high density materials. 3. Replace external wall construction with high Specific Heat Capability materials.	Increasing the thermal mass can store more heat in the structure, which is especially important during winter and summer. This becomes particular beneficial in regions where there is a big difference between day and night outdoor temperatures. The denser the material the higher its thermal mass. Concrete slabs, insulated brick walls, mud bricks, phase change materials, straw bales, water filled containers etc may be used to increase thermal mass.	Priority for thermal improvement: **3**
			Existing dwelling	None		
5.2	Thermal mass	The thermal mass of floor materials does not satisfy the minimum thermal mass requirement	*New dwelling*	Improve the floor construction thermal mass: 1 Increase thickness of floor materials. 2. Replace floor construction with high density materials. 3. Replace floor construction with high Specific Heat Capability materials.	Increasing the thermal mass can store more heat in the structure, which is especially important during winter and summer. This becomes particular beneficial in regions where there is a big difference between day and night outdoor temperatures. The denser the material the higher its thermal mass. Concrete slabs, insulated brick walls, mud bricks, phase change materials, straw bales, water filled containers etc may be used to increase thermal mass.	Priority for thermal improvement: **3**
			Existing dwelling			

Table 17: Examples of design issues found and associated recommendations and references

BCA Climate zone	1 to 3	4 and 5	6	7	8
Direction of heat flow	**down**	**up**	**up**	**up**	**up**
Added insulation recommended	R1.5	RFL plus R2.0 bulk	RFL plus R3.0 bulk	R4.0 bulk	R5.0 bulk
Inherent R-value of a tiled roof with a gypsum plasterboard ceiling and air gap 0.7	0.35	0.35	0.35	0.35	0.35
R-value for the effect of installing RFL (with air space values adjusted)	Not recommended	0.38	R0.38	Not recommended	Not recommended
R-value for the recommended insulation	1.5	2.38	3.38	4	5
Total caculated R-value	2.2	2.73	3.73	4.35	5.35
RFL = Reflective Foil Laminate					

Table 18: Ceiling or under roof insulation value (source: Home Greenhouse Audit Manual, AGO/DEWHA)

BCA Climate zone	1 to 3	4 to 7	8
Insulation recommended	RFL	R1.5 bulk	RFL plus R2.0 bulk
Inherent R-value of a brick veneer wall with a gypsum plasterboard lining and an air gap	0.46	0.46	0.46
R-value for the effect of the RFL and the additional air space	1.02	Not recommended	0.41 (assume 1 air space)
R-value for the recommended insulation	1.02	1.5	2.41
Total calculated R-value	1.48	1.96	2.87
Total R-value proposed	1.4	1.9	2.8
RFL = Reflective Foil Laminate			

Table 19: Wall insulation value (source: Home Greenhouse Audit Manual, AGO/DEWHA)

4. SOFTWARE IMPLEMENTATION

4.1 Interoperability between AccuRate and the Sustainability Advisor

The Sustainability Advisor provides additional functionality for AccuRate. It requires a common data model for sharing with AccuRate. An xml schema was defined to enable data sharing and interoperability between AccuRate and the Sustainability Advisor, Figure 14.

Prior to work commencing on the Sustainability Advisor, AccuRate has all project data in a closed, binary format that did not lend itself to interoperability. It was decided that an XML based persistence mechanism would be developed to output AccuRate project data into a more portable format.

The AccuRate Delphi Code was then modified to allow for published object properties to be read from and written to XML files in addition to the custom binary format previously used. The mechanism provided by Delphi for implementing this behaviour did not provide an XML Schema Definition (XSD) for describing the "vocabulary" of the XML files. Approximately 30 sample AccuRate project files were converted into XML, and an XSD was derived using the Trang utility. The XSD was then used to generate an Eclipse Modelling Framework model (EMF), which in turn was used to generate Java code for reading, writing and manipulating the AccuRate data, and also providing user interface building blocks, Figure 15.

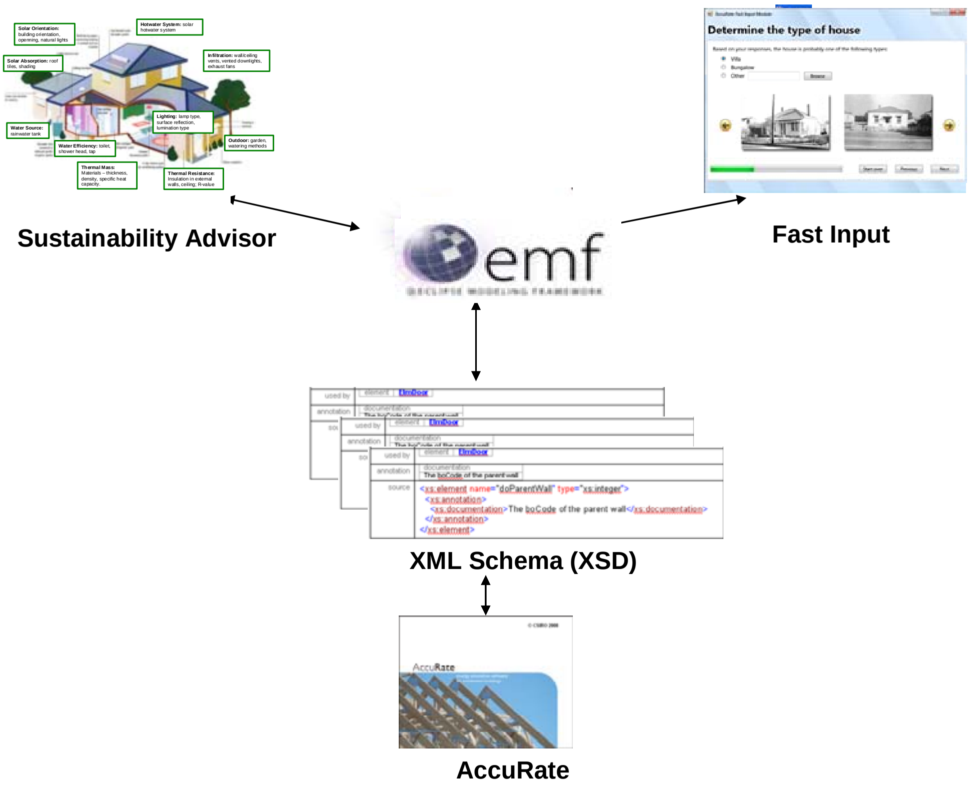


Figure 14 Illustration of the interoperability between AccuRate and the Sustainability Advisor, as well as Fast Input

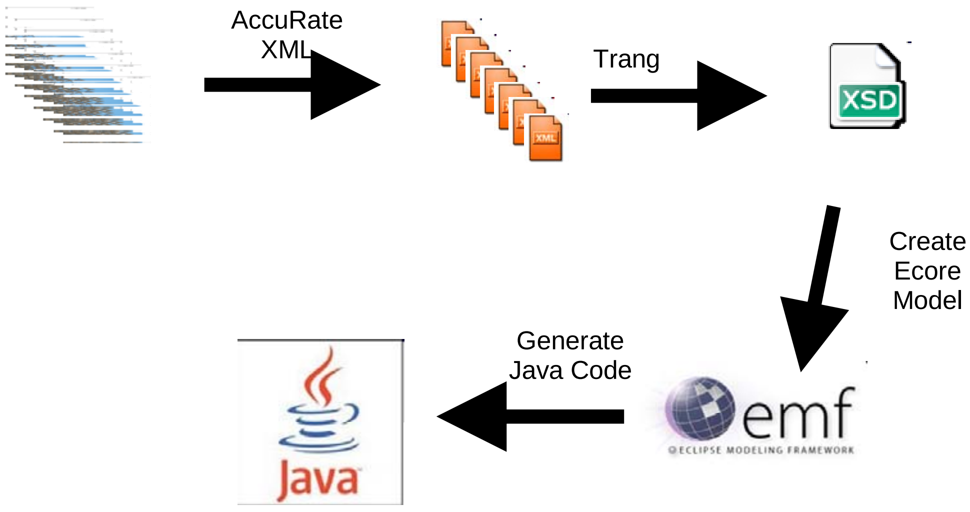


Figure 15 Illustration of the process of creating XML schema (XSD) and Java model from AccuRate project files.

Using the generated Java libraries, The Sustainability Advisor is able to read and write AccuRate project files in a portable format. These files can also be read by the XML enabled version of AccuRate, allowing for round tripping between AccuRate and the Sustainability Advisor applications.

4.2 User Interface

4.2.1 Start

The Sustainability Advisor runs from the AccuRate Sustainability Tool platform as shown in Figure 16.

On initial loading of AccuRate, the Sustainability Advisor icon is disabled. The icon is enabled only after a simulation is performed on the selected building design variation in AccuRate.

4.2.2 Indicators Screen

While the Sustainability Advisor is started, the *Indicators* screen is presented to the user to display the assessment outcomes from AccuRate, and allow users to input the minimal sustainability performance target, Figure 17.

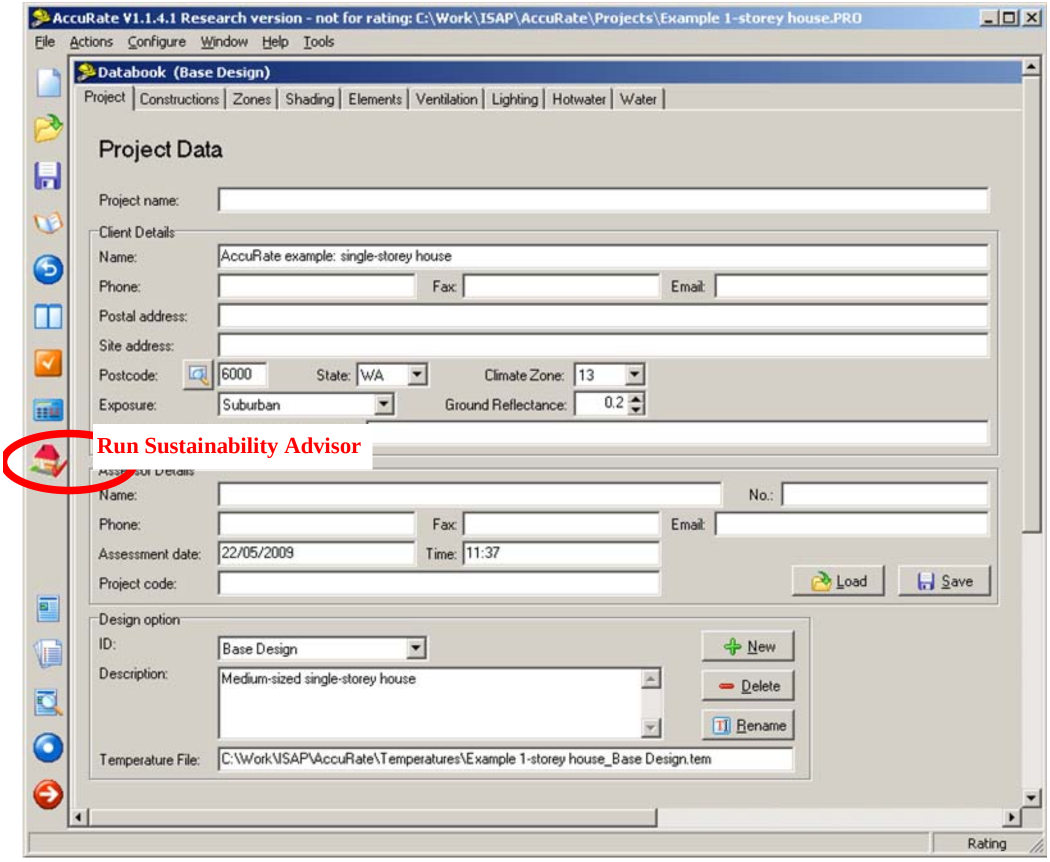


Figure 16 Run the Sustainability Advisor from AccuRate

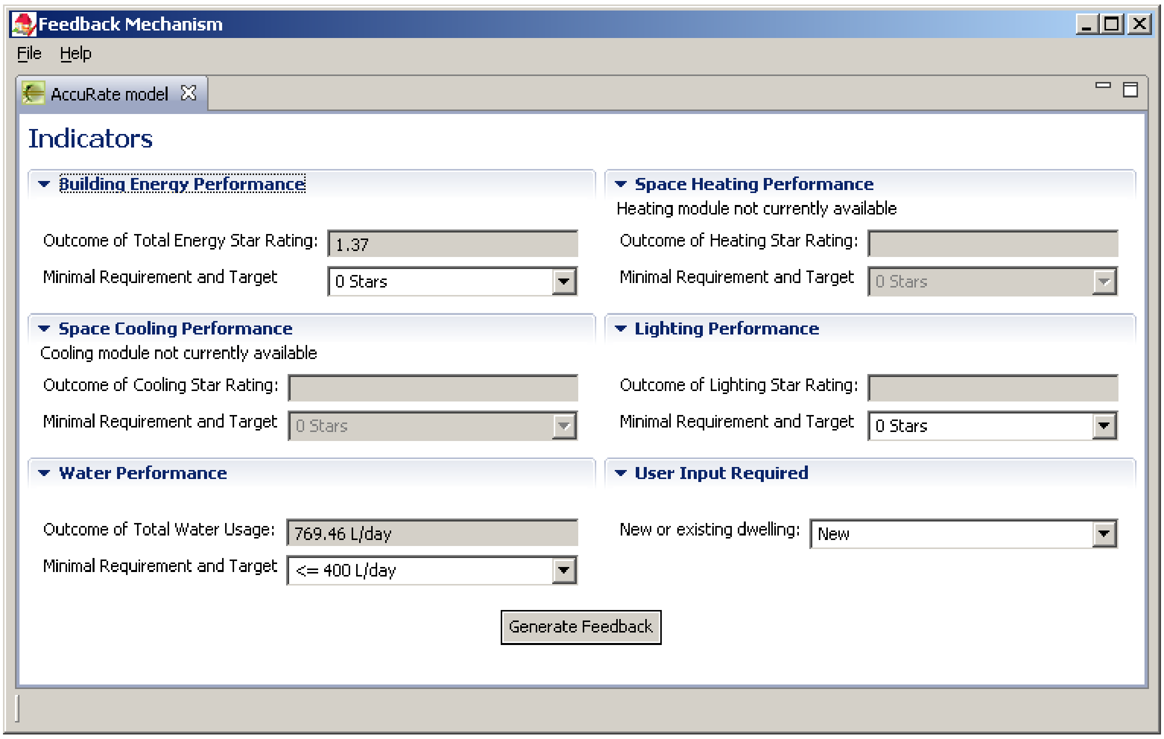


Figure 17 The *Indicators* screen

The "indicators display" displays performance requirements for:

- Building Energy
- Space Heating
- Space Cooling
- Lighting Performance
- Water Performance

The modules for Space Heating and Space Cooling are currently not enabled as separate modules for the application because the key design factors affecting the heating and cooling requirements are not differentiated in the current models. This will be explored further through the ongoing development of the AccuRate-related design models.

For each performance module, there is an assessment outcome from the results of the simulation within AccuRate, and a minimal requirement target that is specified by users.

Users are able to select the minimal requirement target for their building by selecting the drop-down box, and then selecting a target from different choices. An example of selecting a minimal requirement target under the Building Energy Performance is presented in Figure 18.

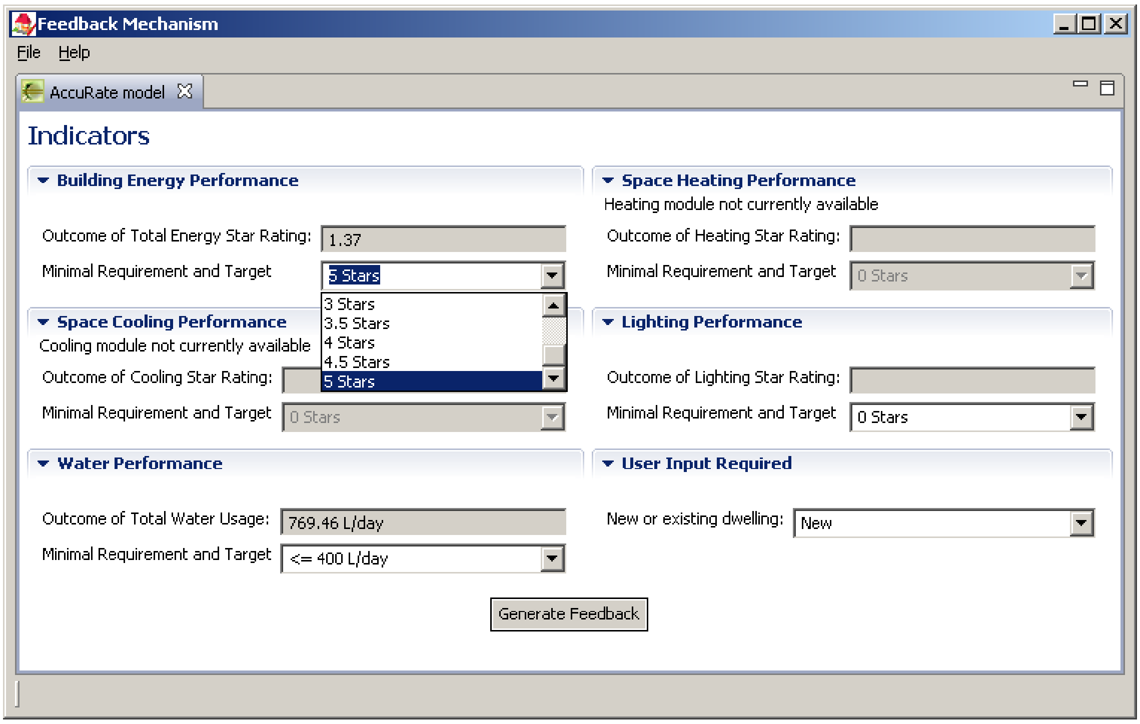


Figure 18 Example of selecting a minimal requirement target from the drop-down box

Once users have chosen all of the performance indicators, the condition of the building will need to be specified, namely, whether the building is a new building design or an existing building. Figure 18 show that the user specifies that this is a new building.

4.2.3 Recommendation-Overview Screen

When all data have been specified, users can press the **Generate Feedback** button to promote the *Recommendations-Overview* screen. The *Recommendations-Overview* screen displays the scenario where the building fails to meet the minimal requirement target. Failed areas are highlighted in red, Figure 19.

Users are able to click the hyperlink under each sustainability performance to view the design issues found and associated recommendations on the *Recommendation-Tree* screen.

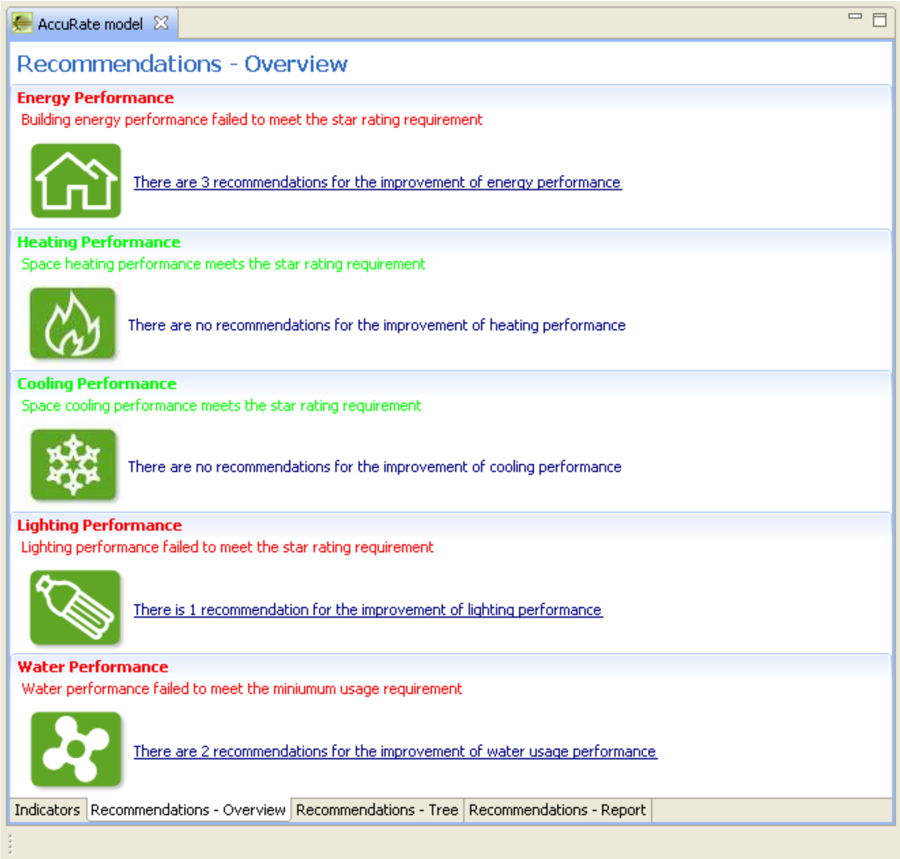


Figure 19 The *Recommendation-Overview* screen

4.2.4 Recommendation-Tree Screen

The *Recommendation-Tree* screen displays the following information:

- The issues found
- The recommendations for improvement
- Reference information
- Comments or alternatives

The tree structure on the left panel displays the list of issues found while the right panel displays the corresponding recommendations and reference information in details, Figure 20.

For each assessed area, the issues found and associated recommendations are ranked in terms of priority. For example, installation of bulk insulation in the ceiling or wall has higher priority compared to installing a solar system for hot water.

Users are able to apply the recommendations for a particular issue to directly perform design changes without having to return to AccuRate. It can be done by right clicking on the issue as shown in Figure 20. The design change function was implemented as a proof of concept demonstration only as it is not included in the exiting contract of work.

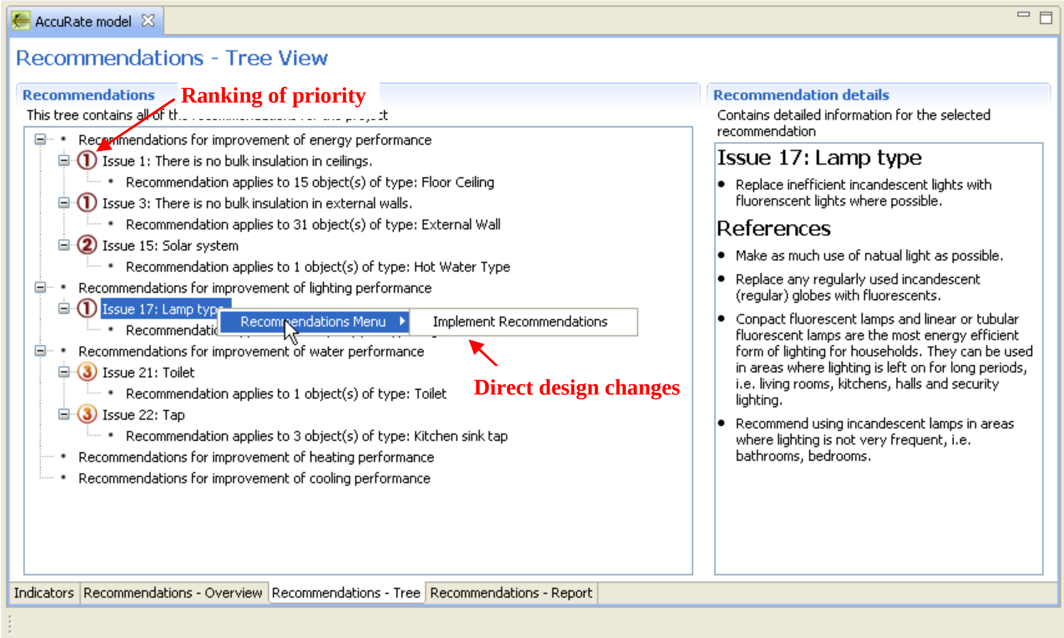


Figure 20 *The Recommendation-Tree* screen

4.2.5 Report

By clicking the *Recommendations-Report* button, users are able to view a printable report containing all of the issues and recommendations suggested for improvement for house owners. Figure 21 presents an example of the report.

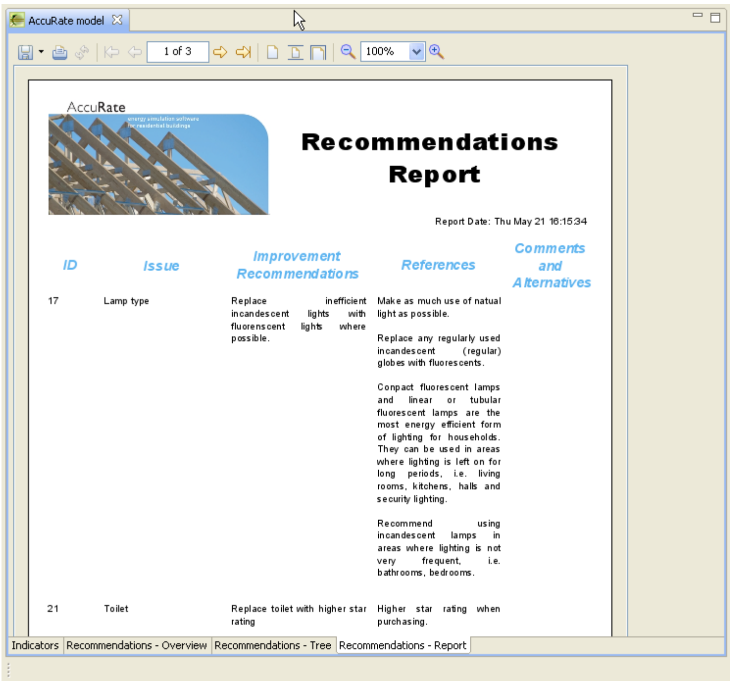


Figure 21 The *Recommendations-Report* page

5. TESTING AND FUTURE DEVELOPMENT

The Sustainability Advisor is a proof of concept tool. It has demonstrated an automated process of diagnosing building design problems using sustainability performance criteria. It provides recommendations on design options that will help house owners to improve the sustainability performance of their home.

The research team has tested the Sustainability Advisor with example building designs which failed to satisfy the proposed sustainability requirement. The results showed that the Sustainability Advisor can provide an important feedback component to the AccuRate sustainability tool and it is feasible to implement it in this way.

For the future development of the Sustainability Advisor, the following areas are suggested:

- Development of automated design changes according to the issues found.
- Incorporation of cost issues in the improvement recommendations of the Sustainability Advisor.
- Integration with 3D visualisation to allow the issues to be highlighted in the 3D building models. An example is shown in Figure 22.
- Providing product libraries for users to select alternatives (such as alternative materials, light fittings, sanitary fixtures and appliances) to test design choices against building sustainability requirements.

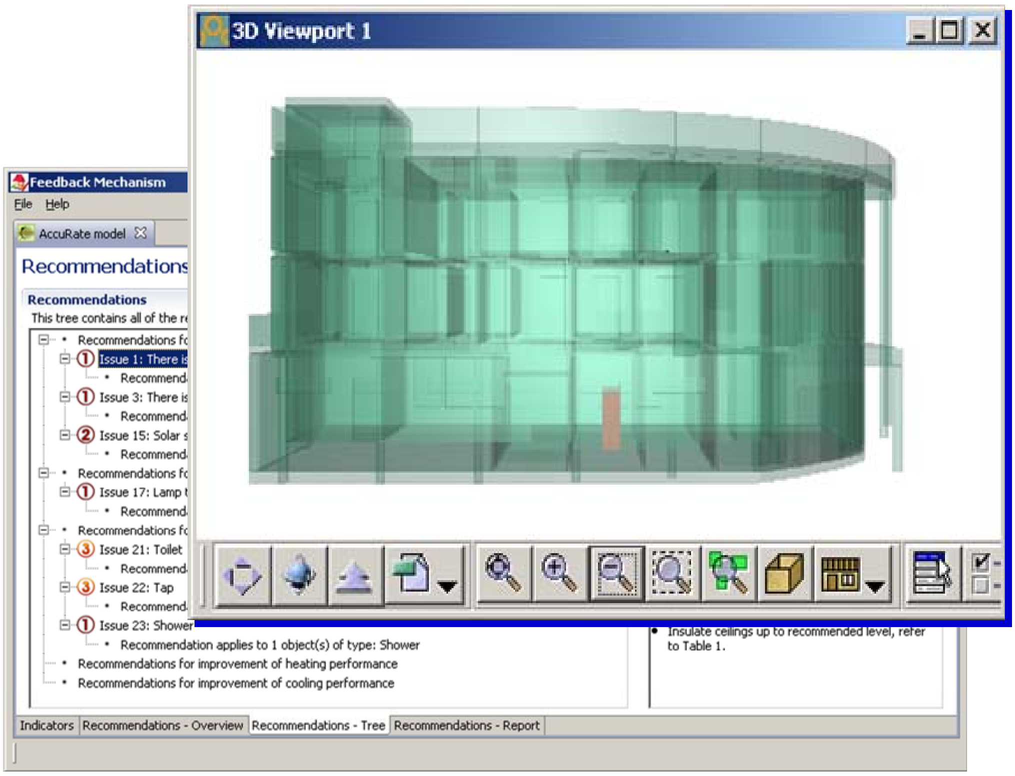


Figure 22 Example of highlighting a problem element in a 3D building

ACKNOWLEDGEMENTS

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APPENDIX A – DECISION TABLES

1a – Check Energy Performance										
		Rules								
Conditions	Outcome of total energy star rating >= minimal requirement	Y	Y	Y	Y	N	N	N	N
	Outcome of heating star rating >= minimal requirement	Y	Y	N	N	Y	Y	N	N
	Outcome of cooling star rating >= minimal requirement	Y	N	Y	N	Y	N	Y	N
Actions	Action 2a: Check thermal resistance (insulation)		X	X	X		X	X	X
	Action 2b: Check thermal mass (building materials)		X	X	X		X	X	X
	Action 2c: Check Infiltration		X	X	X		X	X	X
	Action 2d: Check solar orientation (optional)		X	X	X		X	X	X
	Action 2e: Check solar absorption		X	X	X		X	X	X
	Action 2f: Check energy efficiency systems					X	X	X	X

Note:
Y: Yes;
N: No;
X: Perform the action.

1b – Check Lighting Performance			
		Rules	
Conditions	Outcome of lighting star rating >= minimal requirement	Y	N
Actions	Action 2g - Check lighting system		X

1c – Check Water Performance			
		Rules	
Conditions	Outcome of water consumption (per person) meets state benchmark	Y	N
Actions	Action 2h: Check water system - rainwater tank		X
	Action 2i: Check water system - efficiency systems (toilet, tap, shower)		X
	Action 2j: Check water system – outdoor watering methods		X

2a – Check Thermal Resistance (Insulation)									
		Rules							
Conditions	Insulation in external walls and R-value	Y	Y	Y	Y	N	N	N	N
	Insulation in ceilings or roof ceilings and R-value	Y	Y	N	N	Y	Y	N	N
	Floor insulation and R-value	Y	N	Y	N	Y	N	Y	N
Actions	1: Output issue and recommendation – install insulation in external walls if not available Action 3a: Check insulation R-value in external walls if insulation is available					X	X	X	X
	2: Output issue and recommendation – install insulation in ceilings or roof ceilings if not available Action 3b: Check insulation R-value in ceilings or roof ceilings if insulation is available			X	X			X	X
	3: Output issue and recommendation – install floor insulation if not available Action 3a: Check floor insulation R-value if insulation is available		X		X		X		X

2c – Check Infiltration										
		Rules								
Conditions	Vents in walls or ceiling are not sealed	Y	Y	Y	Y	N	N	N	N
	Vented downlights are not sealed	Y	Y	N	N	Y	Y	N	N
	Exhaust fans are not sealed	Y	N	Y	N	Y	N	Y	N
Actions	1: Output issue and recommendation - infiltration – vents in walls or ceiling					X	X	X	X
	2: Output issue and recommendation - infiltration – vented downlights			X	X			X	X
	3: Output issue and recommendation – infiltration – exhaust fans		X		X		X		X

2e – Check Solar Absorption										
		Rules								
Conditions	Roof tiles have a light color	N	N	N	N	Y	Y	Y	Y
	Window glazing (U-value and SHGC) meet requirements	Y	Y	N	N	Y	Y	N	N
	Windows have shading	Y	N	Y	N	Y	N	Y	N
Actions	1: Output issue and recommendation – solar absorption – roof tiles color	X	X	X	X				
	2: Output issue and recommendation – solar absorption – window glazing			X	X			X	X
	3: Output issue and recommendation – solar absorption – window shading		X		X		X		X

2f – Check Energy Efficiency Systems									
		Rules							
Conditions	Hot water heating type is electricity	Y	Y	N	N				
	Has a solar system for hot water heating	Y	N	Y	N				
Actions	1: Output issue and recommendation – hot water heating type			X	X				
	3: Output issue and recommendation – install solar system for hot water heating		X		X				

2g – Check Lighting Systems									
		Rules							
Conditions	All surface reflection is light	Y	Y	Y	Y	N	N	N	N
	All lumination type is direct	Y	Y	N	N	Y	Y	N	N
	Lamp type	Y	N	Y	N	Y	N	Y	N
Actions	1: Output issue and recommendation - lighting - surface colour					X	X	X	X
	2: Output issue and recommendation - lighting - lumination type			X	X			X	X
	3: Output issue and recommendation - lighting - lamp type		X		X		X		X

2h– Check Water System – Rainwater Tank			
		Rules	
Conditions	Has rainwater tank	Y	N
Actions	1: Output issue and recommendation – rainwater tank		X

2i – Check Water System - Efficiency Systems									
		Rules							
Conditions	Toilet efficiency star rating >= minimal requirement	Y	Y	Y	Y	N	N	N	N
	Tap efficiency star rating >= minimal requirement	Y	Y	N	N	Y	Y	N	N
	Shower efficiency star rating >= minimal requirement	Y	N	Y	N	Y	N	Y	N
Actions	1: Output issue and recommendation – water efficiency systems – toilet type					X	X	X	X
	2: Output issue and recommendation – water efficiency systems – tap type			X	X			X	X
	3: Output issue and recommendation – water efficiency systems – shower type		X		X		X		X

3a – Check Insulation R-value in External Walls			
		Rules	
Conditions	R-value of insulation in external walls is suitable to the climate region	Y	N
Actions	1: Output issue and recommendation – R-value of insulation in externals walls		X

3b – Check Insulation R-value in Ceiling			
		Rules	
Conditions	R-value of insulation in ceiling is suitable to the climate region	Y	N
Actions	1: Output issue and recommendation - R-value of insulation in ceiling		X

3c – Check Insulation R-value in Underfloor			
		Rules	
Conditions	R-value of insulation in underfloor is suitable to the climate region	Y	N
Actions	1: Output issue and recommendation R-value of insulation in underfloor		X

APPENDIX B – RECOMMENDATION KNOWLEDGE

Index	Improvement Area	Issue Found	Recommendation for Improvement		Reference	Priority Ranking
1	Thermal resistance	There is no bulk insulation in ceilings.	*New dwelling*	Install bulk insulation in ceilings to reduce heating and cooling demands. Replace ceiling materials with higher R-value. Increase material thickness	There are two sorts of bulk insulation, loose fill or batts. Batts are commonly used in both ceilings and walls and are made from various materials. Loose fills are used in areas which are difficult to access and are generally best avoided unless necessary because the loose fill will settle over time, reducing the amount of air that is trapped in its bulk. Insulate ceilings up to recommended level, refer to Table 20.	Priority for thermal improvement: **1**
			Existing dwelling	Install bulk insulation in ceilings to reduce heating and cooling demands.		
2	Thermal resistance	The R-value of insulation in ceilings does not satisfy the BCA minimum R-value requirement.	*New dwelling*	Replace insulation materials in ceilings with suitable R-value for the climate zone. The property climate zone is: *value* The R-value of ceiling insulation materials of the property is recommended to be greater than: *value* Increase thickness of ceiling materials.	In general, the higher the R -value, the better the thermal performance. In Australia, R ratings tend to fall between 'R 0' (no thermal performance) and 'R 5' (high thermal performance). 'Up' R values refer to resistance to heat flow upwards. 'Down' R values refer to resistance to heat flow downwards. Reference for roof insulation values is in Table 20.	Priority for thermal improvement: **2**
			Existing dwelling	Install bulk insulation with higher R-value in ceilings suitable for the climate zone. The property climate zone is: *value* The R-value of ceiling insulation materials of the property is recommended to be greater than: *value*		

3	Thermal resistance	There is no bulk insulation in external walls.	*New dwelling*	Install bulk insulation in external walls to reduce heat transfer. Replace external wall materials with higher R-value. Increase external wall material thickness.	There are two sorts of bulk insulation, loose fill or batts. Batts are commonly used in both ceilings and walls and are made from various materials. Loose fills are used in areas which are difficult to access and are generally best avoided unless necessary because the loose fill will settle over time, reducing the amount of air that is trapped in its bulk. Insulate external walls up to recommended level, refer to Table 21.	Priority for thermal improvement: **1**
			Existing dwelling	Install bulk insulation in external walls to reduce heat transfer.		
4	Thermal resistance	The R-value of insulation in external walls does not satisfy the BCA minimum R-value requirement.	*New dwelling*	Replace insulation materials in external walls with suitable R-value suitable for the climate zone. The property climate zone is: *value* The R-value of external wall insulation of the property is recommended to be greater than: *value* Increase thickness of external wall materials.	The higher the R rating is the better the thermal performance. In Australia, R ratings tend to fall between 'R 0' (no thermal performance) and 'R 5' (high thermal performance). 'Up' R values refer to resistance to heat flow upwards. 'Down' R values refer to resistance to heat flow downwards. Reference for wall insulation values is in Table 21.	Priority for thermal improvement: **2**
			Existing dwelling	Install bulk insulation with better R-value in external walls suitable to the climate zone. The property climate zone is: *value* The R-value of external wall insulation of the property is recommended to be greater than: *value*		

5	Thermal mass	The thermal mass of external wall materials does not satisfy the minimum thermal mass requirement	*New dwelling*	Improve the external wall construction thermal mass: 1 Increase thickness of external wall materials. 2. Replace external wall construction with high density materials. 3. Replace external wall construction with high Specific Heat Capability materials.	Increasing the thermal mass can store more heat in the structure, which is especially important during winter and summer. This becomes particular beneficial in regions where there is a big difference between day and night outdoor temperatures. The denser the material the higher its thermal mass. Concrete slabs, insulated brick walls, mud bricks, phase change materials, straw bales, water filled containers etc may be used to increase thermal mass.	Priority for thermal improvement: **3**
			Existing dwelling	None		
5.2	Thermal mass	The thermal mass of floor materials does not satisfy the minimum thermal mass requirement	*New dwelling*	Improve the floor construction thermal mass: 1 Increase thickness of floor materials. 2. Replace floor construction with high density materials. 3. Replace floor construction with high Specific Heat Capability materials.	Increasing the thermal mass can store more heat in the structure, which is especially important during winter and summer. This becomes particular beneficial in regions where there is a big difference between day and night outdoor temperatures. The denser the material the higher its thermal mass. Concrete slabs, insulated brick walls, mud bricks, phase change materials, straw bales, water filled containers etc may be used to increase thermal mass.	Priority for thermal improvement: **3**
			Existing dwelling			

6	Solar absorption	Window glazing	*New dwelling*	Replace windows with better U-value and SHGC.	Windows selection is primarily based on U-value and SHGC. Recommend to select energy-efficient windows in the window library.	Priority for thermal improvement: **2**
			Existing dwelling	None		
7	Solar absorption	Window shading	*New dwelling*	Install shading to windows	Recommend external blinds, shade cloth and awnings on windows, especially those receive direct summer solar radiation. If in a hot climate, shading sections of the house can be done with plants as well as blinds awnings or shade cloth. If shading for passive cooling during summer, recommend the blinds to be flexible, or if fixed, recommend they are positioned so that they let in the maximum amount of winter sun.	Priority for thermal improvement: **4**
			Existing dwelling	Install shading to windows		
8	Solar absorption	Roof tile color	*New dwelling*	Replace roof tiles with light color	The lighter the roof, the greater the heat reflection.	Priority for thermal improvement: **6**
			Existing dwelling	None		
9	Infiltration	Vents in walls or ceilings are not sealed	*New dwelling*	Excessive vents in walls or ceilings may be removed	Excessive vents in walls or ceilings may result in high cooling and heating demands	Priority for thermal improvement: **5**
			Existing dwelling	Excessive vents in walls or ceilings should be sealed		
10	Infiltration	Vented downlights are not sealed	*New dwelling*	Unvented downlights may be used	Excessive vented downlights may result in high cooling and heating demands.	Priority for thermal improvement: **5**
			Existing dwelling	Vented downlights may be replaced with unvented downlights		

11	Infiltration	Exhaust fans are not sealed	*New dwelling*	Exhaust fans should be sealed		Priority for thermal improvement: **5**
			Existing dwelling	Exhaust fans should be sealed		
12	Energy efficiency systems	Air conditioning system	*New dwelling*	Replace air conditioning system with higher star rating	Select an energy efficient air conditioning system. Match the size of a heating or cooling unit to the area applicable, to achieve greatest efficiency and comfort. Use high efficiency (zoned) central system. Use an efficient portable heater for areas of the house which only need heating for very short period. Shade air-conditioner units to improve their efficiency, ensuring that ventilation of the air-conditioner unit is not compromised. Use fans instead of air conditioners where possible.	
			Existing dwelling	Replace air conditioning system with higher star rating		
13	Energy efficiency systems	Hot water heating type	*New dwelling*	Replace the electric storage water heater with an efficient hot water system.	Installing and using solar water over other types of systems can be an	Priority for hot-water system

			Existing dwelling	An electric storage water heater can indirectly produce as much carbon dioxide. Replace the electric storage water heater with an efficient hot water system.	efficient solution because solar systems harness energy from the sun. Install an Electric heat Pump. Heat pump-type hot water systems extract warmth from the air to heat water. These may be currently the most energy efficient type of eletric hot water system. Refurbish to a system with higher Star Rating.. Gas systems typically produce less greenhouse gas emissions and maybe chaper to operate than eletric systems. Install dedicated units. If different parts of your business require significantly different water temperature, it may be more efficient to install separate heaters for high temperature and low temperature areas. Choose the right size of unit. Relocate the water heater. Relocating the water heater as close as possible to the main point of use of the hot water may see significant efficiency saving by reducing heat loss from pipes and by minimising the length of hot water pipes that transport the water from the heater. Insulate the source. Insulate hot water storage tanks and shelter them from the weather. This may help reduce heat loss from the hot water system.	improvement: **1**
14	Energy efficiency	Solar system	*New dwelling*	Install a solar system for hot water heating	Although solar hot water systems are often expensive to purchase, they can	Priority for hot-water system

	systems		*Existing dwelling*	Install a solar system for hot water heating	reduce the running costs and environmental impacts because they utilize the free energy from the sun.	improvement: **2**
15	Lighting	Surface reflection	*New dwelling*	Replace room surface with light color		Priority for lighting system improvement: **3**
			Existing dwelling	Replace room surface with light color		
16	Lighting	Lamp type	*New dwelling*	Replace inefficient incandescent lights with fluorenscent lights where possible.	Make as much use of natual light as possible. Replace any regularly used incandescent (regular) globes with fluorescents. Conpact fluorescent lamps and linear or tubular fluorescent lamps are the most energy efficient form of lighting for households. They can be used in areas where lighting is left on for long periods, i.e. living rooms, kitchens, halls and security lighting. Recommend using incandescent lamps in areas where lighting is not very frequent, i.e. bathrooms, bedrooms.	Priority for lighting system improvement: **1**
			Existing dwelling	Replace inefficient incandescent lights with fluorenscent lights where possible.		
16.2	Lighting	Lumination type	*New dwelling*	Replace indirect lumination with efficient lumination design.	Recommend efficient illumination design and lighting systems.	Priority for lighting system improvement: **2**
			Existing dwelling	Replace indirect lumination with efficient lumination design.	Recommend efficient illumination design and lighting systems.	
17	Water	Water source	*New dwelling*	Install rainwater tank	Recommend reusing rainwater.	Priority for water system

			Existing dwelling	Install rainwater tank	Recommend recycling 'waste' water. Graywater from sinks and showers may be recycled into the garden use through a graywater system.	improvement: **2**
18	Water	Garden or lawn watering method	*New dwelling*	Install garden tap timers if manual sprinklers are installed.	Recommend a thick layer of munch on garden beds to minimise watering. Recommend indigenous species that don't require lots of water and have a higher chance of survival in your area.	Priority for water system improvement: **2**
			Existing dwelling	Install garden tap timers if manual sprinklers are installed.		
19	Water	Toilet	*New dwelling*	Replace toilet with higher star rating	Higher star rating when purchasing.	Priority for water system improvement: **3**
			Existing dwelling	Replace toilet with higher star rating		
20	Water	Tap	*New dwelling*	Replace tap with higher star rating	Higher star rating when purchasing. Ensure mixer taps are purched across the cold-water setting.	Priority for water system improvement: **3**
			Existing dwelling	Replace tap with higher star rating		
21	Water	Shower	*New dwelling*	Replace shower with higher star rating	3-Star rated shower heads can be used to the mains pressure systems, storage systems and gas instantaneous water heaters with temperature control. 3-Star related shower heads are not suitable to electric instantaneous systems.	Priority for water system improvement: **1**
			Existing dwelling	Replace shower with higher star rating		

BCA Climate zone	1 to 3	4 and 5	6	7	8
Direction of heat flow	**down**	**up**	**up**	**up**	**up**
Added insulation recommended	R1.5	RFL plus R2.0 bulk	RFL plus R3.0 bulk	R4.0 bulk	R5.0 bulk
Inherent R-value of a tiled roof with a gypsum plasterboard ceiling and air gap 0.7	0.35	0.35	0.35	0.35	0.35
R-value for the effect of installing RFL (with air space values adjusted)	Not recommended	0.38	R0.38	Not recommended	Not recommended
R-value for the recommended insulation	1.5	2.38	3.38	4	5
Total caculated R-value	2.2	2.73	3.73	4.35	5.35
RFL = Reflective Foil Laminate					

Table 20: Ceiling or under roof Insulation values (source: Home Greenhouse Audit Manual, AGO/DEWHA 2002)

BCA Climate zone	1 to 3	4 to 7	8
Insulation recommended	RFL	R1.5 bulk	RFL plus R2.0 bulk
Inherent R-value of a brick veneer wall with a gypsum plasterboard lining and an air gap	0.46	0.46	0.46
R-value for the effect of the RFL and the additional air space	1.02	Not recommended	0.41 (assume 1 air space)
R-value for the recommended insulation	1.02	1.5	2.41
Total calculated R-value	1.48	1.96	2.87
Total R-value proposed	1.4	1.9	2.8
RFL = Reflective Foil Laminate			

Table 21: Wall insulation values (source: Home Greenhouse Audit Manual, AGO/DEWHA 2002)

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