CHANGING CLIMATE: ERSATZ FUTURE WEATHER DATA FOR LIFELONG SYSTEM EVALUATION

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ABSTRACT

Buildings and their renewable energy systems typically operate for a lifecycle of well over 20 years. Due to this the climate that a new building or renewable energy system will experience, will change over their effective functional lifetime. It is therefore crucial that these buildings and systems are designed with due consideration of a changing climate (BRANZ, 2005).

This paper discusses how Ersatz Future Metrological Year (EFMY) climate files are created and used to more reliably predict future system responses in changed climates.

Using simulation software, comparison is made between the EFMY files representing a future climate and the current weather files to ascertain any costs and benefits that they present.

CREATION OF CLIMATE DATA

The EFMY files are created using rates of climate change over a 1990 baseline (reflecting the weather over the past 40 years). Using up to 20 global climate change models, based on various carbon emission scenarios, the CSIRO provides coincident Projected Change Values (PCVs) for the maximum, mean and minimum temperatures, relative humidity, wind speed and solar radiation (CSIRO, 2010). EFMYs are created from the nominal 1990 Reference Meteorological Years (RMYs) by the hourly-interpolated application of the PCVs.

These future climate estimates are used to simulate the effects of future climate change on the energy consumption and plant sizing of buildings. Similar simulations are also carried out to assess the future impacts on the performance of solar water heaters and building integrated photovoltaics.

Rate of Climate Change Experienced to the Present

Historically, all Reference Meteorological Years (RMYs) created for the Australian Climate Data Bank (ACDB) have until now been based on an implicit assumption that climates are moreorless constant loosely based around the 11 year sunspot cycle. Accordingly, past work in this field has selected real years (initially, in the mid-1980s, called Test Reference Years, (TRYs) and later selected concatenated real months for the RMYs (e.g. Morrison and Litvac, 1999) selected for their closeness to the long term climatic mean (most recently over 41 years – 1967 to 2007). As a result the one year RMY files contain a set of 12 real months taken from the 41 year ACDB set that are chosen to be typical based upon the long term climatic mean (Energy Partners, 2008).

A corollary of this methodology is that the RMYs generated on the constant climate assumption are growing more distant from the current climate with each successive update – we are adding precision by adding later years but our precise results are growing less indicative intrinsically in the same process.

Setting aside that assumption, analysis of the climatic change experienced thus far can be established through comparison of the first decade in the ACDB data sets (1967-1976) and the most recent decade in the ACDB data sets (1998-2007) using annual average hourly values for the following climatic conditions.

- Temperature (°C)
- Relative humidity (%)
- Wind speed (m/s)
- Global solar radiation on the horizontal plane (W/m^2)

The resulting changes (over 31 years between the midpoints of the two decades) were then scaled to “an equivalent change per decade”. Many ACDB sites are not suited for this analysis because of changes in location of the measurement site or because data was not collected for the first decade. Accordingly, a second measure of the rate of changes has been incorporated: a 'line of best fit’ was inserted into the graphs of the available data and the gradient of the trendline calculated for selected locations.

To deal with this issue, and at the same time remove the small discrepancy of the current RMYs centring on 1987 instead of the WMO and IPCC standard of 1990, it is proposed that revised RMYs be developed from the available data 1970 to 2009 inclusive (ignoring the first three years of data already available to us).

Alternative Methodologies

The RMY production process, for each month, selects the closest month to the target parameters [temperature (mean, minimum and maximum), moisture (absolute or relative humidity), wind speed and solar radiation] based on weighted values for these criteria. This process is used for each month and concatenated into a full year with the ends of the months smoothed for physical consistency.

Methods for generating EFMYs have been described earlier (Lee and Ferrari, 2006, 2008). Two processes for changing the RMY to suit future climates defined by suites of Projected Change Values (PCVs) were identified. Software calculations and formula of future climate temperature data using the PCVs are specified below:

Adjusting Temperatures:
Adjust Temp using "monthly PCVs" for MaxTemp and MinTemp and also using "seasonal converted to monthly PCVs" for MeanTemp:
1. For each day, max and min hourly temp values are identified.

2. For each day, mean hourly temp value is calculated (mean of the max and the min, as per BOM standard).

3. The 24 hourly AirTemp values for that day are then adjusted as follows:
Let PCV_MaxTemp be the PCV for MaxTemp for the calendar month concerned.
Let PCV_MinTemp be the PCV for MinTemp for the calendar month concerned.
Let PCV_MeanTemp be the PCV for MeanTemp for the calendar month concerned (as converted from the seasonal value).
For TMax the max hourly temp for the day, adjustment is done using PCV = PCV_MaxTemp.
For TMin the min hourly temp for the day, adjustment is done using PCV = PCV_MinTemp.
Should any hourly value coincide with the calculated value for TMean, the mean hourly temp for the day, adjustment is done using PCV = PCV_MeanTemp.
For "in between" hourly temps, a linear interpolation is made for the relevant PCV.

Synthetic EFMYs

The EFMYs could be based on current RMYs with hourly values "adjusted" in line with CSIRO supplied projected change values (CSIRO, 2010). These could be called "Synthetic EFMYs" made by perturbing values in current RMYs. This is the technique used by Energy Partners when only independent change ranges were available for the four elements from CSIRO (BRANZ, 2005). Since then it has been enhanced by incorporating a clear sky algorithm (ASHRAE, 2009) to concentrate the effect of the PCVs in times of cloud or haze to avoid generating unrealistically high irradiation values.

Realistic EFMYs

Alternatively, EFMYs could be selected from real months, similarly to the RMY production process, but with the "target values" adjusted from the mean temperature (or other parameter) in line with CSIRO supplied projected change values to a "new mean". These could be called "Realistic EFMYs" made from real past months.

The latter methodology was initially preferred for the reason that the "Realistic EFMYs" use months that have actually occurred and therefore are inherently more plausible than the "Synthetic EFMYs". Accordingly a third methodology was also proposed.

Combined Synthetic + Realistic EFMYs

Selection criteria can be agreed and encoded such that the software will preferentially select a real month whenever the criteria are met and otherwise it will take the previous Reference Meteorological Month (RMM) and adjust each hourly value by the CSIRO increment. The process is flagged by the year date in the ACDB file that will be either historic ('70 to '07) or synthetic ('30 or '50). Initial tests were done using an 80%ile criterion where the target values must all fall between the 20%ile and 80%ile values for each month with trials with wider criteria if that results in many synthetic months.

Although the first alternative had the perceived advantage of comprising only weather that has actually happened in that location, it had to be set aside as the technique produced data sets that:

- Were poor fits to the projections;
- Included changes for individual elements which contradicted the projections; and
- Were not credibly different for the six projections (suites of PCVs).

Accordingly, we proceeded with the second alternative: the fully "synthetic" adjusted RMYs.

BUILDING ENERGY SIMULATIONS USING FUTURE CLIMATE DATA

The resultant EFMYs were used in common simulation software packages for residential and office energy performance prediction to represent the range of impacts to be expected in the populated areas of Australia.

Simulations for three emissions scenarios (A1B, B1 and A1Fi) using the INM-CM3.0 and CSIRO-MK3.5

models were performed. The results were then compared with the base case, 1990-RMY, to estimate the impact of the combined scenarios and models on the energy consumption.

RESULTS

Projected changes in future climate

Collection of the outcomes of the models has resulted in two "stories" for each climate era (2030 or 2050) and emission scenario (A1B, B1 and A1Fi). Selection of the global climate models to use for this process was restricted by two factors. Firstly only those models that encompass all four variables needed for this analysis (temperature, humidity, wind speed and solar radiation) could be chosen. Secondly, it is desirable for the same models to be consistent through all locations and eras. From CSIRO's analysis of these results it was found that INM-CM3.0 was an acceptable choice for "most likely" and CSIRO-Mk3.5, which has been tuned to Australian, Southern Hemisphere, conditions more so than the northern hemisphere alternatives, was found to be the "worst case" model. While the term "worst case" is readily understood as being the greatest change to the climate system, because this can result in reductions in energy consumption in cool climates, we have adopted the term "warmest case" to avoid any ambiguity.

Table 2 shows an example of the seasonal changes of mean surface temperature and mean relative humidity that are forecast to occur for Moorabbin (eastern suburban Melbourne) in 2030 and 2050 based upon the selected emission scenarios.

Further to this, monthly changes for maximum and minimum temperature for each location are incorporated into the weather files and an example of this can be seen in Table 3. In this table, models INM-CM3.0 and CSIRO-Mk3.5 correspond to most likely and warmest case as previously stated.

The full details are to be found in the report (CSIRO, 2010) accessible on the exemplary.com.au website. (An update of this work is currently being prepared by CSIRO and should be available for incorporation in results presented at the conference itself.)

ENERGY CONSUMPTION IMPACT ON SAMPLE BUILDINGS

Impact on Dwellings

AccuRate has been used to produce "energy ratings" for a range of nominally 5 star houses whose characteristics are listed in Table 1. This CSIRO software generates these ratings using hour-by-hour simulation of the building envelope but not its services. These ratings establish the total amount of energy added or extracted to keep the building comfortable over a year and compare that with previously determined values to give a rating in stars (with 10 stars indicating that no energy is required for heating and sensible cooling). This calcualted sum is referred to as the energy "demand" to distinguish it from the "consumption" which is the energy bought to achieve that end. In such a case, the presented values correspond to the total yearlong demand in MJ/m^2 and are summarised in Figure 1. These values do not take any account of the efficiency of the heater and cooler which, in the case of air conditioners and heat pumps, is dependent on the temperature of the ambient air as well as on the inherent properties of the appliance. Similarly, the efficiency of the ducting system will be affected by the temperatures in the roof that are a function of ambient temperature, wind speed and solar radiation. Accordingly, the impacts on metered energy consumptions will be greater than indicated by analysis of the simulated demand of the building envelope alone.

Analysis of the hour-by-hour simulation results can also show the peak rate of consumption consumption in mega joules (MJ) for the entire year. These sensible and latent cooling peak values correspond to the non-start-up hour of the year where the rate of total cooling (sensible plus latent) energy consumption was the highest and is expressed as the energy demand for that hour (MJ/h). Thus, the peak energy consumption for total cooling in the 1990-RMY does not necessarily correspond to the same hour in all the scenarios and, hence, the split among sensible and latent load contributions will vary according to the month in which the peak occurs as well as according to the relative sizes of the temperature and humidity PCVs[1]. The direct solar energy will be high in all cases of peak cooling load and absent for the peak heating load and hence this result is insensitive to the solar PCV. This focus on the actual non-start-up peak can result in significant differences when comparing the cooling peak energy consumption of a particular projection with the base case.

[1] Because the energy demands in the start-up hours (7:00 am for living areas, 3:00 pm for sleeping areas) are strongly influenced by the thermal mass of the house as well as the equilibrium load at that time, those results are set aside as not being indicative of the appliance size (power) needed for conditioning the house. Rather than purchase much larger appliances, real households would simply accept a delay in getting to comfort or use timers or remote controls to energise the appliance earlier.

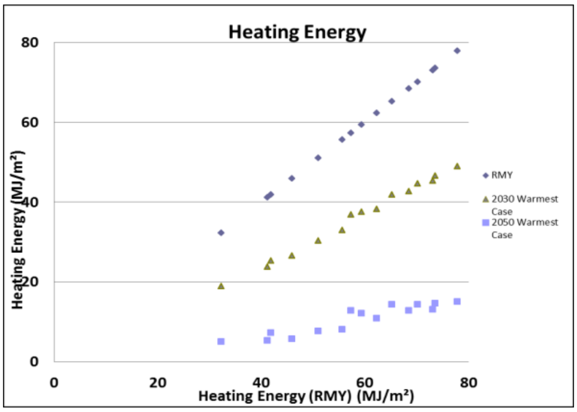

Figure 1 Heating Energy of Dwelling (EFMYs & RMY)

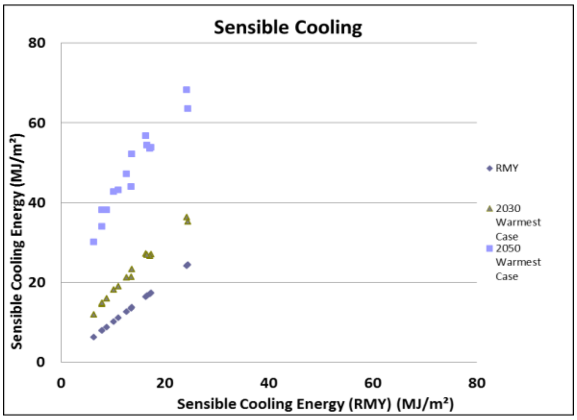

Figure 2 Sensible Cooling Energy of Dwelling (EFMYs & RMY)

Impact on Offices

To assess plant and building energy consumption a comparison is made between the end uses of a 3-storey office building in Adelaide. Here an RMY file used for BCA 2010 regulations is compared against a predicted warmest case weather file for 2030 and 2050. For the purpose of this exercise the 3-storey office model was kept constant.

In Table 4 and Table 5 the base case is presented in the leftmost column, showing the demand and peak consumption in Megajoules (MJ) for the entire year. The peak loads are established by application of the software's auto-sizing routine and, as metered power into the plant, are taken as an indicator of the costs of plant associated with designing HVAC to meet the rigours of the projected future climates. Unlike the residential results, the energy values tabulated here are metered energy values and hence related directly to energy costs. Gas heating metered energy / power has been converted to kWh / W for easy comparison with the other services.

The monthly peak loads, indicative of the cost impacts in the case of a time-of-use demand tariff, are plotted in Figure 3 with the addition of data for Real Time Year (RTY) 2010 as an indicator of inter year variations which underlie the longer term trends. The impact on monthly energy consumption is shown in Figure 4 to illustrate the relative impacts on the heating and cooling demands over the seasons.

As the model buildings include air cooled HVAC, no account is taken of the impact of humidity changes on the HVAC efficiency in its cooling mode for larger buildings where cooling towers are commonly employed.

CONCLUSIONS

Substantial differences are apparent between the Most Likely and the Warmest cases of the projections for both emissions scenarios, indicating wide bands of uncertainty of the impacts on climate of current and projected emissions trends.

Analysis of the existing 44 years of processed weather data from 1967 to 2010 shows evidence of changing (and generally warming) climates although these are not always consistent and often are obscured or exaggerated by the vicissitudes of instrument maintenance and inherent error. Interestingly, the historic trends also show large increases in wind speed for nearly all sites.

Within individual months, the correlations between the four weather elements is often contrary to the projected long term relative shifts between them such that it is generally not possible to select historic months which are indicative of projected future climates in those same calendar months.

While some building energy consumption benefit is established for cool climates, significant energy and HVAC capacity cost is projected to impact on mild and hot climates. Even for cool climates, the lower cost of heating capacity relative to cooling capacity means that significant increases in HVAC costs will apply in those climates too.

The impact on housing energy consumption is substantially greater due to the longer conditioned hours of dwellings. Additionally, the metered energy of offices includes major consumption end uses which are unaffected by climate and damp the apparent impact of a changed climate.

Substantial changes in projected peak loads indicate that provision for future climates should be an integral part of HVAC design processes which are still using "design conditions" established over three decades ago. Similarly, future energy efficiency provisions in the BCA should take account of likely climates in which the proposed buildings will serve. In the first instance, this could be applied in JV3 by requiring that the proposed building not exceed the simulated energy consumption of the Reference Building in either the current or the projected future climate conditions.

The largest percentage changes occur in the mild climates where currently-low space conditioning energy consumptions increase significantly.

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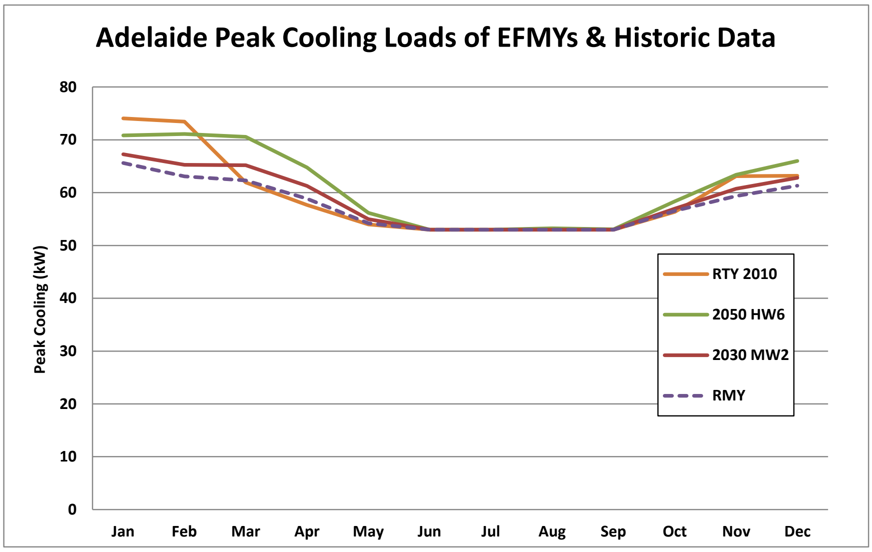

Figure 3 Adelaide Peak Cooling Load Analysis of EFMYs

Table 1
Baseline Constructions and insulations to achieve 6 stars rating

		BCA Climate Zone				
		1	2	5	6	7
		Townsville	Brisbane	Sydney[2]	Melbourne	Canberra
Floor	Finishing	Bare Concrete		Carpet	Bare Concrete	
	Construction and Insulation	Concrete Slab on Ground (CSOG) with no insulation				
Roof and Ceiling	Roof upper surface solar absorptance	0.5				
	Insulation R-value	3.0	2.0	4.0	5.0	6.0
	Emittance of Reflective Foil	0.2 outer 0.05 inner	NA	NA	0.2 outer 0.05 inner	0.2 outer 0.05 inner
External Wall	Insulation R-value	2.5	2.5	2.5	2.5	2.5
Internal Wall	Insulation R-value	NA	NA	NA	2.0	2.0
Fenestration	Glazing	Clear Single Glazing				Single / Double Glaze Clear Glass
	Frame	Aluminium			Improved Aluminium	
	Total U-Value (W/m^2K)	7.32			6.35	(Single) 6.35 (Double) 3.95
	SHGC	0.77			0.77	(Single)0.77 / (Double)0.68
Adjusted Energy (MJ/m^2)		117.8	41.1	37.9	113.3	163.9
Star Rating		6.4	6.2	6.1	6	6

Table 2
Seasonal predicted temperature and humidity changes (example for Moorabbin, Victoria)

CHANGE IN 2030 (A1B) WITH RESPECT TO 1990									
STORY	**MODEL**	**MEAN RELATIVE HUMIDITY (CHANGE % OF ORIGINAL %)**				**MEAN SURFACE TEMPERATURE (CHANGE °C)**			
		DJF	**MAM**	**JJA**	**SON**	**DJF**	**MAM**	**JJA**	**SON**
Most likely (20 models)	INM-CM3.0	-1.08	-0.45	-0.64	-3.1	0.96	0.78	0.69	0.7
Warmest case (2 models)	CSIRO-Mk3.5	-1.68	-2.02	-2.99	-5.26	1.21	1.27	1	1.22
CHANGE IN 2050 (B1) WITH RESPECT TO 1990									
Most likely (18 models)	INM-CM3.0	-0.85	-0.35	-0.51	-2.43	0.76	0.61	0.55	0.55
Warmest case (1 model)	CSIRO-Mk3.5	-1.32	-1.59	-2.35	-4.13	0.95	1	0.79	0.96
CHANGE IN 2050 (A1FI) WITH RESPECT TO 1990									
Most likely (9 models)	INM-CM3.0	-3.1	-1.28	-1.84	-8.84	2.75	2.23	1.98	2.01
Warmest case (1 model)	CSIRO-Mk3.5	-4.81	-5.76	-8.55	-15.02	3.46	3.62	2.86	3.49

[2] NSW is unique in not requiring any particular star rating, but instead requiring simulated consumption of Cooling and Heating to separately fall below an upper limit. Generally these limits (called heating and cooling caps) equate to around 5 stars. Retention of the 6 star criterion for Sydney allows the work to remain valid for Adelaide and Perth as well.

Table 3
Monthly-predicted changes in mean maximum temperature (change °C) relative to 1990 for 2030 A1B

MODEL	SITE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
INM-CM3.0	Brisbane	0.54	0.71	0.88	0.68	0.69	0.69	0.66	0.87	0.70	1.05	0.75	0.67
	Melbourne	0.82	0.94	0.72	0.77	0.71	0.68	0.69	0.70	0.77	0.81	0.89	0.70
	Sydney	0.85	0.96	0.89	0.85	0.81	0.77	0.75	0.90	0.90	1.16	1.17	0.90
CSIRO-Mk3.5	Brisbane	1.20	1.33	1.34	1.38	1.41	1.22	1.23	1.34	1.19	1.31	1.38	1.36
	Melbourne	1.20	1.46	1.41	1.51	1.37	1.13	1.18	1.29	1.47	1.55	1.49	1.43
	Sydney	1.44	1.20	1.48	1.55	1.56	1.31	1.34	1.52	1.61	1.53	1.48	1.45

Table 4
Indicative Changes in Office Energy Consumptions

	CZ5 Adelaide		
Annual Energy (MJ/m²)	**RMY**	**2030MW2**	**2050HW6**
Heating (Gas or Elec. Equiv.)	115	100	76
Cooling	306	307	310
Interior Lighting	115	115	115
Exterior Lighting	0	0	0
Interior Equipment	171	171	171
Exterior Equipment	0	0	0
Fans	129	135	146
Pumps	57	59	41
Heat Rejection	0	0	0
Humidification	0	0	0
Heat/Coolth Recovery	0	0	0
Hot Water	19	19	19
Carpark	0	0	0
Lifts	12	12	12
Total (Excl. Int. Equip.)	753	746	717
Total (Whole Building)	924	917	888

The simulation has been completed without an economy cycle for the 3-Storey Office as it was not common for a small sized building.

Table 5
Indicative Changes in Cooling Peak Load and Total Peak Load

	RMY		2030MW2		2050HW6	
Peak Load [kVA]	Cooling	Total	Cooling	Total	Cooling	Total
Month						
Jan	65.6	137.5	67.3	140.4	70.8	142.3
Feb	63.1	134.0	65.3	137.5	71.1	142.0
Mar	62.3	133.3	65.2	137.7	70.6	141.8
Apr	58.9	129.4	61.3	133.2	64.8	135.3
May	54.2	125.5	55.0	127.7	56.2	127.0
Jun	53.0	125.2	53.0	126.5	53.0	124.9
Jul	53.0	125.2	53.0	126.5	53.0	124.9
Aug	53.0	125.2	53.0	126.5	53.2	125.2
Sep	53.0	125.2	53.0	126.5	53.0	124.9
Oct	56.5	127.3	57.0	128.8	58.4	127.6
Nov	59.4	129.6	60.8	132.3	63.4	133.4
Dec	61.3	132.1	62.8	134.9	66.0	136.7
Maximum	65.6	137.5	67.3	140.4	71.1	142.3
Average	57.8	129.1	58.9	131.5	61.1	132.2

The months with maximum peak load are highlighted in pink in the above table. The maximum peak load increases as we move from the RMY to 2030 and 2050 scenarios , with maximum cooling peak load of 71 kVA and total peak load around 142 kVA in the 2050 warmest case.

The average cooling peak load increases by 1.9% in 2030 and 5.8 % in 2050. The average total peak load in 2030 is predicted to increase by 1.9% and there is an increase by 2.4% in 2050.

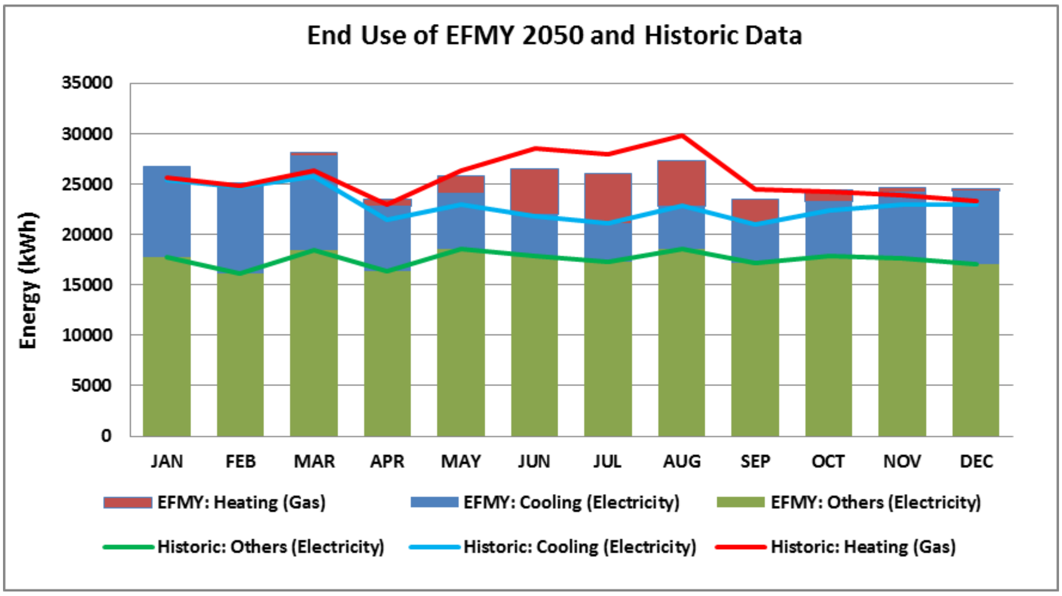

Figure 4 End use energy consumptions of EFMY 2050 compared with the historical RMY