A Case study on the Thermal Comfort of Social Housing in Suffollk Following an Air Source Heat Pump Retrofit

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Abstract
This case study presents the analysis of thermal comfort in fifteen social housing properties across Suffolk following the refurbishment of electric storage heaters with an air source heat pump with wet radiators.

Temperature and relative humidity were monitored at twenty minutes intervals between June 2012 to April 2013.

The average temperatures during monitoring period ranged from 15.3 degrees to 23.8 degrees. While the average relative humidity ranged from 41% to 66.4%. The results presented in this case study show that the use of air source heat pumps to provide space heating and domestic hot water can be easily influenced by factors, such as the building fabric conditions, airtightness, installation and commissioning of equipment and human behavior to be able to deliver thermal comfort.

Keywords Temperature, relative humidity, refurbishment, air source heat pump

1.0 Introduction
This paper presents the case study analysis of temperature and its relation to thermal comfort in fifteen social housing properties across Suffolk following the refurbishment of electric storage heaters with an air source heat pump with wet radiators. The retrofitting was funded by the Renewable Heat Premium Payment scheme and only covered the described retrofit but no upgrade to the building fabric and/or airtightness.

With the domestic sector accounting for 27.7% of the total energy consumption in the United Kingdom for the year 2016 (1), the potential and interest in refurbishing domestic properties has always been high on the agenda. Adding to the argument that at European level, buildings contributed 40% of the total energy consumption, generating 36% of the total CO2 emissions in the EU (2).

The United Kingdom agreed a reduction target to lower CO_2 emission levels by 20% across the EU by 2020 and 80% by 2050 (3). To achieve these targets, efficiency and low carbon technologies, such as air source heat pumps, have been deployed in retrofitting projects and energy and indoor air quality monitoring must be part of the strategy as it provides the collection and analysis of energy performance assumptions in the properties (4).

2.0 Research Methods

Fifteen social housing properties across Suffolk were monitored for internal temperature and relative humidity following the installation of wet radiators and an air source heat pump to provide space heating and domestic hot water for the properties. The properties were situated in locations off the main gas grid, so the space heating was provided by electric storage heaters combined with a night rate electricity tariff. The properties were only monitored after the retrofitting process, so no data of temperature and humidity pre retrofit is available and this is acknowledge as a limitation of the potential of this case study. Furthermore, the research did not have access to temperature set points for the heat pumps or any installation details. Regarding hours of operation for the heat pumps, all tenants were advise to use the wall thermostat to switch on and off the heat pumps, resulting on issues of trying to run a heat pump as a boiler.

A further limitation of the project was the lack of energy consumption prior to refurbishment, follows by a not very successful data collection for energy consumption post refurbishment. In all, these facts meant that no scientific conclusion could be drawn in relation to reducing energy consumption and CO_2 emissions.

The range of properties covered detached, semi detached, mid terrace and end terrace properties with all of them having in common that the retrofitting did not upgrade the fabric or airtightness of the properties. This approach had implications on the performance of the air source heat pumps. It can be said from visual inspection during monitoring data collection that these properties were far from being ideal candidates for the installation of an air source heat pump to provide space heating and domestic hot water.

2.1 Internal temperature and relative humidity

The internal temperature and relative humidity was collected in every property using a LogTag HAXO8 temperature data logger (5) as shown in Figure 1. The HAXO8 temperature data logger was placed in every property in a central location on the ground floor, away from a direct heat source (e.g. radiator) and solar gain, with the purpose of capturing the average temperature of the flat. Only one HAXO8 temperature data logger was placed in each property. The data loggers were set to record temperature data at 20 minutes intervals as suggested by other studies (6). The data was collected for the period from July 2012 to April 2013. The data was manually downloaded to a computer via LogTag interface software and the data logger HAXO8 unit reset to restart the monitoring process.

The data collected, temperature and relative humidity, was analyzed firstly as an average for the total monitoring period, July 2012 to April 2013, and secondly as a monthly average to analyze the temperature and relative humidity variations during the heating season and summer period. The heating season was taken as October 2012 to April 2013 (6), while the summer was considered the period between June to August (7).

Figure 1 – LogTag HAXO8 temperature and humidity data logger

2.2 Weather conditions

Daily historical data for outdoor temperature was collected for the Stansted airport location via Weather Underground, www.wunderground.com. Figure 2 shows the outdoor temperature conditions for the monitoring period July 2012 to April 2013

It can be observed from the outdoor temperature data that the summer period was quite fresh with temperatures below 20 degrees centigrade and only a couple of hot spell periods in July and August 2012.

In terms of the heating season, October 2012 to April 2013, it can be seen in Figure 2 and a few periods of cold weather, with a long cold period occurring in January 2013, which could have an impact on the indoor temperatures of the properties in relation to the air source heat pump performance.

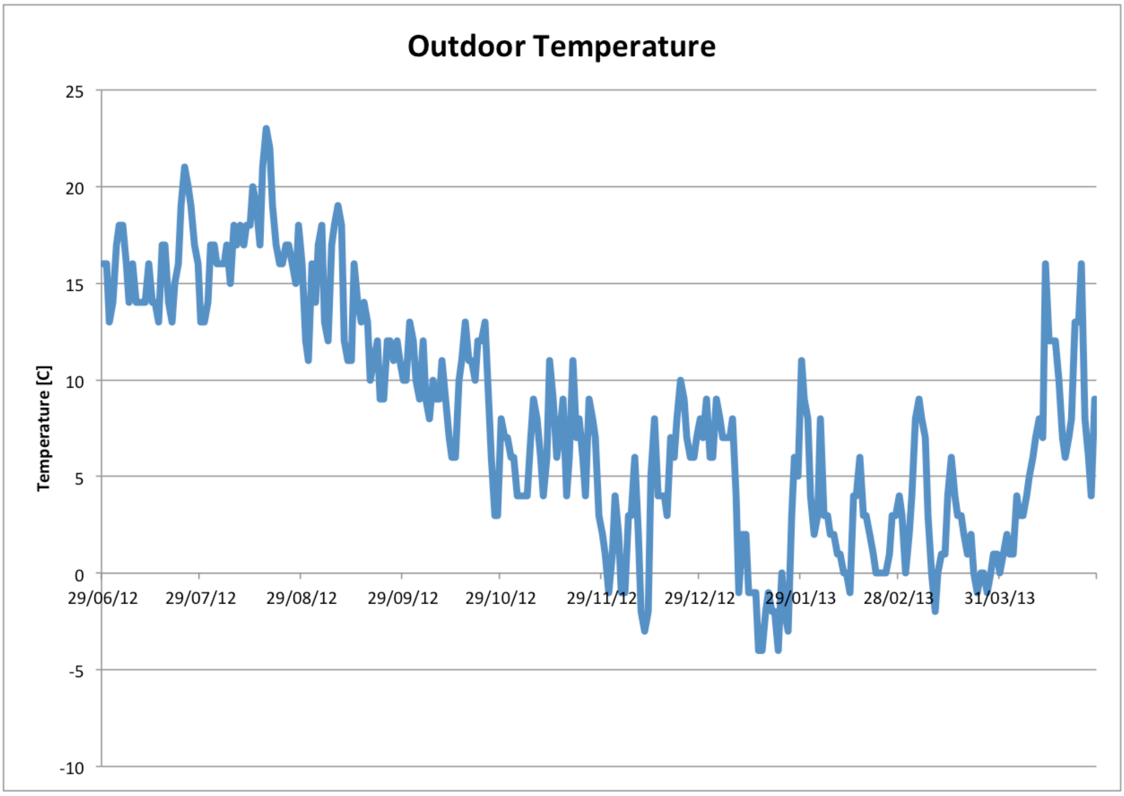

Figure 2 – Outdoor temperature for Stansted airport weather station from July 2012 to April 2013

3.0 Results

The first analysis was to plot the daily indoor temperatures for each property versus the weather outdoor temperature collected, as shown in Figure 3. From the graphs presented in Figure 3, it can be observed that in several cases, such as ARU_03, ARU_04, ARU_09 and ARU_13, the indoor temperature is around 20 degrees centigrade regardless of the outdoor temperature. There were two properties, ARU_01 and ARU_15, in which the internal temperature was by far well above 20 degree centigrade even under freezing outdoor conditions. On the other end of the spectrum, properties ARU_12 and ARU_17 presented indoor temperatures below 15 degrees centigrade.

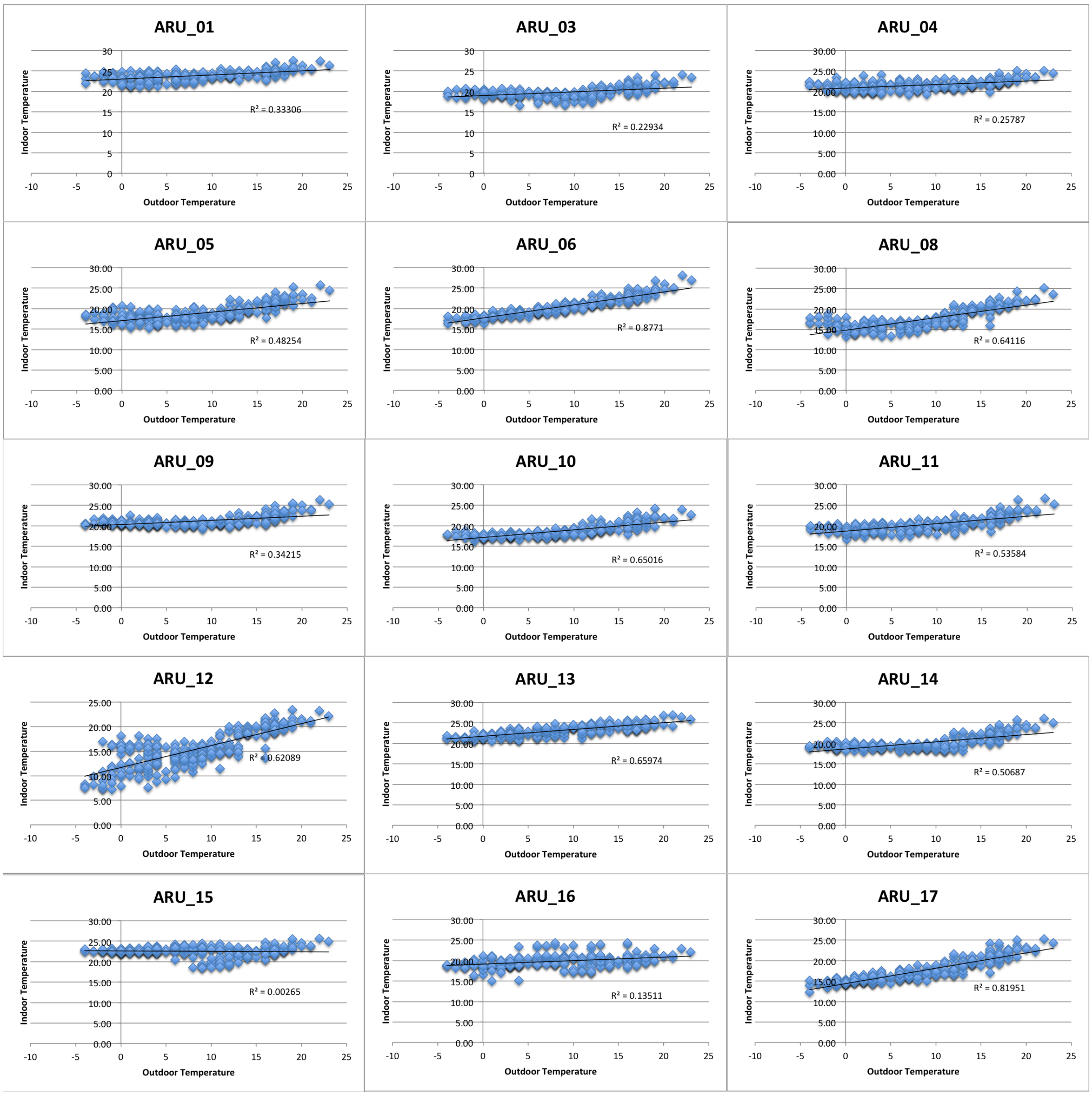

Figure 3 – Indoor temperature versus outdoor temperature for all properties from July 2012 to April 2013

On the one hand, looking at the total period indoor temperature and relative humidity data presented in Table 1 for each property, properties ARU_01, ARU_13 and ARU_15 showed very high indoor temperature values and relatively low humidity values, which would be a consequence of drying the air with a higher heating load. On the other hand, properties ARU_08, ARU_12 and ARU_17 presented low average values of temperature for the whole period and higher relative humidity values, which would be expected in under heated properties.

	Temperature		Relative Humidity	
	Average	SD	Average	SD
ARU_01	23.8	1.1	51.4	8.2
ARU_03	19.7	1.2	61.8	10.9
ARU_04	21.5	1.0	51.9	8.1
ARU_05	18.8	1.9	56.2	8.5
ARU_06	20.3	2.1	60.7	5.9
ARU_08	17.3	2.4	55.1	8.8
ARU_09	21.1	1.1	51.0	7.6
ARU_10	18.7	1.4	58.0	6.6
ARU_11	20.2	1.5	53.0	6.8
ARU_12	15.3	3.5	58.8	8.3
ARU_13	23.1	1.3	41.0	8.2
ARU_14	20.1	1.5	60.6	5.6
ARU_15	22.6	1.2	51.1	9.7
ARU_16	19.8	1.4	50.8	12.1
ARU_17	17.4	2.6	66.4	5.9

23.8
20 Degrees
15.3

100%
50%
0%

Table 1 – Average indoor temperature and relative humidity for the whole monitoring period

While the analysis of temperature and relative humidity for the whole monitoring period presented in Table 1, helped to expand the findings in Figure 3, a more detailed looked was proposed by presenting the average temperature per month as shown in Figure 4 and relative humidity data, as presented in Figure 5.

	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	Apr-13
ARU_01	24.8	24.9	24.5	23.9	23.9	24.0	24.0	23.5	22.2	22.8
ARU_03	20.8	21.8	19.4	18.7	19.3	19.6	19.3	19.3	19.7	19.0
ARU_04	22.3	22.8	21.6	21.8	21.4	22.1	21.2	20.6	20.7	20.2
ARU_05	20.5	22.0	19.7	18.1	17.6	18.6	17.7	18.0	17.8	17.4
ARU_06	22.9	23.7	21.8	20.6	19.7	18.7	18.4	18.7	18.5	19.8
ARU_08	20.5	21.4	19.0	16.9	16.3	16.1	16.7	16.1	14.7	15.0
ARU_09	22.1	23.0	21.2	20.8	21.0	20.9	20.7	20.7	20.5	20.2
ARU_10	20.0	21.3	19.8	18.6	18.1	17.8	17.6	17.8	17.5	17.9
ARU_11	21.4	22.8	21.0	20.2	20.2	20.1	19.7	19.3	18.5	18.4
ARU_12	19.5	20.6	17.9	15.0	14.3	12.0	10.4	11.5	16.4	14.7
ARU_13	24.7	24.0	23.9	24.0	21.8	22.0	22.3	22.2	22.3	23.6
ARU_14	21.7	23.0	20.8	18.9	19.0	19.1	19.4	19.6	19.3	19.7
ARU_15	22.6	23.1	20.8	21.9	23.6	22.9	22.7	22.5	22.9	22.6
ARU_16	20.2	20.6	18.4	20.6	19.9	19.4	19.5	18.9	18.8	22.1
ARU_17	20.4	21.8	19.3	17.3	17.0	15.6	15.3	15.1	15.2	16.7

24.9
20 Degrees
10.4

Figure 4 – Monthly indoor temperature average from July 2012 to April 2013

Looking at the heating season, October 2012 to April 2013, in Figure 4 as already mentioned, properties ARU_08, ARU_12 and ARU_17, presented extremely low indoor temperature values. In terms of the summer period, July and August 2012, several properties are close to unwanted temperature values. In particular, properties ARU_01, ARU_13 and ARU_15, which seemed to have carried forward into the heating season the levels of indoor temperature enjoyed during the summer period, which suggest a likelihood of overheating.

	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	Apr-13
ARU_01	59.4	59.0	53.1	57.7	55.8	44.6	44.2	43.8	47.9	47.6
ARU_03	72.0	72.2	67.4	71.7	64.1	62.3	56.3	46.5	47.1	57.4
ARU_04	59.7	58.6	54.0	55.8	56.8	47.3	47.9	45.9	43.0	49.1
ARU_05	65.6	62.7	58.5	64.6	60.6	52.2	52.6	47.3	45.8	51.1
ARU_06	62.9	60.0	59.9	66.9	66.7	62.4	60.1	54.5	54.6	58.8
ARU_08	63.2	62.6	58.1	62.1	58.0	52.0	49.1	45.2	46.8	52.6
ARU_09	59.6	58.1	53.5	56.7	52.1	48.5	46.7	43.9	42.9	46.7
ARU_10	68.9	66.9	60.0	61.4	57.8	54.4	55.7	50.5	51.5	51.7
ARU_11	61.3	57.9	53.4	57.1	52.8	49.6	50.7	47.9	48.4	50.0
ARU_12	65.7	63.9	57.9	64.9	61.8	60.0	61.7	57.8	45.6	47.9
ARU_13	48.8	53.3	44.6	44.1	44.0	39.5	36.1	33.2	31.3	33.7
ARU_14	62.6	59.6	56.3	67.0	65.0	61.3	60.7	58.6	58.4	56.8
ARU_15	61.4	60.9	62.2	60.9	49.0	44.7	43.7	41.4	40.8	45.2
ARU_16	66.4	69.6	63.4	54.7	48.5	44.8	41.6	40.2	39.1	38.0
ARU_17	71.5	71.5	65.8	69.1	62.6	64.8	64.6	62.1	65.6	65.9

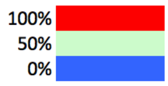

Figure 5 – Monthly indoor relative humidity average from July 2012 to April 2013

In terms of the monthly average relative humidity, the values presented in Figure 5 show healthy levels with the majority of values below the 70% mark for relative humidity. Special attention should be exercised in terms of the relative humidity levels for ARU_12 and ARU_17 during the heating season because of the extremely low indoor temperature values.

4.0 Discussion

Comparing the monthly average indoor temperature, as shown in Figure 4, to the Energy Follow Up Survey 2011 monthly average temperatures (6), the values are well above in all the properties for the summer period of July and August 2013. Furthermore, in terms of heating season, most properties presented slightly higher indoor temperatures, with properties ARU_01, ARU_13 and ARU_15 presented indoor temperatures far higher than the values found in the Energy Follow Up Survey 2011 (6).

Property ARU_12 showed the wider spread of temperature data, as observed in Figure 3, suggesting a sporadic approach to the use of the air source heat pump according to occupancy of the property.

As suggested by the Keep Warm Keep Well booklet (8), properties should be heated at least up to 18 degree centigrade for over 65 years old population and maybe slightly lower for under the age of 65 if active and wearing appropriate clothing, but in this case study, five properties failed to achieve it, with two extreme cases in ARU_12 and ARU_17 presenting unhealthily cold temperature for the heating season.

The findings presented in the results section, showed a wide range of variability in the approach to using the heating system, maybe agreeing on the issues of how sensitive air source heat pumps are to installation and commissioning practices as already reported in the literature (9).

According to the SAP2012 (10), the likelihood levels of overheating are presented in Table 2 and considering no input form heating system.

$T_{threshold}$	Likelihood of high internal temperature during hot weather
< 20.5°C	Not significant
≥ 20.5°C and < 22.0°C	Slight
≥ 22.0°C and < 23.5°C	Medium
≥ 23.5°C	High

Table 2 – Levels of threshold temperature corresponding to likelihood of high internal temperature during hot weather

Taking into consideration the likelihood level presented in Table 2 and comparing them to the indoor temperature values in Figure 4 for the summer period, July and August 2012, which assumes no input from the air source heat pump, three properties are presenting a high likelihood of overheating, while a further six properties showing a medium likelihood. The overheating likelihood highlights the issues of the houses' fabric and airtightness in need of refurbishment.

5.0 Conclusions

The results presented in this case study show that the use of air source heat pumps to provide space heating and domestic hot water, do not automatically translate into achieving thermal comfort, as temperatures and relative humidity will present a wide range of values form overheating to under heating. Giving the variability of indoor temperature in different properties, a more strategic approach must be taken to address the retrofitting challenge facing the United Kingdom if more predictable and homogeneous results should be achieved. Furthermore, the selection of retrofitting technology must be provided following an assessment of the building and then appropriate engagement with stakeholders must be achieve to maximize the technologies retrofitted and avoid the situation during the heating season of under heated properties and over heated properties as presented in this case study.

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Acknowledgements

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