Analysis Report

AirEx - ECO Demonstration Action

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ECO Demonstration Action

Contents

01

ECO Demonstration Action

Summary of Results

This report summarises the results of a large-scale demonstration trial of the innovative AirEx sub-floor heat loss energy saving device, as part of the ECO3 Demonstration Action programme.

The field trial was carried out on 115 occupied properties and monitoring took place during November 2019 – April 2020, with results independently validated by a team of researchers, building physics experts and statisticians.

AirEx is an IoT-enabled smart ventilation control that replaces conventional airbricks in pre-1950s dwellings. The AirEx units dynamically control airflow at sub-floor level, triggered by measured parameters (such as temperature, humidity) and its cloud-based algorithms responsively regulate the otherwise uncontrolled airflow. As such, the AirEx device minimises cold airflow into the underfloor void (properties with suspended ground floor) whilst ensuring sufficient ventilation of the underfloor void to prevent moisture build-up, timber rot or poor indoor air quality.

The project team installed AirEx system on 99 occupied properties and monitored further 16 control group properties. The properties spread across varying climatic regions, with the majority of the homes located in the South West (Portsmouth) area and in the Midlands (Walsall and Wolverton) area; as well as a few Yorkshire based properties. The property types varied between mid-terraced, end-terraced, semi-detached properties and a small number of detached homes too; properties varied between 1 to 6 bedrooms (average: 2.6 bedrooms). In terms of occupancy the project team observed a great variation between 1 to 8 occupants (average: 3.5 occupants). In terms of number of air bricks, the properties varied between 1 and 9 sub-floor airbricks (average: 3.8 airbricks).

The pictures below show a typical mid-terraced property located in the Portsmouth area (one from front & one from rear elevations) and a typical semi-detached property located in the Walsall area (one from front & one from rear elevations):

Figure A

A typical mid-terraced property located in the Portsmouth area

Figure B

A typical semi-detached property located in the Walsall area

The project team installed SmartHTC monitoring equipment in a total of 115 properties. Of these, the team have successfully measured the pre and post Airex whole house heat loss (HTC) in 82 cases (164 valid HTC measurements).

In terms of full HTC calculation, 33 of the original 115 were unsuccessful as a result of Covid-19 lockdown restrictions impacting the team's ability to collect sensors and record final closing meter reads within the heating season period. However, logged room temperature and RH% data, under sub-floor void temperature and RH% sensors as well as open/close data for all 115 does combine to present the team with over 5 million data points, further describing the sub-floor and indoor environment in the homes during the trial.

The independent reviewers of this project believe that this level of granular measurement and the arising product performance understanding is unprecedented, especially under ECO and RdSAP, which typically drives the UK retrofit market.

The project team monitored three key metrics during the trial:

- Whole fabric heat loss, HTC (heat transfer coefficient) pre & post;
- Sub-floor void temperature pre & post;
- Ground floor U-values[1] pre & post.

All three metrics illustrate significant improvement after the Airex installation. See summary tables below:

HTC results Pre & Post intervention	Inc. outliers	Excl. outliers
Comparison of populations	**Mean 16%** (± 9.5%) **reduction** Statistically significant	**Mean 12%** (± 9.1%) **reduction** Statistically significant

Sub-floor temperatures Pre & Post intervention	
Gain in temperature difference (Internal - Void) in dynamic period	**Gain +9.7%**
Gain in temperature difference (Internal - Void) in dynamic period	**Gain of 1.4 degC**

Ground floor U-value results Pre & Post intervention	
Ground floor U-value improvements based on x17 homes sample (ECO trial subset)	**Mean 19.3%** (± 7.5%) **reduction**

All the statistical methods that measured the performance of the Airex system as a way of improving energy efficiency in the houses show a clear performance improvement. The statistical significance is also confirmed by the Wilcoxon Signed Rank Test. The sections 1.1, 1.2, 1.3 provide an overview of each approach.

[1] It is worth noting that the “measured heat loss through the floor” in this context refers to the impact of AirEx that is calculated on the basis of comparing ‘floor-to-external-air’ temperatures, rather than the traditionally, commonly known method of measuring surface temperatures on both sides of the substrate. For example, in case of insulation, U-values would normally be measured on both sides of the floorboard, to capture conductive heat loss. In this particular case, the AirEx product does not add extra insulation layer to the floorboards, instead, it predominantly impacts convective heat loss (through reducing the temperature difference across the floorboards), and contributes to the reduction of air leakage rates.

ECO Demonstration Action

1.1 SmartHTC analysis

1.1.1 Background summary for Smart HTC method

SmartHTC is a technique developed by BTS (Build Test Solutions) for measuring the thermal performance of houses, defined by the 'Heat Transfer Coefficient' or HTC.

The HTC encompasses all of the heat lost from a dwelling during the winter, through the walls, roof, floor and windows, and by air movement from outside to inside the home.

The metric is W/K, the rate of heat loss in watts per degree in temperature difference between inside and out. The lower the number, the better the overall fabric is at retaining heat.

The HTC value taken in isolation does not identify the location of the heat loss paths or which elements of the fabric are worst performing, it is simply a measurement of the overall fabric heat loss. At its heart, Smart HTC is an algorithm that has been built into an online web service product. This allows for automated input of data, HTC calculation and return; all via APIs.

The method has been applied and compared to SAP results in over 200 dwellings over the past two winter seasons and has been shown good agreement when tested alongside conventional co-heating in 43 different field trial properties. Full detailed reporting on the findings of these trials is ongoing but all of BTS's measurements easily fall within the combined uncertainty of co-heating (±10%) and Smart HTC (±15%). Smart HTC results are also highly repeatable, all demonstrating a mean RPD of less than 10%.

Further information about the Smart HTC method can be found in *"ECO3_TAP_SHTC clarification note"* and *"SmartHTC Repeatability note"* documents, supplied to Ofgem as supporting evidence. Further independent validation (conducted by the University of Salford) is expected to be published on the accuracy & repeatability of BTS's SmartHTC method by the early 2021.

1.1.2 Sample size and methodology for SmartHTC approach

The project team installed SmartHTC monitoring equipment in 115 houses. Largely due to covid-19 lockdown, data from 33 houses had to be omitted due to poor quality. Typically this was because we were not able to visit the properties to confirm final meter readings, reset malfunctions in some of the test equipment or collect sensors at the end of the trial. This leaves 82 properties: 66 houses with AirEx fitted and operating; plus 16 control houses which were monitored as control group (i.e. no AirEx fitted, instead using conventional air bricks) where the project team received valid HTC results. Section 2 provides further details on inclusion and omission of potential further 9 outlier properties.

Within the installed group, the AirEx units were operational for half of the monitoring duration, the “dynamic phase” when air bricks open & close in response to measured conditions.; and for the other half of the monitoring duration, the Airex units remained fully open to simulate a ‘pre install” state. The average duration of HTC monitoring for Phase 1 (dynamic stage) was 5.5 weeks, the average duration of HTC monitoring for Phase 2 (‘fully open’ stage) was 4.7 weeks and the average duration of HTC monitoring for the control group properties was 9.2 weeks.

1.1.3 Summary of results (SmartHTC analysis)

The SmartHTC measurements (whole house Heat Transfer Coefficient method) are shown in the left hand chart, excluding 3 outliers. The error bars are the 95% confidence intervals. The Dynamic phase measurements are plotted on the Y axis and the Open measurements are plotted on the X axis. The dotted line is a 1:1 or parity line i.e. no change in performance between the Dynamic and Open periods. The data have a very similar range to the HTC measurements of the control houses. Overall there is a very clear trend of performance improvement during the Dynamic period.

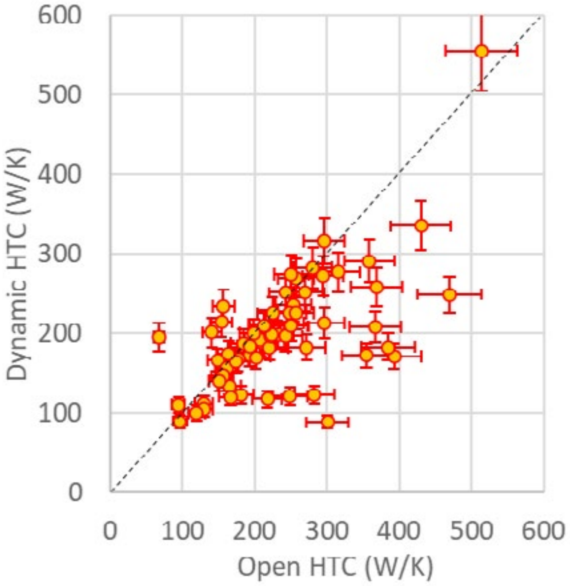


Figure 1

SmartHTC results – dynamic vs open position – regression plot with error bars.

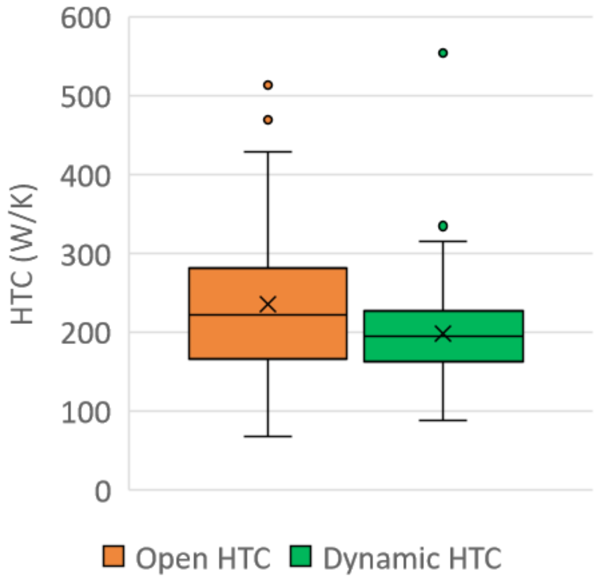


Figure 2

SmartHTC results – box and whisker plot

The box and whisker plot (Fig. 2) of the two datasets is shown (excluding the 3 clear outliers as above), illustrating the lower mean and lower variance of the Dynamic results. The improvement in performance between the two periods can be measured using a Paired Two Sample for Means t-Test. It shows that overall the whole fabric heat loss was reduced by an average of 16% (±9.5%) (mean) after AirEx installation, and that the Median value of the range of savings is 13%. This is a substantial and statistically significant saving (the result robustly passes the t-Test and p-value statistical tests).

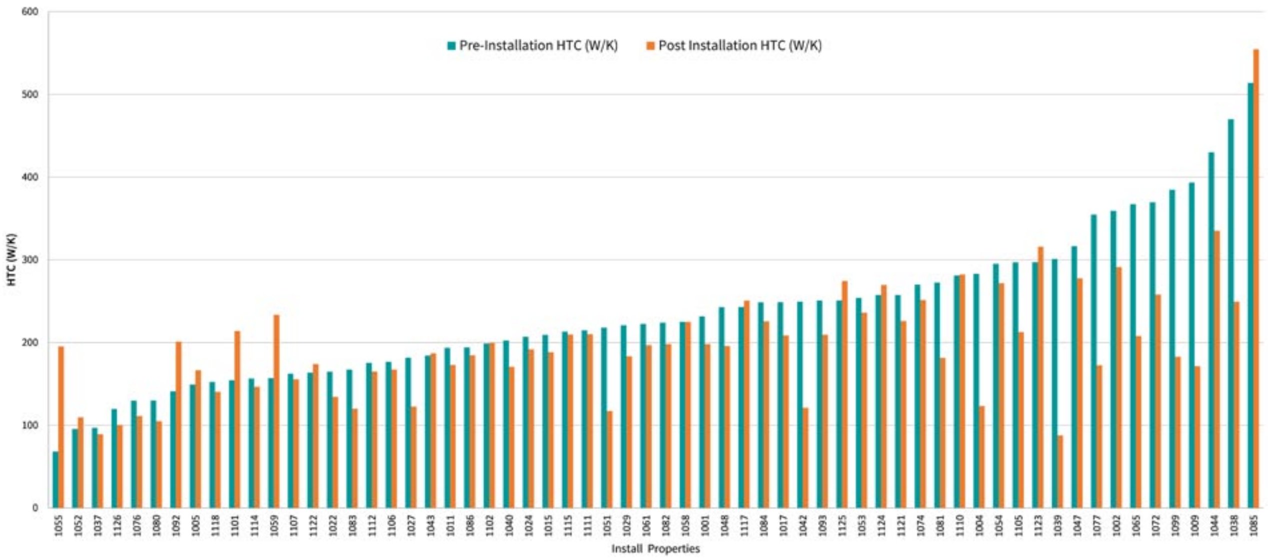
A set of 6 data points are possible outliers, due to the national lockdown preventing access to houses and so the final readings were not independently validated. If we exclude these datapoints, then the same analysis shows that the overall the whole fabric heat loss was reduced by an average of 12% (±9.1%) mean after AirEx installation. This is also statistically significant. We therefore conclude that the average HTC improvement is the in range 12% (±9.1%) – 16% (±9.5%).

To robustly check the results, we also tested against the Wilcoxon Matched Pairs Signed Rank Test (Wilcoxon Signed Rank Test). This is the nonparametric equivalent of the parametric paired t-test, i.e. it is not sensitive to any non-normal distribution of HTC data. (The hypothesis is that there is no difference between the medians of the two cases: pre & post: fully open vs dynamic). The test confirmed the significance between the Open/Dynamic cases, $n = 61$, $T = 350$, $p < 0.05$, with one HTC pair that showed no difference. The statistical case is rejection of a false positive or a Type 1 error. Based on the Wilcoxon Signed Rank Test the median HTC improvement is 9.6%. At 95% confidence interval the margin of error is ±4% (improvement between 5.7% - 13.9%[2]). The test is also passed at $p < 0.01$, so there is a high degree of confidence in the results.

Fig.3 shows the results for all HTC monitored properties within the ‘installed’ group, whereby the blue bars show HTC values in ‘fully open’ mode (simulating ‘pre-install’ stage) and the orange bars show HTC values in ‘dynamic’ mode (air bricks open & closed in response to measured conditions). As we can see on the bar chart below, the HTC values improved (reduced) in the majority of the properties after undertaking AirEx installation (i.e. AirEx units were switched to ‘dynamic’ mode from ‘fully open’ mode).

Figure 3

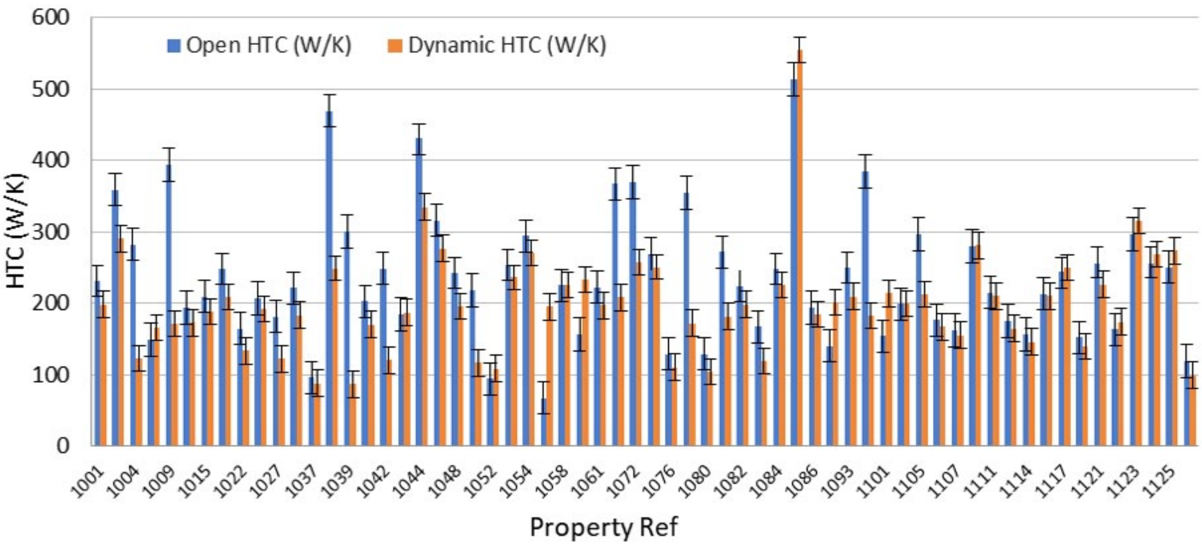
Whole House Heat Transfer Coefficient Pre & Post AirEx Installation



[2] Please note that with Wilcoxon Signed Rank Test uses the median (rather than the average) with a discontinuous function. As such, the results are stated as a median and stated with different amounts plus or minus (they are not symmetrical because the CIs are calculated points from the data).

Figure 4

SmartHTC results (pre & post intervention) – bar chart with error bars



As might be expected, the project team observed a bigger benefit in houses with many airbricks and good cross-flow through the underfloor void (i.e. more ventilation in the void, which can be eliminated by the AirEx system). This aligns with the ISO 13370 calculation method for heat loss via suspended ground floors where vented versus unvented sub-floor voids (vented by air bricks) have different U-values associated. In “Section 2: Technical details” we elaborate on this subject in more detail.

The type of floor covering also seems to show that carpeted floors result in better gain by AirEx than laminate floors, and exposed (bare) floorboards result in the largest gains by AirEx. However, it is worth noting that the sample size available for varying floor covering types was not large enough and therefore the project team believes further research is required to confirm this correlation. We anticipate that this trend is likely due to air infiltration from the void through the carpet which is stopped by laminate. Our air tightness results from earlier trials (mean 9% improvement) support this assumption.

The AirEx vents opening/closing schedule was determined based on the following factors: sub-floor void relative humidity; external relative humidity; time since void RH% is above threshold; wind speed. During the DA study the AirEx units remained open for half of the winter and were in dynamic operation for the second half of the winter. Within dynamic period the bricks were closed 75% of the time and open 25% of the time. The average sub-floor relative humidity was measured at 82% in closed state and at 74% in open state, within the dynamic period.

ECO Demonstration Action

1.2 Floor void & internal temperatures analysis

1.2.1 Background summary for temperature analysis

In addition to the Smart HTC method and the U-value monitoring method, in order to obtain further data on the AirEx system's energy savings performance, the project team monitored the temperatures in multiple locations.

The project team monitored the difference in average air temperature in the floor void before and after installation of the AirEx bricks. This was then corroborated with indoor air temperature readings.

1.2.2 Sample size and methodology for temperature analysis

The project team monitored the entire sample: all 99 properties in the installed group (+6 private homeowner sample, resulting in **105 properties** monitored in total), for the entire duration of the winter: between November 2019 – April 2020. Floor void air temperatures are continuously obtained from the Airex units (half-hourly measurements) once the units are installed, as such, we were able to obtain readings from both open and closed vent states. Sub-floor void air temperatures were monitored at multiple locations in the underfloor void (at each Airex unit, on an extendable sensor arm), and 4 different locations internally (typically 2 locations downstairs and 2 locations upstairs). The average duration for floor void temperature monitoring was 12.5 weeks. This resulted in a very detailed, granular level of raw data (over 5 million data points), which supported the analysis.

1.2.3 Summary of results (temperature analysis)

The graph below shows the overall ΔT gains when the Airex system is open/closed.

Figure 5

Temperature Difference gains when the AirEx system is open vs closed

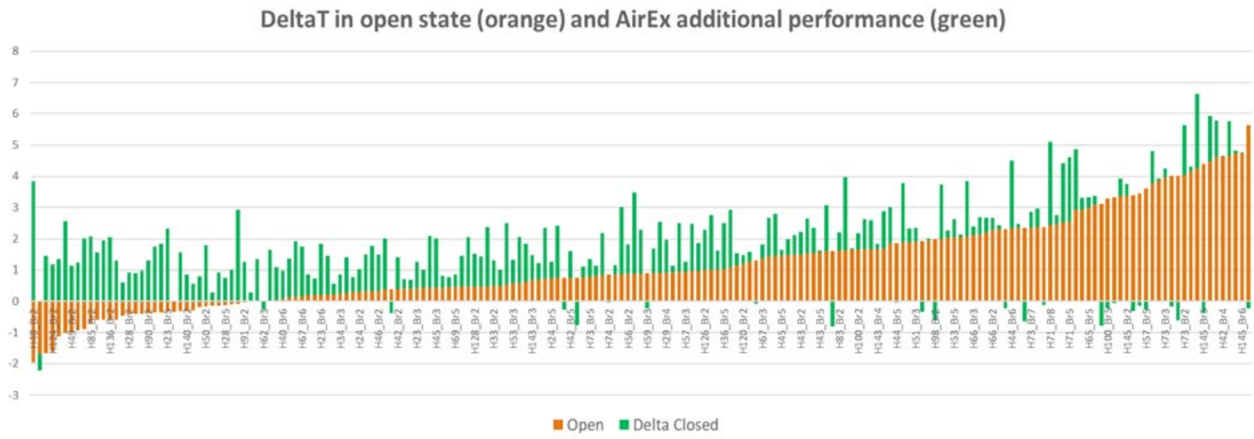
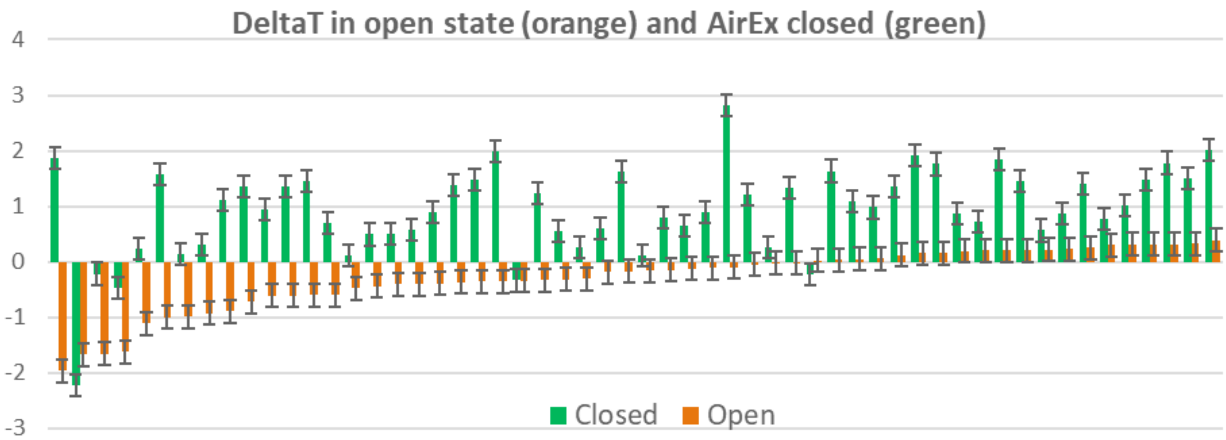


Figure 6

Overall ΔT gains in open/closed position – bar chart with error bars



The green bars show the floor void temperature difference (outside vs void) when the AirEx is closed; orange bars showing floor void temperature difference (outside vs void) when the AirEx is open. It can be seen that there is an improvement across the majority of the full sample such that the void is warmer when the AirEx is in closed (dynamic) mode compared to open.

There are outliers that need further investigation, however, the trial has shown that there are circumstances on cold days between c. 10-15 degrees C when void air temperature does not increase above the void ground temperatures. With this new understanding, a change of the control logic could potentially further improve the impact of AirEx. Further investigation is required to confirm this assumption.

Another illustration of the AirEx performance is shown by the increase in void temperature when the Airex brick is open and closed (measured exclusively in the Dynamic phase), shown on Fig.7.

The chart shows the difference between the void and outside temperatures, in the dynamic period, for the open and closed states. 1:1 line means no change. The data show that the elevation of the void temperature against the outside temperature is almost universally greater when AirEx is closed, compared to the open position.

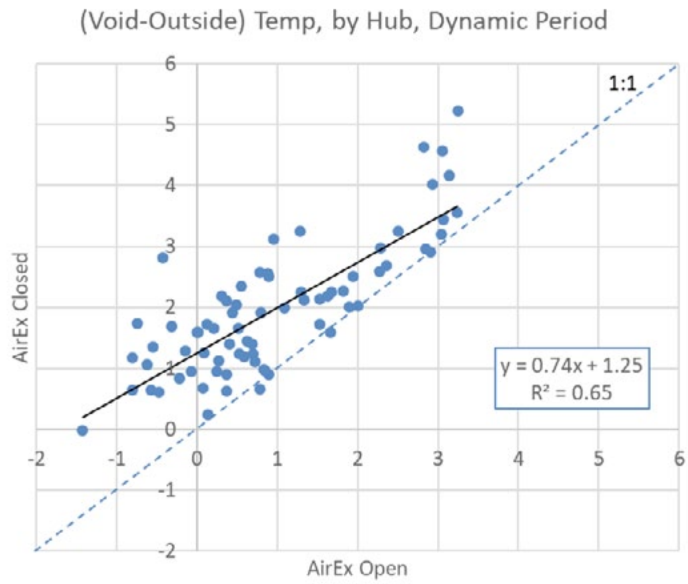


Figure 7

Void ΔT (void-outside) gains in open/closed position – regression plot

The correlation could be interpreted as:

- A fixed improvement of 1.25 degC (the Y intercept) for the AirEx brick in closed position;
- A gain which decreases as the “natural” void temperature (i.e. when the AirEx brick is open) is increasingly higher than the prevailing outside temperature. A high “natural” void temperature tends to happen in warmer weather.

The project team have also analysed how the sub-floor void temperatures vary against external temperature. Fig.8 shows that the ΔT between outside and void. It is greater (the void is warmer) with the AirEx closed and this effect becomes more significant as the external temperature falls. When the outside temperature is zero degrees C, the void is 4.5 degrees warmer with a closed AirEx, but only 1.8 degrees warmer with an open brick. It can be assumed therefore that AirEx’s energy savings impact increase when the weather is colder, when larger heat load is required to warm up the house.

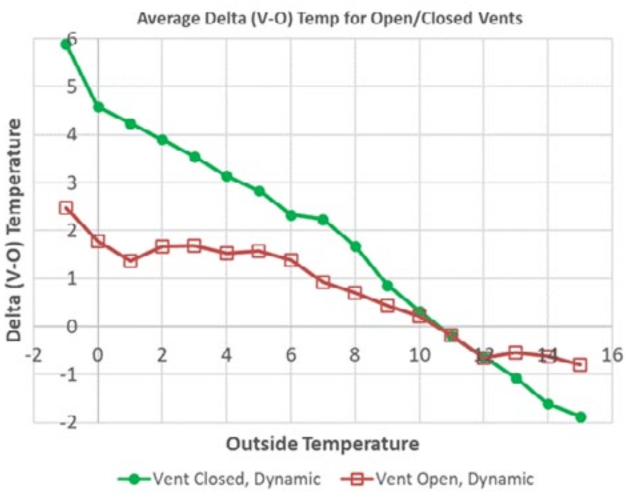


Figure 8

Void ΔT (void-outside) gains in open/closed position, normalised to external weather

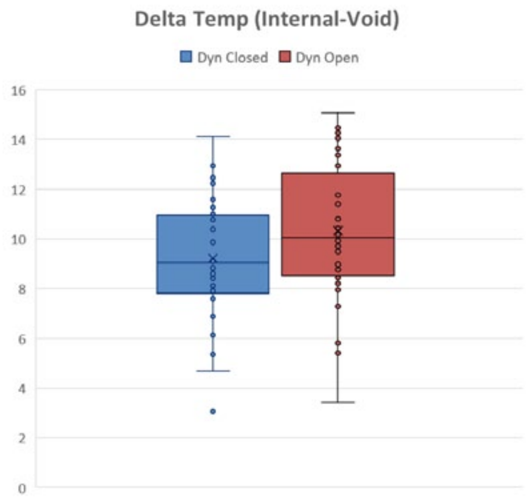


Figure 9

SmartHTC results – box and whisker plot

Lastly, as part of our analysis, floor void temperatures were corroborated with internal temperatures: both of which were measured in a half-hourly basis for the duration of the entire monitoring period. Fig.9 shows that the difference between the internal and void temperatures were lower when the AirEx was closed in the dynamic trial period.

The project team's observation is that this result supports the basic thermodynamic theory behind the AirEx technology. By reducing the temperature gradient across the floor, the heating requirement is reduced. It is also consistent with the U-value analysis in the next section.

Across the study as a whole, the difference between internal and void temperatures decreased by 10.9% on average, when the AirEx was closed. As the void is warmer, the floor will lose less heat (through convective heat loss and reduced air leakage) and it is assumed that there will be an increase in comfort in the rooms above as the floor surface will be slightly warmer.

The results were also confirmed using the Wilcoxon Signed Rank Test to validate the significance of the results. (The hypothesis is that there is no difference between the medians of the two cases: pre & post: open vs closed). The results are significant at 5%. For $n = 71$, $T = 82$, $p < 0.05$. The statistical case is rejection of a false positive or a Type 1 error. The test is also passed at $p < 0.01$, as such, there is a high degree of confidence in the results.

1.3 U-value analysis

1.3.1 Background summary for U-value analysis - methodology

The AirEx product regulates what is otherwise uncontrolled air flow into and out of the underfloor void zone. This has two main effects on the energy performance and comfort of the home.

First, Airex reduces the uncontrolled air movement and thus the associated convection effects – air is instead held within the underfloor zone and in turn serves as an intermediary insulation layer. Secondly, the sealing off of the air bricks reduces uncontrolled air leakage and the associated heat losses and draughts.

The project team undertook in-situ U-value measurements to measure the first aspect.

Thermal transmittance (U-value) is the rate of transfer of heat through matter, in this case through the ground floor. Our base assumption was that through controlling airflow, the air layer at sub-floor void becomes slightly warmer (which is validated in Section 1.2), as such, reduces the thermal transmittance of the ground floor.

Whilst absolute U-value measurement of floors is fraught with challenges, the AirEx team is backed by an experienced team and academic partners with unrivalled know-how and experience to measure U-values in-situ. For the purpose of calculating fabric heat loss reduction, instead of absolute U-values, the emphasis was on U-value difference between pre and post installation (ΔU) which was be sought during testing. Here, the monitoring team ensured that the HFM sensors were placed at exactly the same location both before and after. 3-4 HFMs (Heat Flux Monitoring plates) were installed minimum 3 weeks prior to the installation of AirEx (or, fully open state, to simulate pre-install), and then with the HFMs remaining in-situ untouched for a further 3 weeks post install. Temperature measurement were captured in the form of internal floor surface and room ambient temperature alongside external air temperature housed in a Stephenson screen. Heat flux and temperature measurements were taken in 5 minutes intervals.

It is worth noting that the “measured heat loss through the floor” in this context refers to the impact of AirEx that is calculated on the basis of comparing ‘floor-to-external-air’ temperatures, rather than the traditionally, commonly known method of measuring surface temperatures on both sides of the substrate (i.e. wall, roof, floor). For example, in case of insulation, U-values would normally be measured on both sides of the floorboard. In this particular case, the AirEx product does not add extra insulation layer to the floorboards, instead, it predominantly impacts convective heat loss, and air leakage rates – as such, ground floor U-value is measured and interpreted slightly differently.

1.3.2 Sample size for U-value analysis

The project team was able to carry out U-value tests of floors during the trial on 17 properties (19 attempted, out of which 2 resulted in invalid readings), which showed the improvement in U-value between inside the room and outside the house that results from dynamic Airex operation compared to an open airbrick. This data adds to a previous set of 6 houses in which Airex has been trialled; the results are consistent.

1.3.3 Summary of results (U-value analysis)

During the 2019/20 winter our project team conducted in-situ U-value measurements on 19 occupied properties, as part of the ECO Demonstration Action trial. We obtained valid U-value results for 17 properties. The mean improvement was 19.3% (± 7.5%) with the median 13.4%. The worst was no improvement and the best 52%. The U-values were to an ISO-9869-1 defined uncertainty of 14-28%.

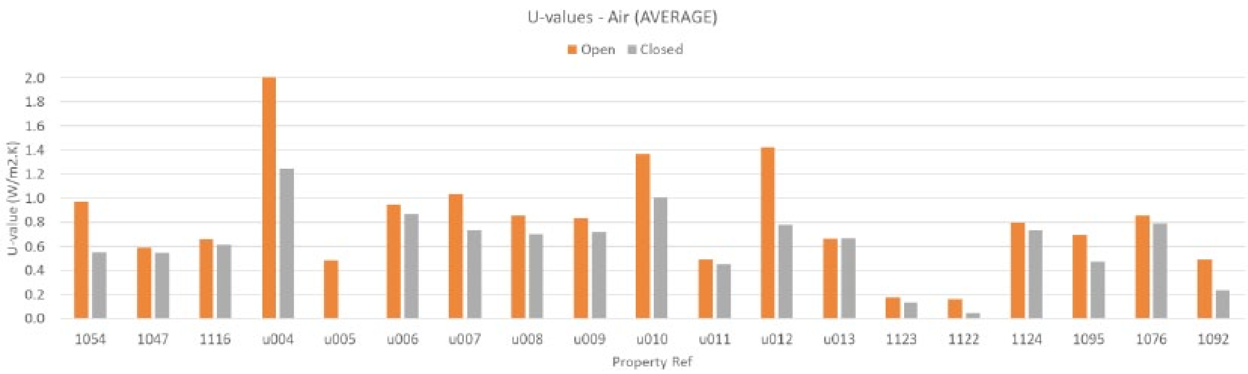


Figure 10

U-value analysis – bar chart

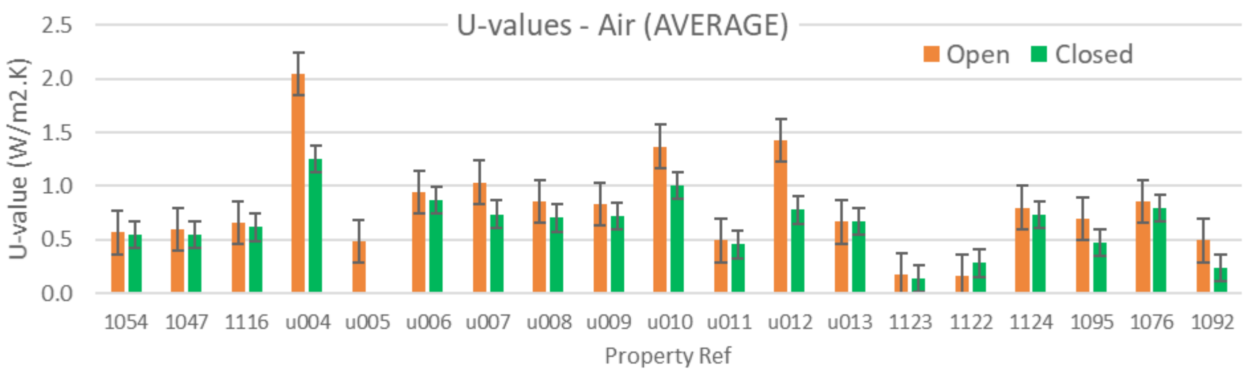


Figure 11

U-value analysis – bar chart with error bars

The results were confirmed using the Wilcoxon Signed Rank Test to validate the significance of the results. (The hypothesis is that there is no difference between the medians of the two cases: pre & post: fully open vs dynamic). The results are significant at 5%. For $n = 18$, T or $W = 12$, $p < 0.05$. The statistical case is rejection of a false positive or a Type 1 error. Based on the Wilcoxon Signed Rank Test the median U-value improvement is 14.6%. When taking into account the 95% confidence interval, the median U-value improvement is between 6.7% and 41.3%[3]). The test is also passed at $p < 0.01$, so there is a high degree of confidence in the results.

To contextualise the results, it is noted that previous independently validated trials shown the following U-value results:

- 2016-17 Sheffield University trial: an average of 38% U-value improvement after the installation of Airex product; based on 4 properties sample
- 2018 Salford University trial: an average of 14% U-value improvement after the installation of Airex product; based on 1 property sample: Salford Energy House (simulation chamber)

Further details, interpretations and conclusions on U-value measurements can be found in Section 2.3.

[3] Please note that with Wilcoxon Signed Rank Test uses the median (rather than the average) with a discontinuous function. As such, the results are stated as a median and stated with different amounts plus or minus (they are not symmetrical because the CIs are calculated points from the data). While this median value is slightly lower (compared to the standard t-test), however, the asymmetric CI highlights the more realistic upper range for potentially greater improvement.

02

ECO Demonstration Action

Technical Details

2.1 HTC analysis

2.1.1 Confidence interval, including / excluding outliers

Confidence Interval for the entire sample

SmartHTC results are calculated with a 95% confidence interval, i.e. provide a margin within which we are 95% confident that the HTC lies within.

There are some important variables in domestic heating assessment that cannot be controlled. Furthermore, we have assessed a range of house types without the objective of getting a normal distribution of similar houses. For both of these reasons, we designed a “within-subjects” or “repeated measures” trial and present the statistical results using t-Test to compare the means of the paired samples. The **performance gain** is statistically significant and is in the range **12%** (±9.1%) **to 16%** (±9.5%), excluding/including the 6 possible outliers described in section 1.1.3. The **Confidence Interval** for these samples is **9.1%** and **9.5%** respectively. Confidence Interval is essentially an alternative way of assessing statistical significance and these are consistent with the t-Tests.

The project team have highlighted the constraints imposed by the covid-19 lockdown. In terms of the results, the outcome has been that 3 clear outliers needed to be excluded from the dataset; and a further 6 data points are possible outliers. However, the improvement in performance between the dynamic and open phases is statistically significant in either case.

For the dataset minus all 9 outliers, our most robust dataset:

- the improvement in the mean HTC is 12% (±9.1%) between the Dynamic/Open phases
- this is statistically significant using either the p-value (alpha = 0.05 or 95% confidence) and the critical value approach

For the dataset minus the 3 clear outliers, our reasonable dataset:

- the improvement in the mean HTC is 16% (±9.5%) between the Dynamic/Open phases
- this is again statistically significant using the same statistical approaches

The generic Confidence Interval (uncertainty interval) supplied by BTS (18%) is a figure for single tests. The Confidence Interval for these samples, excluding/including the 6 possible outliers, is 9.1% and 9.5% respectively.

Uncertainty interval for individual HTC tests

Each single SmartHTC measurement is provided with an uncertainty estimate, typically in the range 15-25% (with 18% average). This figure is an estimate of the accuracy of the HTC measurement, designed to account for any effects caused by the accuracy of monitoring equipment, occupancy, weather or building systems, etc.

In this large “repeated measures” trial, the paired data takes into account many of the underlying variables, as the analysis is simply comparing two HTC measurements on the same house. The key uncertainties are controlled by the paired trial design. These include factors such as sensor accuracy and placement; the accuracy of the energy consumption measurement at the service meters; solar gains; the calculated efficiency of the space and water heating and the split between the two in the case of gas heating. The 95% Confidence Interval for our sample is as a result materially reduced. It is direct calculated from the sample standard deviation and sample size and the generic HTC uncertainty estimate is therefore replaced with a measured data.

2.1.2 Analysis Methods

As discussed in section 1.0 (Limitations), the HTC results are driven by a number of significant and correlated underlying inputs (heating load but also hot water use, reflecting both housing fabric and behavioural factors such as opening and closing of windows and doors) and the observed sample population is not normally distributed. This is expected when there are a number of underlying factors. They are paired or matched results (from the same houses) the appropriate statistical tests to compare the results are the Confidence Intervals and linear regression, as used above.

The void temperature data (internal, void, external) are of high frequency, reflect a simpler physical system and are normally distributed. The temperature results are statistically significant.

2.1.3 Drivers impacting HTC (summary of positive & negative correlations)

During the analysis the project team investigated a number of different factors that could have impacted varying results in HTC gains, such as property type, detachment, occupancy, number of bedrooms, floor area, presence of cross flow, floor covering, % of time AirEx units are open when dynamic, etc.

As the chart shows below, broadly positive correlation was observed with factors[4] such as occupancy, number of bedrooms, total floor / brick, cross flow, air bricks not converted to AirEx.

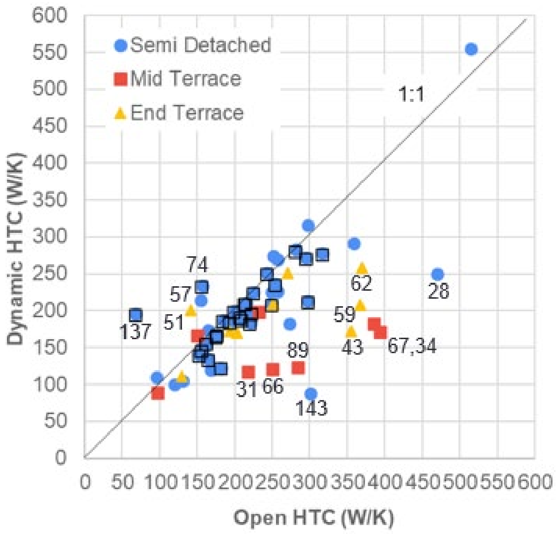
	Detachment	No of occupants	No of bdrms	Total Floor Area (m2)	Suspended Floor Area (m2)	AirEx brick installed	Area/brick	Uninstalled bricks	Crossflow1	LivingCover	Brick open % when Open	Brick open % when Dynamic
Difference	-0.212	0.275	0.281	0.128	-0.069	-0.200	0.245	-0.254	-0.209	-0.069	-0.050	0.121

The next section below summarises the trends of those factors where we observed positive correlation.

4 It is important to note that the sample sizes within each category (detachment types, occupancy levels, etc) were relatively small, therefore these assumptions on relationships between HTC output and property types might not be statistically significant - i.e. correlation may not mean causation. Correlation can be observed between some of the factors and the HTC outputs, but in order to gain strong confirmation on causation, the project team believes that a larger trial would be required.

Detachment

Avg Floor Area	77	66	84
Count	43	8	9
	Semi	Mid	End
Gain (%)	-14.0	-72.1	-30.0



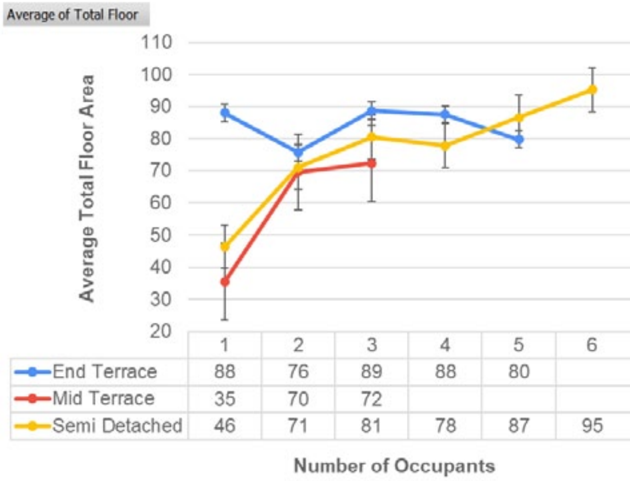


Figure 12

SmartHTC results (dynamic vs open position), based on detachment – regression plot

The largest gains were observed in mid-terraced properties, followed by end-terraced and then semi-detached properties. This aligns with expectations. However, it is important to note that there is autocorrelation between other drivers (e.g. occupancy) - see Fig.12.

Number of Bedrooms

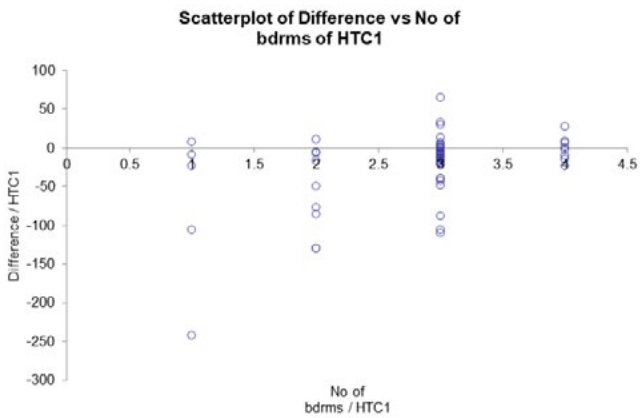
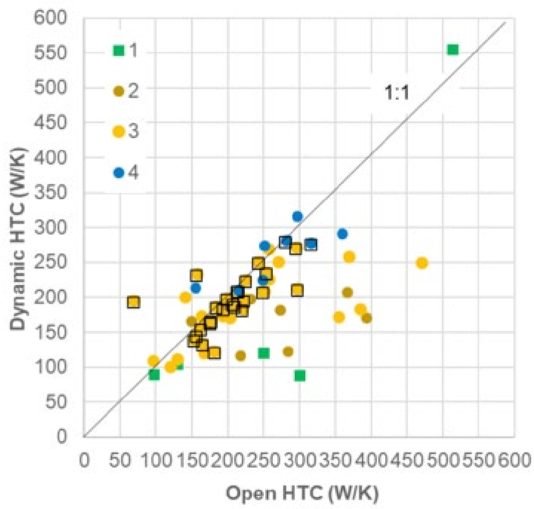


Figure 13

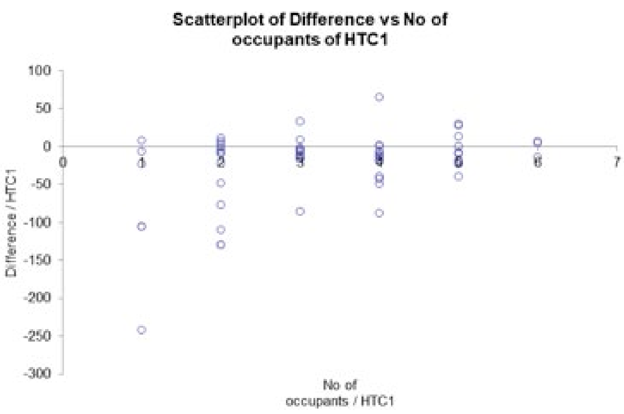
SmartHTC results (dynamic vs open position), based on no of bedrooms – regression plot

Count	5	9	38	8
Number bedrooms	1	2	3	4
Gain (%)	-74.8	-54.5	-15.2	-0.9



The lower the number of bedrooms is, the larger the HTC gain is – this also aligns with the expectations.

Number of Occupants



Count	6	14	11	16	10	3
No occupants	1	2	3	4	5	6
Gain (%)	-79.6	-37.9	-11.2	-16.5	-4.9	-1.3

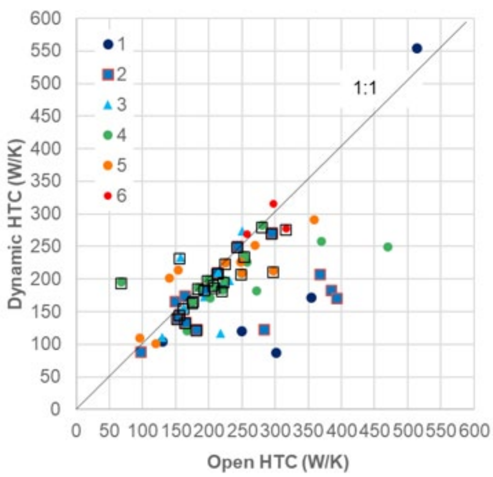


Figure 14

SmartHTC results (dynamic vs open position), based on no of occupant – regression plot

It can be observed that the HTC improvement impact is greater for houses with fewer occupants, as the graph shows above. The number of occupants is plotted along the ‘x’ axis and reduction in energy down the ‘y’ axis. It can be seen that the AirEx system tends to reduce the HTC more as the number of occupants decreases. Conversely, the largest HTC improvement can be observed in properties with 1 or 2 occupants only. The project team assumes that this might be attributed to a possible fluctuation in occupancy numbers (i.e. differences in ‘recorded’ vs ‘actual’ occupancy levels, particularly in more crowded properties), which could have impacted HTC results (by the “unknown occupancy” factor; e.g. people opening windows more frequently, taking hot showers more frequently, etc). Further investigation is required to confirm this assumption.

Crossflow

Count	31	29
Crossflow?	0	1
Gain (%)	-14.4	-34.5

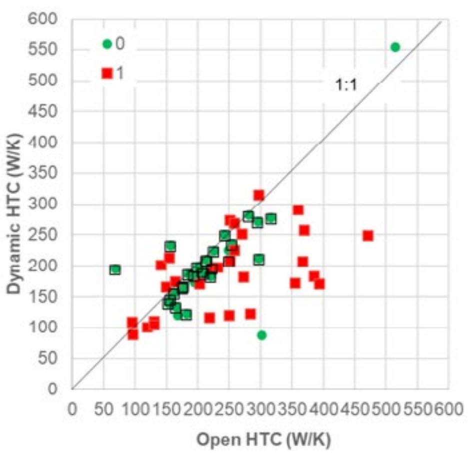
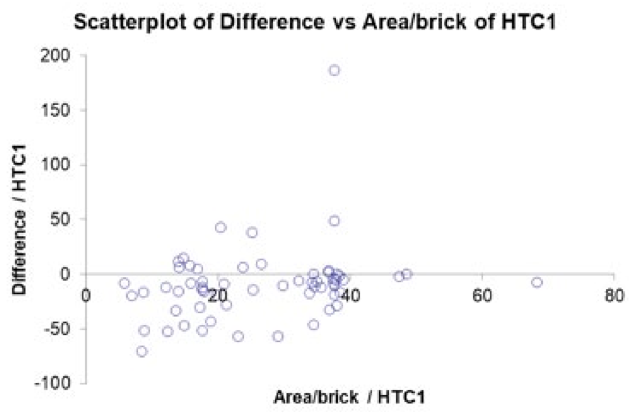


Figure 15

SmartHTC results (dynamic vs open position), based on existence of cross-flow – regression plot

Properties where air bricks are located at minimum 2 different elevations (typically front & rear elevation) have cross-flow; whereas properties with air bricks only on 1 elevation has no cross flow (most of the Walsall properties).
The project team observed that the HTC gains were larger in properties where cross-flow was present. This aligns with expectations. It can be assumed that the AirEx's HTC impact might be higher because the air bricks are simultaneously controlled (cutting out draughts caused by cross flow).

Floor Area / Number of Airbricks



Count	6	12	34	8
	30	50	70	90
Gain (%)	-63.7	-28.1	-21.2	-0.9

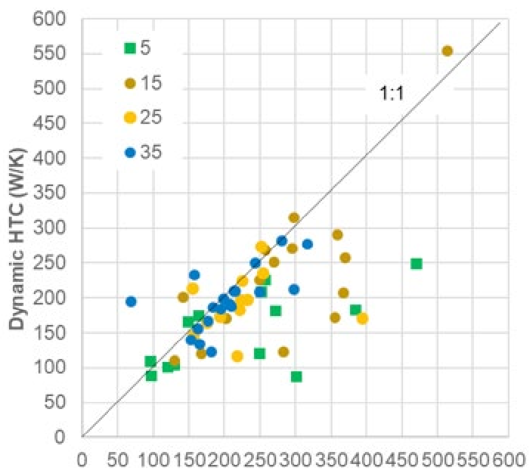


Figure 16

SmartHTC results (dynamic vs open position), based on floor area / no of airbricks – regression plot

As expected, there is better performance for houses with a smaller floor area per air brick. It can be assumed that this might be due to the fact that the air flow into the void when the bricks are open will be greater than with larger area per air brick.

2.1.4. Comparison to existing research on floor heat loss

During the DA submission process it has been raised that according to the accepted wisdom the average heat loss through a floor is approximately 10%, as such, the DA results might over-estimate the savings impact. However, the project team concluded (backed by academic researchers) that the 'accepted wisdom' needs to be challenged in this instance. The reasons are as follows:

- The 10% heat loss through floor is based on models and assumptions, rather than actual in-situ measurements;
- Whilst some existing research state 10% through floor heat loss, other research states 25%, for example: *Harris, D. J., & Dudek, S. J. M. (1997). Heat losses from suspended timber floors. Laboratory experiments measuring heat losses through flooring utilizing a variety of insulation and ventilation rates to determine appropriate strategies for retrofitting insulation. Building Research & Information;*
- The 10% heat loss percentage assumption is purely based on U-values, it does not account for dwelling airtightness (as SAP handles air leakage rates separately). Earlier field trials (conducted on AirEx) shown that opening / closing air bricks does have an impact on dwelling airtightness, with approximate 9% dwelling airtightness improvement for an average property;

- Extensive amount of research from Dr Sofie Pelsmakers demonstrated that the modelled heat losses through ground floor are under-estimated, after having conducted robust in-situ measurements, results are published through peer-reviewed paper from 2017: https://www.tandfonline.com/doi/full/10.1080/09613218.2017.1331315
"if the estimated in-situ floor U-value is significantly greater than assumed and modelled, the benefits of insulating the ground floor might be underestimated, as also noted by Everett, Horton and Doggart (1985) for solid ground-floor heat loss";
- It is also important to consider that evidence demonstrates (see page 290/292 in Dr Pelsmakers' PhD thesis https://discovery.ucl.ac.uk/id/eprint/1505859/1/PELSMAKERS_floorPhD_2016_loRes.pdf) that properties that have been upgraded elsewhere (roofs, walls) except the ground floor, the proportion of ground floor heat loss will be significantly higher; it could be as high as 45% - 60% (purely the U-value, not adjusted for airtightness losses).

2.2 Floor void & internal temperature analysis

2.2.1 Floor void & external temperatures - equation

It is clear from the data (demonstrated by the graphs below) that the void temperature is raised during dynamic period compared to open air bricks. This supports the theory of operation.

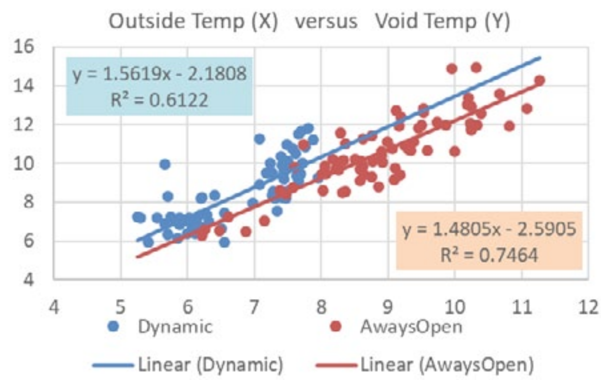


Figure 17

Void ΔT (void-outside) gains in open/closed position – regression plot, averaged by hub (property)

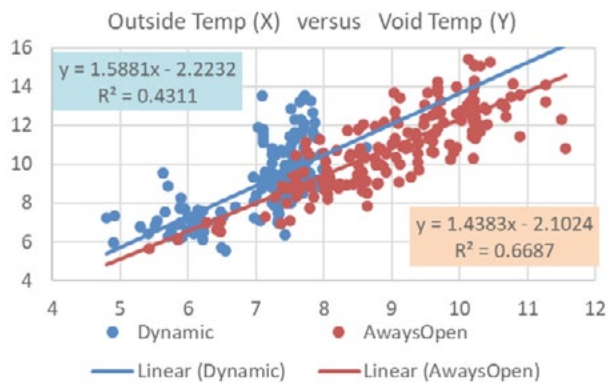


Figure 18

Void ΔT (void-outside) gains in open/closed position – regression plot, averaged by brick unit

2.2.2 The effect of opening on void temperatures

As it is demonstrated on the graph below, the open sub-floor void is more affected by outside temperature than the closed sub-floor void.

Fig.19 demonstrates a Correlation (Pearson) RSq between sub-floor void and outside temperatures. The conclusions are:

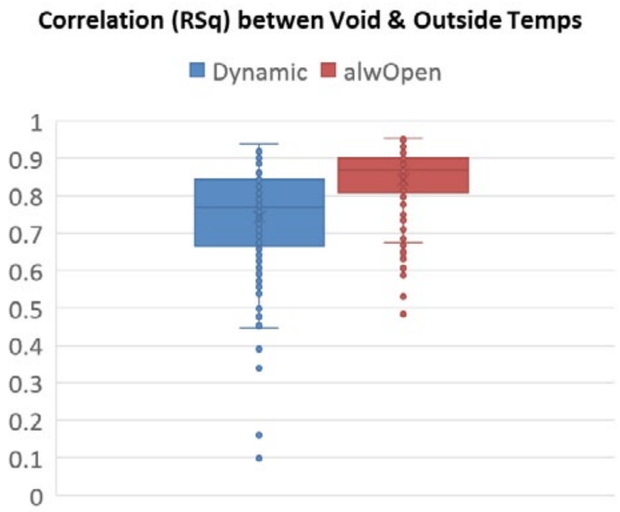


Figure 19

Correlation between void and outside temperature - box & whisker plot

- When the AirEx units are 'always open' mode (to simulate 'pre-install stage), the sub-floor void is consistently more highly correlated with the outside temperature
- Whereas closing the AirEx vents in 'Dynamic' phase "buffers" the sub-floor void against external temperatures

2.2.3 'Ground temperature acts as a buffer'

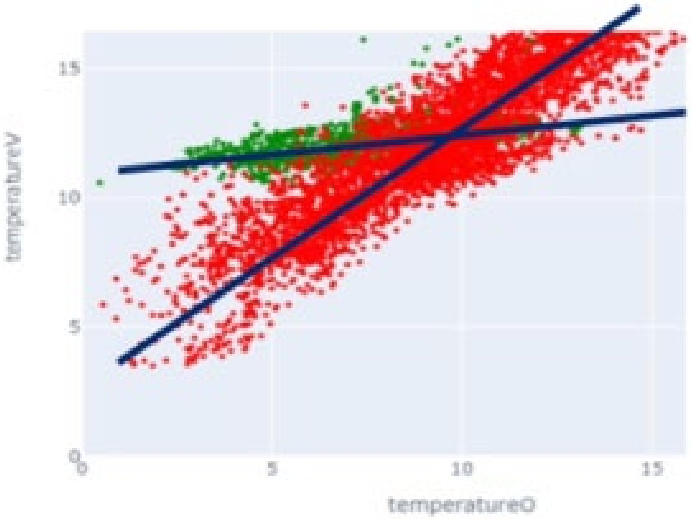


Figure 20

Correlation between void and outside temperature , in the context of ground (soil) temperature

As can be seen on the graph above, during cold periods there is a consistent trend that the sub-floor void temperatures in 'closed' state converge with external temperatures at 10-12 C degrees (10-12 degC is essentially equivalent with the ground temperature).

- The ground temp is relatively unaffected by external air temperature and it appears to buffer the sub-floor void temperature, reverting to this mean;

- It implies that when the external temperature is higher than the void ground temperature, the ground essentially 'cools' the void (i.e. 'buffering effect' of the ground);
- The colder the outside air temperature is, the better AirEx's impact is. A large proportion of heating use is in this external temperature range.

However, an adverse impact can be observed in mild weather (~12 to 18 C degrees) where modest heating is required:

- This implies the impact of AirEx could potentially be improved if the logic changes slightly in this mild weather range (prioritising 'open' command could be more efficient in keeping the underfloor void warm);
- It can be also assumed that a positive cooling effect which could be exploited to cool the house in summer, however, this assumption requires further study.

In regards to the buffering effect of the ground, previous (independent) validation was conducted in 2014. The graph and explanation below demonstrate that the internal ground (soil) temperature vary little within the day.

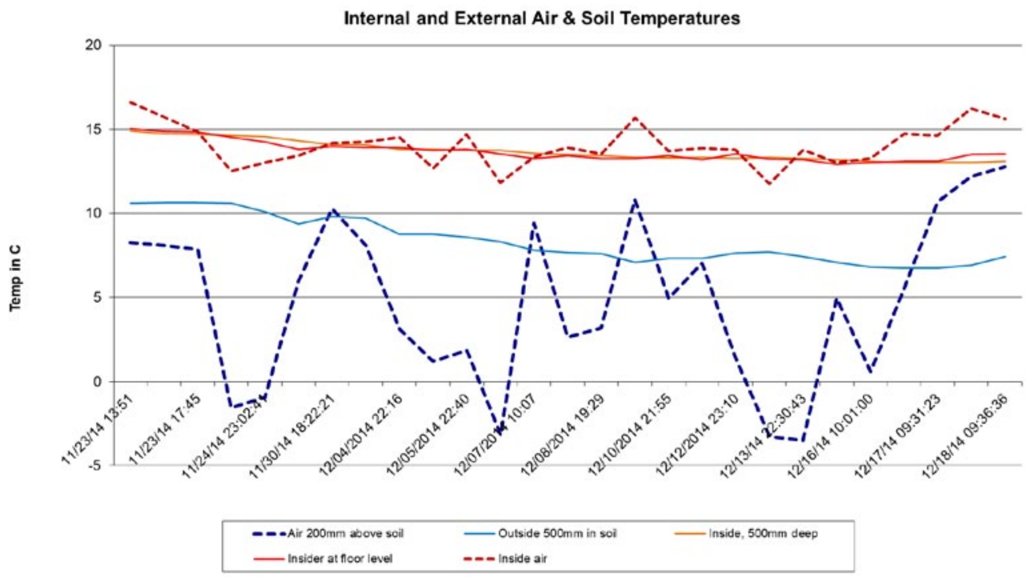


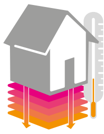
Figure 20

Internal and External air and soil temperatures (study from 2014)

The underground temperature data was based on test results taken between October 2014 and February 2015. Two sets of underground temperature sensors were installed at a property in South Oxfordshire. Each set had 5 calibrated sensors one in the air and 4 at different depths into the ground. One set was installed in October 2014 into the ground outside the house approximately 2m from the foundations. The other set was installed in November 2014 into the ground below a concrete floor (notionally a slab on hard core but due to ground heave this slab is 'suspended' approximately 100mm above hard core).

The external set had one air temperature sensor 200mm above ground, then at 100mm, 500mm, 900mm, 1300mm and 1700mm below the surface, in contact with the soil. The internal set had an air temperature sensor 200mm off the ground within the room but near the external wall, a floor surface temperature sensor beneath carpet then ground sensors at 500mm, 900mm, 1300mm and 1700mm below the surface, in contact with the soil. Measurements were taken a few times a day, and eventually only morning and evening as the ground has a large thermal mass and its temperature varies very, very slowly.

The results in the chart show how the soil 500mm under an unventilated floor slowly reduces in response to outside winter weather but is semi-constant at about 14C. Externally the soil temperature 500mm beneath the surface falls from ~10C to ~7C over the month illustrated. As depth increases, the temperature is more constant and more similar inside and out; e.g. at 1700mm below ground between 23rd November 2014 and 14th February 2015:



	Outside	Inside
Max	13.9	14.4
Average	11.2	12.7
Min	9.4	11.5

2.2.4 Time since closure

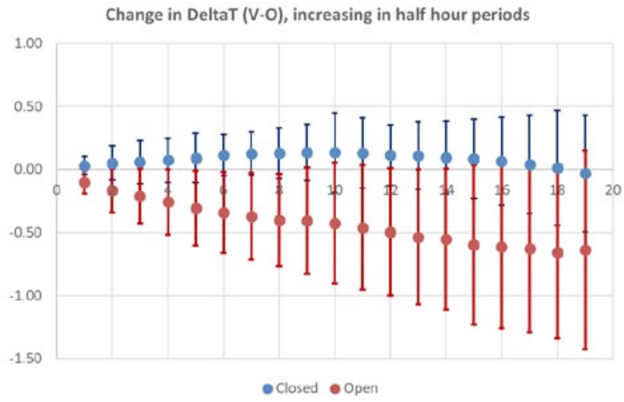


Figure 22

Change in void and outside temperature after closing/ opening, by hour (time since closure)

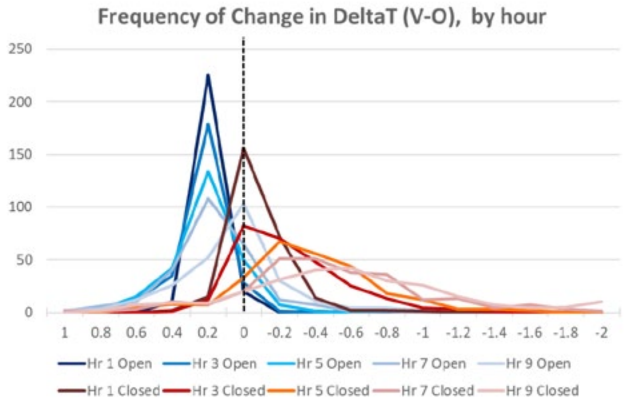


Figure 23

Distribution of ΔT (void – outside) across brick units, by hour (time since closure)

It is to be expected that the void temperature takes time to change and equilibrate after the opening or closing of the AirEx vent. We measured the variation in temperature with time and so could observe this in practice. The above left chart shows the change in the delta (Void – Outside) temperature after opening (in red) or closing (in blue) at AirEx. After closing, the void temperature increases (compared to the outside temperature) for about 10 hours (20 half hour periods) before slightly declining. By contrast, the relative void temperature falls immediately upon opening a vent.

The above right chart shows the distribution of delta (Void – Outside) across many bricks. The blue lines show a tight grouping of delta (Void – Outside), i.e. when closed, the delta stays relatively static. By contrast, after opening, the delta (red lines) show the void temperature "decays" compared to outside, and is different for each void.

With this understanding of temperature changes, the project team assumes that there is further scope to increase the Airex performance by making slight modification to the control logic – again, this requires further study to confirm this assumption.

2.3 U-value analysis

2.3.1 Drivers impacting U-value results

As explained in Section 1.3.3. we obtained valid U-value results for 17 properties. The mean improvement was 19.3% (± 7.5%). The U-values were to an ISO-9869-1 defined uncertainty of 14-28%.

The project team observed some trends that showed larger U-value improvements for mid-terraced properties, followed by end-terraced then semi-detached properties; this aligns with the trends we observed in HTC measurements. Similarly, we observed larger gains for properties with bare floorboards (25% mean improvement) compared to properties with laminate/vinyl floor coverings (17% mean improvement). However, considering that the sample size is reasonably small within each category, we cannot confirm normal distribution for these sub-set of groups, and therefore it is advisable to treat the full set as a sample. When considering the full set, the standard deviation is 16%.

2.3.2 Modelled U-values

We have examined the theory behind AirEx and in particular built a spreadsheet model based on ISO 13370 2017 (Thermal performance of buildings — Heat transfer via the ground — Calculation methods). It was especially useful as it contains methods for calculating the heat loss from suspended floors – noting how closed and open voids require different approaches. We can model this for AirEx and use a proportion of time open with one method and a proportion of time with the other.

The ISO-13370 U-value model for suspended floors with void depths <500mm is based on the combined single U-value for the floor being determined by heat-flow from the internal to the external environment via a number of paths. Firstly, heat is transferred from the floor surface to the sub-floor void by thermal conduction through the floor material (ideally taking account of thermal bridging by e.g. floor joists). Then the heat reaching the sub-floor void is lost to the outside through three main paths:

1. Into the ground underneath the void by conduction;
2. Through the perimeter walls by conduction;
3. Because of air changes by ventilation of the sub-floor void

Within ISO 13370 calculation methods are presented for various floors including suspended floors with and without ventilation. AirEx dynamically changes the way the sub-floor void is ventilated so that when it is closed it is effectively an unventilated sub-floor void but when it is open it reverts to a ventilated sub-floor void. We postulate that the ISO 13370 model for a floor with ventilation should be used to calculate the U value of a floor separately in the two conditions (ventilated and closed) and a duty-cycle then used to produce an average U value for the floor fitted with AirEx.

Inspection of the ISO 13370 model shows that some terms are related to:

1. building geometry
2. ground conditions
3. construction materials
4. air flow in the void.

Terms 1, 2 and 3 do not vary with the type, number or distribution of airbricks and so will not vary with the fitting or operation of AirEx. However, term 4 is altered by airbricks and by the dynamic operation of AirEx.

Within ISO 13370 examination shows that the formula for a ventilated sub floor void can be used throughout but the ventilation terms set to zero when it is closed. Thus, we postulate that if the AirEx is closed 60% of the time and open 40% then the overall U value should calculated as:

$$Ufg;sus;AIREX = Tc * Ufg;sus,unventilated + To * Ufg;sus,ventilated$$

Where:
T_c is proportion of time closed
T_o is proportion of time open
The full detail from ISO 13370 is given below:

$U_{fg;sus}$ is the U value for the whole suspended floor structure including ventilation

$$\frac{1}{Ufg;sus} = \frac{1}{Uf;sus} + \frac{1}{(Ug + Ux)}$$

$U_{f;sus}$ is the U value for the floor structure
U_x is the heat loss in the void and is calculated a long way below.
U_g is U-value of the ground and is calculated:
dg is the equivalent thickness of the ground below the floor (a mathematical concept)

$$dg = dw.e + \lambda g(Rsi + Rf;ins + Rse)$$

dwe is the thickness of the walls
R_{si} is the surface thermal resistance of the floor internally
$R_{f;ins}$ is the thermal resistance of the floor insulation if there is any at the ground.
R_{se} is the surface thermal resistance of the floor externally

And so Ug is:

$$Ug = \frac{2\lambda g}{\pi B + dg} * \ln\left(\frac{\pi B}{dg} + 1\right)$$

λg is the thermal conductivity of the ground and is 1.5 for clay or silt, 2.0 for sand or gravel and 3.5 for rock
B is the ‘characteristic length’ of the floor which is equal to the area divided by half the perimeter.
U_x is the heat loss in the void due to perimeter wall and underfloor space being ventilated and is found from:

$$Ux = 2\frac{h\,Uw}{B} + 1450\frac{\varepsilon\,v\,fw}{B}$$

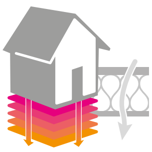
h is the height of the perimeter wall and Uw its U value.
ε is the area of ventilation openings around the perimeter in m² / m
v is the average wind speed at 10m above ground
F_w is the wind shielding factor; 0.02 if sheltered (city centre), 0.05 average, suburban and 0.10 exposed rural.
It is U_x that varies depending on ventilation. In particular, the second term which is important:

$$1450\frac{\varepsilon\,v\,fw}{B}$$

In this term if the parameter ε (the area of ventilation openings) is set to zero (closed AirEx) the term goes to zero.

We postulate that we can model the effect of AirEx by switching this term off if the AirEx is closed and on when AirEx is open according to its duty cycle.

We carried out a few test calculations using this model to investigate the range of impact of closing AirEx and we showed an up to 45% improvement in U value is possible. Two examples for a 6x6m terrace with 2 x 5000mm² bricks per façade are:



Case	U-value Always OPEN	U-value Always CLOSED	Improvement
Solid 9 inch wall, suspended timber floor 4 course above ground level, sand and gravel soil type. *e.g. Victorian terrace*	0.76	0.69	9%
Ditto but floor 200mm above ground on clay and silt soil. *e.g. Victorian terrace*	0.63	0.55	12%
Solid 225 wall below floor, floor 250mm above ground, house built on concrete floor slab with 25mm polystyrene insulation in slab. *e.g. 1970's terrace*	0.79	0.44	45%

2.4 Limitations of the Study

Trial Design
With respect to study design, a large set of households were recruited to the study to test the technology on a range of house types. However, the sample is not intended to be fully representative of UK housing as a whole, because only ECO-eligible households were included in the study (as required by Ofgem) which restricts the sample to socially rented properties.

More broadly, it is not possible to disaggregate the influence of many of the underlying physical house variables (for example property type, detachment, number of bedrooms, etc.). Equally, there will be ‘real life’ differences in householder behaviour (heating use, window opening, etc) which cannot be controlled for. The trial was therefore designed as a paired “repeated measures” trial, which measures the same variable on the same house over different time periods, therefore accounting for some of the underlying unknown variables, and therefore reducing the uncertainties. The trial would need to be significantly larger to investigate these factors in a more in-depth way – which would have meant not meeting the ‘value-for-money’ criteria set by Ofgem.

External Factors
Part of the trial period took place over a period including national lockdown. The possible impact of lockdown on occupants’ behaviour (and hence on HTC results) are explained in the “Data collection” section below.

In addition, the trial took place over relatively extreme UK weather conditions, including a new maximum December temperature, the wettest February on record and unusually sunny April and May (recorded by Met Office). The Dynamic and Open AirEx periods therefore by chance took place in slightly different weather, making normalisation more difficult than would be expected over a typical winter.

Underfloor void uncertainties
Differences in the underfloor void space may be significant between houses. Underfloor voids are little studied and the dynamics of their response to environmental variables is not well understood. The AirEx void temperature data appears to point to a significant influence on the ground temperature in cold periods, effectively buffering the void temperature. The project team speculates that this could vary significantly depending on the underfloor void size, connection to the outside, etc. and a full study of this was outside the scope of the trial. It is expected that through increasing roll-out of the AirEx product, our understanding of the underfloor void environment will increase significantly. Further data will also allow the environment sensing and control system logic to be further improved.

Data collection - SmartHTC
The SmartHTC algorithm makes a number of assumptions in the calculation of the HTC. This includes estimations of the metabolic gains and average daily hot water usage based on the number of occupants listed at each property. Because of the impact of Covid-19 towards the very end of the project, the actual

gains/usage from occupants being home all day during lockdown may have been higher than would otherwise be expected. The project team did not design the trial in anticipation of the significant change of occupancy patterns.

With respect to data measurement, connection to smart meters is difficult due to a national lack of SMETS2 meters in place and connectivity issues with SMETS1 meters. As of June 2020, only a little over 30% of UK households had a smart meter, and the majority of these are SMETS1 meters which are not connected to the DCC (Data Communications Company) and are hence more difficult to connect to. The combination of these factors made it extremely challenging to find a suitable sample of houses with the right type of smart meter, that was functioning, and with the right type of air bricks for the field trial. The connection difficulties and lack of SMETS2 roll-out meant that it was not possible to collect smart meter data, with the result that the uncertainty[5] on the SmartHTC calculations was higher.

All of the sample properties had the required input data for SmartHTC over a minimum of 21 days in both pre & post periods. There were no corrections applied to the data before calculating the HTC. The SmartHTC algorithm itself has in-built corrections designed to compensate for variations in internal and external conditions. Those properties that did not have the required data (e.g. due to temperature sensors failing) were excluded from the data set.

The weather and occupancy conditions were within the operating conditions of SmartHTC (i.e. minimum 7°C temperature difference). The calculation of the HTC and confidence interval is designed to take account of variations of this kind, with each confidence interval levels calculated based on the conditions that occurred during the monitoring, as such, there should not be any implications on the results.

Data collection - U-values

Floor-to-outside-air: The ISO9869 Standard for measuring in-situ thermal transmittance (U-values) defines set criteria for when a test should be ended. These criteria require measurement of the thermal resistance (R-value) using surface temperature sensors on both sides of the substrate being analysed. Because of the specifics of measuring U-values of floors in this project (i.e. floor-to-outside-air, rather than two sides of the floorboards), it was not possible to incorporate this criterion and the U-values presented are purely from the start to the end of the test over whole 24hr periods. The minimum 3-weeks test length would however normally be more than sufficient for the R-value criteria to have converged.

Positioning of Heat Flux Meters (HFM): In all U-value measurements, heat flow meters were generally positioned around the edge of rooms adjacent to an air brick. Because of the occupied nature of the properties, it was impractical and unsafe to locate the heat flow meters within a more central location within a room for such a long period of time. Thermal imaging was used to avoid thermal bridging and

[5] For clarity, HTC uncertainty is a generic figure supplied by BTS for single tests. This is how BTS present with their measurement, it is a calculation of the accuracy of the HTC measurement, in the same way as a temperature sensor would present a measurement +-0.5oC [or 0.1oC/1oC etc.]. Also known as an uncertainty interval or an accuracy estimate. Not to be confused with the Confidence Interval for our whole dataset – as a statistical term.

heat sources (i.e. pipes under the floor). Each heat flow meter incorporated three heat flux plates that were attached to the floor within an approximate area of under 1 m^2 and avoiding any joists. This small area was required to ensure that the single air temperature sensor was within the vicinity of all plates and provided an accurate representation for the ambient temperature at the plate.

Interpretation: By assuming that the floors are of a single homogenous construction, the measured heat flux density at any location in a room will be directly proportional to the temperature difference between the void and ambient internal air temperature at the same location. Taking into account stratification and conductive/convective temperature differences within the room, a measurement closer to external walls will likely have both a lower void and ambient temperature compared to that of a more central location. However, the temperature delta, heat flux density and U-value should remain roughly the same (i.e. we are measuring the ‘relative change’ rather than absolute U-values) and thus it can be interpreted as representative of the entire floor.

We note that, as a new technology with a novel form of “non-physical” intervention, existing physical measurements might not be a 100% suited to measure the AirEx effect. The U-value assessments are proxies for the measuring the outcome of the AirEx intervention, and the project team emphasizes the importance of “relative change”, rather than the “absolute U-value”. Any improvement seen where the heat flow meters were located will be mirrored to varying degrees throughout the rest of the floor. The U-value measurements were performed on a subset of trial properties but the results help validate the physical effect which the SmartHTC results empirically demonstrate. SmartHTC is a measure of whole fabric heat loss, but as the only building element that has essentially changed is the floor, any improvement in HTC should be as a direct result of the air brick being closed.

Data collection - Temperature Data

The weather service the project team uses interpolates data from weather stations and includes corrections for topography and using satellite data to produce the data for a particular location (postcode or lat/long). We have compared this data against weather stations and our own temperature sensors in several locations and shown good agreement.

For all Portsmouth properties, the weather station used is located approximately 10km away to the East. For Walsall properties, the weather station is located at Birmingham Airport, approximately 20km away. When calculating the HTC, the external temperature is averaged over whole 24-hour periods, as such, any minor hourly variation will have limited impact on the mean temperature difference over the entire period. Furthermore, the accuracy of the external temperature measurement is included as a source of uncertainty in the calculation of the confidence interval.

2.5 Cost savings, Lifetime Bills Savings scores

This section outlines the conclusions made on the cost savings impact of AirEx product, using field trial data collected from the ECO DA trial. To determine the average cost savings, the following steps were taken:

- An average property type (that represents the ECO DA sample size the most) was taken into account: a 1930-s cavity walled semi-detached 3-bed house with suspended ground floor;
- Measured (in-situ) whole house HTC values served as a basis of the cost savings calculations (obtained from the ECO DA trial);
- The HTC results were then normalised to 3 different climate regions: South-England, Midlands and Scotland – using the relevant degree day data form each region;
- The annual bills savings and lifetime bills savings were then calculated based on two options: a) gas heated; b) electrically heated homes.

As demonstrated on the tables below: the expected Lifetime Bills Savings for an average Midlands-based gas heated property is £1,845 (±9.5%) (when using 16% HTC results); and it is expected to be £1,311 (±9.1%) (when using 12% HTC results). The monitoring of HTCs occurred throughout a winter season and the opening/closing ratio was carefully recorded, as such, any seasonal impacts are already taken into consideration. The opening/closing ratio is continuously monitored on the sample (and new properties will be added with the increasing roll-out of the AirEx product), as such, it will be possible to further refine the seasonal effect in the future.

The initial fully installed cost of the AirEx system is approximately £450 (based on 5 air brick per property).

Assumptions	
15%	Estimated in-use factor (AirEx)
25	Estimated lifetime in years (AirEx)
0.184	kWh/kg CO_2 conversion for natural gas
0.398	kWh/kg CO_2 conversion for electricity (SAP 2016 factors)
0.97	POPT factor for calculating LBS scores
0.0394	PCDF price (£/kWh) - Gas Boiler
0.184	PCDF price (£/kWh) - Electric Storage

Based on 16% HTC Improvement

	South	Midlands	Scotland	
Whole house **HTC pre-AirEx install**	236 W/K	236 W/K	236 W/K	**HEATING DEMAND**
Whole house **HTC post-AirEx install**	198 W/K	198 W/K	198 W/K	
Whole house **HTC improvement** (%)	16.1%	16.1%	16.1%	
Degree days	1950	2118	2450	
Heating energy demand reduction ΔQ	1,778 kWh/year	1,932 kWh/year	2,234 kWh/year	
Annual savings in £	£70.10	£76.10	£88.00	**GAS**
Lifetime Bill Savings (LBS) score in £	£1,699.20	£1,845.60	£2,134.90	
CO_2 (kg/year) 0.185kWh/kgCO_2	327.2 kg/year	355.4 kg/year	411.1 kg/year	
Annual savings in £	£177.30	£192.60	£222.80	**ELECTRIC**
Lifetime Bill Savings (LBS) score in £	£4,299.70	£4,670.10	£5,402.20	
CO_2 (kg/year) 0.398kWh/kgCO_2	707.80 kg/year	768.78 kg/year	889.29 kg/year	

Figure 24

LBS score estimation for various property archetypes (based on 16% HTC Improvement)
Gas boiler heated, 3 bedroom house, semi-detached, 1930s, cavity walled, with suspended ground floor

Based on 12% HTC Improvement

	South	Midlands	Scotland	
Whole house **HTC pre-AirEx install**	230 W/K	230 W/K	230 W/K	**HEATING DEMAND**
Whole house **HTC post-AirEx install**	203 W/K	203 W/K	203 W/K	
Whole house **HTC improvement** (%)	11.7%	11.7%	11.7%	
Degree days	1950	2118	2450	
Heating energy demand reduction ΔQ	1,264 kWh/year	1,372 kWh/year	1,588 kWh/year	
Annual savings in £	£49.80	£54.10	£62.60	**GAS**
Lifetime Bill Savings (LBS) score in £	£1,207.30	£1,311.30	£1,516.90	
CO_2 (kg/year) 0.185kWh/kgCO_2	232.50 kg/year	252.53 kg/year	292.12 kg/year	
Annual savings in £	£126.00	£136.80	£158.30	**ELECTRIC**
Lifetime Bill Savings (LBS) score in £	£3,055.00	£3,318.20	£3,838.40	
CO_2 (kg/year) 0.398kWh/kgCO_2	502.91 kg/year	546.24 kg/year	631.86 kg/year	

Figure 25

LBS score estimation for various property archetypes (based on 12% HTC Improvement)
Gas boiler heated, 3 bedroom house, semi-detached, 1930s, cavity walled, with suspended ground floor

Based on 6.5% HTC Improvement

	South	Midlands	Scotland	
Whole house **HTC pre-AirEx install**	236 W/K	236 W/K	236 W/K	HEATING DEMAND
Whole house **HTC post-AirEx install**	221 W/K	221 W/K	221 W/K	
Whole house **HTC improvement** (%)	6.5%	6.5%	6.5%	
Degree days	1950	2118	2450	
Heating energy demand reduction ΔQ	718 kWh/year	780 kWh/year	902 kWh/year	
Annual savings in £	£28.30	£30.70	£35.50	GAS
Lifetime Bill Savings (LBS) score in £	£685.90	£745.00	£861.80	
CO_2 (kg/year) 0.185kWh/kgCO_2	132.1 kg/year	143.5 kg/year	166.0 kg/year	
Annual savings in £	£71.60	£77.70	£89.90	ELECTRIC
Lifetime Bill Savings (LBS) score in £	£1,735.70	£1,855.30	£2,180.80	
CO_2 (kg/year) 0.398kWh/kgCO_2	285.70 kg/year	310.30 kg/year	359.00 kg/year	

Figure 26

LBS score estimation for various property archetypes (based on 16% - 9.5% [=6.5%] HTC Improvement)
Gas boiler heated, 3 bedroom house, semi-detached, 1930s, cavity walled, with suspended ground floor

Based on 2.9% HTC Improvement

	South	Midlands	Scotland	
Whole house **HTC pre-AirEx install**	230 W/K	230 W/K	230 W/K	HEATING DEMAND
Whole house **HTC post-AirEx install**	223 W/K	223 W/K	223 W/K	
Whole house **HTC improvement** (%)	2.9%	2.9%	2.9%	
Degree days	1950	2118	2450	
Heating energy demand reduction ΔQ	312 kWh/year	339 kWh/year	392 kWh/year	
Annual savings in £	£12.30	£13.40	£15.50	GAS
Lifetime Bill Savings (LBS) score in £	£298.20	£323.90	£374.70	
CO_2 (kg/year) 0.185kWh/kgCO_2	57.44 kg/year	62.39 kg/year	72.16 kg/year	
Annual savings in £	£31.30	£33.80	£39.10	ELECTRIC
Lifetime Bill Savings (LBS) score in £	£754.70	£819.70	£948.20	
CO_2 (kg/year) 0.398kWh/kgCO_2	124.20 kg/year	134.90 kg/year	156.10 kg/year	

Figure 27

LBS score estimation for various property archetypes (based on 12% - 9.1% [=2.9%] HTC Improvement)
Gas boiler heated, 3 bedroom house, semi-detached, 1930s, cavity walled, with suspended ground floor

Based on 25.5% HTC Improvement

	South	Midlands	Scotland	
Whole house **HTC pre-AirEx install**	236 W/K	236 W/K	236 W/K	**HEATING DEMAND**
Whole house **HTC post-AirEx install**	176 W/K	176 W/K	176 W/K	
Whole house **HTC improvement** (%)	25.5%	25.5%	25.5%	
Degree days	1950	2118	2450	
Heating energy demand reduction ΔQ	718 kWh/year	780 kWh/year	902 kWh/year	
Annual savings in £	£111.00	£120.50	£139.40	**GAS**
Lifetime Bill Savings (LBS) score in £	£2,691.00	£2,922.80	£3,380.90	
CO_2 (kg/year) 0.185kWh/kgCO_2	518.2 kg/year	562.9 kg/year	651.1 kg/year	
Annual savings in £	£280.80	£305.00	£352.80	**ELECTRIC**
Lifetime Bill Savings (LBS) score in £	£6,809.30	£7,396.00	£8,555.30	
CO_2 (kg/year) 0.398kWh/kgCO_2	1,120.94 kg/year	1,217.51 kg/year	1,408.36 kg/year	

Figure 28

LBS score estimation for various property archetypes (based on 16% + 9.5% [=25.5%] HTC Improvement)
Gas boiler heated, 3 bedroom house, semi-detached, 1930s, cavity walled, with suspended ground floor

Based on 21.1% HTC Improvement

	South	Midlands	Scotland	
Whole house **HTC pre-AirEx install**	230 W/K	230 W/K	230 W/K	**HEATING DEMAND**
Whole house **HTC post-AirEx install**	181 W/K	181 W/K	181 W/K	
Whole house **HTC improvement** (%)	21.1%	21.1%	21.1%	
Degree days	1950	2118	2450	
Heating energy demand reduction ΔQ	2,271 kWh/year	2,467 kWh/year	2,854 kWh/year	
Annual savings in £	£89.50	£97.20	£112.40	**GAS**
Lifetime Bill Savings (LBS) score in £	£2,170.00	£2,357.00	£2,726.40	
CO_2 (kg/year) 0.185kWh/kgCO_2	417.90 kg/year	453.91 kg/year	525.06 kg/year	
Annual savings in £	£226.40	£245.90	£284.50	**ELECTRIC**
Lifetime Bill Savings (LBS) score in £	£5,491.10	£5,964.20	£6,899.10	
CO_2 (kg/year) 0.398kWh/kgCO_2	903.94 kg/year	981.82 kg/year	1,135.72 kg/year	

Figure 29

LBS score estimation for various property archetypes (based on 12% + 9.1% [=21.1%] HTC Improvement)
Gas boiler heated, 3 bedroom house, semi-detached, 1930s, cavity walled, with suspended ground floor

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Sponsoring energy supplier: EDF
Trial partners: Portsmouth City Council, Walsall Housing Group & Wolverton Community Energy
Performance monitoring partner: Build Test Solutions
Install partners: InstaGroup, Shropshire Green Energy Centre
Delivery partner: AgilityEco

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