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## Purpose of the Series

The aim of this publication is to provide an opportunity for students to publish the findings of their undergraduate or postgraduate work. Guidance on publication will be given by staff who will act as second authors. It is hoped that by providing a guided transition into the production of papers that students will be encouraged throughout their future careers to publish further papers. Guest papers are welcomed in any field relating to the Built Environment. Please contact E.A.Laycock@shu.ac.uk. A template will be provided on request.

## Acknowledgements

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# CONTENTS

# A LABORATORY STUDY OF THE USE OF LIME STABILISATION ON CONTAMINATED AND UNCONTAMINATED CLAYS

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This study presents the results of experimental research carried out to investigate the effects of lime treatment on naturally deposited kaolinite clay, containing quartz, and a contaminated clay, containing calcium sulfide and heavy metals, known as galligu. The efficacy of lime stabilisation may be evaluated using unconfined compressive strength (UCS) tests which were carried out for different lime contents (0%, 5% and 10% of the sample mass) and various curing times (7, 28 and 90 days). Chemical and mineralogical changes of the two clays were established using X-Ray diffraction (XRD) and X-Ray fluorescence (XRF) in order to establish their effect on the geotechnical properties of the stabilised materials. Lime stabilised clay demonstrated improved geotechnical characteristics including a drop in moisture content (the ratio of the mass of water to the mass of solids in soil), increase in bulk density (the weight of the soil in a given volume, in this case $1m^3$) and decrease in air voids (pockets of air between aggregate particles in the soil). However the net geotechnical improvements in the natural clay were demonstrably less than the galligu, principally in terms of strength. Galligu as recovered has a high moisture content and the alkaline conditions were able to supply sufficient moisture and the optimum chemical environment for effective cation

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exchanges and pozzolanic reactions. For the natural clay the lime addition caused an increase in the optimum moisture needed for effective compaction, which was higher than the natural moisture content of the clay.

Keywords: contaminated land; lime stabilisation; clay; galligu; calcium sulfate

## INTRODUCTION

The stabilisation of soils is an important topic due to the high quantity of low quality soils in the UK (Dexter, 2004). Clay is of particular importance, especially in the north, as it dominates the strata type (British Geological Survey, 2018). Clay minerals exhibit characteristics of affinity for water and the resulting plasticity (ability to be deformed under load) is increased (Bowles, 1989). Therefore on UK earthworks sites clay is often found to be unfit in the natural state for construction purposes due to this high plasticity reducing its strength when used as a fill material.

Quicklime is a popular solution to the high plasticity of clay due to its moisture reduction capabilities. The stabilisation of low quality soils is a more economical and environmentally friendly option to the so called 'dig and dump off site' strategy (Bromage, 2006). By solving the problem on site it avoids the high costs (both direct and indirect) associated with landfill disposal (Hodson, 2010).

Although a number of studies have investigated the effects of lime stabilisation on clay (Beetham et al, 2013; Beetham, 2015; Bell, 1996; Harichane et al, 2012; Louafi et al, 2015; Modarres and Nousady, 2015; Wang et al, 2013; Yam-Nam, 2006), little to no research has examined the effects of lime stabilisation on galligu. This work focuses on remediation of Sighthill Park in Glasgow, with high volumes of galligu which would not have been possible without in-situ remediation.

Galligu is a contaminated by-product of the Leblanc process which was used to convert rock salt into sodium carbonate (Moore et al, 2003). Galligu can have similar characteristics to clay as the by-product material is bound with clay particles, and retaining a high moisture content. This material was disposed of by surface dumping throughout the 19th century. Chemical analysis shows galligu is

high in calcium, as well as potassium, magnesium, arsenic, barium, chromium, lead, copper and zinc (Scientific Analysis Laboratories Ltd., 2016).

The purpose of this study is threefold: to evaluate the use of lime in geotechnically improving soils, to establish the effects and processes of lime on the differing soils, and to compare the usefulness of contaminated soils with more conventionally used soils in the field of land development.

# LITERATURE REVIEW

## Clay Mineralogy and Identification Methods

Clay mineralogy heavily influences the soil's strength in its natural state as well as post stabilisation. Different soil chemistry and mineralogy result in changes to the nature of the reactions between the lime and soil (Beetham et al, 2013). To investigate clay mineralogy, X-Ray diffraction (XRD) and X-Ray fluorescence (XRF) can be useful tools. They identify mineral and chemical compounds through their unique patterns and wavelengths, which act as fingerprints for identification (Sheffield Hallam University, 2018a).

Roger, Glendinning and Dixon (1996) describe the quicklime reaction simplistically as:

Calcium oxide + water → Calcium hydroxide + heat

$$CaO + H_2O \rightarrow Ca(OH)_2 + \text{heat}.$$

Beetham (2015) found that when the lime that is added is greater than the initial consumption of lime (ICL) value, the clay-soil pore water becomes 12.4pH. This high alkaline environment causes calcium, from the added lime, to react with the clay minerals, aluminosilicates, forming cementitious compounds binding the clay particles together. The clay mineralogy influences the rate at which pozzolanic reactions result in increased strength; expansive clay minerals, such as montmorillonite, provide the greatest rate of reactivity enabling maximum efficiency of the pozzolanic reactions. The SEM analysis identified calcium aluminate silicate hydrates (C-A-S-H) as the chemical component for the pozzolanic reaction in the samples a finding supported by XRD results.

Clay particles are almost always hydrated, surrounded by layers of water molecules called adsorbed water (Bowles, 1989). The edges of the clay minerals in the adsorbed layer have net negative charges, leading to attempts to balance the charges by cation attraction, thus assisting the soil-lime reaction through cation exchanges.

*Table 1: Indicative literature on clay mineralogy and laboratory determination of mineralogical contents before and after lime stabilisation.*

| Author (Date) | Focus of work | Summary results | Summary findings |
|---|---|---|---|
| Nayak and Singh (2007) | XRD and XRF used in study aiming to characterise clay samples using a range of instruments | alumina and silica oxide were present in the clays in major quantities, while other minerals such as magnesium and calcium were present in trace amounts. | Characterisation of the XRD patterns indicated the presence of quartz, kaolinite, hematite, illite, and tridymite as the major phases. |
| Modarres and Nousady's (2015) | XRD study on the lime stabilisation of clay samples containing quartz, montmorillonite and kaolinite | in stabilised specimens clay minerals had a lower peak XRD intensity | Attributed to the occurrence of the pozzolanic reaction. Removal of calcium hydroxide and creation of calcite |
| Beetham's (2015) | XRD and scanning electron microscope (SEM) to identify the chemical composition of the pozzolanic reactions | The triaxial shear strength and California Bearing Ratio (CBR) tests saw strength improvements with increased curing time. | attributed to the cation exchanges in the short term and pozzolanic reactions in the longer term, but also to the heat generated in the exothermic reaction between the quicklime and soil moisture in the immediate short term. |

Bell (1993) states that a decrease in strength with excessive lime addition is because lime itself has neither sufficient friction nor cohesion. The optimum lime content is estimated to range between 4.5-8% for soils, with a higher percentage needed for soils with higher clay fractions. Additionally Bell (1993) noted that soil-lime mixtures compacted at moisture contents above the optimum moisture content attain higher strength, after brief curing periods, than samples compacted at moisture contents below the optimum moisture content. This is because the lime is more uniformly diffused and occurs in a more homogenous curing environment at or above the optimum moisture content.

The literature review identified one case where galligu had been stabilised, reported by (Bromage, 2006). In this the top 350mm layer of a 4m deep galligu strata was stabilised and compacted to prevent surface water infiltration and

decrease mobility of the galligu contaminants and various heavy metals including arsenic, zinc and lead.

Methods that have been used throughout the different studies on clay stabilisation and are useful to replicate include measuring an average UCS reading from at least 3 separate samples for each group, to improve the scientific validity of the data. Also increasing the lime dosage up to no more than 10%, with 0% lime acting as the control group, as it has been found that the UCS will reduce after reaching a maximum value. This value is expected to be reached after a lime dosage of between 6-10% and it is of no interest studying the samples after they have reached this value. A summary of the different studies into the stabilisation of clay can be seen in Table 2.

The variables selected for the laboratory study were lime content, curing period duration and material type. The dependent variables include the UCS as the primary focus, and air voids, bulk and dry densities and moisture content as secondary variables.

*Table 2: A summary of the lime stabilisation studies*

| Author/s and Date | Lime Content Conditions (%) | Curing Period Conditions (Days) | Findings |
|---|---|---|---|
| **Beetham (2015)** | 8.5 | 8, 32, 194 | Strength increased with lime & curing time |
| **Bell (1996)** | 2, 4, 6, 8, 10 | 1, 3, 7, 14, 28 | Strength increased with lime (up to 4-6% then decreased to 10%) & curing time |
| **Harichane et al (2012)** | 0, 4, 8, 10 | 1, 7, 28, 90 | Strength increased with lime & curing time |
| **Louafi et al (2015)** | 0, 2, 4, 6, 8 | 1, 7, 14, 21, 28 | Physical and mechanical properties of soil improved with lime & curing time |
| **Modarres and Nousady (2015)** | 3, 6, 9 | 7, 28, 60, 180 | Stabilised samples contained high amounts of calcite |
| **Wang et al (2013)** | 0, 3, 6 | 28, 90 | Strength increased with lime (up to 3% then decreased to 6%) & curing time |
| **Yam-Nam (2006)** | 0, 2, 5, 10, 15 | 0, 7, 28 | Strength increased with lime & curing time |

Samples of both clay and galligu for the laboratory study were sourced from the same site: Sighthill Park in Glasgow, which at the time was an active remediation site. The material for the laboratory testing was sampled by trained VHE geo-environmental engineers using standard sampling procedures, to ensure the samples were as representative of the material as possible.

# PROCEEDURE

## Laboratory Testing

*Sample Preparation:*
Galligu and clay as received were passed through a 20mm sieve, in accordance with BS1377-7-1990 to ensure that the largest particle diameter did not exceed the one-fifth of the diameter of the compaction mould. A trial of the method outlined below was carried out to ensure that the procedure was robust and allowed the creation of replicate samples. The sample conditions summary for the cube moulds can be seen in Table 3. Quick lime percentages were added representative of the sample weights and then mixed into the samples by method of a laboratory mixer to obtain thoroughly mixed, homogeneous samples. The 0% lime conditions acted as the control group for both materials. Fifty-four 100x100mm cube moulds were compacted by method of a 4.5kg hand rammer, displayed in Figure 1, with a fall of 450mm in 5 layers with 27 blows, in accordance with BS1377-4-1990. Following the methodology outlined in BS1377-4-1990, moisture content of the soil prior to compaction was determined using gravimetric losses after drying at 100-105ºC for 24 hours.

*Figure 1: photograph showing the 4.5kg hand rammer. (Credit: S. Williams)*

| UCS Sample Quantity | | | | |
|---|---|---|---|---|
| **Material** | **Lime (% of Sample Mass)** | **Curing Period (Days)** | | |
| | | 7 | 28 | 90 |
| **Clay** | 0 | 3 | 3 | 3 |
| | 5 | 3 | 3 | 3 |
| | 10 | 3 | 3 | 3 (2) |
| **Galligu** | 0 | 3 | 3 | 3 |
| | 5 | 3 | 3 | 3 |
| | 10 | 3 | 3 | 3 |

*Table 3: UCS Sample Conditions Summary Samples made (shown in brackets where number tested different)*

## Cured (conditions):

Mass and dimensions of the specimens was recorded just before UCS testing to ensure no residual moisture with resultant effect on strength.

The dry and bulk densities were established, as well as estimation of the volume of voids.

The UCS measurements were the product of an average of 3 readings from each condition.

As the only British Standard for the UCS test set out the methodology for tests with cylindrical specimens, a German standard was adopted for the deformation rate. The German institute for standardisation (DIN 18137-2:2011-04) states the deformation rate standard for the UCS test is 1% of the initial specimen height per minute. This equates to 1mm per minute for the 100x100mm test samples.

Table 3 shows that one clay +10% lime sample from the 90 days cured condition was lost due to the crumbling of the specimen rendering it untestable.

*Chemical/Mineralogy Analysis*

X-Ray diffraction (XRD) and X-Ray fluorescence (XRF) were utilised to analyse the mineralogy and chemical composition of the natural clay as well as clay and galligu stabilised with 10% lime. This was to establish what minerals and

chemical components are present and are therefore playing a role in the soil-lime reaction and strengthening of the samples. A chemical report undertaken on VHE's behalf by Scientific Analysis Laboratories Ltd. (2016) testing 14 pure galligu samples was analysed with the same aim for the unstabilised galligu.

*Statistical Analysis*

Strength is the most important variable when considering soils for earthworks purposes and was used as the principle dependent variable in statistical tests. A between-variable univariate ANOVA was conducted to test the significance of the main effects, as well as the interactions between the means of the 3 independent variables. Bonferroni post-hoc tests were conducted where the ANOVA results were found to be significant.

# RESULTS

## XRF Characterisation

*Table 4: Chemical Composition of XRF Samples*

| Analyte | Compound formula | Natural Clay | Clay +10% Lime | Galligu +10% Lime |
|---|---|---|---|---|
| | | Concentration (%) | | |
| **Si** | **$SiO_2$** | 55.88 | 56.77 | 6.31 |
| **Al** | **$Al_2O_3$** | 25.47 | 14.88 | 5.37 |
| **Ca** | **CaO** | 7.58 | 21.02 | 77.08 |
| **Fe** | **$Fe_2O_3$** | 4.59 | 3.51 | 0.67 |
| **Mg** | **MgO** | 2.42 | 0.64 | 1.29 |
| **K** | **$K_2O$** | 2.42 | 1.99 | - |
| **Na** | **$Na_2O$** | 0.86 | 0.351 | 0.84 |
| **Ti** | **$TiO_2$** | 0.39 | 0.308 | 0.09 |
| **S** | **$SO_3$** | 0.16 | 0.10 | 8.12 |
| **P** | **$P_2O_5$** | 0.14 | 0.28 | 0.12 |
| **Mn** | **MnO** | 0.09 | 0.16 | - |
| **Cl** | **Cl** | - | - | 0.08 |
| **Sr** | **SrO** | - | - | 0.04 |

Silicon dioxide and alumina and calcium oxide were found in both the natural clay and clay +10% lime samples, as seen in Table 4. Calcium oxide was more prominent in the clay +10% lime sample, whereas more alumina oxide was detected in the natural clay sample. Calcium oxide was found in the galligu +10%

lime sample in high concentrations, alongside sulfur trioxide, silicon dioxide, alumina oxide.

## XRD Characterisation

*Table 5: Chemical Composition of XRD Samples*

| Compound Name | Chemical Formula | Natural Clay Detection Score | Clay +10% Lime | Galligu +10% Lime |
|---|---|---|---|---|
| **Quartz** | $SiO_2$ | 75 | 71 | - |
| **Calcite** | $Ca(CO_3)$ | 53 | 52 | 71 |
| **Calcium Hydroxide** | $Ca(OH)_2$ | - | 41 | 50 |
| **Anorthite** | $CaAl_2Si_2O_8$ | 9 | 4 | - |
| **Kaolinite** | $Al_2Si_2O_5(OH)_4$ | 17 | - | - |
| **Allevardite** | $K_1 Al_4 Si_8 O_20$ | 15 | 7 | 15 |
| **Cronstedtite** | $Fe_3FeSiO_4$ | - | 10 | - |
| **Magnesium Sulfate** | $MgSO_4$ | - | - | 6 |
| **Cordierite** | $Mg_2Al_4Si_5O_{18}$ | - | - | 11 |
| **Calcium Sulfate** | $Ca_2SO_4$ | - | - | 4 |

Table 5 displays the XRD analysis results. Calcium hydroxide was found in both the clay +10% lime and galligu +10% lime specimens in large quantities, but not in the natural clay. Quartz and calcite were present in the clay samples, with generally consistent levels between both the natural clay and clay +10% lime, reducing slightly in the stabilised sample. The kaolinite present in the natural clay sample was not found in the stabilised clay sample at all. The galligu +10% lime sample contained calcite too, in even higher quantities, among magnesium sulfate, cordierite and calcium sulfate.

*Physical properties of compacted clays*

Figure 2 shows the effect of lime on the moisture content in all of the curing period conditions across both materials. The negative correlation is clear,

meaning lime has a universal effect on both galligu and clay; increased lime content results in decreased moisture content. The density of the clay follows a trend of reduction after lime application, whereas the galligu's density increases. These changes can be seen in Figures 3 and 4. A negative correlation between lime application and air voids can be seen in Figure 5. The effect across both materials increased lime content results in decreased air voids.

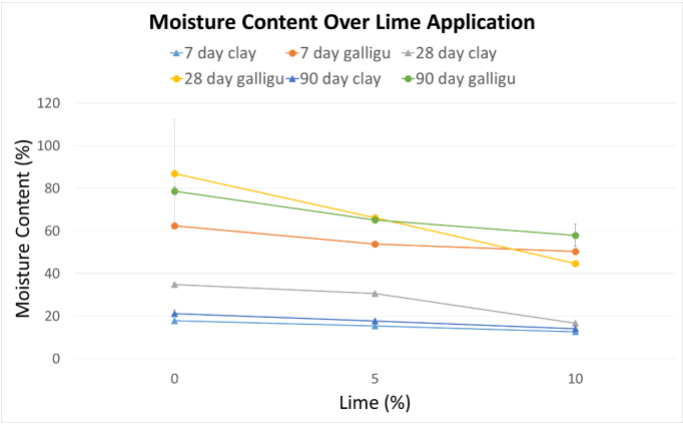


*Figure 2: the effect of lime on the moisture content of the soils, across the different curing periods and material conditions.*

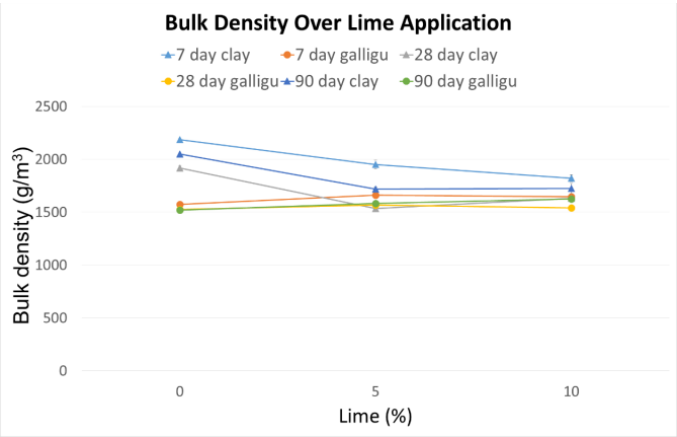


*Figure 3: the effect of lime on the (apparent) bulk density of the soils, across the different curing periods and material conditions; measured at lab conditions.*

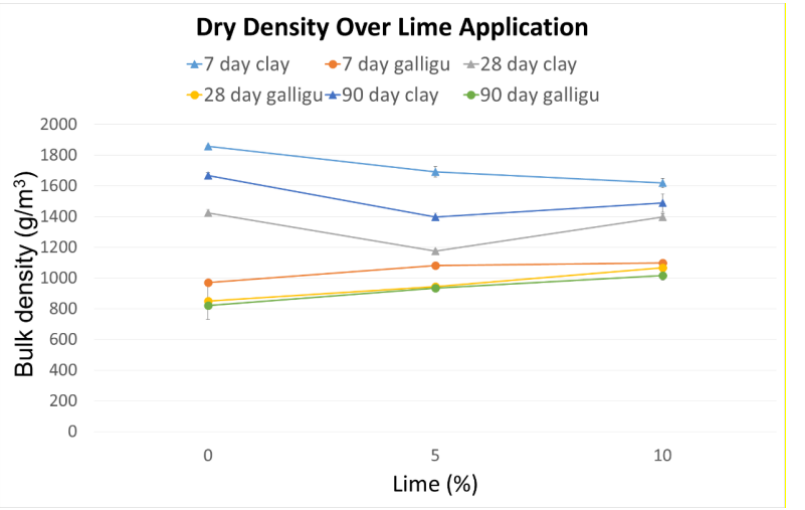


*Figure 4: the effect of lime on the dry density of the soils, across the different curing periods and material conditions. (Measured after oven drying).*

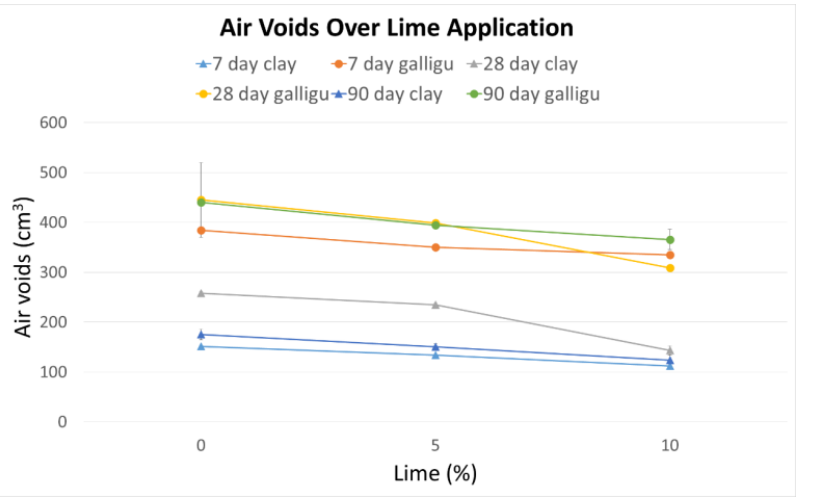


*Figure 5: the effect of lime on the air void quantity in the soils, across the different curing periods and material conditions.*

*Soil Strength*

The means and standard deviations of the primary data can be seen in Table 6.

***Table 6a: Descriptive Statistics*** *Dependent Variable: Unconfined compressive strength of Galligu*

| Galligu | | | | |
|---|---|---|---|---|
| **Lime Content (%)** | **Curing Time (Days)** | **Mean ($N/mm^2$)** | **Std. Deviation** | **N** |
| **0** | 7 | 0.0024 | 138.39 | 3 |
| | 28 | 0.0011 | 120.98 | 3 |
| | 90 | 0.0044 | 877.43 | 3 |
| | **Total** | **0.0026** | **1502.2** | **9** |
| **5** | 7 | 0.005 | 1055.07 | 3 |
| | 28 | 0.0024 | 246.47 | 3 |
| | 90 | 0.0081 | 1240.14 | 3 |
| | **Total** | **0.0052** | **2592.44** | **9** |
| **10** | 7 | 0.0037 | 249.36 | 3 |
| | 28 | 0.0056 | 1405.78 | 3 |
| | 90 | 0.0136 | 1444.43 | 3 |
| | **Total** | **0.0076** | **4630.86** | **9** |
| **Total** | 7 | 0.0037 | 1248.44 | 9 |
| | 28 | 0.0031 | 2108.94 | 9 |
| | 90 | 0.0087 | 4098.31 | 9 |
| | **Total** | **0.0052** | **3688.52** | **27** |

***Table 6b: Descriptive Statistics*** *Dependent Variable: Unconfined compressive strength of natural clay*

| Natural Clay | | | | |
|---|---|---|---|---|
| **Lime Content (%)** | Curing Time (Days) | Mean (N/mm2) | Std. Deviation | N |
| **0** | 7 | 0.0008 | 201.63 | 3 |
| | 28 | 0.0029 | 1095.31 | 3 |
| | 90 | 0.0044 | 2098.36 | 3 |
| | **Total** | **0.0027** | **1951.07** | **9** |
| **5** | 7 | 0.0038 | 848.2 | 3 |
| | 28 | 0.0014 | 276.91 | 3 |
| | 90 | 0.0006 | 373.9 | 3 |
| | **Total** | **0.0019** | **1524.69** | **9** |
| **10** | 7 | 0.0004 | 152.62 | 3 |
| | 28 | 0.0006 | 478.15 | 3 |
| | 90 | 0.0006 | 71.99 | 2 |
| | **Total** | **0.0005** | **287.78** | **8** |
| **Total** | 7 | 0.0017 | 1646.98 | 9 |
| | 28 | 0.0016 | 1168 | 9 |
| | 90 | 0.002 | 2281.38 | 8 |
| | **Total** | **0.0018** | **1670.79** | **26** |

A between-variable univariate ANOVA was conducted to test whether material strength significantly varied by: 1) material (clay, galligu) and 2) lime content (0%, 5% and 10%); and to test how: 3) material influences soil strength in varying levels of lime content; 4) curing time influences strength in varying levels of lime content for each material.

There was a significant main effect of material, $F(1, 35) = 191.45$, $p < .001$, such that galligu (Mean = 0.0052) was stronger than clay (Mean = 0.0018) overall, as seen in Figure 6.

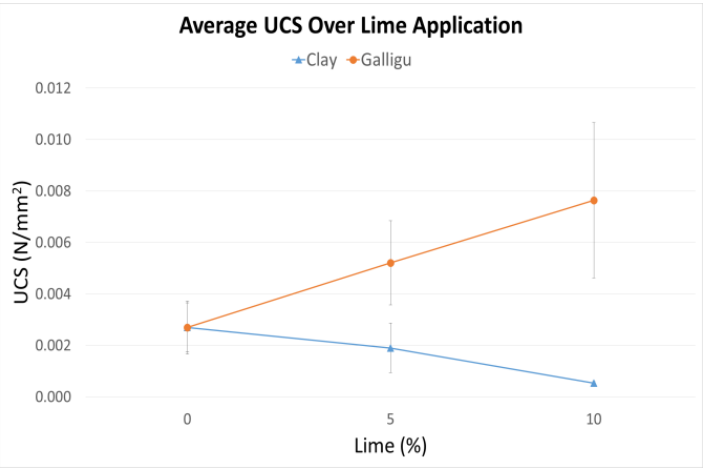


*Figure 6: The average unconfined compressive strength of each material, across the different lime dosages.*

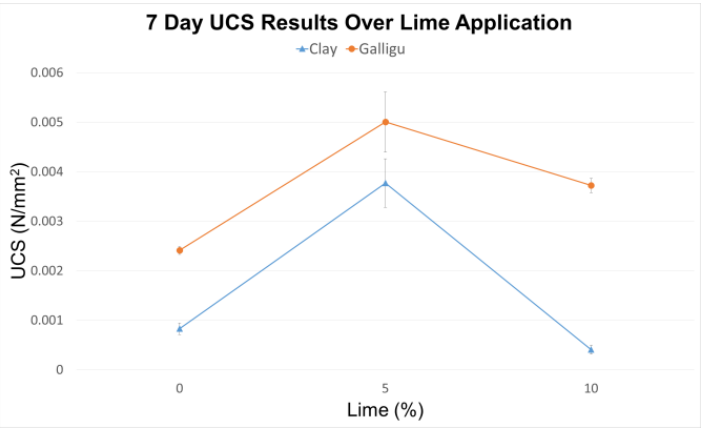


*Figure 7: The effect of lime on the unconfined compressive strength of the soils, across the different material conditions after 7 days of curing.*

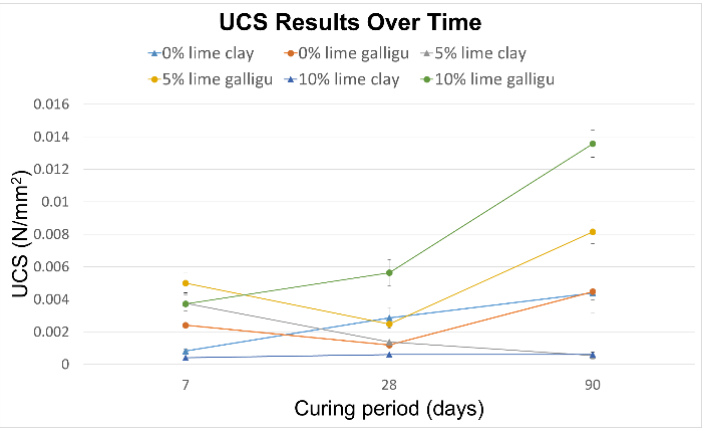


*Figure 8: The effect of curing time on the unconfined compressive strength of the stabilised soils, across the different lime dosages and material conditions.*

There was a significant main effect of lime content $F(2, 35) = 10.46$, $p < .001$, such that strength increased when lime content increased across material and curing time (0%: Mean = 0.0027; 5%: Mean = 0.0036; 10%: Mean = 0.0043).

In order to interpret this finding Bonferroni post-hoc tests were conducted. The factors found to have statistically significant effects are listed below.

| | |
|---|---|
| Figure 6. | Significant two-way interaction between material and lime content across curing time, $F(2, 35) = 66.01$, $p < .001$.<br>For Galligu, strength was highest at 10% lime content (Mean =0.0076)<br>Natural clay was stronger at a lime content of 0% (Mean = 0.0027) |
| Figure 7: | significant increase in strength between lime content at 0% and at 5% ($p = .022$)<br>non-significant difference in strength between lime content at 5% and 10% ($p = .065$) |
| Figure 8. | There was a significant three-way interaction between curing time, lime content and material, $F(4, 35) = 14.38$, $p < .001$.<br>For galligu, curing time increases strength partially in lime contents of 5%<br>Greater strength increase with time for galligu with 10% lime<br>For clay curing time decreases strength in lime contents of 5%<br>For clay with 10% lime content, strength increases at first before stabilising between 28 and 90 days |

# DISCUSSION

## XRD Analysis

The cured galligu +10% lime contained greater quantities of calcite than either the natural clay or the clay and lime, suggesting that the gain in strength is related to the formation of calcite, and highlighting the potential for a higher strength to be found in the galligu (Modarres and Nousady, 2015). Calcium hydroxide was identified as the cementitious chemical component of the lime-soil reaction, although this could only be detected in the natural clay and galligu at 10% lime content. Calcium hydroxide content was greater in the galligu, and it is postulated that high pH of galligu, found in Scientific Analysis Laboratories Ltd.'s chemical report (2016) to be 10.58 as an average of 14 samples due to the high calcium content, aided the pozzolanic reactions between existing aluminosilicates after lime application, as proposed by Beetham (2015).

The laboratory work showed replication in the results gained for natural clay in terms of a reducing moisture content with increasing lime corroborating work by several previous authors (Beetham, et al, 2013; Beetham, 2015; Bell, 1996; Harichane et al, 2012; Louafi et al, 2015; Modarres and Nousady, 2015; Wang et al, 2013; Yam-Nam, 2006). The natural clay has also been previously found to show a decrease in density after lime stabilisation in other studies (Beetham,

2015; Bell, 1996; Harichane et al, 2012; Louafi et al, 2015; Modarres and Nousady, 2015), again seen in this work. Air voids were observed to decrease in volume after the addition of lime to natural clay which correlates with the findings of previous studies (Beetham et al, 2013; Beetham, 2015; Louafi et al, 2015).

A significant increase in UCS strength 0 to 5% lime in clay was found by other researchers (Beetham, 2015; Bell, 1996; Harichane et al, 2012; Louafi et al, 2015; Modarres and Nousady, 2015; Wang et al, 2013; Yam-Nam, 2006) which was only replicated in the 7 day curing period condition.

## *Moisture Content*

The explanation for the negative correlation of increased lime content resulting in decreased moisture content is the exothermic reaction between the lime and water, resulting in evaporation of the soil's moisture in the immediate short term (Beetham, 2015). Galligu had a higher moisture content than clay in all the curing period conditions, highlighting the material's lower quality in this geotechnical characteristic.

### *Soil Density*

The improvement of the density of the galligu can be attributed to the rearrangement of the soil particles, creating a more solid structure. The greater moisture content improves the efficiency of the lime diffusion and provides sufficient water to precipitate pozzolanic hydrates. As the natural clay has a lower moisture content than the galligu, there is insufficient water to effectively complete the reaction of the lime in order to sufficiently bind the soil particles. As a result, the soil dries up and the density of the clay is reduced. Galligu generally had lower bulk and dry densities than those of clay, displaying the material's lower suitability than the clay for earthworks in this area.

### *Air voids*

The reduction in air voids occurs due to the rearrangement of the soil particles after lime application, creating a more homogenous structured arrangement through the moisture reduction of the soils (Louafi et al, 2015). However, in the case of the clay, the reduction in air voids does not result in an increase in density as the soil is too dry to bind together, so although the voids are filled with soil particles, it does not mean the soil is compact or stable.

Galligu had a higher quantity of air voids than clay in all curing period conditions, highlighting the material's lower suitability for earthworks in this category.

### *Soil Strength*

Galligu was found to be the stronger of the two materials in the laboratory study, as confirmed by the between-variable univariate ANOVA. This was an unexpected finding as the high moisture content, high quantity of air voids and the low density of galligu, was expected to reduce the strength potential of the

material in comparison to clay. However, the high strength results can be explained as the higher moisture content in the galligu supplied the lime with adequate water for the cation exchanges in the short term, and for the pozzolanic reactions in the long term, to improve the soil strength (Louafi et al, 2015). In contrast, the clay did not have as much moisture to supply strengthening processes, so was dried out, and even in one case crumbled, thus reducing the strength.

Additionally, soil-lime mixtures compacted at moisture contents above the optimum moisture content attain higher strength after brief curing periods, than samples compacted at moisture contents below the optimum moisture content, such as the clay samples (Bell, 1993). This is due to the lime being diffused more uniformly in materials of a higher moisture content, and therefore the reaction is facilitated in a more homogenous curing environment. Furthermore, more water is needed for the dissociation of lime, accounting for the increase in optimum moisture content in the stabilised material (Harichane et al, 2012). The galligu contained sufficient moisture to reach this increased optimum moisture content; whereas the clay did not. The extent of the lack of moisture in the clay after stabilisation can be seen in Figure 9, displaying a natural clay sample and a clay +10% lime sample. The deformation of the natural clay sample highlights a lack of strength pre-stabilisation as well as post-stabilisation.

However, the secondary data analysis of the NDG readings of stabilised and unstabilised clay and galligu in the field determined clay was stronger than galligu. This was the expected outcome, but conflicts the findings of the primary research. This is likely due to the outside effects in the field, such as moisture input from rain through the infiltration of the soil, influencing the moisture content of the stabilised material and allowing the clay-lime reaction to reach its full potential in strengthening the soil.

It is also worth noting that, while still significant, the difference in strength between clay and galligu in the secondary field data was only 2.23% proctor compaction, whereas galligu was found to be almost 3 times as strong as clay on average in the laboratory. So even with the moisture infiltration in the field assisting the strengthening of the clay when stabilised, the galligu still attains high strength when compared to the clay, whereas in the laboratory, the galligu attains far greater strength than the clay.

*Figure 9: photographs showing a clay +10% lime sample on the left, and a natural clay sample on the right.*

*Optimum Lime Percentage Dosage:*
The optimum lime percentage dosage, out of the 0%, 5% and 10% conditions, for the best UCS results was found to be 10% for galligu. After lime stabilisation the galligu becomes stronger than the clay and continues to strengthen up to 10% lime application, meaning this percentage of lime suits the pozzolanic reactions the best in galligu. The pozzolanic reactions are able to reach higher strengths in galligu as more of the cementing agent, calcium hydroxide, was formed from cation exchanges at an earlier stage due to the higher moisture content in galligu, and can therefore be crystallised during the pozzolanic reactions to improve soil strength.

In clay the contrary is seen as the UCS decreases with lime application, meaning 0% is the optimum dosage for strength in clay. This is because the pozzolanic reactions are not able to crystallise the cementing agent and therefore improve the strength, as the soil had dried too much in the 5% and 10% conditions and could not bind together as well as in the galligu. The lower moisture content of the clay could not supply the lime with enough moisture for an optimum reaction at the earlier stage.

The UCS increase from 0% to 5% lime is due to the modification of the soil's characteristics by the lime through processes such as cation exchanges between silica and alumina, in the lime, and the water producing the gel cementing agent (Louafi et al, 2015). Between the 5% and 10% lime conditions the strength increase is less significant because, in some cases, the maximum UCS value had been reached (Balogun, 1984) as 10% samples were closer to the optimum moisture content than the 5% (Wang et al, 2013).

The secondary data analysis again found contradicting results; that unstabilised clay was stronger than stabilised clay, and that unstabilised galligu was stronger than stabilised galligu. However, this area of the secondary data research must not be considered with too much validity as only the inherently bad material was stabilised on site, because of high stabilisation material costs. In result the poor quality material which was stabilised had a much lower strength than the unstabilised material.

*Effect of Curing Time on Strength Improvement:*

The galligu strengthened with curing time as the pozzolanic reactions were able to reach their full potential and strengthen the soil over time. Whereas the pozzolanic reactions in the clay were not able to reach their full potential and the soil's moisture was dried up, meaning any strength improvements were not as significant as in the galligu. The visual difference between the two material types at the maximum curing time condition of 90 days can be seen in Figure 10 displaying a galligu +10% lime and a clay +10% lime sample, with the galligu sample clearly more structurally stable.

*Figure 10: photograph displaying a galligu +10% lime sample on the left and a clay +10% lime sample on the right after a curing period of 90 days.*

In some cases, as in the clay +5% lime, increased curing time resulted in a further decrease in the soil strength, as the longer the samples were left to cure, the drier the samples became, thus reducing the soil strength. Interestingly the natural samples continued to harden with curing time, due to the warm curing conditions under plastic bags allowing a slight strengthening of the material.

# CONCLUSIONS

- Galligu had more air voids, a higher moisture content and lower bulk and dry densities than clay pre and post stabilisation.
- However, it must be concluded from the laboratory investigation that galligu is more suitable for earthworks than clay, due to the greater UCS results of galligu as strength is what is measured most commonly to validate earthworks sites.
- The effectiveness of lime in geotechnically improving the soils was varied. Galligu responded more effectively to lime stabilisation, increasing in density and strength, whereas the opposite effect was recorded in clay. Air voids and moisture content both reduced universally with lime application across both material types.
- The optimum lime percentage dosage was found to be 10% in galligu and 0% in clay. The high moisture content of the galligu increases the lime application threshold before the maximum UCS is reached, whereas the clay, in laboratory conditions, has a much lower lime application limit before the maximum UCS is reached.
- However, some constraint must be applied when generalising these findings as it is worth noting galligu is a variable material in terms of its geotechnical properties, dependent on what the contaminated material has binded with when dumped. In some cases the waste product has binded with different types of clay, wielding varying high moisture contents, in other cases it has fused with granular material, creating a solid mass. For the purposes of this study the former was used in the laboratory investigation, aiming to find a way to stabilise the worst of the material.
- Nevertheless, this study has identified the key processes occurring in both the clay and galligu when stabilised over a 90 day curing period. Galligu was found to be an effective earthworks material that can be utilised as a fill material on remediation sites once stabilised, or even in its natural state, offering an alternative to the dig and dump remediation method and its associated negative consequences.

## RECOMMENDATIONS

There are several options to further this research:

- One would be to replicate a laboratory study with more targeted lime percentage dosage conditions between 2-12%, to identify with more accuracy the optimum percentage dosages. This research could include the addition of water after the mixing stage before compaction commences, in order to simulate water infiltration in the field.
- Another, and arguably more valid, method would be to undertake field research, similar to the secondary data collection method used in this study, but with a matched pairs design in which the same material is tested before and after stabilisation, instead of different qualities of material being tested and then compared.
- Different variations of clay and galligu could be tested in either of these experimental studies to investigate the difference in geotechnical properties, but also lime stabilisation processes, within the varying materials.
- The use of scanning electron microscope (SEM) analysis could also be incorporated in the research, as another method of analysing the soil mineralogy changes throughout lime stabilisation.

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## REFERENCES

Balogun, L. A. (1984). Influence of geological origin on the geotechnical properties of lime-stabilized laterites. 8th Regional Conference for Africa on Soil Mechanics and Foundation Engineering. Harare, 355-362.

Beetham, P. (2015). Enhancing the understanding of lime stabilisation processes. PhD. Loughborough University.

Beetham, P., Dijkstra, T., Dixon, N., Fleming, P., Hutchison, R., and Bateman, J. (2013). Lime stabilisation for earthworks: A UK perspective. Proceedings of the Institution of Civil Engineers - Ground Improvement. 168(2), 81-95.

Bell, F. (1996). Lime stabilization of clay minerals and soils. Engineering Geology. 42(4), 223-237.

Bell, F. (1993). Engineering treatment of soils. London: E. & F.N. Spon.

British Geological Survey (2018). Geology of Britain Viewer. [Online]. Last accessed: 12th January 2018, from: http://mapapps.bgs.ac.uk/geologyofbritain/home.html

British Standards Institution. (1990). BS 1377-4:1990: Methods of test for Soils for civil engineering purposes — Part 4: Compaction related tests. BSI.

British Standards Institution. (1990). BS 1377-7:1990: Methods of test for Soils for civil engineering purposes — Part 7: Shear strength tests (total stress). BSI.

Dexter, A. (2004). Soil physical quality Part I: Theory, effects of soil texture, density and organic matter, and effects on root growth. Geoderma, 120(3-4), 227-239.

Bowles, J. (1989). Physical and geotechnical properties of soils. New York: McGraw-Hill.

Bromage, A. (2006). Cement offers real solution for brownfield land remediation. Concrete, 40(1), 39-40.

Moore, H. M., Fox, H. R., and Elliott, S. (2003). Land reclamation: Extending the boundaries: Proceedings of the Seventh International Conference of the International Affiliation of Land Reclamationists, Runcorn, United Kingdom, 13-16th May 2003. Lisse: Balkema.

Harichane, K., Ghrici, M. and Kenai, S. (2012). Effect of the combination of lime and natural pozzolana on the compaction and strength of soft clayey soils: a preliminary study. Environmental Earth Sciences. 66(8), 2197-2205.

Hodson, M. (2010). The Need for Sustainable Soil Remediation. Elements, 6(6), 363-368.

Louafi, B., Hadef, B. and Bahar, R. (2015). Improvement of Geotechnical Characteristics of Clay Soils Using Lime. Advanced Materials Research. 1105(1), 315-319.

Modarres, A., and Nosoudy, Y. (2015). Clay stabilization using coal waste and lime — Technical and environmental impacts. Applied Clay Science, 117(1), 281-288.

Nayak, P., and Singh, B. (2007). Instrumental characterization of clay by XRF, XRD and FTIR. Bulletin of Materials Science, 30(3), 235-238.

Scientific Analysis Laboratories Ltd. (2016). Certificate of Analysis. (1-17, Rep. No. 583874-1). Glasgow.

Sheffield Hallam University (2018a). X-ray diffraction (XRD). [Online]. Last accessed: 11th February 2018, from: https://www.shu.ac.uk/research/specialisms/materials-and-engineering-research-institute/facilities/x-ray-diffraction

The German institute for standardisation. (2011). (DIN) 18137-2:2011-04: Soil, investigation and testing - Determination of shear strength - Part 2: Triaxial test. DIN.

Wang, D., Abriak, N., Zentar, R. and Chen, W. (2013). Effect of lime treatment on geotechnical properties of Dunkirk sediments in France. Road Materials and Pavement Design, 14(3), 485-503.

WYG. (2016). Detailed Quantitative Risk Assessment Report (1-61, Rep. No. A091465). Glasgow.

Yam-nam, E. (2006). Geotechnical and ground improvement aspects of motorway embankments in soft clay, Southeast Queensland. PhD. Griffith University.

# AN INVESTIGATION OF THE IMPLEMENTATION OF ENERGY SAVING AND EMISSION REDUCING TECHNOLOGIES IN THE UK FOOD RETAIL INDUSTRY

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The implementation of innovative technology which reduces energy usage and harmful emissions is a vital to tackling the issue of environmental sustainability in food retail. This study aimed to discover the main drivers and barriers faced by retailers when making decisions regarding the implementation of new technologies, specifically their refrigeration equipment. The project also aimed to utilise the barriers and drivers present to form a coherent example of an approach which retailers could consider adopting. A mixed method approach to the investigation was used, as it capitalised upon the advantages of quantitative and qualitative research, which is needed when tackling an issue with both technical and political aspects. The research involved testing the cost-effectiveness and soft benefits of currently available innovative technologies by using monitoring data to measure the energy usage and other parameters of Aerofoil technology. Additionally, experts from major food retailers were interviewed to identify their decision-making processes and the main drivers and barriers affecting them. The study into Aerofoils found that they cost-effectively saved a significant amount of energy whilst also providing soft benefits to the retailer. The main driver, and barrier, facing the decision-making process of retailers was found to be profitability. Both the quantitative and qualitative research showed that the barrier of profitability can be overcome by taking advantage of Enhanced Capital Allowances and working closely

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with technology developers. Exploration into views on the European Union's fluorinated gas regulation found that it can act as both an incentive or barrier to reducing environmental impact. The study establishes the importance of retailers' involvement in the technology development process and recommends a holistic approach focusing on energy usage reduction to be most lucrative for both the retailer and the environment.

**Keywords:** Food Retail, Energy, Sustainability, Technology, Emissions

# INTRODUCTION

The UK food retail market is worth £184bn per annum (IGD, 2017) and is an economically competitive environment. It is one of the most environmentally impacting industries in the UK, meaning there is need for serious thought into the reduction of energy usage and emissions. Harmful emissions in the food retail industry mostly come from energy usage, but the direct emissions resulting from refrigerant leakage also have environmental implications. A method of increasing the rate of development and implementation of innovative technologies is therefore essential.

Policies emanating from UK law, the European Union (EU) and internationally, can provide a significant amount of persuasion to retailers; however, some can be difficult to accommodate as they are not always technology neutral (Peters, 2017). The UK government's Enhanced Capital Allowances (ECA) scheme incentivises the usage of energy saving technology through tax breaks. The scheme should effectively encourage the development of technologies, although a decision to invest in the latest advancements may be hindered by the faith in the capability of currently available equipment. To theorise an effective way of reducing environmental impact, the extent to which these policies act as drivers and barriers to the progressive implementation of technologies, must be understood.

# RESEARCH METHOD

The purpose of this paper is to provide an insight into the drivers and barriers affecting the retailer's decision-making when implementing energy efficient technologies; focusing on refrigeration. The underlying philosophical ambition of the research is to reduce emissions and energy consumption, thereupon reducing anthropogenic influence on climate change. A focus on the decision-making

process of the retailer and the effectiveness of Aerofoils as a technology have been chosen. The methodology chosen is that of mixed methods; Greene et al (2001) considered the benefits of this to be increased insightfulness, validity and comprehensiveness. The approach used in this paper uses a quantitative study of Aerofoil effectiveness to aid qualitative research into the understanding of retailers' decision-making processes.

The quantitative monitoring data was collected through two secure online databases, owned by a food retailer, to validate the effectiveness of Aerofoil technology in comparison to current technologies. As this data was commercially sensitive, a letter of consent, confirming agreed use of the data, was obtained. This collection method was chosen because it produced accurate and professional data as it was gathered by a professional trusted source through the use of probes in the system. The analysis of qualitative research involved producing visual graphs and finding relevant economical representations of what the datasets meant.

The qualitative data used interviews, undertaken allowed respondents to say as much as they would like and use spontaneity in their answers to provide rich data for analysis (Oppenheim, 1992). With solid quantitative data to support the process, interviewees were asked specifically about the realistic benefits and what the results would mean in a real-world situation in terms of further implementing the technology. The calibre of the interviewees is important to this research as they must have adequate knowledge of how and why decisions in the food retail industry are made. The participants chosen were therefore from the industry and hold a position of influence where new technology implementation is concerned. The participants include professional experts from 3 different major retailers in the industry, with a combined experience of over 60 years. The participants were named Expert A, Expert B and Expert C. The interviews were analysed by linking findings to themes found in the literature review.

The findings from this analysis were used to form a comprehensive overview of the current decision-making process and generate a concept of how it can be improved. This is known as embedding the data, which involves one data set providing a supportive role for the other (Creswell & Clark, 2007); Greene et al (1989:259) defined this as "development". In an area of research such as this one, a purely qualitative investigation may not hold significant weight to enable the development of a conclusion.

# LITERATURE REVIEW

## Energy Consumption and Emissions

The energy consumption and Greenhouse Gas (GHG) emissions originating from food retail industry outlets are considerable, they are responsible for around 3% of total energy usage and 1% of total GHG emissions in the UK (Tassou et al,

2011). With the chilled and frozen food market growing, the UK represents Europe's largest market for chilled prepared foods (Mylona et al, 2017a).

The ability to model energy performance benefits the endeavour to reduce environmental impact (Ma et al, 2012), as food outlet buildings have complex interlinked heat exchanges in the buildings, modelling their performance is difficult (Mylona et al, 2017a).

## Key Policies

Gamel et al (2017) stated that renewable energy investments in retail are *"increasingly affected by policy measures and subsidies"* (Gamel et al, 2017:92). Despite this, they do not show exactly how policies affect the decision-making process.

The current most important refrigerant regulation in the EU is 517/2014 on F-gases; the target is to reduce the use of F-gases by 79% by 2030 compared to the 1990 levels, aiming to reduce the impact of refrigerant leakage, or direct emissions (European Commission, 2014). The regulation targets a distinct area of technology hence affecting the decisions made in the food retail industry across the EU (Polzot et al, 2016).

Peters (2017) believes that the F-gas regulation could have been calibrated more effectively as to consider the life cycle impacts of systems, by using the Total Equivalent Warming Impact (TEWI). He believes the current F-gas regulation does not encourage the development of new technology, and that using the TEWI assessment would create a 'technology neutral' industrial agenda (Peters, 2017) as it is the sum of direct and indirect GWP discharged (Islam et al, 2017). Despite this, retailers must react accordingly to current policies.

In addition to this, subsidised schemes, backed by the government act as strong incentives for the use of innovative and sustainable technologies in retail. The Enhanced Capital Allowance (ECA) scheme allows companies to pay less tax on their profits when they have invested in technology specified on the Energy Technology List (ETL) (Carbon Trust, 2014). The ECA scheme gives 100% tax relief for the first year of system operation on the *"qualifying capital expenditure"* (Carbon Trust, 2014, p. 4). Whereas there is sufficient literature covering what ECA is, there is an absence of papers regarding the level of its usage. The ETL shows a wide range of products which have been certified (ETL, 2018), showing that the scheme must have significant prominence in the industry and it is worth researching further to find out its effect on retailers' decision-making.

## Innovative Technologies

Technological innovation in the food retail industry is at an all-time high as retailers have set their own impressive internal targets (British Retail Consortium, 2014). As changes may affect profitability (McCright et al, 2016), retailers can be pessimistic of the solutions available. It is therefore vital that end users consider a wide range of solutions, in order to achieve environmental goals (Peters, 2017).

A low-cost technology which can effectively achieve economic payback is heat recovery. Heat recovery is where the heat emitted from a refrigeration system is used for space or water heating. The integration of refrigeration and HVAC systems reduce the volume of natural gas burned for heating (Kolokotroni et al, 2015). Waitrose quote a reduction in operating costs of £65,000 per store per year (Peters, 2017), demonstrating it as an example being implemented effectively to benefit both the environment and the retailer.

A technology focusing on reducing emissions is $CO_2$ refrigeration systems, carbon dioxide is a natural refrigerant with a GWP of just 1. This means that it is much less harmful to the environment when refrigerant leakage occurs, it is therefore seen as an attractive and simple option. Aldi's plans to convert all stores to $CO_2$ is based on them seeing a reduction in potential refrigerant gas carbon emissions by 99% from doing so (Cooling Post, 2017). One disadvantage of $CO_2$ systems is that the refrigerant needs to be run at much higher pressures than HFCs and therefore uses more energy (Peters, 2017). It is believed that by embracing a gas leakage reduction strategy instead, direct benefits to the environment would be maximised, and expenditure minimised (Churchyard & Bailey, 2012). To reduce leak rates at these higher pressures, there must be additional training to carry out maintenance; this could be a challenge (Peters, 2017).

Aerofoils are a simpler technology, they guide the cold air in the display case away from the shop aisle, this keeps cold air circulating within the system and improves efficiency (Aerofoil, 2018). This is seen as attractive to supermarkets as it can aid refrigeration performance without having to put doors on display cases (RAC, 2015). A paper by Foster et al (2014) studied the impact Aerofoils had on the energy consumption of a system, the air guides reduced energy consumption by 17%. As there is little other research, that has been published, past the point of Aerofoil's launch in 2016 and subsequent usage by multiple supermarkets, further research into the technology will provide an insight into how they have become widely implemented and validate energy savings previously seen. To increase the implementation of new technologies, it must be understood how current technologies succeed.

## Commercial Approach

A paper from the U.S. EPA (Environmental Protection Agency), by Klemick et al (2015), looked at energy efficient supermarket refrigeration system investment decisions. Their findings suggested that retailers do not have the information

available to make decisions about these technologies. However, the paper mentions that they exclude hypermarkets (Klemick et al, 2015), meaning the businesses, which hold a large proportion of the market share, are not represented. This significantly affects the relevancy of the paper as a whole and re-opens the gap in the literature concerning the decisions made.

A non-regulatory barrier experienced by decision-makers is the 'energy efficiency paradox', in which the perception of energy efficient technologies is that they have higher risk than other investments, or do not have the payback potential of investments with the same perceived risk (CSE & ECI, 2012). Further research into the possible presence of an energy efficiency paradox in the food retail industry could support further understanding of the decision-making process.

# RESULTS

The qualitative research was undertaken to gain an insight into the success of an energy and emission reducing technology, with the view to utilising the information found in the interviewing process. Basing the analysis on the structure of the literature review ensured that all research objectives were met.

## Energy Consumption and Emissions

The interviewing process was utilised to find the current state of the industry regarding the understanding of its own emissions and energy usage. The response from candidates was that the issue was very much apparent to retailers. All three experts expressed a keen interest in the subject and also conveyed the importance of it to their respective businesses.

Candidates were all at liberty to divulge information regarding the internal quotas to which they work towards; and three similarities were identified. Firstly, the targets were set at the very highest level of the business, showing the importance of including every aspect of the company in the reduction of environmental impact. Secondly, the quotas all referred to energy as the commodity to which the target is set, this was as expected because the reduction in energy usage is what will drive the most difference in carbon emitted. Finally, the targets set were all long-term targets, showing that the retailers were all prepared to commit to a sustained journey of betterment.

An important point raised when discussing internal quotas was that they are generally based on energy usage because the energy bills faced by retailers is one of their biggest costs, and that reducing this cost will increase the margin of profit to be made.

## Policies

The results from the interviewing process lead to the realisation that policies can be both beneficial and detrimental to the encouragement of reducing environmental impact.

The most debatable policy, that sparked differing opinions through interviews, was the EU Fluorinated Gas Regulation, which aims to reduce the usage of HFC refrigerants due to their high Global Warming Impact (GWP). The experts' views were varied, one suggesting that it is not a barrier, another suggesting that its aggressiveness has provoked some change and the final expert strongly believing that the regulation is a massive barrier. Surprisingly, the expert with the view against the regulation also had the most cognizant reasoning behind their views. The recurring theme for the argument against the regulation is that it only provokes a movement to the use of a different refrigerant and not towards developing new technologies. Another important point is that the natural refrigerants types to which it forces a change, are less energy efficient to run, increasing the respective energy usage and increasing the indirect environmental impact of the system. The regulation provides a seemingly unwarranted focus on direct refrigerant impact (referring to when refrigerant leakage occurs) rather than the holistic view of including both indirect and direct environmental impact.

As for providing agitation to provoke retailers to act on climate change mitigation strategies, it may motivate change, but this may not be in the correct direction and may cause more damage through indirect impact if the change is not correctly managed.

## Innovative Technologies

To achieve a reduction in environmental impact, the production and development of the currently available innovative technologies must be investigated to determine whether a lack of available technology is a barrier to achieving this.

This paper uses the technology of Aerofoils to study whether or not this is the case.

The analysis of two energy usage datasets spanning 6 months allowed for the moving averages graph, shown in figure 1, to be constructed. The lengthy duration chosen solidified any findings as it spanned the same 6-month period, of June to January, in both datasets. The data also allowed for calculations to be made on average energy consumption, meaning that a quotable figure for percentage saving of 18.9% could be calculated. This supported the figures found by Foster, McAndrews and Evans (2014) and showed that the rate of return based on the chilled cabinet energy savings alone was 3.14 years, which is well below the 5-year target of many end users.

Analysis was also carried out on a 24-hour dataset, giving information on how the Aerofoil technology impacted the actual performance of the system. The study of

the 6-month datasets showed that the summer periods showed proportionately better energy savings than the winter months, this led to a theory that the Aerofoils must be positively affecting system stability instead of purely energy usage. The software used did not allow for data extraction as comma-separated values (CSVs), therefore the graphs (figures 2 and 3) were visually compared.

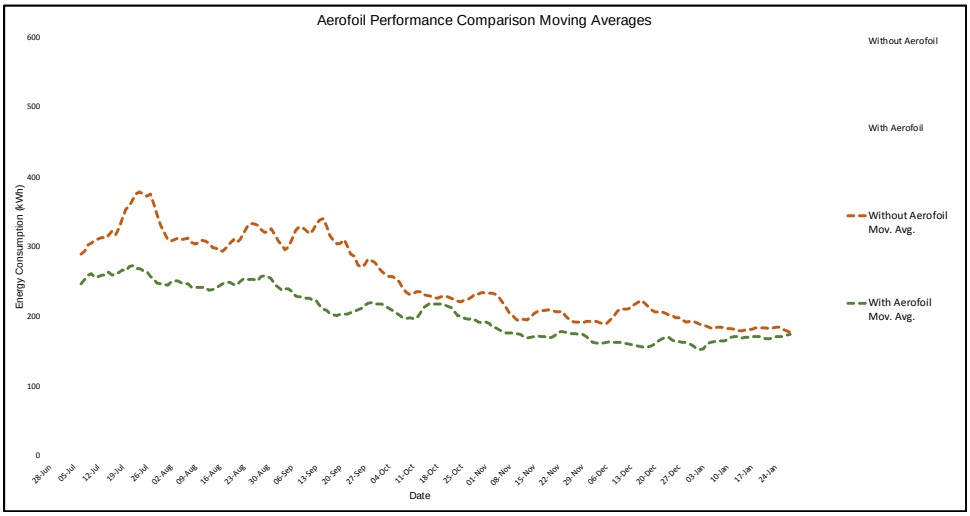


*Figure 1. Moving average comparison of a system with and without Aerofoils.*

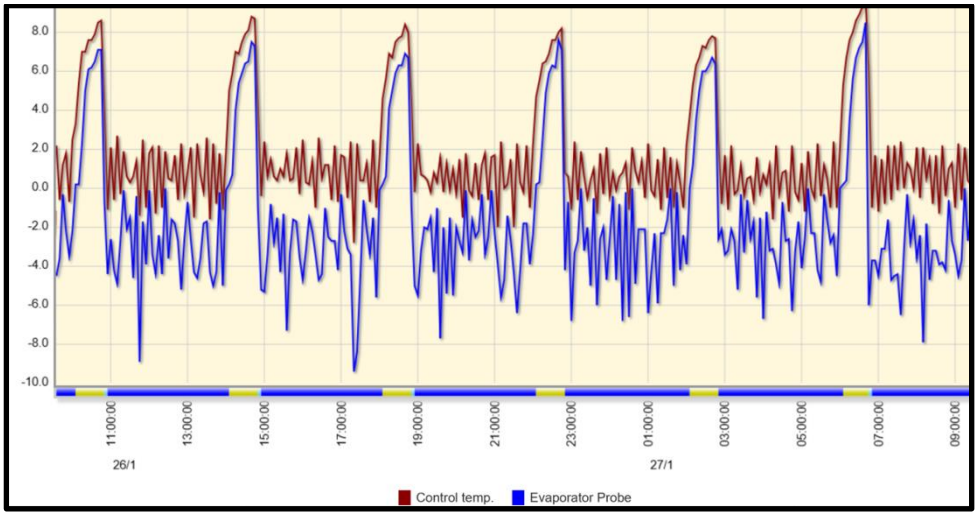


***Figure 2.*** *System with Aerofoils – Control & Evaporator Probe Temperature*

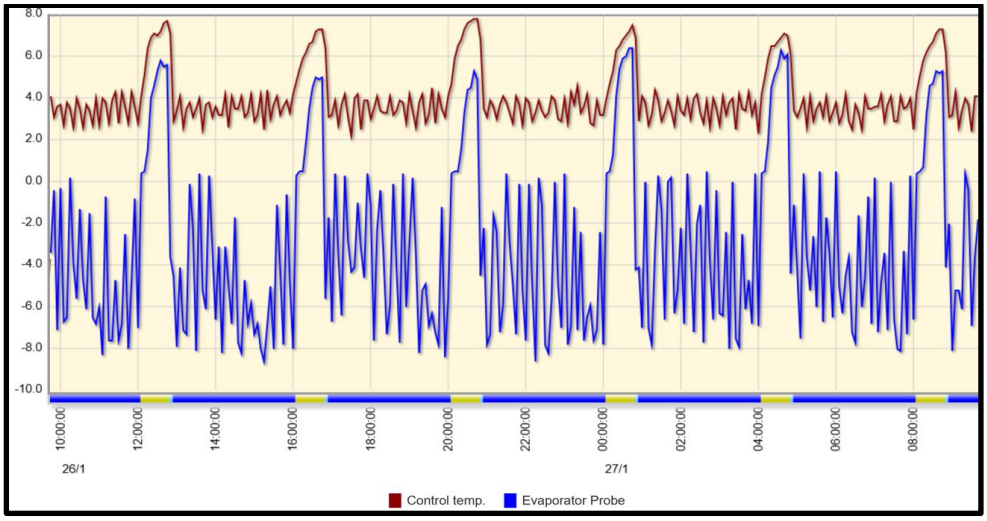


***Figure 3.*** *System without Aerofoils – Control & Evaporator Probe Temperature*

The 24-hour data shows that the system with Aerofoils experiences consistently higher evaporator temperatures whilst still achieving lower control temperatures. This shows that the system efficiency is better due to the energy efficiency being higher (Sun et al, 2017). The visual differences between the temperature variabilities illustrates the fact that the system is more stable with Aerofoils installed.

*Commercial Approach*

Interviewing the experts revealed that the retailers' approach is to tackle the issue holistically and with long term goals, with one expert even stating that the company had made much more progress since longer term targets were put in place. This is because it allows them to focus on the overall impact on the business's profitability; reinstating the fact that money is a main driver in the industry. As this is the case, the preferred payback rates for end users are astringent, candidates confirming that they are tasked with finding 4 to 5-year payback periods. It came as little surprise that, when asked about the ECA scheme, all three candidates expressed the usefulness and impact that it has had on their decision making. The ECA scheme allows for shorter payback periods to be achieved and therefore positively impacts both the retailer and consequently the environment.

Existing relationships between suppliers and developers of technologies was found to be an important aspect to the decision-making process that had not become apparent through initial research. One expert also outlined the importance of not only having a working relationship with the developers but also playing a part in the development of the technology itself. This allows the end user to ensure that the product will deliver to specification.

The findings from interviewing indicated that softer benefits also have an impact on retailers' decision-making. Aspects such as customer satisfaction and maintenance costs may not be as conspicuous as savings from energy reduction, but they can facilitate more sales or less maintenance needed, therefore affecting the profit margin. One candidate brought light to the fact that soft benefits can work in the opposite direction also, for example, the usage of natural refrigerants requires more specialist training for maintenance and therefore a 'soft barrier' is established.

*Establishing an Optimal Approach*

Utilising the findings from the previous sections of results, it became possible to formulate a guideline for decision-makers regarding the optimal approach to tackling the issue of environmentally friendly technology implementation.

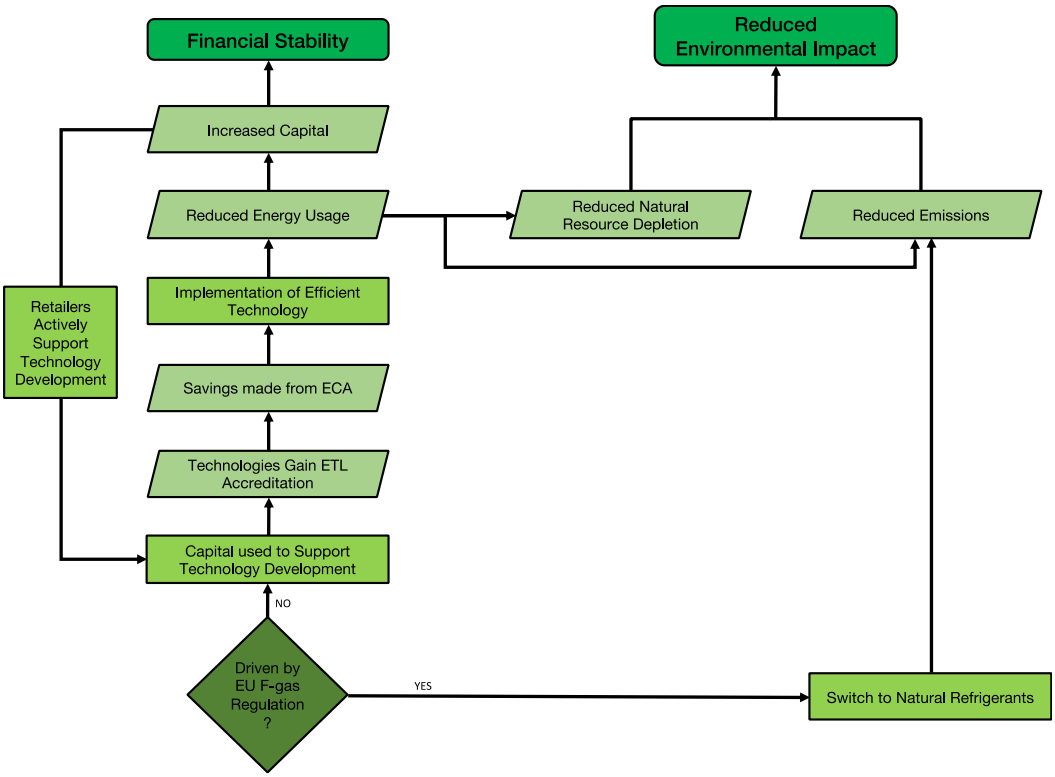


*Figure 4 Flow Diagram of optimal approach to be taken by retailers.*

It had been established that profitability was the most prominent driver in the industry and therefore the reduction of energy was the most sensible avenue to focus on when attempting to reduce environmental impact. This is because focusing solely on the reduction of direct emissions does not holistically encompass the entire business and actually reduces less carbon than if energy usage was reduced.

Figure 4 depicts a pathway which retailers should be able to use in order to reach an end goal of both environmental protection and financial gain.

# CONCLUSIONS

The research into technology implementation in the food retail industry has successfully led to several verdicts, involving policies, technologies and the role of the retailers. The most influential driver, and barrier, was found to be profitability, however this is influenced by other aspects.

The study demonstrates that the UK government-backed ECA provides a vital incentive to retailers; the effectiveness of this scheme is reflected by the extent to which it is already utilised by retailers. Additionally, the research in this paper shows that the active involvement of retailers in technology development will provoke growth in this area as well as producing more capable technologies for ECA, whilst giving retailers confidence that the product will meet objectives.

The investigation also covered the views on the EU F-gas regulation, and the reasons behind the views. It has led to the conclusion that the regulation imposes aggressive objectives on retailers and centres the focus on a switch to natural refrigerants rather than on reducing the environmental impact holistically. As a result there is little opportunity for retailers to benefit economically, due to no reduction in energy bills. The decision was made that the optimal approach should focus on the reduction of energy, as it motivates change whilst achieving a more holistic end goal.

Aerofoil technology was analysed and was found to be an incredibly cost-effective solution. This investigation showed that there are technologies currently available that provide energy benefits without a large volume of capital needed. The results showed that Aerofoils are effective due to being developed in conjunction with retailers; demonstrating the need for retailers to actively support technology development.

The exploration into the current commercial approach not only found profitability from energy reduction as the main driver but also found several soft benefits which can affect decision-making. Customer satisfaction, maintenance costs and publicity are all aspects which cannot be overlooked when developing new technologies; this emphasises the need for retailers to be actively involved in the development of technologies, as the retailer can ensure that these aspects are not neglected.

The optimal approach for increasing energy saving and emission reducing technology implementation would need to incorporate the opportunity for retailers to benefit financially. Retailers must also be assured that the technology they are investing in will deliver adequate results, whilst guaranteeing that the needs of the customer and standards of equipment are met. This implies that the optimal approach would be to focus on actively supporting the development of energy saving technologies, with a view to them becoming ETL accredited. This would facilitate the best financial outcome for the retailer whilst ensuring the continual advancement of technological development and implementation in the industry.

If the research was to be repeated, time permitting, the legitimacy of the findings would be strengthened by interviewing a greater number of influential experts.

# REFERENCES


Aerofoil. (2018). How it works. Retrieved from https://www.aerofoil-energy.co.uk/index.php/how-it-works

British Retail Consortium. (2014). A better retailing climate: Driving resource efficiency. British Retail Consortium. Retrieved from https://brc.org.uk/media/43305/a-better-retailing-climate-driving-resource-efficiency.pdf

Carbon Trust. (2014). Commercial and retail refrigeration equipment. London: Carbon Trust. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/376186/ECA769_Commercial___retail_refrigeration_equipment.pdf

Churchyard, B., & Bailey, J. (2012). Evaluation of available refrigeration systems in the retail sector. Surrey: Institute of Refrigeration. Retrieved from http://www.realskillseurope.eu/app/images/news/Bailey4thOctl2012London%20final.pdf

Cooling Post. (2017). Aldi to convert all UK stores to CO2. Cooling Post Retrieved from https://www.coolingpost.com/uk-news/aldi-to-convert-all-uk-stores-to-co2/

Creswell, J. W., & Plano Clark, V. L. (2007). In Creswell J. W. (Ed.), Designing and conducting mixed methods research. California: Sage. 10.1111/j.1753-6405.2007.00096 Retrieved from http://www.sagepub.com/sites/default/files/upm-binaries/10981_Chapter_1.pdf

CSE, & ECI. (2012). What are the factors influencing energy behaviours and decision-making in the non-domestic sector?: A rapid evidence assessment. London: Department of Energy and Climate Change. Retrieved from https://www.cse.org.uk/downloads/reports-and-publications/behaviour-change/factors_influencing_energy_behaviours_in_non-dom_sector.pdf

ETL. (2018). Find ETL products. Retrieved from https://etl.beis.gov.uk/engetl/fox/live/ETL_PUBLIC_PRODUCT_SEARCH

European Commission. (2014). (May, 2014). Regulation (EU) no 517/2014 of the European parliament and of the council, on fluorinated greenhouse gases and repealing regulation (EC) no 842/2006. Paper presented at the Strasbourg, France. Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2014.150.01.0195.01.ENG

Foster, A., McAndrew, P., & Evans, J. A. (2014). Novel Aerofoils used for reducing energy consumption and improving temperature performance for multi-deck refrigerated display cabinets. Paper presented at the *Conference on Sustainability and the Cold Chain,* Twickenham. Retrieved from http://researchopen.lsbu.ac.uk/869/1/Air%20deflector%20paper%20v4.pdf

Gamel, J., Menrad, K., & Decker, T. (2017). Which factors influence retail investors' attitudes towards investments in renewable energies? *Sustainable Production and Consumption, 12*(Supplement C), 90-103. 10.1016/j.spc.2017.06.001 Retrieved from http://www.sciencedirect.com.lcproxy.shu.ac.uk/science/article/pii/S2352550917300192

Greene, J. C., Caracelli, V. J., & Graham, W. F. (1989). Toward a conceptual framework for mixed-method evaluation designs. *Educational Evaluation and Policy Analysis, 11*(3), 255-274. 10.2307/1163620 Retrieved from http://www.jstor.org/stable/pdf/1163620.pdf?refreqid=excelsior:017c5d09d700ed01577e5476be1156dd

Greene, J. C., Benjamin, L., & Goodyear, L. (2001). The merits of mixing methods in evaluation. *Evaluation, 7*(1), 25-44. 10.1177/13563890122209504 Retrieved from http://journals.sagepub.com/doi/pdf/10.1177/13563890122209504

IGD. (2017). *UK food and grocery.* Watford: The Institute of Grocery Distribution. Retrieved from https://www.igd.com/Portals/0/Downloads/Infographics/UK-food-and-grocery.pdf

Islam, M. A., Srinivasan, K., Thu, K., & Saha, B. B. (2017). Assessment of total equivalent warming impact (TEWI) of supermarket refrigeration systems. *International Journal of Hydrogen Energy, 42*(43), 26973-26983. 10.1016/j.ijhydene.2017.07.035 Retrieved from http://www.sciencedirect.com.lcproxy.shu.ac.uk/science/article/pii/S0360319917327684

Klemick, H., Kopits, E., & Wolverton, A. (2015). *The energy efficiency paradox: A case study of supermarket refrigeration system investment decisions*. Washington, DC: U.S. Environmental Protection Agency. Retrieved from https://www.epa.gov/sites/production/files/2016-03/documents/2015-03.pdf

Kolokotroni, M., Tassou, S. A., & Gowreesunker, B. L. (2015). Energy aspects and ventilation of food retail buildings. *Advances in Building Energy Research, 9*(1), 1-19. 10.1080/17512549.2014.897252 Retrieved from http://www.tandfonline.com/doi/abs/10.1080/17512549.2014.897252

Ma, Y., Kelman, A., Daly, A., & Borrelli, F. (2012). Predictive control for energy efficient buildings with thermal storage: Modeling, stimulation, and experiments. *IEEE Control Systems, 32*(1), 44-64. 10.1109/MCS.2011.2172532 Retrieved from https://pdfs.semanticscholar.org/ae79/0f26ef665087bb791a3603fcd4b20332969e.pdf

McCright, A. M., Marquart-Pyatt, S. T., Shwom, R. L., Brechin, S. R., & Allen, S. (2016). Ideology, capitalism, and climate: Explaining public views about climate change in the United States. *Energy Research & Social Science, 21*(Supplement C), 180-189. 10.1016/j.erss.2016.08.003 Retrieved from http://www.sciencedirect.com.lcproxy.shu.ac.uk/science/article/pii/S2214629616301864

Mylona, Z., Kolokotroni, M., & Tassou, S. A. (2017). Frozen food retail: Measuring and modelling energy use and space environmental systems in an operational supermarket. *Energy and Buildings, 144*(Supplement C), 129-143. 10.1016/j.enbuild.2017.03.049 Retrieved from http://www.sciencedirect.com/science/article/pii/S0378778817309544

Oppenheim, A. N. (1992). *Questionnaire design, interviewing, and attitude measurement*. London: Continuum.

Peters, T. (2017). *Retail refrigeration: Making the transition to clean cold*. Birmingham: University of Birmingham. Retrieved from https://www.birmingham.ac.uk/Documents/college-eps/energy/Publications/Retail-Refrigeration.pdf

Polzot, A., D'Agaro, P., Gullo, P., & Cortella, G. (2016). Modelling commercial refrigeration systems coupled with water storage to improve energy efficiency and perform heat recovery. *International Journal of Refrigeration, 69*(Supplement C), 313-323. 10.1016/j.ijrefrig.2016.06.012 Retrieved from http://www.sciencedirect.com.lcproxy.shu.ac.uk/science/article/pii/S0140700716301748

RAC. (2015). Aerofoils take flight in UK. Retrieved from https://www.racplus.com/features/aerofoils-take-flight-in-uk/8678307.article

Sun, W., Yue, X., & Wang, Y. (2017). Exergy efficiency analysis of ORC (Organic Rankine Cycle) and ORC-based combined cycles driven by low-temperature waste heat. *Energy Conversion and Management, 135*(1), 63-73. 10.1016/j.enconman.2016.12.042 Retrieved from https://www.sciencedirect.com/science/article/pii/S0196890416311323

Tassou, S. A., Ge, Y., Hadawey, A., & Marriott, D. (2011). *Energy consumption and conservation in food retailing*. London: Elsevier Ltd.10.1016/j.applthermaleng.2010.08.023 Retrieved from http://www.sciencedirect.com.lcproxy.shu.ac.uk/science/article/pii/S1359431110003510

# A CONCEPTUAL AND LITERATURE REVIEW OF THE EFFECTIVENESS OF BREEAM

**Jack Sewell & Douglas J. Fraser**[5]

*Jack Sewell, the primary researcher, undertook the basis of this review in preparation for his dissertation, whilst reading BSc (Hon) Environmental Science. Douglas Fraser (corresponding author) is a Principal Lecturer and research supervisor in the field of environmental science.*

The literature examining BREEAM was explored to extract an overview of the effectiveness of the method in assessing sustainability in built developments. It was found that BREEAM is a respected assessment tool, with much potential to develop into a valuable driver towards sustainable development in the construction industry. Shortfalls were discovered in the way the method has been used, *e.g.* in the industry understanding of sustainable development as a holistic concept; in the focus on short-term financial rewards; in the lack of site-specific consideration of the application of solutions.

**KEY WORDS:** BREEAM, Sustainable Development, Environmental Assessment, Literature Review

## INTRODUCTION

Over the last thirty years, the increasing attention on, and requirements for consideration of the built environment, has resulted in a range of assessment methods. One of the foremost assessment methods used in developments is the Building Research Establishment Environmental Assessment Method (BREEAM).

In order to conduct our own evaluation of the effectiveness of BREAM as a valuable assessment of the sustainability of a built development, we reviewed the existing literature. This paper presents our review of the literature. Our

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subsequent investigation was designed to fill in blank areas of analysis and user opinion (Sewell & Fraser, 2018a).

This review of literature follows the following structure:

- Definition of sustainability.
- Definition of BREEAM.
- BREEAM as an assessment tool.

# LITERATURE REVIEW

## Definition of Sustainability

BREEAM is self-styled as the world's first sustainability assessment system (BREEAM, 2017a), however as the term 'sustainability' is so variably defined, its interpretation has a profound impact on the effectiveness of any assessment method.

A major barrier to understanding how sustainable a development can be, or ought to be, is in the different meanings of the word 'development'. To a builder, it can simply be the planning and execution of a building project, for profit. That is the sense in which the word is most used in the construction industry and a sustainable development, in that case, is one which is commercially viable, at least until the developer has delivered the project. Developers are known to have published priorities which are solely company orientated:

> "*profit, cash* [for shareholders] *and financial stability*" (Bender, 2018 n.p.).

However, in the originally intended (WCED, 1987) sense of the term 'sustainable development', the word has a much greater meaning. Development includes a historical context - societal transformations, it has associations with 'progress' and 'modernity'. It has negative consequences in the utilization of more resources and global inequity. Development also includes policy to bring about such changes through governance, public and business actions (Sumner & Tribe, 2008). When this kind of development is working in a positive way towards husbandry of resources and societal equity, it is called sustainable development.

BREEAM is a mechanism to encourage a wider consideration of the impact of the building development on the greater environment, in the long term.

The concept of sustainability is probably as old as humanity, or at least since the advent of horticulture and animal husbandry. The first laws covering the concept of sustainability are often cited as mediaeval, although the term 'sustainable' is modern and retrospectively applied. In 1355, Charles, King of Bohemia (later Charles IV, Holy Roman Emperor) produced what became known as *Maiastas Carolina*, which included rules on the harvesting of timber from woodland. William the Conqueror's restrictive Forest Laws from the 11$^{th}$ to the 13$^{th}$

Centuries were also designed to conserve the royal hunting resources (Young, 1979). However, although employing elements of sustainability, they were largely about consolidating political power and do not fit well with modern ideals of sustainable development. More recently, the Arts and Crafts movement of the late 19th century, UK, was a warning against the increasing resource consumption of industrialisation, which also commodified societies. It was an attempt to draw respect to artisan skills, cooperation within community and interdependence with the natural resources.

Management to sustain a resource for its own sake (and not primarily the owner's) probably originated as a concept in forestry in the 18th Century (Wiersum, 1995). Since this time, sustainability has adopted different definitions, depending on the profession of the definer (Morelli, 2013). For example, Callicott and Mumford (1997, p32) very authoritatively and convincingly argue for ecological sustainability as a service "*meeting human needs without compromising the health of ecosystems*". Foy (1990, p771) defines an economic aspect of sustainability as a service "*that minimises costs of meeting standards for protecting environmental assets*" and that current economic decisions should avoid passing on, or creating disproportionate costs on the economies of future generations. In terms of society, McKenzie (2004, p12) defines sustainability as "*a process within communities that can achieve that [positive] condition*", where positive conditions are the maintenance of a just and equitable society. In that human communities are dependent on employment, businesses are necessarily involved in the structure and of society, few more explicitly than the construction industry, which designs, costs and provides many of the physical limits of our living spaces.

Questioning sustainability in a broader sense, Kuhlman & Farringdon (2010) dislike the narrowness of narrowly themed definitions, concluding that sustainability can only be achieved if all the dimensions (social, environmental and economic) have been equitably considered, whilst also accounting for long-term effects and needs. This view is inspired by the oft quoted definition in *Our Common Future* (a.k.a. *the Brundtland Report*), the published output from the World Commission on Environment and Development, held in 1982:

> [Sustainable development is] "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs.*" (WCED, 1987 n.p.).

This is the opening statement in a much ignored chapter, which does give many examples of how to interpret and act on the sentiment in the statement. But, the rest of the report remaining largely unread, it is difficult to attain such an aspiration without guidance or instruction. There have been many further attempts at subject-specific definitions of sustainability, but they all rely on the

inclusion of three themes, all of which are essential to stability, like a three-legged stool (Young, 1997), or three pillars of responsibility, holding up the lintel of sustainability (Figure 1). The three themes of concern are society, environment and economy.

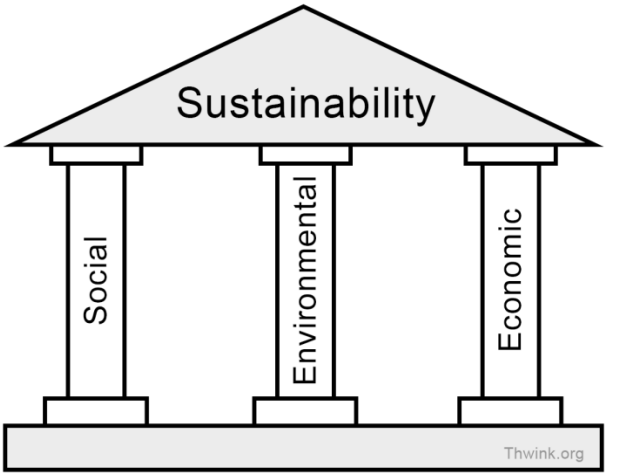


*Figure 1: The Pillar Model of Sustainability (Thwink.org, 2014)*

Elkington (1997) introduced the principle of the triple bottom line, referring to the economic performance of those three themes, all of which must be effective to reach sustainability. This sentiment has been repeated by Tanguay *et al.* (2009) and Reith & Orova (2015) all of whom conclude that development can only be sustainable if it deals effectively with all three themes. The three pillar model and the triple bottom line concept allow one to regard each theme as independent of each other. In fact, society creates an economy; the economy feeds back on society; society lives within an environment; economy relies on resources derived from the environment. The three themes of environment, society and economy can be presented as three spheres of influence, all overlapping to an extent in a Venn diagram (Figure 2). The degree of overlap represents interdependence of the themes.

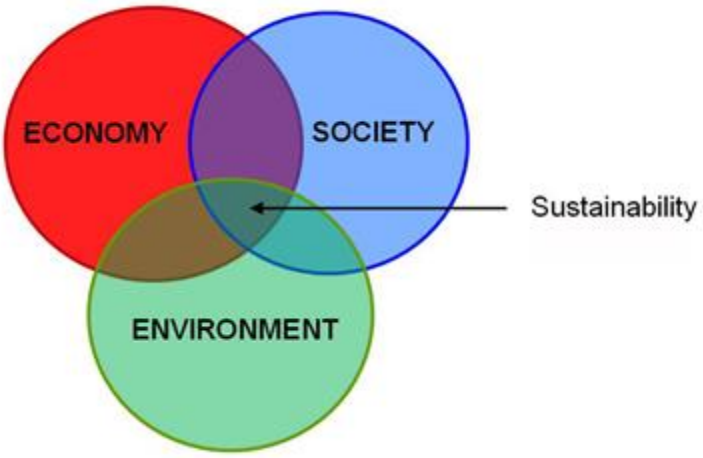


***Figure 2**: Venn diagram of sustainable development (after Willard, 2010)*

As human impacts are now all-pervasive, we must regard the environment as the world. All societies therefore live within the environment. The powerful economies exist within certain societies. This reality suggests a hierarchy in these spheres, placing the economy within the society, which is itself within the environment (Figure 3). This is known as the Nested Dependencies Model (Willard, 2010) and encourages a more global vision and realistic view of a development's role and impact in the environment.

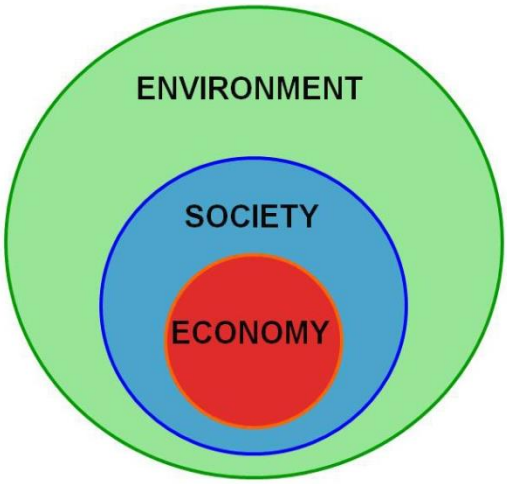


***Figure 3**: The Nested Dependencies Model of sustainable development (image: Doppelt, 2012)*

Thus to be an effective assessment of the sustainability of a building development, any methodology must consider impacts on these three themes over the life-cycle of the development.

### *Definition of BREEAM*

It is in this definition of development, that BREEAM seeks to act as an aid to project design and evaluation. The models are still more aspirational than helpful; however a great deal of detail is given in the United Nations Organisation's (2017) seventeen Sustainable Development Goals, many of which directly affect construction projects.

The importance of sustainability in the built environment is not a new idea (Wu, 2014), and the concept has progressively pervaded governmental policies since the inception of 'sustainable development' by the WCED (1987). There are several and varying assessment tools designed to address the sustainability of a development, but, available since 1990, BREEAM is regarded as the first tangible environmental assessment method (Turner & Arif, 2012), and the world's leading sustainability assessment method (BREEAM, 2017b).

How an assessment tool is defined tells of what it seeks to achieve. Evaluating the effectiveness of BREEAM presents challenges because it is not definitively defined. This is due to a number of factors: conflicting opinions within the literature; differing statements made by BREEAM across web pages and documents; the evolving nature of the mechanism itself.

BREEAM was the first environmental assessment method for buildings and produced by the Building Research Establishment (BRE) in 1990. The system methodology was developed in collaboration with private developers in the UK (Ding, 2008) as a result of industrial sectors recognising their detrimental impact on the environment (Haapio & Viitaniemi, 2008). Currently, it is the most widely recognised and used assessment method; the numbers of BREEAM certified and BREEAM registered buildings are 560,872 and 2,262,650 respectively (BREEAM, 2017a). This compares impressively with what is, arguably, its closest alternative method - LEED (Leadership in Energy and Environmental Design) (Nguyen & Altan, 2011), which has 89,600 buildings certified, as of January 2017 (USGBC, 2017).

In the academic literature, BREEAM is generally held in high regard, acknowledging its suitability for assessing environmental criteria (*e.g.* Cole, 1998; Todd *et al.*, 2001; Ding, 2008; Turner & Arif, 2012). Nine years after its inception, it was lauded as the first real attempt to "*establish comprehensive means of simultaneously assessing a broad range of environmental considerations in buildings*" (Crawley & Aho, 2010).

The inherent flexibility in BREEAM is intended to allow for more suited application in a range of types of sites as well as for the evolution and betterment of the method (BREEAM, 2017b). BREEAM (2017a) began with the claim that

the method was "*the world's leading sustainability assessment method*", but also "*the world's foremost environmental assessment method and rating system*" (BREEAM, 2017c). The difference might show evolution or it might evidence an identity crisis and lack of clarity over whether it assesses sustainability or aspects of the environment. That said, BREEAM (2011) did outline how they set standards for best practice in sustainable building design, but state that the assessment method is recognised as a measure of environmental performance and not sustainable performance.

### *BREEAM as an Assessment Tool*

A large proportion of literature concerned with defining and assessing sustainability, agrees that BREEAM is an assessment of sustainability (*e.g.* Zanni, Soetanto & Ruiker, 2014; Andrade, Bragança & Camões, 2016). Four studies assume the sustainability impact, but focus on comparing multiple assessment methods for their framework and criteria weightings. They do not explicitly address it validity as a measure of sustainability (Schwartz & Raslan, 2013; Seinre, Kurnitski & Voll, 2014a; Seinre, Kurnitski & Voll, 2014b; Ferreira, Pinhero & Brito, 2014).

There are many studies which add to a conflicting perception of how to define BREEAM by referring to it solely as an environmental assessment method. Nguyen and Altan (2011) compare multiple assessment methods, but have no clear focus. Widely cited work by Ding (2008) and the earlier work by Forsberg and Malmborg (2004) examined the role of assessment methods when measuring sustainable construction and what is required within an assessment to measure sustainability. Interestingly, all the studies that define BREEAM as a sustainability assessment tool are more recent, the earliest being Chandratilake and Dias (2012).

A degree of confusion is understandable when details of the method itself are reviewed (*e.g.* Schweber & Haroglu, 2014). The method in the UK assesses developments against nine separate categories, with unequal weightings (Figure 4).

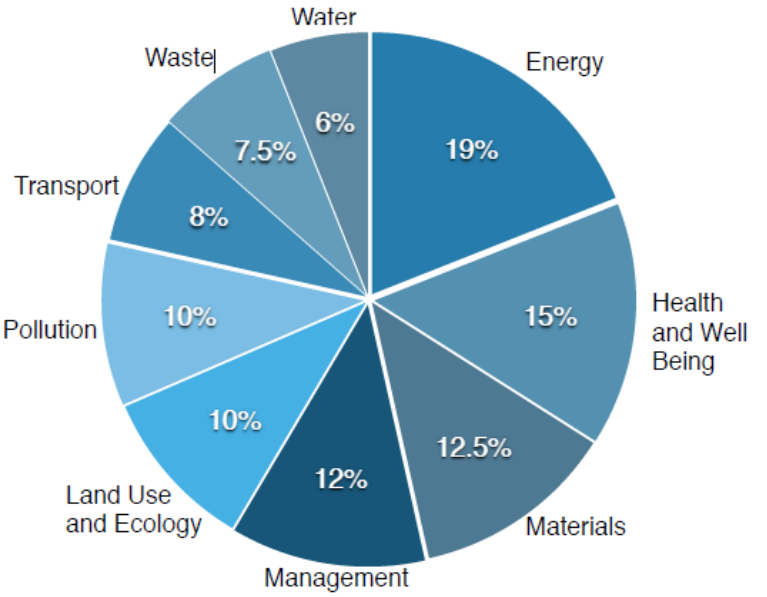


***Figure 4**: Total percentage weightings of coarse categories in BREEAM (2016)*

The weightings suggest that energy will be the most important of all criteria in every case, when in reality geographical variations can favour very different best solutions (Aspinall *et al*., 2012). Whilst the sheer number of environmental categories skews the assessment in favour of this theme, it does render BREEAM the most effective assessment tool for measuring the environmental performance of a building (Alyami & Rezgui, 2012; Reith & Orova, 2015). Despite this potential shortcoming in wider sustainability assessment, there are reviewers who acknowledge the large emphasis that BREEAM places on setting standards for best practice in sustainable building design, construction and operation (Schweber, 2013; Schweber & Haroglu, 2014; Nesteby *et al*., 2016).

Some authors argue against the popular opinion by challenging the ability of BREEAM to assess aspects of the environmental theme. Observations of the assessment, and of professional perceptions, have led to conclusions that BREEAM could be carried out without much involvement of the ultimate users of the development (Turner & Arif, 2012; Alwaer, Sibley & Lewis, 2007). Say and Wood (2008) identified that some of the environmental credits do not inherently possess the potential to provide life-cycle payback of costs to the owner. This subsequently leads to the favouring of monetary beneficial credits over site-specifically suitable environmental credits. More recently, it has been determined that the data collection process of BREEAM is one of the worst of the top five building assessment methods (Nguyen & Altan, 2011). This can also lead to the favouring of economically beneficial credits. For example, the information

required to achieve the materials credits is lengthy and time-consuming (especially if the design team are inefficient), for not a high percentage of credits. The equivalent number of credits could be 'traded' for the production of a specialised report, for additional fees. Having said that, the ever evolving nature of BREEAM, resulting from frequent review, provides an opportunity to remove such inconsistencies and loop-holes (Aspinall *et al*., 2012). A consequence of evolution has resulted in BREEAM being promoted as a design tool, which could promote sustainable design and construction. The success of this new role is greatly affected by the extent of sustainable development-mind-set in the design team involved in the project (Schweber & Haroglu, 2014). This work does show that BREEAM has potential to promote standards for best practice in design for sustainable development, despite its shortfalls which lead sustainable development experts to be less accepting of BREEAM's ability to achieve genuine sustainability (Schweber, 2013). Some criticism is levelled at BRE in its provision of quality assurance (Aspinall *et al*., 2012).

The adaptability of the method, its emphasis on energy credits and its market driven character, however, is also seen as an advantage in driving a response to the significant global energy footprint (40%) of the built environment; and is more successful in this respect than is LEED (Schwartz & Raslan, 2013). The energy credit determination in BREEAM is derived from environmentally relevant considerations (energy consumption, delivered energy and carbon dioxide emissions) compared with simply the cost saving calculations of LEED. Lee and Burnett (2008) determined that no matter what the percentage level of credits was, the reduction in energy usage was always greater in BREEAM assessed buildings, compared to LEED and HK-BEAM. Other early evaluations of BREEAM also conclude that the success of other methods measuring environmental aspects of developments have been dwarfed by the success of BREEAM (Cole, 2005; Haapio & Viitaniemi, 2008).

# CONCLUSION

BREEAM is widely regarded as a very useful tool for assessing the environmental performance of a development, but does not address the wider issues of sustainable development, such a geographical site suitability of solutions and long term environmental footprint. It is therefore not a proficient measure of sustainability within the generally accepted definition of sustainable development. The main concerns from the literature are:

## Positive

- BREEAM effectively addresses the environmental performance of a building.

- Early involvement of an assessor in the project design is beneficial to the assessment.

## Negative

- BREEAM is seen to involve much less client participation than other assessment methods.
- There is a lack of incorporation of social and economic dimensions of sustainable development.
- BREEAM does not allow for adequate consideration of the variation in needs or opportunities indifferent geographical locations.
- BREEAM can be regarded as a box-ticking exercise more to satisfy financial considerations than to find the most suitable solution for sustainability.
- The ability of the BRE to provide effective quality assurance.

The flexible nature of the assessment tool and the intention of BRE to update and progress the methodology presents a good chance of BREEAM maturing and achieving its goal. To this end, the building users, designers and developers must have a common understanding of the real definition of sustainable development.

# REFERENCES


Alyami, S. and Rezgui, Y., 2012. Sustainable Building Assessment Tool Development Approach. *Sustainable Cities and Society* **5**: 52-62.

Alwaer, G., Sibley, M. and Lewis, J., 2007. Different Stakeholder Perceptions of Sustainability Assessment. *Architectural Science Review* **51** (1): 48-59.

Andrade, J., Braganҫa, L. and Camões, A., 2016. Steel Sustainability Assessments - do BSA tools really assess steel properties? *Journal of Constructional Steel Research* **120**: 106-116.

Aspinall, S., Sertyesilisik, B., Sourani, A. and Tunstall, A., 2012. How Accurately Does BREEAM Measure Sustainability? *Scientific Research* **3**: 1-8.

Bender, R. 2018. Interview with Professor Ruth Bender (Cranfield University) about building company senior executive bonuses. *Today*. BBC Radio 4, broadcast on Tuesday 9th January, 2018. [on line] http://www.bbc.co.uk/programmes/b09kq180#play from 1hr 24min - 1hr 27min.

BREEAM, 2011. *The World's Foremost Environmental Assessment Method and Rating System for Buildings*. [on line] http://www.breeam.com/filelibrary/

BREEAM, 2016. *Scoring and Rating*. [online] http://www.breeam.com/communitiesmanual/content/00_introduction/05_scoring_and_rating_proposals.htm.

BREEAM, 2017a. *Home*. [online]. http://www.breeam.com/

BREEAM, 2017b. *Why BREEAM?* [online] http://www.breeam.com/why-breeam

BREEAM (2017c). Best of BREEAM 2017: Exceptional sustainable places and project teams from the BREEAM Awards 2017. [pdf]. Available at: http://www.breeam.com/filelibrary/BREEAM%20Awards/BREEAM-Awards-2017/

Callicott, J. and Mumford, K., 1997. Ecological Sustainability as a Conservation Concept. *Conservation Biology* **11** (1): 32-40.

Chandratilake, S. and Dias, W., 2012. Sustainability Rating Systems for Buildings: comparisons and correlations. *Energy* **59**: 22-28.8

Cole, R., 1998. Emerging Trends in Building Environmental Assessment Methods. *Building Research and Information* **26** (1): 3-16.

Cole, R., 2005. Building environmental assessment methods: redefining intentions and roles. [online]. *Building Research and Information* **33** (5): 455-467.

Crawley, D. and Aho, I., 2010. Building Environmental Assessment Methods: applications and development trends. *Building Research and Information* **27** (4-5): 300-308.

Ding, G., 2008. Sustainable Construction - the toll of environmental assessment tools. *Journal of Environmental Management* **86** (3): 451-464.

Doppelt, B., 2012. *The Power of Sustainable Thinking: How to Create a Positive Future for the Climate, the Planet, Your Organization and Your Life*. Earthscan.

Elkington, J.B., 1997. *Cannibals with Forks: The Triple Bottom Line of 21st Century Business*. [e-book in English and French]. Oxford, Capstone Publishing. Available at: http://appli6.hec.fr/amo/Public/Files/Docs/148_en.pdf.

Ferreira, J., Pinheiro, M and Brito, J., 2014. Portuguese Sustainable Construction Assessment Tools Benchmarked with BREEAM and LEED: an energy analysis. *Energy and Buildings* **69**: 451-463.

Forsberg, A. and Malmborg, F., 2004. Tools for Environmental Assessment of the Built Environment. *Building and Environment* **39** (2): 223-228.

Foy, G., 1990. Economic Sustainability and the Preservation of Environmental Assets. *Environmental Management* **14** (6): 771-778.

Haapio, A. and Viitaniemi, P., 2008. A Critical Review of Building Environmental Assessment Tools. *Environmental Impact Assessment Review* **28** (7): 469-482.

Kuhlman, T. and Farringdon, J., 2010. What is Sustainability? *Sustainability*. **2**: 3436-3448.

Lee, W. and Burnett, J., 2008. Benchmarking energy use assessment of HKBEAM, BREEAM and LEED. [online]. *Building and Environment* **43** (11): 1882-1891.

McKenzie, S., 2004. Social Sustainability: towards some definitions. *Hawke Research Institute Working Paper Series*. No 27. Magill: Hawke Research Institute, University of South Australia. [online] http://w3.unisa.edu.au/hawkeinstitute/publications/downloads/wp27.pdf

Morelli, J., 2013. Environmental Sustainability: a definition for environmental professionals. *Journal of Environmental Sustainability* **1** (1): 1-9.

Nesteby, Å.I., Aarrestad, M.E., Lohne, J. and Bohne, R.A., 2016. Integration of BREEAM-NOR in Construction Projects: utilising the Last Planner System. *Energy Procedia* **96**: 100-111.

Nguyen, B. and Altan, H., 2011. Comparative Review of Five Sustainable Rating Systems. *Priced Engineering* **21**: 476-386.

Reith, A. and Orova, M., 2015. Do green neighbourhood ratings cover sustainability? *Ecological Indicators*. **48**: 660-672.

Say, C and Wood, A., 2008. Sustainable Rating Systems Around the World. [online]. *CTBUH Journal* **1** (2): 18-29.

Schwartz, Y. and Raslan, R., 2013. Variations in Results of Building Energy Simulation Tools and their Impact on BREEAM and LEED Ratings: a case study. *Energy and Buildings* **62**: 350-359.

Schweber, L., 2013. The Effect of BREEAM on Clients and Construction Professionals. *Building Research and Information* **41** (2): 129-145.

Schweber, L. and Haroglu, H., 2014. Comparing the Fit Between BREEAM Assessment and Design Processes. *Building Research and Information* **42** (3): 300-317.

Seinre, E., Kurnitski, J. and Voll, H., 2014a. Building Sustainability Objective Assessment in Estonian Content and a Comparative Evaluation with LEED and BREEAM. *Building and Environment* **82**: 110-120.

Seinre, E., Kurnitski, J. and Voll, H., 2014b. Quantification of Environmental and Economic Impact for Main Categories of Building Labelling Schemes. *Energy and Buildings* **70**: 145-158.

Sewell, J.E. and Fraser, D.J. (*2018a)* A Study of the Effectiveness of BREEAM as an Assessment Tool for Sustainability, by Interview of Practitioners. *The Sheffield Hallam University Built Environment Research Transactions* **10** (1) 59-69

Sumner, A. and Tribe, M., 2008. *International development studies: theories and methods in research and practice*. Sage: London.

Tanguay, G. A., Rajaonson, J., Lefebvre, J-F and Lanoie, P., 2009. Measuring the Sustainability of Cities: A Survey-Based Analysis of the Use of Local Indicators. Cirano: Scientific Series. [online] http://www.cirano.qc.ca/pdf/publications/2009s-02.pdf.

Thwink.org, 2014. Finding and Resolving the Root Causes of the Sustainability Problem: *The Three Pillars of Sustainability*. [on line] http://www.thwink.org/sustain/glossary/ThreePillarsOfSustainability.htm

Todd, J.A., Crawley, D., Geissler, S. and Lindsey, G., 2001. Comparative Assessment of Environmental Performance Tools and the Role of the Green Building Challenge. *Building Research and Information* **29** (5): 324-335.

Turner, N. and Arif, M., 2012. BREEAM Excellent: Business Value vs Employee Morale. *Journal of Physics: Conference Series.* **364**: 1-8.

United Nations' Organisation, 2017. *Sustainable Development Goals* [on line] http://www.un.org/sustainabledevelopment/sustainable-development-goals/

USGBC, 2017. *Benefits of Green Building*. [online] http://www.usgbc.org/articles/green-building-facts.

WCED, 1987. *Our Common Future*. Oxford: Oxford University Press.

Wiersum, K., 1995. Two Hundred Years of Sustainability in Forestry: lessons from history. *Environmental Management* **19** (3): 321-329.

Willard, B., 2010. Sustainability Advantage Blog: 3 Sustainability Models. July 20th, 2010. [on line] http://sustainabilityadvantage.com/2010/07/20/3-sustainability-models/

Wu, J., 2014. Urban Ecology and Sustainability: the state-of-the-science and future directions. *Landscape and Urban Planning* **125**: 209-221.

Young, C.R., 1979. *The Royal Forests of Medieval England*. University of Pennsylvania Press: USA.

Young, J., 1997. A Framework for the Ultimate Environmental Index: putting atmospheric change into context with sustainability. *Environmental Monitoring and Assessment* **46** (1): 135-149.

Zanni, M., Soetanto, R. and Ruikar, K., 2014. Defining the Sustainable Design Process: methods for BIM execution planning in the UK. *International Journal of Energy Sector Management* **8** (4): 562-587.

# A STUDY OF THE EFFECTIVENESS OF BREEAM AS AN ASSESSMENT TOOL FOR SUSTAINABILITY

**Jack Sewell & Douglas J. Fraser**[6]

*Jack Sewell, the primary researcher, undertook the basis of this review in preparation for his dissertation, whilst reading BSc (Hon) Environmental Science. Douglas Fraser (corresponding author) is a Principal Lecturer and research supervisor in the field of environmental science.*

The increasing environmental obligations on the built environment have resulted in a range of assessment methods. A currently predominant choice, applied by developers and consultants is the Building Research Establishment Environmental Assessment Method (BREEAM). Our interviews with BREEAM-certified professionals evaluated the proficiency of BREEAM as a measure of sustainability and noted the nature of flaws in its current application. Primary research methods were in-depth, semi-structured interviews, developed from a thematic analysis of the previously published literature review. Results acknowledged that BREEAM is essentially an efficient tool for assessing the environmental performance of a development and that the evolving nature of BREEAM gives it the greatest potential to develop into a proficient measure of sustainability. However, this study concluded that BREEAM is not currently a proficient test for sustainability, as it does not address enough of the fundamental principles of sustainable development. If sustainability is the aim, then attention should focus on the following;

- Product lifetime economics need to be built into the assessment.
- Attention should be paid to the geographical location and environmental properties of the site.
- Post construction, continual monitoring of effectiveness and evaluation of impacts should be carried out.

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**KEY WORDS:** BREEAM, Sustainable Development, Environmental Assessment, Methodology Appraisal

# INTRODUCTION

As BREEAM is a leading sustainability assessment system (BREEAM, 2017a,b), the efficacy of its application is dependent on the assessors' interpretations of the term 'sustainable development'.

Our review of literature on BREEAM produced the following conclusions:

"*BREEAM is widely regarded as a very useful tool for assessing the environmental performance of a development, but does not address the wider issues of sustainable development, such as geographical site suitability of solutions and long term environmental footprint. It is therefore not a proficient measure of sustainability within the widely accepted definition of sustainable development. The main concerns from the literature are:*

*"Positives*

- *BREEAM effectively addresses the environmental performance of a building.*
- *Early involvement of an assessor in the project design is beneficial to the assessment.*

*"Negatives*

- *BREEAM is seen to involve much less client participation than other assessment methods.*
- *There is a lack of incorporation of social and economic dimensions of sustainable development.*
- *BREEAM does not allow for adequate consideration of the variation in needs or opportunities in different geographical locations.*
- *BREEAM can be regarded as a box-ticking exercise more to satisfy financial considerations than to find the most suitable solution for sustainability.*
- *The ability of the BRE to provide effective quality assurance.*

*"The flexible nature of the assessment tool and the intention of BRE to update and progress the methodology presents a good chance of BREEAM maturing and achieving its goal. To this*

*end, the building users, designers and developers must have a common understanding of the real definition of sustainable development.*" (Sewell & Fraser, 2018b).

These conclusions were used to inform an interview method for canvassing expert opinion on the effectiveness of BREEAM as an assessment method for sustainability.

The aim of this study was to evaluate the proficiency of BREEAM as a measure of sustainability and to note the nature of any flaws in its current application. A phenomenological approach was used, considering both primary and secondary data. Primary research methods were in-depth, semi-structured interviews with six, experienced, BREEAM-certified professionals, who together represented a total of 35 years of assessment experience. The results were considered in the context of already published, secondary information.

# METHOD

This study evaluated the level of proficiency with which BREEAM measures sustainable development. A comprehensive literature review provided *a priori* evaluative research conclusions (presented above). Richness and current professional depth of opinion was added to this overview by appraising the opinions of experts, specifically chosen because of their relevant experience.

Interviewees were self-selected by response to an invitation via LinkedIn (the professional networking website) and by word-of-mouth amongst the primary researcher's personal professional contacts.

The method used was semi-structured interviews, which are the result of pre-planning (Literature Review: Sewell and Fraser, 2018b) and design of questions before the interview, as with structured interviews, but with the added opportunity for interviewees to elaborate on and explain further through open-ended questions (as Alsaawi, 2014). Importantly, the interviewer, too, had experience of BREEAM and was able to interpret and seek further clarity all the better for his subject-knowledge. Interviews were carried out by telephone to allow the researcher to take advantage of conversational cues and immediate clarification. The interviews were recorded (with permission) to aid analysis.

The interviews were piloted twice, amended and finally carried out with six, active, BREEAM- accredited professional assessors. The interviewees held a combined total of 35 years as accredited assessors. The interviewees had experience of working with other UK-based methodologies, such as Code for Sustainable Homes, Home Quality Mark and SKA Rating (RICS). Two interviewees had worked with the international methods: LEED (Leadership in Energy and Environmental Design), *Passivhaus* and Greenstar.

The range and style of interview questions was guided by the issues brought forward in an extensive literature review and further developed in the two pilot interviews. In order to evaluate the BREEAM methodology against the BRE stated purpose and against current definitions and intensions of sustainable development, transcribed interviews were phenomenologically analysed in a four-stage process (Marton, Carlsson & Halasz, 1992):

- Identifying data in 'pool of meaning', grouping similar sets of data;
- Contrasting these groups of data.
- Engaging an independent judge to establish reliability.
- Post-coding into themes before independent review.

Piloting the interview with an assessor developed and honed the final set of questions used in the interviews, see Figure 5.

1. How long have you worked on BREEAM projects?
2. How long have you been a licensed assessor?
3. On how many projects have you acted as a consultant from the beginning of the design?
4. How would you define BREEAM?
5. What would you class as the main aspects of sustainability in the built environment?
6. What do you consider successful about BREEAM as an assessment method?
7. What do you consider to be weak points about BREEAM as an assessment method?
8. Have you ever worked with any other assessment methodologies? *e.g.* LEED, CASBEE, Green Building Tool.
9. How do you feel these differ from or compare to BREEAM?
10. How would you define a sustainable development?
11. Do you feel the greatest emphasis on sustainable development is, or should be implemented in the design phase?
12. Why do you feel this?
13. Of all the sections within BREEAM, do you feel there is a larger emphasis on environmental aspects than any other?
14. For a development to be truly sustainable, do you feel that all aspects of sustainability should be addressed equally?
15. What do you feel are the key factors that lead to a sustainable development or building? *e.g.* a communicative design team

16. Within the 2014 BREEAM manual, there were a lot of changes, for example the evidence detail for each credit became very vague. What are your opinions on this?
17. How much of an impact do you feel they have on the suitability of the assessment method to measure sustainability?
18. It is currently being proposed that the new version of BREEAM will include another stage for certain credits to cover post-occupation. Do you feel this will bring value to the assessment? If so how?
19. Do you feel that BREEAM is an 'afterthought' or an 'add-on' to gain planning approval, as opposed to a voluntarily engaged assessment?
20. If yes, how do you feel this could be improved?

***Figure 5****: Semi-structured interview questions used in this study.*

# RESULTS

## Interview Post-coding

The information coalesced into the following themes, which allowed for richer interpretation for the discussion section:

- Factors affecting sustainability / sustainable development
- Environmental aspects of sustainability
- Social aspects of sustainability
- Economic aspects of sustainability
- Design tool for setting standards
- Sustainability assessment tool
- Defining sustainable development
- Experience with assessment methodologies
- Positives of BREEAM
- Negatives of BREEAM
- Improvements required for BREEAM.

*Questions 1 and 2: Interviewee Profiles*

Six interviewees were randomly chosen. Two interviewees were known to the researcher, having responded to the word-of-mouth invitation. Four were

previously unknown, but responded to the LinkedIn request for participants. Their levels of experience as BREEAM assessors were varied (see Figure 6).

| Interviewee Identifier | Time working with BREEAM (years) | Time as a licensed BREEAM assessor (years) |
|---|---|---|
| A | 4 | 1 |
| B | 3.5 | 1.5 |
| C | 7 | 5 |
| D | 12 | 8 |
| E | 8 | 8 |
| F | 10 | 10 |

***Figure 6**: The number of years for which interviewees' had experience of BREEAM and, specifically, as licensed assessors.*

*Question 3: How often BREEAM is applied from the start of a project.*
Our interviewees reported a varied range of rates for where BREEAM was considered from the beginning of a project - between 6 and 100%.

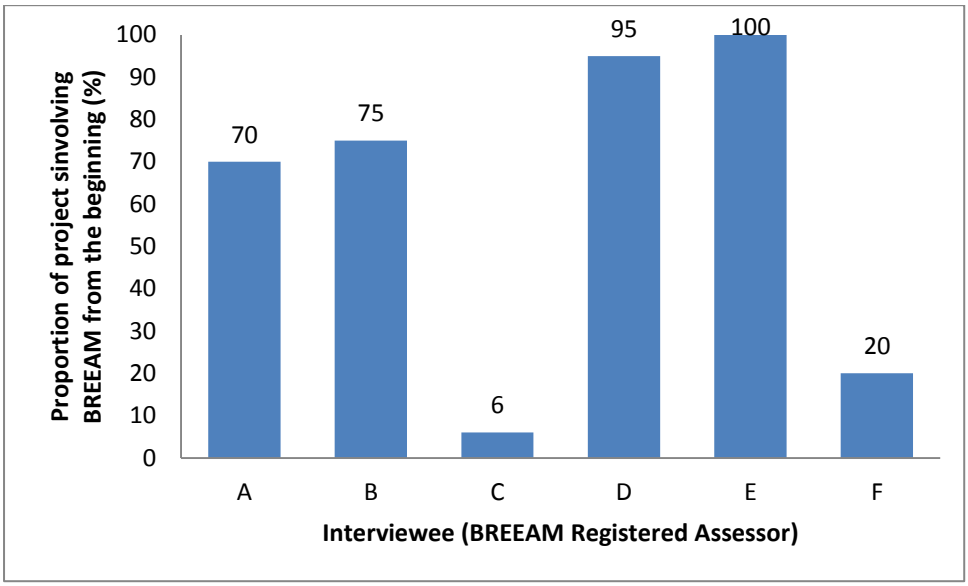


***Figure 7**: In the interviewees' experience, the percentage of projects where BREEAM was applied from the start of the project design.*

In case there has been an increase, or decrease in BREEAM involvement over the range of years spanned by our interviewees' experience, a comparison was made

between years of experience and number of projects involving BREEAM from inception. Figure 8 shows no correlation.

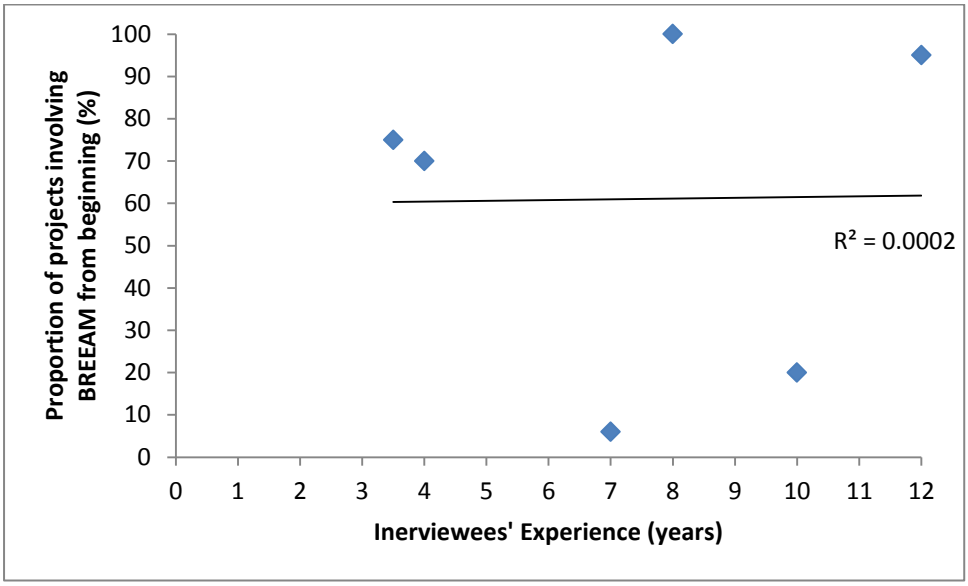


***Figure 8**: Correlation of interviewees' years of BREEAM experience with how many projects they knew to have involved BREEAM consideration from early design.*

*Question 4: How the participants defined BREEAM*

The majority of interviewees defined BREEAM in accordance with the Building Research Establishment definition. Two interviewees made reference to the method as a design tool for best practice in sustainable building. Only one interviewee acknowledged all three aspects of the 'triple bottom line' (social, environmental, economical) as key to sustainability in the built environment. No other interviewees mentioned economic considerations, but their responses concerned energy efficiency, reducing carbon emissions and the health and wellbeing of future occupants. One interviewee added that continued innovation in building design is key to sustainability.

*Questions 5 to 20: answers are summarised in the following discussion.*

# DISCUSSION

The principle behind the assessment method, as well as its mandatory nature, was commended by all the assessors, half of whom praised its level of detail, using the descriptions "*in-depth*" and "*holistic*". One interviewee commented on the method's ease of use; another pointing out that the tick-box nature had the

positive effect of setting clear targets for building and stakeholders. There were several comments about the method acting as a tool for design training, which could lead to the setting of good practice industry standards, raising awareness, encouraging creative thinking and going above and beyond the building regulations, as well as allowing for definitive, measurable comparability between buildings.

Half of the interviewees believed that the tick-box format leads to a major failure in the method. One believed that the simplistic mechanism results in the favouring of credits that are most beneficial to the developers' costs. This can mean that buildings that are *BREEAM Excellent* or *BREEAM Outstanding*, do not necessarily run as sustainable buildings once occupied and have less value than the rating claims. Lack of evaluation of the relative appropriateness and site-specific effectiveness of sustainability features is apt to give as much credit for inappropriate design and missed opportunities as for geographically optimal design considerations. Without long-term accountability or site specific justification, the range of options on the list allows for commercial expediency to dominate long-term sustainability benefits. There was a consensus that a BREEAM certificate does not really show that a building is performing as designed. One interviewee stated that a fundamental final flaw in BREEAM certification is that a large proportion of the QA team are not experienced building professionals. It is almost as if sometimes the assessors are using a different definition of the words 'sustainable' and 'development' than are the developers.

Assessors recognised the importance of being involved right from the start of a project to enable better understanding of the construction and for giving better advice. However, only one of the interviewees reported having been involved in this way in all projects. Interviewees reported that many clients were simply uninterested in the use of BREEAM. The reported rate of BREEAM consideration from the beginning of a project was very varied, so an average value is meaningless (Fig. 7). Comparing number of years of assessor experience with number of projects involving BREEAM from the outset also showed no correlation, $R^2$=0.0002 (Fig. 8). This suggests a varied interest in applying BREEAM from clients. Our interviewees reported that clients had variable understanding and interest in BREEAM.

Those with experience of *Passivhaus* and Greenstar believed that these international accreditations offer methodological opportunities for removing some of the frustrations of BREEAM. On the other hand, although LEED is more adaptable than BREEAM, it is largely short-term-cost-driven; and LEED is more client-driven, whilst BREEAM (to its credit) involves more client participation.

## Summary

- Although professionals disagreed with a statement that all aspects of sustainability should be addressed in equal measure, the lack of societal focus meant that a fundamental dimension of sustainability was not being addressed.
- The lack of consideration of the unique set of features for the specific geographical location of every site means that the assessment fails to understand the sustainability requirements of individual developments.
- BREEAM fails to incorporate sufficient client participation. There was a consensus that this was amongst the fundamental factors in the success of a sustainable development.
- The complexity of the assessment means that it is often perceived and used as a 'tick-box exercise'. In the hands of less experienced assessors, this allows for the favouring of monetarily expedient design choices. Such decisions are likely to result in more profitable buildings, potentially at the expense of more sustainable buildings.
- The lack of effective post-construction evaluation means that BREEAM can fail to meet a component of sustainability: continual improvement. However, this is expected to be incorporated in the next issue of BREEAM.
- Minimal recognition of the importance of early assessor involvement and project lifetime design team engagement were both highlighted as inadequacies in more clearly facilitating a sustainable development.

# CONCLUSIONS

1. *Positive:*
   BREEAM was unanimously regarded as a successful model for an environmental assessment method.
   It has potential to be a valid measure of 'sustainable development' only if that term is understood in its broadest sense, and if its application is involved (as BRE intended) at the initial design stages of a development.
2. *Negative:*
   As it is currently used, BREEAM fails to address key aspects of sustainable

development and so is not deemed a proficient test of sustainability (sustainable development).

3. *Recommendations:*

The flexibility of design and review by its creators, results in an ongoing evolution of the BREEAM assessment. This provides potential for it to become proficient in the future. To achieve this goal, the following is recommended:

- Although the three pillars of sustainable development should not necessarily be addressed in equal measure in every development, the current general lack of societal focus has a major negative impact on effective sustainability.
- Geographical location is not adequately considered in the application of possible sustainability measures.
- BREEAM fails to sufficiently incorporate client participation or user needs, especially in the long term.
- The complexity of the assessment, being reduced to an apparent tick-box exercise masks the true potential, especially to those not familiar with either the construction industry options or with sustainability.
- Choice of sustainability measures is often decided on immediate monetary costs, instead of longer-term appropriateness for site and to users.
- Lack of long-term, post-construction evaluation renders BREEAM ineffective at measuring a development's continual improvement (although this is expected to be incorporated in the next issue of BREEAM).
- Where developers' have minimal recognition of the importance of early assessor involvement in the design, it renders BREEAM a retrospective fix, at best.
- Assessors may not all have built environment industry experience, leading to misunderstandings in advice given and options requested.

# REFERENCES

Alsaawi, A., 2014. A Critical review of Qualitative Interviews. *European Journal of Business and Social Sciences*. **3**(4): 149-156.

BREEAM, 2017a. *Home*. [online]. http://www.breeam.com/

BREEAM, 2017b. *Why BREEAM?* [online] http://www.breeam.com/why-breeam

Marton, F., Carlsson, M. and Halasz, L., 1992. Differences in Understanding and the use of Reflective Learning in Reading. *British Journal of Educational Psychology*. **62**(1): 1-16.

Sewell, J.E. and Fraser, D.J., (*2018b)* A Conceptual and Literature Review of the Effectiveness of BREEAM. *The Sheffield Hallam University Built Environment Research Transactions* **10** (1) 45-58