Reinforced Autoclaved Aerated Concrete (RAAC) in England: Assessment of number of RAAC panels

Prepared by WSP UK Ltd.

RR1212 (2025)

Research Report

Prepared 2024

First published 2025

Reinforced autoclaved aerated concrete (RAAC) is a form of construction used in England between the 1950s and 1990s. RAAC panels were used for walls, floor and roofs. RAAC was used across a range of different residential, commercial and government buildings. Recent years have seen a small number of RAAC panel failures.

To aid future assessments of the risk posed by RAAC panels, this report estimates the number of RAAC panels in England from archive data and past WSP surveys of building estates.

Based on the information available and the modelling techniques employed, it is estimated that there there are between 1.3 million and 4.4 million RAAC panels in England. These RAAC panels are spread between an estimated 9,000 and 33,000 buildings across a variety of sectors. There is a large range provided for these estimates, reflecting the limited data available at the time of writing.

The likely risks of RAAC panel collapse, and how those risks can be reduced through different monitoring and mitigation measures are addressed in HSE report RR1213 - Reinforced Autoclaved Aerated Concrete (RAAC) in England: Assessment of risk of collapse.

DOI: https://doi.org/10.69730/hse.25rr1212

This report and the work it describes were funded by the Health and Safety Executive. Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.

Reinforced Autoclaved Aerated Concrete (RAAC) in England: Assessment of number of RAAC panels

Zachariah Wynne, WSP
Philip Carey, WSP
Matthew Palmer, WSP

WSP UK Ltd.
62-64 Hills Road, Cambridge, CB2 1LA, UK.

WSP is an engineering professional services consultancy with experience in the identification and assessment of reinforced autoclaved aerated concrete (RAAC). WSP have been appointed by the Health and Safety Executive to provide an estimation of the number of RAAC panels in England and assess the potential risks which RAAC may pose.

Key Messages

- Reinforced autoclaved aerated concrete (RAAC) panels are a form of construction material. They were used for walls, floor and roofs in residential, commercial and government buildings built or modified between the 1950s and the 1990s in England.

- WSP compiled and reviewed available data to estimate the number of RAAC panels in England.

- Based on the information available and the modelling techniques employed, it is estimated that there are between 1.3 million and 4.4 million RAAC panels in England.

- These RAAC panels are spread between an estimated 9,000 and 33,000 buildings across a variety of sectors.

- It is likely that the majority of RAAC panels are located in non-residential buildings, and that they are predominantly used in the construction of roofs. The highest number of panels is likely to be found in factories and warehouses.

- There is a large range provided for these estimates, reflecting the limited data available at the time of writing. This range may be narrowed as further information and data on RAAC prevalence becomes available.

Executive Summary

Background

This report presents an initial estimate of the number of Reinforced Autoclaved Aerated Concrete (RAAC) panels in England. RAAC was used throughout construction projects in England between the 1950s and 1990s due to being a lightweight and relatively low-cost material.

Note: The approximate number of RAAC panels in England as presented in this report are estimates only. There is a large degree of uncertainty in these estimates, reflecting the limited data available at the time of writing.

The estimated number of RAAC panels derived in this report is to be used to inform later stages of work in which WSP will liaise with wider stakeholder groups and experts on the potential risks posed by RAAC panels in England. This work is documented in HSE report RR1213.

Methods

To determine an as accurate as possible estimate for the number of RAAC panels in England, WSP compiled and reviewed available data on the number of buildings constructed in different sectors in England during different construction periods and the likely prevalence of RAAC within those periods. This was based on anonymised data from past WSP surveys and typical panel usage in buildings with RAAC. These WSP surveys included targeted visual surveys of buildings across a variety of sectors to determine the presence of RAAC. The information collected from these surveys was combined with other information about the building including its construction date and gross internal floor area.

Findings

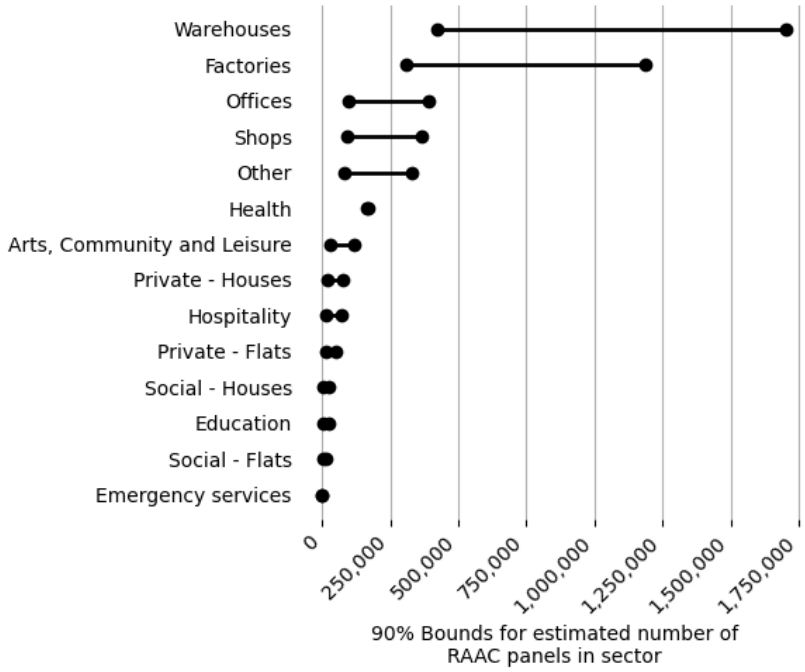

Figure 1. Summary of estimated number of RAAC panels by building sector. Error bars show range in which 90% of analysis simulations fall.

Based on the information available and the modelling techniques employed, there is a 90% likelihood that there are between 1.3 million and 4.4 million RAAC panels in England. These panels may be spread between 9,000 and 33,000 buildings across a variety of sectors. It is likely that the majority are located in commercial buildings and that they are predominantly used in the construction of roofs.

There is a large range provided for these estimates, reflecting the limited data available at the time of writing. This range may be narrowed as further information and data on RAAC prevalence becomes available.

Conclusions

A review of the available information suggests that RAAC panels may be present across a broad range of building sectors in England and may be found in any buildings built or modified between the 1950s and 1990s.

The data would suggest that RAAC panel use in England peaked in the 1970s and that it is primarily used in roof construction. It is more likely to be found in non-residential buildings.

Contents

Key Messages **4**

Executive Summary **4**

Background 5

Methods 5

Findings 6

Conclusions 6

1 Introduction **9**

1.1 Background 9

1.2 Research aim 9

1.3 Scope of report 10

1.4 Report structure 10

2 Methodology **11**

2.1 Model structure 11

2.2 Number of buildings 11

2.3 Gross internal floor area and number of storeys 12

2.4 Estimated RAAC prevalence 12

2.5 RAAC Type and average RAAC panel sizing 12

2.6 Statistical model formulation 13

3 Taxonomy of buildings **20**

4 Data sources **22**

4.1 Residential buildings 22

4.2 Non-residential buildings 22

4.3 RAAC prevalence 22

5 Model parameters **23**

5.1 Non-Residential 23

5.2 Residential 29

6 Model outputs **33**

6.1 Tabulated model data – non-residential (landscape format) 35
6.2 Tabulated model data – residential (landscape format) 53

7 Discussion 63
7.1 Sector specific model outputs 63
7.2 Impact of key modelling assumptions 68

Conclusions and recommendations 69

8 References 71

9 Appendix A – Model outputs by sector 73
9.1 Residential 73
9.2 Non-Residential 75

1 Introduction

1.1 Background

Reinforced Autoclaved Aerated Concrete (RAAC) panel construction is a form of construction used in England from the 1950s to the 1990s. RAAC panels were used for walls, floors and roofs across a range of residential, commercial and government buildings. Recent years have seen a number of RAAC panel failures[1] (Standing Committee on Structural Safety, 2019), resulting in an increased awareness of this form of construction and the potential risks posed by these panels.

This report brings together available information on the building stock of England, an approach to approximating historic use of RAAC, and an estimate as to the current number of RAAC panels in England.

What is RAAC?

For the purposes of this report, RAAC is defined as having four key characteristics:

1. It has a chemically aerated concrete mixture,
2. The aerated concrete mixture was hardened through an autoclave process,
3. It contains reinforcement bars,
4. It does not contain aggregate.

RAAC panels in England were produced and marketed under a wide range of different names including Siporex, Durox, Ytong, Durisol, Argex and Leca. RAAC panels are known to have been manufactured domestically and are also likely to have been imported from Europe and the wider world.

1.2 Research aim

To develop an informed assessment of the potential risks posed by RAAC and derive an appropriate strategy for mitigating those risks, it is crucial to understand how and where RAAC was historically used in construction.

This report provides an initial estimate of the potential number of RAAC panels in England, so that the scope of any potential risks from RAAC can be appropriately assessed. Alongside this, it presents estimates of the building sectors in which these panels may be

[1] https://www.cross-safety.org/uk/safety-information/cross-safety-alert/failure-reinforced-autoclaved-aerated-concrete-raac-planks

present, so that risks can be assessed as part of the broader context of building ownership and maintenance, and that any mitigation of risks can be tailored as appropriate.

1.3 Scope of report

This report provides an initial estimate of the number of RAAC panels in maintained buildings in England.

These estimates are based on publicly available datasets, or data collected independently by WSP (and anonymised) as part of other previous or ongoing RAAC panel surveys. While every effort has been made to ensure the data used is accurate and up to date, the accuracy of the estimates is limited by the accuracy of these datasets. Every effort has been made to reflect the uncertainty in the data within the estimates of the number of RAAC panels.

This report, which forms phase one of a wider project to assess the risks posed by RAAC panels, does not include:

- Estimates of the number of RAAC panels in Wales, Scotland or Northern Ireland.
- Any analysis or assessment of the likelihood of failure of RAAC panels or similar products.
- A comprehensive list of all known buildings containing RAAC in England.

The findings of this report are based on a review of information available as of 20 October 2023.

1.4 Report structure

Section 2 presents an overview of the methodology for estimating the number of RAAC panels in England. To arrive at these estimates, data has been collated from a broad range of sources.

Section 3 describes the taxonomy used in classifying buildings in England for the purpose of estimating the likelihood that they contain RAAC panels. The key data sources used for estimating the number of buildings by sector in England are described in Section 4. Details of the key input parameters used in the statistical analysis are provided in Section 5.

Summary and tabulated model outputs are presented in Section 6, with a discussion of the outputs presented in Section 7.

The conclusion summarises the findings of this report, alongside providing recommendations for further actions.

2 Methodology

To estimate the number of RAAC panels in England, a statistical model of buildings in England has been created. This model has been constructed using the inputs and methodology detailed in this section.

2.1 Model structure

To estimate the number of RAAC panels in a subset of buildings in England, where the subset may be a particular sector of buildings, period of construction, and/or form of construction, the model requires estimates of the following inputs:

- The number of buildings in the subset,
- The average gross internal floor area (GIFA) of buildings in the subset,
- The average number of storeys of buildings in the subset,
- The prevalence of RAAC in the subset of buildings,
- How RAAC is distributed within floor elements, wall elements and roof elements for the subset of buildings.

From these inputs, the model creates estimates of:

- The number of buildings in the subset which contain RAAC,
- The number of RAAC panels in the subset of buildings.

2.2 Number of buildings

Based on available information, a taxonomy of buildings has been created. This taxonomy is based on previous established taxonomies[2] of buildings in England and is such that all maintained buildings in England can be classified to a single building sector.

Within each sector, the available information has been reviewed to estimate:

- A lower bound estimate of the number of buildings in England,
- A modal[3], or most reported, estimate of the number of buildings in England,
- An upper bound estimate of the number of buildings in England.

[2] Building taxonomies have been adapted from those used in the English Housing Survey and the Non-domestic National Energy Efficiency Data-Framework.

[3] Throughout this report, the word ‘modal’ refers to the value that falls at, or close to, the peak of a distribution.

Where possible, and where information is available, the number of buildings in a sector has been subdivided based on periods of construction.

2.3 Gross internal floor area and number of storeys

The GIFA provides an indication of the likely floor, wall and roof areas of a building. Estimates have been compiled for:

- A lower bound estimate of the GIFA for each building sector,
- A modal, or most reported, estimate of GIFA for each building sector,
- An upper bound estimate of the GIFA for each building sector.

Given the scarcity of GIFA information by building sector, separate GIFAs are not provided for different periods of construction.

Alongside the average GIFA, estimates have been made of the average number of storeys of the buildings within each sector. The average number of storeys is used to adjust the GIFA for estimating the average areas of walls, floor and roofs within each building.

2.4 Estimated RAAC prevalence

Within each sector and each period of construction, separate estimates have been made for the RAAC prevalence or the percentage likelihood of a building containing RAAC. Separate estimates are made for:

- A lower bound estimate of the number of buildings containing RAAC: This is equal to the number of buildings which are known to contain RAAC.
- A modal, or most likely, estimate of the number of buildings containing RAAC: This estimate is based on WSP's collective knowledge, as established from previous RAAC surveys and extrapolation of available surveys of RAAC prevalence, manufacture and use.
- An upper bound estimate of the number of buildings containing RAAC: This is a conservative estimate of the possible number of buildings which may contain RAAC, based on detailed surveys undertaken by WSP.

2.5 RAAC Type and average RAAC panel sizing

Based on prior survey information, estimates have been made of the percentage of RAAC panels that are used in roofs, walls and floors.

The area of RAAC floor panels in a building is taken as the average GIFA, divided by the average number of storeys, and then multiplied by the average number of storeys minus one (on the basis that it is unlikely that the ground floor of a building is constructed from RAAC floor panels).

The area of RAAC roof panels in a building is taken as the average GIFA, divided by the average number of storeys.

The area of RAAC wall panels in a building is taken as the number of storeys, multiplied by four times the square root of the average GIFA divided by the number of storeys, multiplied by an average storey height of 3.0m. This is based on buildings having a footprint which is approximately square.

To convert area of RAAC to number of RAAC panels, the area is divided by the average RAAC panel dimension of 3.0m x 0.6m, as derived from previous RAAC surveys undertaken by WSP and archival RAAC manufactures information.

2.6 Statistical model formulation

For each building sector and period of construction, the distribution of the potential number of buildings, the average GIFA, and the likelihoods of containing RAAC wall/roof/floor panels are described by scaled skew-normal distributions (Azzalini and Capitanio 1999).

For the lower bound (N_{min}), modal value (N_{modal}) and upper bound (N_{max}) values defined for each distribution, the skew ($\tilde{\mu}_3$) of the distribution is approximated as:

$$\tilde{\mu}_3 \approx \frac{3(\mu - N_{modal})}{\sigma}$$

where σ and μ are approximated as:

$$\sigma \approx \frac{N_{max} - N_{min}}{4}$$

$$\mu \approx N_{min} + 2\sigma$$

This distribution is then normalized to the range N_{min} to N_{max}.

Figure 2 shows examples of 1,000,000 samples drawn from the skewed normal distributions for the number of buildings, average GIFA and likelihood of containing RAAC panel walls/floors/roofs. A sample size of 1,000,000 was empirically selected to ensure that the variation in the bounds of the 90% probability density for the number of RAAC panels was fewer than 1,000 panels during independent simulations.

In Figure 2, the top subplot shows a histogram of the independent simulations of the number of buildings in the sector which have been randomly sampled from the scaled skew-normal distribution. Simultaneously to randomly sampling the number of buildings in the sector, a separate random sample is generated of the average GIFA of the buildings in that sector. A histogram of these independent simulations of the average GIFA is shown in the middle subplot of Figure 2. A third random sample is generated of the likelihood that the buildings in the sector contain RAAC. A histogram of these independent simulations of

the likelihood of containing RAAC, stratified by the likelihood of containing RAAC panels as walls, floors and roofs, is presented in the lower subplot of Figure 2.

The methodology for combining the separate random samples of the number of buildings in a sector, the average GIFA and the likelihood of containing RAAC to estimate the number of buildings containing RAAC in that sector and the number of RAAC panels in that sector is described in the sections below.

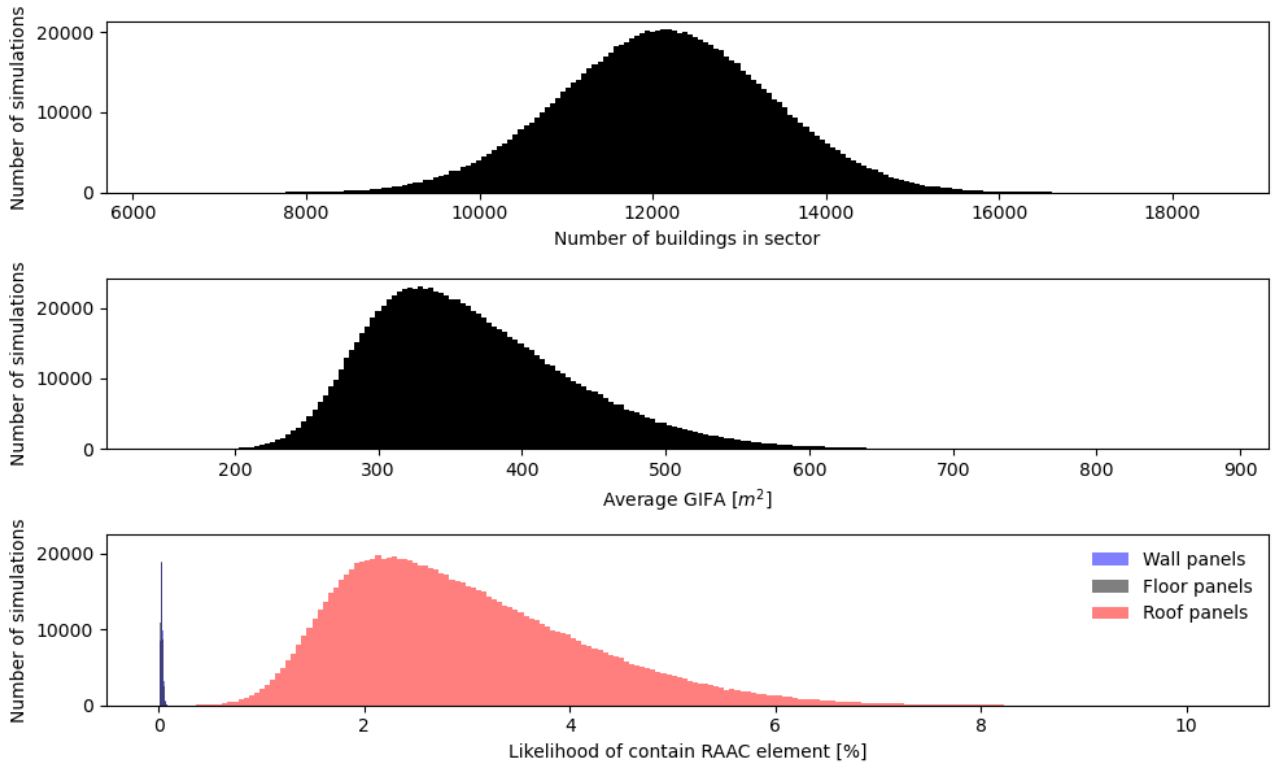

Figure 2. Example of distributions of number of buildings, average gross internal floor area (GIFA), and likelihood of containing RAAC. Histograms are based on 1,000,000 independent samples from scaled skew-normal distributions.

2.6.1 Notes on model selection

A wide range of methods were considered for estimating the number of RAAC panels in England, from localised random sampling of buildings to attempting to obtain manufacturing quantities of RAAC panels in the UK.

The key drivers when selecting the model adopted for the report are as follows:

- There is a scarcity of information currently available. There are absences of data on the number of buildings in England, the types and sizes of buildings in England, the age of buildings in England, historic patterns of renovation and expansion of buildings in England, manufacturing quantities of RAAC panels and RAAC removal, among others.
- There are strong asymmetries in the information currently available. An example of this is that while the lower bound of number of buildings which contain RAAC may be

known, there is much greater uncertainty as to the upper bound number of buildings which might contain RAAC. Similarly, while the majority of publicly known buildings with RAAC are primarily public sector, there is evidence that RAAC has also been used in the private sector; it may be that the private sector is less likely to report RAAC being present.

- The model was selected to minimise the number of assumptions and hyperparameter inputs required. If a more complex statistical model was used, there would be a higher likelihood that systematic bias is inadvertently introduced into the results, resulting in skewed results.

On the basis of the requirements above, a scaled skew-normal distribution is adopted throughout the statistical model to reflect the asymmetry in available information, based on similar uses in modelling risk in financial markets (Adcock, Eling and Loperfido 2015) and the spread of COVID-19 (Maleki et al. 2020).

Advantages of scaled skew-normal model

Beyond offering a method for reflecting the asymmetry in available information, the formulation of the scaled skew-normal distribution, as introduced at the beginning of this section, has an additional advantage. As the distance between our expected modal value, as derived from current information, and our upper bound value increases, the true modal value of the distribution, as approximated through the scaled skew-normal distribution, increases. As discussed further in Section 5, this is a useful characteristic for the purposes of modelling RAAC prevalence, as it reflects the likelihood that the assessment of RAAC prevalence based on previous limited RAAC surveys is an underestimate of the true prevalence of RAAC.

If a symmetric distribution centred around the known number of buildings with RAAC was adopted within the model, there is a significant risk of severely underestimating the number of RAAC panels in England, as it is unlikely that the majority of buildings have been inspected for RAAC.

Similarly, a truncated normal distribution is not believed to be an appropriate method for estimating the number of RAAC panels in England. If a truncated distribution for the minimum number of buildings that contain RAAC was used, a significant likelihood would be assigned to the conclusion that all buildings containing RAAC have been identified. This conclusion is not currently supported by the data underpinning the statistical model. Any truncation of the distributions for likelihood of buildings containing RAAC would also mask the significant uncertainty that arises from not knowing the ‘true’ number of buildings within each sector. As discussed later in this report, this uncertainty in the number of buildings in a sector is a key source of the deviation between the upper and lower bound estimates of the number of RAAC panels by sector.

In contrast to adopting truncated distributions, the scaled skew-normal distribution adopted in the modelling assigns a very small likelihood (~<1%) to there being fewer buildings with RAAC than have currently been identified, reflecting a small possibility that there are errors

in the reported number of buildings for a sector. It then assumes that the number of buildings containing RAAC is greater than the minimum, on the assumption that not all buildings have been inspected.

While a more complex statistical model could be adopted, in which the known number of RAAC panels was separated from the likely uncertainty within the data, modelling with the scaled skew-normal distribution was selected to minimise the number of model inputs and to aid readability and interpretability of the results.

Spatial Variation of RAAC Usage

While a spatial variation in RAAC prevalence across England has been hypothesized, this has not been included in the model. If more information on the spatial variation in RAAC usage was available, this would likely improve the efficacy and fidelity of the estimates of RAAC prevalence presented in this document. The key barriers to implementing spatial data when estimating RAAC prevalence in England are a lack of data on the spatial distribution of buildings by sector, a lack of data on where RAAC producing factories/RAAC import locations were in the UK, and a potential reporting bias which may be present within existing datasets. For example, areas with relatively high instances of publicly known RAAC-containing buildings may result in a better awareness of RAAC, resulting in greater levels of further RAAC identification.

2.6.2 Notes on random sampling

Throughout the modelling, large-sample random sampling of the scaled skew-normal distributions is used to generate simulations of potential numbers of buildings, average GIFAs and likelihood of those buildings containing RAAC.

Large-sample random sampling has been used as a computationally efficient method of approximating the convolution of the three scaled skew-normal distributions (number of buildings, average GIFA and likelihood of containing RAAC), which form the inputs for the statistical model.

Approximating the continuous scaled skew-normal distribution with a large number of independent samples results in truncation of the extreme outliers of the distribution (due to the low likelihood of a sample being drawn from the extreme tails of the continuous distribution). To overcome this, the selected number of simultaneous samples (1,000,000) has been empirically selected to ensure that the variation in the bounds of the 90% probability density for the total number of RAAC panels in England was fewer than 1,000 panels during independent simulations.

2.6.3 Estimated number of buildings with RAAC elements

To estimate the number of buildings with RAAC wall, floor, or roof panels, 1,000,000 simultaneous samples were randomly generated from the distributions of RAAC likelihood (bottom subplot of Figure 2) and the distribution of number of buildings in the sector (top subplot of Figure 2). The result, shown in Figure 3, approximates the results of convolving

the scaled skew-normal distributions for the number of buildings in the sector with the likelihood of containing RAAC elements.

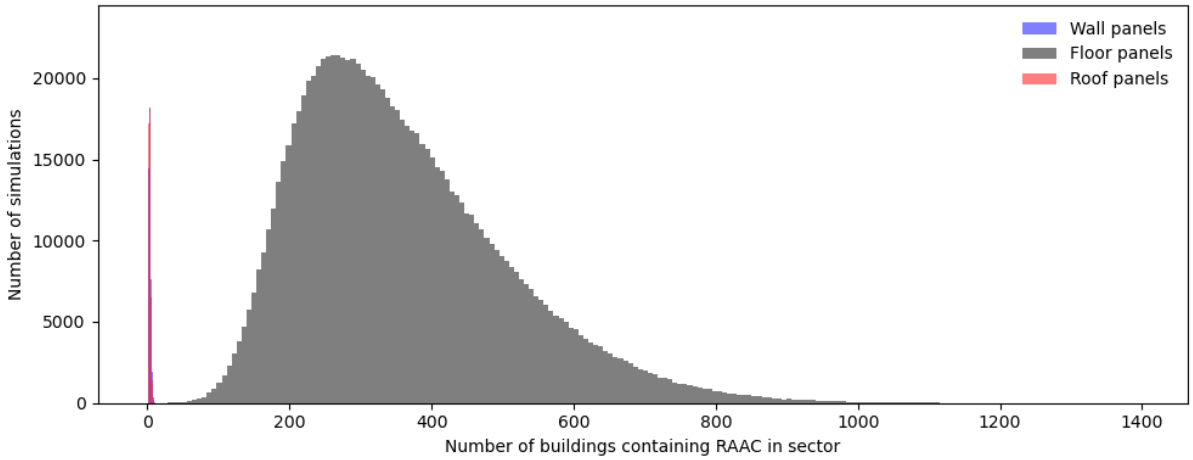

Figure 3. Example of distributions of number of buildings containing RAAC roof, wall and floor panels. Histograms are based on simultaneous sampling of 1,000,000 independent samples from scaled skew-normal distributions.

The total number of buildings containing RAAC in a sector is then taken as the sum of the number of buildings containing RAAC wall panels, floor panels or roof panels, as shown in Figure 4.

Note: This conservatively assumes that a building having RAAC wall, floor, or roof panels is mutually exclusive. This does not impact the estimates of the number of RAAC panels, but it is likely that the number of buildings with RAAC from the model is an overestimate, as RAAC wall, roof, and floor panels may co-exist within a single building. However, at present, there is insufficient data to include this co-existence within the statistical model.

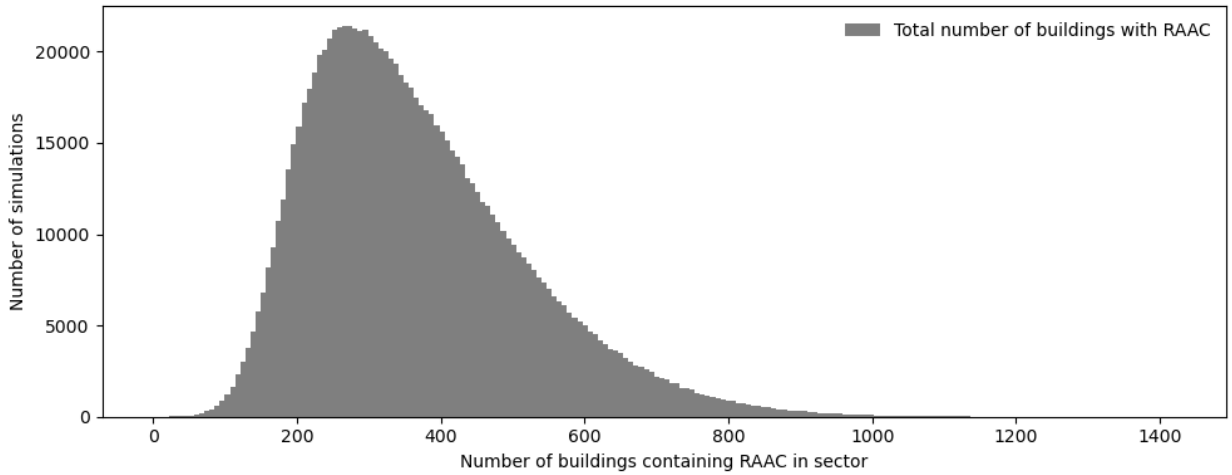

Figure 4. Example of distributions of number of buildings containing RAAC panels. Histogram is based on simultaneous sampling of 1,000,000 independent samples from scaled skew-normal distributions.

The total number of buildings containing RAAC in England is estimated by sorting the distributions by RAAC likelihood and summing the distributions from all periods of construction and building sectors. Sorting the distributions by RAAC likelihood prior to summing is carried out to reflect the likely correlation between RAAC prevalence across all sectors. For example, if RAAC was widely used in one building sector, it is likely to have also been widely used in other building sectors. Failing to account for this correlation of RAAC prevalence across sectors would underestimate the lower and upper bound number of buildings with RAAC.

2.6.4 Estimated number of RAAC panels

The number of RAAC panels within a sector for each period of construction is estimated by taking 1,000,000 simultaneous random samples from the distributions of RAAC likelihood (bottom subplot of Figure 2), the distribution of number of buildings in the sector (top subplot of Figure 2) and the average GIFA (middle subplot of Figure 2).

Using the relationships between GIFA and area described in Section 2.5 gives an estimate of the total area of RAAC wall/floor/roof panels. This area is divided by 3m x 0.6m = 1.8m^2 – the average area of a RAAC panel used in England – to estimate the number of RAAC wall/floor/roof panels.

The total number of RAAC panels in a sector and period of construction is estimated by sorting the distributions by their associated RAAC likelihood and summing the estimated number of RAAC wall/floor/roof panels, as shown in Figure 5. As described above, sorting of the distributions by RAAC likelihood is carried out to reflect the correlation in RAAC prevalence between sectors.

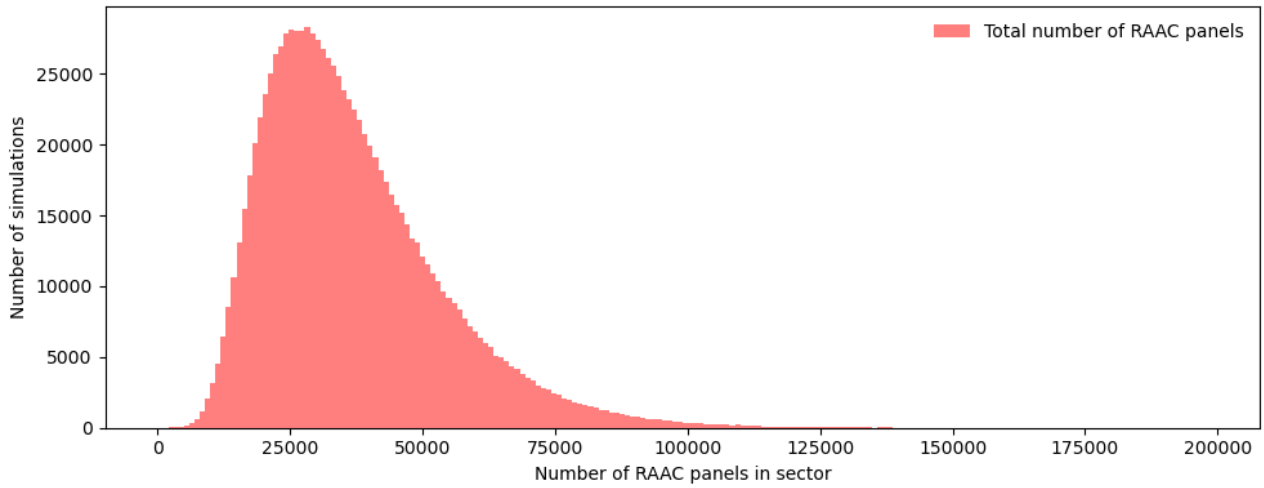

Figure 5. Example of distributions of number RAAC panels. Histogram is based on simultaneous sampling of 1,000,000 independent samples from scaled skew-normal distributions.

As discussed further in Section 5, the sum number of RAAC panels for healthcare buildings built between 1971 and 1995 has been adjusted to reflect the approximately 160,000 RAAC panels which are present in seven large NHS hospitals. This adjustment is

carried out to reflect the presence of RAAC in outlier buildings, which are not well characterised by the statistical model employed in the wider analysis. This is the only manual adjustment to the estimated number of RAAC panels. While a more complex statistical model could be developed to account for the presence of outlier buildings within each sector, it is deemed unlikely that further large outlier buildings containing RAAC would not be known at the time of writing.

The total number of RAAC panels in England is estimated through sorting the distributions of number of RAAC panels from all periods of construction and building sectors by their associated RAAC likelihood and summing across the distributions. As described above, sorting of the distributions by RAAC likelihood is carried out to reflect the correlation in RAAC prevalence between sectors.

3 Taxonomy of buildings

As discussed in the previous section; to arrive at an accurate estimate of the number of RAAC panels in England, an assessment must be made of the number of buildings in the UK. As no authoritative list of buildings in England is publicly available, a taxonomy of buildings has been created. This taxonomy combines data from multiple different sources, as described in Section 4, to arrive at estimates of the number of buildings by sector.

The taxonomy adopted in this report is divided into residential and non-residential buildings to reflect the differing prevalence of RAAC in different sectors.

Residential buildings are subcategorized into social houses, private houses, social flats and private flats. Houses are defined as terraced houses, semi-detached houses, detached houses and bungalows. Flats are defined as buildings with more than three storeys that are purpose built low-rise, high-rise flats, or converted flats. Data for the number of residential buildings in England is drawn from the 2019 English Housing Survey[4].

Within this report, non-residential buildings are classified according to the taxonomy of buildings from the Non-domestic National Energy Efficiency Data-Framework 2022 (ND-NEED 2022), reproduced in Table 1. This subdivision by building sectors is carried out to reflect differing average GIFAs, which strongly impact estimates of the number of RAAC panels.

[4] More recent data from the English Housing Survey is available. However, recent versions of the English Housing Survey do not include vacant properties and may underestimate the number of residential buildings in England, as of 2023.

Table 1. Taxonomy of non-residential buildings adapted from the ND-NEED 2022.

ND-NEED Building Sector	Broad Description
Arts, Community and Leisure	Cinemas, Community centres, Libraries/Museums, Sports centres, Sports grounds
Education	Nurseries, State schools, Private schools, Universities
Emergency services	Ambulance/Fire stations, Police stations
Factories	Factories
Health	Healthcare
Hospitality	Restaurants, Hostels, Hotels, Holiday homes/Guesthouses, Pubs
Offices	Offices
Shops	Shops
Warehouses	Warehouses
Other	Bus stations/moorings, Cemeteries, Docks, Electricity hereditaments (including power stations and premises), Garages, Markets, Military premises, Sewage treatments

4 Data sources

4.1 Residential buildings

Data for the number of residential buildings and average GIFA of residential buildings in England is adapted from the English Housing Survey data on stock profile, as used within the 2019-2020 English Housing Survey housing stock estimates (Ministry of Housing, Communities & Local Government 2020a). This dataset provides an estimate for the number of social and private flats and houses constructed within pre-defined construction periods. The 2019 data has been used within this report as it includes vacant properties. The sampling and weighting methodology used in constructing this dataset, alongside likely sources of error and limitations of the data, is described in the 2019-2020 English Housing Survey Technical Report (Ministry of Housing, Communities & Local Government 2020b).

4.2 Non-residential buildings

Data for the number of non-residential buildings and average GIFA of non-residential buildings in England, stratified by sector and period of construction, is adapted from data from the ND-NEED 2022 (Department for Business, Energy & Industrial Strategy 2022a).

Notes on the sampling methodology, sources of bias and error, buildings excluded from the dataset and dataset weighting for these estimates are given in the ND-NEED methodology 2022 (Department for Business, Energy & Industrial Strategy 2022b).

4.3 RAAC prevalence

Primary data sources reviewed to identify the prevalence of RAAC include:

- The Department for Education (DfE) RAAC surveys, which have identified 214 schools with RAAC and counting out of the 22,047 state funded schools in England,
- A WSP survey of buildings, undertaken as part of a wider series of RAAC surveys, which includes data from 758 buildings,
- The WSP survey of NHS Property Services managed buildings, which identified seven buildings with RAAC out of 3,000 buildings surveyed,
- Data from the ongoing RAAC monitoring of Hinchingbrooke Hospital and James Paget Hospital, undertaken by WSP,
- An extensive literature review of historical RAAC records including manufactures guidance, publicity material and academic texts.

The data provided above is based on the information available in October 2023.

5 Model parameters

This section provides a description of the basis for each of the input parameters used when modelling the number of RAAC panels in England.

5.1 Non-Residential

The ND-NEED provides estimates of the number of non-residential buildings within a sector constructed in England and Wales for each period of construction. As the ND-NEED dataset covers both England and Wales, the data must be adjusted for use within this analysis, which covers only England.

5.1.1 Number of buildings

For each sector of non-residential buildings, the following methodology has been used to estimate the lower bound, modal value and upper bound estimates for the number of buildings in England.

Estimates of the modal number of buildings within each sector built in each construction period, as defined within the ND-NEED data, are based on the ratio of the population of England and Wales. The population of England is approximately 55.98 million. The population of Wales is approximately 3.14 million. In the absence of further data, the modal estimates for the number of buildings in England for each sector constructed within each construction period is derived based on the assumption that the number of buildings is proportional to the ratio of populations between the nations. Therefore, the modal number of buildings in each period of construction is taken as 94% of the number reported in the 2022 ND-NEED data, with the number of buildings which are missing construction dates[5] divided equally between all periods of construction.

The lower bound estimates of the number of buildings in each sector in each construction period is taken as 70% of the number of buildings reported within the ND-NEED data for that building sector and construction period. This number is designed to reflect the potential for concentrated periods of construction in Wales where the number of buildings constructed in England may be lower and to account for uncertainties within the ND-NEED methodology, which may result in an overestimate of the number of buildings.

The upper bound estimates of the number of buildings in each building sector and construction period is taken as 100% of the number of buildings reported within the ND-NEED data plus 50% of the number of buildings where the period of construction is unknown. This is equivalent to assuming that no buildings in each sector were constructed in Wales during a given construction period and that a large proportion of buildings which

[5] The number of buildings which are missing construction dates are inferred through comparison of the number of buildings reported in Table 1 and Table 3B of the 2022 ND-NEED dataset.

are missing construction dates were constructed in each construction period. This number also accounts for uncertainties within the ND-NEED methodology, which may result in an underestimate of the number of buildings in each sector and construction period.

The simulated possible numbers of buildings stratified by construction period and building type for commercial buildings are given in Figure 6.

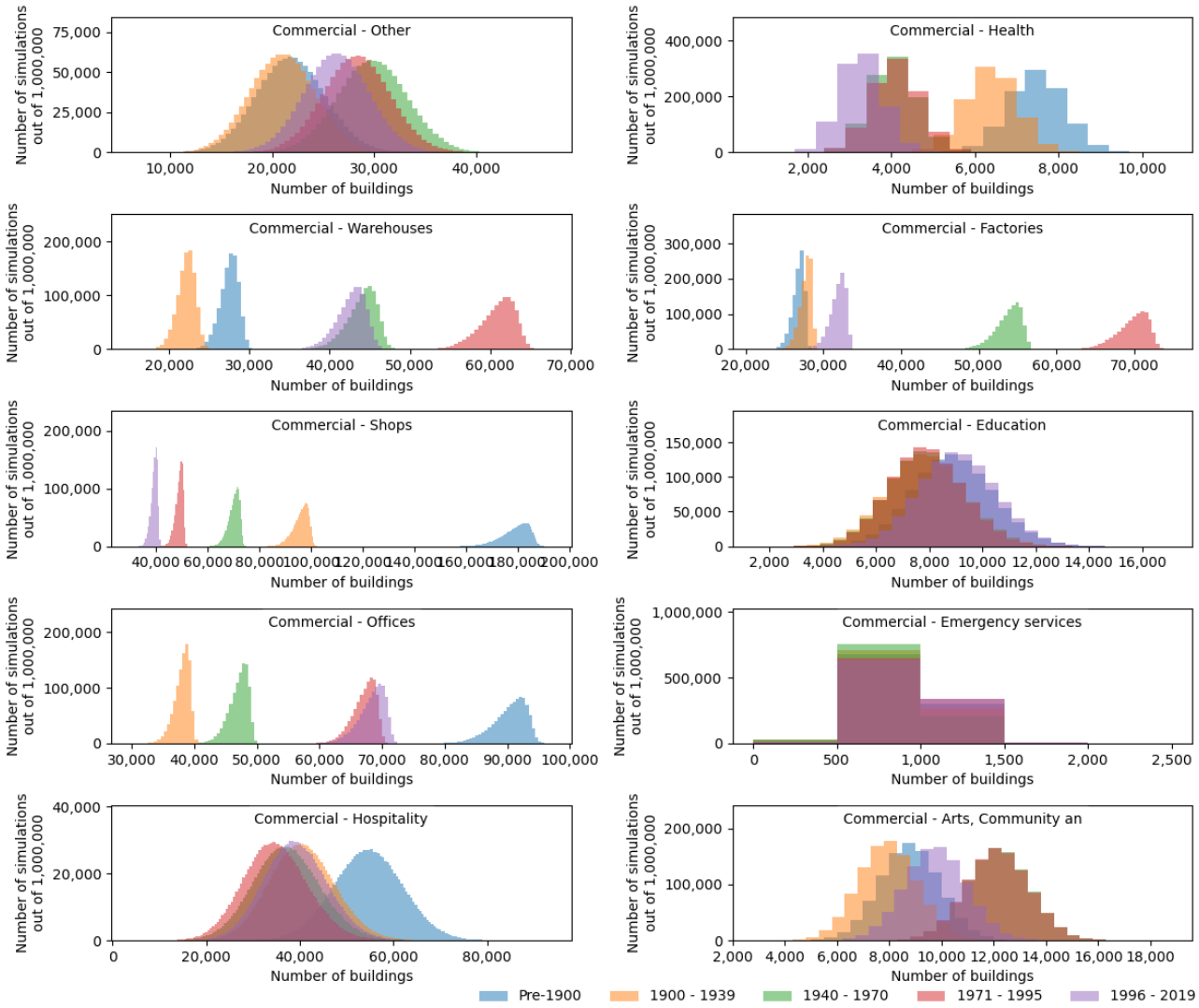

Figure 6. Simulated distributions of commercial buildings by sector and period of construction. Histogram bin width of 500 buildings used throughout.

5.1.2 Average gross internal Floor Area

While the ND-NEED provides a breakdown of the number of buildings within each sector with a specific GIFA, it does not provide a breakdown of GIFA data by period of construction.

In the absence of more detailed information, the modal value of GIFA for all periods of construction for each sector is taken as the average GIFA across all building sizes reported in the ND-NEED data for each sector. The lower bound GIFA for all periods of construction is taken as 40% of the average GIFA reported for that building sector,

reflecting the possibility that the GIFA in each construction period may be substantially lower than the average. The upper bound GIFA for all periods of construction is taken as 300% of the average GIFA for that building sector, reflecting the possibility that the floor area in each construction period may be substantially higher than the average. This adjustment in the lower and upper bound GIFA further accounts for the possibility that buildings with RAAC may have substantially different GIFA from the wider building stock, which cannot be estimated from the data which is currently available.

The simulated average GIFA stratified by building type for non-residential buildings is plotted in Figure 7.

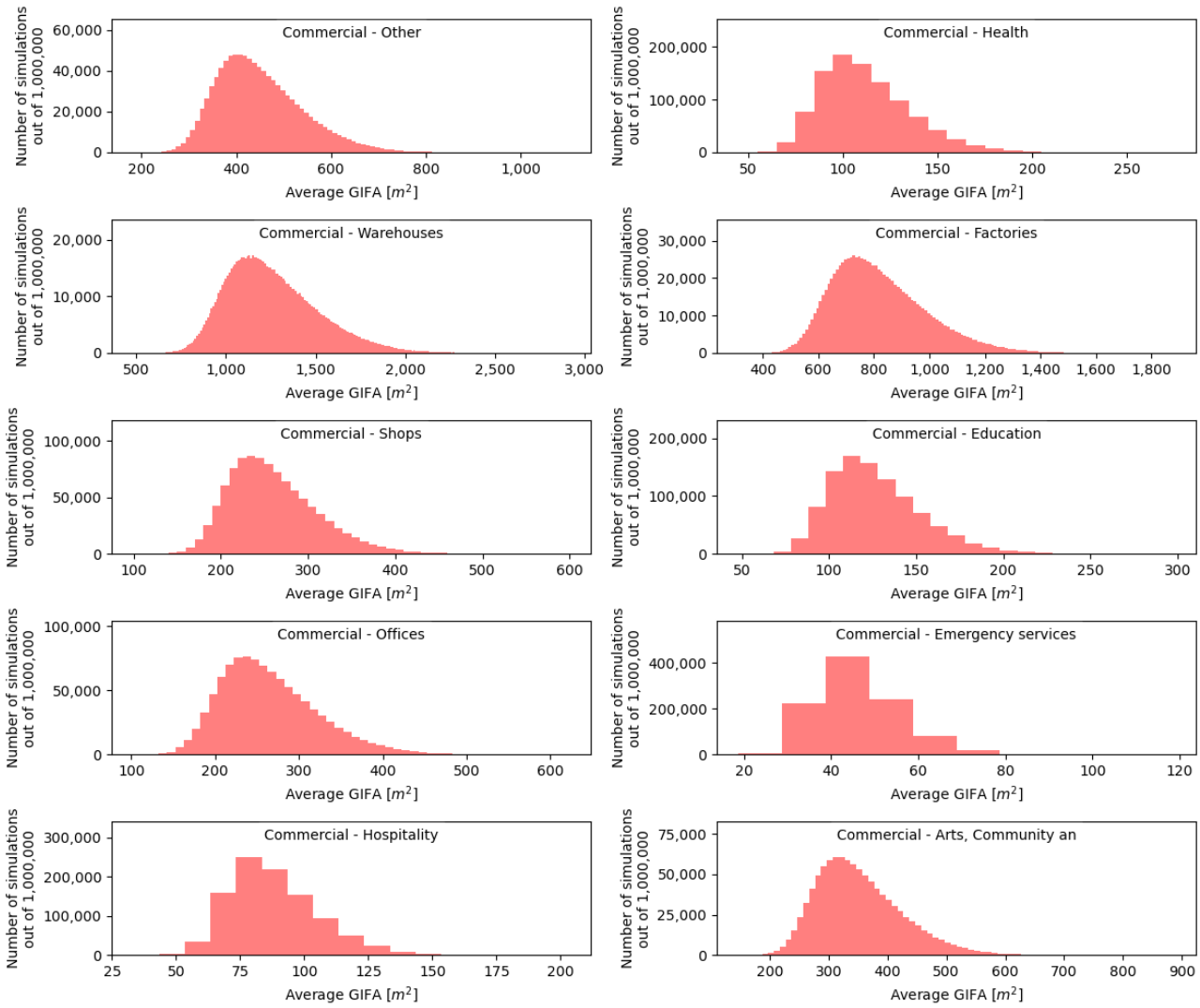

Figure 7. Simulated distributions of average GIFA distributions of commercial buildings by sector and period of construction. Histogram bin width of 10m2 used throughout.

5.1.3 Average number of storeys

The average height of non-residential buildings in England is not known. After a review of available information for the United States (Li et al. 2020), Germany (Frantz et al. 2021) and China (Huang et al. 2022), an average height of two storeys has been selected for all

non-residential buildings sectors. This assumes that the number of buildings with more than two storeys is outnumbered by the number of single storey buildings in England.

5.1.4 Likelihood of containing RAAC

The likelihood of a building within each sector and period of construction containing RAAC has been estimated through combining information from previous RAAC prevalence surveys.

The estimated lower bound likelihoods of buildings within each sector containing RAAC is based on the number of buildings which are known to contain RAAC at the time of writing. This information has been compiled from news outlets, public statements and previous RAAC surveys.

Note: Relative to the number of buildings within each sector, the number of known RAAC buildings is very small. Therefore, across most sectors, the lower bound RAAC likelihood based on current information has been taken as zero. However, if in future revisions of the estimates, a comprehensive number of RAAC buildings by sector is known, and the number results in a non-negligible lower bound RAAC likelihood for a given sector and period of construction, the lower bound likelihood should be adjusted to reflect this value.

The baseline modal estimate for the likelihood of any non-residential building containing RAAC, in the absence of sector specific or construction period specific information, has been taken as 0.72%. This number is based on combining data from:

- The DfE RAAC surveys, which have identified 214 schools and counting with RAAC out of the 22,047 state funded schools in England.
- The WSP survey of NHS Property Services managed buildings, which identified 7 buildings with RAAC out of 3,000 buildings surveyed.

Therefore, of a total of 25,047 buildings assessed, 0.88% of buildings (221 buildings) have been confirmed to have RAAC. The portfolio of buildings surveyed includes a wide range of periods of construction and construction types and is geographically diverse. Therefore, in the absence of further data, it believed to be broadly representative of RAAC prevalence in English non-residential buildings.

As surveys are ongoing at the time of writing, it is expected that the number of schools with RAAC is higher than that currently reported within the DfE. Therefore, it is likely that the modal RAAC likelihood based on the datasets described above will increase over time. This effect is already indirectly accounted for within the statistical model due to the formulation of the scaled skew-normal distributions, as described previously in Section 2.6, which increase the true modal value of the generated distribution when the distance between the upper bound and inputted modal value is large.

The baseline upper bound likelihood of non-commercial buildings containing RAAC panels has been taken as 9.0%. This number is based on a survey of buildings undertaken by WSP as part of a wider RAAC prevalence survey. This survey identified that 9.0% of

buildings (68 buildings) contained RAAC, out of a total of 758 buildings where the presence or absence of RAAC could be determined. While the buildings included within this survey are of a diverse variety of ages and construction types, they form part of a self-selected sample in which a large number of sites were not surveyed, as they were deemed unlikely to contain RAAC. By taking a RAAC likelihood of 9.0% as an upper bound, it is assumed that all buildings ruled out of the wider RAAC survey are of equal likelihood of containing RAAC as those included within the sample of buildings surveyed. By extension, through applying this upper bound RAAC likelihood to all non-residential building sectors, it is conservatively assumed that the non-residential building sectors may have an equal likelihood of containing RAAC as the sample of buildings surveyed.

Adjustment for historic patterns of RAAC usage

To reflect the periods in which RAAC was used in England, the baseline modal and upper bound likelihoods of buildings containing RAAC are adjusted based on the prevalence of RAAC by period of construction, as identified through the WSP survey of buildings conducted as part of a wider RAAC prevalence survey. After resampling and subsampling of the dataset to account for the bias of construction years within the sample set, the analysis identified that, on average, 15% of RAAC-containing buildings were constructed in the 1950s, 26% were constructed in the 1960s, 34% were constructed in the 1970s, and 24% were constructed in the 1980s, as highlighted in Figure 8. While buildings containing RAAC that were constructed before 1950 and after 1990 are known to exist, this number was deemed to fall within the margin of error for estimating the number of RAAC panels using the statistical model detailed in this report.

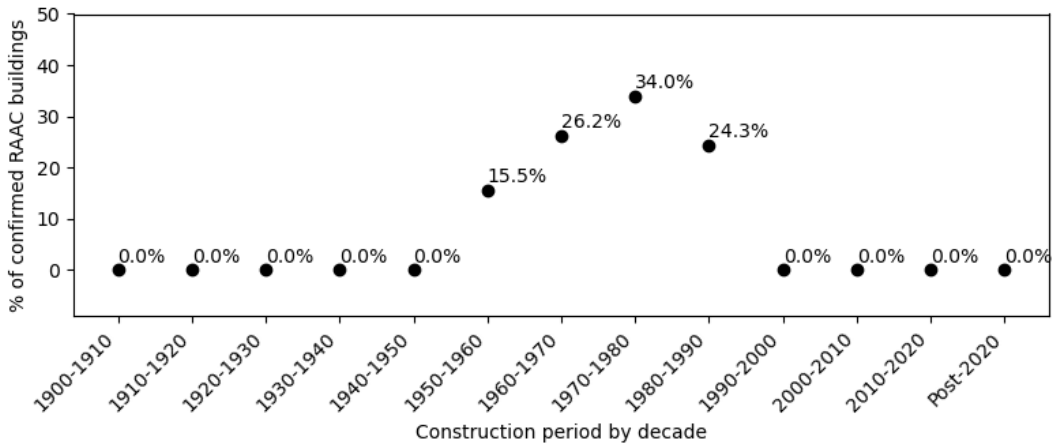

Figure 8. RAAC prevalence by decade of construction, as identified from the WSP survey of buildings as part of a wider RAAC survey. Pre-1900 buildings are excluded from plot.

The ND-NEED dataset seperates buildings into five periods of construction:

- Pre-1900,
- 1900-1939,
- 1940-1970,

- 1971-1995,
- 1996-2019.

Based on the analysis described above, the modal and upperbound likelihood of a building containing RAAC for all non-residential buildings built pre-1940, or post-1995 is taken as zero. For buildings built between 1940 and1970, the baseline modal and upper bound likelihood of a building containing RAAC is adjusted by a factor of 0.834 (reflecting the lower prevalence of RAAC during this time) to give a modal likelihood of containing RAAC of 0.73% and an upperbound likelihood of containing RAAC of 7.51%. For buildings built between 1971 and 1995, the modal and upper bound likelihood of a building containing RAAC is adjusted by a factor of 1.166 (reflecting the higher prevalence of RAAC during the 1970s and 1980s) to give a modal likelihood of containing RAAC of 1.17% and an upperbound likelihood of containing RAAC of 10.50%.

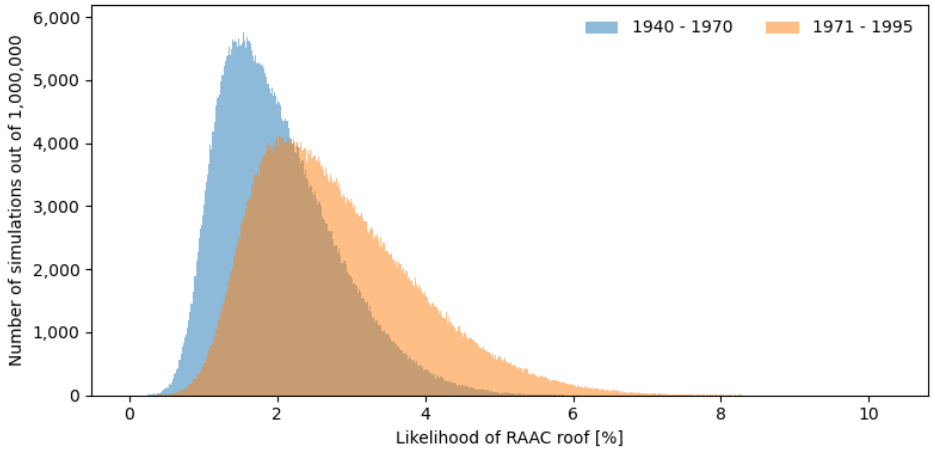

Figure 9. Simulated distribution of likelihood of RAAC roof for non-residential buildings by period of construction. Histogram bin width of 0.01% used throughout.

For non-residential buildings with RAAC, it is assumed that 98% of these buildings contain RAAC roof panels (which gives the distribution of likelihoods of RAAC roofs plotted in Figure 9), 1% contain RAAC floor panels and 1% contain RAAC wall panels. These numbers are derived from the survey of buildings undertaken by WSP as part of a wider RAAC prevalence survey. As discussed in previous sections, no additional allowance is made for co-existence of RAAC panel types within a single building, as this does not impact the estimated number of RAAC panels.

5.1.5 Model adjustment for known RAAC

WSP is aware of approximately 160,000 RAAC panels in seven large NHS hospitals in England. These hospitals have GIFAs that are much greater than the average GIFA of healthcare buildings as reported within the ND-NEED dataset.

In recognition of these known RAAC panels and the fact that they are in buildings that are poorly approximated within the statistical model using the average GIFA, an additional 160,000 RAAC panels is added to the sum number of RAAC panels for healthcare

buildings. The estimated number of healthcare buildings with RAAC is not adjusted, as the RAAC prevalence on a building level is already captured through the lower bound RAAC likelihood value.

No other adjustments for known RAAC are made in the current model. While other RAAC-containing properties are known, these buildings have GIFAs that are closer to the range of average GIFAs used within the model. Therefore, the estimated number of panels already accounts for these known RAAC panels.

5.2 Residential

Within the statistical model, residential buildings are split into four categories:

1. Private housing: Houses,
2. Social housing: Houses,
3. Private housing: Flats,
4. Social housing: Flats.

The 2019-20 EHS provides separate estimates of:

- The number of private and social housing dwellings in England according to period of construction.
- The number of private and social housing dwellings in England according to property type.

5.2.1 Number of buildings

As the EHS does not provide estimates of the type of dwellings constructed in each period of construction, the modal estimates are defined by assuming the period of construction and the dwelling type are uncorrelated. Based on the estimates provided in the EHS, it is assumed that 13.8% of the private properties constructed in each construction period are flats and 30.7% of the social housing properties constructed in each construction period are flats.

The lower bound estimates for each type of residential dwelling in each construction period is taken as 5% of the number of dwellings constructed within that period. The upper bound estimates for each type of residential dwelling in each construction period is taken as 95% of the number of dwellings constructed within that period. This bounds the possibility that construction of houses or flats may be concentrated within specific periods of construction, as is known to be the case for purpose built social housing flats that were largely built in the post-war period.

Note: the number of flats provided within the model is number of individual flats, not blocks of flats.

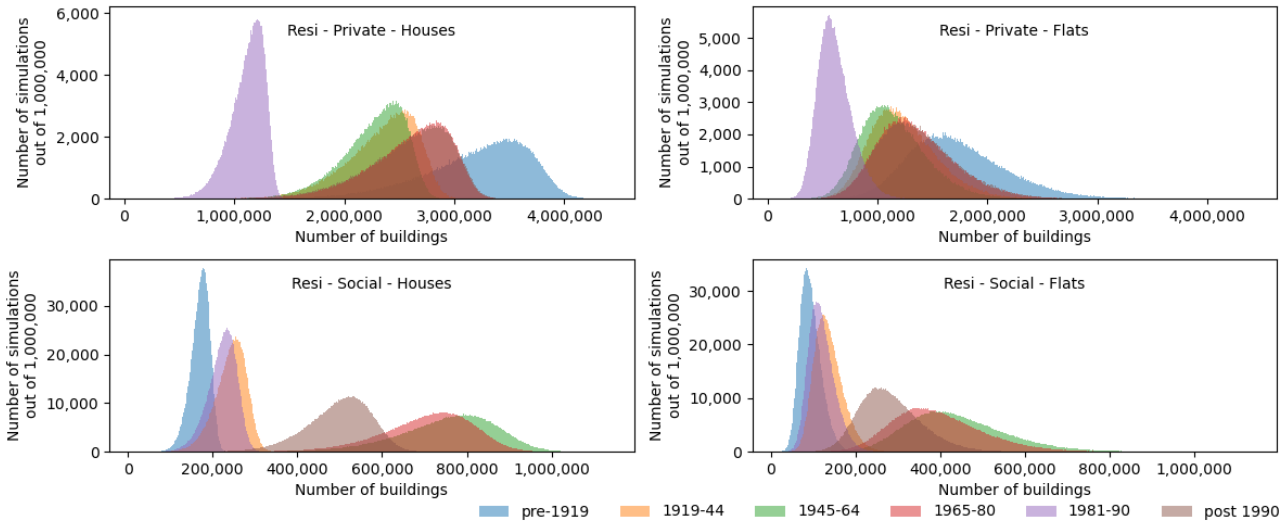

Figure 10. Simulated distributions of residential buildings by sector and period of construction. Histogram bin width of 2,000 used throughout.

5.2.2 Average gross internal floor area

The EHS provides average GIFAs for dwellings based on period of construction and dwelling types but does not provide a breakdown for social and private housing. As the range of average GIFAs reported across the periods of construction (from 89m^2 to 106m^2) is small compared to the range of GIFAs reported for dwelling types (103m^2 for houses; 61m^2 for flats), the lower bound, modal and upper bound values for the floor areas are assumed to be constant across periods of construction.

The average GIFA for each dwelling type is taken as the modal value. A value of 50% of the average GIFA for each dwelling type is taken as the lower bound average GIFA. A value of 150% of the average GIFA for each dwelling type is taken as the upper bound average GIFA. No distinct in GIFA is made between social and private housing. This adjustment in the lower and upper bound GIFA accounts for the possibility that buildings with RAAC may have substantially different GIFA from the wider building stock, which cannot be estimated from the data currently available.

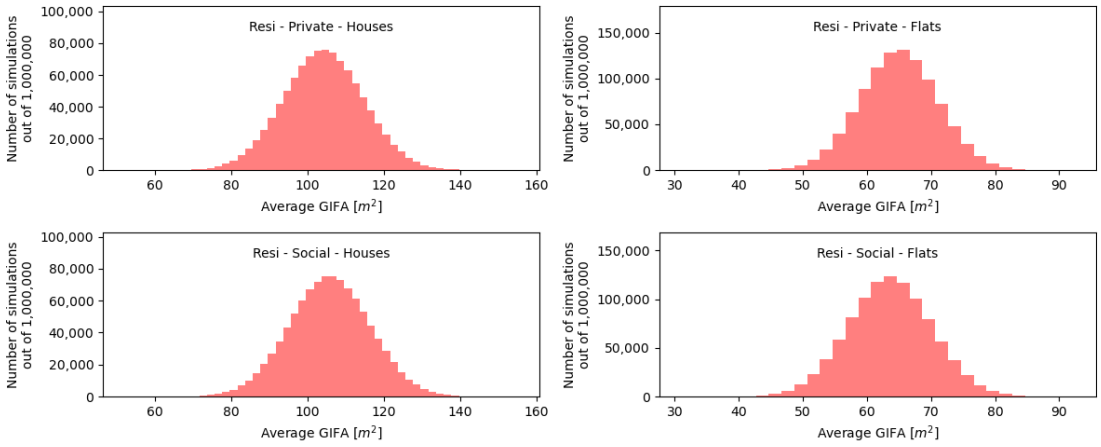

Figure 11. Average GIFA distributions of residential buildings by sector and period of construction. Histogram bin width of 2 m^2 used throughout.

5.2.3 Average number of storeys

For social and private ownership, the number of storeys has been inferred from data on the number of bungalows provided in the EHS. This indicates that 8.5% of private houses are bungalows and 19.8% of social housing houses are bungalows. On the assumption that bungalows are single storey and houses are two storeys, the average number of storeys for private houses is taken as 1.91; the average number of storeys for social housing houses is taken as 1.72.

Note: While there will be houses with more than two storeys that are not explicitly accounted for in the method above, this will be counteracted by the smaller average GIFA of bungalows and is not believed to meaningfully impact the estimates of number of RAAC panels in England.

For social and private housing flats, the number of storeys has been taken as one, as the numbers provided by the EHS are for flats, not blocks of flats.

5.2.4 Likelihood of containing RAAC

In England, it is known that RAAC was used in the construction of large residential estates, such as the Bluehouse estate in Laindon, Basildon, which was constructed in the early-1960s and demolished in the 1990s. However, relative to non-residential buildings, the prevalence of RAAC in existing residential buildings is likely to be lower. This is a result of a lower uptake of RAAC by house builders due to the limited advantages of RAAC for small scale construction and a higher demolition rate for known RAAC residential buildings.

Due to a lack of comprehensive surveys for RAAC prevalence in residential buildings in England, the likelihood of residential buildings containing RAAC has been inferred from the data for non-residential buildings. As with non-residential buildings, the lower bound RAAC likelihood for all residential building sectors is based on the number of buildings within that sector and period of construction that are known to contain RAAC. Given the number of residential buildings in England, this gives a lower bound likelihood of close to zero.

The baseline modal likelihood (0.009%) and upper bound likelihood (0.09%) of residential buildings containing RAAC are taken as two orders of magnitude lower than the equivalent likelihood for non-residential buildings. This reflects the known lower uptake of RAAC for residential buildings and the broader availability of other, more attractive, prefabricated building methods for residential buildings.

Adjustment for historic patterns of RAAC usage

As with the non-residential RAAC likelihoods, the baseline RAAC prevalence likelihoods are adjusted using the RAAC prevalence by decade of construction data extracted from the WSP survey of buildings undertaken as part of a wider RAAC survey. After this adjustment, all residential buildings constructed prior to 1945, or after 1990, are given modal and upper bound RAAC likelihoods of 0%. For buildings constructed between 1945 and 1964, the baseline RAAC likelihoods are adjusted by a factor of 0.834 to give a modal

RAAC likelihood of 0.007% and an upper bound RAAC likelihood of 0.075%. For buildings constructed between 1965 and 1980, the baseline RAAC likelihoods are adjusted by a factor of 1.204 to give a modal RAAC likelihood of 0.011% and an upper bound RAAC likelihood of 0.11%. For buildings constructed between 1980 and 1990, the baseline RAAC likelihoods are adjusted by a factor of 0.972 to give a modal RAAC likelihood of 0.008% and an upper bound RAAC likelihood of 0.088%. Simulated distributions of RAAC likelihood are plotted in Figure 12.

As with non-residential buildings containing RAAC, it is assumed that 98% of residential buildings with RAAC contain RAAC roof panels, 1% contain RAAC floor panels and 1% contain RAAC wall panels.

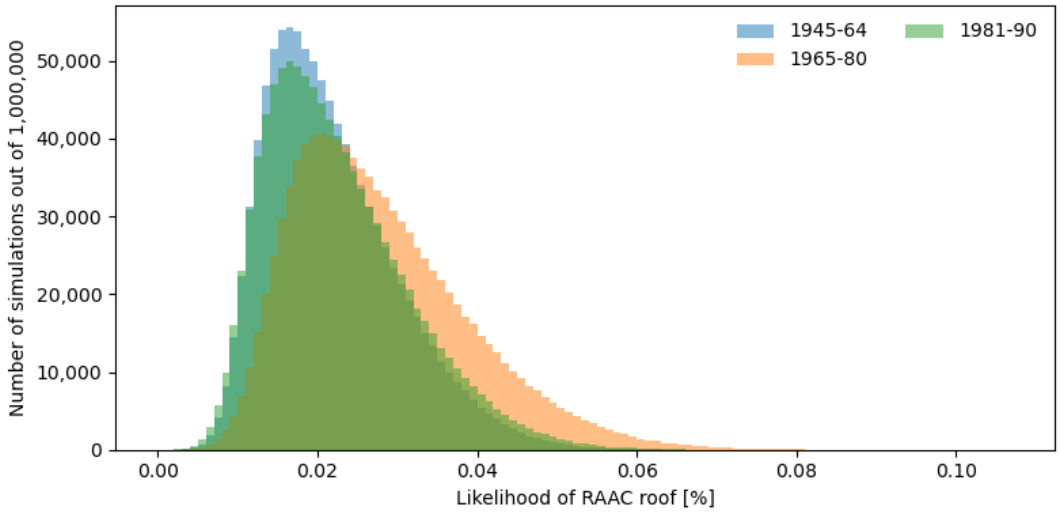

Figure 12. Likelihood of RAAC roof for residential buildings by sector and period of construction. Histogram bin width of 0.001% used throughout.

5.2.5 Model adjustment for known RAAC

No adjustments to the residential building sector output have been made to account for known RAAC panels.

6 Model outputs

The number of buildings with RAAC and the number of RAAC panels, summed across all sectors, are presented in Figure 13. The values are based on the statistical model described in Section 2 and the model parameters described in Section 5.

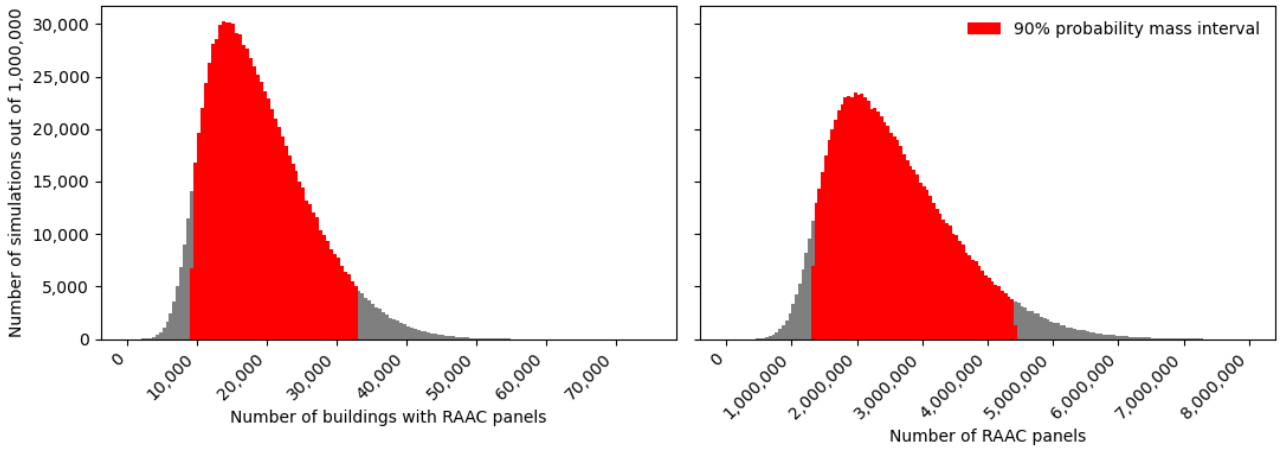

Figure 13. Estimated number of buildings with RAAC and number of RAAC panels in England. Left subplot histogram bin width of 1,000. Right subplot histogram bin width of 50,000.

As shown by the 90% probability mass interval[6] in Figure 13, there is 5% likelihood that there are fewer than 9,000 buildings with RAAC in England and a 5% likelihood that there are more than 33,000 buildings with RAAC. Accounting for the variation in building GIFA between sectors, this translates to a 90% likelihood that there are between 1,300,000 and 4,400,000 RAAC panels in England. For benchmarking purposes, across the 20-year period between 1965 and 1985 where RAAC was in widespread use, and assuming 300 working days in a year, these bounds would translate to an average RAAC panel production rate of 217 panels per day and 733 panels per day, respectively. Given what is known of historic RAAC manufacture in England, both numbers appear feasible.

The number of buildings with RAAC, stratified by building sector, are plotted in Figure 14. A discussion of sector-specific results, alongside plots of results by sector, is presented in Section 7.1. Separate plots of the estimated number of RAAC containing buildings and RAAC panels, stratified by sector, are provided in Appendix A.

[6] The central section of the histogram, which contains 90% of the simulation results. The bounds of this interval are calculated through magnitude ranking of the large-sample random simulation results.

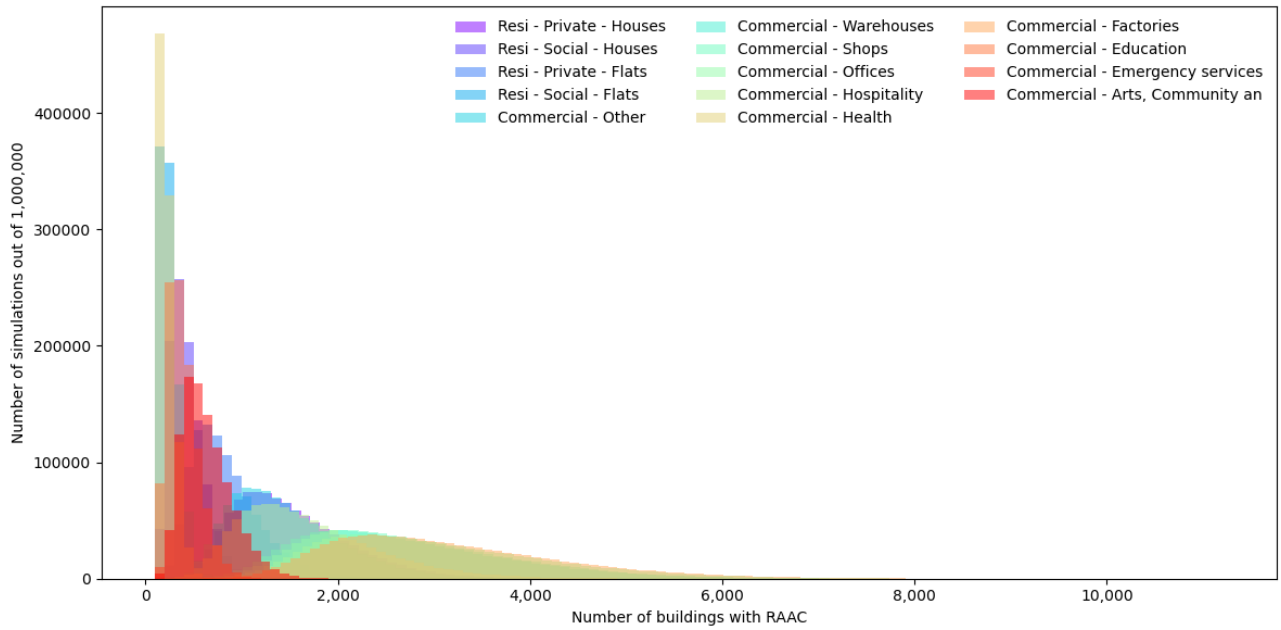

Figure 14. Estimated distributions of buildings containing RAAC by sector. Histogram bin width of 100 used throughout. Simulations with fewer than 100 buildings in sector excluded from plot.

The number of RAAC panels, stratified by building sector, are plotted in Figure 15. A discussion of sector-specific results, alongside plots of results by sector, is presented in Section 7.

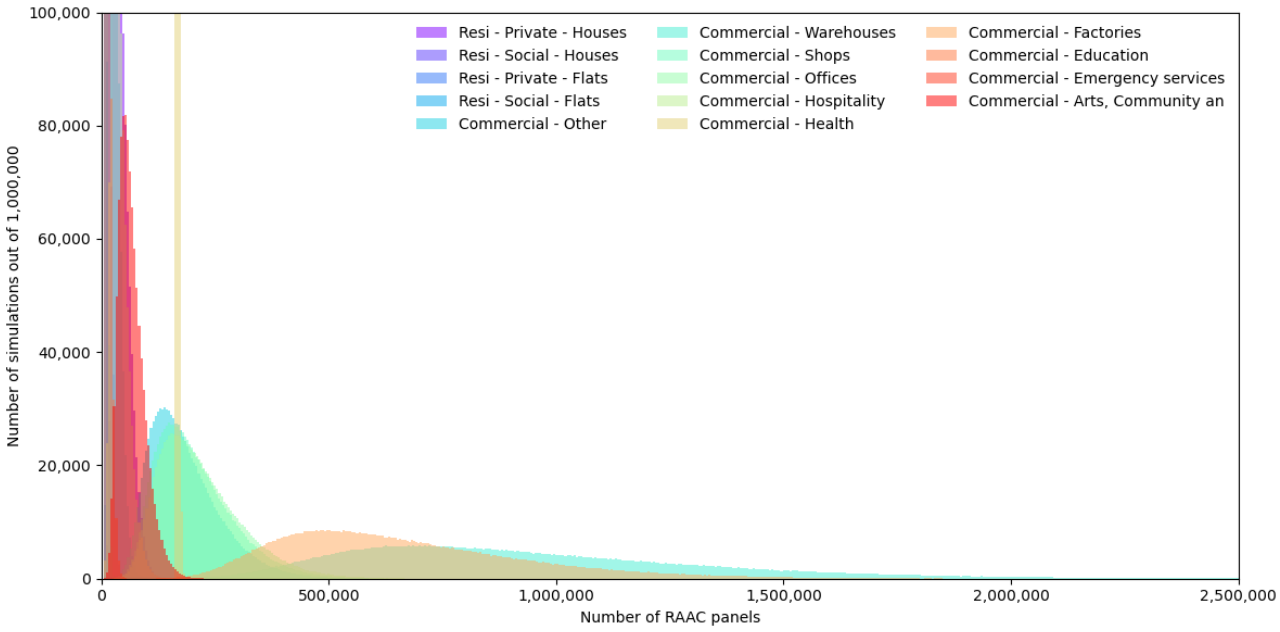

Figure 15. Estimated distributions of number of RAAC panels by sector. Histogram bin width of 100 used throughout. Simulations with fewer than 5,000 RAAC panels in sector excluded from plot. Y-axis curtailed at 100,000 simulations and x-axis curtailed at 2,500,00

6.1 Tabulated model data – non-residential (landscape format)

6.1.1 Notes on tabulated model data – non-residential

Sectors and period of construction

Adapted from those used in 2022 Non-domestic National Energy Efficiency Data (ND-NEED) Framework.

Number of buildings

Modal value adapted from 2022 ND-NEED values, adjusted based on ratio of populations of England and Wales. Lower bound value taken as 70% of number reported in ND-NEED. Upper bound value taken as 100% of ND-NEED value.

Average GIFA

Modal GIFA adapted from average values in the 2022 ND-NEED. Lower bound GIFA taken as 40% of modal value. Upper bound GIFA taken as 300% of modal value.

Average number of storeys

Average value taken based on review of information for United States, Germany and China.

Estimated likelihood of containing RAAC

Lower bound calculated based on number of buildings known to contain RAAC. Non-residential modal values based on RAAC prevalence calculated from Department of Education RAAC identification surveys, and WSP survey of NHS Property Services managed buildings. Upper bound value based on a survey of buildings undertaken by WSP as part of a wider RAAC prevalence survey.

RAAC prevalence values adjusted for periods of construction using data from survey of buildings undertaken by WSP as part of a wider RAAC prevalence survey.

Model adjustment for known RAAC

The number of RAAC panels in health buildings built between 1971 and 1995, demarked with an *, has been manually adjusted to include the approximately 160,000 RAAC panels that are known to be present in seven large NHS hospitals in England. These buildings are considered as outliers within the analysis.

No other adjustment of model outputs for known RAAC has been undertaken for non-residential buildings.

Table 2. Model inputs for non-residential buildings in England

Sector	Period of Construction	Average number of storeys across sector	Number of buildings – Lower Bound	Number of buildings - Modal	Number of buildings – Upper Bound	Average GIFA (m2) – Lower Bound	Average GIFA (m2) – Modal	Average GIFA (m2) – Upper Bound
Other	Pre-1900	2.00	7,000	21,000	38,400	183	366	1,098
Other	1900 - 1939	2.00	6,300	20,060	37,460	183	366	1,098
Other	**1940 - 1970**	**2.00**	**13,300**	**29,460**	**46,860**	**183**	**366**	**1,098**
Other	**1971 - 1995**	**2.00**	**11,200**	**26,640**	**44,040**	**183**	**366**	**1,098**
Other	1996 - 2019	2.00	9,800	24,760	42,160	183	366	1,098
Warehouses	Pre-1900	2.00	18,900	27,780	31,380	484	969	2,906
Warehouses	1900 - 1939	2.00	15,400	23,080	26,680	484	969	2,906
Warehouses	**1940 - 1970**	**2.00**	**32,200**	**45,640**	**49,240**	**484**	**969**	**2,906**
Warehouses	**1971 - 1995**	**2.00**	**45,500**	**63,500**	**67,100**	**484**	**969**	**2,906**
Warehouses	1996 - 2019	2.00	31,500	44,700	48,300	484	969	2,906

Sector	Period of Construction	Average number of storeys across sector	Number of buildings – Lower Bound	Number of buildings - Modal	Number of buildings – Upper Bound	Average GIFA (m2) – Lower Bound	Average GIFA (m2) – Modal	Average GIFA (m2) – Upper Bound
Shops	Pre-1900	2.00	142,800	192,160	192,760	100	199	598
Shops	1900 - 1939	2.00	76,300	102,860	103,460	100	199	598
Shops	**1940 - 1970**	**2.00**	**55,300**	**74,660**	**75,260**	**100**	**199**	**598**
Shops	**1971 - 1995**	**2.00**	**38,500**	**52,100**	**52,700**	**100**	**199**	**598**
Shops	1996 - 2019	2.00	30,800	41,760	42,360	100	199	598
Offices	Pre-1900	2.00	71,400	96,280	96,880	103	205	616
Offices	1900 - 1939	2.00	30,100	40,820	41,420	103	205	616
Offices	**1940 - 1970**	**2.00**	**37,100**	**50,220**	**50,820**	**103**	**205**	**616**
Offices	**1971 - 1995**	**2.00**	**52,500**	**70,900**	**71,500**	**103**	**205**	**616**
Offices	1996 - 2019	2.00	53,900	72,780	73,380	103	205	616
Hospitality	Pre-1900	2.00	21,000	54,200	93,200	33	67	200

Sector	Period of Construction	Average number of storeys across sector	Number of buildings – Lower Bound	Number of buildings - Modal	Number of buildings – Upper Bound	Average GIFA (m2) – Lower Bound	Average GIFA (m2) – Modal	Average GIFA (m2) – Upper Bound
Hospitality	1900 - 1939	2.00	8,400	37,280	76,280	33	67	200
Hospitality	**1940 - 1970**	**2.00**	**6,300**	**34,460**	**73,460**	**33**	**67**	**200**
Hospitality	**1971 - 1995**	**2.00**	**4,200**	**31,640**	**70,640**	**33**	**67**	**200**
Hospitality	1996 - 2019	2.00	7,700	36,340	75,340	33	67	200
Health	Pre-1900	2.00	4,200	7,640	10,640	45	90	270
Health	1900 - 1939	2.00	3,500	6,700	9,700	45	90	270
Health	**1940 - 1970**	**2.00**	**1,400**	**3,880**	**6,880**	**45**	**90**	**270**
Health*	**1971 – 1995***	**2.00**	**1,400**	**3,880**	**6,880**	**45**	**90**	**270**
Health	1996 - 2019	2.00	700	2,940	5,940	45	90	270
Factories	Pre-1900	2.00	21,000	28,400	28,700	313	625	1,875
Factories	1900 - 1939	2.00	21,700	29,340	29,640	313	625	1,875

Sector	Period of Construction	Average number of storeys across sector	Number of buildings – Lower Bound	Number of buildings - Modal	Number of buildings – Upper Bound	Average GIFA (m2) – Lower Bound	Average GIFA (m2) – Modal	Average GIFA (m2) – Upper Bound
Factories	**1940 - 1970**	**2.00**	**42,700**	**57,540**	**57,840**	**313**	**625**	**1,875**
Factories	**1971 - 1995**	**2.00**	**55,300**	**74,460**	**74,760**	**313**	**625**	**1,875**
Factories	1996 - 2019	2.00	25,200	34,040	34,340	313	625	1,875
Education	Pre-1900	2.00	2,100	8,420	16,820	48	96	289
Education	1900 - 1939	2.00	1,400	7,480	15,880	48	96	289
Education	**1940 - 1970**	**2.00**	**1,400**	**7,480**	**15,880**	**48**	**96**	**289**
Education	**1971 - 1995**	**2.00**	**1,400**	**7,480**	**15,880**	**48**	**96**	**289**
Education	1996 - 2019	2.00	2,100	8,420	16,820	48	96	289
Emergency Services	Pre-1900	2.00	0	800	2,000	19	38	113
Emergency Services	1900 - 1939	2.00	0	800	2,000	19	38	113

Sector	Period of Construction	Average number of storeys across sector	Number of buildings – Lower Bound	Number of buildings - Modal	Number of buildings – Upper Bound	Average GIFA (m2) – Lower Bound	Average GIFA (m2) – Modal	Average GIFA (m2) – Upper Bound
Emergency Services	**1940 - 1970**	**2.00**	**0**	**800**	**2,000**	**19**	**38**	**113**
Emergency Services	**1971 - 1995**	**2.00**	**0**	**800**	**2,000**	**19**	**38**	**113**
Emergency Services	1996 - 2019	2.00	0	800	2,000	19	38	113
Arts, Community and Leisure	Pre-1900	2.00	3,500	8,500	14,500	147	294	883
Arts, Community and Leisure	1900 - 1939	2.00	2,800	7,560	13,500	147	294	883
Arts, Community and Leisure	**1940 - 1970**	**2.00**	**6,300**	**12,260**	**18,500**	**147**	**294**	**883**
Arts, Community	**1971 - 1995**	**2.00**	**6,300**	**12,260**	**18,500**	**147**	**294**	**883**

Sector	Period of Construction	Average number of storeys across sector	Number of buildings – Lower Bound	Number of buildings - Modal	Number of buildings – Upper Bound	Average GIFA (m2) – Lower Bound	Average GIFA (m2) – Modal	Average GIFA (m2) – Upper Bound
and Leisure								
Arts, Community and Leisure	1996 - 2019	2.00	4,200	9,440	15,500	147	294	883

Table 3. Estimated likelihood of non-residential buildings in England containing RAAC

Sector	Period of Construction	Estimated likelihood of containing RAAC (2 s.f.) – Lower Bound	Estimated likelihood of containing RAAC (2 s.f.) – Modal	Estimated likelihood of containing RAAC (2 s.f.) – Upper Bound
Other	Pre-1900	0.00%	0.00%	0.00%
Other	1900 - 1939	0.00%	0.00%	0.00%
Other	**1940 - 1970**	**0.00%**	**0.73%**	**7.51%**
Other	**1971 - 1995**	**0.00%**	**1.03%**	**10.49%**
Other	1996 - 2019	0.00%	0.00%	0.00%
Warehouses	Pre-1900	0.00%	0.00%	0.00%
Warehouses	1900 - 1939	0.00%	0.00%	0.00%
Warehouses	**1940 - 1970**	**0.00%**	**0.73%**	**7.51%**
Warehouses	**1971 - 1995**	**0.00%**	**1.03%**	**10.49%**
Warehouses	1996 - 2019	0.00%	0.00%	0.00%
Shops	Pre-1900	0.00%	0.00%	0.00%

Sector	Period of Construction	Estimated likelihood of containing RAAC (2 s.f.) – Lower Bound	Estimated likelihood of containing RAAC (2 s.f.) – Modal	Estimated likelihood of containing RAAC (2 s.f.) – Upper Bound
Shops	1900 - 1939	0.00%	0.00%	0.00%
Shops	**1940 - 1970**	**0.00%**	**0.73%**	**7.51%**
Shops	**1971 - 1995**	**0.00%**	**1.03%**	**10.49%**
Shops	1996 - 2019	0.00%	0.00%	0.00%
Offices	Pre-1900	0.00%	0.00%	0.00%
Offices	1900 - 1939	0.00%	0.00%	0.00%
Offices	**1940 - 1970**	**0.00%**	**0.73%**	**7.51%**
Offices	**1971 - 1995**	**0.00%**	**1.03%**	**10.49%**
Offices	1996 - 2019	0.00%	0.00%	0.00%
Hospitality	Pre-1900	0.00%	0.00%	0.00%
Hospitality	1900 - 1939	0.00%	0.00%	0.00%
Hospitality	**1940 - 1970**	**0.00%**	**0.73%**	**7.51%**

Sector	Period of Construction	Estimated likelihood of containing RAAC (2 s.f.) – Lower Bound	Estimated likelihood of containing RAAC (2 s.f.) – Modal	Estimated likelihood of containing RAAC (2 s.f.) – Upper Bound
Hospitality	**1971 - 1995**	**0.00%**	**1.03%**	**10.49%**
Hospitality	1996 - 2019	0.00%	0.00%	0.00%
Health	Pre-1900	0.00%	0.00%	0.00%
Health	1900 - 1939	0.00%	0.00%	0.00%
Health	**1940 - 1970**	**0.00%**	**0.73%**	**7.51%**
Health*	**1971 – 1995***	**0.00%**	**1.03%**	**10.49%**
Health	1996 - 2019	0.00%	0.00%	0.00%
Factories	Pre-1900	0.00%	0.00%	0.00%
Factories	1900 - 1939	0.00%	0.00%	0.00%
Factories	**1940 - 1970**	**0.00%**	**0.73%**	**7.51%**
Factories	**1971 - 1995**	**0.00%**	**1.03%**	**10.49%**
Factories	1996 - 2019	0.00%	0.00%	0.00%

Sector	Period of Construction	Estimated likelihood of containing RAAC (2 s.f.) – Lower Bound	Estimated likelihood of containing RAAC (2 s.f.) – Modal	Estimated likelihood of containing RAAC (2 s.f.) – Upper Bound
Education	Pre-1900	0.00%	0.00%	0.00%
Education	1900 - 1939	0.00%	0.00%	0.00%
Education	**1940 - 1970**	**0.00%**	**0.73%**	**7.51%**
Education	**1971 - 1995**	**0.00%**	**1.03%**	**10.49%**
Education	1996 - 2019	0.00%	0.00%	0.00%
Emergency Services	Pre-1900	0.00%	0.00%	0.00%
Emergency Services	1900 - 1939	0.00%	0.00%	0.00%
Emergency Services	**1940 - 1970**	**0.00%**	**0.73%**	**7.51%**
Emergency Services	**1971 - 1995**	**0.00%**	**1.03%**	**10.49%**
Emergency Services	1996 - 2019	0.00%	0.00%	0.00%

Sector	Period of Construction	Estimated likelihood of containing RAAC (2 s.f.) – Lower Bound	Estimated likelihood of containing RAAC (2 s.f.) – Modal	Estimated likelihood of containing RAAC (2 s.f.) – Upper Bound
Arts, Community and Leisure	Pre-1900	0.00%	0.00%	0.00%
Arts, Community and Leisure	1900 - 1939	0.00%	0.00%	0.00%
Arts, Community and Leisure	**1940 - 1970**	**0.00%**	**0.73%**	**7.51%**
Arts, Community and Leisure	**1971 - 1995**	**0.00%**	**1.03%**	**10.49%**
Arts, Community and Leisure	1996 - 2019	0.00%	0.00%	0.00%

Table 4. Model outputs - Non-residential buildings

Sector	Period of Construction	Number of buildings containing RAAC – Lower Bound	Number of buildings containing RAAC – Upper Bound	Number of RAAC panels – Lower Bound	Number of RAAC panels – Upper Bound
Other	Pre-1900	0	0	0	0
Other	1900 - 1939	0	0	0	0
Other	**1940 - 1970**	**295**	**1,106**	**33,547**	**147,675**
Other	**1971 - 1995**	**393**	**1,465**	**44,295**	**196,290**
Other	1996 - 2019	0	0	0	0
Warehouses	Pre-1900	0	0	0	0
Warehouses	1900 - 1939	0	0	0	0
Warehouses	**1940 - 1970**	**461**	**1,613**	**144,930**	**591,892**
Warehouses	**1971 - 1995**	**796**	**3,087**	**259,395**	**1,158,296**
Warehouses	1996 - 2019	0	0	0	0
Shops	Pre-1900	0	0	0	0

Sector	Period of Construction	Number of buildings containing RAAC – Lower Bound	Number of buildings containing RAAC – Upper Bound	Number of RAAC panels – Lower Bound	Number of RAAC panels – Upper Bound
Shops	1900 - 1939	0	0	0	0
Shops	**1940 - 1970**	**660**	**2,375**	**44,446**	**188,214**
Shops	**1971 - 1995**	**695**	**2,416**	**46,062**	**188,530**
Shops	1996 - 2019	0	0	0	0
Offices	Pre-1900	0	0	0	0
Offices	1900 - 1939	0	0	0	0
Offices	**1940 - 1970**	**523**	**1,745**	**35,282**	**140,105**
Offices	**1971 - 1995**	**932**	**3,474**	**59,493**	**262,486**
Offices	1996 - 2019	0	0	0	0
Hospitality	Pre-1900	0	0	0	0
Hospitality	1900 - 1939	0	0	0	0
Hospitality	**1940 - 1970**	**338**	**1,408**	**7,161**	**34,780**

Sector	Period of Construction	Number of buildings containing RAAC – Lower Bound	Number of buildings containing RAAC – Upper Bound	Number of RAAC panels – Lower Bound	Number of RAAC panels – Upper Bound
Hospitality	**1971 - 1995**	**388**	**1,729**	**8,399**	**43,119**
Hospitality	1996 - 2019	0	0	0	0
Health	Pre-1900	0	0	0	0
Health	1900 - 1939	0	0	0	0
Health	**1940 - 1970**	**41**	**157**	**1,200**	**5,233**
Health*	**1971 – 1995***	**54**	**221**	**161,581***	**167,403***
Health	1996 - 2019	0	0	0	0
Factories	Pre-1900	0	0	0	0
Factories	1900 - 1939	0	0	0	0
Factories	**1940 - 1970**	**593**	**1,954**	**114,769**	**452,424**
Factories	**1971 - 1995**	**963**	**3,445**	**182,517**	**769,371**
Factories	1996 - 2019	0	0	0	0

Sector	Period of Construction	Number of buildings containing RAAC – Lower Bound	Number of buildings containing RAAC – Upper Bound	Number of RAAC panels – Lower Bound	Number of RAAC panels – Upper Bound
Education	Pre-1900	0	0	0	0
Education	1900 - 1939	0	0	0	0
Education	**1940 - 1970**	**72**	**309**	**2,266**	**11,234**
Education	**1971 - 1995**	**99**	**405**	**3,087**	**14,680**
Education	1996 - 2019	0	0	0	0
Emergency Services	Pre-1900	0	0	0	0
Emergency Services	1900 - 1939	0	0	0	0
Emergency Services	**1940 - 1970**	**8**	**33**	**91**	**464**
Emergency Services	**1971 - 1995**	**11**	**49**	**134**	**667**
Emergency Services	1996 - 2019	0	0	0	0
Arts, Community and	Pre-1900	0	0	0	0

Sector	Period of Construction	Number of buildings containing RAAC – Lower Bound	Number of buildings containing RAAC – Upper Bound	Number of RAAC panels – Lower Bound	Number of RAAC panels – Upper Bound
Leisure					
Arts, Community and Leisure	1900 - 1939	0	0	0	0
Arts, Community and Leisure	**1940 - 1970**	**129**	**475**	**12,679**	**54,993**
Arts, Community and Leisure	**1971 - 1995**	**171**	**654**	**15,768**	**69,303**
Arts, Community and Leisure	1996 - 2019	0	0	0	0

6.2 Tabulated model data – residential (landscape format)

6.2.1 Notes on tabulated model data – Residential

Sectors and period of construction

Adapted from those used in 2019-2020 English Housing Survey (EHS).

Number of buildings

Modal value adapted from 2019-2020 EHS. Lower bound taken as 5% of modal value. Upper bound taken as 95% of modal value.

Number of flats is reported as the number of individual flats, not blocks of flats.

Average GIFA

Modal GIFA adapted from the 2019-2020 EHS. Lower bound GIFA taken as 50% of modal value. Upper bound GIFA taken as 150% of modal value.

Average number of storeys

Value inferred from data in 2019-2020 EHS.

Estimated likelihood of containing RAAC

Lower bound calculated based on number of residential buildings known to contain RAAC. Modal and upper bound values taken as two orders of magnitude lower than equivalent values for non-residential buildings to reflect known lower usage of RAAC in residential buildings. RAAC prevalence adjusted for differing construction periods reported for non-residential and residential buildings.

Model adjustment for known RAAC

No adjustments to the residential building sector outputs have been made to account for known RAAC panels.

Table 5. Model inputs for residential buildings in England

Sector	Period of Construction	Average number of storeys across sector	Number of buildings – Lower Bound	Number of buildings - Modal	Number of buildings – Upper Bound	Average GIFA (m2) – Lower Bound	Average GIFA (m2) – Modal	Average GIFA (m2) – Upper Bound
Private Houses	Pre-1919	1.91	232,349	4,007,606	4,414,624	52	103	155
Private Houses	1919-44	1.91	168,013	2,897,936	3,192,255	52	103	155
Private Houses	**1945-64**	**1.91**	**158,630**	**2,736,093**	**3,013,975**	**52**	**103**	**155**
Private Houses	**1965-80**	**1.91**	**187,090**	**3,226,969**	**3,554,704**	**52**	**103**	**155**
Private Houses	**1981-90**	**1.91**	**80,516**	**1,388,765**	**1,529,810**	**52**	**103**	**155**
Private Houses	post 1990	1.91	189,229	3,263,873	3,595,357	52	103	155
Social Houses	Pre-1919	1.72	12,939	179,271	245,847	52	103	155

Sector	Period of Construction	Average number of storeys across sector	Number of buildings – Lower Bound	Number of buildings - Modal	Number of buildings – Upper Bound	Average GIFA (m2) – Lower Bound	Average GIFA (m2) – Modal	Average GIFA (m2) – Upper Bound
Social Houses	1919-44	1.72	18,902	261,882	359,137	52	103	155
Social Houses	**1945-64**	**1.72**	**59,830**	**828,935**	**1,136,777**	**52**	**103**	**155**
Social Houses	**1965-80**	**1.72**	**56,489**	**782,641**	**1,073,290**	**52**	**103**	**155**
Social Houses	**1981-90**	**1.72**	**17,432**	**241,520**	**331,213**	**52**	**103**	**155**
Social Houses	post 1990	1.72	39,256	543,877	745,856	52	103	155
Private Flats	Pre-1919	1.00	232,349*	1,427,838*	4,414,624*	31	61	92
Private Flats	1919-44	1.00	168,013*	1,032,482*	3,192,255*	31	61	92
Private Flats	**1945-64**	**1.00**	**158,630***	**974,821***	**3,013,975***	**31**	**61**	**92**
Private Flats	**1965-80**	**1.00**	**187,090***	**1,149,711***	**3,554,704***	**31**	**61**	**92**
Private Flats	**1981-90**	**1.00**	**80,516***	**494,792***	**1,529,810***	**31**	**61**	**92**

Sector	Period of Construction	Average number of storeys across sector	Number of buildings – Lower Bound	Number of buildings - Modal	Number of buildings – Upper Bound	Average GIFA (m2) – Lower Bound	Average GIFA (m2) – Modal	Average GIFA (m2) – Upper Bound
Private Flats	post 1990	1.00	189,229*	1,162,859*	3,595,357*	31	61	92
Social Flats	Pre-1919	1.00	12,939*	79,515*	245,847*	31	61	92
Social Flats	1919-44	1.00	18,902*	116,157*	359,137*	31	61	92
Social Flats	**1945-64**	**1.00**	**59,830***	**367,672***	**1,136,777***	**31**	**61**	**92**
Social Flats	**1965-80**	**1.00**	**56,489***	**347,138***	**1,073,290***	**31**	**61**	**92**
Social Flats	**1981-90**	**1.00**	**17,432***	**107,125***	**331,213***	**31**	**61**	**92**
Social Flats	post 1990	1.00	39,256*	241,235*	745,856*	31	61	92

Table 6. Estimated likelihood of residential buildings in England containing RAAC

Sector	Period of Construction	Estimated likelihood of containing RAAC (2 s.f.) – Lower Bound	Estimated likelihood of containing RAAC (2 s.f.) – Modal	Estimated likelihood of containing RAAC (2 s.f.) – Upper Bound
Private Houses	Pre-1919	0.00%	0.00%	0.00%
Private Houses	1919-44	0.00%	0.00%	0.00%
Private Houses	**1945-64**	**0.00%**	**0.01%**	**0.08%**
Private Houses	**1965-80**	**0.00%**	**0.01%**	**0.11%**
Private Houses	**1981-90**	**0.00%**	**0.01%**	**0.09%**
Private Houses	post 1990	0.00%	0.00%	0.00%
Social Houses	Pre-1919	0.00%	0.00%	0.00%
Social Houses	1919-44	0.00%	0.00%	0.00%
Social Houses	**1945-64**	**0.00%**	**0.01%**	**0.08%**
Social Houses	**1965-80**	**0.00%**	**0.01%**	**0.11%**
Social Houses	**1981-90**	**0.00%**	**0.01%**	**0.09%**

Sector	Period of Construction	Estimated likelihood of containing RAAC (2 s.f.) – Lower Bound	Estimated likelihood of containing RAAC (2 s.f.) – Modal	Estimated likelihood of containing RAAC (2 s.f.) – Upper Bound
Social Houses	post 1990	0.00%	0.00%	0.00%
Private Flats	Pre-1919	0.00%	0.00%	0.00%
Private Flats	1919-44	0.00%	0.00%	0.00%
Private Flats	**1945-64**	**0.00%**	**0.01%**	**0.08%**
Private Flats	**1965-80**	**0.00%**	**0.01%**	**0.11%**
Private Flats	**1981-90**	**0.00%**	**0.01%**	**0.09%**
Private Flats	post 1990	0.00%	0.00%	0.00%
Social Flats	Pre-1919	0.00%	0.00%	0.00%
Social Flats	1919-44	0.00%	0.00%	0.00%
Social Flats	**1945-64**	**0.00%**	**0.01%**	**0.08%**
Social Flats	**1965-80**	**0.00%**	**0.01%**	**0.11%**
Social Flats	**1981-90**	**0.00%**	**0.01%**	**0.09%**

Sector	Period of Construction	Estimated likelihood of containing RAAC (2 s.f.) – Lower Bound	Estimated likelihood of containing RAAC (2 s.f.) – Modal	Estimated likelihood of containing RAAC (2 s.f.) – Upper Bound
Social Flats	post 1990	0.00%	0.00%	0.00%

Table 7. Model outputs - Residential buildings

Sector	Period of Construction	Number of buildings containing RAAC – Lower Bound	Number of buildings containing RAAC – Upper Bound	Number of RAAC panels – Lower Bound	Number of RAAC panels – Upper Bound
Private Houses	Pre-1919	0	0	0	0
Private Houses	1919-44	0	0	0	0
Private Houses	**1945-64**	**245**	**894**	**7,208**	**27,481**
Private Houses	**1965-80**	**341**	**1,342**	**9,669**	**39,784**
Private Houses	**1981-90**	**117**	**467**	**3,364**	**14,072**
Private Houses	post 1990	0	0	0	0
Social Houses	Pre-1919	0	0	0	0
Social Houses	1919-44	0	0	0	0
Social Houses	**1945-64**	**71**	**282**	**2,299**	**9,483**
Social Houses	**1965-80**	**95**	**379**	**3,037**	**12,675**

Sector	Period of Construction	Number of buildings containing RAAC – Lower Bound	Number of buildings containing RAAC – Upper Bound	Number of RAAC panels – Lower Bound	Number of RAAC panels – Upper Bound
Social Houses	**1981-90**	**29**	**105**	**943**	**3,578**
Social Houses	post 1990	0	0	0	0
Private Flats	Pre-1919	0	0	0	0
Private Flats	1919-44	0	0	0	0
Private Flats	**1945-64**	**105**	**480**	**3,605**	**17,048**
Private Flats	**1965-80**	**182**	**812**	**5,774**	**26,868**
Private Flats	**1981-90**	**63**	**285**	**2,002**	**9,468**
Private Flats	post 1990	0	0	0	0
Social Flats	Pre-1919	0	0	0	0
Social Flats	1919-44	0	0	0	0
Social Flats	**1945-64**	**38**	**172**	**1,237**	**5,887**

Sector	Period of Construction	Number of buildings containing RAAC – Lower Bound	Number of buildings containing RAAC – Upper Bound	Number of RAAC panels – Lower Bound	Number of RAAC panels – Upper Bound
Social Flats	**1965-80**	**51**	**231**	**1,710**	**7,979**
Social Flats	**1981-90**	**13**	**58**	**423**	**1,979**
Social Flats	post 1990	0	0	0	0

7 Discussion

The results presented in the previous section highlight the uncertainty as to how many RAAC panels there are in England. This uncertainty is caused by:

- Datasets used within the analysis being limited to those that are publicly available, or those compiled by WSP.
- Limited scope and number of buildings covered by previous surveys,
- A lack of reliable data on building sizes (as the dataset of known RAAC buildings used within the model is derived from the data available to WSP). This impacts the conversion from a building containing RAAC to number of RAAC panels within that building.
- Potential variation in prevalence of RAAC across different sectors (due to the limited scope of the RAAC prevalence surveys included in the datasets).

7.1 Sector specific model outputs

The breakdown of projected number of RAAC panels by sector, presented in Figure 15, provides a road map for reducing this uncertainty in the estimated number of RAAC panels in England.

7.1.1 Factories and Warehouses

The greatest uncertainty in the projected number of RAAC panels in England comes from the uncertainties in the data for factories and warehouses. Approximately 1,000,000 warehouses and 132,000 factories were built during the period when RAAC was in use in England. Compared to other commercial sectors, factories and warehouses have a much larger average GIFA.

The larger average GIFA results in greater uncertainty in the GIFA of factories and warehouses containing RAAC. This uncertainty, combined with a lack of data on RAAC prevalence in factories and warehouses, results in broad projections for the total number of RAAC panels in factories and warehouses of between 750,000 panels and 2,840,000 panels, as shown in Figure 16. These values seem plausible, as WSP is aware of a single factory in England that contains more than 50,000 RAAC panels, and other factories in England that have more than 10,000 RAAC panels. If RAAC prevalence is consistent across non-residential building sectors, it would suggest that there may be more RAAC panels in factories and warehouses than all other sectors of non-residential buildings combined.

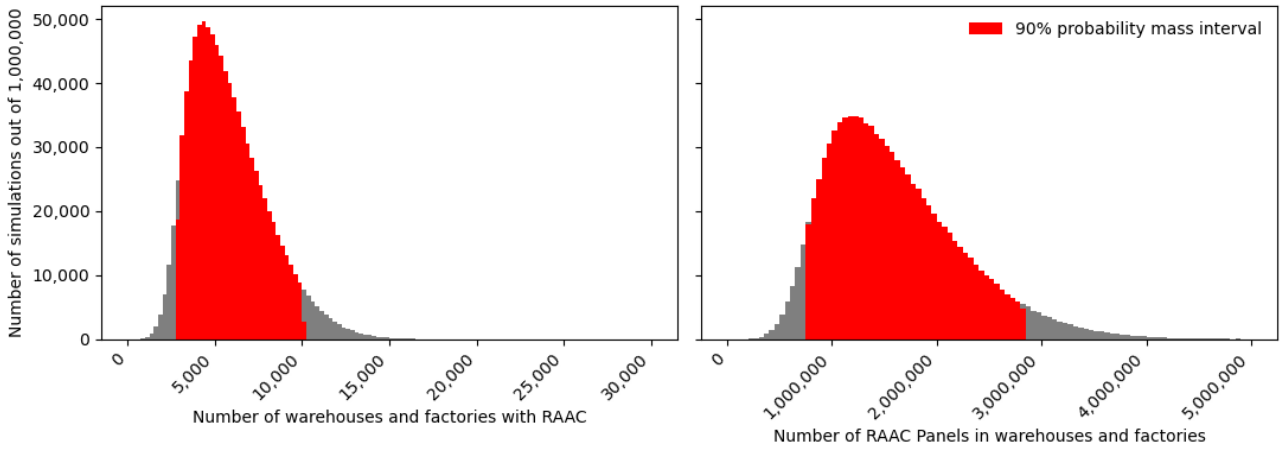

Figure 16. Estimated number of factories and warehouses with RAAC and number of RAAC panels in factories and warehouses in England. Left subplot histogram bin width of 500. Right subplot histogram bin width of 50,000.

The numbers presented above assume that the prevalence of RAAC in factories and warehouses is similar to that in buildings previously surveyed by WSP, schools surveyed as part of the DfE RAAC surveys and properties owned by NHS Property Services (the data from which formed the basis for the baseline RAAC prevalence in non-residential buildings). The RAAC prevalence in factories and warehouses may be lower than buildings that formed part of previous RAAC surveys, due to an increased availability of alternative forms of construction, or an increased likelihood that RAAC roofs have been replaced.

To capture the potential difference in RAAC prevalence, further targeted and comprehensive surveys of factories and warehouses would be required.

7.1.2 Offices, Shops and Hospitality

It is estimated that there may be a similar number of offices, retail and hospitality buildings containing RAAC panels as factories and warehouses, as shown in Figure 17. However, as these sectors have a lower average GIFA compared to factories and warehouses, this results in a lower total number of RAAC panels – between 220,000 and 810,000 panels across the three sectors.

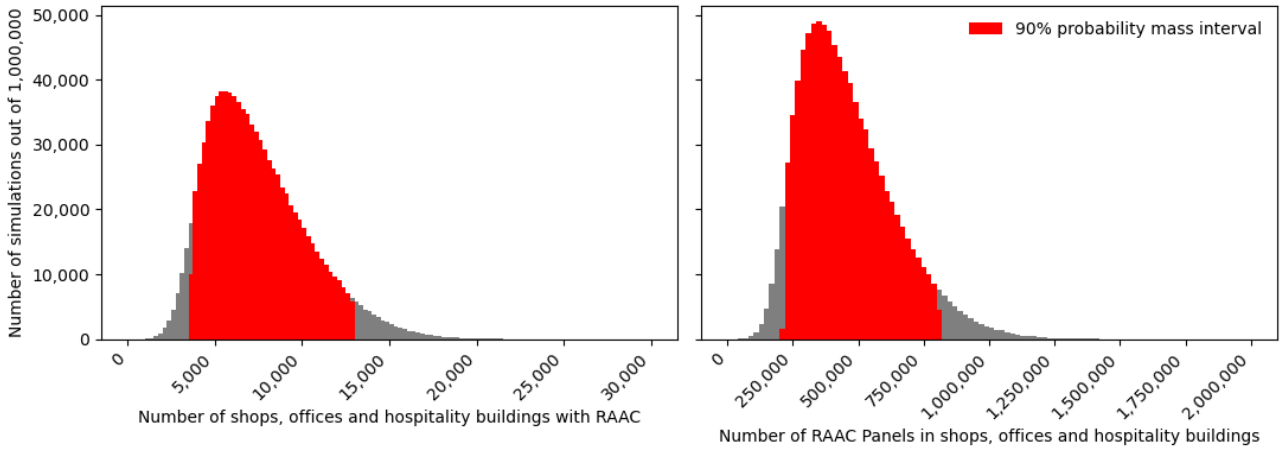

Figure 17. Estimated number of shops, offices and hospitality buildings with RAAC and number of RAAC panels in shops, offices and hospitality buildings in England. Left subplot histogram bin width of 250. Right subplot histogram bin width of 20,000.

As with factories and warehouses, as most of these buildings are privately owned, RAAC may have been removed since construction. Alternatively, it may be that there is a lower RAAC prevalence in these sectors, due to a tendency towards multi-storey or small-scale construction, both of which have been anecdotally reported as less likely to include RAAC panels. Despite these reports, at present there is a lack of publicly available data to assess RAAC prevalence in offices, shops and hospitality buildings. The likelihood of RAAC being present in these sectors is further complicated by the ownership model of the buildings, which are more likely to be leased to the occupants. Whether this increases or decreases the likelihood of RAAC being present is unknown.

7.1.3 Arts, Community & Leisure, Education, Health and Emergency Services

If RAAC prevalence is consistent across non-residential building sectors, it is likely that arts, community and leisure, education, health and emergency service buildings will make up a small fraction of the total number of buildings with RAAC, as these sectors make up a smaller fraction of the building stock constructed when RAAC was in use in England. However, as these buildings tend to be of a similar average size to offices, they have the potential to contain between 200,000 and 315,000 RAAC panels, as shown in Figure 18.

Note: These numbers include approximately 160,000 RAAC panels located in seven NHS hospitals, as discussed in Section 5.1.

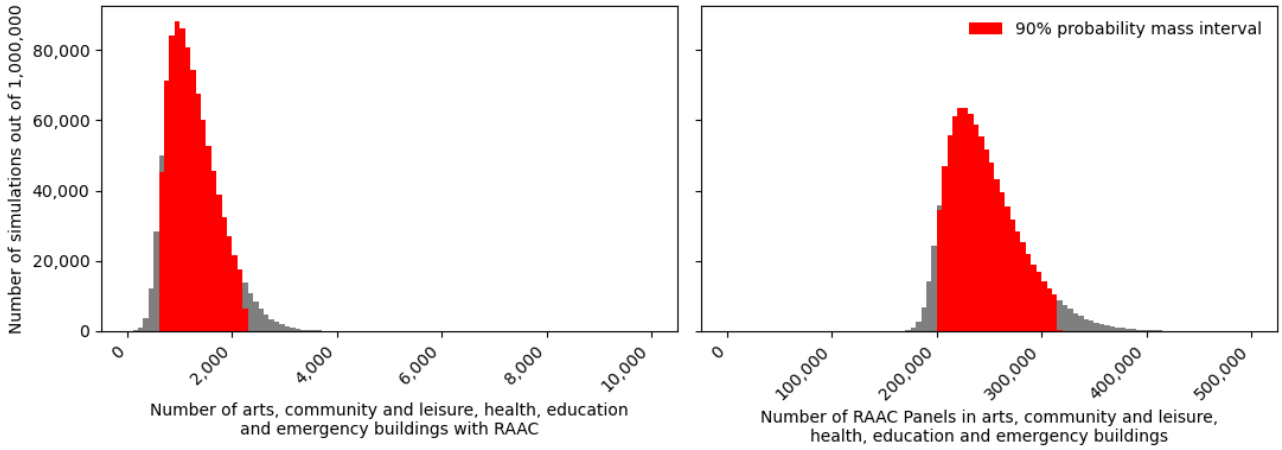

Figure 18. Estimated number of arts, community and leisure, health, education and emergency services buildings with RAAC and number of RAAC panels in arts, community and leisure, health, education and emergency services buildings in England. Left subplot histogram

Whether buildings in these sectors are more likely to contain RAAC is unclear. A larger number of buildings in these sectors are explicitly known to contain RAAC relative to other non-residential building sectors. However, this may be because these buildings are more likely to be owned and operated by the state or local authorities and have been compelled to report the presence of RAAC.

7.1.4 RAAC in other non-residential buildings

The ‘other’ building category used by the ND-NEED dataset covers a broad array of buildings including bus stations, moorings, cemeteries, docks, electricity hereditaments (including power stations and premises), garages, markets, military premises and sewage treatment works.

As shown in Figure 19, the model projects that there may be between 700 and 2,500 buildings in these sectors that include RAAC, which is similar to the potential amount in the arts, community and leisure, education, health and emergency service sectors. However, the average GIFA of buildings categorised as “other,” as reported in the ND-NEED data, is large relative to other building sectors, at 366m^2. This results in the potential for these buildings to contain between 82,000 and 330,000 RAAC panels. Given the diversity of buildings categorised within the “other” category, and the lack of data for those buildings, there is significant uncertainty in these projections.

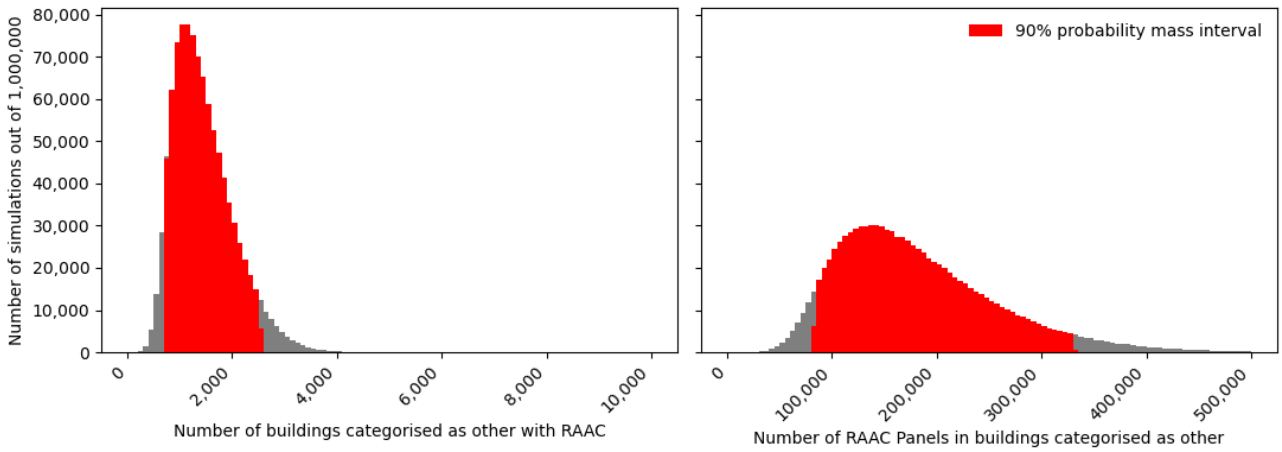

Figure 19. Estimated number of buildings categorised as part of the 'other' non-residential building sector with RAAC and number of RAAC panels in buildings categorised as part of the 'other' non-residential building sector. Left subplot histogram bin width of 100. Right subplot histogram bin width of 5,000.

7.1.5 Residential

As discussed in previous sections, a key assumption within the statistical model is that the likelihood of residential buildings containing RAAC is two orders of magnitude lower than non-residential buildings. Despite this lower likelihood of containing RAAC, there may still be a significant number of residential buildings in England that contain RAAC. As plotted in Figure 20, it is estimated that there may be between 1,400 and 5,200 buildings containing RAAC.

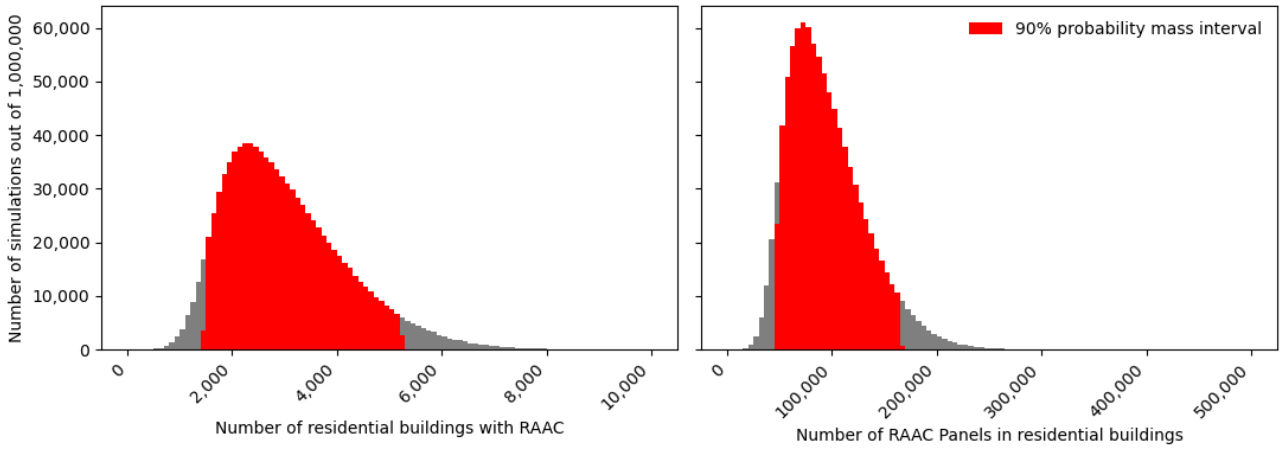

Figure 20. Estimated number of residential buildings with RAAC and number of RAAC panels in residential buildings. Left subplot histogram bin width of 100. Right subplot histogram bin width of 5,000.

Across these buildings, there may be between 46,000 and 165,000 RAAC panels (approximately the same number as RAAC panels which may be concentrated in arts, community and leisure, education, health and emergency services buildings). The high number of potential RAAC buildings, despite the decreased likelihood of containing RAAC,

is a result of the much higher number of residential buildings in England relative to other building sectors.

7.2 Impact of key modelling assumptions

In the absence of more detailed information, the statistical model includes several broad modelling assumptions that should be revisited if further information becomes available.

It has been assumed that the prevalence of RAAC across non-residential buildings sectors is broadly similar. That is, if there was a high use of RAAC in one sector, there will be similar levels of RAAC use in other sectors. It is plausible that RAAC may have been used in some sectors more than others, due to differing client requirements. Conversely, it is also plausible that a building designer or contractor who was familiar with RAAC construction may have employed it across multiple projects, regardless of individual project requirements. This issue is compounded by whether there are differing levels of structural renovation across sectors. It may be that the initial RAAC prevalence was near uniform across non-residential building sectors, but that some sectors have replaced the RAAC panels with other forms of construction. At present, there is insufficient data to include variation in RAAC use across non-residential building sectors.

Similarly, the baseline modal and upper bound RAAC likelihoods used across all building sectors are broad, reflecting the current uncertainty in the likely RAAC prevalence in England. While there have been increased levels of public sector buildings that have self-reported the presence of RAAC, the number of buildings that have been checked for RAAC is unknown. Therefore, the RAAC likelihoods have been derived from comprehensive, detailed building surveys carried out by qualified and experienced professionals. The key limitation of these surveys is that they represent only a small fraction of buildings in England.

As discussed in previous sections, the likelihood of residential buildings containing RAAC is assumed to be two orders of magnitude lower than non-residential buildings. This is primarily based on the very small number of residential buildings known to contain RAAC in England, alongside limited archival records which indicate a much lower uptake of RAAC in residential construction. If the prevalence of RAAC in residential buildings is found to be higher than the assumed upper bound, the number of buildings with RAAC in England and the number of RAAC panels in England may be significantly higher than predicted, due to the large number of residential buildings in England.

No allowance has been made within the statistical model for parts of a building having RAAC panels. The WSP survey of buildings undertaken as part of a wider RAAC survey has highlighted that RAAC has been used in later extensions to buildings constructed prior to 1960, and that these extensions may use RAAC for only part of the building footprint. This factor is not believed to significantly affect the estimated number of RAAC panels, as the uncertainty in the fraction of a building’s footprint that features RAAC is small when compared to the uncertainty in the average GIFA and the estimated RAAC prevalence.

Conclusions and recommendations

Based on a review of available information, it is estimated that there are between 1.3 million and 4.4 million RAAC panels in England. These panels may be spread between 9,000 and 33,000 buildings across a variety of sectors.

Note: The approximate number of RAAC panels in England, as presented in this report, is an estimate only. There is a large degree of uncertainty in these estimates, reflecting the limited data available at the time of writing.

It is likely that the majority of these RAAC panels are roof panels and that they are predominantly concentrated in non-residential buildings. Assuming that RAAC prevalence is similar across all non-residential building sectors, it is expected that a significant number of these RAAC panels will be located in factories and warehouses.

It is recommended that the input data used in these estimates is periodically reviewed and revised as necessary to reflect the current knowledge of RAAC prevalence by building sector in England.

A register of known RAAC-containing buildings that captures characteristics including GIFA, number of storeys, types of RAAC present and construction dates is not currently available.

Such a register would aid future updating of the estimates presented in this report and allow for further refinement of the key modelling assumptions used in this work. However, without records of how many buildings have been surveyed where RAAC has not been identified, a register of RAAC-containing buildings can only be used to inform the lower bound estimate of number of RAAC panels, as the RAAC prevalence across the broader building stock will remain unknown.

Targeted RAAC prevalence surveys would allow the modal and upper bound likelihood of RAAC prevalence to be refined, reducing the broader uncertainty in the estimated number of RAAC panels in England.

As discussed in the previous section, there are a number of modelling assumptions and uncertainties that could be addressed through further targeted RAAC prevalence surveys:

- For a RAAC prevalence survey to significantly reduce uncertainty in the predicted number of RAAC panels in England, it should target:
    - Sectors that contain large numbers of buildings that were built when RAAC was in widespread use in England (such as residential properties),
    - Sectors that have large GIFAs (such as warehouses and factories).

- Steps should be taken to ensure that the RAAC prevalence surveys are broadly representative of the building stock within that sector and/or period of construction. For example, ensuring surveys are geographically diverse, reflect the mixture of ownership and facilities management models for that sector, and include a range of building sizes.

- It is recommended that RAAC prevalence surveys are targeted on a sector-by-sector basis, rather than targeting several sectors. This would allow a more accurate stratification of RAAC prevalence by building sector, without introducing uncertainty into the building sector classification used within a multi-sector RAAC prevalence survey.

8 References

Azzalini and Capitanio (1999), *Statistical applications of the multivariate skew-normal distribution*, Journal of the Royal Statistical Society, Series B (Statistical Methodology), 61, 579-602. arXiv:0911.2093.

Adcock, Eling and Loperfido (2015), *Skewed distributions in finance and actuarial science: a review*, The European Journal of Finance, 21:13-14, 1253-1281, DOI: 10.1080/1351847X.2012.720269

Department for Business, Energy & Industrial Strategy (2022a). *Non-domestic National Energy Efficiency Data Framework 2022.* London, UK. Available at: https://www.gov.uk/government/statistics/non-domestic-national-energy-efficiency-data-framework-nd-need-2022

Department for Business, Energy & Industrial Strategy (2022b). *Non-domestic National Energy Efficiency Data Framework 2022: Methodology.* London, UK. Available at: https://www.gov.uk/government/statistics/non-domestic-national-energy-efficiency-data-framework-nd-need-2022

Frantz, Schug, Okujeni, Navacchi, Wagner, van der Linden, and Hostert (2021). *National-scale mapping of building height using Sentinel-1 and Sentinel-2 time series.* Remote Sensing of Environment 252: 112128.

Huang, Chen, Xu, Liu, Wang, Liu, Clinton, and Gong (2022). *Estimating building height in China from ALOS AW3D30*. ISPRS Journal of Photogrammetry and Remote Sensing 185: 146-157.

Li, Zhou, Gong, Seto, and Clinton (2020). *Developing a method to estimate building height from Sentinel-1 data*. Remote Sensing of Environment 240: 111705.

Maleki, Mahmoudi, Wraith and Pho (2020), *Time series modelling to forecast the confirmed and recovered cases of COVID-19*, Travel Medicine and Infectious Disease, 37, article 101742.

Ministry of Housing, Communities & Local Government (2020a), *English Housing Survey 2019 to 2020: headline report*. London, UK. Available at: https://www.gov.uk/government/statistics/english-housing-survey-2019-to-2020-headline-report

Ministry of Housing, Communities & Local Government (2020b), *English Housing Survey 2019 to 2020: technical report*. London, UK. Available at: https://www.gov.uk/government/publications/english-housing-survey-2019-to-2020-technical-report

Standing Committee on Structural Safety (2019), *SCOSS Alert – May 2019: Failure of reinforced autoclaved aerated concrete (RAAC) planks*. London, UK. Available at: https://www.cross-safety.org/uk/safety-information/cross-safety-alert/failure-reinforced-autoclaved-aerated-concrete-raac-planks

9 Appendix A – Model outputs by sector

9.1 Residential

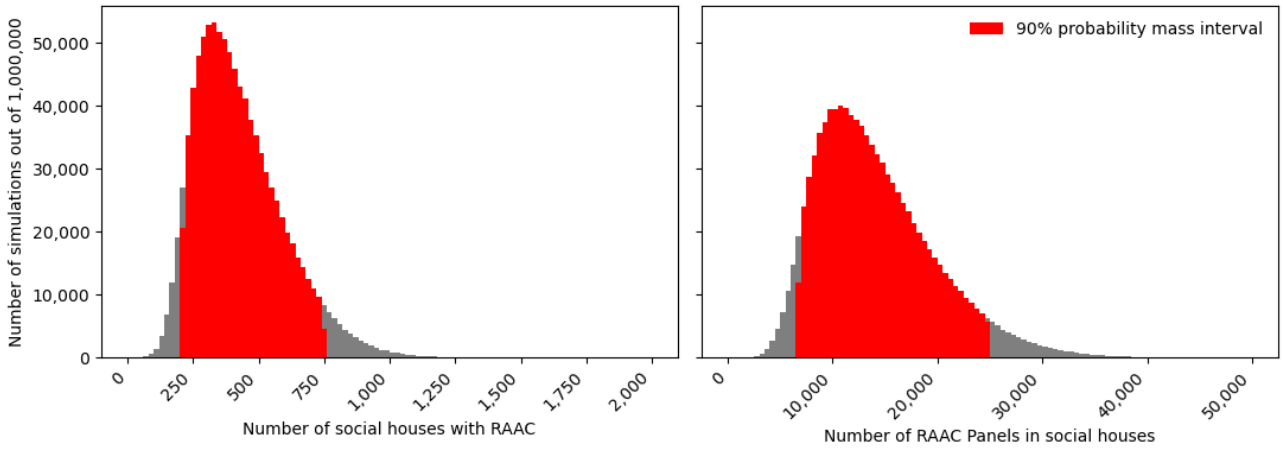

Figure 21. Estimated number of social houses with RAAC and number of RAAC panels in social houses. Data shown in 100 bins across plotted range.

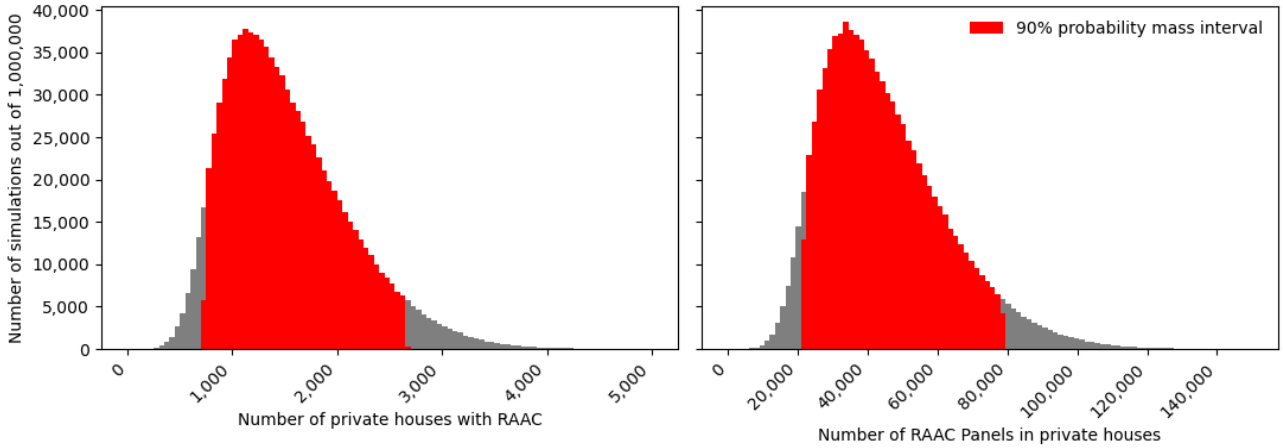

Figure 22. Estimated number of private houses with RAAC and number of RAAC panels in private houses. Data shown in 100 bins across plotted range.

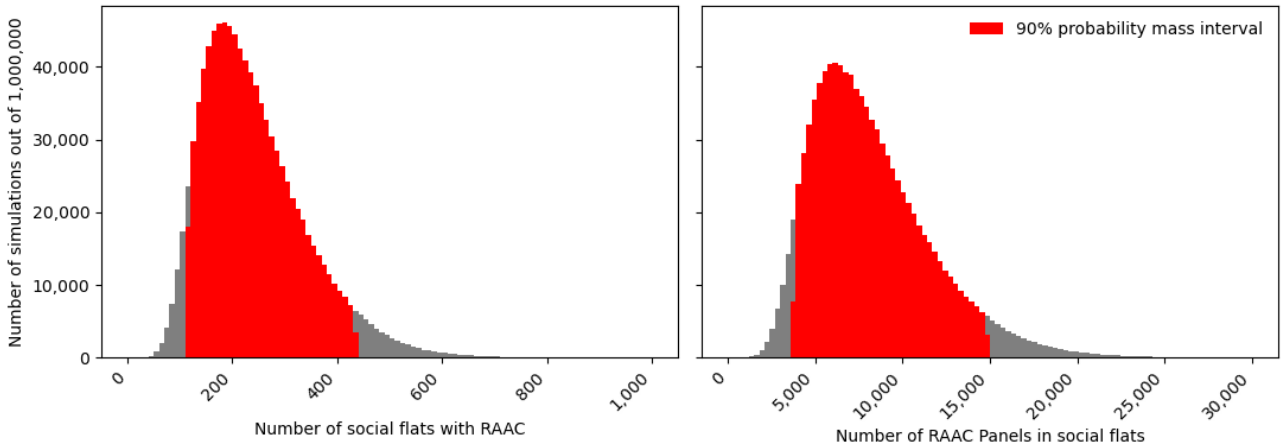

Figure 23. Estimated number of social flats with RAAC and number of RAAC panels in social flats. Data shown in 100 bins across plotted range.

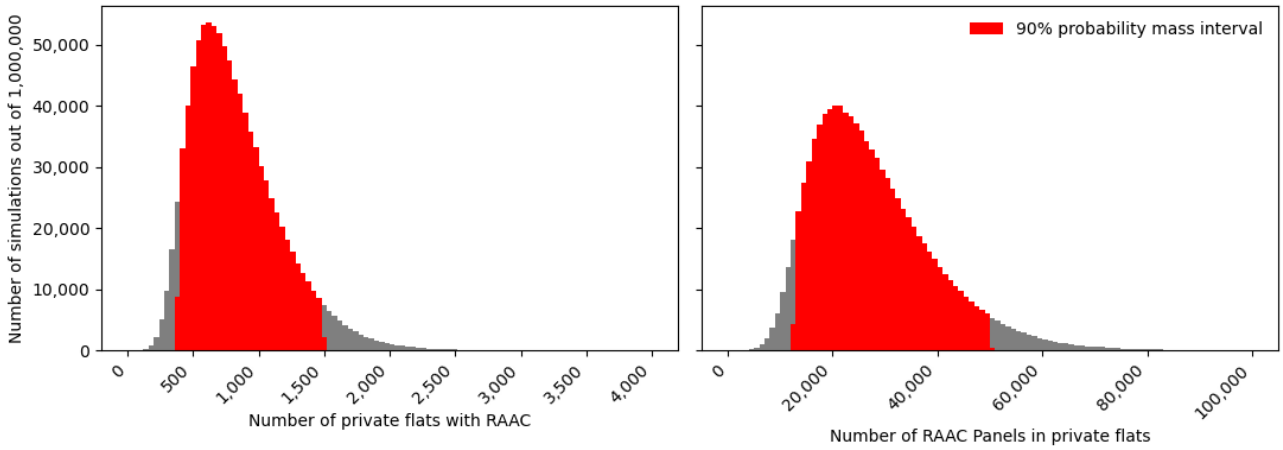

Figure 24. Estimated number of private flats with RAAC and number of RAAC panels in private flats. Data shown in 100 bins across plotted range.

9.2 Non-Residential

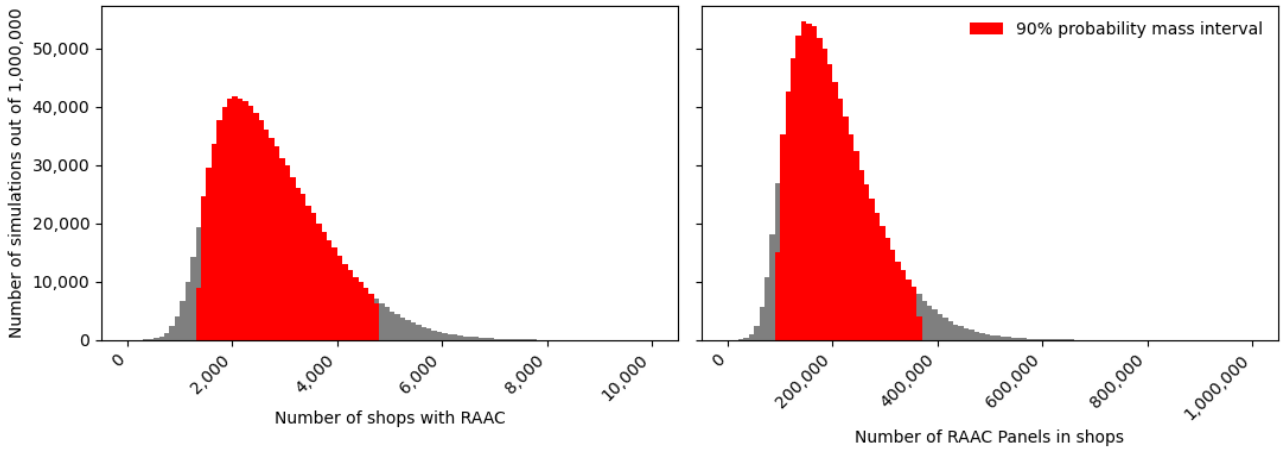

Figure 25. Estimated number of shops with RAAC and number of RAAC panels in shops. Data shown in 100 bins across plotted range.

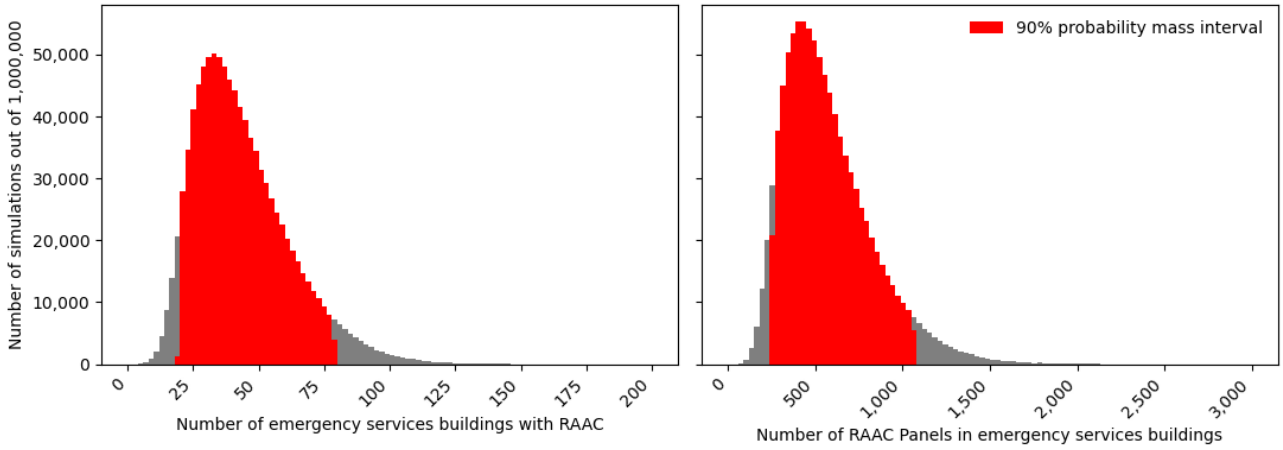

Figure 26. Estimated number of emergency services buildings with RAAC and number of RAAC panels in emergency services buildings. Data shown in 100 bins across plotted range.

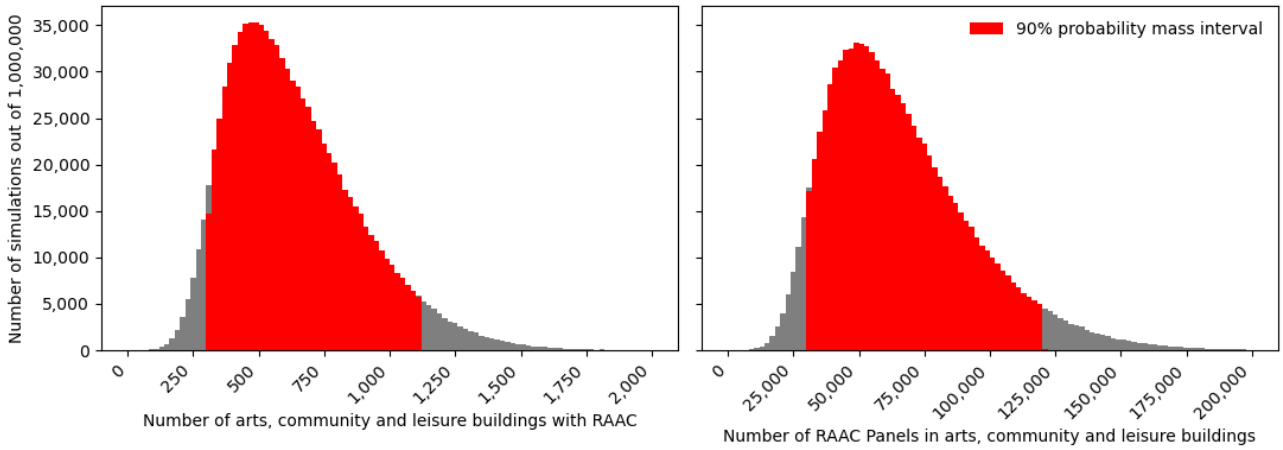

Figure 27. Estimated number of arts, community and leisure buildings with RAAC and number of RAAC panels in arts, community and leisure buildings. Data shown in 100 bins across plotted range.

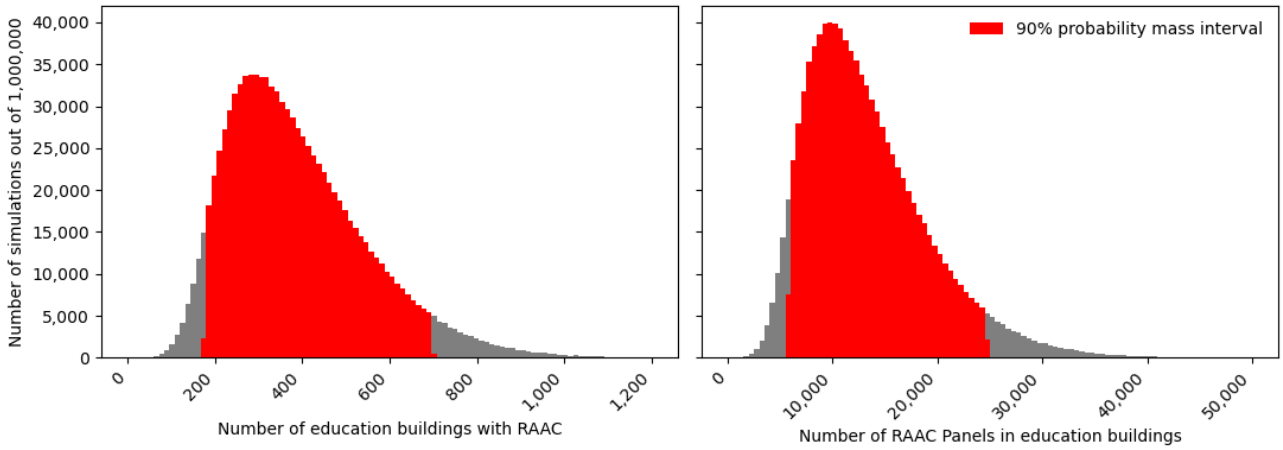

Figure 28. Estimated number of education buildings with RAAC and number of RAAC panels in education buildings. Data shown in 100 bins across plotted range.

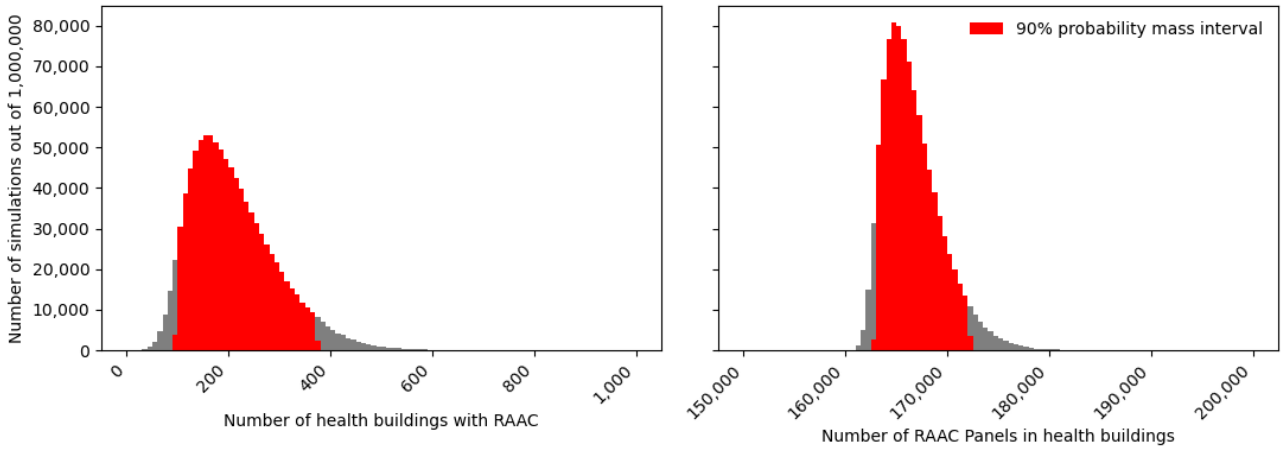

Figure 29. Estimated number of health services buildings with RAAC and number of RAAC panels in health buildings. Data shown in 100 bins across plotted range. Note: Values adjusted to reflect 160,000 known RAAC panels in seven large NHS hospitals.

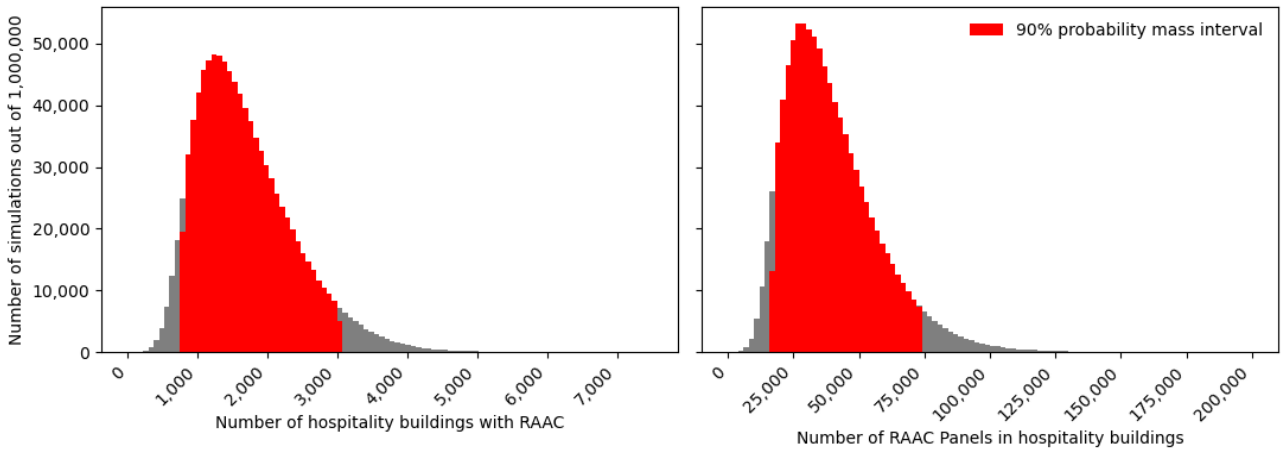

Figure 30. Estimated number of hospitality buildings with RAAC and number of RAAC panels in hospitality buildings. Data shown in 100 bins across plotted range.

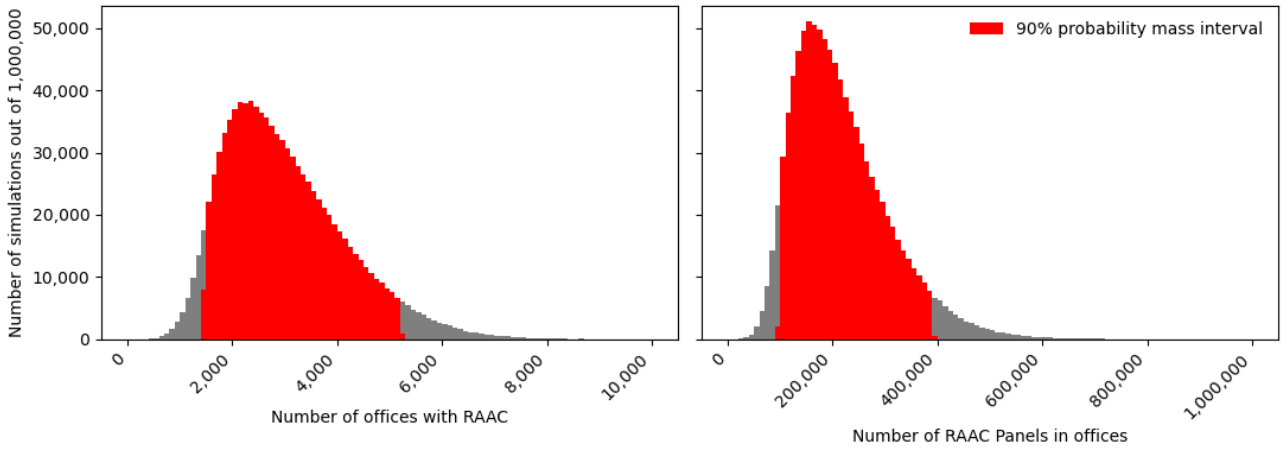

Figure 31. Estimated number of offices with RAAC and number of RAAC panels in offices. Data shown in 100 bins across plotted range.

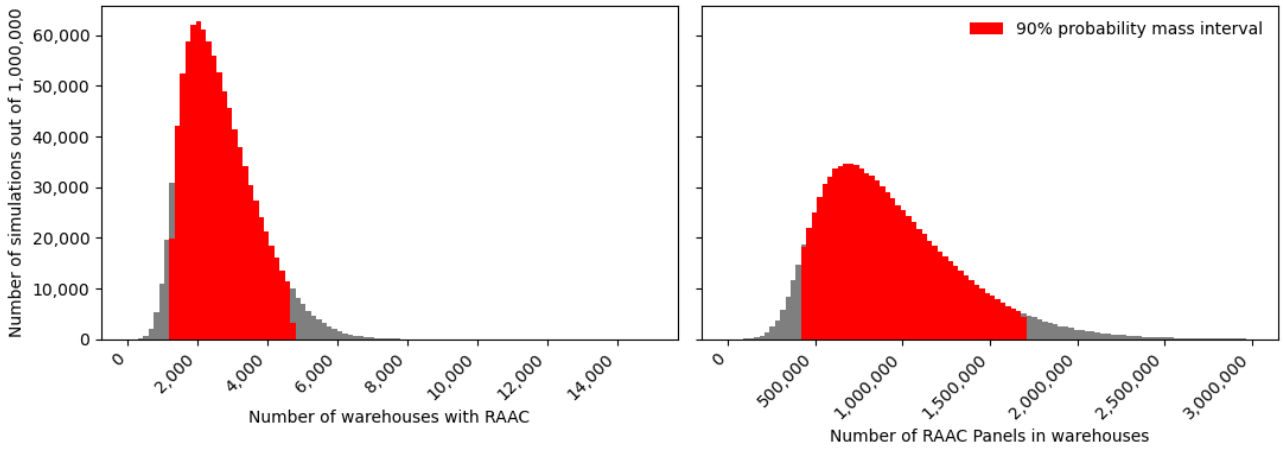

Figure 32. Estimated number of warehouses with RAAC and number of RAAC panels in warehouses. Data shown in 100 bins across plotted range.

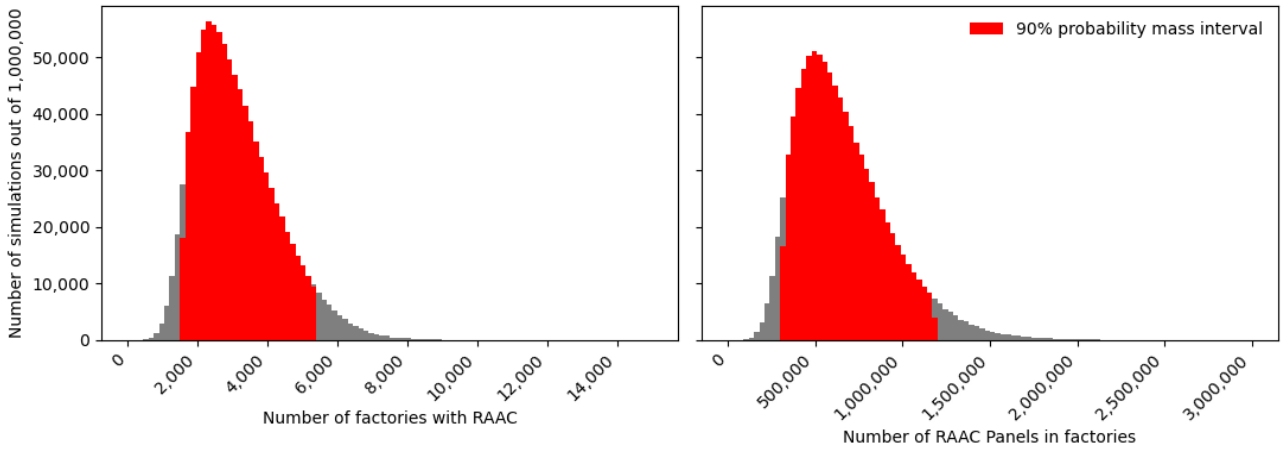

Figure 33. Estimated number of factories with RAAC and number of RAAC panels in factories. Data shown in 100 bins across plotted range.

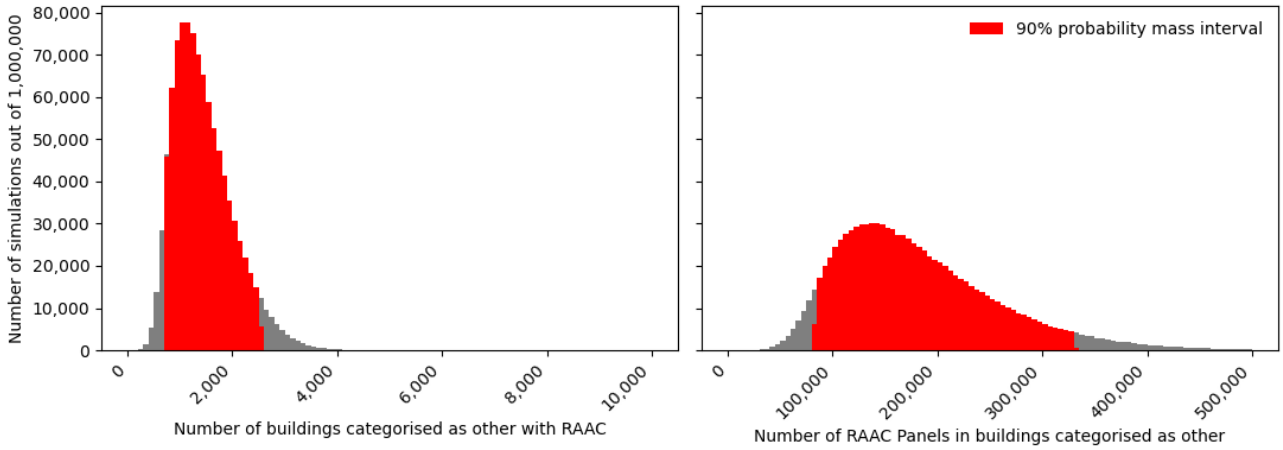

Figure 34. Estimated number of buildings categorised as other with RAAC and number of RAAC panels in buildings categorised as other. Data shown in 100 bins across plotted range.

Reinforced autoclaved aerated concrete (RAAC) is a form of construction used in England between the 1950s and 1990s. RAAC panels were used for walls, floor and roofs. RAAC was used across a range of different residential, commercial and government buildings. Recent years have seen a small number of RAAC panel failures.

To aid future assessments of the risk posed by RAAC panels, this report estimates the number of RAAC panels in England from archive data and past WSP surveys of building estates.

Based on the information available and the modelling techniques employed, it is estimated that there there are between 1.3 million and 4.4 million RAAC panels in England. These RAAC panels are spread between an estimated 9,000 and 33,000 buildings across a variety of sectors. There is a large range provided for these estimates, reflecting the limited data available at the time of writing.

The likely risks of RAAC panel collapse, and how those risks can be reduced through different monitoring and mitigation measures are addressed in HSE report RR1213 - Reinforced Autoclaved Aerated Concrete (RAAC) in England: Assessment of risk of collapse.

DOI: https://doi.org/10.69730/hse.25rr1212

Published by the Health and Safety Executive 02/25