

# Defining and identifying complex-to-decarbonise homes and retrofit solutions

Annex A – technical report



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## Annex introduction

This technical annex accompanies the main report for 'Defining and identifying complex-to-decarbonise homes and retrofit solutions'. This annex provides more detail on the methodology across the research streams, which were introduced in the main report. It also maps evidence availability to the study's 12 research questions and identifies evidence gaps. This annex is for readers who wish to understand the research streams and synthesis processes in more detail.

The annex uses the terminology complex-to-decarbonise (CTD) homes, where relevant, to describe homes which have been identified as those with either one, or a combination of, certain physical, locational, occupant demographic, or behavioural attributes that prevent the effective decarbonisation of that home until they are addressed. These attributes might constrain the design and delivery of measures to improve energy efficiency, decarbonise heating, or realise occupant benefits (e.g., increased comfort and affordability of domestic heat and energy). These effects may be amplified by one or a combination of numerous system-level factors including financial (e.g., feasibility and affordability of measures), economic (e.g., supply chain and materials availability), and/or organisational capacity and capability (e.g., workforce skills).

This CTD terminology has been developed in this research and is informed by evidence which recommends several improvements on existing terminology such as 'hard-to-treat' and 'hard-to-decarbonise'. These existing terms were used in the original scope and research questions, and therefore they are used in this annex where relevant for the methodology processes such as evidence gathering.

## Methodology overview

This section presents the methodology for each research stream, including limitations for each of them.

### Rapid evidence review

#### Methodology

RERs are deployed in fields where rapid, rigorous, and focused analysis is required related answer a question of current interest or to inform policy and practice<sup>1</sup>. We deployed an RER approach which included novel data gathering approaches and stakeholder feedback. The review was guided by STARR/UK government RER principles<sup>2</sup> to synthesise findings that

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<sup>1</sup> Ganann, R., Ciliska, D., Thomas, H., 2010. Expediting systematic reviews: methods and implications of rapid reviews. *Implementation Science* 5, 56. <https://doi.org/10.1186/1748-5908-5-56>

<sup>2</sup> NERC, DEFRA, 2015. *The Production of Quick Scoping Reviews and Rapid Evidence Assessments*.

address the RER's aims as described. The approach consisted of three stages:

- Stage A – Evidence Compilation: which aimed to identify and create a database of relevant literature.
- Stage B – Evidence Analysis: which appraised and synthesised evidence.
- Stage C – Informing the Development of a Definition of CTD homes: which focused on developing requirements for agreeing a definition for CTD homes.

The RER search and screening strategy identified 400 documents that were deemed relevant and available for this study and could potentially help address the research questions and highlight key evidence gaps.

The analysis approach consisted of:

**Categorisation and Appraisal:** Using EPPI-Reviewer, a web application that enables researchers to upload studies for screening, complete keywording and data extractions and analyse the results. Metadata 'tags' were used to categorise/map selected evidence against research questions defined by BEIS which broadly fell under the following categories:

- Defining and identifying HTT/HTD homes.
- Challenges, factors, and considerations affecting retrofitting of HTT/HTD homes.
- Evidence on existing approaches to retrofitting HTT/HTD homes.

The sources were then assessed and ranked using a further set of criteria covering quality, robustness, data availability and inclusion of HTT/HTD typologies.

**Extraction and Synthesis:** Relevant data was then extracted and checked by a second reviewer. This data was synthesized using the metadata tags to generate findings to answer the research questions identified. More relevant/robust evidence was given greater weight to ensure robustness and minimise interpretation bias.

**Identifying the Evidence Gap:** As part of the analysis current knowledge gaps and key areas where further research and analysis would be required were defined.

## Limitations

RER methods are subject to several limitations, namely (1) RER consist of a small number of shortcuts in comparison to more detailed evidence assessments (e.g. systematic reviews). This does make them more vulnerable to bias and errors, for example the literature search may be less comprehensive, or restricted by filters such as English language, introducing publication bias. This limitation however is deemed appropriate in the case of this study, given the study's requirement for balancing speed and quality. (2) RER evidence sources may miss insights not yet captured in published sources – particularly relevant for emerging or contested concepts such as HTT or HTD homes. This effect of this limitation is reduced through the

inclusion of multi-stakeholder interviews (see below). Errors were mitigated through a multistep process for agreeing search criteria to ensure validity and relevance to the research questions.

## Data survey

### Methodology

The survey format consisted of a series of structured questions hosted on google forms. Participants were recruited using an email invitation to existing networks and known experts in this field, posting on LinkedIn and sharing details on wide-reaching portals such as the Unlock NetZero newsletter. The survey responses were then analysed and collated as part of the evidence considered in the RER report. The survey questions are presented further below.

### Limitations

Non-probability self-selection sampling is subject to several limitations: (1) self-selection bias can introduce errors resulting characteristics of the participant (e.g. extreme positive or negative views) and reduce the representativeness of findings whereby certain demographics/characteristics are more likely to respond. This limitation is deemed acceptable given the purpose of the data survey was to compliment more robust methodologies, with greater focus on surfacing other current industry literature that may exist (but not be publicly available) and to support participant recruitment.

## Qualitative interviews

### Methodology

Interviewees were sought from across the built environment and decarbonisation ecosystem, recruited via existing networks and targeted outreach via social media networks (e.g. LinkedIn), including industry and professional groups. We recruited across industry organisations, third-sector and civil society organisations, and academic and regulatory bodies. We developed separate interview guides for these three groups.

Interviews also provided an additional route to identifying case studies. An outline of the sample interviewed (and of the case studies) is shared below (Table 1). A full account of all interview and case study participants is shared in Annex A.

**Table 1 Interview and case study sample**

Stakeholder/organisation	Type & interview guide	Interview sample	Case study sample
Small industry (< 50 employees)	Industry	8	2
Medium to large industry (>= 50 employees)	Industry	8	1
Trade/sectoral association	Industry	7	0
Housing association/trust	Academic & regulatory	5	3
Local Authority/collaborative hub	Academic & regulatory	8	0
Policy/standards body	Academic & regulatory	5	2
Academic institution	Academic & regulatory	4	0
Social/consumer organisations	Third-sector and civil society	5	2

The interviews were semi-structured, and covered topics drawing on the outcomes of the RER to answer the research questions. The topic guides can be found in Annex A.

Fifty telephone and web-based interviews were conducted lasting between 45 and 75 minutes. Interviews were audio recorded and transcribed. Interviewer notes were produced and used alongside the transcript for analysis.

Thematic analysis was undertaken using Dedoose coding software. Excerpts were coded against a coding structure derived from the outcomes of the RER. Overall, for the 50 interviews a total 2,265 excerpts were applied to codes (from a code list of 363) for 4,226 total code applications.

Initial inductive coding was then complemented with deductive coding, drawing out new themes for review and potential inclusion, as well as analysis of code co-occurrences. This process was deployed as it enables the analysis to integrate multiple perspectives and data sources, highlights similarities and differences between participants, and generates unexpected insights. Figure 1 outlines the thematic analysis process.

**Figure 1 Phased approach to thematic analysis<sup>3</sup>**



<sup>3</sup> Nowell LS, Norris JM, White DE, Moules NJ. Thematic Analysis: Striving to Meet the Trustworthiness Criteria. International Journal of Qualitative Methods. December 2017.

## Limitations

Qualitative interviews provide experience, observation and viewpoints that are valuable for mixed methods research which seek to understand meaning and relationships between attributes across different stakeholder groups. However, qualitative analysis has several limitations: (1) Suitable weighting is required in the synthesis process to reflect the nature of the concepts analysed – estimates for weightings were made via literature, and validated with qualitative data, reducing the impact of analysis errors. (2) Sampling bias was mitigated with a quota approach across stakeholder types, however recruitment of certain groups was challenging. Private landlords and some third-sector and civil society organisations were non-responsive to several rounds of engagement. The impact of having a smaller sample of third-sector and civil society was mitigated by utilising the rich dataset that emerged on social factors from interviewing other participants. (3) Careful analysis by several researchers also reduces error, where unique or outlier responses are found these are logged as potential perspectives and insights of value, but treated as not representing wider group views or norms.

## Identification Framework development process

### Methodology

The framework was developed using an iterative process, informed by RER and qualitative interview insights as well as feedback from DESNZ stakeholders. Building on knowledge from the RER relating to existing models and datasets, emergent insights from the qualitative interviews combined with DESNZ stakeholder feedback were used to develop use cases for the framework and principles describing its focus (i.e., its aim) and intended functionality (i.e., how it may be used). Insights from the RER and qualitative interviews were then used to generate a list of physical, technical and occupant attributes that may render a home to be CTD and weight<sup>4</sup> them according to their relative importance.

To develop a flexible, comprehensive framework that can be responsive to the needs of potential stakeholders and achievable within the scope of this project, the development was based on the following steps:

1. Understanding existing approaches and datasets: Findings from the RER relating to existing models and datasets were used to identify, map and document data availability and limitations, and assess how previous HTT and/or HTD identification methodologies considered and implemented attribute identification and categorisation.
2. Development of use cases: Emergent insights from the qualitative interviews were used to develop high-level (initial) use cases for the framework, DESNZ stakeholder feedback was then used to refine these use cases.

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<sup>4</sup> Weighting assigns a coefficient to a variable through which its effect on the calculation process to reflect its importance.



3. Definition of framework principles: Use case feedback from the qualitative interviews and DESNZ stakeholders was used to define a set of framework principles describing its focus and intended functionality.
4. Attribute identification, mapping, and weighting: Insights from both the RER and the qualitative interviews were integrated to inform the development of a list of physical, technical and occupant attributes.
5. Development and implementation of the framework structure: We refined the structure using DESNZ stakeholder feedback, framework implementation structure was automated through the generation of custom Python<sup>5</sup> scripts.

Annex B sets out the CTD Identification Framework in detail.

## Limitations

The limitation of the framework development mainly concerns the design of the user interface, as a consequence of limited time and resources and in being beyond the research scope. A key design decision was made to focus on the completeness and the high flexibility of the framework, leading to a compromise of its user-friendliness. Further:

- Python was used to facilitate rapid prototyping, which entails a certain degree of technicality as a prerequisite to conduct analysis using the framework.
- The requirement for flexibility leads to a data-agnostic framework, which was deemed of high importance, but it means users are required to curate datasets to be used, and to determine weights to be assigned.
- Limited access to datasets also limits the delivery of comprehensive dataset interfacing components (harmonisers), where customisation is needed for new datasets.

## Case studies

### Methodology

Table A1 above presents the broad categories of the case study organisations, and Annex C presents the case study set. Case studies participants were recruited through the qualitative interviews, where relevant projects were identified by interviewees. Additional participants were recruited with targeted outreach and calls for participants through existing networks (as per the qualitative interviews) and at a national retrofit event. Ten case studies were identified that met selection criteria developed with DESNZ which included geography, tenure, archetype, and socio-economic demographics (e.g. vulnerable occupants). Case studies were selected to ensure they provided a diverse set of examples which covered key themes from the RER, and stakeholder interviews.

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<sup>5</sup> Python is an object-oriented, high-level programming language, which encourages program modularity and code reuse.

We developed an initial case study template alongside qualitative interview scripts and further refined this using the findings from the RER and follow-up interviews with participants. The case study template was populated during the interview by the interviewer, and used post-interview to check and refine details with input from participants. Finally, we summarised and anonymised the content to form the case studies as presented in Annex C.

## Limitations

Case study methods are subject to several key limitations: (1) they are subject to bias at several stages, including data collection, analysis, and reporting. Data selection and interpretation can be influenced by the opinions, assumptions, and preferences of the researcher; (2) case studies provide a reflection on experience, which may introduce positivity bias or confirmation bias; (3) provide a limited snapshot view of an example with enables limited analysis and interpretation. This limitation is deemed acceptable given the purpose of the case studies to compliment other methodologies and provide additional deeper insights.

## Synthesis

### Methodology

The iterative synthesis process consisted of continued interpretation and data validation across the research team, which included the following:

1. The RER was used to develop the interview scripts, and code interview data. Throughout this process codes were validated across the interview team and RER/identification framework development team. The final code structure was agreed by the research teams and DESNZ.
2. The Stakeholder Interview Analysis document was developed using the agreed code structure. Key themes were drawn out, with coded responses regularly shared across the interview team for interpretation and reflection, which was recorded to inform the final report.
3. The RER/identification framework development team drew on interview excerpts throughout the framework development process, to validate attributes against RQs, assess attribute relationships and co-occurrences and define weightings (e.g. identify primary and secondary attributes). The interview team supported validation through the review of the Identification Framework.
4. Case studies were developed following the identification of key themes from the stakeholder interview process. Case study themes were assessed by both teams, and emerging case studies were reviewed for further insights to inform both the final report, and the Identification Framework.

## Qualitative interview information

This section sets out further detail on the qualitative interviews, with the interview sample and the interview guides used. The interview guides were developed using insights from the RER and were tailored for each of the three interview groups – an industry interview guide, an academic/regulatory interview guide, and a social organisation/community interview guide. The interview guides follow the interview sample below.

### Interview sample

**Table 2 Participant details<sup>6</sup>**

Stakeholder / organisation type	Participant role
Local authority / collaborative hub	Energy Manager
Local authority / collaborative hub	Retrofit Manager
Policy/standards body	Managing Director
Large industry (>=50 employees)	Energy Service Director
Small industry (<50 employees)	Architect
Social/consumer organisation	Policy Advisor
Large industry (>=50 employees)	Director of Sustainability
Academic institution	Professor of Sustainable and Environmental Design
Trade/sectoral association	Director
Small industry (<50 employees)	Managing Director
Social/consumer organisation	Head of Policy
Social/consumer organisation	Head of Policy
Social/consumer organisation	Associate Director
Housing association/trust	Sustainability and Retrofit Manager

<sup>6</sup> Third sector/charitable organisation / co-operative/ not-for-profit organisations were approached but are under-represented in the final sample. This has been considered in the analysis and final recommendations.

<b>Stakeholder / organisation type</b>	<b>Participant role</b>
Small industry (<50 employees)	Director
Local authority / collaborative hub	Retrofit Programme Director
Housing association/trust	Senior Retrofit Building Surveyor
Third sector /Charitable organisation /co-operative /not-for-profit	Project Manager
Trade/sectoral association	Director of Policy
Small industry (<50 employees)	Advisor
Policy / standards body	Senior Energy Advisor
Trade/sectoral association	CEO
Local authority / collaborative hub	Head of Regional Programmes
Small industry (<50 employees)	Managing Director
Large industry (>=50 employees)	Director of Policy and External Affairs
Local authority / collaborative hub	Policy Manager
Large industry (>=50 employees)	Director
Large industry (>=50 employees)	Architect
Trade/sectoral association	Policy Officer
Academic institution	Research Fellow
Large industry (>=50 employees)	Head of Carbon Reduction Solutions
Policy / standards body	Head of Climate Change
Trade/sectoral association	Policy Manager
Small industry (<50 employees)	Heating Engineer
Large industry (>=50 employees)	CEO
Social/consumer organisation	Head of Whole Home Retrofit

<b>Stakeholder / organisation type</b>	<b>Participant role</b>
Large industry (>=50 employees)	Planning and Delivery Manager
Large industry (>=50 employees)	National Decarbonisation Manager
Small industry (<50 employees)	Retrofit assessor
Local authority / collaborative hub	Energy Projects Manager
Small industry (<50 employees)	Managing Director / Lead Architect
Small industry (<50 employees)	Chartered Surveyor
Small industry (<50 employees)	Managing Director
Small industry (<50 employees)	Architect
Trade/sectoral association	Policy Manager
Housing Association/Trust	Head of Assets and Stock Investment
Small industry (<50 employees)	Director
Local authority / collaborative hub	Energy Policy Advisor
Small industry (<50 employees)	Retired Architect
Large industry (>=50 employees)	Technical Support

## Interview guides

### Industry interview guide

#### Interview script

Thank you for agreeing to take part in this study. I work for DG Cities, an innovation consultancy that works to improve the built environment. We are working with University College London (UCL) and on behalf of the UK government's Department for Business, Energy and Industrial Strategy to develop a definition of, and framework of approaches to improve, hard to treat and hard to decarbonise homes.

This interview is an opportunity for you to share your knowledge and experience of 'hard to treat' or 'hard to decarbonise' homes and their occupants. We will be asking you about your

background, the approaches and challenges to working with a hard to treat or hard to decarbonise home.

We would like to record this interview, for transcription purposes. Once I have transcribed the interview to ensure I've captured all of your data accurately, the video will be deleted.

Are you happy with all of the information I have provided?

Do you have any questions?

You are free to withdraw from this interview at any time or ask questions at any point.

### **Introductory Questions**

Thank you for sharing details of your role via email ahead of this interview, your role at [ORGANISATION] sounds really interesting, and relevant to our research.

[IF FOLLOW UP NEEDED] Please can I clarify whether...

[IF NOT ANSWERED QUESTIONS] I'd like to ask a few brief questions about yourself before we begin.

1. Could you please tell me a bit about yourself?
  - a. Where do you work?
    - i. What is the purpose of this organisation?
    - ii. How does this interact with the home decarbonisation sector?
  - b. What is your role?
  - c. How long have you worked in this industry?

### **Hard to Treat Definition**

[Priority Section]

2. How would you define or describe a hard to treat or hard to decarbonise home?
3. What characteristics do you think makes a home hard to treat or hard to decarbonise?

Prompts:

- Locational (e.g. proximity, exposure, accessibility)
- Physical (e.g. Building fabric, Cavity wall, flat roof, mansard roof, Windows, Floor, Heritage/conservation/aesthetic values, Building form, non-standard)
- Social (e.g. Ownership: social/private landlord, home-owners, demographic attributes, Habits/behaviours/characteristics)

4. Aside from the categories we discussed, are there any other characteristics you consider to make these homes hard to treat or hard to decarbonise?
5. Do any of the characteristics you have already described stand out as more likely to mean a property is hard to treat or hard to decarbonise?
6. Why?
7. What types of home do you consider to have the characteristics you have described above?

Prompt:

- Redbrick terrace
- High rise
- Conservation

The UK Climate Change Committee defines hard-to-decarbonise homes as: "Homes can be considered to be 'hard to decarbonise' if they are 'hard to treat' &/or do not have cost-effective options for low carbon heating and energy efficiency"

8. What do you think of this definition?
9. How would you distinguish between hard to treat and hard to decarbonise homes?
10. Is a definition that is universally used in your industry or place of work?

### **Hard to Decarbonise and Hard to Treat Attributes**

I'm now going to ask you about the breadth of your experience with hard to treat or hard to decarbonise homes, and their general attributes.

[Priority]

11. Could you give a brief description of your experience with hard to treat or hard to decarbonise homes?

[Priority]

12. What were the characteristics of the properties or groups of properties, or the issues the properties have, which in your view mean it was hard-to-treat or hard to decarbonise?

*If participant just lists attributes, ensure they tie these back to building archetypes/experiences rather than just getting a list of their knowledge.*

Physical attribute prompts:

- Building fabric
- Cavity wall
- Roof (flat roof, mansard roof)
- Windows
- Floor
- Heritage/conservation/aesthetic values
- Building form
- non-standard

Locational attributes:

- proximity
- exposure
- accessibility

Occupant attributes:

- Ownership: social/private landlord, home-owners
- demographic attributes
- Habits/behaviours/characteristics

[Priority]

13. How would you describe the building archetype?

- Age?
- Materials?
- Location?
- Uses?

[Optional]

Additional prompts:

14. What prompted you to address the challenges in these homes?

15. Did you successfully change the EPC rating or reduce the carbon output of this house?



## Designing and developing the project

With the feature[s] that make the properties hard to treat and hard to decarbonise in mind, I'm going to ask you more questions about these properties and how you develop the projects that are aimed to treat /decarbonise these properties.

[Priority]

16. Could you please describe the planning and retrofit coordination process that you use?

Prompts:

- Did you use PAS2035? If yes, how useful did you find it to assess hard to treat and hard to decarbonise homes?
- What pathways were identified as possibilities for this property type?
- Why?
- Do you approach this process differently when dealing with a hard to treat or hard to decarbonise home?

[Priority]

17. How did you decide on the approach?

Prompts:

- Did they have to weigh up financial cost vs carbon saving
- What was affordable given time/budget constraints
- Were there any restrictions on carrying out the desired/possible work?

*If participant is too general, ask for specifics about types of properties each description applies to i.e. 'what property type did this affect?', 'why is this more challenging for hard to treat or hard to decarbonise homes?'*

[Priority]

18. In your experience do you see any possible risks to the fabric of the building by retrofitting the property? If yes, what were they?

[Priority]

19. What approaches, strategies or pathways would you use to improve the energy efficiency of these properties?

Prompts - which of these did your approach include?

- Insulation
  - Cavity Wall Insulation

- External Solid Wall Insulation
- Internal Solid Wall Insulation
- Loft Insulation
- Pitched Roof Insulation
- Flat Roof Insulation
- Room in Roof Insulation
- Floor Insulation
- Park Home Insulation
- Heating Control and delivery
  - Heating Controls
  - Hot Water Tank Insulation
  - Hot Water Tank Thermostats
  - Rad
- Windows and Doors
  - Double or Triple Glazing
  - Draught Proofing
  - Energy Efficient Windows and Doors
  - Secondary Glazing
- Electricity Related
  - Energy efficient lighting
- Retrofit assessment
- Retrofit coordination
- Remediation
  - Structural repairs
  - Damp proofing
- Ventilation
  - positive input ventilation (PIV)
  - mechanical extract ventilation (MEV)
  - mechanical ventilation with heat recovery (MVHR)
  - Prevailing Wind Systems
  - Passive ventilation
  - Trickle vents

- Air bricks
- Lifestyle changes
- Other measures: \_\_\_\_\_
- If relevant:
  - Pathways e.g., PAS2035

20. What approaches, strategies or pathways would you use to progress this home or these properties onto alternative heating options?

Prompts: which of these did your approach include?

- Low carbon heating related]
  - Electricity Related
  - Solar PV
  - Wind turbine
- Electricity Related
  - Energy efficient lighting
  - Solar PV
  - Wind turbine
  - Energy efficient lighting
  - Battery storage
- If relevant:
  - Pathways e.g. PAS2035

Follow up: How did this choice of heating system influence the choice of other measures needed to decarbonise the home/these homes?

21. Have you previously identified that some of the above measures are unsuitable for the types of hard to treat or hard to decarbonise homes that you work with? If yes, why?

[Priority]

22. What rules and regulations do you need to consider or comply with when designing your approach?

Prompts:

- Government legislation
- Building regulations
- Planning rules and requirements
- Local authority guidance

- Industry standards
- Installer certification bodies (TrustMark, MCS)
- scheme providers

[Priority]

23. What type of budgets do you work with and how are your projects generally funded?
- a. Grants (government grant? If so, what)
  - b. Loans (bank? Green financing? Obtain details)
  - c. Personal funding (i.e., savings, other?)

Prompt:

- Were you or other stakeholders in the project able to access any financial schemes, grants or loans to aid in the delivery of the project? If yes, what were they?

[Optional]

24. Have you encountered any financial challenges when trying to deliver retrofit measures to hard to treat or hard to decarbonise properties? If yes, what were they?

*Ask how these challenges vary if the property is hard to treat and decarbonise vs. not.*

Prompts:

- Budget constraints
- Access to financial resources
- Unexpected costs

[Priority]

25. What stakeholders do you need to engage to develop and deliver your approach?

Prompts:

- Distribution Network Operators
- Local authorities
- External contractors

## **Delivering the project**

I'd now like to talk about your experience of delivering a project; from deciding on the approach, through any surveying that was required, through the fitting of measures, working with contractors etc. We're interested in understanding the steps involved in completing the project, and particularly what makes it harder to treat or decarbonise than other homes.

[Priority]

26. How long does it generally take to deliver the projects that you work on?

[Priority]

27. What materials were required to deliver this project?

[Optional]

28. Did you work with external stakeholders to deliver the project? If yes, who were they and what were their roles?

[Priority]

29. What challenges do you face when delivering these measures on hard to treat or hard to decarbonise homes?

Prompts:

- Supply chain issues
- Local skills
- Getting planning permissions
- Access to the correct materials
- District Network Operators
- Stakeholder issues
- Resident resistance

Follow Up:

- How did you overcome these challenges?
  - Invest in skills
  - Obtain new certifications for supply chain/skills?

[Optional]

30. How are occupants involved in the improvements?

[Optional]

31. In your experience, do the residents stay in-situ during these projects?

- a. If yes, how did you mitigate the risk of disruption?

[Priority]

32. How did the delivery and challenges of this project vary from the delivery on a project on a non-hard to treat or hard to decarbonise home?

[Priority]

33. What lessons did you learn from this project?

[Priority]

34. If you were able to, what would you do differently?

a. What additional work would you propose and/or deliver for this particular project?

[Optional section based on stakeholder's prior discussion]

### **Measurement/Evaluation**

[Priority]

35. What specific metrics did you use to measure the impact of your project?

a. Carbon-savings?

b. Bill-savings?

c. How were measures reported?

d. Who were measures reported to?

[Priority]

36. What was the impact of your approach?

a. At what point did you measure impact?

b. Did you measure return-on-investment?

[Optional]

37. How did residents or occupiers affect the impact of your project?

[Optional]

38. Has your approach been replicated more broadly? If no, why?

[Optional]

39. How was the project evaluated?

## **Final Comments and questions:**

[Priority]

40. What are your key 'best practice' takeaways from your projects working on hard to treat and hard to decarbonise homes?

Prompts: What worked for you, working with these types of home?

[Priority]

41. What didn't work for you, working with these types of home?

Prompts:

- systems in place
- technology
- information available
- participants

[Priority]

42. What would have made things easier for you to undertake this project?

[Priority]

43. What would you want to do, to make homes easier to decarbonise?

## **Case study**

As mentioned over email, we are also developing case studies of specific examples projects and approaches designed to tackle Hard to Treat Homes and Hard to Decarbonise homes or support their occupants. You said that you [DO/DON'T] have a case study that you'd like to share.

### **If no to case study:**

44. Why not?

Prompts:

- a. Does nothing come to mind?
- b. Do you not have examples of such homes being treated?
- c. Did you require more time to put something together?

Before we end the interview, you have any other comments or reflections that you would like to share relating to hard to treat or hard to decarbonise homes?

Great. That is the end of my questions. Thank you again for agreeing to take part in this study. Your interview will be transcribed and the recording of the interview will be deleted. Your data will be stored anonymously. If you have any questions in the future, please don't hesitate to contact me.

### **If yes to case study:**

Thanks for this offer, we really appreciate it. The case studies will form the next stage of our research. If suitable, we may contact you to ask for more information on the case study you mentioned

I have some initial questions about the case study:

45. Can you please give me a brief description of this project?
46. What were the characteristics of the property (or properties) you were working on and why were they hard-to-treat?
47. What approach did you choose to treat this home and why?

Before we end the interview, you have any other comments or reflections that you would like to share relating to hard to treat or hard to decarbonise homes?

Great. That is the end of my questions. Thank you again for agreeing to take part in this study. Your interview will be transcribed and the recording of the interview will be deleted. Your data will be stored anonymously. If you have any questions in the future, please don't hesitate to contact me.

## **Academic/regulatory bodies interview guide**

### **Interview script**

Thank you for agreeing to take part in this study. I work for DG Cities, an innovation consultancy that works to improve the built environment. We are working with University College London (UCL) and on behalf of the UK Government's Department for Business, Energy and Industrial Strategy to develop a definition of, and framework of approaches to improve, hard to treat and hard to decarbonise homes.

This interview is an opportunity for you to share your knowledge and experience of 'hard to treat' or 'hard to decarbonise' homes and their occupants. We will be asking you about your background, the approaches and challenges to working with a hard to treat or hard to decarbonise home.

We would like to record this interview, for transcription purposes. Once I have transcribed the interview to ensure I've captured all of your data accurately, the video will be deleted.

Are you happy with all of the information I have provided?

Do you have any questions?



You are free to withdraw from this interview at any time or ask questions at any point.

## **Introductory Questions**

Thank you for sharing details of your role via email ahead of this interview, your role at [ORGANISATION] sounds really interesting, and relevant to our research.

[IF FOLLOW UP NEEDED] Please can I clarify whether...

[IF NOT ANSWERED QUESTIONS] I'd like to ask a few brief questions about yourself before we begin.

1. Could you please tell me a bit about yourself?
  - a. Where do you work?
    - i. What is the purpose of this organisation?
    - ii. How does this interact with the home decarbonisation sector?
  - b. What is your role?
  - c. How long have you worked in this industry?

## **Hard to Treat and Hard to Decarbonise Definition**

[Priority]

2. How would you define or describe a hard to treat or hard to decarbonise home?

[Priority]

3. What characteristics do you think makes a home hard to treat or hard to decarbonise?

Prompts: Physical, Locational, Social

4. Aside from the categories we discussed are there any other characteristics you consider to make homes hard to treat and hard to decarbonise?
5. Why?

[Optional]

6. Do any of the characteristics you have already described stand out as more likely to mean a property is hard to treat or decarbonise?

[Priority]

7. Are there any particular types of homes that you consider to have the characteristics you have described above?

Prompt:

- Red-brick terrace
  - High rises
  - Conservation
8. What sources of information do you use to identify a hard to treat or hard to decarbonise home?
    - a. How do you use this information?
  9. What are the benefits/drawbacks of the information?
    - a. Where are there information gaps?

[Priority]

The UK Climate Change Committee defines hard-to-decarbonise homes as: "Homes can be considered to be 'hard to decarbonise' if they are 'hard to treat' &/or do not have cost-effective options for low carbon heating and energy efficiency measures"

10. What do you think of this definition?

[Optional]

11. How would you distinguish between hard to treat and hard to decarbonise homes?
12. Is there a definition that is universally used in your place of work or industry?

## **Experience with hard to treat or hard to decarbonise homes**

[Priority]

13. Could you please describe your experience with policy or practice related to hard to treat or hard to decarbonise homes?

In the following sections, I will ask you specifically about different aspects of hard to treat and hard to decarbonise homes. The questions will specifically ask about the technical, policy and social aspects of these homes in turn.

## **Technical and policy influences**

[Priority]

14. What do you believe are the key technical challenges that industry face when assessing how to decarbonise these homes?

[Priority]

15. What do you believe are the key technical challenges that consumers face?

[Optional]

16. Do the barriers change based on the home's location, either across the country or in terms of rurality or size?

[Optional]

17. How do the barriers to decarbonising homes change based on the technical aspects of home?

[Priority]

18. Are you aware of what current policy and guidelines suggest for assessing how to decarbonise these homes?

[Priority]

19. What barriers do these policies create for addressing hard to treat homes?

Prompt:

- Legal barriers
- Planning barriers

[Priority]

20. Have you experienced these barriers in relation to projects that you have worked on? If so, how?

Prompt: Alternatively, have you heard about these barriers from others?

21. Were there any barriers that you anticipated but did not experience, when working with these policies?

Prompt: What was the root cause of these barriers?

[Priority]

22. How would you improve the impact of policies in this space?

## **Social questions and policy influences**

[Priority]

What are the social challenges that relate to or result from a hard to treat or hard to decarbonise homes?

Prompts:

- Fuel poverty
- In-just transition

If regulatory body:

23. What barriers do you currently face to reduce the effects of hard to decarbonise or hard to treat homes on these residents?

[Priority]

24. Have you observed any traits, beliefs, assumptions or behaviours that have made retrofitting or decarbonising a home particularly difficult?

- Traits i.e., demographics such as socioeconomic status, age etc.
- Beliefs i.e., about technology, sustainability, the council, assumptions about policy etc
- Behaviours such as drying clothes inside, cooking, ventilation.

[Priority]

25. How do the policies and associated challenges impact the social challenges you described?

[Priority]

26. What would you recommend changing to improve the social outcomes of these policies?

## Case study

As mentioned over email, we are also developing case studies of specific examples projects and approaches designed to tackle Hard to Treat Homes and Hard to Decarbonise homes or support their occupants. You said that you [DO/DON'T] have a case study that you'd like to share.

If no to case study:

27. Why not?

Prompts:

- a. Does nothing come to mind?
- b. Do you not have examples of such homes being treated?
- c. Did you require more time to put something together?

Before we end the interview, you have any other comments or reflections that you would like to share relating to hard to treat or hard to decarbonise homes?

Great. That is the end of my questions. Thank you again for agreeing to take part in this study. Your interview will be transcribed and the recording of the interview will be deleted. Your data will be stored anonymously. If you have any questions in the future, please don't hesitate to contact me.

Thanks again!

If yes to case study:

Thanks for this offer, we really appreciate it. The case studies will form the next stage of our research. If suitable, we may contact you to ask for more information on the case study you mentioned.

I have some initial questions about the case study:

28. Can you please give me a brief description of this project?
29. What were the characteristics of the property (or properties) you were working on and why were they hard-to-treat?
30. What approach did you choose to treat this home and why?

Great. That is the end of my questions. Thank you again for agreeing to take part in this study. Your interview will be transcribed, and the recording of the interview will be deleted. Your data will be stored anonymously. If you have any questions in the future, please don't hesitate to contact me.

## Social organisation/community interview guide

### Interview Script

Thank you for agreeing to take part in this study. I work for DG Cities, an innovation consultancy that works to improve the built environment. We are working with University College London (UCL) and on behalf of the UK Government's Department for Business, Energy and Industrial Strategy to develop a definition of, and framework of approaches to improve, hard to treat and hard to decarbonise homes.

This interview is an opportunity for you to share your knowledge and experience of 'hard to treat' or 'hard to decarbonise' homes and their occupants. We will be asking you about your background, the approaches and challenges to working with a hard to treat or hard to decarbonise home.

We would like to record this interview, for transcription purposes. Once I have transcribed the interview to ensure I've captured all of your data accurately, the video will be deleted.

Are you happy with all of the information I have provided?

Do you have any questions?

You are free to withdraw from this interview at any time or ask questions at any point.

## **Introductory Questions**

Thank you for sharing details of your role via email ahead of this interview, your role at [ORGANISATION] sounds really interesting, and relevant to our research.

[IF FOLLOW UP NEEDED] Please can I clarify whether...

[IF NOT ANSWERED QUESTIONS] I'd like to ask a few brief questions about yourself before we begin.

1. Could you please tell me a bit about yourself?
  - a. Where do you work?
    - i. What is the purpose of this organisation?
    - ii. How does this interact with the home decarbonisation sector?
  - b. What is your role?
  - c. How long have you worked in this industry?

## **Hard to Treat and Hard to Decarbonise Definition**

[Priority]

2. How would you define or describe a hard to treat or hard to decarbonise home?

[Priority]

3. What characteristics do you think makes a home hard to treat or hard to decarbonise?

Prompts: Physical, Locational, Social

4. Aside from the categories we discussed are there any other characteristics you consider to make homes hard to treat and hard to decarbonise?
5. Why?

[Optional]

6. Do any of the characteristics you have already described stand out as more likely to mean a property is hard to treat or hard to decarbonise?

[Priority]

7. What type of homes do you consider to have the characteristics you have described above?

i.e., red-brick terrace, high rises etc.

[Priority]

The UK Climate Change Committee defines hard-to-decarbonise homes as: “Homes can be considered to be ‘hard to decarbonise’ if they are ‘hard to treat’ &/or do not have cost-effective options for low carbon heating”

8. What do you think of this definition?

[Optional]

9. How would you distinguish between hard to treat and hard to decarbonise homes?

[Priority]

10. Is there a definition that is universally used in your place of work or industry?

### **Your clients/service users**

[Priority]

11. Could you please describe the types of clients or service users that you work with?

Prompts

- Socio-economic factors
  - Tenure type
  - Owner-occupiers
  - Private landlords/tenants
  - Social landlords/tenants
- Locational
  - where do they live (rural, cities)
  - what types of properties do they tend to live in? (High rise etc)
- Household characteristics
  - On or off gas grid?

[Priority]

12. How do you engage with your service users?

i.e., face to face meetings, phone calls etc

[Priority]

13. Could you please describe your experience with hard to treat or hard to decarbonise homes?

[Priority]

14. How does living/working with hard to treat or hard to decarbonise homes affect these users day to day lives?
  - a. How do experiences differ across groups?
  - b. Any common challenges?
  - c. Any unique challenges?

## **Behaviours**

[Priority]

15. Have you observed any traits, beliefs or behaviours that affect a residents/clients or service user's experiences in these homes?

Prompts:

- Traits i.e. demographics such as socioeconomic status, age, etc
- Beliefs i.e. about new technology, sustainability, the council etc
- Behaviours such as drying clothes inside, cooking, ventilation

[Priority]

16. How do you try to mitigate the effects of living in these homes for these residents?

[Priority]

17. What barriers do you currently face to decarbonise these homes?

If dealing with tenants/landlords:

- What challenges do you face when working with social/private landlords?
- What challenges do you face when working with tenants?
- What measures do you think your users can install or afford on their own?

If dealing with owner occupier,

- Why are they not decarbonising their homes?
- What support do you feel that they need?
- What measures do you think your users can install or afford on their own?
- What do you see the role of government in this?

## **Solutions**

[Priority]



18. What approaches would you recommend to reduce the impact of hard to treat or hard to decarbonise homes on residents?

*If unsure, read list:*

- Loft insulation
- Full Boiler replacement with boiler
- Installation of heat pump (air or ground source)
- Boiler improvement
- Draught proofing
- External wall insulation
- Smart meters / smart devices
- Lifestyle changes
- Other measures: \_\_\_\_\_

19. Why?

20. Would you consider (the above that are not mentioned), if not, why not?

[Priority]

21. Are there any challenges that you currently face, or foresee facing, with offering these solutions to your service users/clients/residents?

If landlord users,

- How would you suggest that we engage with the private/social landlords of these properties to propose these solutions?
- What do you envisage might be the barriers to this?

If tenant users,

- How would you suggest that we engage with the private/social landlords of these properties to propose these solutions?
- What do you envisage might be the barriers to this?

If owner-occupier,

- How would you suggest that we engage with the private/social landlords of these properties to propose these solutions?
- What do you envisage might be the barriers to this?

[Optional]

22. How would you suggest that we engage with users - residents/owners/landlords - of hard to treat or hard to decarbonise properties to propose some of these solutions?

### **Case study**

As mentioned over email, we are also developing case studies of specific examples projects and approaches designed to tackle Hard to Treat Homes and Hard to Decarbonise homes or support their occupants. You said that you [DO/DON'T] have a case study that you'd like to share.

If no to case study:

23. Why not?

Prompts:

- a. Does nothing come to mind?
- b. Do you not have examples of such homes being treated?
- c. Did you require more time to put something together?

Before we end the interview, you have any other comments or reflections that you would like to share relating to hard to treat or hard to decarbonise homes?

Great. That is the end of my questions. Thank you again for agreeing to take part in this study. Your interview will be transcribed and the recording of the interview will be deleted. Your data will be stored anonymously. If you have any questions in the future, please don't hesitate to contact me.

If yes to case study:

Thanks for this offer, we really appreciate it. The case studies will form the next stage of our research. If suitable, we may contact you to ask for more information on the case study you mentioned

I have some initial questions about the case study:

24. Can you please give me a brief description of this project?
25. What were the characteristics of the property (or properties) you were working on and why were they hard-to-treat?
26. What approach did you choose to treat this home and why?

Before we end the interview, you have any other comments or reflections that you would like to share relating to hard to treat or hard to decarbonise homes?

Great. That is the end of my questions. Thank you again for agreeing to take part in this study. Your interview will be transcribed and the recording of the interview will be deleted. Your data

will be stored anonymously. If you have any questions in the future, please don't hesitate to contact me.

# Data survey

This section provides readers with the set of questions that were asked of stakeholders who take part in the data survey.

## Data survey questions

The data survey questions were:

1. What are the main building form and fabric attributes that may render a home to be HTT/HtD? Please add up to 3 responses
2. Please provide explanations for the above (optional)
3. What are the main attributes related to where the home is situated that may render it to be HTT/HtD? Please add up to 3 responses
4. Please provide explanations for the above (optional)
5. What are the characteristics, habits and behaviours that residents may have that may render a home to be HTT/HtD? Please add up to 3 responses
6. Please provide explanations for the above (optional)
7. Please add Project Name, Location, Organisation, Link (if possible)

## Mapping of evidence to research questions (RQs)

This section presents the full set of RQs and maps the evidence to these, to demonstrate areas of higher and lower evidence availability and quality. This section keeps the original HTT/HTD terminology used in the RQs, but it should be noted that the research subsequently developed the CTD terminology and the RQs are used in the main report in reference to CTD homes.

Findings have been developed through synthesis of the RER, interviews and case study research, focusing on areas of consensus. Where a finding is demonstrated more by one of these research methods, or with conflicting evidence between methods, this is noted. For example, interviews and case studies have provided more insights for certain research questions, especially in reference to social challenges and employed approaches, to help fill some identified evidence gaps from the RER.

Each of the research questions (RQs) is shown with a rating for the level of evidence availability and quality from the research methods – the RER and the interviews and case studies (fieldwork). These are structured by the three broad research question groups. The rating scale used is low (1), medium (2) and high (3). Further, the key findings presented in this report that are relevant to each research question are shown.

### RQ Group 1: Defining and identifying HTT/HTD homes

**Table 3 RQ Group 1**

Research Question	RER	Fieldwork	Report finding #
<b>RQ1 - How can HTT homes be defined?</b>	2	3	F1, F2, F3
RQ1a - What definitions/frameworks for HTT buildings are currently being used, and what are the merits and drawbacks of these?	2	3	F1
RQ1b - What is the range of different technical, physical and material attributes that make a home HTT, from a whole house retrofit perspective?	2	3	F1, F6
<b>RQ2 - How can we identify Hard-to-treat homes?</b>	2	2	F1, F4

<b>Research Question</b>	<b>RER</b>	<b>Fieldwork</b>	<b>Report finding #</b>
RQ2a - What datasets and/or variables can we use to identify HTT homes?	2	2	F4,
RQ2b - What analytical methods can we use to identify HTT homes?	3	2	F4
RQ2c - How does a change of building use affect the identification of HTT homes?	1	2	Not evidenced
<b>RQ3 - What are the current estimates for the number of HTT homes in the UK?</b>	2	1	Not evidenced
<b>RQ4 - What is the regional/spatial distribution of HTT homes?</b>	1	1	Framework report
<b>RQ5 - How do regulations (UK and international) on homes consider HTT/HTD homes?</b>	1	2	F7
RQ5a - What regulations apply to different HTT/HTD properties?	1	2	F7

## RQ Group 2: Understanding the challenges of retrofitting HTT/HTD homes

**Table 4 RQ Group 2**

<b>Research Question</b>	<b>RER</b>	<b>Fieldwork</b>	<b>Report finding #</b>
<b>RQ6 -What are the technical challenges associated with improving the energy performance and decarbonising HTT homes?</b>	3	3	F1, F5, F6
RQ6a – What are the risks to the fabric of the building with retrofitting energy efficiency measures and moving to low carbon heating in HTT homes?	2	2	F6

Research Question	RER	Fieldwork	Report finding #
RQ6b – What geographic/spatial factors need to be considered?	2	2	F4, F8 Framework report
<b>RQ7 - What are the regulatory considerations and challenges for retrofitting HTT homes?</b>	2	2	F7, F5, F6
RQ7a - What are the legal/regulatory/planning barriers?	3	3	F7
RQ7b - What regulations apply to different HTT properties?	2	1	Not evidenced
<b>RQ8 - What are the social challenges associated with improving the energy performance and decarbonising HTT homes?</b>	2	3	F8
RQ8a - What socio-economic factors should be considered?	2	2	F8, F13
RQ8b - What distributional demographic (spatial) aspects need to be considered?	2	1	F4
RQ8c - What occupier and/or owner behaviours and lifecycle considerations should be considered?	1	2	F8, F13

## RQ Group 3: Evidence of existing approaches to retrofitting HTT/HTD homes

The case studies could also be specifically tagged to these RQs for evidence on existing approaches. All the case studies are relevant to several of the RQs here as well as to those concerning identification (RQ group 1) and challenges (RQ2 group 2). Annex C sets out the case studies and their findings in detail.

**Table 5 RQ Group 3**

Research Question	RER	Fieldwork	Report finding #
<b>RQ9 - What practical approaches could be applied/adapted to retrofitting HTT homes?</b>	2	2	F9, F11, F12, F13, Case Studies
RQ9a - What practical approaches could be applied/adapted to retrofitting HTT buildings? Including in commercial & public buildings, UK and international	1	1	Not evidenced
RQ9b - For HTT homes that are unsuitable for conventional insulation, what are the options to decarbonise and improve their energy efficiency?	2	2	F11, Case Studies
RQ9c - When, in the lifecycle of a building, should retrofit interventions be implemented?	2	2	Not evidence
RQ9d - How effectively do the risk pathways under PAS 2035 consider HTT homes? Risk pathway C	1	3	F10
RQ9e - How can this translate into consumer advice for owners and occupiers?	1	2	F15, F10 Framework uses
RQ9f - How can the risk of disruption be mitigated for occupiers?	1	2	F13, Case Studies
RQ9g: How might we engage residents/owners of HTT/HTT properties?	2	3	F8, F13, Case Studies
<b>RQ10 - What are the cost implications for the different approaches to retrofitting and installing low carbon heating, in different types of HTT homes?</b>	2	2	F3
<b>RQ11 - Does the evidence suggest that HTT homes should be considered</b>	2	2	Framework report



Research Question	RER	Fieldwork	Report finding #
<p><b>differently from other homes by policies on energy efficiency and heating (incentives, informational etc.) and regulations (minimum standards, bans of heating types, and their enforcement)?</b></p>			
<p><b>RQ12 - What are the implications for future retrofit schemes and regulations?</b></p>	2	2	Conclusions

# Evidence gaps and developing the evidence base

This section presents the resulting evidence gaps from the RQ evidence mapping and considers how the evidence base may be developed.

As demonstrated with the three RQ group tables above, across the RER and the interviews and case studies (qualitative research) there remain areas of less coverage, consistency and/or quality. These are those RQs that have a low-low or low-medium rating across the two research methods, which are:

- RQ2c - How does a change of building use affect the identification of HTT homes?
- RQ3 - What are the current estimates for the number of HTT homes in the UK?
- RQ4 - What is the regional/spatial distribution of HTT homes?
- RQ5 - How do regulations (UK and international) on homes consider HTT/HTD homes?
- RQ5a - What regulations apply to different HTT/HTD properties?
- RQ7b - What regulations apply to different HTT properties?
- RQ8b - What distributional demographic (spatial) aspects need to be considered?
- RQ8c - What occupier/owner behaviours and lifecycle elements should be considered?
- RQ9a - What practical approaches could be applied to retrofitting HTT buildings?
- RQ9e - How can this translate into consumer advice for owners and occupiers?
- RQ9f - How can the risk of disruption be mitigated for occupiers?

These RQs may require further research and development of the evidence base for CTD homes. The definition and identification framework developed in this research study can play an important role here, in identifying the data that could be used or is needed, alongside other emerging tools and monitoring approaches to increase evidence for approaches that are applied to CTD homes.

Other evidence inconsistencies identified through the synthesis for this report include which physical attributes that exist for CTD homes (presented in the main report and the framework report) are primary and fundamental attributes and form particular archetypes, and which are more secondary or 'aggravating' attributes. The development of a more comprehensive framework with research to inform attribute weighting and interactions can help increase its value across the use cases. There was a lack of understanding and certainty by many interviewees on the regulatory environment, and what was most pertinent and needed to be considered for different CTD homes, suggesting that there is a need to clarify this environment and signpost organisations to required policy and regulatory requirements.

The current literature and evidence are also lacking in both the coverage and incorporation of the social, socio-economic and behavioural elements for CTD homes in relation to other attributes and across the identification/assessment, design and planning, delivery and post-work project environments. However, there was a consistent acknowledgement of their importance by interviewees and exemplar approaches to incorporate and address these factors presented and with the case studies. This suggests more could be done to bring these into CTD identification – as the developed framework intends to do.

The interviews and case studies have identified that a wealth of experience and information is held by actors across the industry. The data survey (with its questions presented in this annex) unearthed information that may not be in the public domain or may not be being utilised or brought in to complement other datasets as well as it could. There is a need and opportunity in capturing best practice, examples and their data as well as clarifying the information that would be needed to fill these evidence gaps.

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