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Zero carbon non-domestic buildings

Phase 3 final report

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AECOM

July 2011
Department for Communities and Local Government

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1 An AECOM-led consortium, which comprises AECOM, Europe Economics and Davis Langdon, was commissioned by the Department for Communities and Local Government to undertake the following project: "New Non-Domestic Buildings (Phase 3): Further development of the evidence base on energy and carbon emission performance standards for new non-domestic buildings and the zero carbon ambition". This work was carried out between September 2010 and March 2011, and follows two previous phases of work undertaken by the same consortium of partners in 2008 and 2009.

Background – previous phases of work

2 Phase 1 of the work supported the development of an initial impact assessment for the Department for Communities and Local Government on its Zero Carbon non-domestic buildings policy.

3 In Phase 2, which also resulted in an impact assessment and consultation on the definition of zero carbon non domestic buildings published in November 2009, the consortium produced carbon abatement cost curves for the first time in connection with the definition of zero carbon non-domestic buildings on behalf of DCLG. Eleven building types were analysed ranging from city centre offices to country hotels. The building models were taken from those developed for Part L 2010 with some variations for location. For example the single hotel model in Part L 2010 was expanded into three hotel models (five-star city centre, three-star out of town and country) to allow for location specific variables such as wind speed. As a contract variation AECOM were commissioned to examine the impact of zero carbon policy on the public sector. Consequently six public sector buildings were also analysed but were not incorporated into the cost benefit analysis or subsequent impact assessment. The models for these were generally developed in partnership with Government departments such as the Prisons Service.

4 Phase 2 assumed a best practice level of energy efficiency before the application of low and zero carbon technologies. Consequently some expensive demand-side measures were introduced before more cost-effective low and zero carbon technologies.

Phase 3 – latest work

5 Since the Phase 2 work was completed Part L 2010 has been brought into legislation and the associated latest iteration of the Simplified Building Energy model (SBEM) (4.1) has been published. During this time DCLG also completed the public consultation begun in 2009. Phase 3, which began in September 2010, sought to further develop the evidence base for zero carbon build standards, take into consideration the responses to the consultation and address some of the limitations of the Phase 2 work: Namely:

- A review of the scope of an energy efficiency standard, analysis of what form the standard should take and quantification of the energy efficiency values.
- Re-calculation of achievable carbon compliance target levels given the fairly substantial changes to SBEM since the 2006 Part L and feedback from the public consultation.
- Incorporation of the public sector buildings into the economic (cost benefit) analysis.

Energy efficiency metric

6 Section 2 of this report deals with the initial two energy efficiency questions:

- The scope of the metric, i.e. should the energy performance standard only relate to the performance of the building fabric, or should the standard include the impact of services too?
- The specification of the standard, i.e. should it prescribe minimum performance standards for each element included in the standard, or should it be an overall performance target? If the latter, should the performance measure be an absolute value in kWh/m2.annum (as recommended for dwellings), or relative to some defined benchmark?

7 **Scope of the energy efficiency standard**: AECOM recommends that the energy efficiency standard should be based on an appropriate envelope specification, with a separate set of minimum efficiencies for the main services equipment. This integrates with the design process as fabric measures are the principal domain of the architect whereas the services measures are the principal domain of the services engineers.

8 In contrast to the domestic fabric energy efficiency standard, the envelope standard should focus on achieving an appropriate balance between reducing space heating, space cooling and electric lighting demand. This is because of the significant energy consumed from the use of electric lighting in many non-domestic buildings and the role of delivering better day-lighting through improved fabric design to reduce this energy consumption.

9 The energy demand should be met efficiently through high efficiency equipment that is effectively controlled. This is being addressed through the implementation of the Energy Related Products Directive which will set minimum European-wide building service efficiencies. It is understood that the efficiencies for many (if not all) building services will need to be transposed into national law by 2019. DCLG may wish to improve upon these efficiency values in Part L 2019. Furthermore, prior to transposition, it is proposed that DCLG continues to adopt minimum elemental performance standards as currently used in Part L.

10 **Specification of the fabric energy efficiency standard**: On balance, it is recommended that a set of minimum fabric elemental standards offers the best overall approach to standard setting. This is a continuation of the traditional approach in Part L. Furthermore, it constrains the performance of the fabric in practical design terms that can be readily understood by all members of the industry.

11 It is noted that this differs somewhat from the approach for dwellings which is adopting two target levels for overall fabric performance – the fabric energy efficiency standard

approach. Fundamentally, there is synergy between the two approaches in that the fabric energy efficiency standard levels are based on assumptions as to what are reasonable achievable elemental standards in different dwelling types. However, the fabric energy efficiency standard approach presents this information as an overall performance target (i.e. in $kWh/yr/m^2$) rather than its minimum component efficiencies. It is likely to be more difficult to develop a performance-based approach for non-domestic buildings, as it would be difficult to determine a small set of target levels given the wide variation of building types and end uses. Furthermore, it would be difficult to apply this approach given the multiple non-domestic compliance tools which typically predict similar but different energy performance for the same building model.

12 A potential benefit of the fabric energy efficiency standard approach is that is does allow credit to be obtained from designing a more efficient built form. As part of a contract variation, further consideration was given to the need to incentivise built form and, if so, how to apply it.

Cost benefit analysis

13 In order to develop the energy efficiency and carbon compliance target values, it was necessary first to undertake cost benefit analysis. This comprised two stages:

- Stage 1: Cost curves were produced for each building type. These cost curves prioritised the order of the fabric, services and low and zero carbon technology options by the cost of saving carbon emissions (maximum $kg.CO_2$ saving/ £). These curves were compiled using capital cost data from published sources and industry based estimates. Additional cost curves for information only were produced based on life-cycle costs, and were not used for Stage 2. This work is discussed in Sections 3 and 4.
- Stage 2: The information in the cost curves was used as inputs to a cost benefit model (i.e. the capital costs of achieving these reductions, the energy saved and the associated CO_2 reductions). Carbon emission standards were determined for the different buildings types such that the imposed cost increase (over cost) is the same across all building types. Three trajectories were considered (low, medium, high), representing increasing requirements for on-site carbon mitigation on the approach to zero carbon in 2019.

14 Further work would need to be done when proposing and consulting on final regulatory changes to optimise the cost effectiveness of the policy and consider the implications of policy costs as a proportion of build costs for different building types. The method adopted here was considered proportionate for this stage of development work.

15 Three key outputs from Stage 2 were as follows:

- Proposals for carbon compliance for the trajectory to zero carbon (i.e. carbon emissions standards for 2013, 2016 and 2019).
- The cost and benefits associated with each trajectory.
- The volume of carbon saved for each trajectory.

Carbon compliance target levels

16 As noted above, carbon compliance target values were proposed for Part L 2019 for a range of building types, as well as providing an indication of carbon emission standards for Part L 2013 and Part L 2016. The percentage carbon savings vary between building types based on achieving a similar cost of compliance i.e. for each £1 spent on carbon mitigation there are a range of carbon savings across different buildings.

17 Section 5 also outlines where further refinements will be necessary to the process for setting Part L 2019 compliance targets:

- More detailed analysis of significant sector specific energy uses e.g. assessing improved efficiency display lighting which may be a major benefit in sectors such as retail and the supermarket where current analysis suggests cost-effective improvements are harder to achieve.
- Sensitivity analysis should be undertaken to understand the influence of different choices of building models for each non-domestic sector on the results.
- The inclusion of any new regulated energy demands if they are introduced into Part L compliance calculations e.g. vertical transport, external lighting and air curtains.
- Updating targets in line with changes to the National Calculation Methodology, including the carbon emission factors.
- Updating targets in line with changes in element performance and cost. This work has predicted future levels of energy and carbon performance and the costs for achieving this. This needs to be refined based on actual trends.
- The building targets will need to be specified in a simpler form that can be applied in a useable manner across all types of buildings.

18 Furthermore, it is expected that the underpinning cost benefit analysis will need to be refined. Whilst the current analysis was appropriate for this stage of development work, more detailed analysis is expected prior to making regulatory change to more accurately represent the cost to business.

Minimum elemental energy efficiency values

19 To determine the elemental energy efficiency minima, the cost curves produced in Stage 1 of the cost benefit analysis were reviewed:

- For each building type, the Part L 2019 carbon compliance level (using the medium scenario) was plotted on each capital and lifecycle cost curve.
- Then the optimised energy efficiency measures that fell within the carbon compliance target were listed. This was undertaken separately for the capital and lifecycle cost curves to identify any significant differences.
- This was then used to define the minimum energy efficiency standards for the different fabric and services elements.

20 It is important to note that the standards proposed are for Part L 2019 (because they assume cost reductions brought about by experience of new technologies gained between now and 2019) and not necessarily those that will be recommended for Part L 2013 or Part L 2016.

21 **Fabric:** Overall, the analysis suggests that the maximum fabric U-values should remain as currently implemented in Part L 2010. There appears little, if any, benefit in increasing the minimum standards further. Further consideration is necessary as to the minimum standards for air permeability and thermal bridging. There is currently a lack of robust cost data on achieving different standards of performance and it would be helpful to engage further with stakeholders on this.

22 **Services:** Overall, the analysis suggests that improvements to the efficiencies of building services provide a cost-effective means of moving further towards zero carbon. In practice, the minimum energy efficiency values will be significantly influenced by the Energy Related Products Directive. In the absence of the new European approach to setting energy performance standards, Section 6 presents suggested elemental minimum performance criteria in a similar format, though generally higher values, to those currently adopted in the Non-Domestic Building Services Compliance Guide that supports Part L 2010.

The impact of built form

23 As a contract variation, a further piece of work was commissioned to look further into the impact of built form on energy and carbon performance. This is presented in Section 7.

24 There are a number of advantages in continuing with the Part L 2010 approach to set energy efficiency standards in elemental terms and set carbon targets buildings in ‘relative’ terms, expressed as percentage improvements on a notional building of the same size and shape. However, a potential downside of this approach is that it does not incentivise more energy or carbon efficient built forms.

Does built-form have a significant impact on CO_2 emissions?

25 Modelling was undertaken using both SBEM and a Dynamic Simulation Model (DSM) to investigate the impact of shape, size and orientation on the energy and carbon performance of three building types (an office, a warehouse and a hotel). The results showed that, in many cases, the impact of built form had a tendency to increase certain aspects of energy use and reduce others. This demonstrates the play-off between daylight, heat losses and heat gains.

26 In some cases, changes in built-form can have a large impact on carbon emissions although this depends on the building type and the services strategy employed. In general, the modelling found that lower glazing percentages and larger floor to façade ratios resulted in greatest reductions in emissions at least where an air-conditioning services strategy is maintained (savings of order of 15-20 per cent). Larger carbon reductions appear possible (up to 30 per cent reduction) from changes to built-form which result in the ability to implement a lower carbon servicing strategy such as natural ventilation or mixed mode. Further work would be necessary to introduce built-form into an energy or carbon standard e.g. the impact of optimisation of the façade (external shading, U-value, etc) to better control solar gain and conduction losses.

Should built-form be incentivised?

27 Zero Carbon policy already incentivises built-form since the requirement is for zero regulated emissions. A more efficient built-form will reduce carbon emissions and help achieve this target. However, calculations suggest that it is unlikely to be a sufficient incentive.

28 It is likely that the optimum shape for a building will depend on its use, and in particular, on the level of internal gains. It is likely to be difficult to incentivise different buildings types. This is particularly the case in the context of mixed-use buildings and if there are changes of use, neither of which are uncommon situations.

29 It is also important to note that other influences also help to shape built-form. Key influences include commercial viability (maximising the usable area of the building within the constraints of the site boundary) and functional use (in some building types, requirements for the relative organisation of internal spaces strongly influence built form). A key concern would be that by driving energy efficient built-form, there could be a negative impact on these other requirements of the building.

30 Furthermore, it should be noted that changing shape will influence more than just energy efficiency. It is likely that changing the shape will alter the net to gross area of the building. Thus although the energy per unit total floor area might be improved through adopting the more energy efficient shape, the number of occupants in the building may reduce, such that the energy used per occupant increases. In that context, a very important question is which is the more efficient building?

How might built-form be incentivised?

31 The report presents proposals for how built-form may be incentivised. These include regulatory and non-regulatory means.

32 It might be appropriate to give good design guidance on the percentage floor area of a building that should be well daylit to minimise the amount of electric lighting. Such guidance should not only suggest minimum areas, but also how those areas might be achieved. Daylit areas can be created in buildings with deep floor plates through internal atria, lightwells etc.

33 An alternative is to introduce a regulation. The results of this study suggest a simple daylight performance standard within building regulations would not necessarily lead to CO_2 emissions savings. The simple modelling undertaken here showed that benefits from greater daylighting were outweighed by increases in conduction losses and the need to treat solar gains. The results suggest that high performance electric lighting modelled here may, in some circumstances, be as efficient as daylighting once direct heat gains and losses are taken into consideration. However, this is clearly not always the case in practice particularly where the façade has been carefully optimised. Further work would be needed to develop a daylight performance standard (which may not be simple) to address the range of non-domestic building types and the complexity of the facades.

34 Other alternatives considered including using a “form factor adjustment” to modify the carbon compliance target. Again, it is suggested that the task of developing robust form factors for all sizes, shapes and uses of a building would be very difficult, especially in the context of mixed use developments.

35 Overall, the complex interaction of built-form elements on overall CO_2 emissions means that a built-form parameter in Building Regulations (e.g. daylight performance standard or

form factor) would be difficult to implement and may lead to perverse outcomes. Because of this, it is recommended that no specific incentive for built form be included in the target setting mechanism. It is clear from the analysis that optimisation of façade design is the area most likely to yield savings. Improved education of building designers on the impact of façade design on Part L compliance is recommended.

36 The largest carbon reductions from changes to built-form occurred in the modelling where the building form results in the ability to implement a lower carbon servicing strategy such as natural ventilation or mixed mode. The office shows a 30 per cent drop in emissions from the adoption of natural ventilation. At present the National Calculation Methodology does not incentivise this approach since the notional building has the same servicing strategy as the actual building. Furthermore, the Carbon Trust recommends that two thirds of new buildings need to be narrow plan and naturally ventilated by 2020[1] to achieve the 80 per cent target cut in carbon emissions by 2050.

37 At present the energy performance certificate methodology already incentivises a lower carbon servicing strategy in that the reference building (the energy performance certificate equivalent of the notional building) is mixed mode. One approach may be to adopt this strategy for Part L. Care would need to be taken, however, to ensure that buildings requiring cooling were given alternative routes to compliance.

The cost of achieving zero carbon

38 Three zero carbon scenarios were considered in the cost-benefit analysis - low, medium and high scenarios. These scenarios were chosen by DCLG after analysis of the initial results of the Phase 3 modelling and feedback from the 2009 consultation. These represented different trajectories to zero carbon, but were chosen for illustrative purposes, and should not be seen therefore as definitive Government policy on 2019 zero carbon targets:

- The low scenario assumed carbon compliance of 44 per cent compared to Part L 2006, with additional carbon emissions addressed by allowable solutions.
- The medium scenario assumed carbon compliance of 49 per cent compared to Part L 2006, with additional carbon emissions addressed by allowable solutions.
- The high scenario assumed carbon compliance of 54 per cent compared to Part L 2006, with additional carbon emissions addressed by allowable solutions.

39 A change from the Phase 2 analysis was the full inclusion of public sector buildings into the economic analysis. This did not result in significant changes in the overall cost benefit analysis as the area of new public sector floorspace built each year is quite low compared to that of commercial floorspace.

40 All three scenarios yield a net benefit when the social value of carbon savings is taken into account. The low scenario results in a net benefit of about £2.2bn (over a 10 year policy period), the medium scenario results in a net benefit of about £1.7bn, while the high scenario yields a net benefit of £1.2bn. However, when looking at the net financial cost, i.e. before carbon savings are taken into account, all three scenarios result in a net cost.

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[1] *Building the Future Today*, Carbon Trust 2009.

1 Introduction

41 An AECOM-led consortium, which comprises AECOM, Europe Economics and Davis Langdon, has been commissioned by the Department of Communities and Local Government to undertake the following project: “New Non-Domestic Buildings (Phase 3): Further development of the evidence base on energy and carbon emission performance standards for new non-domestic buildings and the zero carbon ambition”. This work was carried out between September 2010 and March 2011, and follows two previous phases of work undertaken by the same consortium of partners in 2008 and 2009.

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42 Phase 1 of the work supported the development of an initial Impact Assessment for the Department for Communities and Local Government on its zero carbon non-domestic buildings policy.

43 In Phase 2, which also resulted in an impact assessment and consultation on the definition of zero carbon non domestic buildings published in November 2009, the consortium produced carbon abatement cost curves for the first time in connection with the definition of zero carbon non-domestic buildings on behalf of DCLG. Eleven building types were analysed ranging from city centre offices to country hotels. As a contract variation AECOM were commissioned to examine the impact of zero carbon policy on the public sector. Consequently six public sector buildings were also analysed but were not incorporated into the cost benefit analysis or subsequent impact assessment.

44 Phase 2 assumed a best practice level of energy efficiency before the application of low and zero carbon technologies. Consequently some expensive demand-side measures were employed before low and zero carbon technologies.

Phase 3 – latest work

45 Since the Phase 2 work was completed Part L 2010 has been brought into legislation and the associated latest iteration of SBEM (v4.1) has been published. During this time DCLG also completed the public consultation begun in 2009. Phase 3, which began in September 2010, sought to further develop the evidence base for zero carbon build standards, take into consideration the responses to the consultation and address some of the limitations of the phase 2 work: Namely:

- A review of the scope of an energy efficiency standard, analysis of what form the standard should take and quantification of the energy efficiency values.
- Re-calculation of achievable carbon compliance target levels given the fairly substantial changes to SBEM since the 2006 Part L and feedback from the public consultation.

- Incorporation of the public sector buildings into the economic (cost benefit) analysis.

46 Section 2 of this report addresses the initial two energy efficiency questions:

- The scope of the metric, i.e. should the energy performance standard only relate to the performance of the building fabric, or should the standard include the impact of services too?
- The specification of the standard, i.e. should it prescribe minimum performance standards for each element included in the standard, or should it be an overall performance target? If the latter, should the performance measure be an absolute value in kWh/m^2 annum (as recommended for dwellings), or relative to some defined benchmark?

47 Sections 3 to 6 propose energy and carbon standards based on detailed cost benefit analysis:

- Carbon compliance target values for Part L 2019 for a range of building types, as well as providing an indication of carbon emission standards for Part L 2013 and Part L 2016.
- Minimum elemental energy efficiency values for both fabric and services.

48 Section 7 presents a further piece of work commissioned as a contract variation to look further into the impact of built form on energy and carbon performance:

- How built-form influences energy demand and carbon emissions.
- Whether built-form should be incentivised.
- Regulatory and non-regulatory means to incentivise built-form.

49 Section 8 presents the results of the cost benefit analysis carried out for this work:

- Proposed carbon standards for Part L 2013, 2016 and 2019 for three different trajectories (Section 5 focuses on the central trajectory).
- The cost and benefits associated with each trajectory.
- The volume of carbon saved for each trajectory.

2 A discussion on energy efficiency

Introduction

50 This section is intended as a discussion of the issues surrounding the specification of an energy efficiency standard for non-domestic buildings as part of the zero carbon hierarchy. Subsequent sections present the methodology for calculating the energy efficiency standard, as well as proposals for the standard itself.

51 In particular, this section reviews the following key issues:

- The scope of the metric, i.e. should the energy performance standard only relate to the performance of the building fabric, or should the standard include the impact of services too?
- The specification of the standard, i.e. should it prescribe minimum performance standards for each element included in the standard, or should it be performance based? If the latter, should the performance measure be an absolute value in kWh/m^2.annum, or relative to some defined benchmark?

52 In reviewing the options, it is important to bear in mind the arguments for setting an energy efficiency standard as detailed in the 2009 DCLG consultation on zero carbon standards for new non-domestic buildings. For convenience, these arguments are reproduced below:

a) *The reasons for setting a high level of energy efficiency for non-domestic buildings are exactly the same as those for homes:*

  i) *Whole life cost: in general, energy efficiency measures will often entail lower life-cycle costs than low and zero carbon technologies (fuel, maintenance, replacement). Because those cost differentials may not be fully reflected in the market price of the building, the developer might, in the absence of a minimum energy standard, choose a carbon compliance strategy which does not minimise whole life costs.*

  ii) *Robustness: energy efficiency measures are less dependent than low and zero carbon technologies upon the behaviour of occupants in order to realise carbon savings. For example, occupants cannot easily 'turn off' the insulation in an exterior wall, and will not need to service or replace that insulation in order to maintain its effectiveness. That is not equally true of low and zero carbon technologies.*

  iii) *Future-proofing: buildings are long-lived assets (although non-domestic buildings tend to be renovated more frequently than homes), and the cost of retrofitting is high. It may therefore be appropriate to seek an energy efficiency standard which we will not regret at a later date, once the implications of long term carbon reductions and energy security are better understood. At the same time, future-proofing also means building to a standard which we will not regret in terms of climate change adaptation (in particular overheating).*

  iv) *Energy security: in general, reducing energy demand by a given amount should be more conducive to our energy security goals than meeting that energy demand with* *on-site low and zero carbon technologies. Low and zero carbon technologies may be intermittent (not generating energy when it is most needed, e.g. solar photovoltaics) or require scarce resources (e.g. biomass). Hence demand reduction provides greater energy security than providing equivalent on-site energy.*

b) *It is also important that energy efficiency standards follow the current principles of the Building Regulations: that they are functional, non-prescriptive requirements which are technologically neutral and do not stifle innovation.*

53 In reviewing the arguments, it is important to recognise that any energy efficiency standard is part of an integrated performance pyramid. Therefore, its purpose is to support the higher levels of the hierarchy, i.e. carbon compliance and zero carbon standards. In reviewing this hierarchy, it is useful to note the steps in the overall process of achieving a carbon emissions standard:

- Reducing the service demand for (e.g.) heating, cooling, and electric lighting.
- Meeting the required demand efficiently through high efficiency equipment that is effectively controlled.
- Servicing that equipment with low carbon energy supplies.
- Generating further renewable energy to offset remaining emissions.

54 It is clear that items c) and d) can only relate to the higher levels in the zero carbon hierarchy. Therefore the first key question is where the boundary of the energy efficiency standard should be drawn – just at the level of service demand, or whether equipment efficiency should also be included. Once that fundamental issue has been determined, the way of expressing that standard then has to be decided. These issues are discussed in the following sections.

The scope of the energy efficiency standard

55 To set the debate about the scope into context, we begin by looking at the issues raised in paragraph 52a), to identify how the choice of scope might impact on the achievement of the four different objectives:

- **Whole life cost**: the purpose of the energy efficiency standard is to ensure that carbon compliance is not achieved through superficially attractive low and zero carbon measures, since these are rarely as cost effective over the building life as energy efficiency measures. Without an energy efficiency standard, the financial incentives offered by feed-in tariffs and the renewable heat incentive might further encourage the inappropriate application of low and zero carbon technology. It is clear that many parts of the construction industry place emphasis on reducing first costs, because in many situations, the developer/owner of the building has no direct responsibility for operating costs. This first-cost mentality applies equally to fabric and equipment/systems, and so if the purpose is to drive solutions towards better life-cycle performance, it suggests that the scope of the standard should address both fabric and services. It is also relevant to note that in many non-domestic building types, we are well into the area of diminishing returns as far as improving U-values are concerned, and so driving better system efficiencies may deliver the best improvement in life cycle performance.
- **Robustness:** there is a perception that energy efficient fabric is more robust than systems and equipment, because fabric is less vulnerable to the vagaries of user

behaviour. The argument then follows that the energy efficiency standard should prioritise fabric above services. Whilst it is true that the efficiency of fabric measures is less dependent on user behaviour than the efficiency of building services equipment, there is another dimension that needs to be borne in mind. The effectiveness of fabric insulation is very dependent on the build quality; small defects can result in substantial degradations in performance, and such defects are difficult if not impossible to fix in a completed building. This means that the robustness issue needs to address build quality just as much as driving improved fabric standards. In a similar way, services improvements have to address proper commissioning and maintenance as well as better theoretical standards. Although system performance may suffer more from user abuse, it is much easier to rectify inefficient operation through re-commissioning. Indeed the equipment can be replaced with higher efficiency equivalents as technology advances, and this can have a positive impact on life cycle performance. The robustness criterion therefore suggests that both fabric and services issues need to be addressed, but as well as well as driving better theoretical standards for both fabric and systems, development of the energy efficiency standard should also pay attention to:

i) giving greater emphasis to designing with user needs in mind;
ii) installation quality;
iii) effective commissioning;
iv) appropriate user training; and
v) given the scale and speed of change required, real robustness is likely to require effective monitoring and feedback mechanisms too.

- **Future proofing**: the argument about long life assets is particularly true of the building fabric, since most building services equipment will be replaced on a much shorter time horizon than the fabric itself. As technology improves, each services replacement is likely to deliver improved efficiency. This results in an interesting dilemma in terms of an investment strategy to minimise whole life costs – is the available capital best invested all up front, or spread more evenly over the building life? If the energy efficiency standard forces too high a standard (and too great a cost) on day one, then the investment may not be available ten years down the road, when advancing technology may be able to deliver a much better return than could have been achieved by an initial over-specification. This highlights the importance of appropriate energy efficiency standards for renovation/refurbishment work. It also suggests that it is important to achieve an appropriate balance in the initial specification of the fabric and services. This can best be achieved by addressing both fabric and services in the energy efficiency standard.

  Turning to the adaptation issue, the most relevant impact is likely to be in respect of overheating. In most buildings, the tendency to overheat is driven more by internal and solar gains rather than U-values, and so an energy efficiency standard is likely to have little impact in this area. The main building design aspect of significance is control of solar gain, and the solar gain limit introduced in Part L 2010 should help address this issue. However, this limit may need to be further tightened to unsure comfort can be maintained in a changing climate without the need for air conditioning. Any tightening of the solar gain criteria will need to be considered carefully in relation to the potential impact on lighting. Reducing window areas or g-values to further reduce solar gain could reduce levels of daylight, and therefore increase the demand for electric lighting.

- **Energy security:** energy security is really about reducing the demand for fuels (including electricity). In terms of preserving our energy supplies, it does not matter whether a demand for 100kWh of cooling is met by a chiller with a coefficient of performance of 6.0, or the demand is reduced to 50kWh but met with a chiller with a CoP of 3.0. Since energy demand is a function of both reducing demand and meeting that demand efficiently, this criterion suggests that both fabric and services should be included in the energy efficiency standard. Achieving an appropriate level of energy security will adopt an approach that can be achieved in a robust way at the lowest life cycle cost. Whether this is demand reduction-led, or high-efficiency led is likely to vary with building type and also with time, as the relative costs of different technologies changes. This highlights the fact that the energy efficiency standard may need constant review, since the cost benefit of performance shifts will vary across technology sectors – what may be the preferred strategy today may not be in 5-10 years time.

56 Other issues that should be considered are:

- The interaction between the energy efficiency and carbon compliance standards: it is important that the two standards work together rather than conflict. In essence, our vision of the role of the energy efficiency standard is that it should constrain the ways in which the carbon compliance can be achieved, but not to be so constraining as to dictate solutions. The carbon compliance standard can be achieved through a combination of load reduction, improved equipment efficiency and low carbon fuel selection. Until the overall framework is decided, it is impossible to predict how the two standards will interact, but it is thought likely that the likelihood of adverse interaction will be reduced the simpler the form of the energy efficiency standard.
- Integration with the design process: an important consideration will be to structure the targets such that they find a natural place in the design process, since this will minimise implementation costs. In that context, one approach might be to separate the energy efficiency standard to envelope and services performance, since fabric measures are the principal domain of the architect and services measures are the principal domain of the building services engineer. A disadvantage of this approach is that it might maintain the “silo mentality”, whereas advanced energy efficiency standards demand a truly integrated design approach, a philosophy that should be stimulated by the increasing interest in Building Information Modelling. An alternative approach would be to continue with the current approach of limits on design flexibility, with separate minimum performance standards for each main building element. This has the advantage of enabling a clear separation of fabric and services issues, whilst providing an easily understood basis of communication within the design team.
- Awareness of building complexity: it is important to recognise that in the non-domestic sector, buildings range from the domestic scale to the very large, from simple heated-only buildings to ones with very complex and sophisticated servicing needs. This suggests that the approach to setting an energy efficiency standard should either be:
    i) simple, so as not to disadvantage the builders of small, simply serviced buildings; or
    ii) graduated in complexity, with the more complex methods being used for the more complex buildings. There is no merit in complexity for complexity’s sake, so this route is only worth following if a more detailed approach offers real benefits against one or more of the four criteria listed in paragraph 6.

57 Based on the above generalised discussion, we recommend that the energy efficiency standard should be based on the architect achieving an appropriate envelope specification, with a separate set of minimum efficiencies for the main services equipment. In deciding the boundaries between these two categories, the key debate relates to lighting – the envelope design is critical in delivering good levels of daylight, whilst the specification of the lighting systems determines the efficiency and controllability of electric lighting provision. In the non domestic scenario, it is felt important that an envelope energy efficiency standard should address more than just heating and cooling. This is because daylighting is such an important issue in modern buildings. In the building types investigated by AECOM, the energy demand for lighting ranges between 13 per cent and 65 per cent of the total energy demand. Because of the carbon impact of electricity use, the relative importance in terms of CO_2 emissions is much greater. Because of the importance of lighting, it is felt that a standard similar to that adopted for dwellings would be inappropriate for non-domestic; lighting amounts to about 50 per cent of the energy demand even in a simple heated only office building, and so cannot therefore be ignored. Therefore it is recommended that daylight should be included in the envelope energy efficiency standard so that this best established of all the low and zero carbon technologies is utilised appropriately. However, electric lighting efficiency should also be addressed under the systems category to ensure that when required, the electric lighting is both efficient and well controlled to the available natural light.

58 The importance of lighting is emphasised by the curves that underpin the LT[2] optimisation tool, an example of which is shown in Figure 1. It shows the energy demand for heating, cooling and lighting as a function of window area. The three separate curves shown for cooling relate to different degrees of window shading (1.0 represents no shading, 0.35 is good shading). In this passively designed south facing zone, heating demand remains relatively constant with increased window area (increased beneficial solar gains balance increased conduction losses). However, cooling increases substantially, whereas lighting demand reduces, giving an optimum glazing ratio of around 35 per cent in this particular case (although this optimum will vary with orientation, climate, U-values and internal gains). What is of particular note is how the total energy demand increases substantially either side of the optimum value. This emphasises that a metric that ignores one of these three interacting energy flows is likely to lead to inappropriate design solutions. The LT curves highlight one of the problems associated with developing an energy efficiency standard. There are so many interacting variables that it is difficult to develop a robust optimal standard.

[2] "LT" stands for "Lighting and Thermal", and was a popular passive design tool.

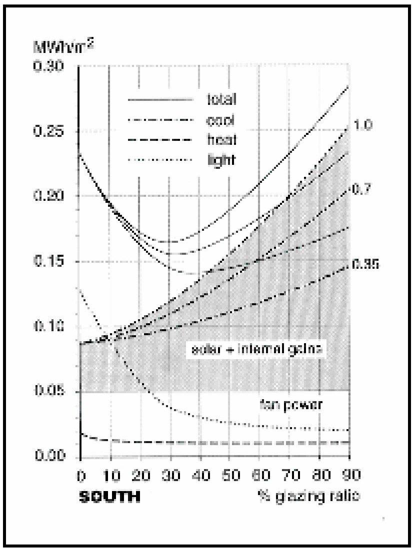

Figure 1: Energy demand for heating, cooling and lighting as a function of window area

59 The appropriateness of this three-term scope for the fabric energy efficiency standard can then be tested by posing the question about whether the carbon compliance standard then adequately addresses all other energy concerns. In principle it does not, because the proposed limited scope of the fabric energy efficiency standard would allow the specification of low efficiency equipment serviced by renewable fuels. In practice, this may not be a problem, because of the impact of the Energy Related Products Directive[3], which will define minimum acceptable efficiencies for building services systems across Europe and will be required to be transposed into national law. It is recommended that the European mechanisms be used as the basis of achieving the desired levels of system efficiency. At the least any national energy efficiency standard will need to be based on the same performance assessment methods as adopted under the Directive (likely to be system rather than component based). A difficulty is that the assessment methods and minimum performance levels under the Directive are still to be finalised for many products and systems. It would therefore seem sensible, in the short term, to continue with the type of (component-based) services performance criteria currently used in Part L. As the European minimum efficiencies are finalised, the new assessment methods can be adopted and the minimum efficiency values reviewed. Clearly, the UK cannot set national standards that are poorer than the European minima, but if thought appropriate, the standards could be raised above these values. It is anticipated that, based on the current Directive timetable, most, if not all, non-domestic building services will be addressed by the Directive prior to implementation of Part L 2019 when zero carbon for new non-domestic buildings is due to be implemented.

60 If this approach is accepted, it means that the fabric part of the energy efficiency standard should focus on achieving an appropriate balance between heating, cooling and lighting demand. The next question is how that standard should be defined and measured.

[3] The Energy Using Products Directive (EuP) was replaced in 2009 with the Energy Related Products Directive, with an extended scope.

Measuring the energy efficiency standard

61 A key question is how to measure the energy efficiency metric that is used to define the standard. Should it be an absolute value in $kWh/m^2.yr$, or a relative value based on comparison with a reference building? In addition, how should any such calculated performance metric relate to the standards that are familiar to designers and builders, and which form the language of design communication (U-values, specific fan power etc)?

Absolute value

62 The first question when considering an absolute standard is how the energy flows should be normalised. It is usual practice to normalise by total floor area, but it is important to bear in mind that compared to dwellings, there is a much wider range of built form in the non-domestic sector. To illustrate the important impact this has on an absolute energy metric, Figure 2 compares the energy demands of a shallow and a deep plan office for the same elemental specification and pattern of use. It shows a substantial variation in energy demand per unit of total floor area. A large reason for these significant differences is that the envelope energy flows only impact on the perimeter zone of the building (typically within 6m of the facade). Therefore, if the energy efficiency metric is based on normalising the energy flows across the complete floor plate, the ease with which the standard could be achieved will depend on the depth of the building.

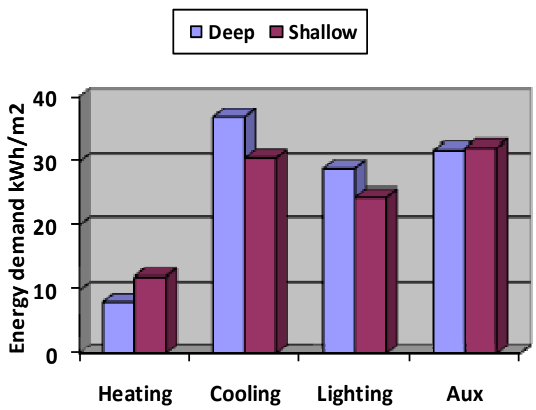

Figure 2: Energy demands of a shallow and a deep plan office

63 Basing the standard on total floor area might push the design towards narrower floor plates, which in buildings with high internal gains, may be the more efficient shape making it easier to achieve the standard. The main concern with such an argument is that experience suggests that energy efficiency is usually a weak driver of built form – how to deliver the required net floor area required for commercial viability within the boundaries of the site, and the organisation of the activities within the building are far more important. To that end, it is felt that an absolute kWh/total floor area would be inappropriate, since we do not want to optimise a secondary design issue if that were to compromise key commercial viability/usability criteria. This could be particularly important in the context of redeveloping inner city brown field sites, since wider environmental considerations would wish to encourage such development. It is thought that constraints on shape might

discourage investment in restricted urban sites and redirect it toward greenfield development, where there is much greater design freedom.

64 Another potential danger is that kWh/total floor area might encourage tall thin buildings as well as longer, narrower ones. In such a situation, a measure that only addresses heating, lighting and cooling would be misleading, since it would ignore the very significant impact of vertical transport on overall emissions in tall buildings.

65 One way of not discriminating against deep plan buildings would be to normalise the heating, cooling and lighting demands by the area of the perimeter zones. Such an approach of course has the additional logic that the facade design only impacts on the perimeter zones. Since the National Calculation Methodology requires the building to be subdivided into core and perimeter zones, the required calculation could easily be determined without any additional effort on the part of the assessor (although it would require some small tweaks to SBEM and other accredited tools)[4].

66 A problem with defining an absolute energy efficiency standard is that for the same elemental specification, the magnitude of the energy flows will depend on the use of the building, as illustrated by Figure 3. It can be argued that these variations can be accommodated by setting different standards for different building types, but it is suggested that such an approach is fraught with danger. Many developments are speculative; others are mixed use. Varying the energy efficiency standard by building type might encourage "compliance game playing", whereby the designers adjust the assumed building use until they achieve the answer they wish to achieve. This danger has been reduced by the approach adopted by Part L 2010 of linking the occupancy to the Planning Use Class, but there is still the danger associated with subdividing the building into areas of different activity.

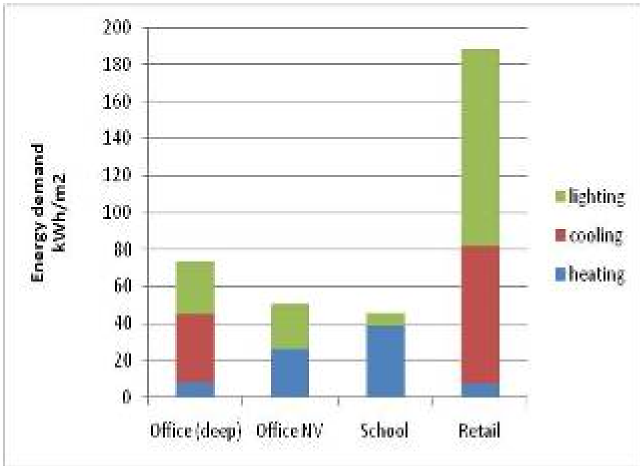

Figure 3: Energy uses in different building types

67 Another problem about an absolute standard is that the heating, cooling and lighting demands have to be aggregated to arrive at an overall energy demand (unless separate targets are set for each end use). The difficulty is that a kWh of heating is very different in terms of impact (in both financial and environmental terms) than a kWh of lighting or cooling. This could be addressed by converting all energies into primary energy terms

[4] See Section 7 which considers the impact of built form on zero carbon standard setting.

using standardised conversion factors, but such a metric then becomes very similar to the carbon compliance metric. This is because a primary energy target and the carbon compliance target are both calculated by summing the end-use energy demands after they have been multiplied by a conversion factor. In the case of the primary energy target, the conversion factor turns energy demand into primary energy. Under carbon compliance, the conversion factor turns energy demand into CO_2 emissions. Gas and electricity are the principal fuels used in non-domestic buildings, and the various factors for these fuels are summarised in the following table[5]. It can be seen that the ratio of the gas and electric conversion factors are very similar. Therefore setting a primary energy target would have almost the same effect as a carbon compliance target, and would constrain the design in a very similar way (this may be less true in the future as the grid decarbonises). This means that such an additional energy target delivers little additional benefit in terms of influencing the outcome of the design process, but adds design and regulatory burdens.

Table 1: Conversional factors for gas and electricity

Conversion factor	Gas	Electricity	Ratio
Primary energy (-)	1.02	2.92	2.86
CO_2 emissions ($kgCO_2/kWh$)	0.198	0.517	2.61

68 A final argument against an absolute standard is that it can only be contemplated in the context of a single calculation tool. Given the number of tools approved for use for compliance purposes in non-domestic buildings, it would seem impractical to have an absolute standard. The alternative would be to legislate that a particular calculation tool be used, but this would put up implementation costs, because designers might need to use multiple assessment tools for different aspects of design and compliance. Indeed, the standard might need to be redefined every time a tool was updated (or we would have to accept that the compliant solutions would have to be adapted). Further, currently Part L assesses the building against regional weather data. Adopting an absolute standard would either mean a different standard must be developed for each separate climate zone, or solutions that meet the standard would vary by region.

69 It is felt therefore that allowing the performance based alternative is inappropriate because:

- There is no robust way of aggregating the separate energy demands without applying primary energy factors. As explained in paragraph 67, such an approach would not deliver any significant benefit over and above the carbon compliance standard. It is suggested that the fact that there is an over-arching performance based standard at the level of carbon compliance legitimises a “looser-fit” elemental energy efficiency standard.
- It does not necessarily deliver a robust solution; the required aggregate performance might be achieved by specifying a very high level of performance in one element (e.g. vacuum windows), but very ordinary performance in other aspects. Then if that element fails to perform to expectations, or is later replaced by a standard component,

[5] The Government’s Standard Assessment Procedure for Energy Rating of Dwellings 2009 edition, Table 12

the required overall levels of performance are not achieved.

Relative value

70 The principal feature of a relative approach is that it bases the standard in the context of a building of the same size, shape and use as the actual building, and therefore eliminates the impacts of these variables on the calculated performance. In essence, it calculates the fabric energy efficiency standard by summing the energy flows through an envelope of the same size and shape as the actual building, and which has defined elemental standards. Stated in this way, it begs the question as to whether it would be just as easy to define the energy efficiency standard in terms of an elemental specification, since it is that, and that alone that determines the value of the relative standard.

71 A simple elemental approach has both advantages and disadvantages:

- The main advantage is that it constrains the performance of the envelope in practical design terms that can be readily understood by the designer. This is especially important for simpler buildings, where designer input is relatively small. A further benefit is that it can link directly to rating labels, which in turn can provide a stimulus for product innovation.
- It is a disadvantage in that an elemental specification might be seen as a prescriptive standard.

72 It is suggested that the advantage outweighs the disadvantage when set in the context of an intermediary design target. This is because setting the energy efficiency standard at a level relaxed back a bit from where design norms are expected to be would allow some flexibility in the trade-off between fabric and system measures. Thus the energy efficiency standard becomes a target to be significantly improved upon, rather than merely achieved.

73 On balance, it is therefore felt that a set of elemental standards offers the best overall approach, especially as it can then be related directly to the refurbishment standards, thereby setting a consistent approach to standard setting in both new and existing buildings. Whether different elemental standards need to be set for different building types will have to be decided once the detailed analysis is complete, but it will probably make sense to continue with a relaxed window U-value standard in buildings with high internal gains.

74 However, there is a problem associated with setting the energy performance standard in purely elemental terms. The specific set of parameters that define the standard may be less than optimum for a particular building type. For example, if the building performance is absolutely dominated by high internal gains, it may be appropriate to relax wall and window U-values to reduce cooling demand. To avoid this problem, three possibilities might be considered:

a) Setting the elemental standards at a level that will not overly compromise the extreme building type. This means that the standards would be based on the exception rather than the norm. This would be potentially misleading and would certainly lose the advantage listed in paragraph 71 above.

b) Define different elemental standards for different building types, although the problem described in paragraph 66 might also apply here. This approach also has a disadvantage in that the use of the building may well change with time, and if the fabric is optimised to a particular use, that solution may be very sub-optimal following a change of use.

c) Set the elemental standard at a level that would be acceptable in a wide range of simpler buildings, but allow the designer to demonstrate that relaxing the elemental standard reduces energy demand. Such an approach is allowed currently in respect of glazing U-values (see note 2 to Table 4 of Approved Document L2a (2010)). Glazing U-values is likely to be the main criterion where such an approach is valid, but even then there should be constraints on how much relaxation should be allowed. This is because if U-values are made worse than about $2.7 W/m^2K$, thermal comfort requirements will require perimeter heating to be provided, even if the space overall is calling for cooling.

75 Approach c) is recommended having the most appropriate balance between simplicity and rigorousness.

76 Bearing in mind the importance of daylight, it might be necessary to introduce an additional elemental standard that ensures appropriate daylight provision. The current approach that concentrates on electric lighting efficiency standards is inadequate, in that it fails to provide a driver for sensible daylight design. Specifying minimum light transmittances would also be inadequate – it is the combination of glazing area, light transmittance and window shape that is crucial. Similar arguments hold true in the context of solar gain in summer, so the daylight metric might best be integrated with the solar gain procedures. It has been suggested that the Lighting Energy Numeric Indicator (LENI) approach based on EN 15193, which measures the energy required to light a building (see paragraph 163 for more details), might be a suitable basis for this additional elemental standard.

Recommended approach

77 When considering where we might go with an energy performance standard, it is worth noting where we start from. Currently, Approved Document L2A (2010) constrains energy demand elementally through guidance on "no-worse-than" U-values, limits on solar gain and minimum plant efficiencies. The previous discussion has suggested that any alternative approach will not offer anything substantially better. Given industry's repeated requests for a consistent methodology, it would seem appropriate that the current approach of setting limits on design flexibility be maintained.

78 However, given the greater emphasis that government is likely to want to place on reducing energy demand as part of the overall zero carbon package, it is suggested that the limits on design flexibility become a regulatory requirement, rather than merely guidance.

79 The building services efficiencies must be at least as good as those proposed in the Energy Related Products Directive (see paragraph 59) and may have to follow the more systems-based methodology of the Directive. It should also be noted that in future, the Directive might also address fabric elements. In 2009 the Directive was extended to cover energy-related products (those which have a significant impact on energy consumption). Consequently eco-design requirements could in future be set on a wider range of products, including windows and construction materials, although these do not directly consume energy[6].

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[6] www.euractiv.com/en/energy-efficiency/eco-design-requirements-energy-using-products-eup-linksdossier-188172. The Commission is due to publish its second working plan, including proposals for standards on energy related

80 Irrespective of how extensively the Energy Related Products Directive standards are set, government and industry need to work together to determine the appropriate elemental standards that should provide the basis of the zero carbon energy efficiency standard. This work is necessary so that should the Directive's requirements not materialise, appropriate standards can still be set. If the Directive does propose setting standards for windows and opaque fabric, then the work can provide input to the UK negotiating position when agreeing the European standards.

81 A set of elemental minima addresses the four key criteria as follows:

- **Whole life cost**: it is much easier to develop (and review/revise) whole life cost minima on an elemental basis.
- **Robustness**: elemental performance standards relate to real world elements rather than design abstractions. As such, it is much easier to assess their dependence on user behaviour, and thereby prioritise those elements that are key to delivering consistent and reliable performance.
- **Future proofing**: as outlined under a) above, determining the standard is most easily done elementally. Because it is likely that the standard will need changing with time as the relative cost effectiveness of different technologies changes, the burden of this activity is likely to be reduced if an elemental approach is adopted.
- **Energy security**: adopting an elemental approach allows great flexibility in how and where government wants to influence energy efficiency. For example, it could start just with fabric elements, then be extended into services, and ultimately into appliances and even conversion efficiency of renewable energy systems.

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products, in 2011.

3 Carbon compliance methodology and assumptions

Introduction

82 In order to develop the energy efficiency and carbon compliance targets a multi-stage approach was undertaken:

a) AECOM carried out an analysis of the scope for reducing carbon emissions in a range of new buildings using fabric, building services and low and zero carbon measures. Cost curves for carbon reduction for each building type were compiled using capital and life cycle cost data from published sources and industry based estimates provided by Davis Langdon.

b) The costs of achieving these reductions, the energy saved and the associated CO_2 reductions were then used as inputs to the cost benefit model developed by Europe Economics. This provided, amongst other outputs, carbon compliance target values for each building type for 2019.

c) Elemental energy efficiency minima were then derived based on what measures could cost-effectively be delivered (using the cost curves in (a)) as part of achieving the carbon compliance target values.

83 The main assumptions and the methodology undertaken are set out in more detail below. The results of the analysis are provided in the following sections.

Key assumptions

Building types

84 Seventeen different building types were modelled using SBEM v.4.1.a (11 private sector and six public sector buildings). The building types were selected to cover a variety of sizes, uses and building locations. The building types are shown in Table 2. This is a wider range of building types than was analysed for the 2010 amendment to Part L and allows a more detailed analysis of how the scope for emissions reductions may vary between buildings, locations and uses.

85 In this case, the extensive parametric analyses (see paragraph 92) required the use of the SBEM engine for building energy modelling. It is noted that recent software improvements have sought to more closely align SBEM and DSM outputs. A direct comparison of the alternative software procedures has been made as part of the investigation into the effects of built form on building energy demand (see Section 7).

Building fabric and service options

86 The choice of fabric and service options considered in this analysis is shown in Table 3. They range from a basic level of performance (Part L 2006 backstop values with the exception of air-permeability which is set at 7.5 $m^3/m^2/hr$) to advanced. The most realistic construction solution was selected for each building type.

Low and zero carbon options

87 The low and zero carbon technology options considered in this analysis are set out in Table 4a. Examples from existing buildings have been drawn on where relevant to identify low and zero carbon options which are appropriate to individual building types.

88 Table 4b shows the use of wind and biomass by location. In particular, it was assumed that wind and biomass were not installed in urban locations.

Table 2: Building types

Building type	Location	Size (m^2 TFA)	Number of floors
Deep Plan Office (air conditioned)	Urban	30,000	10
Shallow Plan Office (air conditioned)	Suburban	4,500	3
Shallow Plan Office (heated)	Rural	1,600	2
High Street Retail	Urban	30,000	2
5 Star Hotel	Urban	15,200	12
Out-of-town Supermarket	Suburban	5,110	1
Primary School	Suburban	4,500	1
Warehouse	Suburban	4,900	1
Acute Hospital	Suburban	18,500	7
Cultural	Urban	2,100	1
Defence	Suburban	2,775	1
Prison	Rural	7,300	3
Secondary School	Urban	11,100	2
Retail Warehouse	Suburban	4,900	1
3 Star Hotel	Suburban	8,000	4
Country Hotel	Rural	2,550	3
Mini Supermarket	Urban	800	4 (under block of flats)

Table 3: Fabric and services options

Building element	Reference	Level A	Level B	Level C
Floor u-value ($W/m^2.K$)	0.25	0.20	0.15	0.10
Roof u-value ($W/m^2.K$)	0.25	0.20	0.15	0.10
Wall u-value ($W/m^2.K$)	0.35	0.25	0.20	0.15
Window u-value ($W/m^2.K$)[1] /g-value/light transmittance	2.0 / 0.7 / 0.8	1.6 / 0.4 / 0.67	1.3 / 0.4 / 0.67	0.8 / 0.6 / 0.74
Air permeability ($m^3/m^2.h$)	7.5	5	3	1
Lighting (lm/W)	55	65	75	
Lighting occupancy sensors	No	Yes		
Lighting daylight sensors	No	Yes		
Heating efficiency (%)	84%	86%	89%	91%
Heat recovery (%)	0%	40%	50%	70%
Cooling (SEER)	2.5	3.0	3.5	4.5
Air handling unit SFP (W/l/s)	2.2	2.0	1.8	
Terminal unit SFP (W/l/s)	0.8	0.6	0.5	0.3

[1] Chosen on the basis of U-value, moving from double to triple glazing

Table 4a: Low and zero carbon technology options for use on or near new non-domestic buildings

LZC	Assumed Efficiencies	Notes and assumptions	Reference
Gas fired combined heat and power (CHP)	Output (kW) Heat (%) Elec (%) 0-50 55 25 50-300 49 31 300-1000 45 35 1000-3000 43 37	Efficiencies vary depending on size	Averaged from supplier specifications, AECOM November 2010
Biomass combined heat and power (CHP)	Output Heat (%) Elec (%) 0-500kW 50 15 500-20000 63 17	Small scale assumes Organic Rankine Cycle, large scale assumes steam turbine. Assesses the economic advantages /disadvantages of allowing surplus heat in pursuance of a zero carbon standard.	The Potential and Costs of District Heating Networks, Poyry/Faber Maunsell report for DECC, April 2009
Gas-fired Trigeneration	CHP efficiencies as above Absorption chiller = 67%	Absorption chiller assumed to be low-temperature hot water fired,	The illustrated Guide to Renewable Technologies, BSRIA 2008
Biomass-fired Trigeneration	CHP efficiencies as above Absorption chiller = 67%	Absorption chiller assumed to be low-temperature hot water fired.	The illustrated Guide to Renewable Technologies, BSRIA 2008
Biomass heating	87%	Urban: Wood Pellet Edge of Town: Wood Pellet Rural: Wood Chip	The illustrated Guide to Renewable Technologies, BSRIA 2008
Solar Thermal	Evacuated Tube, system efficiency 70%	Limited to roof area – assume flat roof with panels tilted south. 1m^2 Solar Thermal to every 2m^2 roof area to allow for overshadowing and maintenance.	The illustrated Guide to Renewable Technologies, BSRIA 2008
Open loop Ground Source heating and cooling	Heating: 420% Cooling: 540%	Considered to be delivered via heat pump – no direct cooling 45°C heating flow 6°C cooling flow	Averaged from manufacturer's data
Closed loop ground source heating & cooling	Under 100kW: Heating: 350% Cooling: 420% Over 100kW: Heating: 370% Cooling: 520%	Considered to be delivered via heat pump – no direct cooling 45°C heating flow 6°C cooling flow	Averaged from manufacturer's data
Photovoltaics	15% Monocrystalline, equivalent to 850 kWh/kW(p), 7m^2 per kW(p)	Limited to roof area – assume flat roof with panels tilted south. 1m^2 PV to every 2m^2 roof area to allow for overshadowing and maintenance.	Capturing Solar Energy, CIBSE Knowledge Series, 2006
Wind Power		Not included in Urban Buildings or Urban Regeneration Development Scenario. Fixed average wind speeds assumed, resulting in a load factor that is further modified by a terrain factor.	50kW turbine chosen by default as the most economic – compared with smaller sizes - assuming suitable for building location.

Table 4b: LZC options by location

	Include Biomass?	Biomass Type?	Include Wind?
Urban	N	N/A	N
Suburban	Y	Pellet	Y
Rural	Y	Woodchip	Y

Costs

89 **Fabric and services measures**: The capital and maintenance cost of improving fabric and building services are set out in detail in Appendix A (Tables A.1 and A.2). These are based on values in the 2010 Parts L and F Consultation Stage Impact Assessment which have been reviewed as part of this project and, where necessary, revised[7].

90 **Low and zero carbon technologies**: The capital and maintenance costs for low and zero carbon technologies based on information on existing low and zero carbon technology projects and on estimates from industry sources are set out in detail in Appendix A (Table A.3).

91 **Learning effects:** Learning effects have been incorporated into the analysis to take into account the potentially declining cost of carbon mitigating technologies that would be expected over time as a technology matures. Appendix Table A.4 shows the learning rates that have been applied. These show the cost in a given year as percentage of the cost in 2010. These have been updated technology by technology looking at learning effects both for the capital cost of equipment and for installation costs[8].

Methodology

Preparation of cost curves

92 Cost curves were produced for each building type. These are cost curves that prioritise the order of the fabric, services and low and zero carbon technology options by the cost of saving carbon emissions (maximum Kg.CO_2 saving/ £). Two curves were produced for each building type: (i) one using capital cost data, and (ii) one using life cycle cost data.

93 To derive these curves, estimates had to be made of the change in carbon emissions and cost of varying the fabric, services and low and zero carbon options. This was undertaken separately for each building type. Furthermore, it was undertaken in two iterations. The energy saving from low and zero carbon technologies (and the carbon emissions reductions associated with their delivery) depend on the energy demand. The energy demand depends on the balance between reducing energy demand and delivering low carbon supply in achieving zero carbon. The first iteration provided a measure of this energy demand which could be used in the second iteration to provide a more accurate

[7] *Proposals for the 2010 amendments of Part L and Part F of the Building Regulations – Consultation*, Volume 1, Annex B, Table A2.2

[8] The principal source on learning effects is work carried out by Cyril Sweett for the Zero Carbon Hub [provided December 2010].

assessment of the energy savings from each low and zero carbon technology installation.

94 **Iteration 1:**

- **Fabric and services calculations:** A fixed set of specifications was selected and the energy and carbon savings were calculated using SBEM by varying each element in turn (using the options outlined in Table 3), starting with the value at the reference specification (just worse than Part L 2006 compliant) and ramping up to an advanced specification. In this first iteration, while each element was varied the rest of the specification was kept constant using values from the Part L 2010 notional building. This iteration around a reasonably advanced performance specification was carried out in order to minimise synergistic effects[9]. This was combined with the cost data for improving each element (see Section 3.2) to determine the cost per tonne of carbon saved in improving the performance of each fabric and service element.
- **Low and zero carbon technology calculations:** On the first iteration, the energy profiles from each of the buildings from Phase 2 were taken and the carbon savings that can be achieved from the application of the low and zero carbon technologies were determined.
- **Cost curves**: The curves for each building type were generated by starting with the reference set of specifications (see Table 3)[10]. Then in turn, the fabric, service, low and zero carbon technology solution with the lowest cost per tonne of carbon saved was added to the curve.

95 **Iteration 2:**

- **Fabric and services calculations:** This was a repeat of the first iteration. However, the default set of specifications was based on a first estimate of the minimum elemental energy efficiency standards.
- **Low and zero carbon technology calculations:** On the second iteration, the energy profile for each of the buildings was based on a first estimate of the minimum elemental energy efficiency standards, and this was used to determine the carbon savings.
- **Cost curves**: The curves were produced in a similar manner to the first iteration. The cost associated with each element option (fabric, building service, low and zero carbon technology) was detailed in Section 3.2.

96 The low and zero carbon technology analysis was undertaken using a combination of IES dynamic simulation modelling and an AECOM tool known as Adapt FM. SBEM was limited for this task as it only provides monthly profiles and has limitations in modelling the full range of low and zero carbon technologies considered in this work:

- IES was used as it generates hourly energy demand profiles which can more

[9] We were aware that there will be synergistic effects e.g. improving the lighting efficiency (and hence reducing internal gains) will reduce the benefit of a high efficiency chiller. To partially take account of this, we wished the default set of specifications to be close to the expected final solution. This work has highlighted those fabric and services elements that are most cost-effective to improve and, in further refinement of this work, these elements should be focussed on and the impact of synergistic effects more accurately accounted for.

[10] An alternative approach would have been for the cost curves to start from a Part L 2010 compliant solution as this is the current standard. However, this would have required judgement as to the most cost-effective compliant solution for each building type. Hence, the base case was chosen to be a much less efficient solution and the analysis determined the most cost-effective solution for Part L 2010 and beyond.

accurately assess how the output from low and zero carbon generation matches demand and the extent to which electricity-generating technologies export to the grid when they produce more energy than the building needs. The overall energy demand from IES was calibrated to be consistent with the SBEM overall energy demand.

- Adapt FM was then used to determine the carbon savings associated with the various low and zero carbon technology options to meet the energy demands, as well as the amount of electricity that electricity-generating technologies export to the grid when they produce more energy than the building needs.

Cost benefit model

97 The cost curves were one input into a cost benefit model. The model takes the energy savings and associated emissions reductions identified for each building type together with the costs of achieving those reductions and estimates the private and social costs and benefits which would result if those changes were aggregated across all new non-domestic new build over a period of years.

98 This work was undertaken by Europe Economics. It is presented in more detail in Section 8. The key output for the purpose of developing the energy efficiency standard is estimates of carbon compliance targets for each building type for 2019. Section 8 also provides further details of the cost and benefits of implementing the zero carbon policy options considered here.

Elemental energy efficiency minima

99 To determine the elemental energy efficiency minima, the cost curves produced were reviewed:

- For each building type, the carbon compliance level was plotted on each capital and lifecycle cost curve.
- Then the optimised energy efficiency measures that fell within the carbon compliance target were listed. This was undertaken separately for the capital and lifecycle cost curves to identify any significant differences.
- This was then used to define the minimum energy efficiency standards for the different fabric and services elements.

100 This process and the results are described in more detail in Section 6.

4 Cost curves

Explanation of the cost curves

101 The cost curves are re-produced in full in Appendix B. For each building type there are two curves: one for capital cost only and the other for lifetime costs:

- The horizontal axis shows the carbon reduction from Part L 2006 compliance. As noted in paragraph 97, for this analysis, each building started from the same set of baseline specifications. This resulted in a different level of carbon performance for each building type (e.g. some complied with Part L 2006 using the baseline specifications and others did not).
- The vertical axis for the first capital cost curve shows the cumulative capital cost of meeting a certain carbon compliance level. The vertical axis on the lifecycle cost curve shows the discounted cumulative present value costs (capital, replacement and maintenance), minus the present value of energy benefits, both over the life of the building. So where this curve is downward sloping, the income stream from energy saved is potentially greater than the total stream of costs, even without putting a value on carbon.
- Each additional element added in turn is shown by a new coloured bar on the graph.

102 The graphs here and in Appendix B show the current 2010 cost of measures. The ordering of measures by cost effectiveness is based on 2010 costs and therefore reflects the costs of development today. However, for the purposes of carrying out the cost benefit analysis (see Section 8), learning effects have been applied as, year by year, the real cost of certain technologies decreases.

103 Additional work has been carried out to assess the impact of having a low carbon district heating system available. This has been fed into the cost benefit analysis. Assessment of minimum carbon compliance levels has, however, been carried out based only on standalone buildings since the policy cannot assume the presence of district heating in all cases.

104 Example cost curves are shown in Figures 4a and 4b. These show the capital and life cycle costs curves for the deep plan air conditioned office respectively. In particular, it is noted that for sections of the life cycle curves, improving carbon performance can also lead to reduced overall lifecycle cost. This shown by a downward sloping cost curve.

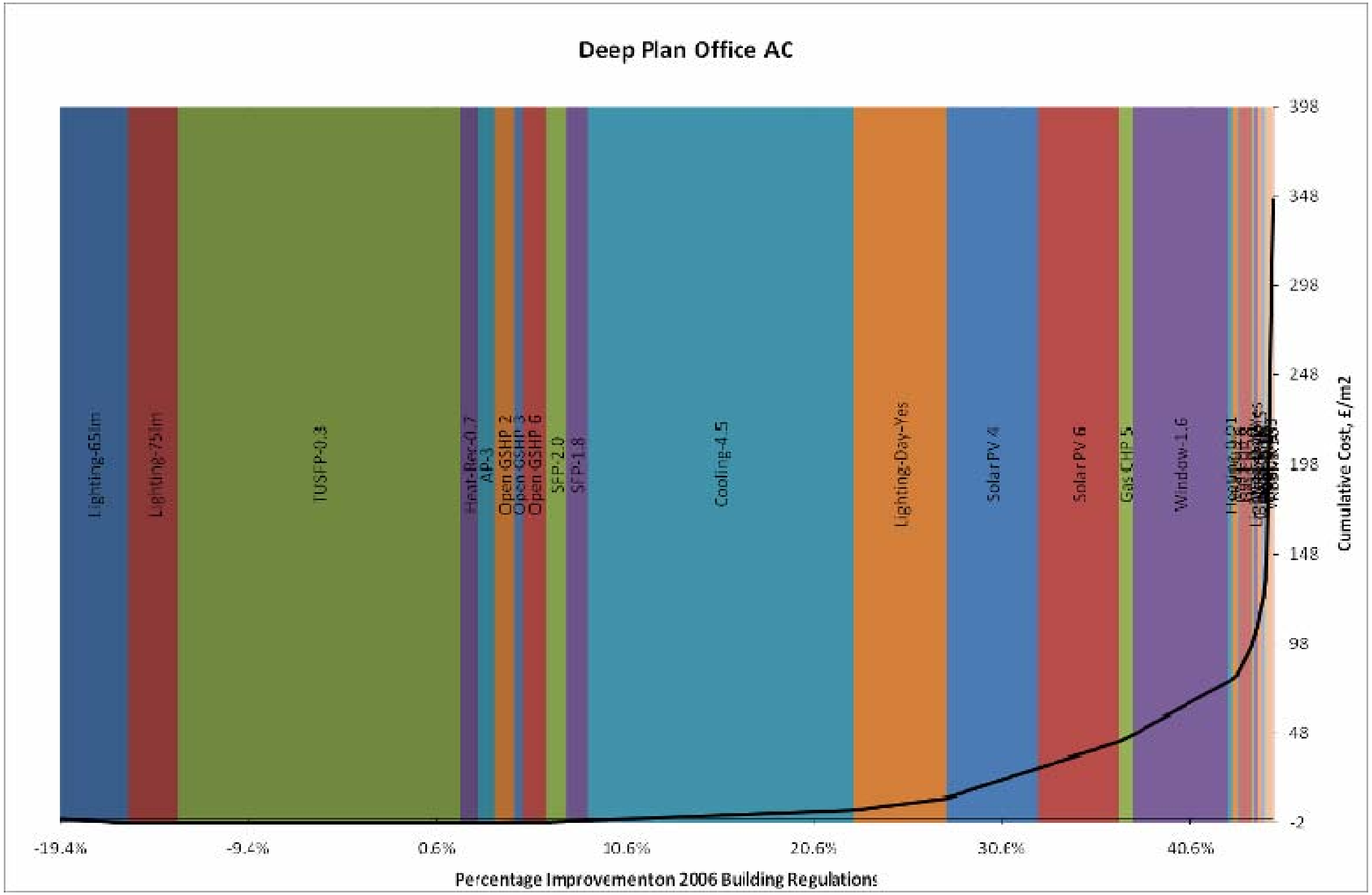


Figure 4a: Capital cost curve for Deep Plan Office AC

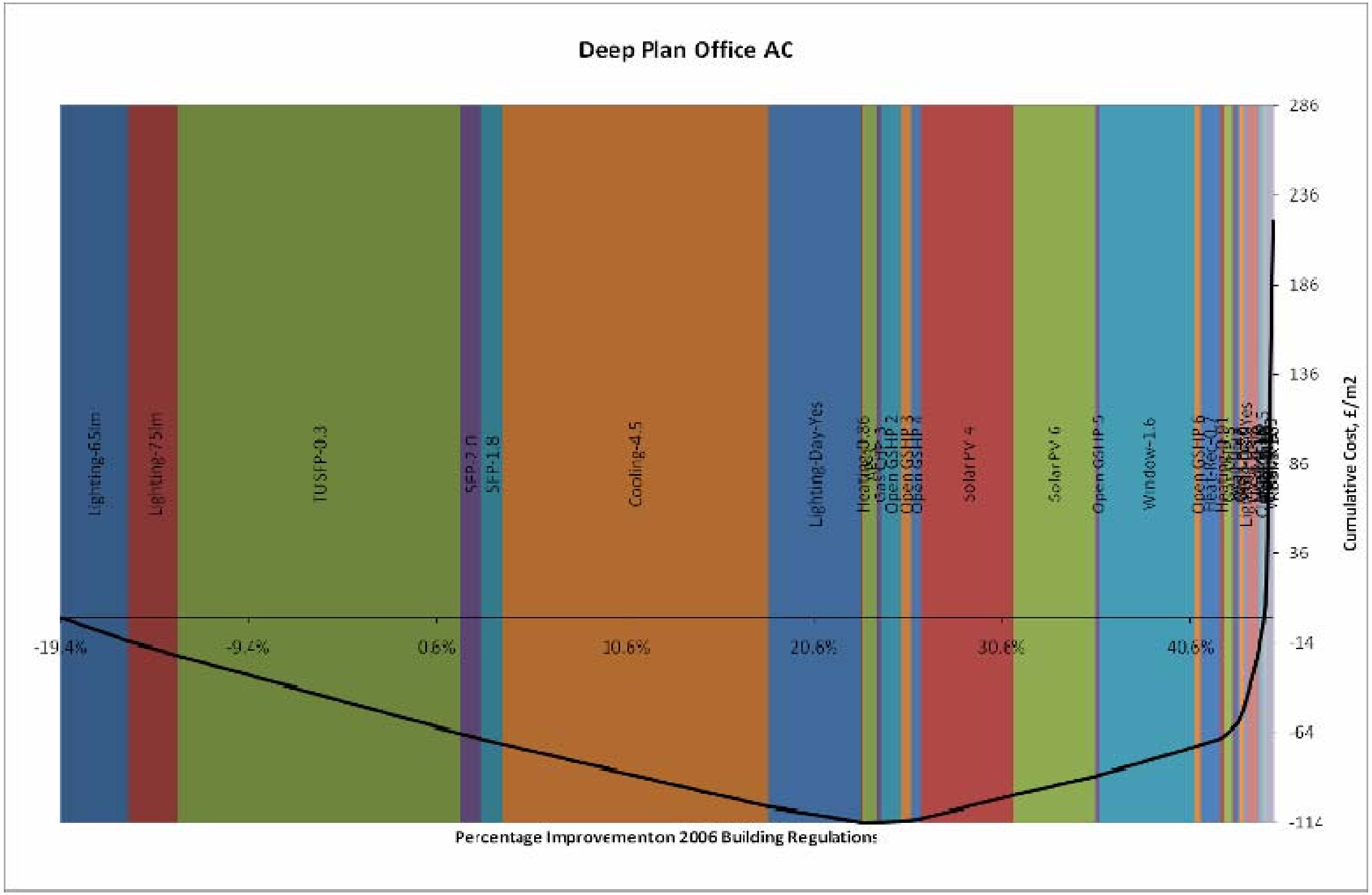


Figure 4b: Lifecycle cost curve for Deep Plan Office AC

5 Carbon compliance target values

Equalising cost of compliance

105 The Phase 2 and follow up Phase 3 carbon abatement cost curves emphasise the large variation in both the maximum achievable carbon compliance levels and the cost of mitigating carbon in different building types.

106 A single carbon compliance level for all building types would impose unfairly high costs on certain types of buildings. This was the conclusion reached for 2010 Part L and these disparities in cost become greater as the carbon target becomes more challenging. In a similar manner to 2010 Part L, the approach taken was to set carbon compliance levels in different buildings such that the imposed cost increase (over cost) is the same across all building types[11]. This was used as a first iteration proxy in advance of further refinement to equalise the cost of compliance (see paragraph 112).

107 The overall carbon reduction possible is heavily influenced by build rates. Over 40 per cent of the non-domestic floor area built in any one year is for offices and therefore this building type has a disproportionate impact on achievable carbon reductions. Retail and distribution warehouses are similarly influential.

Carbon compliance values

108 Following analysis of the responses to the November 2009 consultation, analysis of the initial findings from the early stages of this project and discussion between DCLG and AECOM/Europe Economics, DCLG decided that three scenarios should be explored, delivering different aggregate carbon reductions over the build mix. These were chosen for illustrative purposes, and should not be seen therefore as definitive Government policy proposals on 2019 zero carbon targets:

- **Low**: To achieve an aggregate carbon reduction of 44 per cent compared to Part L 2006
- **Medium**: To achieve an aggregate carbon reduction of 49 per cent compared to Part L 2006
- **High**: To achieve an aggregate carbon reduction of 54 per cent compared to Part L 2006

109 The carbon compliance target values provided by the cost benefit analysis for the medium

[11] Note however that the approach taken in Part L 2010 was subtly different from that applied in this analysis since it attempted to define a common notional building specification based on equalising the marginal abatement cost of each measure applied across all of the building types. By contrast in this work, different specifications for different buildings have be applied in order to equalise the cost of compliance across building types in pursuance of a particular carbon standard. This results in the lowest overall cost of meeting a particular aggregate carbon reduction but may be difficult to implement in policy.

scenario for 2019 are shown in Table 5. This table gives a broad indication of the direction of travel between now and 2019 for one of the scenarios (all three are described in more detail in Chapter 8), but the building target values and aggregated target values are the results of AECOM/Europe Economics' modelling, and do not indicate Government policy or regulatory ambitions. Any statements of policy or changes to the Building Regulations would be subject to the normal full consultation and impact assessment process. However, the different scenarios and the accompanying cost curves provide a useful sense of the implications for different building types of varying levels of ambition. Some of the technical reasons why it would not be possible to pin down 2019 build standards now include:

- Further refinements to include other sector specific regulated energy use. For example, improved efficiency display lighting may be a major benefit in some sectors, e.g. retail and supermarket, where the current analysis suggests cost-effective improvements are harder to achieve.
- The Part L 2010 consultation document proposed the introduction of other energy demands for building services into future revisions of Part L. These include vertical transport, external lighting and air curtains. These will provide further opportunities for improvements which will be non-uniform across the building sectors.
- Refinements to the energy modelling software which are likely to impact some energy uses (and thus some building types) more than others. This includes changes as part of the implementation of the recast of the Energy Performance of Buildings Directive and the Energy Related Products Directive. In addition, there are continuing efforts to minimise differences in achieving Part L compliance with SBEM and DSMs. As an example, a direct comparison of SBEM and a DSM is presented in Section 7 which could influence future work.
- Whilst an attempt has been made to predict future trends in element performance and cost, the implementation of the Zero Carbon standard in 2019 is 8 years away and these parameters may therefore change.
- The building targets will need to be specified in a form that can be applied in a usable manner across all types of buildings. Assuming that a concurrent notional building approach is adopted, as introduced in Part L 2010 for non-domestic buildings, the notional buildings will need to be defined and the choice of specifications for these buildings will impact on the percentage reduction achieved for each building type.
- We have based this analysis on specific building designs for each sector. Sensitivity analysis should be undertaken to understand the influence of different choices of building models on the results.

110 As will be apparent from the table there is a wide range of target carbon compliance levels in 2019 for different building types, ranging from just 12 per cent for high street retail to 82 per cent for a prison. This wide extent comes as a result of a number of important factors:

Differing cost of meeting carbon reductions

111 All of the buildings in 2019 are subject to a similar cost of compliance (£/m^2). However £1 spent on carbon mitigation results in different carbon savings in different buildings. A policy that seeks to fairly distribute the burden of zero carbon will therefore see differing carbon compliance levels. This means that the same cost per m^2 delivers a saving of 12 per cent in a high street retail building but 82 per cent in a prison.

112 Further work would need to be done when proposing and consulting on final regulatory changes to optimise the cost effectiveness of the policy and consider the implications of policy costs as a proportion of build costs for different building types. The method adopted here was considered proportionate for this stage of development work.

Basing carbon reduction on percentages

113 Part L 2010 bases compliance on percentage reductions in carbon emissions. The percentage reduction is compared to the carbon emissions of a building of the same type, size and shape built to 2006 standards. As an example, the baseline emissions of the cultural building (concert auditorium) are 123 kg.CO_2/m^2 whereas in the rural office they are 19 kg.CO_2/m^2. This means that a 20 per cent saving in carbon emissions results in much higher *absolute* carbon reduction in the cultural building than the office (24.6 kg.CO_2/m^2 vs.3.8 kg.CO_2/m^2).

Part L 2006 resulted in different levels of performance from different buildings

114 The reference elemental specifications imposed on all of the building types (upon which carbon savings are constructed) result in different levels of compliance with Part L 2006. As shown in the graphs appended to this report the reference specification when applied to the supermarket[12] results in a building which is 52.6 per cent adrift from 2006 compliance. By contrast the same specification applied to the distribution warehouse results in a building that is 18.9 per cent better than 2006 compliance. This means that the supermarket has to implement a lot of costly measures even before it begins to improve on 2006.

Carbon mitigation limitations of certain building types

115 The analysis carried out is predicated on the fact that building locations and topologies restrict the amounts and types of carbon mitigating technologies available. For example a tall city centre office block will have a small area of roof available for the installation of photovoltaic panels (in comparison with overall floor area), no access to wind and, potentially, restricted access to biomass technologies. By comparison, the suburban office block (say in an out-of-town business park) will have much greater access to these technologies. This explains why the city centre office has a theoretical maximum carbon reduction of approximately 40 per cent whereas the suburban office has a greater theoretical maximum carbon reduction of over 100 per cent.

116 Access to certain technologies also reduces the cost of meeting carbon reductions. The naturally ventilated, rural office has higher emissions relating to heating and therefore biomass technologies[13], that are capitally fairly inexpensive, result in cheaper early

[12] Part of the reason for this lies in the way SBEM treats different building types. In the case of the supermarket the actual building used a relatively typical (for a supermarket) but energy inefficient constant air volume HVAC system. The notional building does not specify the HVAC system but instead optimises the auxiliary energy based on a set formula and resulted in much lower emissions than the reference specification. As a consequence a lot of measures had to be implemented in the supermarket just to comply with 2006 Building Regulations.

[13] It is acknowledged that Part L 2010 removes an incentive for implementing low carbon heating technologies in that the notional building features the same heating fuel as the actual. This study however has included the carbon reduction from these technologies in order to establish the cost benefit of different measures including low carbon heating fuels to help achieve zero carbon. The intention is that the energy efficiency standards should be sufficient to ensure that LZCs are not implemented at the expense of energy inefficient buildings. Furthermore, whilst a primary energy standard may not be so effective to control the use of conventional fuel sources (see Paragraph 67), it may be better placed to limit the amount of LZC technologies such biomass required per dwelling.

emissions reductions than are apparent in the city office (which has low heating requirements and no access to biomass). The lifecycle analysis is important in these cases in that it reveals where capitally cheap technologies such as a biomass have relatively higher lifecycle costs than other technologies, such as photo voltaics, that have lower running costs (e.g. because of the need to pay for biomass fuel over the lifecycle).

Differing baseline emissions

117 A building with low baseline energy use such as the naturally ventilated office (2006 compliant emissions of 18.7 kg.CO_2/m^2) has less carbon to mitigate to become zero carbon than a building with higher baseline emissions such as the supermarket (54.7 kg. CO_2/m^2). This means that a proportionately smaller amount of renewables (and potentially Allowable Solutions) is required in order to reach zero carbon.

Table 5: Assumed regulated emissions reductions by building type, energy efficiency and carbon compliance – medium scenario

Building type	2013	2016	2019
Deep Plan Office Air Con	21%	26%	33%
Shallow Plan Office Air Con	27%	32%	40%
Shallow Plan Office Heated	30%	43%	62%
High Street Retail	12%	12%	12%
5 Star Hotel	20%	26%	33%
Out-of-town Supermarket	12%	12%	19%
Retail Warehouse	44%	54%	60%
Distribution Warehouse	55%	66%	72%
Acute Hospital	31%	40%	55%
Cultural	21%	24%	29%
Defence	42%	48%	56%
Prison	65%	72%	82%
Secondary School	30%	36%	47%
Primary School	23%	57%	60%
3 Star Hotel	27%	34%	53%
Country Hotel	34%	56%	72%
Mini Supermarket	12%	12%	17%
Aggregate reduction	33%	41%	49%

Source: Europe Economics

6 Minimum elemental energy efficiency values

Introduction

118 Having reached the conclusion in Section 3 that the most appropriate approach to an energy efficiency standard is to retain the elemental approach currently employed in Part L 2010 the next question to ask is what values this standard should take. This section proposes a methodology for establishing an appropriate energy efficiency back-stop and makes an initial assessment of their likely values. It is important to note that these are proposed standards for 2019 and would not necessarily be proposed for Part L 2013 or Part L 2016, as these proposals assume that technologies have developed and costs have fallen by 2019.

119 For each building type the following was undertaken:

- The carbon compliance target level for each building type for the medium scenario in 2019 was plotted on the building's capital and lifecycle cost curves.
- The optimised energy efficiency measures that fell within the carbon compliance target were identified.

120 Tables 6 to 9 show the optimised energy efficiency measures:

- Tables 7 and 9 show the results for heated only buildings based on capital and lifecycle costs respectively.
- Tables 6 and 8 show the results for heated and cooled buildings based on capital and lifecycle costs respectively.

121 The tables highlight those elements that have been selected in the cost curves to be better than the reference set of specifications (shown in Table 3).

Building fabric energy efficiency standards

122 **Wall, floor and roof U-values:** The reference set of U-values is the fabric backstop values in Part L 2006 and 2010 (they are identical). There appears to be no consistent benefit in improving these U-values across either heated only or heated and cooled buildings. Furthermore, where it is identified as beneficial, the impact of making these improvements appears to be relatively small, saving carbon by only 1 or 2 per cent. This appears to suggest that it may be preferable to retain the minimum fabric energy efficiency values used in Part L 2010.

123 **Window U-values:** For particular heated and cooled buildings, it is beneficial to improve the window U-value from 2.2 to 1.6 W/m^2.K. In this case, the impact on carbon reduction is larger than for the fabric elements above (5-15 per cent). However, further investigation highlighted that the selection was more to do with a reduction in g-value from 0.7 to 0.4 which reduces solar gains and the need for space cooling. This is better addressed in Criteria 3 of Part L (limiting the effects of solar gains in summer) rather than included in any energy efficiency standard. Again, the results suggest that the window energy

efficiency standard should be the same as for Part L 2010 (i.e. 2.2 $W/m^2.K$). It is worth reviewing also whether the heat and light transmittance of glazing should have a minimum performance too in any standard.

124 **Air permeability:** In each case, the air permeability has been set at 3 $m^3/hr/m^2$. We were unable to obtain robust data on the cost to achieve different air permeability levels. Anecdotally, we have been informed that there should be no additional capital cost to achieve 3 $m^3/hr/m^2$, it more relates to the quality of construction. It would be useful, going forward, to discuss with stakeholders their experience and the cost that should be assigned to improvements in air permeability as well as to thermal bridging. Alternatively, it may be simpler to directly agree energy efficiency standards for air permeability and thermal bridging through stakeholder engagement based on the level of improvement which is judged to be reasonably achievable through better quality of construction (i.e. with no or minimal additional capital cost). It is noted that moving from the base value of 7.5 to 3 $m^3/hr/m^2$ saves from 1 to 8 per cent carbon emissions and the higher savings occur both for some heated and some heated and cooled buildings[14].

125 **Capital vs life cycle costs:** For several building types, the life cycle analysis suggests that it is cost-effective to install higher standards of fabric performance as part of meeting the carbon compliance target. However, these higher standards of performance just come in within the carbon compliance level and to provide the developer with sufficient design flexibility, it would be prudent not to implement these higher standards in any energy efficiency target.

Building services energy efficiency standards

126 **Lighting**: As noted in Table A.2, increasing the lighting efficiency from 65 to 75 Luminaire Lumens per circuit watt was estimated to be cost neutral since the additional cost of the lamp and fitting was assumed to be offset by the need for fewer fittings. The extent to which this is true is, of course, limited by loss of uniformity and this may need further testing in a greater number of scenarios and room types than was possible in the scope of this study.

127 As a result of the neutral cost increase, it is perhaps unsurprising that the maximum modelled 75 luminaire lumens per circuit watt is beneficial in all of the buildings. Indeed higher lighting efficiency was the most beneficial measure in almost all of the buildings when measured against the cost of carbon. With LEDs projected to have an efficiency of more than 150 lamp lumens per circuit watt in 2020[15], 75 Luminaire Lumens per circuit watt is seen as an achievable maximum average efficacy across a building lighting installation, particularly by 2019.

128 **Occupancy Control**: This was not found to be beneficial in any building. It is thought that assumptions in the National Calculation Methodology are underestimating savings from occupancy control, and it would be something that could be considered further.

129 **Daylight control:** The results showed that daylight control was beneficial in all but one of the heated buildings and half of the heated and cooled buildings. The buildings that did

[14] It should be noted that air permeability is a measure of building performance with all openings in the closed position. However, some buildings are not operated in that way, particularly in relation to major entrance doorways, which may result in an increase in operating carbon emissions.

[15] Market Transformation Programme, DEFRA. See Best Available Technology report for Commercial Lighting: http://www.mtprog.com/cms/product-strategies/subsector/commercial-lighting

not benefit from daylight control were predominantly those with many fully internal or poorly day-lit rooms such as the hospital and cultural building (which is dominated by the auditorium). It is proposed that daylight control of lighting be made a requirement as part of the zero carbon energy efficiency standards. However, rooms that cannot make use of daylight control such as fully internal rooms (cinema, theatre etc) are exempt. Note that daylight control was modelled as a dimming rather than on/off system.

130 **Heat recovery:** A heat recovery efficiency of 70 per cent was found to be beneficial in all buildings with centralised mechanical ventilation. Savings ranged from 3 per cent to 7 per cent and were generally high in priority when measured against the cost of carbon. It is recommended therefore that heat recovery be required in centralised mechanical ventilation systems at a minimum of 70 per cent. It is noted that certain centralised mechanical ventilation systems such as split supply and extract systems (with run-around coils) may find this standard challenging and it would benefit from discussion with stakeholders. Other examples of heat recovery may include recirculation dampers.

131 **Heating efficiency:** The results showed that for all of the heated buildings and most of the heated and cooled buildings, it was beneficial to improve boiler efficiency from 84 to 91 per cent. This saved between 1 and 4 per cent of the carbon emissions. Whilst relatively low on its own, it is the combination of improvements to multiple elements that is important. It is proposed that the minimum heating efficiency standard is set at 91 per cent for boilers. Consideration is needed as to whether there should be different values for different fuel types as is the case with Part L 2010. Furthermore, there are other types of heating systems (e.g. radiant heaters) which need to set at a similarly challenging minimum level of performance.

132 **Cooling efficiency:** The results showed that for all of the heated and cooled buildings, it was beneficial to improve the cooling efficiency from a seasonal energy efficiency ratio (SEER) of 2.5 to 4.5 for an air cooled chiller. This saved between 3 and 15 per cent of the carbon emissions. It is proposed that the minimum SEER is set at 4.5 for air cooled chillers. It is noted that Part L sets different elemental backstop values for different chiller types (e.g. water cooled) and similarly challenging minimum levels of performance need to be agreed. Similarly it is recognised that buildings using chillers for summertime peak lopping (such as mixed mode) may find an SEER of 4.5 more challenging and this needs to be addressed.

133 **Air distribution systems Specific Fan Power (SFP):** In all buildings with an air handling unit, it proved beneficial to improve the SFP from 2.2 to 1.8 W/l/s. It saved between 2 and 8 per cent of the carbon emissions. It is proposed that the maximum SFP is set at 1.8 W/l/s for central mechanical ventilation systems including heating and cooling (as is the case for Part L 2010). In all buildings with a fan coil unit, it proved beneficial to improve the SFP from 0.8 to 0.3 W/l/s. It saved between 1 and 15 per cent of the carbon emissions. It is proposed that the maximum SFP is set at 0.3 W/l/s for fan coil units. It is noted that Part L sets different elemental backstop SFP values for different air distribution systems than those reported here and similarly challenging levels of performance need to be agreed. Further work is required to account for the need (and cost of) bigger ducts and plantrooms to achieve these higher specific fan powers.

134 **Capital vs Life cycle costs:**

- For many of the building service performance factors (heating and cooling efficiency, specific fan power), they are more cost-effective in the life cycle analysis. Whilst the optimum standard of performance does not differ between the cost and life cycle analysis, these factors appear higher up the hierarchy of cost-effective elements to introduce. This is because the life cycle analysis takes account of the energy cost savings from using a more efficient building service.

- Moving from 0 per cent to 70 per cent heat recovery appears less cost-effective in the life cycle calculations. This is because the lifecycle analysis introduces increased electricity costs from the operation of heat recovery and the cost of electricity increases faster proportionately than the cost of gas saved over the lifecycle.

Discussion of the energy efficiency standards

135 This work has proposed minimum elemental performance standards. Furthermore, it has indicated which elements have the greatest impact on reducing the carbon emissions from operating the building.

136 This discussion should be placed in the context of the proposals in Section 2:

- The building services efficiencies will need to be aligned with those established via the Energy Related Products Directive, at least in terms of assessment methods.
- The minimum performance standards set via the Energy Related Products Directive should be reviewed. National standards cannot be set that are poorer than these minima, but if thought appropriate, the standards could be raised above the Directive values.
- In future, the Energy Related Products Directive might also address fabric elements.

137 It appears likely that the Directive's assessment methods and minimum performance levels are to be on a system-basis rather than component-basis (the assessment methods and performance levels are still to be finalised). This is particularly relevant for building services. In the absence of the new system approach, the analysis presented here has developed component-based minimum performance criteria as currently used in Part L.

138 However, it is important to recognise that the results and implications of this analysis may change in any systems-based approach. For example, the preferred minimum system performance level is not necessarily simply the addition of the minimum component levels developed here. The energy performance assessment methodology developed via EPRD for the systems approach may be different to those used at the component level.

139 In addition, whilst learning rates (see Appendix A, Table A.4) have been applied to the costs of technologies and an attempt has been made to predict future trends in element performance (e.g. chiller efficiency) the implementation of the zero carbon standard in 2019 is 8 years away and these parameters may therefore change.

140 Hence, in the context of developing minimum energy efficiency standards for zero carbon non-domestic buildings, the analysis presented in this report and in ensuing stakeholder engagement is most helpful in identifying the likely future trends for minimum performance levels required for building service components rather than a definitive publication of the government's intended standard in 2019.

Table 6: Optimised Energy Efficiency Measures based on Capital Cost Curves for Heated and Cooled Buildings

	Reference Case	1- Deep Plan Office AC	2- Shallow Plan Office AC	4- High Street Retail	5- 5 Star Hotel	6- Out-of-town Supermarket	9- Acute Hospital
Floor U-value	0.25			0.15		0.2	
Roof U-value	0.25			0.1			
Wall U-value	0.35			0.25	0.25		
Window U-value	2				1.6	1.6	1.6
Air Permeability	7.5	3	3	3	3	3	3
Lighting	55	75	75	75	75	75	75
Lighting Occupancy Control?	No						
Lighting Daylight Control?	No	Yes	Yes	Yes	Yes	Yes	
Heating Efficiency	0.84			0.91	0.91	0.91	0.91
Heat Recovery Efficiency	0	0.7	0.7		0.7	0.7	0.7
Cooling Efficiency	2.5	4.5	4.5	4.5	4.5	4.5	4.5
AHU SFP	2.2	1.8	1.8		1.8	1.8	1.8
Terminal Unit SFP	0.8	0.3	0.3	0.3	0.3	N/A	N/A

Table 7: Optimised Energy Efficiency Measures based on Capital Cost Curves for Heated Only Buildings

	Reference Case	3- Shallow Plan Office HT	7- Primary School	8- Warehouse	12- Prison	13- Secondary School	14- Retail Warehouse
Floor U-value	0.25			0.2			0.2
Roof U-value	0.25			0.15			
Wall U-value	0.35	0.25		0.25	0.25		0.25
Window U-value	2						
Air Permeability	7.5	3	3	3	3	3	3
Lighting	55	75	75	75	75	75	75
Lighting Occupancy Control?	No						
Lighting Daylight Control?	No	Yes	Yes	Yes		Yes	Yes
Heating Efficiency	0.84	0.91	0.91	0.91	0.91	0.91	0.91
Extract Heat Rec. Eff.	0	N/A	N/A	0.7	N/A	0.7	0.7
Cooling Efficiency	2.5	N/A	N/A	N/A	N/A	N/A	N/A
AHU SFP	2.2	N/A	N/A	1.8	N/A	N/A	1.8
Extract SFP	0.8	N/A	0.3	0.3	0.3	0.3	0.3

Table 8: Optimised Energy Efficiency Measures based on Life Cycle Cost Curves for Heated and Cooled Buildings

	Reference Case	1- Deep Plan Office AC	2- Shallow Plan Office AC	4- High Street Retail	5- 5 Star Hotel	6- Out-of-town Supermarket	9- Acute Hospital
Floor U-value	0.25			0.1		0.2	
Roof U-value	0.25			0.1		0.15	
Wall U-value	0.35			0.25	0.25	0.25	
Window U-value	2	1.6			1.6	1.6	1.6
Air Permeability	7.5	3	3	3	3	3	3
Lighting	55	75	75	75	75	75	75
Lighting Occupancy Control?	No						
Lighting Daylight Control?	No	Yes	Yes	Yes	Yes	Yes	Yes
Heating Efficiency	0.84	0.86	0.86	0.91	0.91	0.91	0.91
Heat Recovery Efficiency	0		0.7		0.7	0.7	0.7
Cooling Efficiency	2.5	4.5	4.5	4.5	4.5	4.5	4.5
AHU SFP	2.2	1.8	1.8		1.8	1.8	1.8
Terminal Unit SFP	0.8	0.3	0.3	0.3	0.3	N/A	N/A

Table 9: Optimised Energy Efficiency Measures based on Life Cycle Cost Curves for Heated Only Buildings

	Reference Case	3- Shallow Plan Office HT	7- Primary School	8- Warehouse	12- Prison	13- Secondary School	14- Retail Warehouse
Floor U-value	0.25			0.15			0.2
Roof U-value	0.25			0.15			
Wall U-value	0.35	0.25		0.25	0.25		0.25
Window U-value	2						
Air Permeability	7.5	3	3	3	3	3	3
Lighting	55	75	75	75	75	75	75
Lighting Occupancy Control?	No						
Lighting Daylight Control?	No	Yes	Yes	Yes		Yes	Yes
Heating Efficiency	0.84	0.91	0.91	0.91	0.91	0.91	0.91
Extract Heat Rec. Eff.	0	N/A	N/A	0.7	N/A	0.7	0.7
Cooling Efficiency	2.5	N/A	N/A	N/A	N/A	N/A	N/A
AHU SFP	2.2	N/A	N/A	1.8	N/A	N/A	1.8
Extract SFP	0.8	N/A	0.3	0.3	0.3	0.3	0.3

7 Built-form

Introduction

141 The analysis conducted throughout the rest of this report ignores the effect on energy consumption of altering the architectural form of a building. This is primarily because the carbon methodology (the National Calculation Methodology) used since 2006 in Building Regulations Part L compares the carbon emissions of a proposed building with a notional building of the same form (but different fabric and services performance) and hence the effects of built-form are excluded from the assessment.

142 To build a complete picture it is important to analyse all possible cost effective carbon reduction measures. This chapter therefore examines the extent to which built-form reduces absolute carbon emissions and, if significant, the extent to which optimising built-form could be incentivised either through regulation or other mechanisms.

143 This chapter includes the following:

- It discusses the case for incentivising built-form.
- It then proposes and analyses various methods of incentivising built-form.
- Analysis is then presented on the impact of built-form on both energy demand and carbon emissions for different building types.
- It then discusses the impact of these results on incentivising built-form.

144 It is important to note that in considering extending the scope of the regulations to incentivise energy efficient built form, every effort must be taken to identify and assess possible unintended negative consequences.

Should energy efficient built-form be incentivised?

145 Without doubt, the shape, size and orientation of a building have an influence on energy demand. In the non-domestic arena, there is an energy efficiency argument for adopting non-compact shapes (i.e. narrow-plan rather than square in plan). This is because it allows greater utilisation of daylight and natural ventilation[16], even though conduction losses and gains may increase. Increased conduction can be a benefit or a penalty, depending whether the building is heating or cooling dominated respectively. Identifying where the balance point lies (and how it might shift as insulation standards become more stringent, internal gains vary and the grid de-carbonises) will be an important issue.

146 To provide a sense of scale the blue bars in Figure 5 show how the conduction losses (per unit temperature difference) from a building will vary depending on built form. The example shows the sum of area and U-values for four built forms, each providing 15,000m^2 total floor area. The U-values are taken as those adopted in the 2010 Part L notional building, and

[16] Natural ventilation is often, though not necessarily, more carbon efficient than mechanical ventilation. Mechanically ventilated buildings can make use of heat recovery to offset fan energy consumption. The benefits of heat recovery will increase as the grid decarbonizes. The main difference between the two forms of ventilation occurs once mechanical cooling is provided, and space temperatures are maintained <24oC all year round. In such situations, the difference is perhaps less to do with servicing strategy and more to do with expectations of thermal comfort.

assume 40 per cent vertical glazing with no rooflights.

147 The four built-forms are as follows.

- "Compact" is square in plan and eight storeys high.
- "Shallow" has a fixed 15m plan width and is on three storeys.
- "Tall" is square in plan, but is 15 storeys high.
- "Single" is also square in plan, but only single storey.

148 The results show that the "shallow" building has almost double the conduction heat loss in comparison to the "compact" form. However, as the red bar shows, in this example where the occupant density is assumed to be 1 person per 12m^2, the conduction losses are far outweighed by the heat loss through operation of the ventilation system (which is independent of built-form).

149 In a space with a higher occupant density, such as a classroom, the relative significance of the conduction heat loss compared to ventilation heat loss is even less. However, in less densely occupied spaces, this trend will reverse.

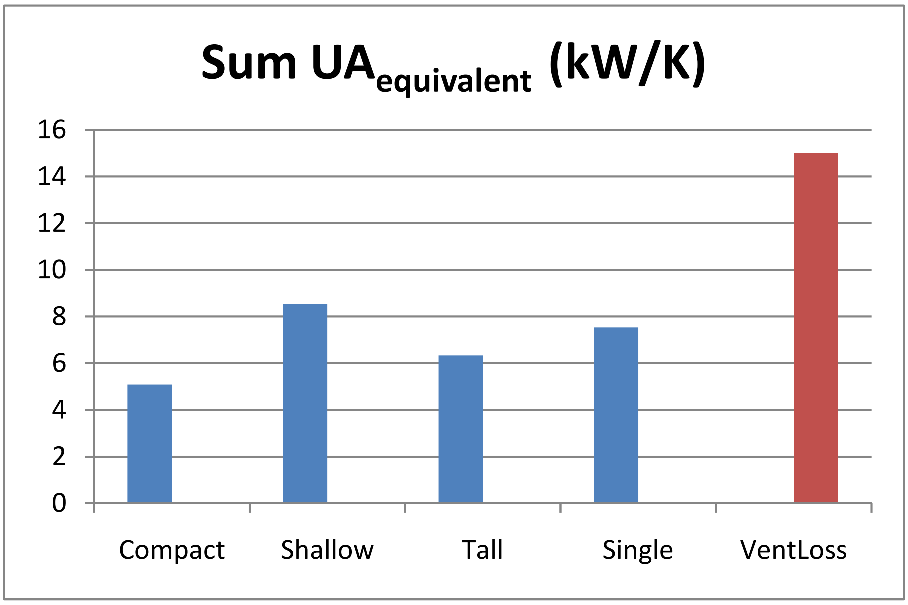


Figure 5: Conduction heat loss for different built forms

150 Figure 6 shows the proportion of the total floor area that is in a daylit zone (i.e. within 6m of the facade). This illustrates the potential for reducing electric lighting use with built form. This has a double benefit in that electric lighting gains are also reduced with a consequent reduction in cooling demand. However, this benefit has to be offset against an inevitable increase in window solar load, demanding careful design of the facade. In buildings dominated by heat losses, increased solar gain can be beneficial but the more energy intensive buildings seek to minimise window solar gain.

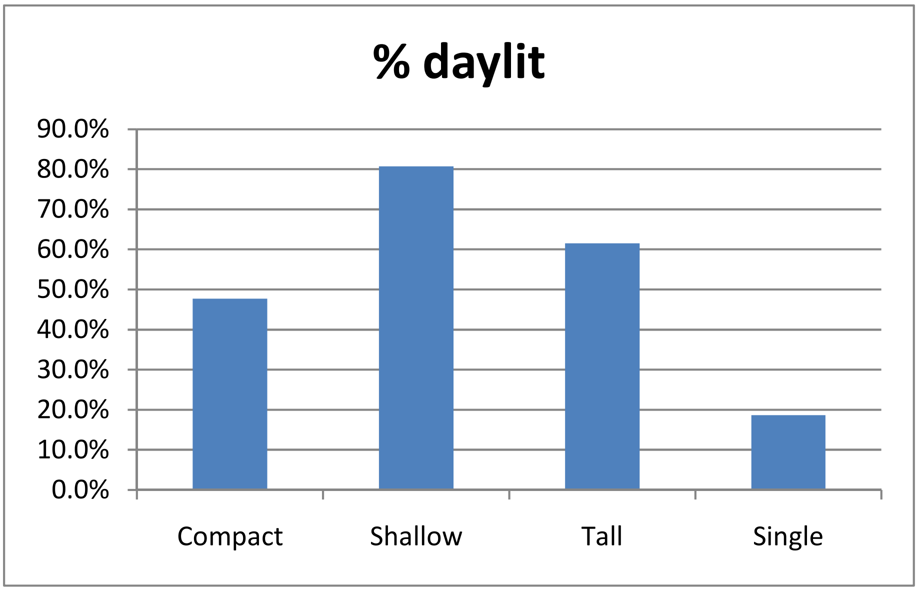


Figure 6: The proportion of the total floor area in the daylit zone

151 From this generic discussion in paragraphs 146 to 151, it follows that the optimum shape for a building is likely to vary depending on its use, and in particular, on the level of internal gains. If this is the case, then developing a robust incentive for energy efficient built form will be difficult in the context of mixed-use buildings and if there are changes of use, neither of which are uncommon situations.

152 It is also important to note that other influences also help to shape built form. Key influences are:

- Commercial viability – maximising the usable area of the building within the constraints of the site boundary. This is often a particularly important issue for congested city centre locations where land costs are high.
- Functional use – in some building types, requirements for the relative organisation of internal spaces will strongly influence built form. For example, the needs for infection control in hospitals, the arrangement of storage racking and loading bay doors in a warehouse.

153 A key concern would be that by driving energy efficient built-form, there could be a negative impact on these other requirements of the building. Indeed it might have adverse energy implications beyond the building boundary. If a requirement for energy efficient form meant a particular site could not be developed in a commercially viable way, the development might move out of the city centre and away from the main public transport hubs – the building might be more energy efficient, but the overall operation of the building would not be.

154 As part of this debate, it should be noted that changing shape will influence more than just energy efficiency. It is likely that changing the shape will alter the net to gross area of the building. Thus although the energy per unit total floor area might be improved through adopting the more energy efficient shape, the number of occupants in the building may reduce, such that the energy used per occupant increases. In that context, a very important question is which is the more efficient building?

155 Initial feedback from the 2010 revision to Part L suggests that small buildings are finding it more difficult to comply, particularly in warehouse type buildings. Factoring size into the target would help to ameliorate this concern. Two factors that might contribute to this size effect have been suggested:

- The increased relative importance of thermal bridges in small buildings.

- The fact that in large warehouses, even without any insulation, the U-value of the floor tends to zero because the heat loss, which primarily occurs at the edges of the slab, become spread over a proportionately larger floor area. Smaller warehouses will have a much greater floor U-value for the same floor construction, and therefore would have to work harder in other areas to achieve the same Building Emission Rate. However, if the National Calculation Methodology has been implemented properly, this should not be an issue, since the National Calculation Methodology specifies that if the actual floor has a U-value less than $0.22W/m^2K$ with no insulation added, then the same value as in the actual should be used in the notional building.

156 Moving towards zero carbon, there is another concern about small buildings, i.e. that some costs are more or less fixed irrespective of building size (e.g. an inverter). There may also be economies of scale, such that (e.g.) the cost of allowable solutions is cheaper. As an illustration, figures taken from a particular manufacturer's data suggest that the installation cost per kWh generated would be about 25 per cent less for a 50kW wind turbine compared to a 15kW unit.

157 It has also been suggested that some builders deliberately have gone for inefficient shapes to make compliance with Part L easier. This assertion was made following Part L 2006; the argument was that in compact dwellings where the energy demand is dominated by hot water, it was easier to achieve a 25 per cent saving by increasing the perimeter space heat loss as a fraction of the total. Although this is true in theory, there has been no evidence that it had happened in practice. The extra costs of constructing "the star shaped bungalow" would be very significant and would be unlikely to create significantly more usable space. In any event, the 2010 concurrent notional building approach has eliminated this potential problem, at least as far as non-domestic buildings are concerned.

158 In a similar vein, facade costs are often one of the largest elements of a cost plan. Therefore designers and developers are likely to need a good reason for increasing their costs by adopting other than compact shapes[17].

159 It is important to note that there are several energy demands that are currently unregulated, but that will be affected by changes to built form. Hence it is vital to consider the wider picture to ensure that energy savings made from changes to built form are not lost through increases in energy use elsewhere. As an illustration, reductions in regulated energy might be achieved by maximising available daylight through adopting a narrow floor plate. Although the internal lighting demand should be considerably lower than in an equivalent building with a compact shape, the reverse is likely to be the case for the external lighting, especially if the whole perimeter must be lit for security reasons. Similarly, if a high rise building with a relatively small floor plate is created, then again internal lighting demand might be reduced through more effective use of daylight, but vertical transport energy will increase substantially.

160 A related concern is that optimising built-form to minimise regulated energy demand might also negatively impact on aspects of regulated demand that are currently not well modelled in the compliance tools, e.g. auxiliary energy. Moving away from compact shapes is likely to increase pipe and duct runs, increasing pressure losses and duct leakage. Currently, SBEM just applies an auxiliary energy per unit floor area based on system type. To avoid unintended consequences, it would be necessary for the models to be substantially enhanced to include explicit models of the energy distribution systems based on the lengths, sizes and insulation of duct and pipe runs etc. This would involve a substantially

[17] It is perhaps important that designers are made aware of all the energy/CO_2 impacts of less compact shape. Using less compact forms can reduce operating energy demand through better use of daylight etc, but less compact shapes also result in increased use of materials, and hence an increase in embodied energy/carbon. As operating CO_2 emissions approach zero, this will be an increasingly significant issue in the overall picture. This is particularly the case since all the embodied carbon must be invested on day one to save operating carbon through the building life. This has implications for the atmospheric CO_2 levels, at least in the critical short to medium term.

greater effort in terms of data input, although this could be automated if Building Information Modelling became a universal design strategy.

Methods of incentivising efficient built-form

161 To be viable, any regulatory method of incentivising built form must sit within the proposed structure of the zero carbon build standard:

- The energy efficiency standard; AECOM's proposal is that this should be a series of elemental standards, similar in form to compliance criterion 2 in the 2010 Part L.
- The carbon compliance level, covering regulated energy demands; the assessment methodology is currently anticipated as being similar to the 2010 Part L, i.e. based on a concurrent notional building of the same size and shape as the actual building which effectively results in different percentage targets for different buildings (i.e. the aggregate approach).
- The zero carbon target; this is proposed as an absolute carbon target [18] – 0.0 $kgCO_2/m^2.y$.

162 The following discussion looks at how it might be possible to incentivize efficient built form at the three levels of the zero carbon pyramid.

At the energy efficiency level

163 As currently proposed, the energy efficiency standard will be based on elemental standards. In that context, the main possibility seems to be to encourage more effective use of daylight. Two possible approaches have been considered, the first of which would be non-regulatory:

- It might be appropriate to give good-practice guidance on the percentage floor area of a building that should be well daylit. Such guidance should not only suggest minimum areas, but also how those areas might be achieved. Daylit areas can be created in buildings with deep floor plates through internal atria, lightwells etc. This approach might be further encouraged by information that substantiates the claim that perimeter space is much more valuable and productive space than areas deep in the core of the building. Some countries in the EU have stipulated this by law[19].
- Via the regulations, specifying a maximum allowable LENI value (Lighting Energy Numerical Indicator)[20]. LENI is the $kWh/m^2.y$ used to illuminate the spaces in the building, based on the combined effect of natural and electric light. The method is set out in EN 15193, and was developed specifically for certification purposes. There are five concerns with this approach:
    - i) There may not be much design flexibility, since the standard for electric lighting in the 2010 concurrent notional building is already pretty demanding, and so significantly improving on it might be difficult, at least in the shorter term.
    - ii) The modelling of daylight in SBEM is fairly crude and would need to be made more sophisticated to provide a robust measure of daylight availability. For example the

[18] Although this same target could be expressed as a 100% reduction, it is more usefully expressed as an absolute figure, since it emphasises that all buildings will have to achieve the same absolute standard.

[19] German Workplace Ordinance requires workers to have direct visual contact with the outside world. Whilst the minimum distance from a window is not stipulated this has generally been interpreted as being 6m for reasons of occupational health. The regulation has had a significant impact on the plan depths of German office buildings. See: The European office: office design and national context; Juriaan van Meel, 2000. Access to a window is also credited in BREEAM.

[20] For a brief description see (e.g.):- http://www.cibse.org/content/Julie_Uploads/Energy%20in%20Lighting%20-%20Lou%20Bedocs.pdf

effects of different shading devices, variable densities of surrounding buildings, room shape etc. would need to be accounted for.

iii) The frequent mismatch between theoretical predictions of lighting system performance and the actual outcome. “Blinds down, lights on” is a common occurrence in nominally daylit spaces.

iv) Achieving a target LENI could be met through a scheme that delivers poor lighting quality. The industry has often criticised Part L’s lighting requirements for this very reason, and so it is interesting to note that it is the industry that is pushing LENI strongly. The industry solution to this problem is to emphasise the importance of meeting parallel standards on lighting requirements (e.g. EN 12464-1 Lighting of work places, and EN 12193 Indoor sports lighting).

v) The savings on electric lighting through better daylight may be offset through increased heat loss and solar heat gain.

164 Other possible elemental standards include:

- A heat loss parameter; this has been discounted in the non-domestic sector because the appropriate value of this parameter is more dependent on internal gains than it is on shape – reducing heat loss beyond a certain point is not helpful in a cooling dominated building. It also disregards the significant benefits of daylight, which can be a very significant proportion of the energy demand (and carbon burden) in many non-domestic building types.
- Auxiliary energy; again, this has been discounted, at least until modelling rigour improves substantially (see paragraph 160). A further complication with this approach is that it would probably require different auxiliary energy targets to be set for each system type, unless the regulations were to be used to push designers in the direction of preferred systems for different types of buildings.

At the carbon compliance level

165 As previously noted, the current proposal for carbon compliance is to set the target by calculating the CO_2 emissions from a notional building of the same size and shape as the actual building, and with a defined (concurrent) set of elemental properties. Such an approach must be adapted if we are to incentivize built form.

166 Two approaches have been considered as follows:

- Basing the notional building on a fixed, energy efficient shape irrespective of the shape of the actual building. It is thought that such an approach is impracticable, and/or open to abuse, because it would be difficult to allocate the different activity areas into the new geometry. To avoid “manipulation to advantage”, this process would have to be automated, a task which would be extremely difficult to achieve.
- Applying a “form factor adjustment”, i.e. making the carbon compliance target harder for buildings with less optimal built forms. The adjustment could be based on (e.g.) the ratio of envelope area to total floor area. The main concern is to ensure that robust factors are developed that would be appropriate across the wide percentage mix of heating/cooling/lighting and auxiliary energy found in buildings. It was suggested that much as with the dwellings fuel factor, the impact of such a form factor could be reduced by making it a weak function of envelope area/total floor area, e.g. by taking its square root (or even some higher root). It is likely that a form factor would have to vary, depending on the proportion of heat/cooling/lighting/auxiliary energy demands in the actual building. In turn, this is likely to make the task of developing robust form factors for all sizes, shapes and uses of a building very difficult, especially in the context of mixed use developments. A similar approach could be taken to deal with size as well as built form. As discussed in paragraphs 158 and 159, smaller buildings may find it harder

to meet carbon compliance standards. Therefore, if the regulations wish to recognise that smaller buildings may find it more challenging to meet the target, the carbon compliance targets could potentially be adjusted by building size.

At the zero carbon level

167 Zero carbon is an absolute carbon target (i.e. 0 $kgCO_2/m^2/yr$). There is an inherent incentive to adopt an energy efficient built form, since the designer/developer must adopt an appropriate mix of energy efficiency/energy generation strategies to meet the target at an acceptable cost, whilst still meeting all of the other requirements of the design brief. Shape and orientation are two of the tools in the designer's toolbox that will enable carbon savings. Elemental standards for fabric and systems, choice of fuels, on-building renewable energy systems and allowable solutions are the other ingredients in the mix.

168 The question remains as to relative cost/benefits of optimised shape versus allowable solutions, as there may not be sufficient differential to drive the design towards a more energy efficient shape. However, as stressed earlier, energy efficiency is only one driver of shape and form. It is a moot question as to whether the regulations should drive the design towards a particular solution rather than letting it be determined by operational practicalities and overall economics.

169 Since the zero carbon target implicitly addresses the issue of built form (to a degree at least), a question remains as to the merit of introducing an interim constraint to cover the period between 2013 and 2019. This could be achieved by adopting a CO_2 target over and above the minimum on-site carbon compliance target. Hence for Part L 2013 and Part L 2016 there would be minimum energy efficiency and carbon targets as per Part L 2010. In addition there would be a higher absolute target to be met either by additional on-site reductions or off-site 'allowable solutions'. However, we note the complexities of developing such an interim carbon standard e.g. mechanisms will need to be put in place for allowable solutions, and it is debatable that the extra cost of allowable solutions would be sufficient to incentivise action to address the building design[21].

Non-regulatory drivers

170 Although this section particularly focuses on how built form might be addressed in the regulations, consideration should always be given to the possibility of non-regulatory drivers that might be more effective and/or involve lower costs. Possible non-regulatory drivers would include:

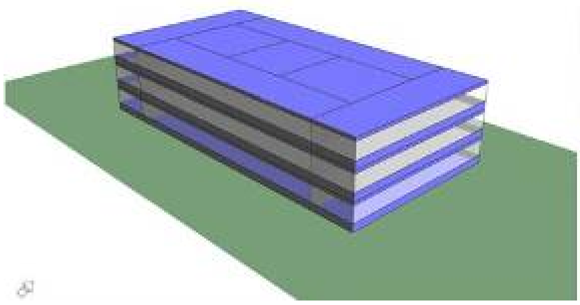
- Better design guidance on the impact of built form on energy efficiency (and space efficiency, construction cost etc).
- Emphasising that improving energy efficiency by optimising built form will improve energy performance certificate ratings and thereby, potentially enhance asset value.

Methodology: Modelling carried out

171 Three buildings, taken from the zero carbon analysis in the previous sections, have been subject to built-form modelling; the air-conditioned office, the distribution warehouse and the hotel. It should be noted that there were two types of air-conditioned office and three types of hotel in the zero carbon analysis. However since these buildings differed primarily by virtue of their built-form (number of storeys, footprint) the variations in built-form analysed in this work encompassed each of the building types.

[21] It should be noted that a similar proposal (though not specifically to address built-form) was proposed in the 2009 DCLG consultation. The early trial of allowable solutions was supported by consultees, but the concept of making this a regulatory requirement was much less popular.

172 Air-conditioned offices take up the greatest share of the build-rate and therefore most of the analysis has concentrated on this type of building. The baseline office building upon which modifications in built form have been made is based on the narrow plan, air-conditioned office analysed as part of the zero carbon work.



173 The specification of fabric and services was fixed at the minimum energy efficiency standards proposed in Section 6.

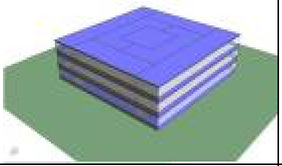
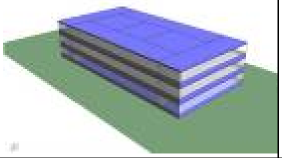
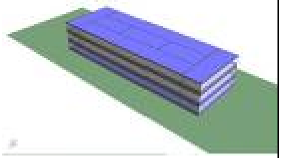
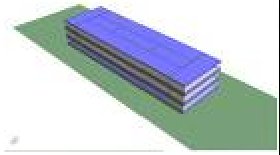
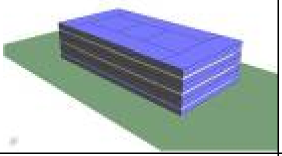
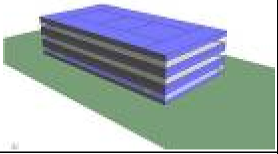
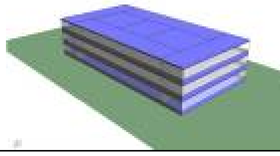
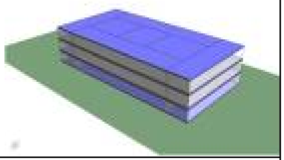
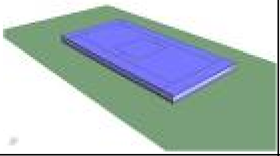
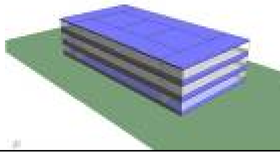
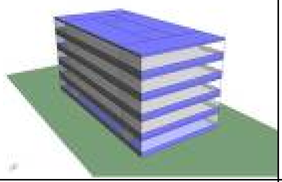
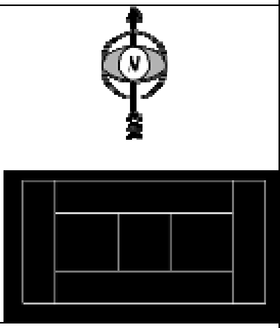
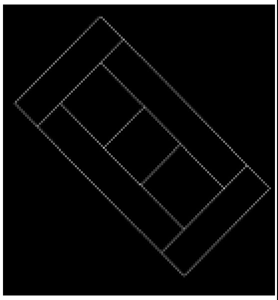
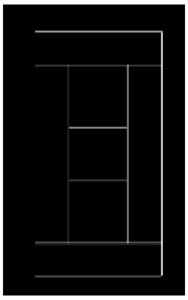
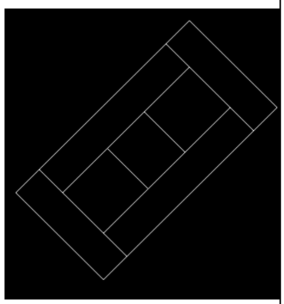
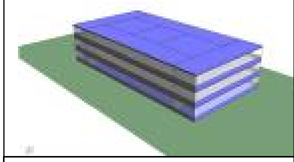
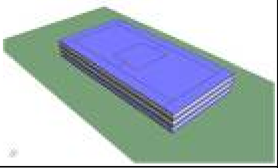
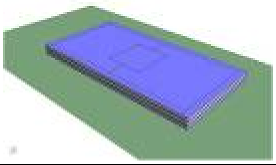
174 Five built-form variables were then tested as shown in Table 10:

- aspect ratio;
- percentage glazing;
- number of floors;
- orientation; and
- overall scale as shown in Table 10.

175 Each variable was adjusted in turn with all other variables kept fixed. The baseline building had a footprint of 3000m^2, an aspect ratio of 2:1, 60 per cent glazing, 3 floors and orientated North/South (i.e. the major building axis runs east/west).

176 In addition, the 3:1 aspect ratio office was run with natural ventilation to test the proposition that this floor plate is capable of lower carbon emissions thanks to the ability to choose a lower carbon form of servicing.

Table 10: Built-Form modelling

Aspect Ratio	 Aspect Ratio, 1:1	 Aspect Ratio, 2:1	 Aspect Ratio, 3:1	 Aspect Ratio, 4:1
Glazing %	 Glazing 20% of facade	 Glazing 40% of facade	 Glazing 60% of facade	 Glazing 80% of facade
Number of Floors	 Floors, 1	 Floors, 3	 Floors, 5	
Orientation	 Orientation, 0	 Orientation, 45	 Orientation, 90	 Orientation, 135
Scale	 Scale 1, 3000m^2	 Scale 2, 12,000m^2	 Scale 4, 48,000m^2	

177 The national calculation methodology was carried out in both SBEM and the IES Dynamic Simulation Model (DSM) in order to establish if the two different approaches value changes in built-form differently. In a further iteration, the daylight percentage calculation was carried out using the more sophisticated Radiance package within IES in addition to the standard National Calculation Methodology approach in the DSM software (which is the same as SBEM). Results are generally presented from the DSM/Radiance runs unless indicated otherwise.

CO_2 emission factors

178 It is important to note that the same 2019 projected CO_2 emission factors have been used in the built-form modelling as for the rest of the zero carbon analysis. For the sake of clarity these are:

Carbon Factors	**$kgCO_2/kWh$**
Gas	0.227
Electricity	0.412

179 An important consequence of using the 2019 projected CO_2 emission factors is that, because gas has a higher factor and electricity has a lower factor than current 2010 building regulations, built form changes that result in electricity demand reductions (daylighting for example) are less valued than savings in heating demand.

Results

180 The results from the air-conditioned office building are presented in Table 11. For each of the built-form options examined, the absolute energy demand is presented alongside the CO_2 emissions.

Table 11: Energy use and carbon emissions resulting from different built forms and servicing strategies, air-conditioned office, DSM/Radiance

							Energy demand (heat, electricity) associated with use, kWh/m²					Resultant CO_2 emissions, kg.CO_2/m²		
Description	Aspect Ratio	Glazing Type	No. Floors	Orientation	Scale	Floor Area, m²	Heating	Cooling	Aux	Lighting	DHW	Electricity	Gas	Total
Base Case	2	60	3	0	1	3004	20.6	8.2	15.2	11.9	2.9	15.7	4.7	20.4
Aspect Ratio, 1:1	1	60	3	0	1	2996	20.9	8.5	15.1	12.6	2.9	16.1	4.8	20.8
Aspect Ratio, 2:1	2	60	3	0	1	3004	20.6	8.2	15.2	11.9	2.9	15.7	4.7	20.4
Aspect Ratio, 3:1	3	60	3	0	1	2997	22.0	8.4	15.4	11.2	2.9	15.6	5.0	20.6
Aspect Ratio, 4:1	4	60	3	0	1	2993	22.6	8.5	15.6	10.9	2.9	15.6	5.1	20.7
Glazing 20%	2	20	3	0	1	3004	11.9	4.6	11.6	15.5	2.9	14.3	2.7	17.0
Glazing 40%	2	40	3	0	1	3004	16.1	6.4	13.4	13.4	2.9	14.9	3.6	18.5
Glazing 60%	2	60	3	0	1	3004	20.6	8.2	15.2	11.9	2.9	15.7	4.7	20.4
Glazing 80%	2	80	3	0	1	3004	24.8	10.1	16.8	11.9	2.9	17.2	5.6	22.8
Floors, 1	2	60	1	0	1	3004	26.0	4.8	13.1	13.8	2.9	14.2	5.9	20.1
Floors, 3	2	60	3	0	1	3004	20.6	8.2	15.2	11.9	2.9	15.7	4.7	20.4
Floors, 5	2	60	5	0	1	3004	24.9	9.9	16.3	10.4	2.8	16.3	5.7	21.9
Orientation, 0	2	60	3	0	1	3004	20.6	8.2	15.2	11.9	2.9	15.7	4.7	20.4
Orientation, 45	2	60	3	45	1	3004	21.0	8.8	16.1	11.9	2.9	16.3	4.8	21.1
Orientation, 90	2	60	3	90	1	3004	21.4	9.0	15.8	11.9	2.9	16.3	4.9	21.1
Orientation, 135	2	60	3	135	1	3004	21.2	8.7	16.1	11.9	2.9	16.3	4.8	21.1
Scale, 1	2	60	3	0	1	3004	20.6	8.2	15.2	11.9	2.9	15.7	4.7	20.4
Scale, 2	2	60	3	0	2	12015	11.8	6.0	12.7	15.2	2.9	15.1	2.7	17.8
Scale, 4	2	60	3	0	4	48060	8.5	4.8	11.2	17.2	2.9	14.9	1.9	16.8
Nat. Vent	3	60	3	0	1	3004	36.1	0.0	0.9	11.1	2.8	6.1	8.2	14.3

Discussion

Aspect ratio

181 As expected, increasingly narrow floor plans have the effect of increasing daylighting and hence reducing electric lighting. Energy use for lighting decreases by 13 per cent between an aspect ratio of 1:1 and 4:1.

182 However, increasingly narrow floor plans also result in an increase in both heating and cooling requirements (per m^2) as narrower floor plates have a greater envelope per m^2 of floor area.

183 The overall result of these two conflicting processes is broadly similar carbon emissions across the different aspect ratios. These vary from 20.4 to 20.8. $Kg.CO_2/m^2$ which is only a 2 per cent change.

184 As discussed later, the main potential advantage of narrower floor plates is the ability to choose lower carbon servicing strategies such as natural or mixed mode ventilation.

Glazing percentage

185 Also as expected, up to a certain limit, increasing glazing percentage results in greater daylighting and hence reduced electric lighting. This effect diminishes once the daylight percentage results in lighting being off for most of the day or the increase in glazing area is below working plane (as full height glazing) which does not contribute towards task lighting. Lighting energy consumption reaches a minimum at 60 per cent glazing.

186 As for aspect ratio there is a play-off between daylight, heat loss and heat gain. Higher glazing percentages result in higher heat loss and solar gain. The lowest carbon emissions were found in the 20 per cent glazed office. The reference 60 per cent glazed office had 20 per cent higher emissions. Although the results for this building model suggest greater carbon savings as the glazing area is reduced it is acknowledged that more in-depth modelling and optimisation of the façade (external shading, U-value, etc) may lead to different conclusions.

187 To some extent heat losses through glazing are mitigated by winter-time heat gains but the relatively poor U-value (2.0 W/m^2K) chosen through the zero carbon marginal abatement analysis perhaps explains why increasing glazing results in a net increase in carbon emissions. Improvements in U-value beyond 2.0 W/m^2K were deemed to be very expensive for the resultant carbon saving and were hence rejected. Similarly the performance of the lighting system is relatively good (75 luminaire lumens/watt) such that the influence of electric lighting reductions is smaller.

Number of floors

188 The scenarios examining the effect of building height sought to maintain the same floor area with increasing numbers of floors and as a consequence the building becomes progressively narrower plan as the height is increased.

- The heat loss initially decreases with storey height due to the reduction in the roof and floor areas but the heat loss then increases again as the impact of the increasingly narrow floor plan starts to dominate.
- Cooling loads increase with the number of storeys as a consequence of the greater amount of glazing per m^2 of office area.
- Auxiliary energy in SBEM changes as a secondary consequence of changes in heating and cooling loads.
- Lighting energy decreases with floor height as the building becomes narrower and daylighting is improved.

189 Overall the combination of these factors leads to highest CO_2 emissions in the taller office block where emissions are 9 per cent higher than the single storey building. This may imply that making buildings taller to increase daylight (as a result of narrower floor plates) increases emissions. Furthermore, there would be a significant increase of vertical transport emissions.

Orientation

190 Buildings orientated with their principle facades facing north/south generally have the lowest energy use of all possible orientations. This is as a result of increased access to low angle winter sun (beneficial heat gain) and the relative ease with which south orientated glazing reflects high angle summer sun. The models substantiate this rule showing a 3.4 per cent increase in emissions for other orientations.

191 Further work could be carried out to improve the benefits of the southerly orientation through improved shading design. No external shading was modelled.

Scale

192 For the scale analysis an attempt was made (as with number of floors) to fix all other parameters and hence the need to fix the number of storeys results in an increasingly deep plan building. The effect of increasing scale was therefore a fairly dramatic reduction in carbon emissions resulting from an ever greater ratio between floor plate and envelope. The smallest scale has emissions 21 per cent higher than the largest scale examined.

Servicing strategy

193 Deep plan buildings are generally incapable of being naturally ventilated since wind induced air-flows cannot generate high enough pressures to get sufficient fresh air to the centre of the building. A general rule of thumb is that single sided ventilation is only possible up to 2.5 times the floor to ceiling height and cross ventilation is possible up to five times the building height. This implies a limit to plan depth of around 12 to 15m for a naturally ventilated office[22].

194 Although the servicing strategy of a building is not directly related to built form, narrow plan buildings are more easily able to adopt lower carbon strategies such as natural ventilation and mixed mode and hence the emissions of a naturally ventilated 3:1 aspect ratio office are presented. These show emissions reductions of 30 per cent on the baseline air-conditioned office building. This is a greater carbon saving that the other aspects of built form investigated here.

Results and discussion from other buildings modelled

195 The results and a discussion of their implications for the distribution warehouse and hotel are presented below.

Distribution warehouse

196 The same built form scenarios as the office were analysed in the Warehouse with the exception of glazing area. The warehouse only features a small amount of rooflight glazing and hence it was considered that this would not significantly impact the results.

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[22] Applications Manual 10: *Natural Ventilation in Non-Domestic Buildings*, CIBSE 2005

Table 12: Energy use and carbon emissions resulting from different built forms and servicing strategies, distribution warehouse, DSM/Radiance

						Energy demand (heat, electricity) associated with use, kWh/m^2					Resultant CO_2 emissions, kg.CO_2/m^2		
Description	Aspect Ratio	Orientation	Roof type	Scale	Floor Area, m²	Heating	Cooling	Aux	Lighting	DHW	Electricity	Gas	Total
Base Case	2.5	0	1	1	5262	28.1	0.9	3.7	11.0	8.9	6.5	8.4	14.9
Aspect Ratio, 1:1	1.0	0	1	1	5253	27.2	0.9	3.7	11.5	8.9	6.6	8.2	14.8
Aspect Ratio, 1:2.5	2.5	0	1	1	5262	28.1	0.9	3.7	11.0	8.9	6.5	8.4	14.9
Aspect Ratio, 1:4	4.0	0	1	1	5912	31.9	1.1	4.8	11.0	8.9	7.0	9.3	16.2
Orientation, 0	2.5	0	1	1	5262	28.1	0.9	3.7	11.0	8.9	6.5	8.4	14.9
Orientation, 45	2.5	45	1	1	5262	28.2	0.9	3.7	11.0	8.9	6.4	8.4	14.8
Orientation, 90	2.5	90	1	1	5262	28.0	0.8	3.2	11.0	8.9	6.2	8.4	14.6
Orientation, 135	2.5	135	1	1	5262	28.2	0.8	3.6	10.9	8.9	6.4	8.4	14.8
Pitched roof	2.5	0	1	1	5262	28.1	0.9	3.7	11.0	8.9	6.5	8.4	14.9
Flat roof	2.5	0	2	1	5037	29.4	1.0	3.9	10.7	9.1	6.4	8.7	15.2
North-lights	2.5	0	3	1	5037	35.0	0.6	3.9	13.8	9.1	7.6	10.0	17.6
Double height	2.5	0	4	1	5037	70.6	0.6	4.0	11.7	9.3	6.7	18.1	24.9
Scale, 1	2.5	0	1	1	5262	28.1	0.9	3.7	11.0	8.9	6.5	8.4	14.9
Scale, 2	2.5	0	1	2	21047	24.3	0.6	2.9	10.9	8.9	5.9	7.5	13.5

197 The overall impact of built form measures in the warehouse is less significant than for the office. If the double height warehouse and larger scale warehouse (essentially different buildings) are excluded, carbon emissions range from 14.9 kg.CO_2/m^2 to 17.6 kg.CO_2/m^2 which implies that built form leads to a variation of 18 per cent on absolute emissions.

198 A more compact form (1:1 aspect ratio) leads to lower per m^2 heating loads and therefore carbon emissions. Orientation makes little difference to performance as most glazing is in the roof where orientation is unimportant. The greatest impact on CO_2 is the design of the rooflights where north-lights result in a reduction of daylight and hence increase in lighting loads. It is interesting to note that this is one area where the National Calculation Methodology already incentivises built form; the notional building has fixed glazing percentages (and U/G values) and therefore optimising these leads to percentage savings against the notional to some extent.

Hotel

199 Energy use in the hotel is very heavily dominated by domestic hot water usage. It was expected that built form would have a smaller impact on carbon emissions (at least in percentage terms) than the previous buildings. However, it was felt important to investigate a range of building types.

Table 13: Energy use and carbon emissions resulting from different built forms and servicing strategies, hotel, DSM/Radiance

						Energy demand (heat, electricity) associated with use, kWh/m^2					Resultant CO_2 emissions, $kg.CO_2/m^2$		
Description	*Aspect Ratio*	*Courtyard*	*Glazing Type*	*No Floors*	*Floor Area, m^2*	*Heating*	*Cooling*	*Aux*	*Lighting*	*DHW*	*Electricity*	*Gas*	*Total*
Base Case	2.5	N	29%	3	1920	18.9	3.4	12.6	8.4	152.7	10.0	39.0	49.0
With Courtyard	2.5	Y	29%	3	2000	28.1	2.7	14.0	6.7	146.6	9.6	39.6	49.3
Without Courtyard	2.5	N	29%	3	1888	26.6	3.3	13.6	9.1	155.3	10.7	41.3	52.0
Glazing 29%	2.5	N	29%	3	1920	18.9	3.4	12.6	8.4	152.7	10.0	39.0	49.0
Glazing 43%	2.5	N	43%	3	1920	21.7	4.3	14.2	8.4	152.7	11.1	39.6	50.7
Glazing 57%	2.5	N	57%	3	1920	28.9	4.7	15.7	7.0	152.7	11.3	41.2	52.5
No. Floors	2.5	N	29%	2	2000	28.1	2.7	14.0	6.7	146.6	9.6	39.6	49.3
No. Floors	2.5	N	29%	3	1920	18.9	3.4	12.6	8.4	152.7	10.0	39.0	49.0
No. Floors	2.5	N	29%	5	2000	20.3	2.8	12.0	6.0	146.6	8.6	37.9	46.4

200 Carbon Emissions range from a low of 46.4 $kg.CO_2/m^2$ to a high of 52.5 $kg.CO_2/m^2$ which gives a range of 13 per cent. The greatest saving here appears to be from moving to a greater number of floors leading to less roof heat loss. The occupancy profile of the hotel sees little daytime occupancy meaning that the impact of daylighting and daylight control of lighting is diminished. Like the previous two building types glazing percentage has a large impact on CO_2 with greater glazing percentages increasing emissions.

Differences between SBEM, DSM, Radiance and SBEM daylighting methodologies

201 As discussed in the methodology, each of the scenarios was run using:

- DSM software with SBEM daylighting.
- DSM software with radiance daylighting.
- SBEM alone.

202 This was to investigate if the various calculation engines value changes in built form differently.

203 The following three graphs plot energy demand calculated in the different calculation engines for heating, cooling and lighting in each of the 21 different office scenarios.

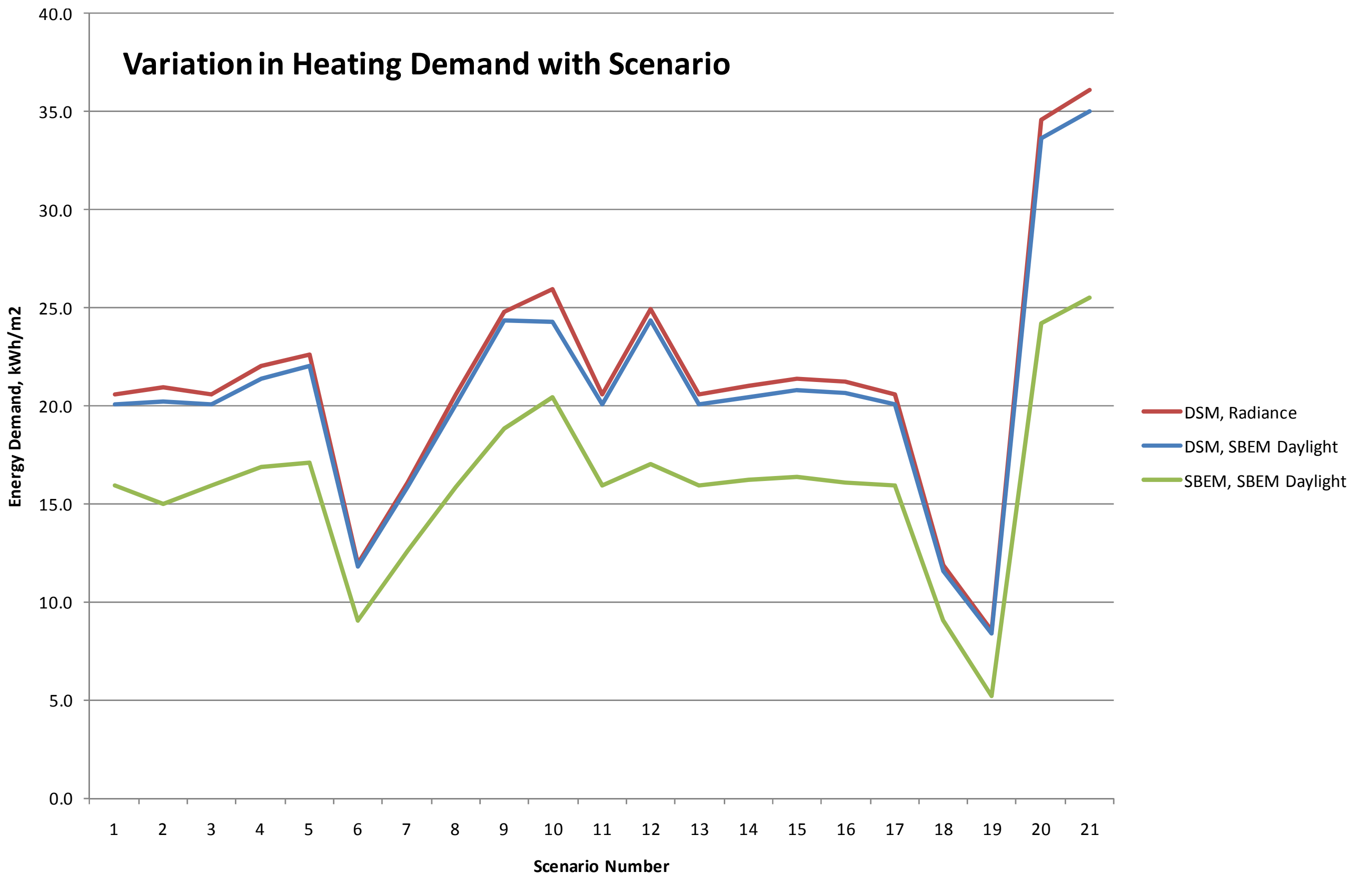

Figure 7: Variation in heating demand for different calculation engines

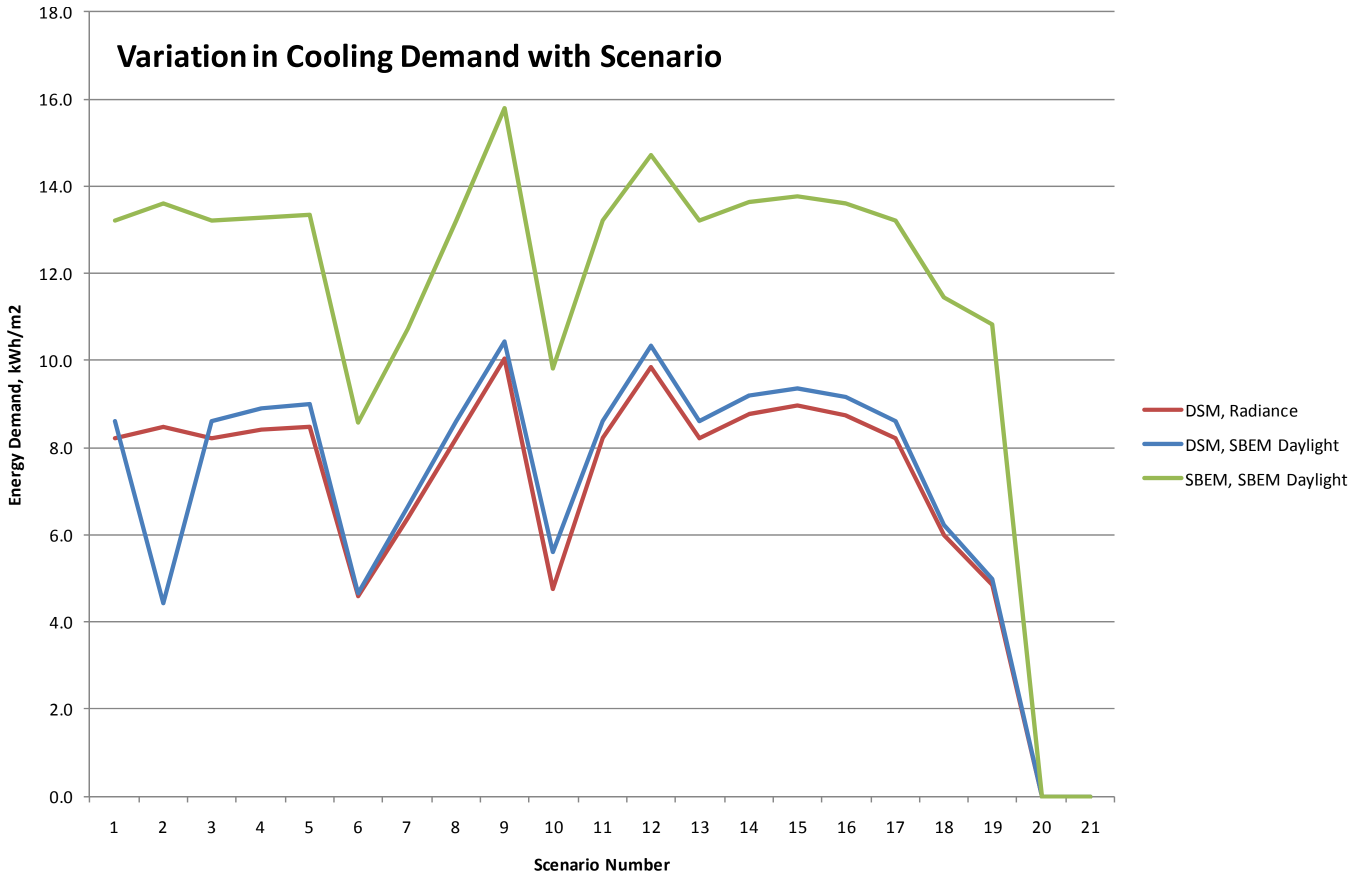

Figure 8: Variation in cooling demand for different calculation engines

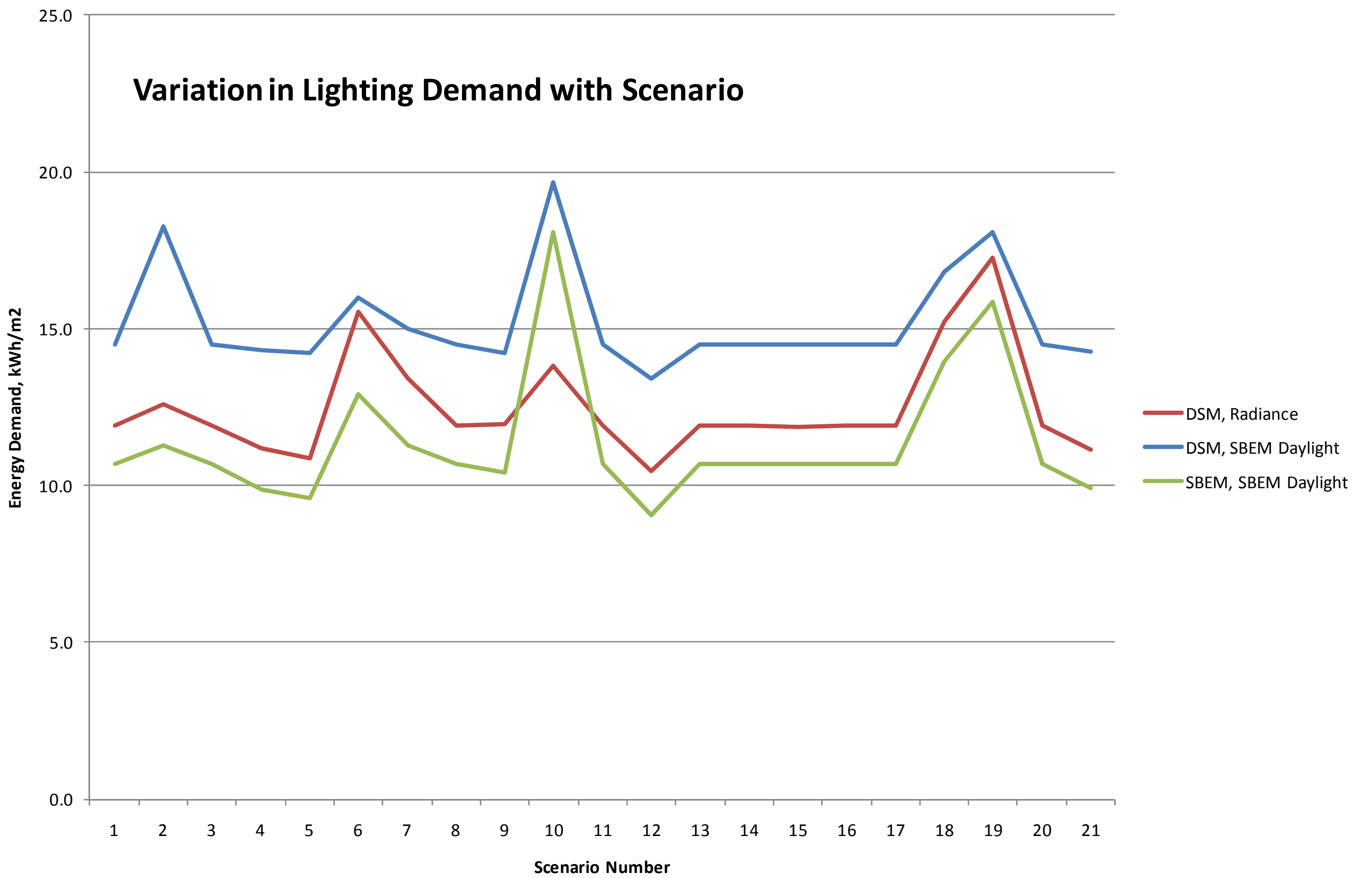

Figure 9: Variation in lighting demand for different calculation engines

204 The results show that the three engines produce broadly similar trends in energy demand as a result of changes to built form. As has been reported elsewhere SBEM tends to produce lower overall heating demand and higher cooling demand. Importantly the three engines produce very similar overall CO_2 emissions as the following graph demonstrates. The results indicate that the monthly SBEM methodology and associated simplified daylighting calculation is adequate, at least for the limited built-form scenarios modelled. As noted in the discussion of results the biggest savings appear to come from optimisation of heat gain, heat loss and daylighting. Further work would need to be carried out to establish if SBEM is sufficiently able to model complex shading topologies which were not examined in this study.

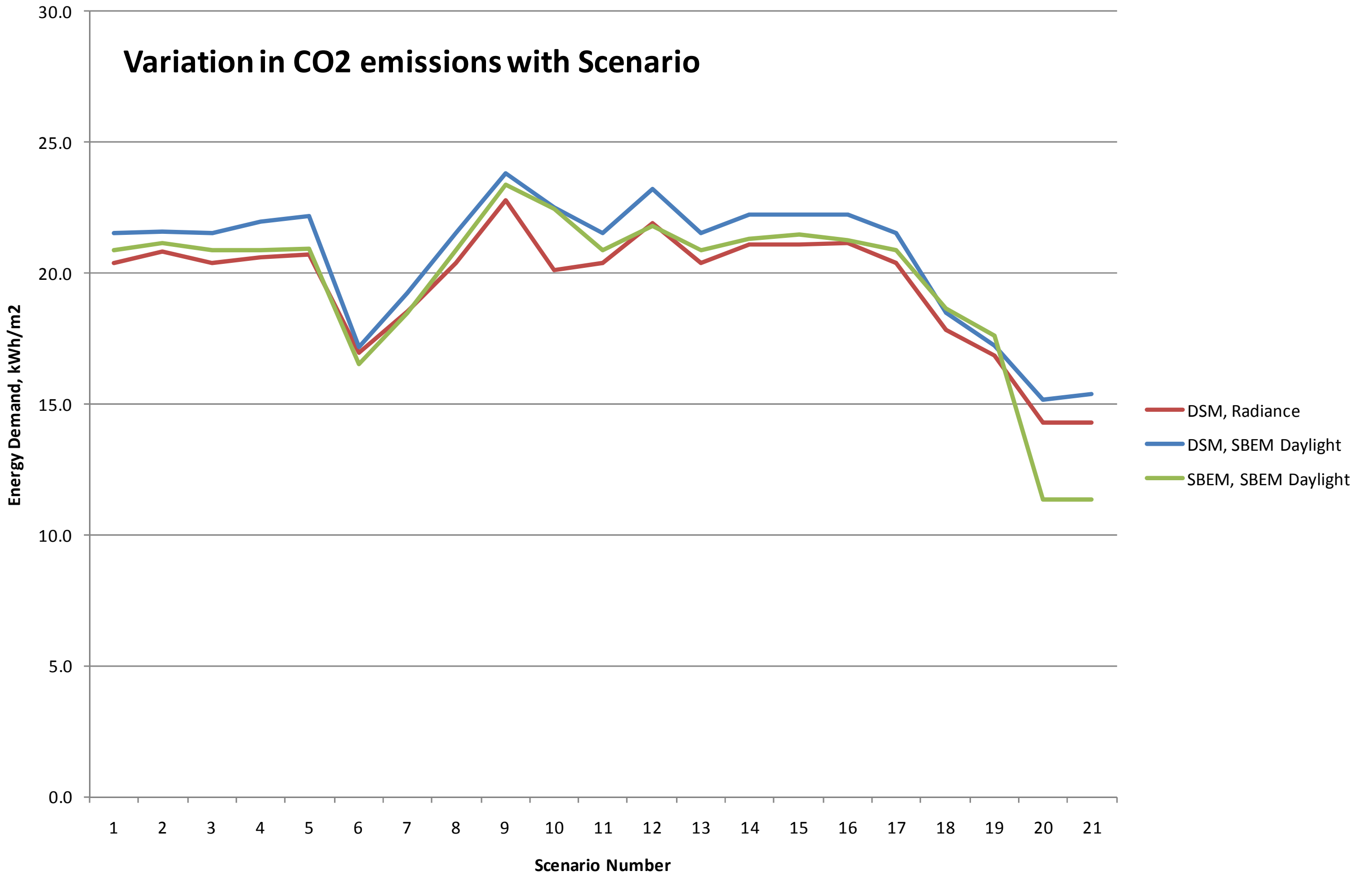

Figure 10: Variation in CO_2 emissions for different calculation engines

Built-form conclusions

Does built-form have a significant impact on CO_2 emissions?

205 Undoubtedly changes in built-form can have a large impact on carbon emissions although this depends on the building type and the services strategy employed. In general the modelling found that lower glazing percentages and larger floor to façade ratios resulted in lower emissions at least where an air-conditioning services strategy is maintained.

How might built form be incentivised?

206 The results of increasing the glazing ratio suggest that introducing a simple daylight performance standard within building regulations would not necessarily lead to CO_2 emissions savings. The results from this study showed that benefits from greater daylighting were outweighed by increases in conduction losses and the need to treat solar gains. The optimum amount of daylighting will depend on the building. However, the work demonstrates that by setting a simple standard based, say, on a minimum amount of daylight may lead to greater carbon emissions for at least some buildings. The results suggest that high performance electric lighting assumed for Part L 2019 may, in some circumstances, be as efficient as daylighting once direct heat gains and losses are taken into consideration although this is clearly not always the case in practice particularly where the façade has been carefully optimised.

207 This is not to say therefore that a minimum daylight performance standard could not be set. However, further work would be needed in order to develop a daylight performance standard which may not be in a simple form or simple to develop as it would have to appropriately address the range of non-domestic building types and the complexity of façade related issues.

208 Interestingly the National Calculation Methodology already incentivises this optimisation to a certain extent since the National Calculation Methodology notional building has fixed glazing characteristics that can be improved upon. The extent to which SBEM is able to model this optimisation needs further investigation.

209 Zero Carbon policy also incentivises built-form since the requirement is for zero carbon emissions. A more efficient built-form will reduce carbon emissions and help achieve this target. However, this is unlikely to be a sufficient incentive. The 17 per cent saving in the office building from optimising the glazing percentage would result in the need for less allowable solutions. This would amount to an allowable solutions saving for a developer of £8/m^2 if allowable solutions were valued at £75/tonne over a 30 year life. This is unlikely to incentivise a design team to change the glazing design.

Should built form be incentivised?

210 The complex interaction of built-form elements on overall CO_2 emissions means that a built-form parameter in Building Regulations would be difficult to implement and may lead to perverse outcomes. Because of the real danger of perverse outcomes, it is recommended that no specific incentive for built-form be included in the target setting mechanism. It is clear from the analysis that optimisation of façade design is the area most likely to yield savings. This is already incentivised to some extent through the National Calculation Methodology though the ability of software to reflect this requires further investigation. Improved education of building designers on the impact of façade design on Part L compliance is recommended.

Should a lower carbon servicing strategy be incentivised?

211 Large carbon reductions from changes to built-form occur where the building form results in the ability to implement a lower carbon servicing strategy such as natural ventilation or mixed mode. The office shows a 30 per cent drop in emissions from the adoption of natural ventilation. At present the National Calculation Methodology does not incentivise this approach since the notional building has the same servicing strategy as the actual building.

212 A report by the Carbon Trust[23] which examines how the UK can get to the 80 per cent target cut in carbon emissions by 2050 emphasises the importance of absolute demand reductions in new buildings through such measures as lower carbon servicing strategies. The UK renewables resource is finite and hence would not be able to meet ever increasing building energy demands. The Carbon Trust report recommends that two-thirds of buildings need to be narrow plan and naturally ventilated by 2020.

213 At present the energy performance certificate methodology already incentivises a lower carbon servicing strategy in that the reference building (the energy performance certificate equivalent of the notional building) is mixed mode. One approach may be to adopt this strategy for building regulations in 2013. Care would need to be taken, however, to ensure that buildings requiring cooling were given alternative routes to compliance.

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[23] *Building the Future Today*, Carbon Trust 2009.

8 Cost benefit analysis

Introduction

214 This section presents the results of the cost benefit analysis undertaken by Europe Economics.

215 The methodology adopted was similar to that presented in the impact assessment on the definition of zero carbon non-domestic buildings published in November 2009. Essentially, it comprised a two-stage approach:

- **Stage 1:** The scope for reducing emissions in a range of new buildings using energy efficiency and low and zero carbon technology options was assessed. Cost curves for carbon reduction were compiled using capital cost data from published sources and industry based estimates. These cost curves were developed by AECOM and the information has already been presented in Section 4.
- **Stage 2:** The information in these costs curves was used as inputs to a cost benefit model (i.e. the capital costs of achieving these reductions, the energy saved and the associated CO_2 reductions). This provided aggregate estimates of social costs and benefits across all new non-domestic buildings. This work was undertaken by Europe Economics.

216 Key outputs presented in this section include:

- Proposals for carbon compliance for the trajectory to zero carbon (i.e. carbon emissions standards for 2013, 2016 and 2019).
- The cost and benefits associated with each trajectory.
- The volume of carbon saved for each trajectory.

217 This section is divided into two parts:

- Key assumptions used for the Stage 2 analysis are presented. Many have been updated since the November 2009 IA.
- The results of the analysis.

Key assumptions

Building types

218 Seventeen building types were analysed as detailed in Section 3.2. This included (unlike the November 2009 IA analysis) six public building types.

Build rates

219 In order to move from the analysis of individual buildings to an aggregate view for all new build it is necessary to make assumptions about the rate of new build for each of the building types analysed. Given the uncertainty in looking at building rates as far ahead as 2031 any assumptions can only be indicative of possible outcomes and not definitive projections.

220 The build rates assumed in the November 2009 IA have been retained. These were based on analysis by the Building Research Establishment of building rates over the past decade. This suggested that there had been an average annual building rate of about 8.2 million square metres. Over 40 per cent of this was accounted for by deep plan office space, over 35 per cent by warehouses and over 10 per cent by retail units. We have made separate assumptions about build rates for the new categories of public sector buildings based on the floor area of the existing stock giving an annual build rate of 1.2 million square metres for the public sector buildings included in the analysis.

221 For most building types we have assumed 40 per cent of new build (by floor area) will be linked to district heating schemes with the remainder being stand alone. In four categories – shallow plan heated offices, defence buildings, prisons and country hotels – no district heating has been assumed. Non-urban buildings are assumed to have the option of using either woodchip or pelleted biomass fuel. It must be emphasised that these build rates and the split between stand alone and district heating only provide an indicative breakdown between categories.

Costings

222 **Energy efficiency measures and low and zero carbon technologies:** The capital cost of improving energy efficiency from improved fabric and building services and the capital and maintenance costs for low and zero carbon technologies is presented in Section 3.2. The 2010 cost of biomass fuel is assumed to be £0.0195/kWh for wood chip, and £0.033/kWh for wood pellets.

223 **Learning effects:** Learning effects for the use of low and zero carbon technologies are presented in Section 3.2

224 **Allowable solutions:** To achieve net zero carbon emissions on-site through energy efficiency and carbon compliance can be prohibitively expensive and often not technically possible, In these circumstances there will need to be investment in further emissions reduction, beyond the on-site minimum requirement, to meet the zero carbon standard through (predominantly) offsite measures These other investments, collectively described as ‘allowable solutions’, have not been specified in detail but DCLG has advised that a generic net cost of £75/tonne CO_2 should be included in the analysis. In addition to this cost, allowable solutions are credited with a CO_2 reduction split equally between reduced gas and fossil fuel electricity usage.

225 **Energy and carbon values:** In order to estimate the full social costs and benefits of the scenarios it is necessary to put values on the energy savings, CO_2 reductions and other impacts over the lives of the assets covered by the policy. The Department of Energy and Climate Change publishes guidance on the appropriate values to be used prepared by the interdepartmental analysts group. We have used the relevant values from the version of this guidance published in June 2010[24]. For the main analysis the central fuel price and carbon values have been used.

Cost benefit modelling

226 The cost benefit model takes the energy savings and associated emissions reductions identified for each building type together with the costs of achieving those reductions and estimates the social costs and benefits which would result if those changes were aggregated across all new non-domestic build over a period of years.

227 For the reference case and each policy option it is assumed that the policy will be operative for 10 years after the point at which the zero carbon target becomes a requirement for new

[24] *Valuation of energy use and greenhouse gas emissions for appraisal and evaluation*, DECC June 2010

build in 2019. Allowing for a two-year build time, this means that new buildings completed up to 2031 are included in the analysis

228 The savings and costs are estimated over the life of each asset and are all relative to a Part L 2010 energy and emissions baseline. No allowance is made for the replacement of assets at the end of their life. For building fabric and services assumed lives range between 15 and 60 years, for low and zero carbon technologies the assumed life is between 15 and 25 years depending on the technology.

229 Gas and electricity savings as a result of the policy are valued at the variable element of the respective commercial price, in line with the interdepartmental analysts group guidance. Carbon savings arising from reductions in gas consumption are valued at the price of non-traded carbon provided in the interdepartmental analysts group guidance, while carbon savings from reductions in electricity consumption are valued at the EU Emission Trading Scheme permit price.

230 The 2010 interdepartmental analysts group guidance also contains provision for attributing an additional value to reductions in energy consumption which reduces the level of delivered renewable energy the UK is required to achieve in 2020. In line with the guidance, a value of £18/MWh is attributed to the avoided costs of renewables. This is only counted as a benefit up to 2020, the year set for achieving the target.

231 In assessing the impact of a zero carbon policy it is important to differentiate between reductions in emissions which can be attributed to that policy and reductions which would have occurred anyway in response to other pre-existing policy initiatives. For the counterfactual of what would occur even without the zero carbon policy, estimates have been incorporated into the model based on assumptions agreed with DCLG about the impact of other policies. The 25 per cent CO_2 reductions proposed for 2010 under the Part L and F Consultation is assumed to be implemented and the costs and benefits from this, modelled using the aggregate 25 per cent approach. This provides the reference case against which the policy options are compared.

232 Other policies that have been quantified in the counterfactual include the Carbon Reduction Commitment, the Energy Performance of Buildings Directive, and the impacts of smart metering and the market transformation programme. Where relevant, the effects of these policies have been split into the impacts on regulated gas use, regulated electricity use and unregulated electricity use.

233 The gross values of carbon savings estimated for moving from the reference case to the alternative zero carbon policy options have been reduced by the value of carbon savings attributed to these other policies. The estimated gross cost of carbon compliance measures in new buildings and additional allowable solutions to meet the zero carbon targets also needs to be adjusted to reflect costs that would be incurred in response to these other policies. Overall reductions of approximately 19 per cent have been incorporated into the final analysis. These reductions are related to the levels of carbon savings attributed to other policies.

Results

234 Costs and benefits have been estimated for three scenarios each representing different trajectories for moving to the full zero carbon target in 2019. These are compared with the baseline of the 25 per cent CO_2 reduction built into the 2010 revisions to Part L of the Building Regulations:

- Low scenario: this prioritises the new building’s contribution to off-site measures by setting lower carbon compliance targets and increasing the use of allowable solutions.
- Medium scenario: this sets more stretching on-site measures, and deploys allowable

solutions for the remaining emissions.

- High scenario: this sets the most stretching target for on-site measures, and deploys allowable solutions for the remaining emissions.

235 The three scenarios are summarised in Table 14.

Table 14: Trajectories on the path to zero carbon

	2010 – 2013	2013 – 2016	2016 – 2019	2019 – 2029 regulated energy
Low scenario				
Target reduction at building level – regulated energy (%)	25%	32%	38%	44% + allowable solutions
Medium scenario				
Target reduction at building level – regulated energy (%)	25%	33%	41%	49% + allowable solutions
High scenario				
Target reduction at building level – regulated energy (%)	25%	35%	44%	54% + allowable solutions

Low scenario

236 Under the low scenario the stepping stones to meeting the zero carbon target are a 32 per cent aggregate reduction in carbon compliance standard from 2013, 38 per cent from 2016 and 44 per cent plus allowable solutions to reach zero carbon (100 per cent regulated energy) from 2019.

237 The target carbon compliance reductions for individual building types under the low scenario are shown in Table 15. It is assumed that from 2019 onwards, the remaining regulated emissions not addressed through carbon compliance are abated through allowable solutions.

Table 15: Assumed regulated emissions reductions by building type, energy efficiency and carbon compliance – low scenario

Building type	2013	2016	2019
Deep Plan Office Air Con	21%	25%	29%
Shallow Plan Office Air Con	27%	28%	35%
Shallow Plan Office Heated	28%	38%	50%
High Street Retail	12%	12%	12%
5 Star Hotel	19%	24%	29%
Out-of-town Supermarket	12%	12%	12%
Retail Warehouse	42%	53%	57%
Distribution Warehouse	54%	63%	68%
Acute Hospital	30%	37%	45%
Cultural	21%	23%	25%
Defence	42%	46%	51%
Prison	62%	70%	76%
Secondary School	30%	34%	42%
Primary School	19%	33%	48%
3 Star Hotel	26%	32%	40%
Country Hotel	31%	51%	66%
Mini Supermarket	12%	12%	12%
Aggregate reduction	32%	38%	44%

238 Table 16 sets out the costs and benefits associated with the low scenario using energy efficiency and carbon compliance for reductions up to the 44 per cent target level and allowable solutions to achieve the zero carbon target from 2019. This table show the incremental costs and benefits of each step towards achieving the full zero carbon target relative to the Reference case of continuing with the 25 per cent target from 2010 onwards.

239 All values are expressed in net present value terms. The final total covers the incremental costs and benefits associated with new non-domestic buildings started in the period 2013 to 2029. Energy and emissions savings from buildings started prior to 2013 are attributable to the planned changes to Part L of the Building Regulations and are taken into account in the Reference Case. The costs and benefits have been adjusted for the estimated impact of other policies already in place (see paragraphs 231 to 233 above).

240 This analysis shows that over the policy period up to 2029 the incremental cost of the low scenario would be about £2.8bn net present value. This would be partly offset by energy savings valued here at just under £1bn net present value. There is a further benefit of just over £4.0bn attributable to the value of CO_2 reductions. This results in a net benefit for the low scenario of about £2.2bn net present value.

Table 16: Costs and benefits relative to 2010 reference case – low scenario £m net present value

	2010 – 2013	2013 – 2016	2016 – 2019	2019 – 2029 regulated energy		Total
Target reduction regulated (%)	25%	32%	38%	44%	Allowable solutions	
Target reduction unregulated (%)	0%	0%	0%			
Energy savings	0	86	195	749	0	945
Incremental costs	0	(134)	(230)	(1,207)	(1,383)	(2,819)
Sub-total	0	(48)	(35)	(457)	(1,383)	(1,874)
Carbon savings - ETS	0	4	20	76	1,893	1,988
Carbon savings - non-ETS	0	23	20	48	1,953	2,020
Total carbon savings	0	27	40	124	3,845	4,008
Net benefit/cost excl. avoided renewables	0	(21)	5	(333)	2,463	2,134
Avoided renewables	0	7	36	0	0	36
Net benefit/cost incl. avoided renewables	0	(14)	41	(333)	2,463	2,170

Medium scenario

241 Under the medium scenario the steps towards meeting the zero carbon target are a 33 per cent aggregate reduction in CO_2 from 2013, 41 per cent from 2016 and 49 per cent plus allowable solutions to reach zero carbon (100 per cent regulated) from 2019.

242 The target carbon compliance reductions for individual building types under the medium scenario are shown in Table 17. It is assumed that from 2019 onwards, the remaining regulated emissions not addressed through carbon compliance are abated through allowable solutions.

Table 17: Assumed regulated emissions reductions by building type, energy efficiency and carbon compliance – medium scenario (same as Table 5)

Building type	2013	2016	2019
Deep Plan Office Air Con	21%	26%	33%
Shallow Plan Office Air Con	27%	32%	40%
Shallow Plan Office Heated	30%	43%	62%
High Street Retail	12%	12%	12%
5 Star Hotel	20%	26%	33%
Out-of-town Supermarket	12%	12%	19%
Retail Warehouse	44%	54%	60%
Distribution Warehouse	55%	66%	72%
Acute Hospital	31%	40%	55%
Cultural	21%	24%	29%
Defence	42%	48%	56%
Prison	65%	72%	82%
Secondary School	30%	36%	47%
Primary School	23%	57%	60%
3 Star Hotel	27%	34%	53%
Country Hotel	34%	56%	72%
Mini Supermarket	12%	12%	17%
Aggregate reduction	33%	41%	49%

243 Table 18 sets out the costs and benefits associated with the medium scenario using energy efficiency and carbon compliance for reductions up to the 49 per cent target level and allowable solutions to achieve the zero carbon target from 2019. This table show the incremental costs and benefits of each step towards achieving the full zero carbon target relative to the Reference case of continuing with the 25 per cent target from 2010 onwards. The costs and benefits attributable to allowable solutions are shown separately.

244 This analysis shows that over the policy period up to 2029 the incremental cost of the medium scenario would be about £3.5bn net present value. This would be partly offset by energy savings valued here at £1.3bn net present value. There is a further benefit of just under £4bn attributable to the value of CO_2 reductions. This results in a net benefit for the medium scenario of about £1.7bn net present value.

Table 18: Costs and benefits relative to 2010 reference case – medium scenario £m net present value

	2010 – 2013	2013 – 2016	2016 – 2019	2019 – 2029 regulated energy		Total
Target reduction regulated (%)	25%	33%	41%	49%	Allowable solutions	
Target reduction unregulated (%)	0%	0%	0%			
Energy savings	0	103	236	1,081	0	1,317
Incremental costs	0	(145)	(297)	(1,894)	(1,258)	(3,448)
Sub-total	0	(42)	(61)	(813)	(1,258)	(2,131)
Carbon savings - ETS	0	6	25	111	1,764	1,899
Carbon savings - non-ETS	0	23	22	42	1,820	1,884
Total carbon savings	0	30	47	152	3,584	3,783
Net benefit/cost excl. avoided renewables	0	(12)	(14)	(660)	2,327	1,652
Avoided renewables	0	17	43	0	0	43
Net benefit/cost incl. avoided renewables	0	4	28	(660)	2,327	1,695

High scenario

245 Under the high scenario the steps to meeting the zero carbon target are a 35 per cent aggregate reduction in carbon compliance standard from 2013, 44 per cent from 2016 and 54 per cent plus allowable solutions to reach zero carbon (100 per cent regulated) from 2019.

246 The target carbon compliance reductions for individual building types under the high scenario are shown in the table below. It is assumed that from 2019 onwards, the remaining regulated emissions not addressed through carbon compliance are abated through allowable solutions.

Table 19: Assumed regulated emissions reductions by building type, energy efficiency and carbon compliance – high scenario

Building type	2013	2016	2019
Deep Plan Office Air Con	22%	29%	36%
Shallow Plan Office Air Con	27%	35%	45%
Shallow Plan Office Heated	34%	50%	73%
High Street Retail	12%	12%	14%
5 Star Hotel	22%	29%	35%
Out-of-town Supermarket	12%	12%	26%
Retail Warehouse	46%	57%	63%
Distribution Warehouse	57%	68%	75%
Acute Hospital	33%	45%	58%
Cultural	22%	25%	31%
Defence	43%	51%	60%
Prison	68%	76%	86%
Secondary School	31%	42%	52%
Primary School	25%	48%	66%
3 Star Hotel	28%	40%	63%
Country Hotel	38%	66%	73%
Mini Supermarket	12%	12%	22%
Aggregate reduction	35%	44%	54%

247 Table 20 sets out the costs and benefits associated with the high scenario using energy efficiency and carbon compliance for reductions up to the 54 per cent target level and allowable solutions to achieve the zero carbon target from 2019. This table show the incremental costs and benefits of each step towards achieving the full zero carbon target relative to the Reference case of continuing with the 25 per cent target from 2010 onwards.. The costs and benefits attributable to allowable solutions are shown separately.

248 This analysis shows that over the policy period up to 2029 the incremental cost of the high scenario would be just over £4bn net present value. This would be partly offset by energy savings valued here at £1.6bn net present value. There is a further benefit of £3.7bn attributable to the value of CO_2 reductions. This results in a net benefit for the high scenario of about £1.2bn net present value.

Table 20: Costs and benefits relative to 2010 reference case – high scenario £m net present value

	2010 – 2013	2013 – 2016	2016 – 2019	2019 – 2029 regulated energy		Total
Target reduction regulated (%)	25%	35%	44%	54%	Allowable solutions	
Target reduction unregulated (%)	0%	0%	0%			
Energy savings	0	136	307	1,322	0	1,628
Incremental costs	0	(169)	(458)	(2,529)	(1,159)	(4,146)
Sub-total	0	(33)	(151)	(1,207)	(1,159)	(2,517)
Carbon savings - ETS	0	11	35	138	1,693	1,866
Carbon savings - non-ETS	0	23	20	35	1,747	1,802
Total carbon savings	0	34	55	174	3,439	3,668
Net benefit/cost excl. avoided renewables	0	1	(96)	(1,033)	2,280	1,151
Avoided renewables	0	17	54	0	0	54
Net benefit/cost incl. avoided renewables	0	17	(42)	(1,033)	2,280	1,205

Conclusions from the analysis of the three scenarios

249 As can be seen in the tables above, all three scenarios considered in the cost-benefit analysis, i.e. the low, medium and high scenarios, yield a net benefit when carbon savings are taken into account. However, when looking at the net financial cost, i.e. before carbon savings are taken into account, all three scenarios result in a net cost.

250 Unsurprisingly, as the trajectories get tougher, moving from the low to the high scenario, the net financial cost increases, and the net benefit of the policy overall decreases. Interestingly, the converse is true for the ranges considered for the 2013 step (32 per cent in the low scenario, 33 per cent in the medium scenario, and 35 per cent in the high scenario), i.e. as the carbon compliance target for 2013 is made tougher the policy becomes more beneficial over the period 2013-15. This result arises because the technology choices to meet the carbon compliance targets have been optimised based on capital costs only; therefore, while the ordering of technologies is optimal in terms of capital costs, the ordering may be somewhat different when lifecycle costs and benefits are taken into account.[25,26]

[25] For example, looking at the capital cost curve for the distribution warehouse, biomass heating appears very early on before technologies such as daylight control, because biomass heating is a very cost-efficient technology based on capital cost alone. However, when considering the lifecycle cost curve for the distribution warehouse, biomass

251 Overall, the low scenario yields the highest net benefit over the policy period.

Cost effectiveness

252 The three scenarios can be compared using a measure of cost effectiveness. This (calculated in line with the interdepartmental analysts group guidance) provides an indicative measure of the cost per tonne of CO_2 in the Emissions Trading Scheme (ETS) and non-Emissions Trading Scheme sectors. The values shown in Table 21 broadly follow the findings described above from the main cost-benefit tabulations. The policy shows greater cost effectiveness, (i.e. lower values), the less onerous are the carbon compliance standards in the years up to 2019.

Table 21: Cost effectiveness of zero carbon policy options - £/tCO_2

	Low	Medium	High
Non-traded (£/tCO_2)	(10)	19	54
Traded (£/tCO_2)	(3)	5	16

Reductions in CO_2

253 Table 22 shows the estimated reductions in the volumes of CO_2 that might be achieved in each policy period under the three policy options over and above reductions achieved in the 2010 baseline. These volumes have been estimated over the life of the assets covered by the policy.

heating does not appear and daylight control appears much earlier in the curve because relatively large energy savings can be achieved for little cost over the lifecycle of the asset.

[26] Further work would need to be done when making regulatory changes to assess the real impact of equal £/m^2 costs in relation to different £/m^2 build costs for different building types, and on different sectors (i.e. where building costs make up a business's costs to a greater or lesser degree). The method of equalising costs by m^2 was considered a proportionate approach for this stage of development work.

9 Conclusions

Table 22: Volume of CO_2 reduced in each policy period relative to baseline. $mtCO_2$

		2013 (3 years)	2016 (3 years)	2019 (10 years incl allowable solutions)
Low	Non-traded	1	1	10
	Traded	0	1	76
Med	Non-traded	1	1	10
	Traded	0	2	74
High	Non-traded	1	1	11
	Traded	3	2	73

Scope of energy efficiency standard

254 As recommended in Section 2, the energy efficiency standard should be based on an appropriate envelope specification, with a separate set of minimum efficiencies for the main services equipment. This integrates with the design process as fabric measures are the principal domain of the architect whereas the services measures are the principal domain of the services engineers.

255 In contrast to the domestic fabric energy efficiency standard, the envelope standard should focus on achieving an appropriate balance between reducing space heating, space cooling and electric lighting demand. This is because of the significant energy consumed from the use of electric lighting in many non-domestic buildings and the role of delivering better day-lighting through improved fabric design to reduce this energy consumption.

256 It is important to also set minimum building service efficiency levels. The energy demand should be met efficiently through high efficiency equipment that is effectively controlled. This is being addressed through the implementation of the Energy Related Products Directive which will set minimum European-wide building service efficiencies. It is understood that the efficiencies for many (if not all) building services will need to be transposed into national law by 2019. DCLG may wish to improve upon these efficiency values in Part L 2019. Furthermore, prior to transposition, it is proposed that DCLG continues to adopt minimum elemental performance standards as currently used in Part L.

Metric of energy efficiency standard

257 On balance, Section 2 proposes that a set of minimum elemental standards offers the best overall approach to standard setting. This is a continuation of the traditional approach in Part L. Furthermore, it constrains the performance of the envelope in practical design terms that can be readily understood by all members of the industry. In contrast to the domestic performance-based (fabric energy efficiency standard) approach, it is difficult to determine a small set of absolute values ($kWh/yr/m^2$) given the wide variation of building types and end uses and difficult to apply an absolute approach given the multiple non-domestic compliance tools which predict different energy and carbon performance for the same building model.

258 A potential benefit of the absolute approach is that is does allow the benefit from a more efficient built form. However, it is unclear whether it is necessary to incentivise more energy efficient built form and, if so, how to apply it in a sensible manner that is appropriate for the range of non-domestic building types and takes into account other commercial and functional factors that influence built-form. The built form analysis that has been undertaken (see below) suggests that it would be difficult to incorporate a built-form parameter into the target setting process in a suitably robust form.

Minimum elemental energy efficiency values

259 The values proposed here are for Part L 2019. We would not necessarily propose these values for Part L 2013 or Part L 2016.

260 **Fabric:** Overall, the analysis suggests that the maximum fabric U-values should remain as currently implemented in Part L 2010. There appears little, if any, benefit in increasing the minimum standards further. Further consideration is necessary as to the minimum standards for air permeability and thermal bridging. There is currently a lack of robust cost data on achieving different standards of performance and it would be helpful to engage further with stakeholders on this.

261 **Services:** Overall, the analysis suggests that improvements to the efficiencies of building services provide a cost-effective means of meeting zero carbon. In practice, the minimum energy efficiency values will be significantly influenced by the Energy Related Products Directive. This is expected to require national implementation of new system-based building services energy assessment methodologies and minimum standards of performance prior to 2019, although we may choose to select higher minimum standards of performance. In the absence of the new approach, we have proposed component-based minimum performance criteria as currently used in Part L.

262 **Built-form:** The built-form analysis does not support the adoption of a built-form parameter (such as a daylighting standard) in the zero carbon definition. The interaction of built form elements is too complex to implement through the National Calculation Methodology and is likely to lead to perverse outcomes. Improved education of building designers on the impact of façade design on Part L compliance is recommended.

263 **Servicing Strategy:** There is clearer evidence that adoption of natural ventilation and mixed mode servicing strategies in buildings leads to large carbon savings that are not currently incentivised by Building Regulations. Adoption of the energy performance certificate methodology whereby the notional building is mixed mode may be a suitable approach. This has the secondary effect of incentivising built form in that very deep plan buildings are generally unable to be serviced in this way and the reduction of close mechanical temperature control requires building designers to consider passive design in a more intelligent way to minimise overheating. The Carbon Trust *Building the Future Today* report on pathways to 2050 emphasises the need for a much larger percentage of the new build stock to be serviced in a way that reduces overall demand for electricity.

Carbon compliance target values

264 Sections 5 and 8 propose carbon compliance target values for Part L 2019 for a range of building types, as well as providing an indication of carbon emission standards for Part L 2013 and Part L 2016. The percentage improvements in carbon reductions vary between building types based on achieving a similar cost of compliance. £1 spent on carbon mitigation results in different carbon savings in different buildings.

265 Section 5 also outlines further refinements necessary to the Part L 2019 compliance targets:

- More detailed analysis of significant sector specific energy uses.
- Sensitivity analysis should be undertaken to understand the influence of different choices of building models for each non-domestic sector on the results.
- The inclusion of any new regulated energy demands as they are introduced into Part L compliance calculations.
- Updating targets in line with changes to the National Calculation Methodology, including the carbon emission factors.
- Updating targets in line with actual (as opposed to predicted) trends in element performance and cost.
- The building targets will need to be specified in a simpler form that can be applied in a useable manner across all types of buildings.

266 Furthermore, it is expected that the underpinning cost benefit analysis will need to be refined. Whilst the current analysis was appropriate for this stage of development work, more detailed analysis is expected prior to making regulatory change to more accurately represent the cost to business.

Cost benefit analysis

267 All three scenarios considered in the cost-benefit analysis, i.e. the low, medium and high scenarios, yield a net benefit when the social value of carbon savings is taken into account. The low scenario results in a net benefit of about £2.2bn (over the policy period), the medium scenario results in a net benefit of about £1.7bn, while the high scenario yields a net benefit of £1.2bn. However, when looking at the net financial cost, i.e. before carbon savings are taken into account, all three scenarios result in a net cost.

10 Glossary

BER	Building Emission Rate (the Building Emission Rate must be less than or equal to the Target Emission Rate for Part L compliance)
COP	Coefficient of Performance
DSM	Dynamic Simulation Model (suitably approved DSM software can be used to assess Part L compliance)
G-value	A measure of the transmission of solar radiation through a glazed element. The higher the g-value, the greater is the solar transmittance through that element.
LZC	Low and zero carbon technology
NCM	National Calculation Methodology (the system of rules for calculating the BER and TER for buildings)
SBEM	Simplified Building Energy Model (software tool for calculating BER and TER to assess Part L compliance)
SEER	Seasonal Energy Efficiency Ratio
TER	Target Emission Rate (the maximum level of carbon emissions to comply with Part L)
TFA	Total Floor Area
U-value	A measure of the conduction of heat across a fabric element. The higher the u-value, the greater is the rate of heat loss through that element

Appendix A – Cost data

Table A.1: Fabric Costs

Element	Reference		Level A		Level B		Level C	
	Target value	Average Cost	Target value	Incremental Cost	Target value	Incremental Cost	Target value	Incremental Cost
Roofs (£/m²)								
Composite Panel System	U = 0.25	80	U = 0.2	3	U = 0.15	5	U = 0.1	10
Profiled Metal		98		8		11		19
Flat		158		6		9		11
Walls (£/m²)								
Masonry Cavity	U = 0.35	108	U = 0.25	3	U = 0.2	8	U = 0.15	19
Lightweight Metal Frame (LMF)		327		3		4		7
Composite Facade Systems		75		3		6		7
Floors (£/m²)								
Solid	U = 0.25	100	U = 0.2	2	U = 0.15	7	U = 0.1	15
Suspended		84		3		8		14
Windows and Rooflights	U = 2.0 g = 0.7 T_L = 0.8	153	U = 1.6 g = 0.41 TL = 0.67	52	U = 1.3 g = 0.41 T_L = 0.67	148	U = 0.8 g = 0.6 T_L = 0.74	228

Notes:

Air Permeability was assumed to be 3 m³/hr.m².yr

Thermal Bridging was assumed as per BRE IP 1/06 (2006)

No additional maintenance costs were assumed in going from the reference specification to Level A, B or C.

Table A.2: Building services costs

	Reference		Level A		Level B		Level C	
Element	Details	Unit Cost	Details	Unit Cost	Details	Unit Cost	Details	Unit Cost
Lighting (£/fitting)	55 lm/W	£150	65 lm/W	£165	75 lm/W	£165	-	-
Lighting Control (£/m²)	-	£13	-	£13	-	-	-	-
Central mechanical ventilation, with heating cooling and heat recovery, Specific Fan Power (£/AHU)	2.2	£14,800	2	£15,800	1.8	£16,800	-	-
Fan Coil Units, Specific Fan Power (£/FCU)	0.8	£650	0.6	£650	0.5	£650	0.3	£650
Gas boilers (£/boiler)	84% seasonal efficiency	£7,000	86% seasonal efficiency	£7,000	88% seasonal efficiency	£10,500	91% seasonal efficiency	£10,500
Air cooled chiller, SEER (£/chiller)	2.5	£45,000	3	£55,000	3.5	£60,000	4.5	£60,000

Notes:

No additional maintenance costs were assumed in going from the Reference specification to Level A, B or C.

Lighting: Increasing lighting efficiency from 65 to 75 Luminaire Lumens per circuit watt has been estimated to be cost neutral since the additional cost of the lamp and fitting is offset by the need for fewer fittings to achieve the same light output.

Fan Coil Units: Electronically commutated motors giving a specific fan power of 0.3 w/l/s are now seen as standard on most fan coil unit installations hence the neutral cost difference between an FCU SFP of 0.8 (standard AC motor).

Heat recovery was assumed at 70 per cent efficiency. The carbon benefit of other efficiency levels was modelled however it was difficult to obtain consistent cost data about varying heat recovery efficiencies and therefore the data is presented with and without heat recovery at 70 per cent.

Table A.3: LZC Costs

	£ per kW(e)	£ per kW(e)	£ per kW(e)	£ per kW(e)	£ per m2	£ per m2	£ per kW	£ per kW	£ per l/sec	£ per kW
Size	Gas CHP	Gas Trigen	Biomass Heating	Biomass CHP	Biomass Trigen	Solar Thermal	Solar PV	Wind	Open GSHP	Closed GSHP
0.6	3000	3200	650	6700	6850	750	700	13000	650	1400
2.5	3000	3200	650	6700	6850	750	700	5350	600	1400
5	3000	3200	650	6700	6850	750	700	4600	550	1400
6	3000	3200	650	6700	6850	750	700	3850	550	1400
10	3000	3200	650	6700	6850	750	700	3350	550	1400
15	3000	3200	650	6700	6850	750	700	2800	550	1400
20	3000	3200	650	6700	6850	750	700	2800	550	1400
30	3000	3200	650	6400	6545	750	700	2800	500	1400
40	2500	2700	650	6100	6240	750	700	2800	400	1350
50	2000	2200	650	5800	5935	750	700	2800	400	1300
60	1800	2000	600	5500	5635	750	700	2800	400	1200
70	1500	1700	550	5200	5330	750	630	2800	350	1100
80	1300	1500	500	5000	5130	750	630	2800	350	1050
90	1200	1400	400	4750	4880	750	630	2800	350	950
100	1100	1300	350	4500	4600	750	630	2800	350	850
110	1100	1300	350	4500	4600	750	630	2800	350	850
120	1000	1200	350	4500	4600	750	630	2800	350	850
130	1000	1200	300	4500	4600	750	630	2800	350	850
140	900	1200	300	4500	4600	750	630	2800	350	850
150	900	1200	300	4500	4600	750	630	2300	350	800
160	900	1100	300	4500	4600	750	630	2300	350	800
170	900	1000	300	4500	4600	750	630	2300	350	800
180	900	1000	250	4500	4600	750	630	2300	350	800
190	800	950	250	4500	4600	750	630	2300	350	800
200	800	900	200	4500	4600	700	630	2300	350	800
300	700	850	200	4500	4600	700	570	2300	350	750
400	700	850	200	4500	4600	700	570	2300	350	700
500	700	800	200	4500	4600	700	570	2300	350	650
600	600	899	200	4500	4600	700	570	2300	350	650
700	600	750	200	4500	4600	700	510	2300	350	650
800	600	700	200	4500	4600	700	510	1800	350	600
900	600	700	150	4500	4600	700	510	1550	350	600
1000	500	650	150	4500	4600	700	510	1300	350	600
2000	500	600	100	4500	4600	700	510	1000	350	550
3000	400	550	100	4000	4100	700	510	750	350	500
4000	400	500	100	4000	4100	700	510	750	350	500
5000	350	450	100	4000	4100	700	510	750	350	450

Maintenance	80	100	15	180	100	8.5	7.5	15	150	6

Table A.4 Learning Rates

	Technology (global market)						Installation (UK market)					
	Solar Thermal	Solar PV	GSHP	Biomass Heating	Gas CHP	Biomass CHP	Solar Thermal	Solar PV	GSHP	Biomass Heating	Gas CHP	Biomass CHP
Unit	kWth	MW	kWth	kWth	kWe	kWe	installation	installation	kWth	installation	kWe	kWe
2010	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
2011	89%	80%	90%	85%	90%	90%	95%	95%	94%	87%	96%	99%
2012	82%	70%	85%	76%	85%	84%	93%	93%	90%	83%	94%	98%
2013	77%	63%	81%	71%	81%	80%	91%	91%	87%	81%	91%	98%
2014	73%	57%	78%	67%	78%	77%	89%	89%	85%	79%	90%	98%
2015	70%	53%	75%	64%	76%	75%	88%	88%	84%	78%	88%	97%
2016	67%	50%	73%	61%	74%	73%	87%	87%	82%	77%	86%	97%
2017	65%	48%	71%	59%	72%	71%	86%	86%	81%	76%	85%	97%
2018	62%	45%	69%	57%	70%	69%	85%	85%	80%	75%	83%	97%
2019	60%	43%	68%	55%	69%	68%	84%	84%	80%	74%	82%	96%
2020	58%	42%	66%	54%	67%	67%	83%	83%	79%	73%	81%	96%
2021	56%	40%	65%	52%	66%	66%	83%	83%	78%	73%	79%	96%
2022	55%	39%	64%	51%	65%	65%	82%	82%	78%	72%	78%	96%
2023	53%	38%	62%	50%	64%	64%	82%	82%	77%	72%	78%	96%
2024	51%	36%	61%	49%	62%	63%	81%	81%	77%	71%	77%	96%
2025	50%	35%	60%	48%	61%	62%	81%	81%	76%	71%	76%	96%
2026	50%	35%	60%	48%	61%	62%	81%	81%	76%	71%	76%	96%
2027	50%	35%	60%	48%	61%	62%	81%	81%	76%	71%	76%	96%
2028	50%	35%	60%	48%	61%	62%	81%	81%	76%	71%	76%	96%
2029	50%	35%	60%	48%	61%	62%	81%	81%	76%	71%	76%	96%
2030	50%	35%	60%	48%	61%	62%	81%	81%	76%	71%	76%	96%
2031	50%	35%	60%	48%	61%	62%	81%	81%	76%	71%	76%	96%
2032	50%	35%	60%	48%	61%	62%	81%	81%	76%	71%	76%	96%
2033	50%	35%	60%	48%	61%	62%	81%	81%	76%	71%	76%	96%
2034	50%	35%	60%	48%	61%	62%	81%	81%	76%	71%	76%	96%
2035	50%	35%	60%	48%	61%	62%	81%	81%	76%	71%	76%	96%
2036	50%	35%	60%	48%	61%	62%	81%	81%	76%	71%	76%	96%
2037	50%	35%	60%	48%	61%	62%	81%	81%	76%	71%	76%	96%
2038	50%	35%	60%	48%	61%	62%	81%	81%	76%	71%	76%	96%
2039	50%	35%	60%	48%	61%	62%	81%	81%	76%	71%	76%	96%
2040	50%	35%	60%	48%	61%	62%	81%	81%	76%	71%	76%	96%
2041	50%	35%	60%	48%	61%	62%	81%	81%	76%	71%	76%	96%
2042	50%	35%	60%	48%	61%	62%	81%	81%	76%	71%	76%	96%
2043	50%	35%	60%	48%	61%	62%	81%	81%	76%	71%	76%	96%
2044	50%	35%	60%	48%	61%	62%	81%	81%	76%	71%	76%	96%
2045	50%	35%	60%	48%	61%	62%	81%	81%	76%	71%	76%	96%
2046	50%	35%	60%	48%	61%	62%	81%	81%	76%	71%	76%	96%
2047	50%	35%	60%	48%	61%	62%	81%	81%	76%	71%	76%	96%
2048	50%	35%	60%	48%	61%	62%	81%	81%	76%	71%	76%	96%
2049	50%	35%	60%	48%	61%	62%	81%	81%	76%	71%	76%	96%
2050	50%	35%	60%	48%	61%	62%	81%	81%	76%	71%	76%	96%
	% breakdown of capital cost											
	Solar Thermal	Solar PV	GSHP	Biomass Heating	Gas CHP	Biomass CHP						
Tech	80%	80%	50%	70%	80%	70%						
Install	20%	20%	50%	30%	20%	30%						

Appendix B – Cost curves

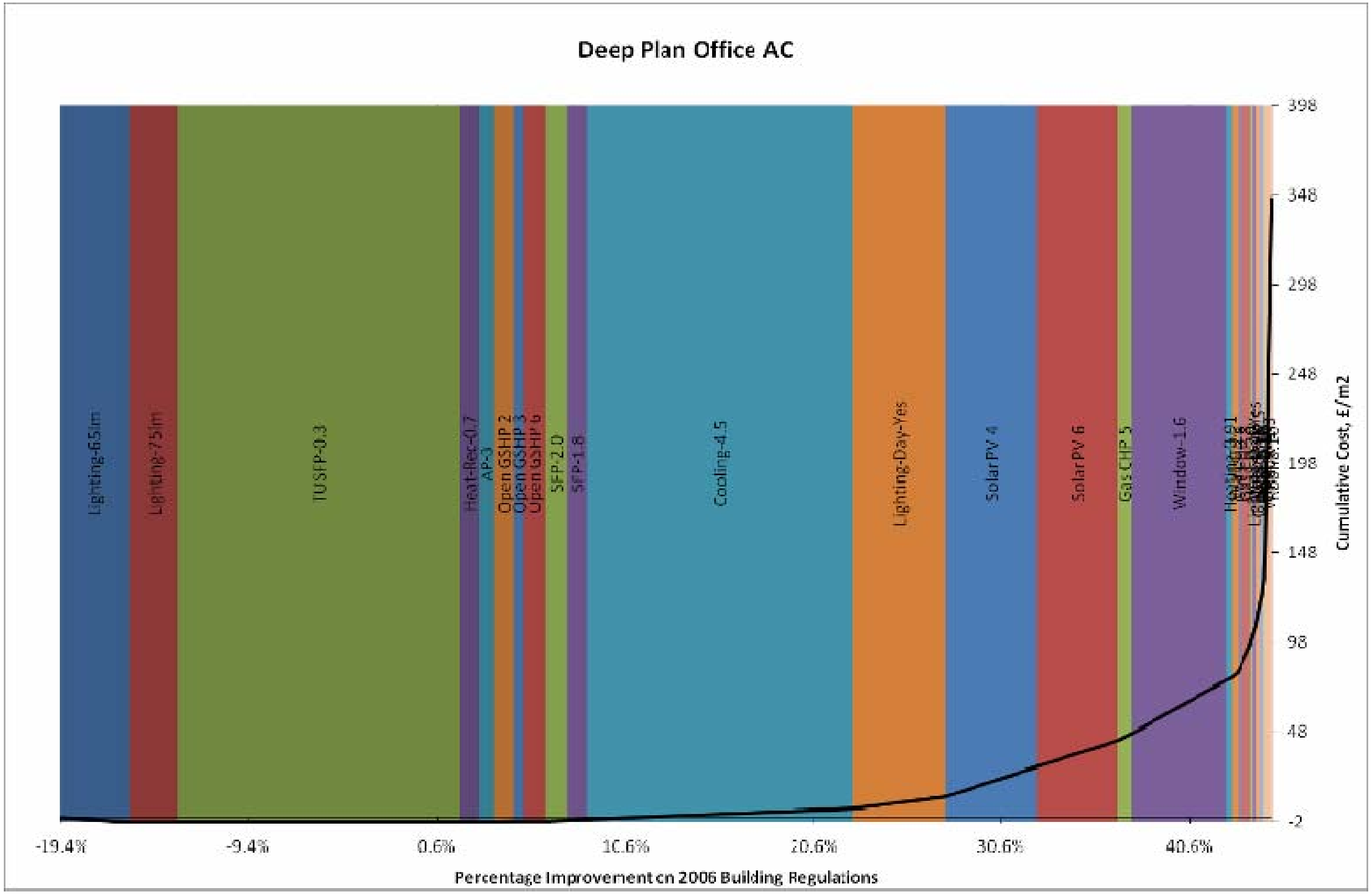

Figure B.1a: Capital cost curve for Deep Plan Office AC

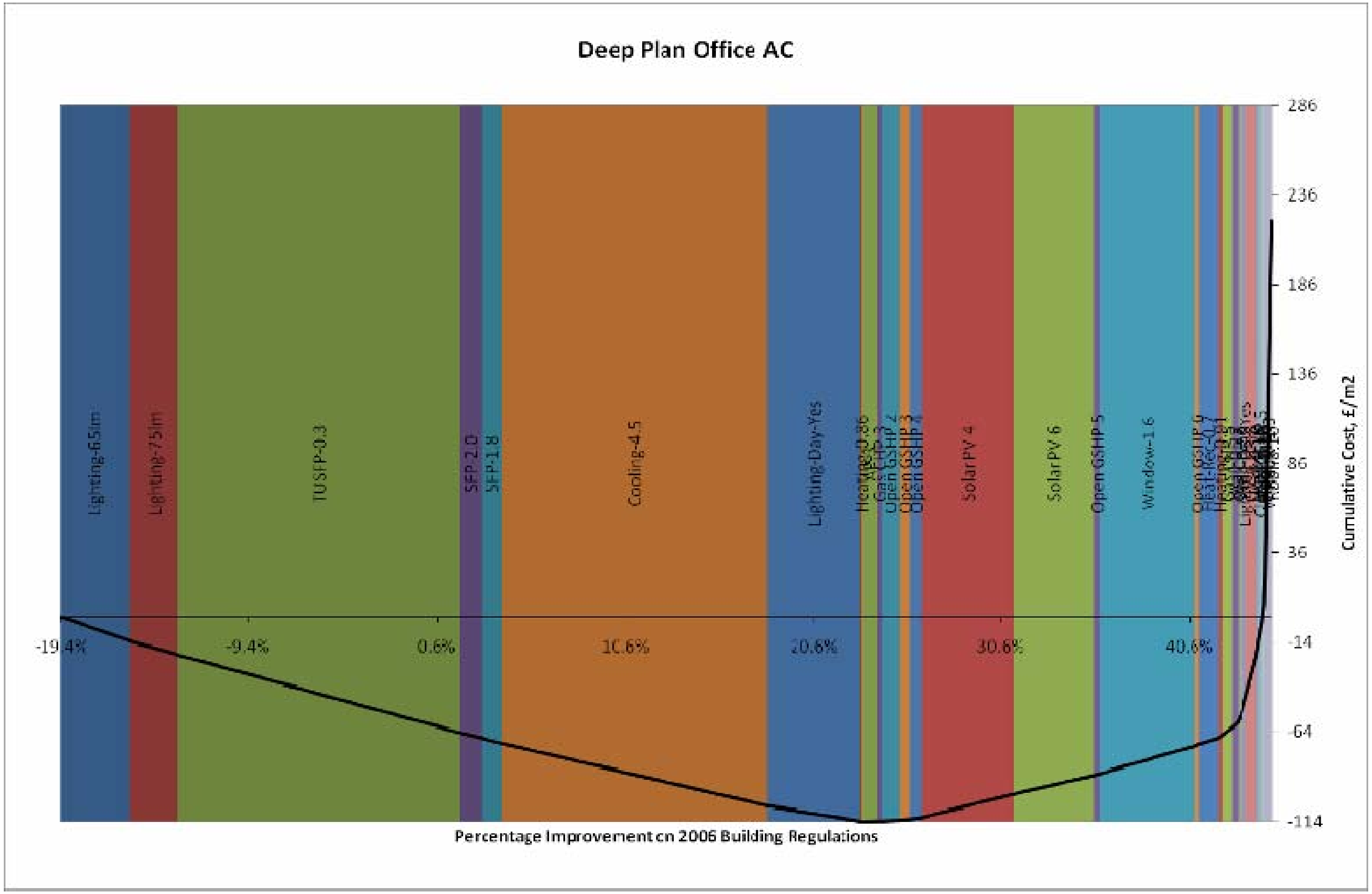

Figure B.1b: Lifecycle cost curve for Deep Plan Office AC

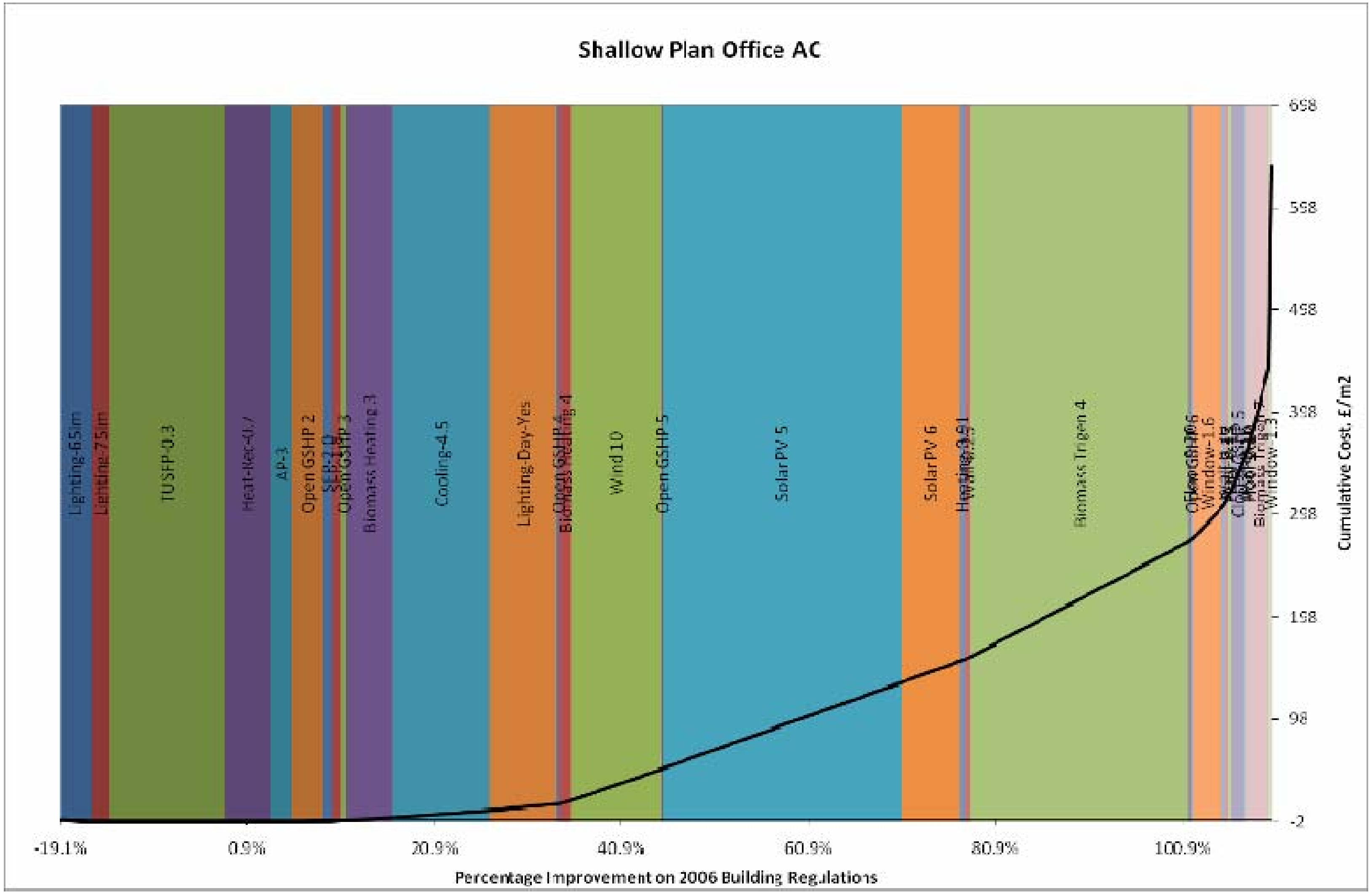

Figure B.2a: Capital cost curve for Shallow Plan Office AC

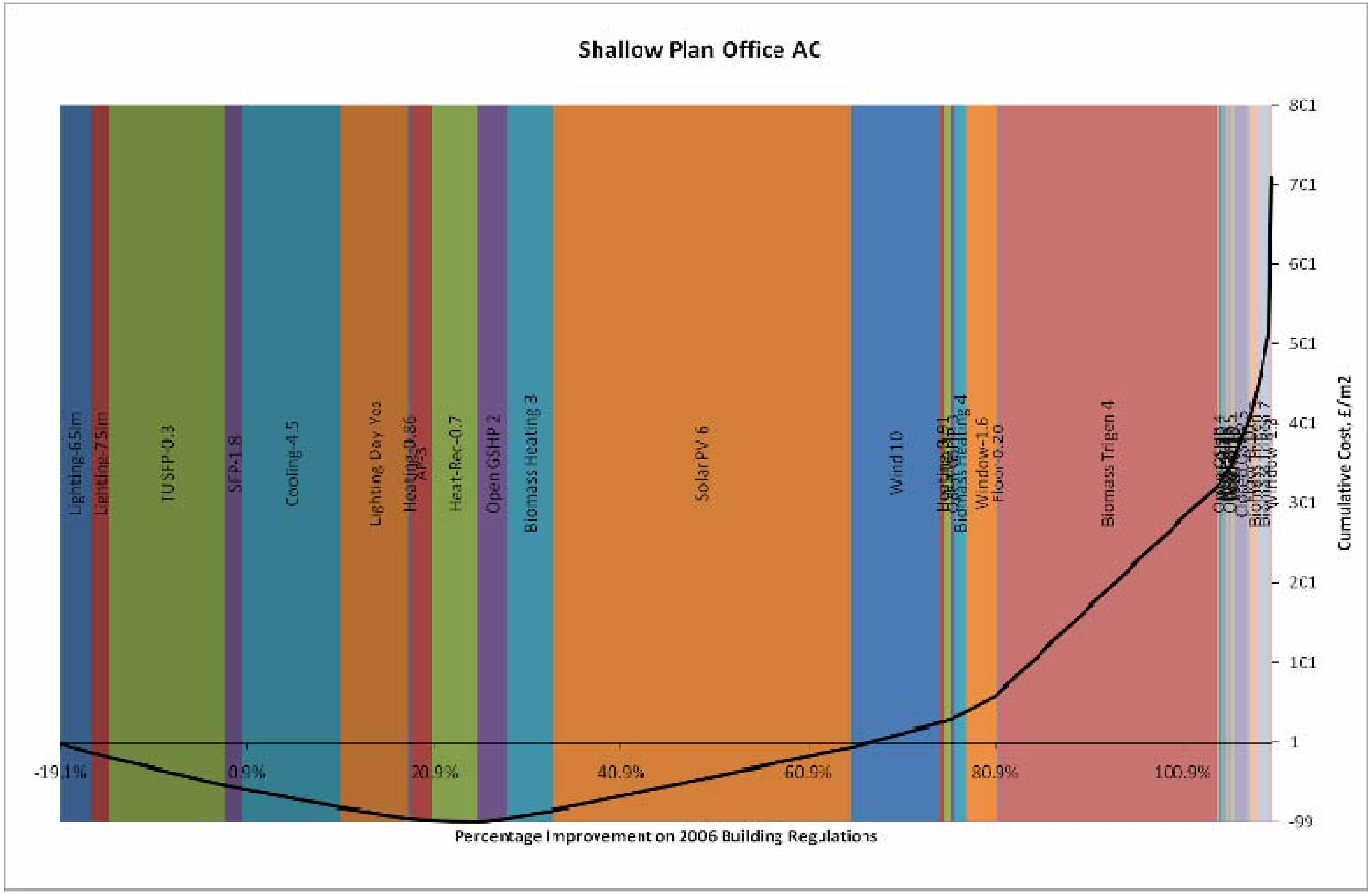

Figure B.2b: Lifecycle cost curve for Shallow Plan Office AC

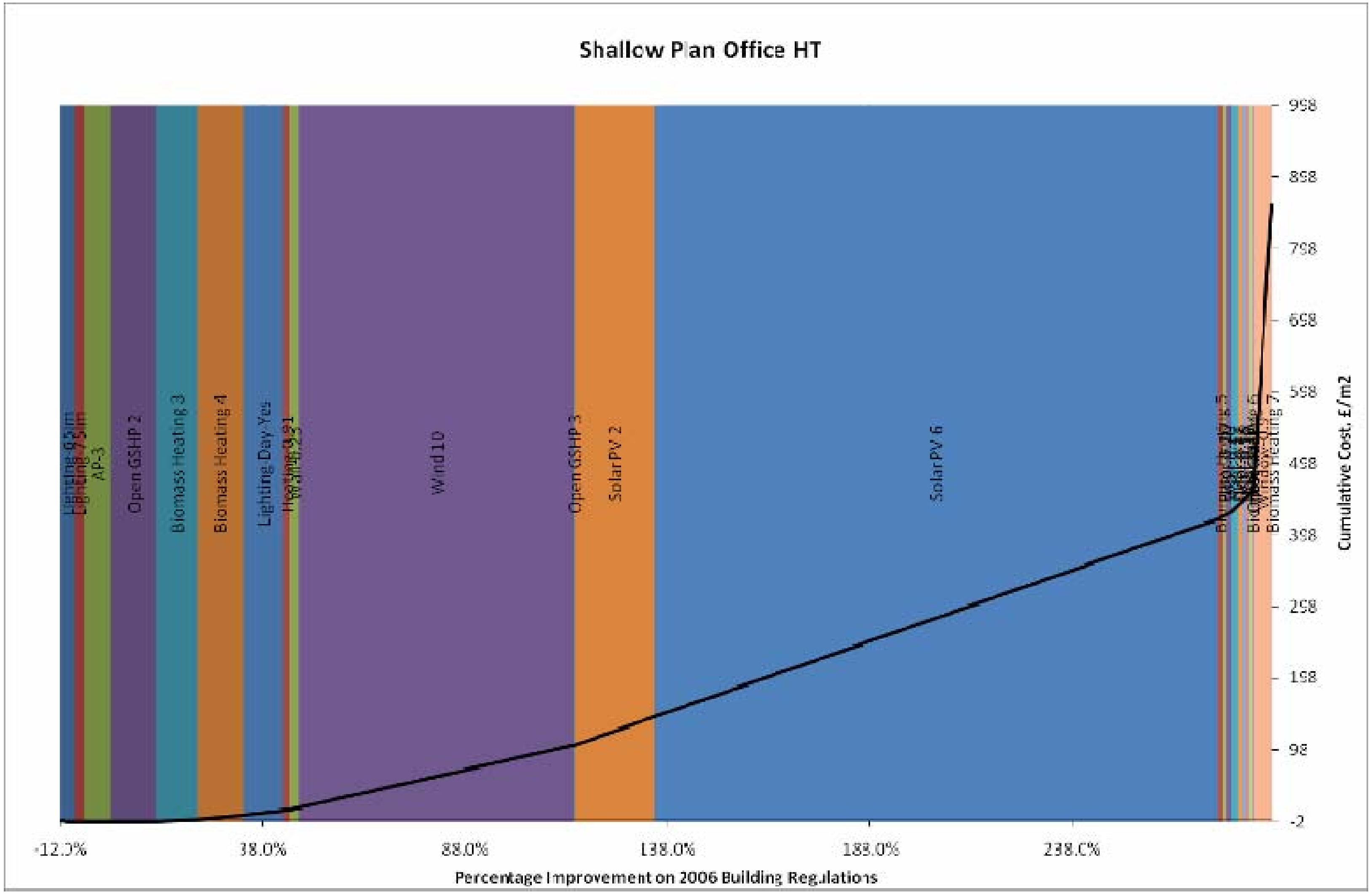

Figure B.3a: Capital cost curve for Shallow Plan Office Heated Only

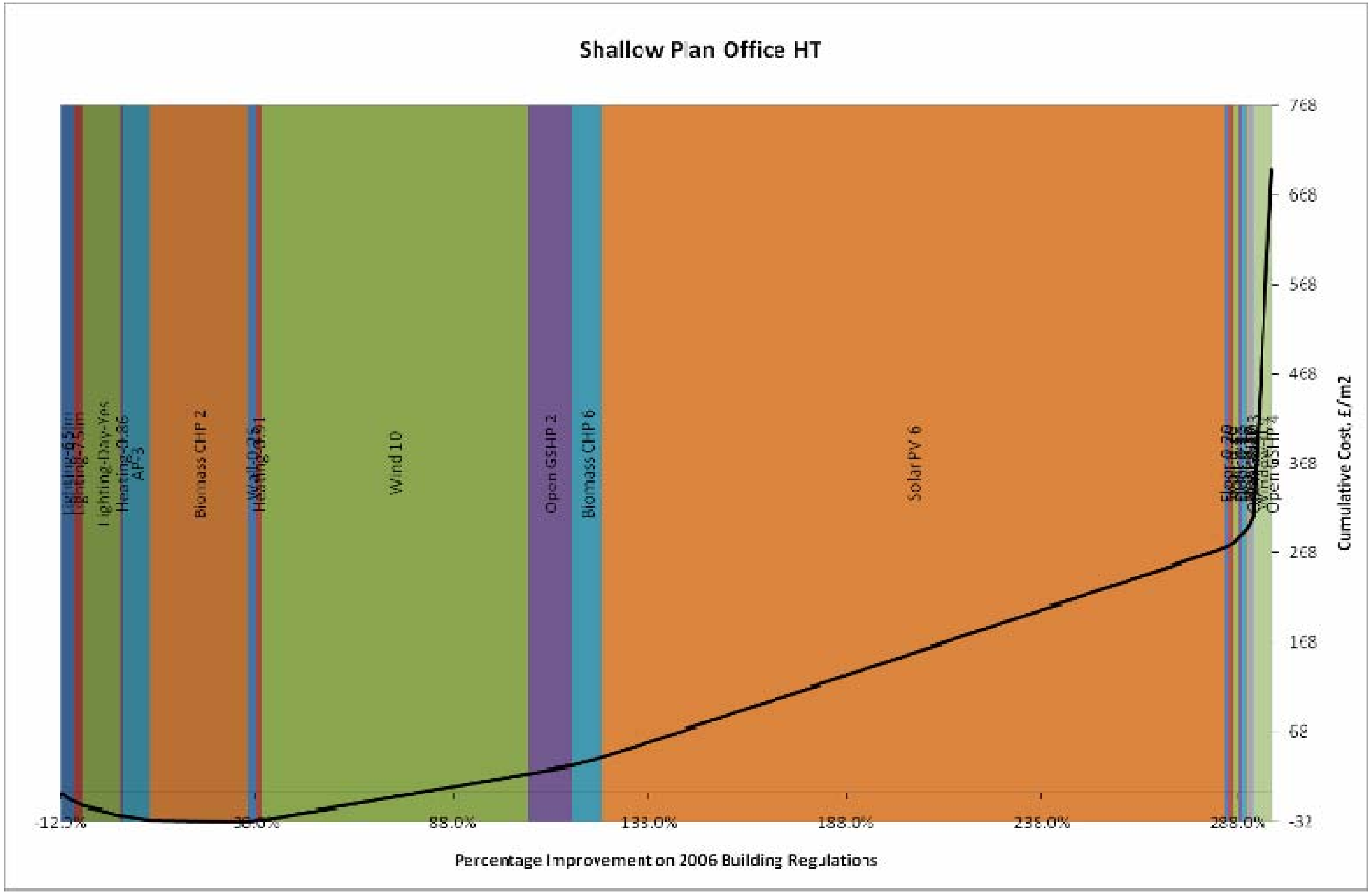

Figure B.3b: Lifecycle cost curve for Shallow Plan Office Heated Only

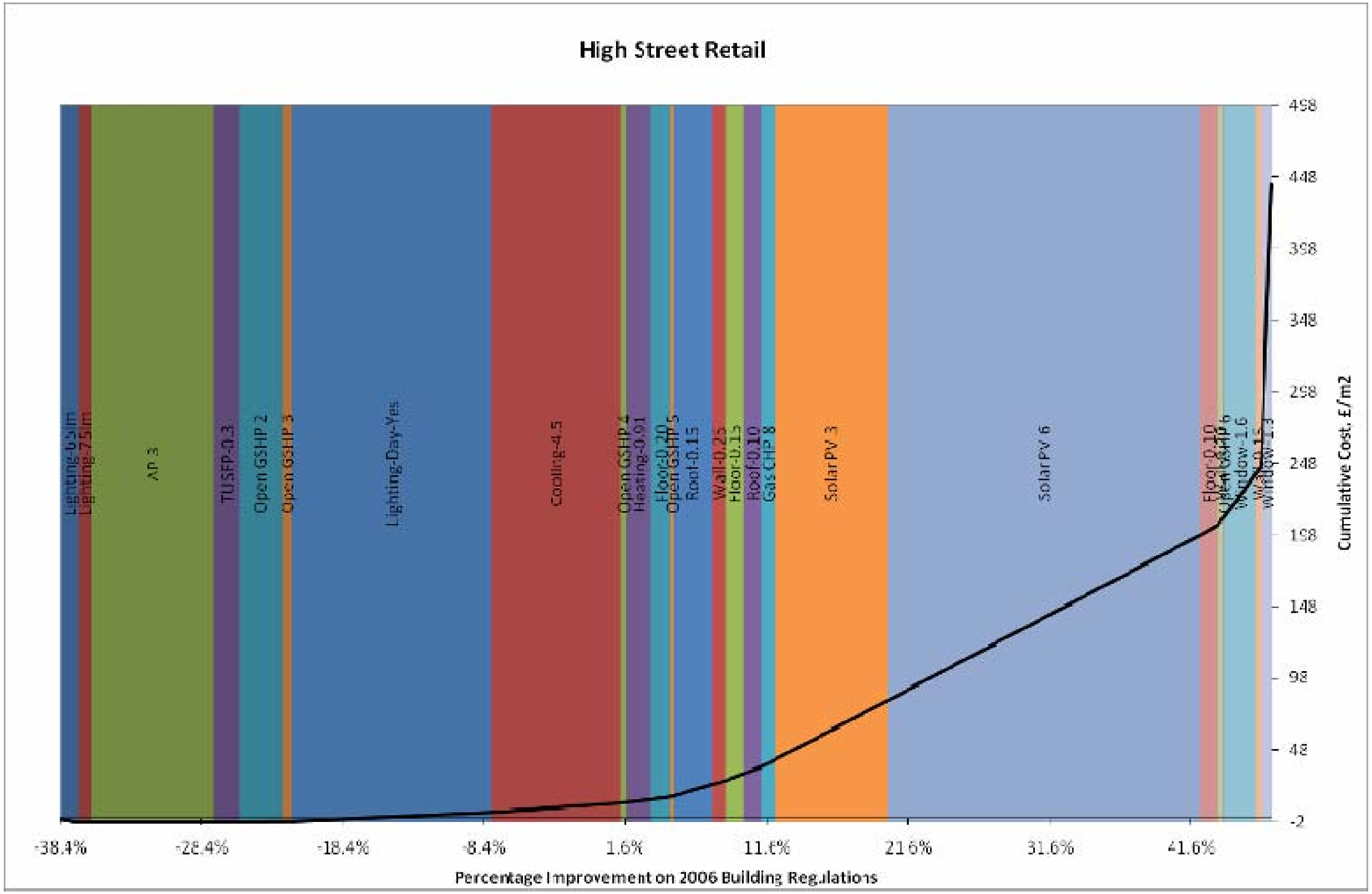

Figure B.4a: Capital cost curve for High Street Retail

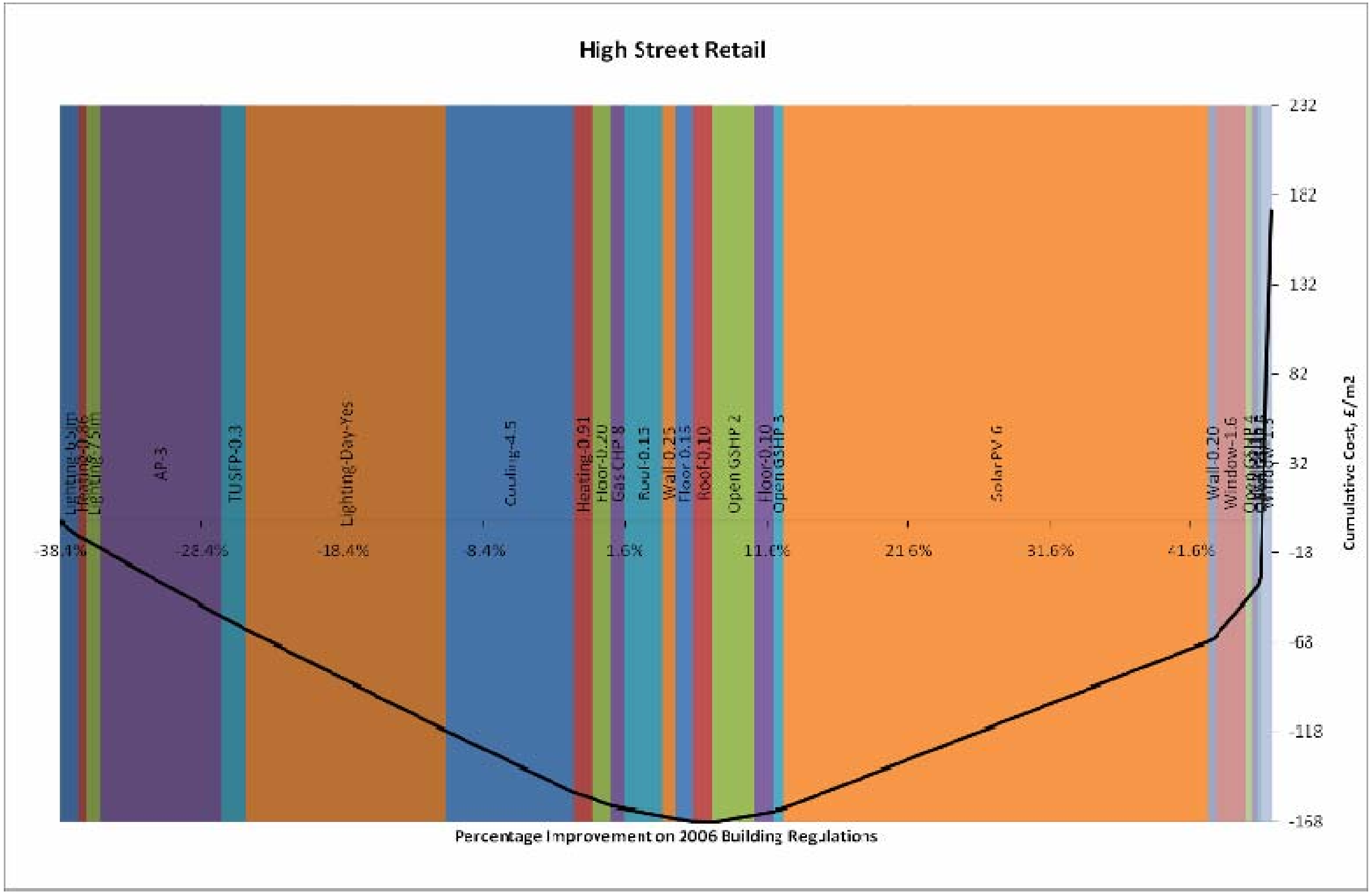

Figure B.4b: Lifecycle cost curve for High Street Retail

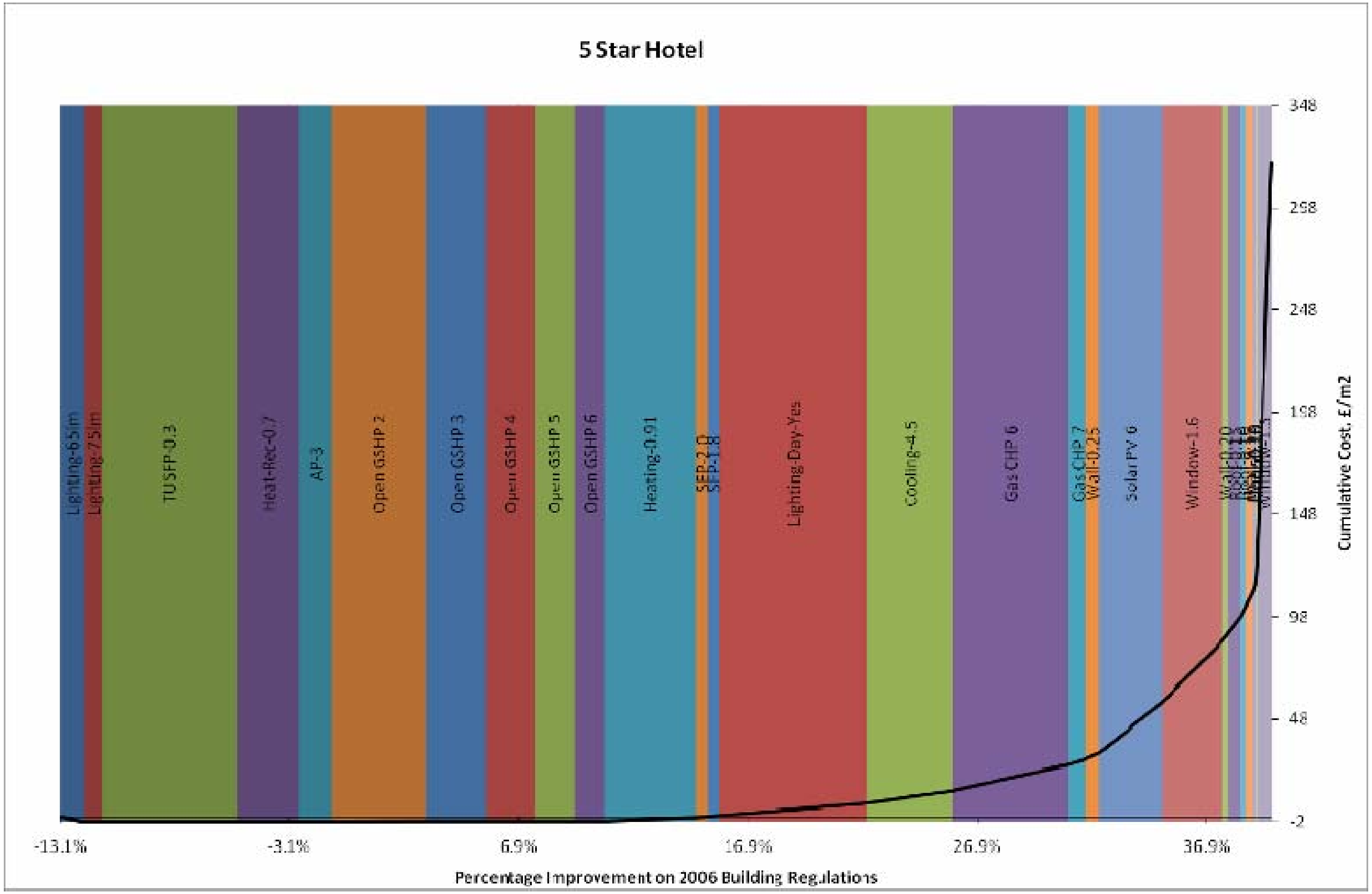

Figure B.5a: Capital cost curve for 5 Star Hotel

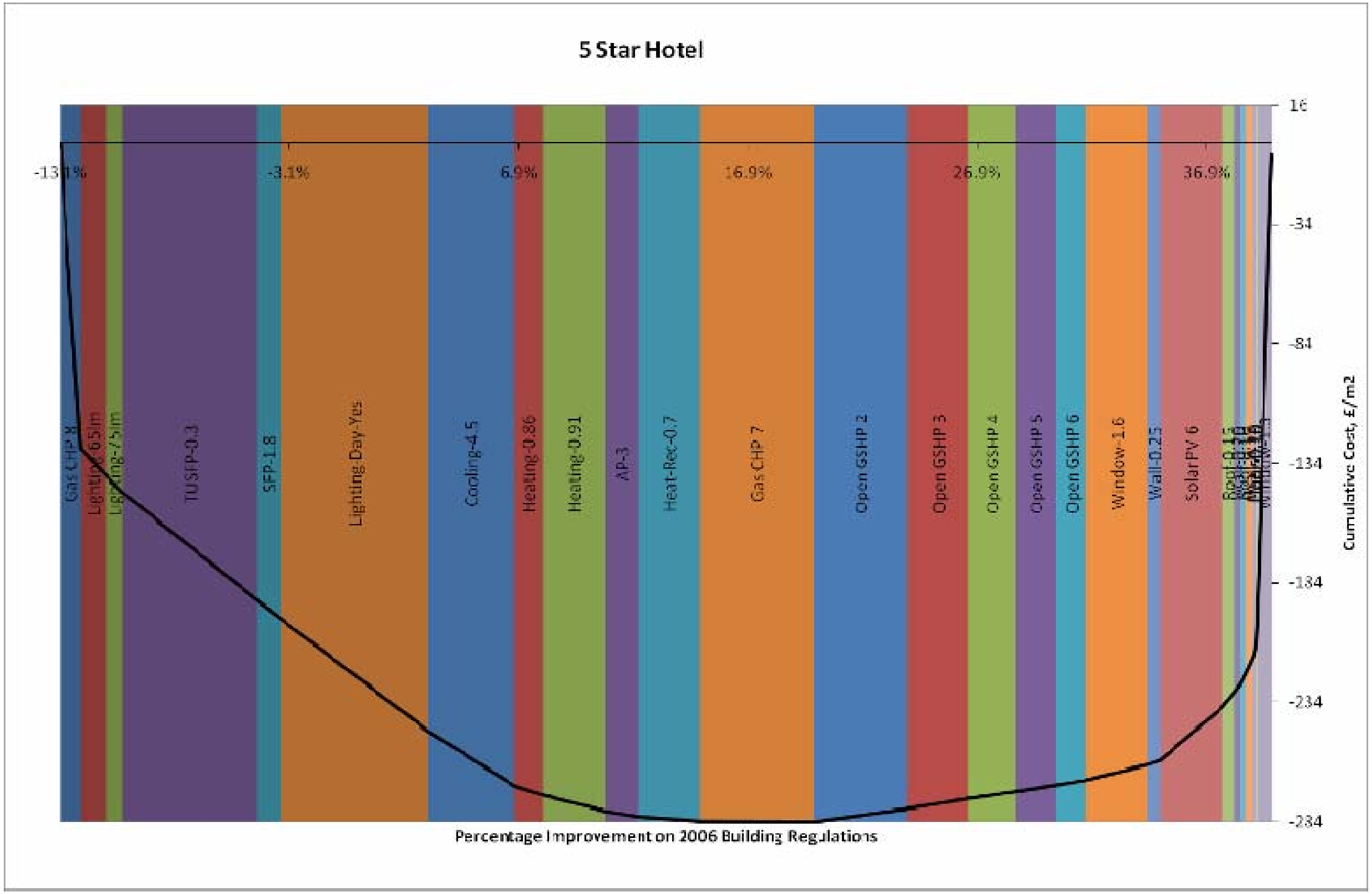

Figure B.5b: Lifecycle cost curve for 5 Star Hotel

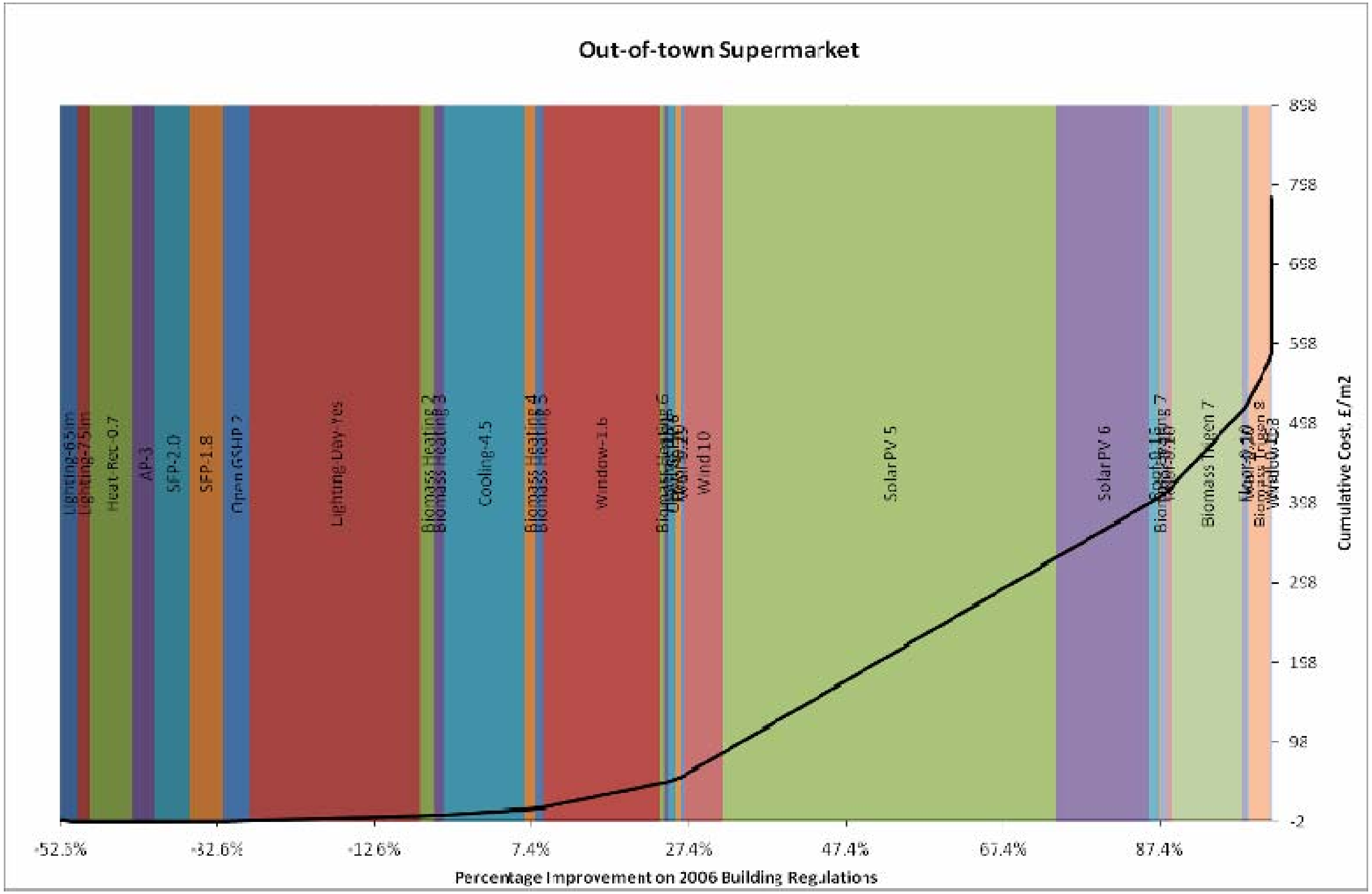

Figure B.6a: Capital cost curve for Out-of-town Supermarket

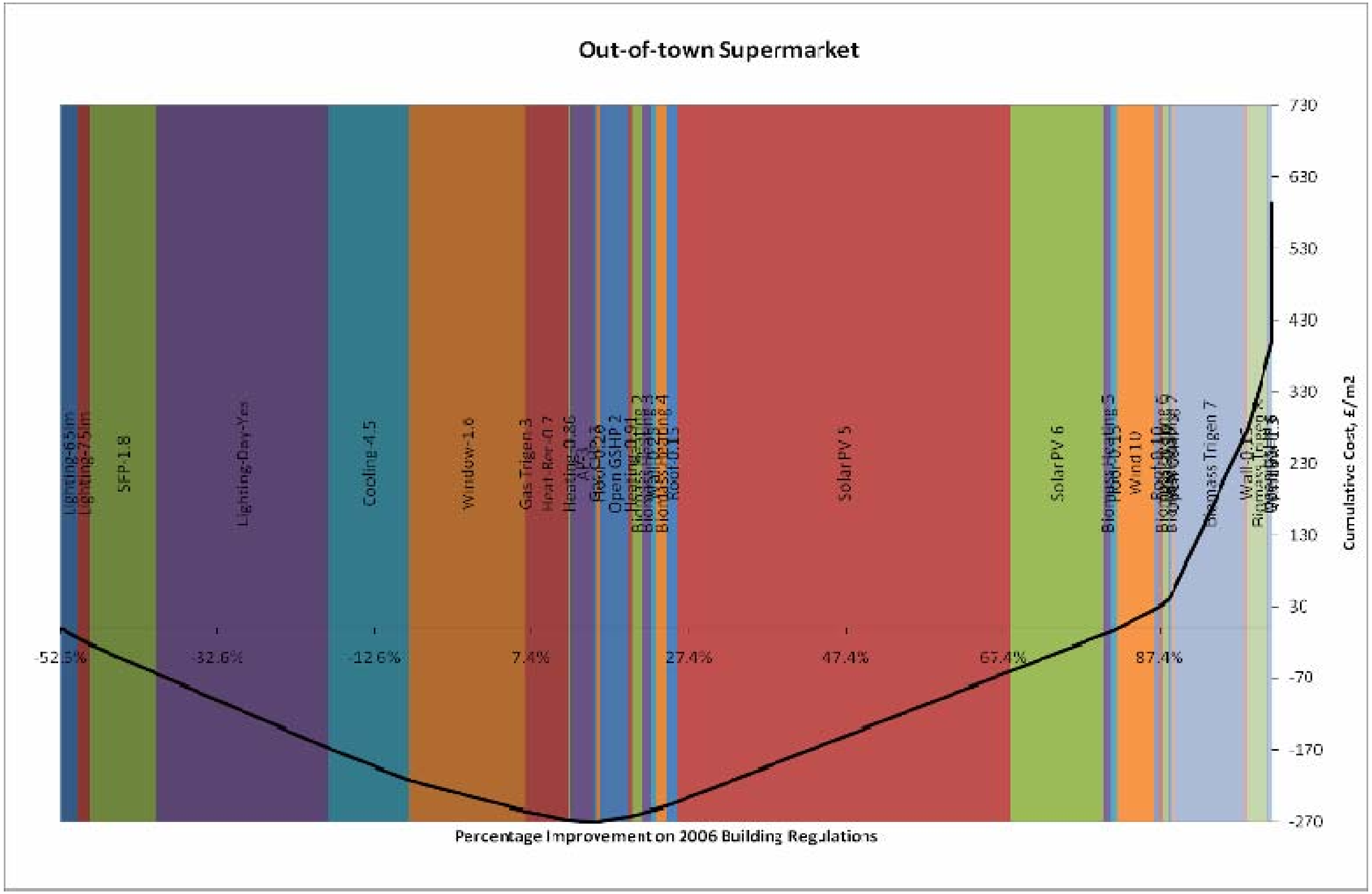

Figure B.6b: Lifecycle cost curve for Out-of-town Supermarket

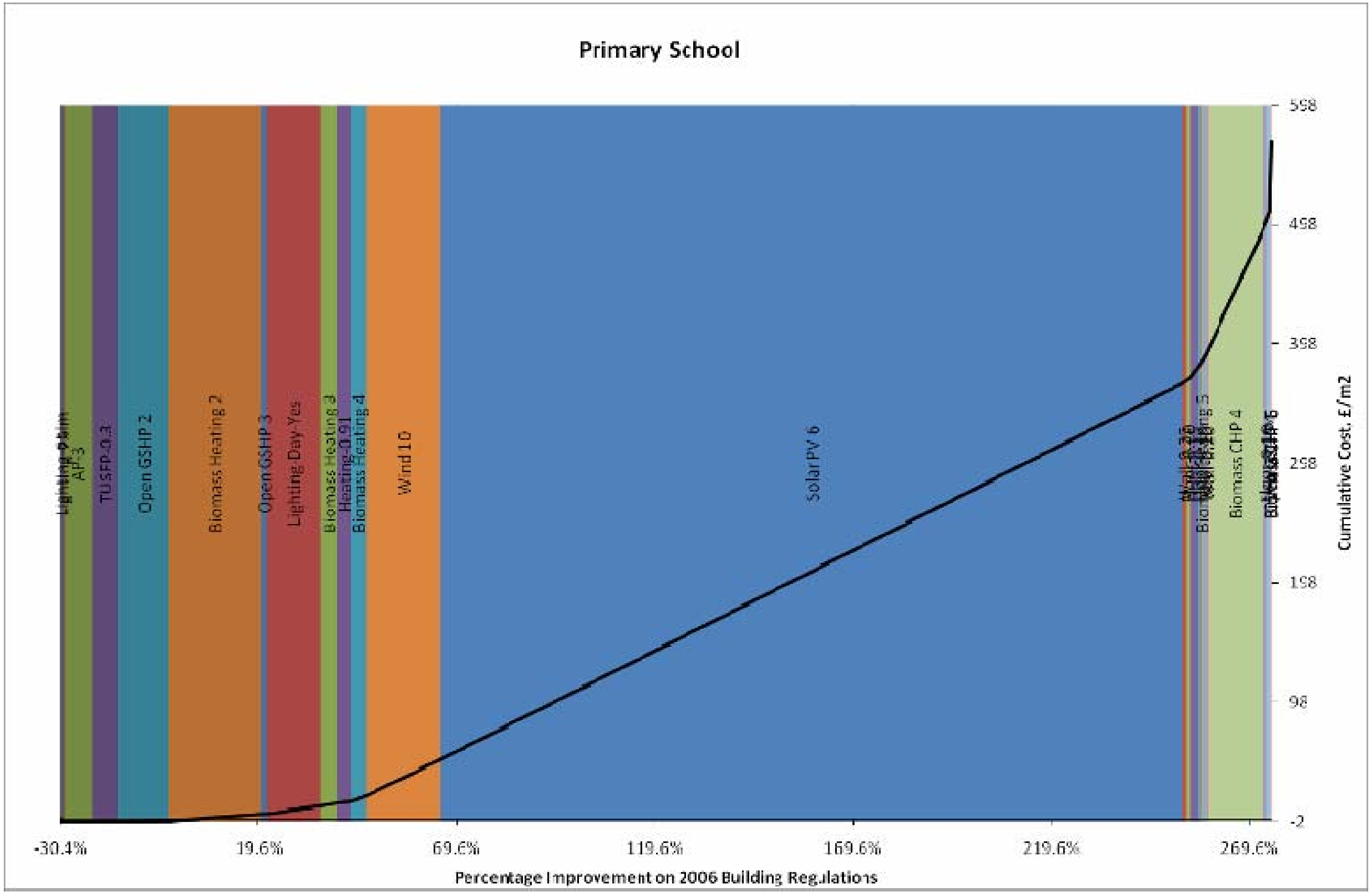

Figure B.7a: Capital cost curve for Primary School

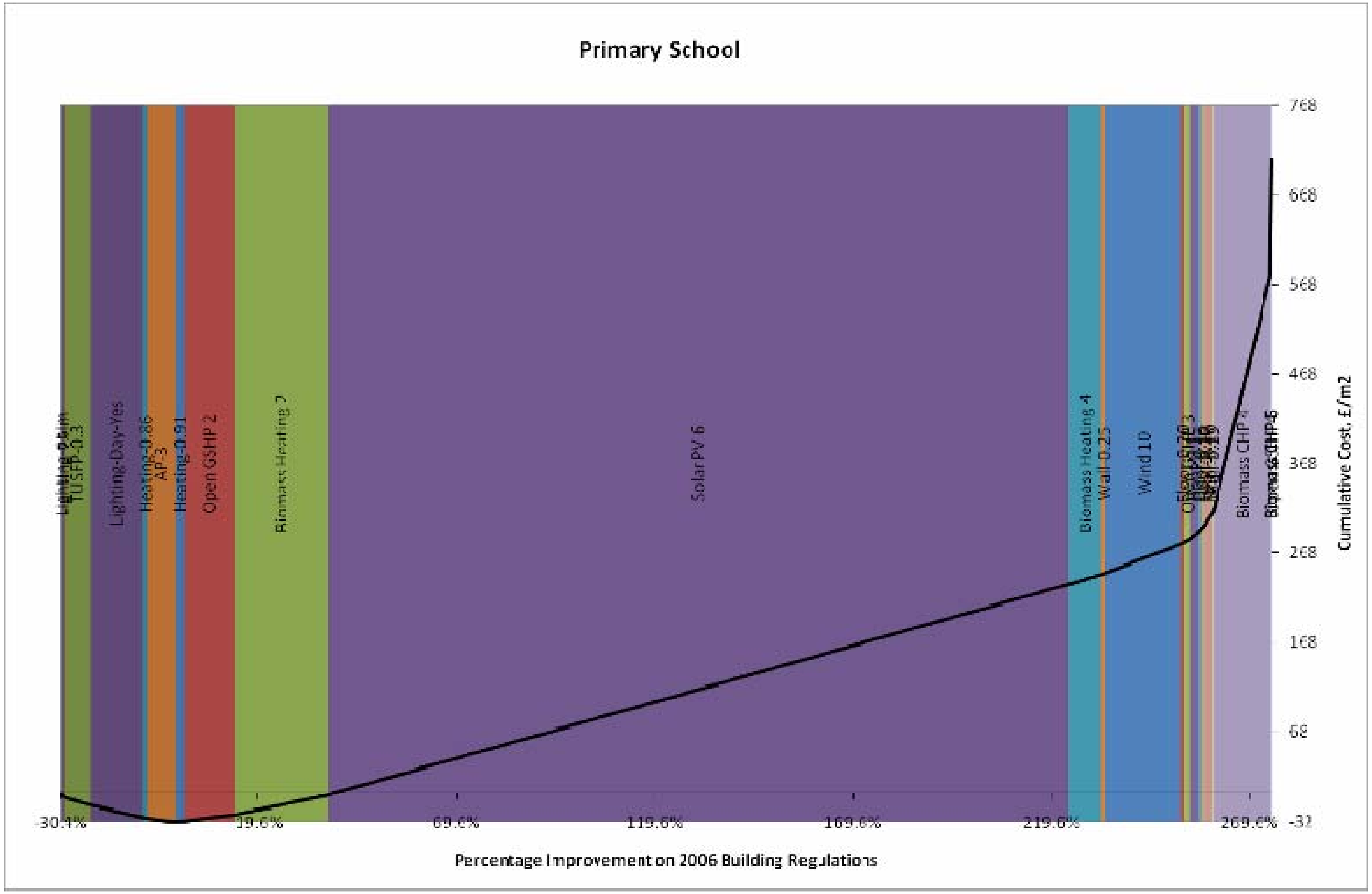

Figure B.7b: Lifecycle cost curve for Primary School

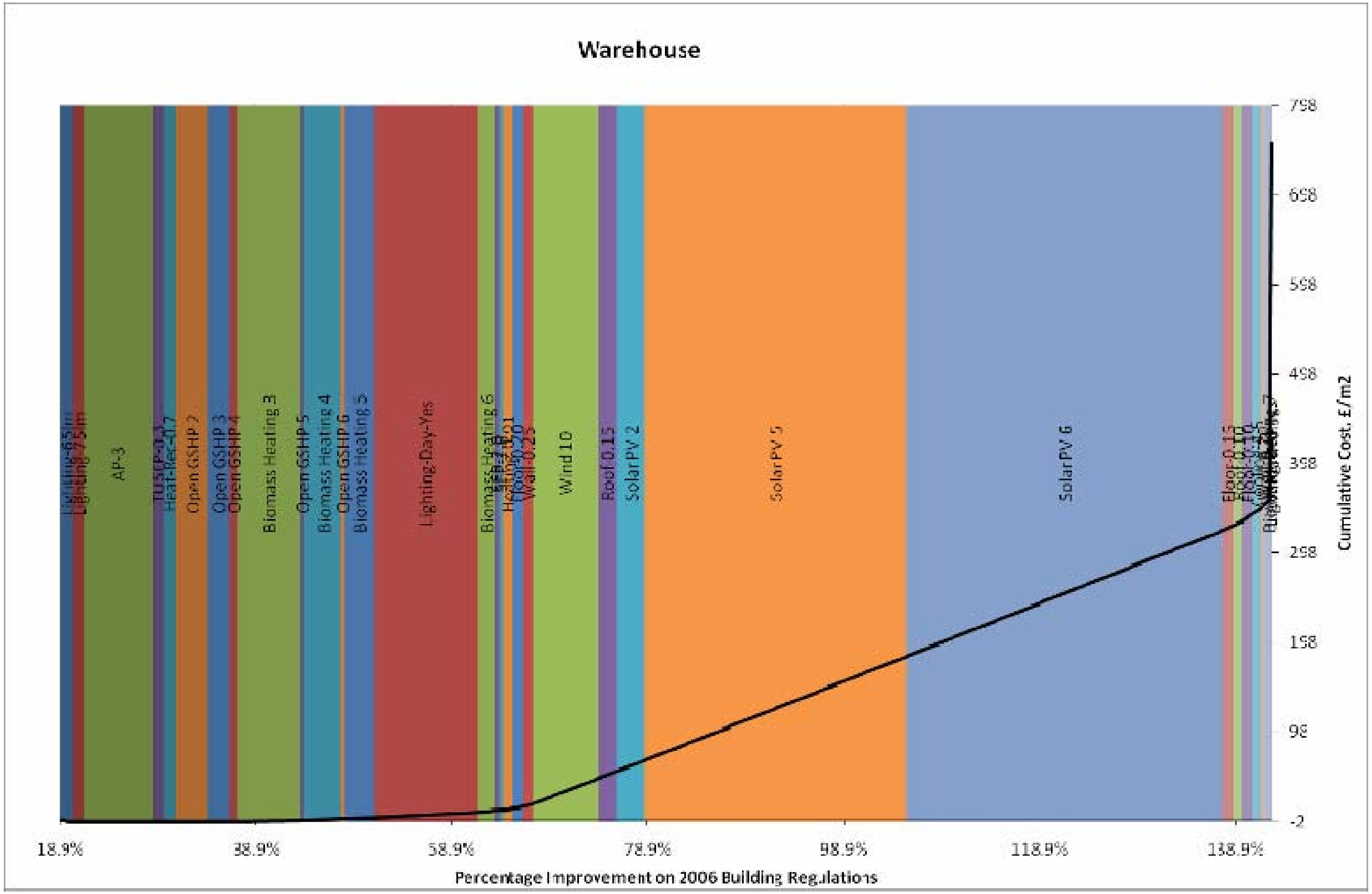

Figure B.8a: Capital cost curve for Warehouse

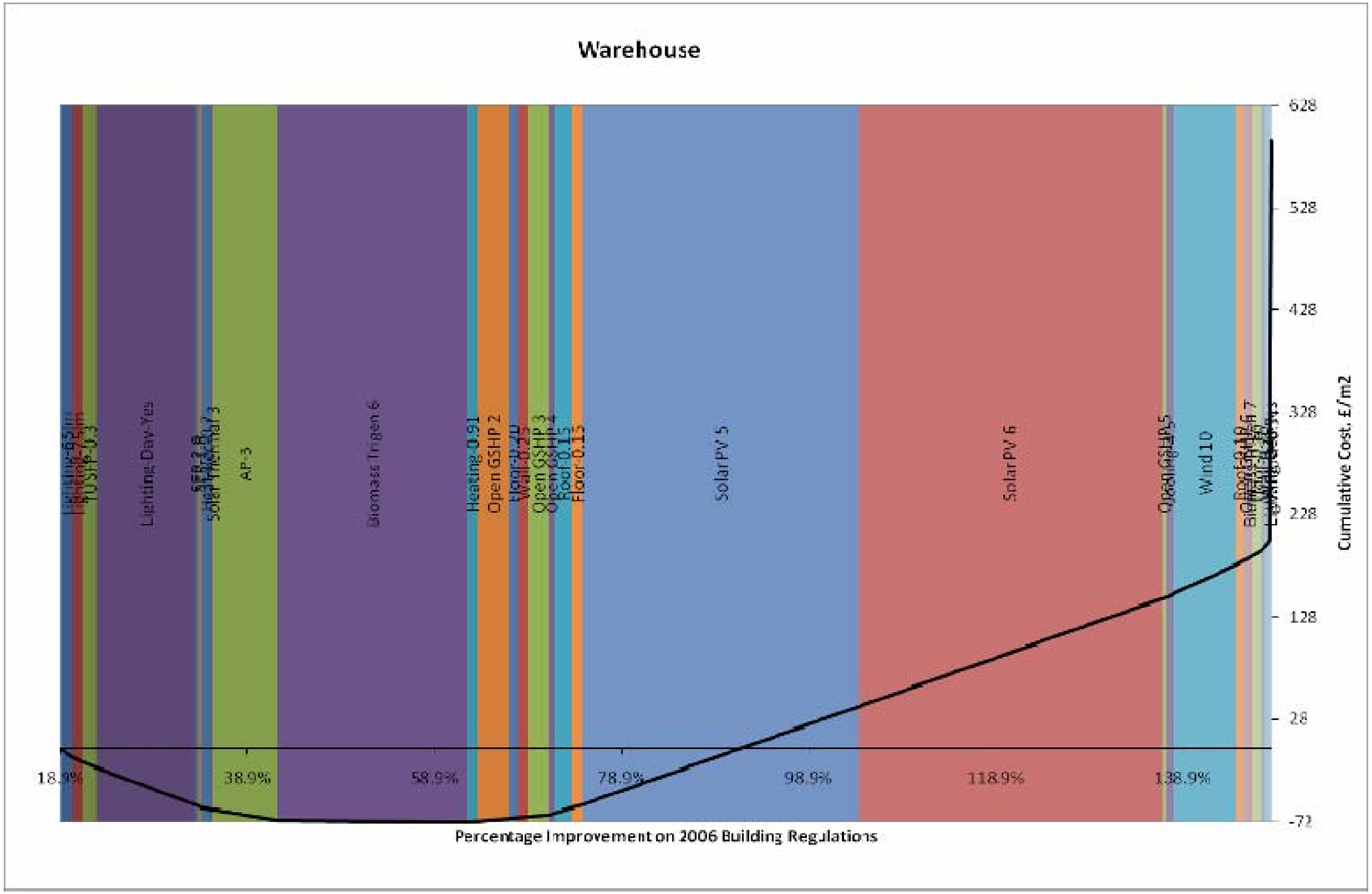

Figure B.8b: Lifecycle cost curve for Warehouse

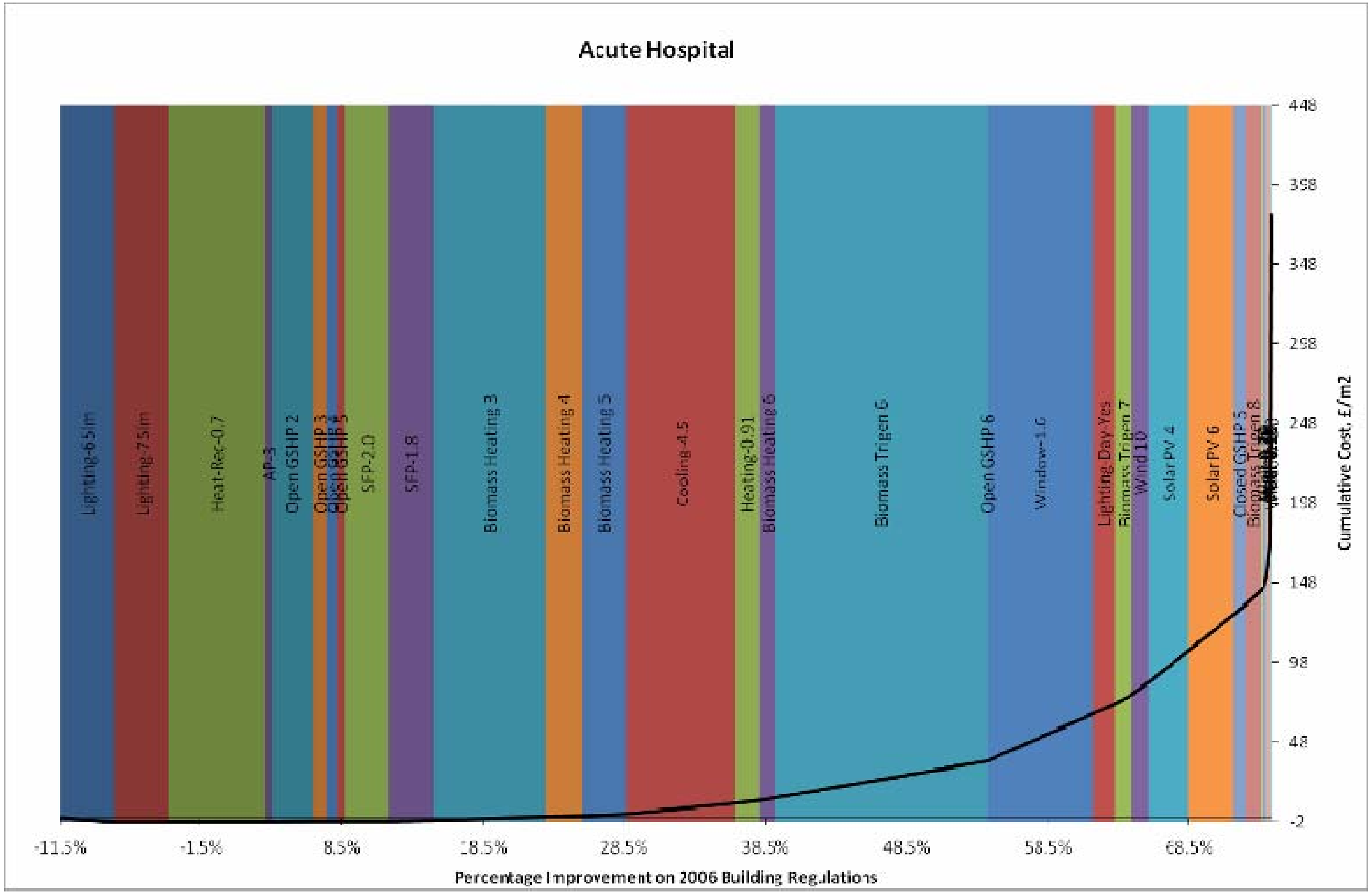

Figure B.9a: Capital cost curve for Acute Hospital

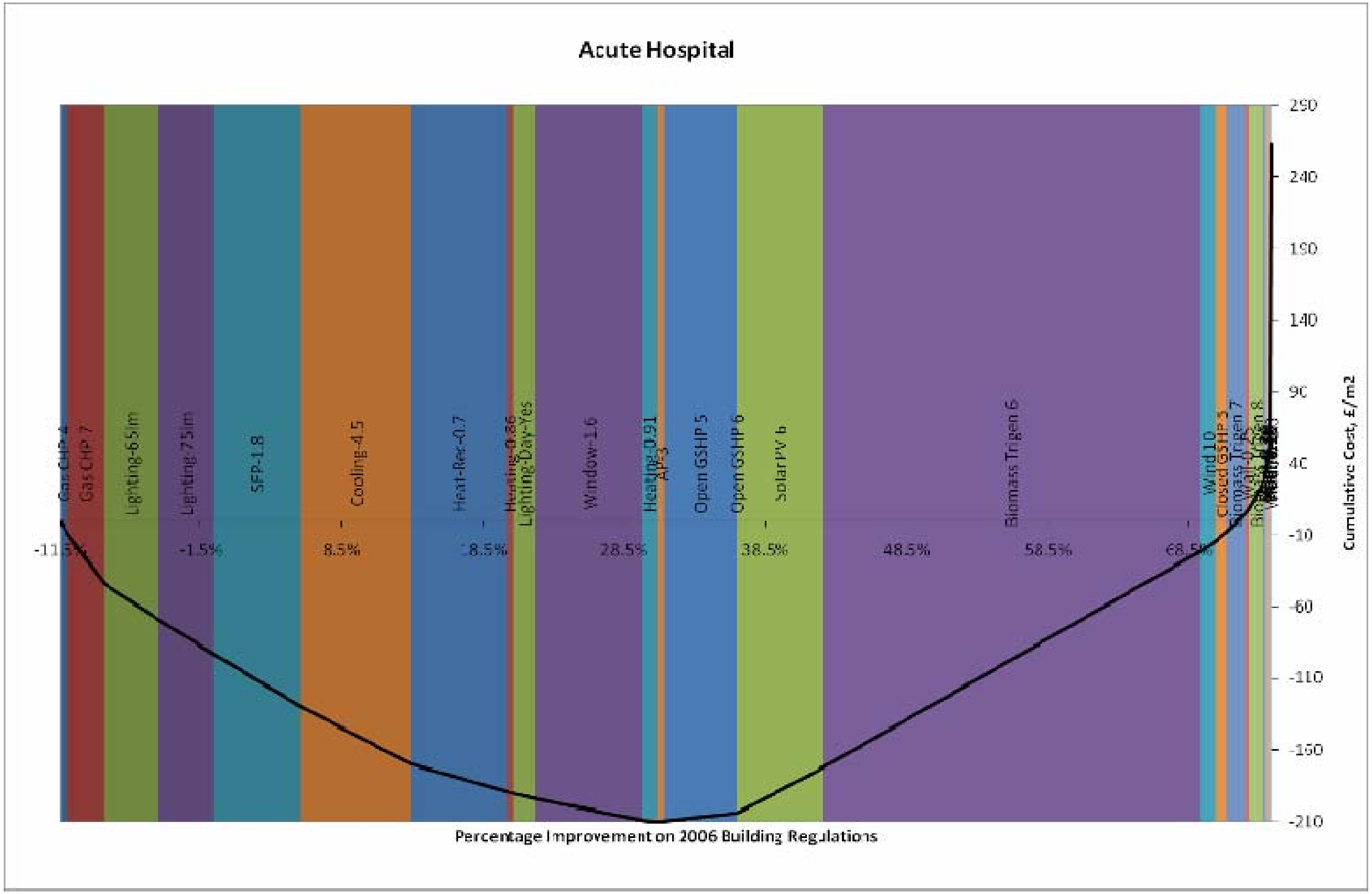

Figure B.9b: Lifecycle cost curve for Acute Hospital

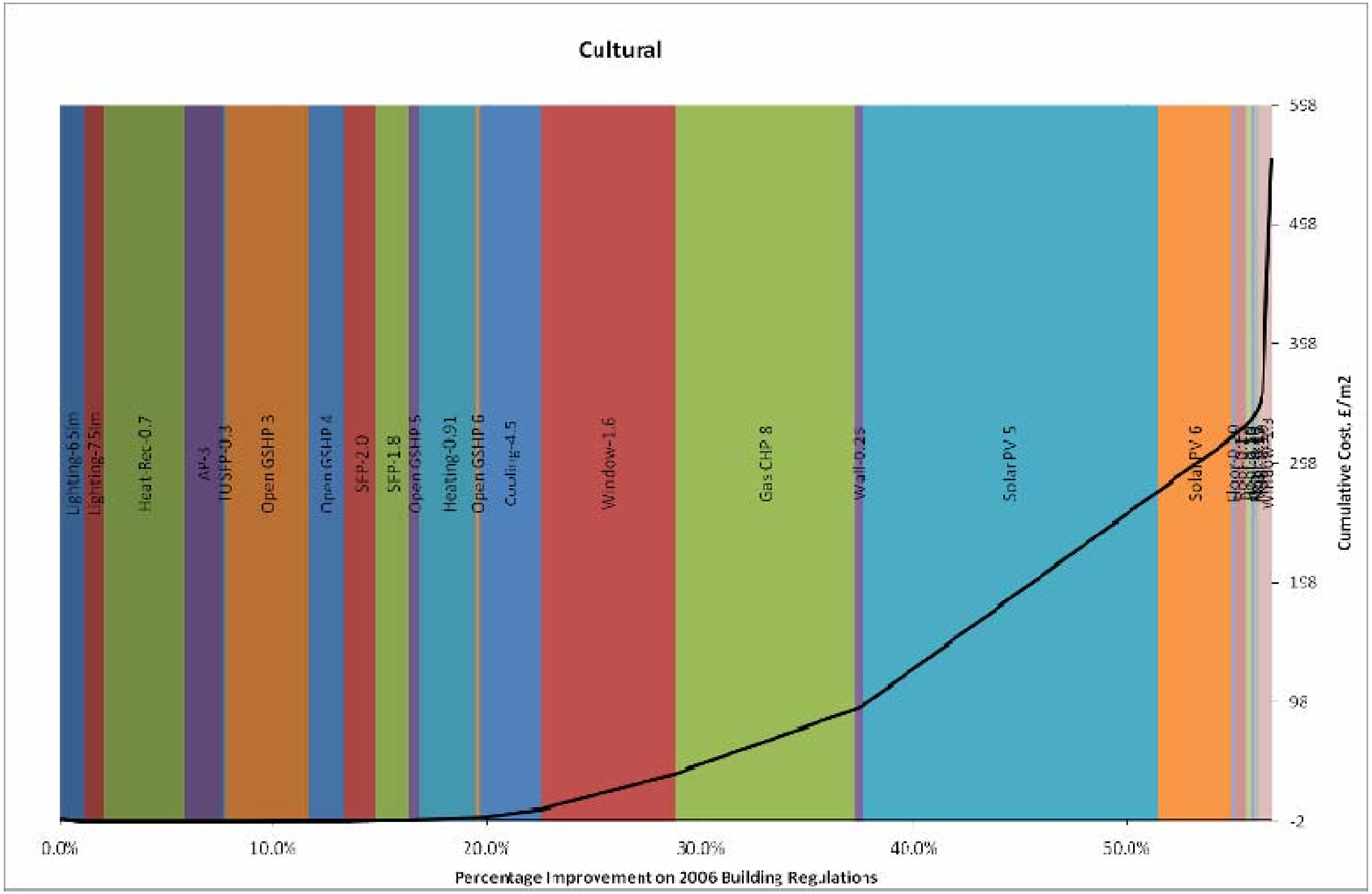

Figure B.10a: Capital cost curve for Cultural

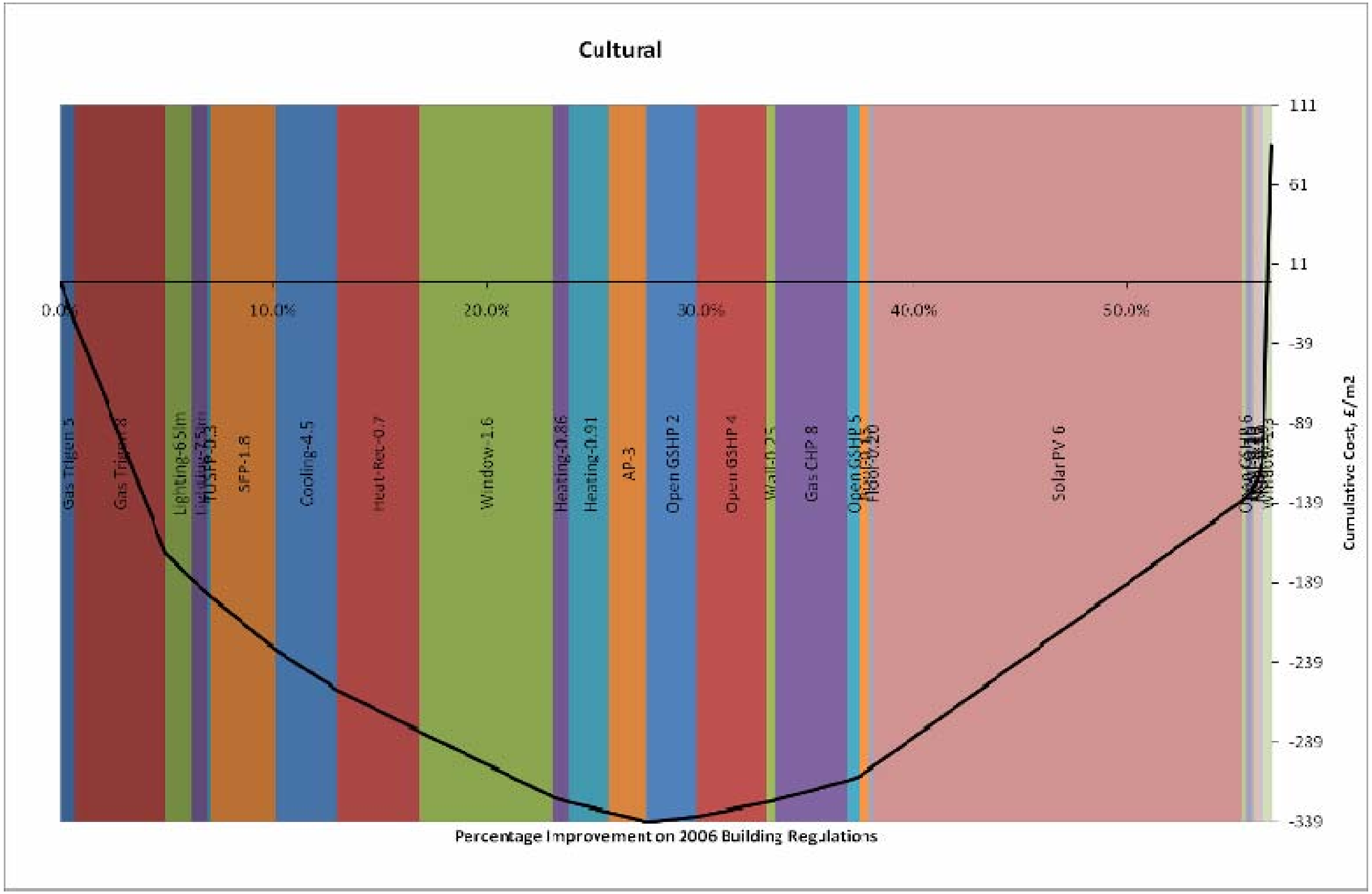

Figure B.10b: Lifecycle cost curve for Cultural

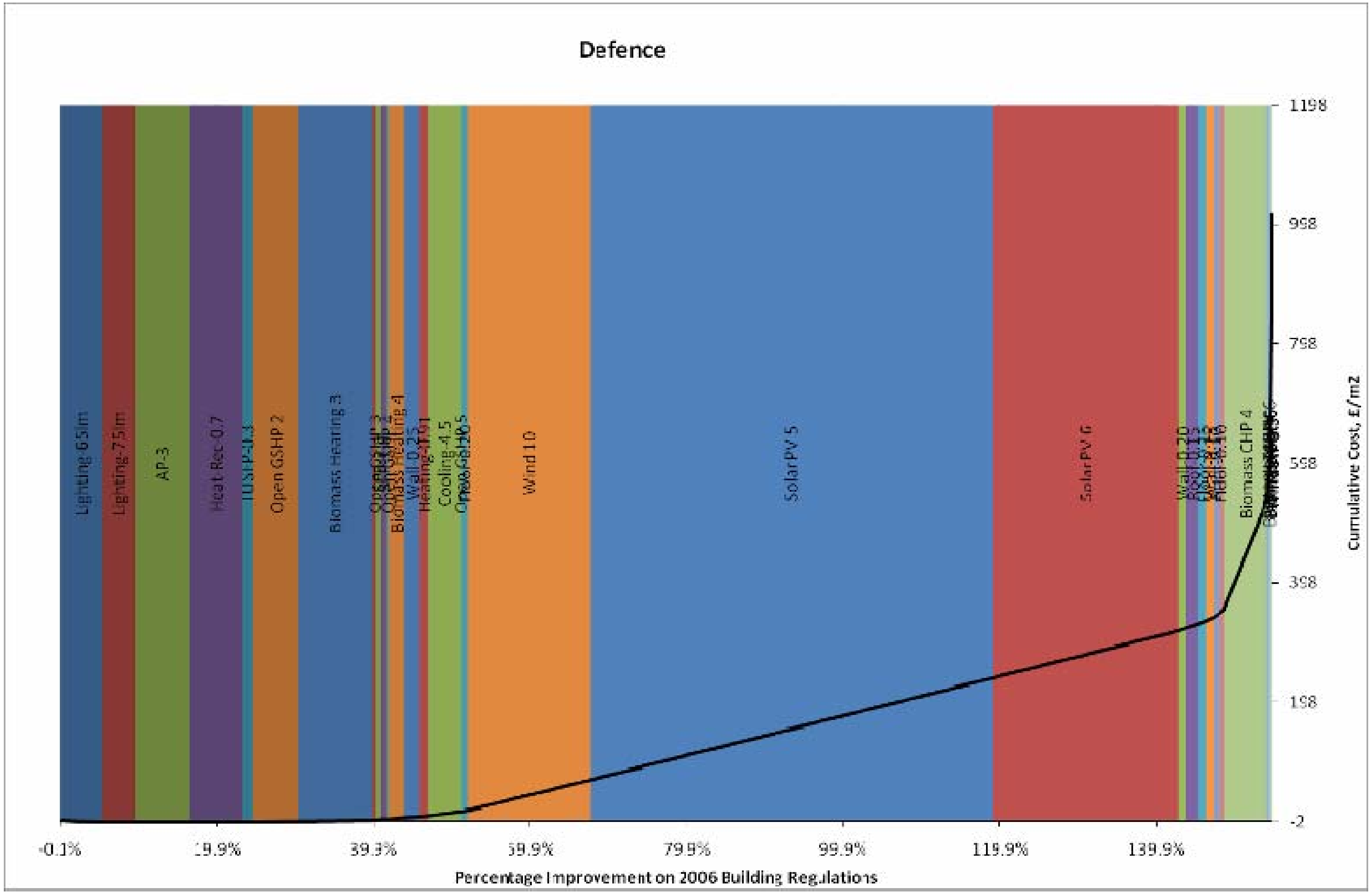

Figure B.11a: Capital cost curve for Defence

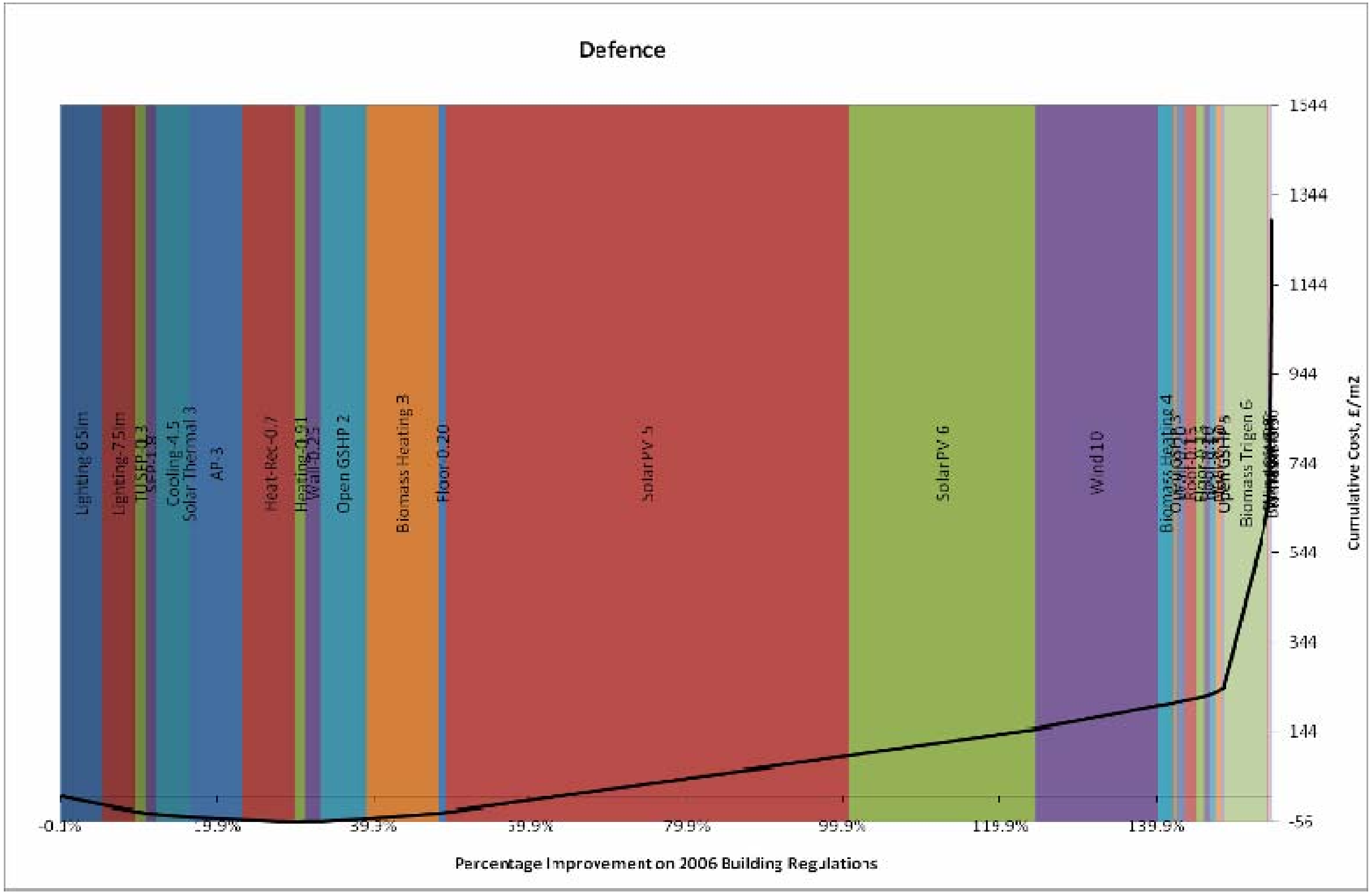

Figure B.11b: Lifecycle cost curve for Defence

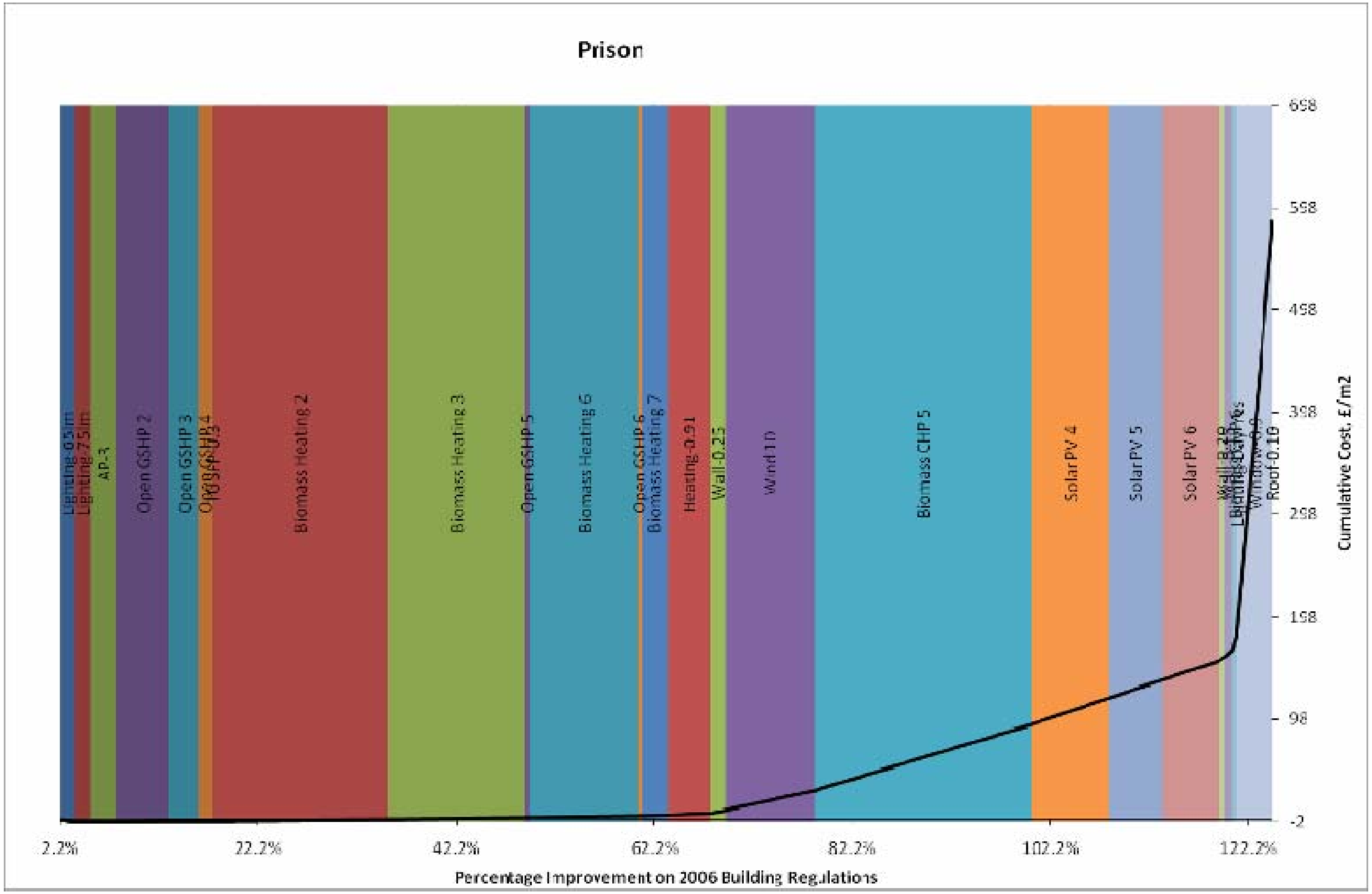

Figure B.12a: Capital cost curve for Prison

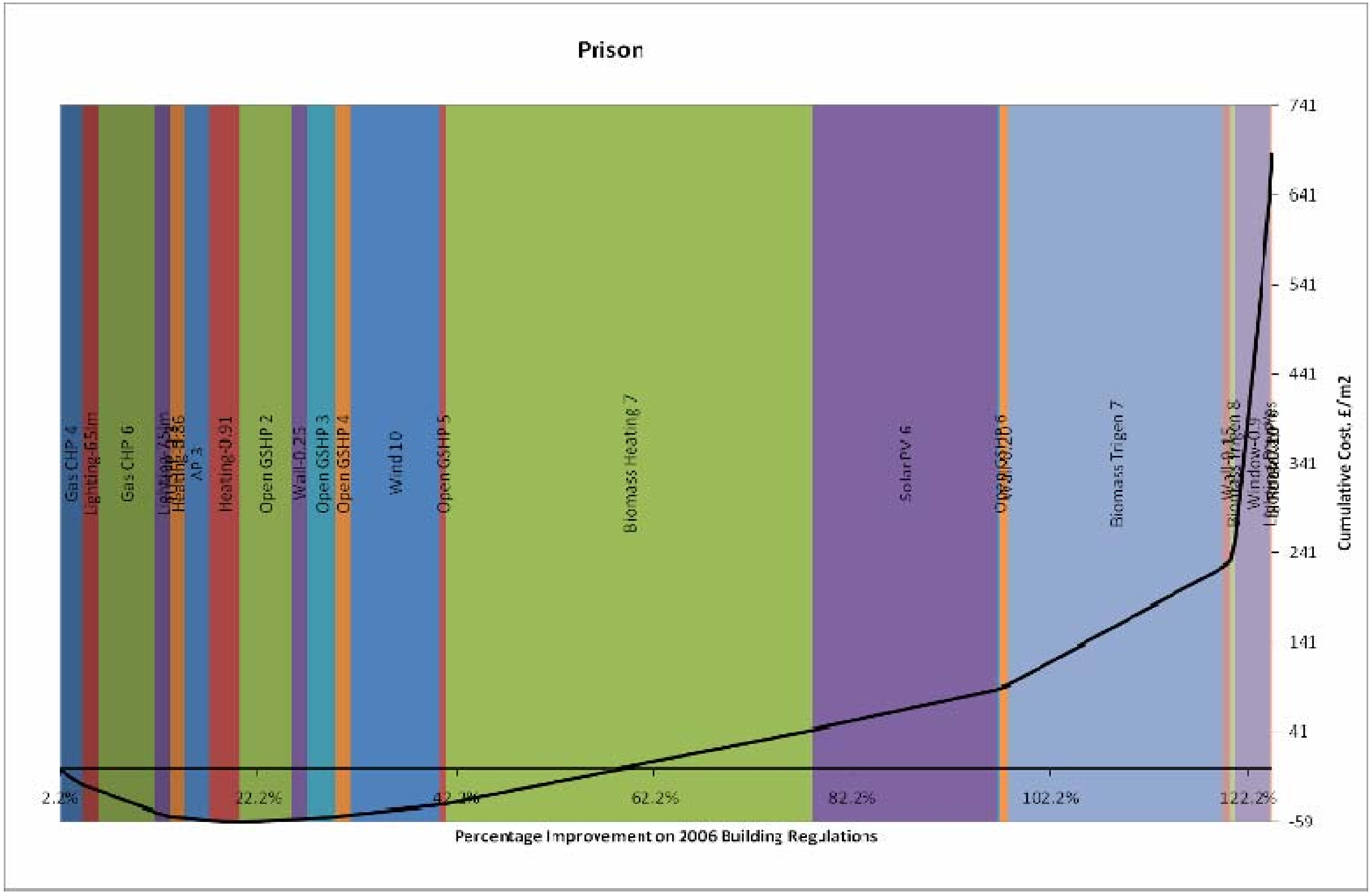

Figure B.12b: Lifecycle cost curve for Prison

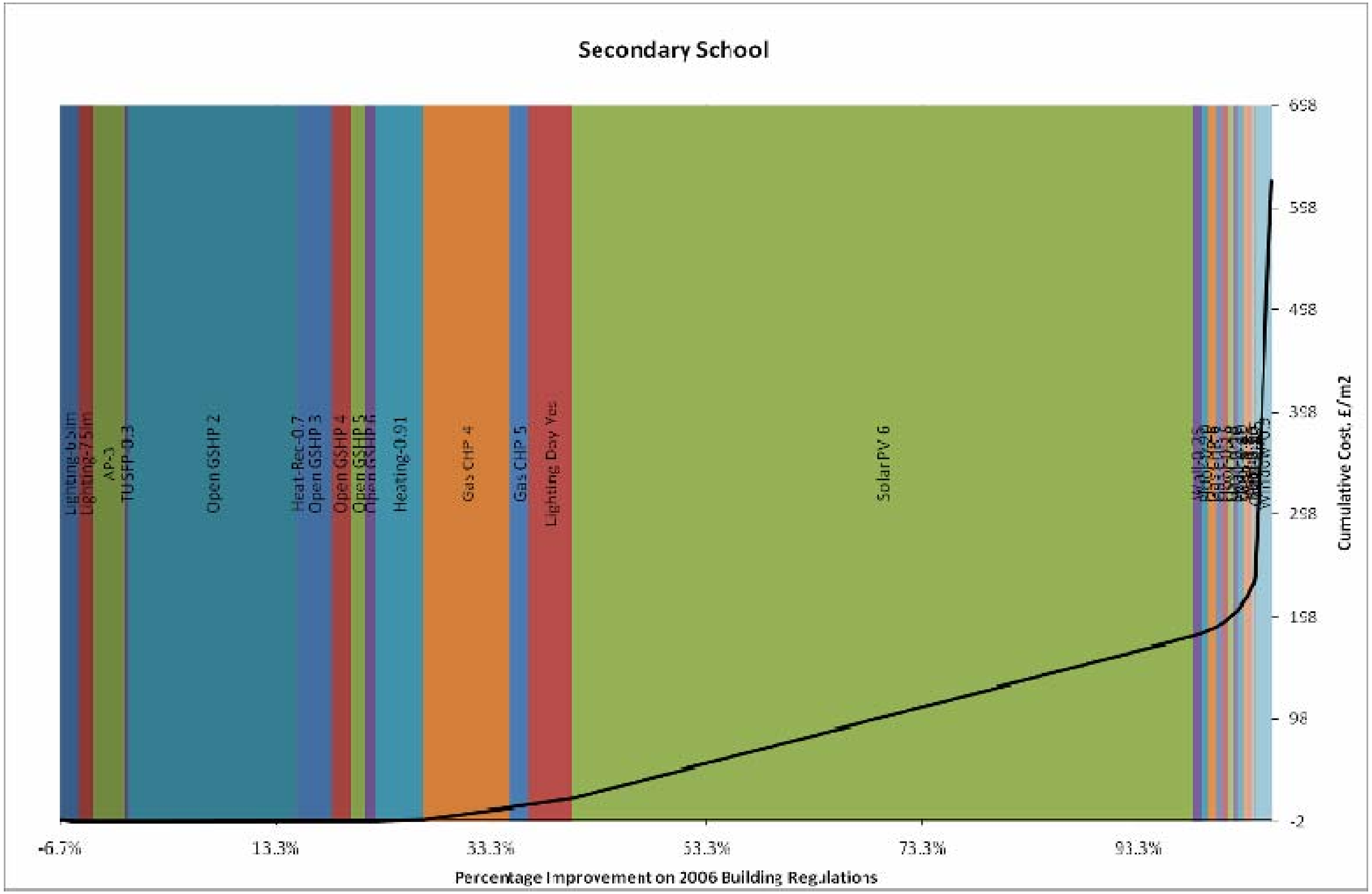

Figure B.13a: Capital cost curve for Secondary School

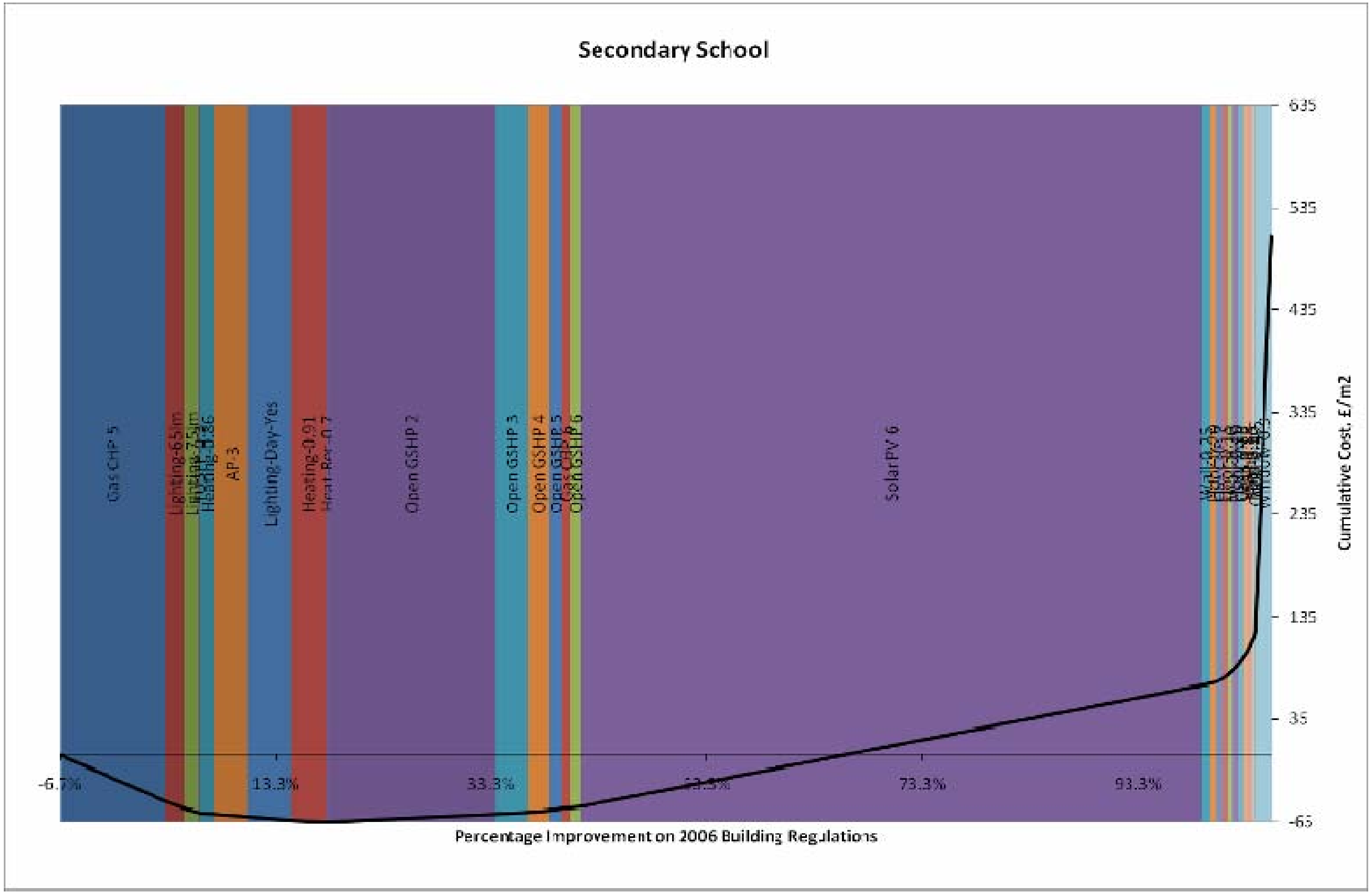

Figure B.13b: Lifecycle cost curve for Secondary School

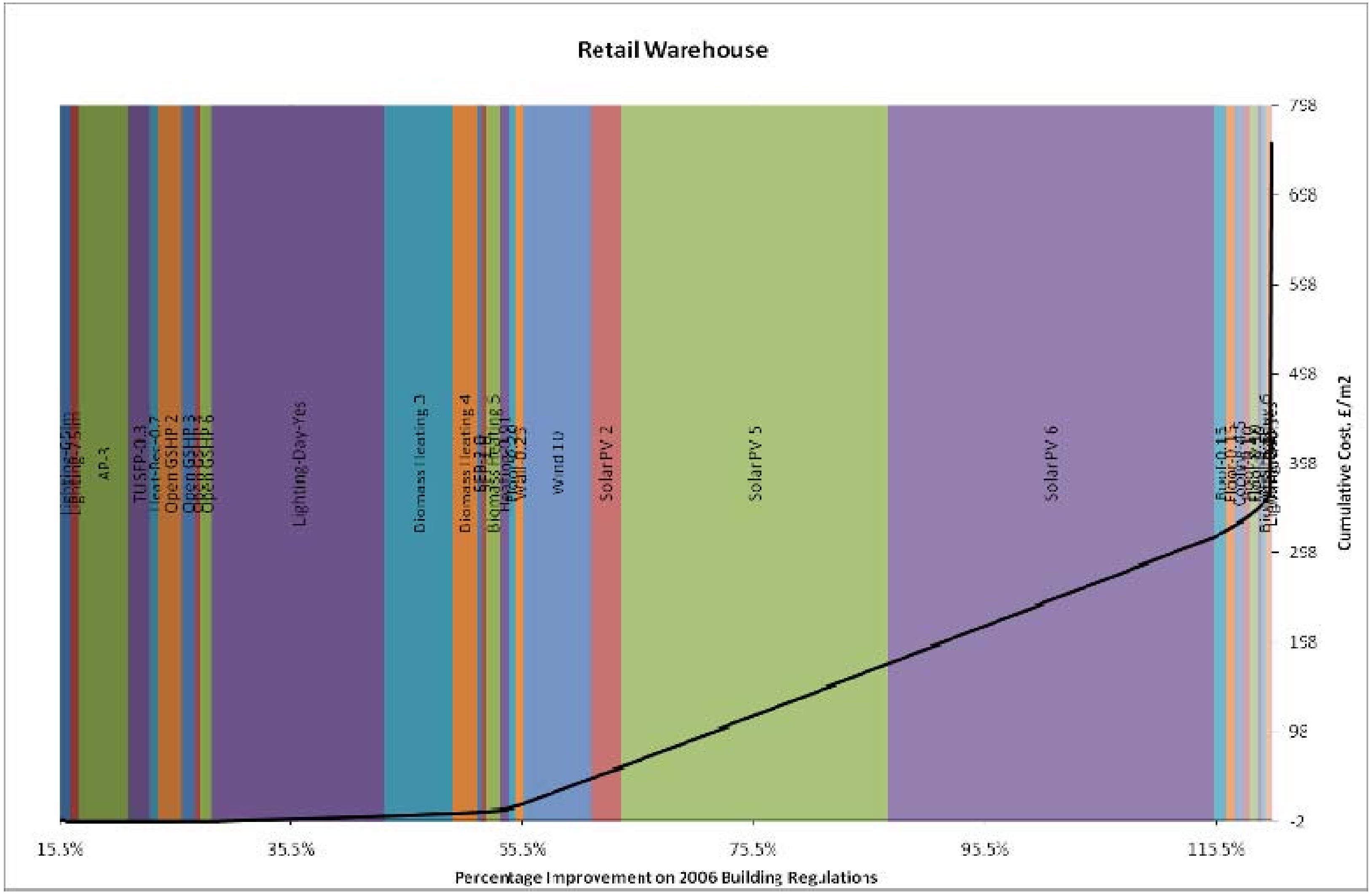

Figure B.14a: Capital cost curve for Retail Warehouse

Figure B.14b: Lifecycle cost curve for Retail Warehouse

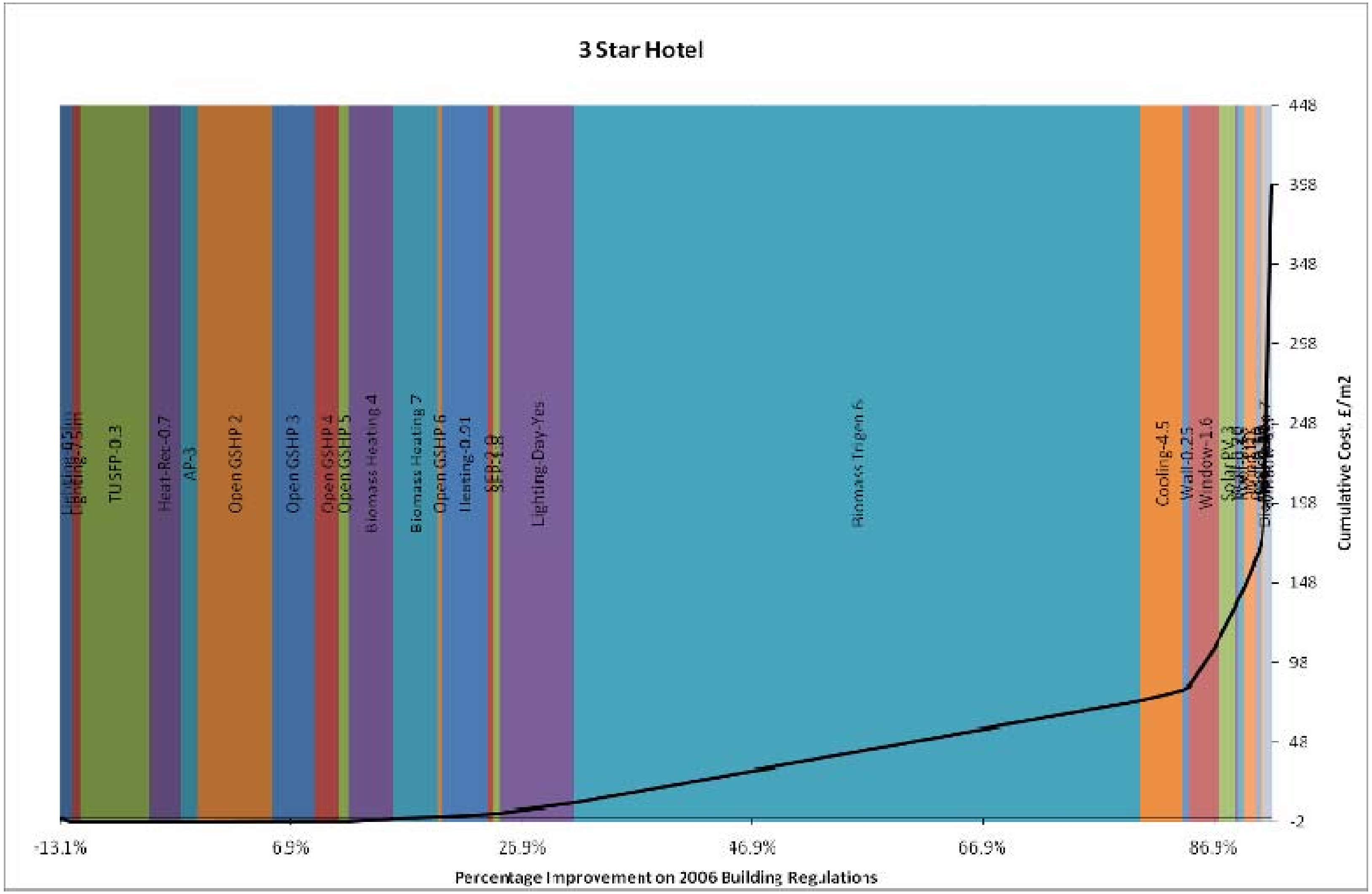

Figure B.15a: Capital cost curve for 3 Star Hotel

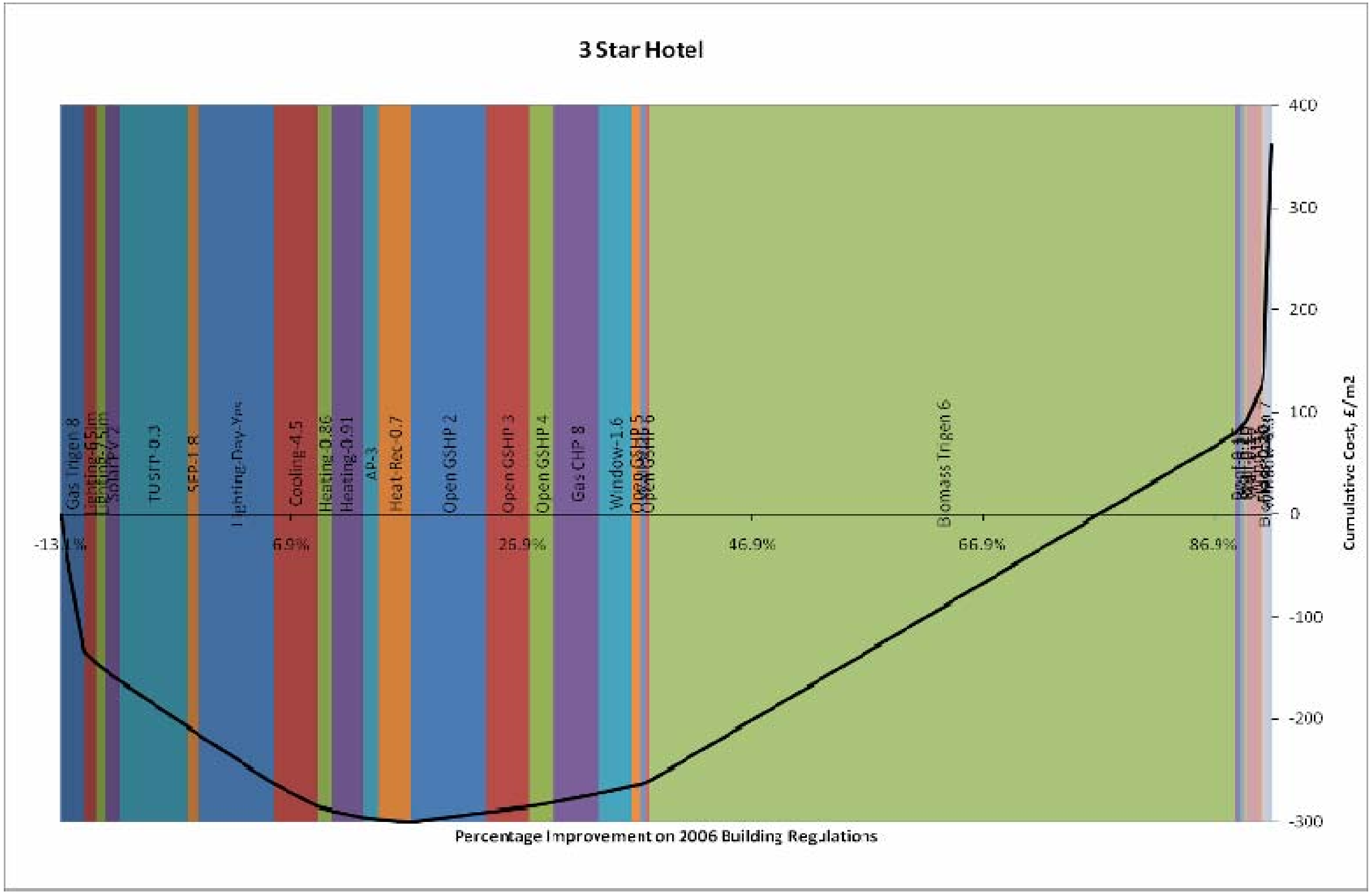

Figure B.15b: Lifecycle cost curve for 3 Star Hotel

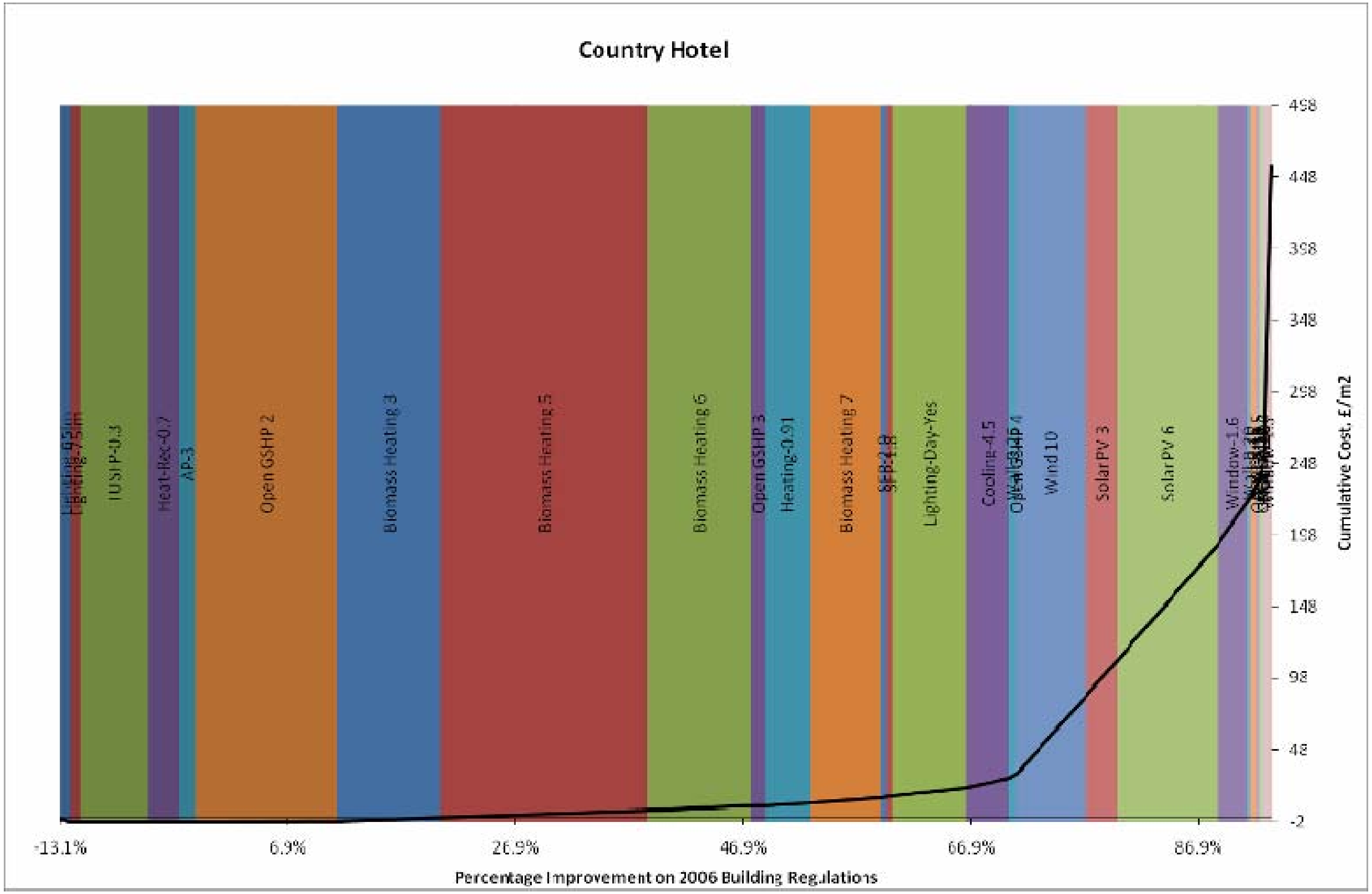

Figure B.16a: Capital cost curve for Country Hotel

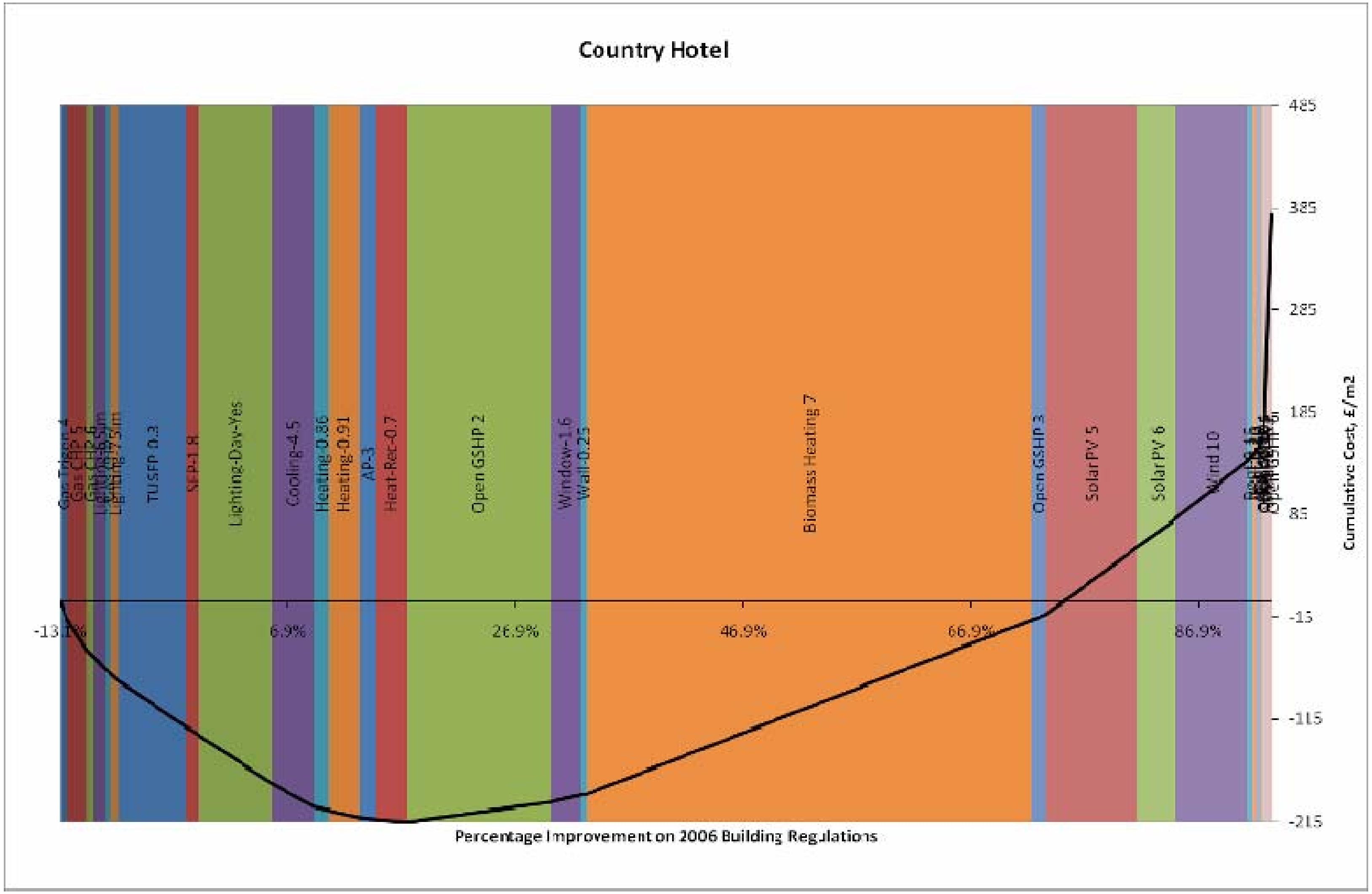

Figure B.16b: Lifecycle cost curve for Country Hotel

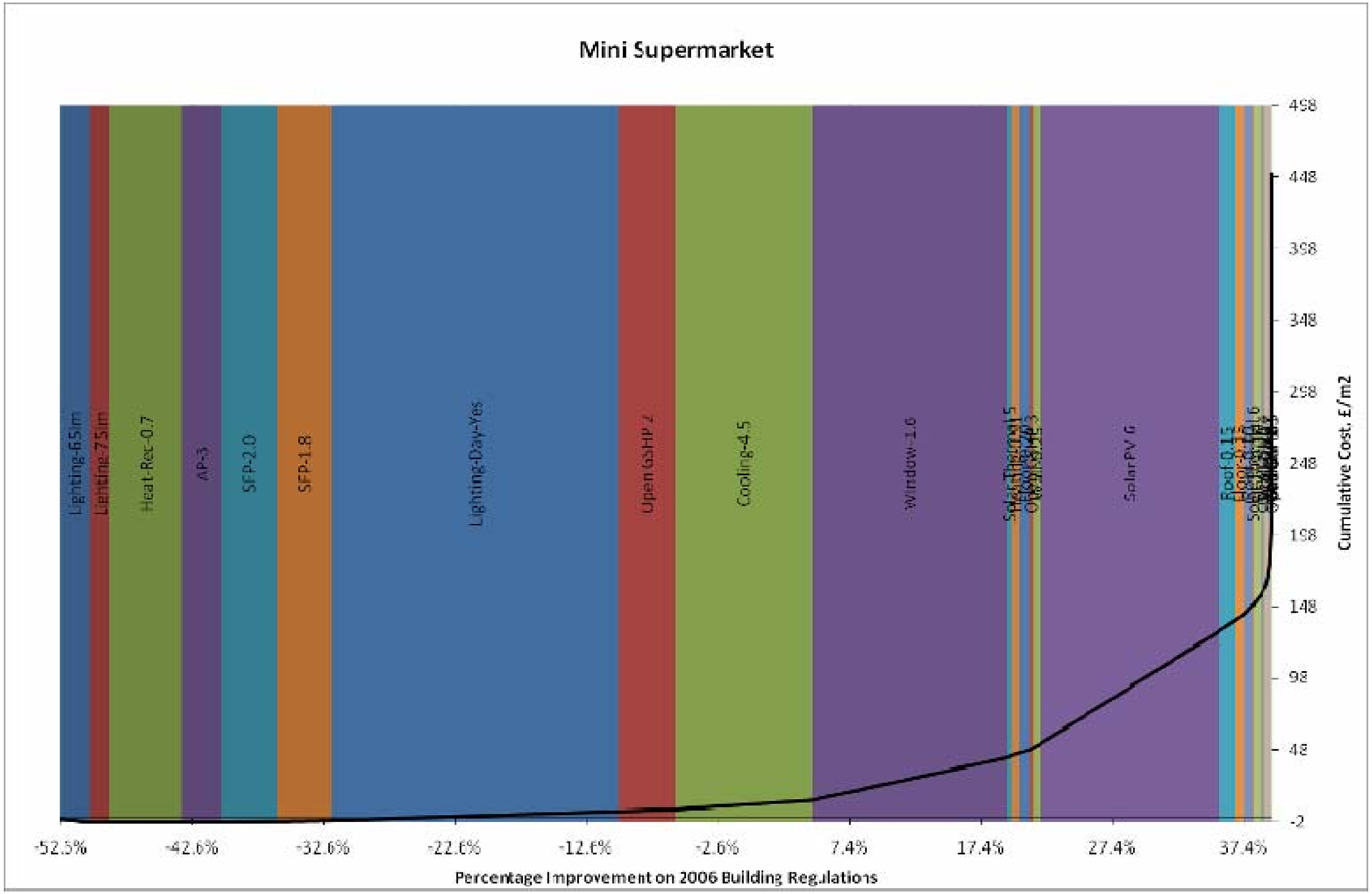

Figure B.17a: Capital cost curve for Mini Supermarket

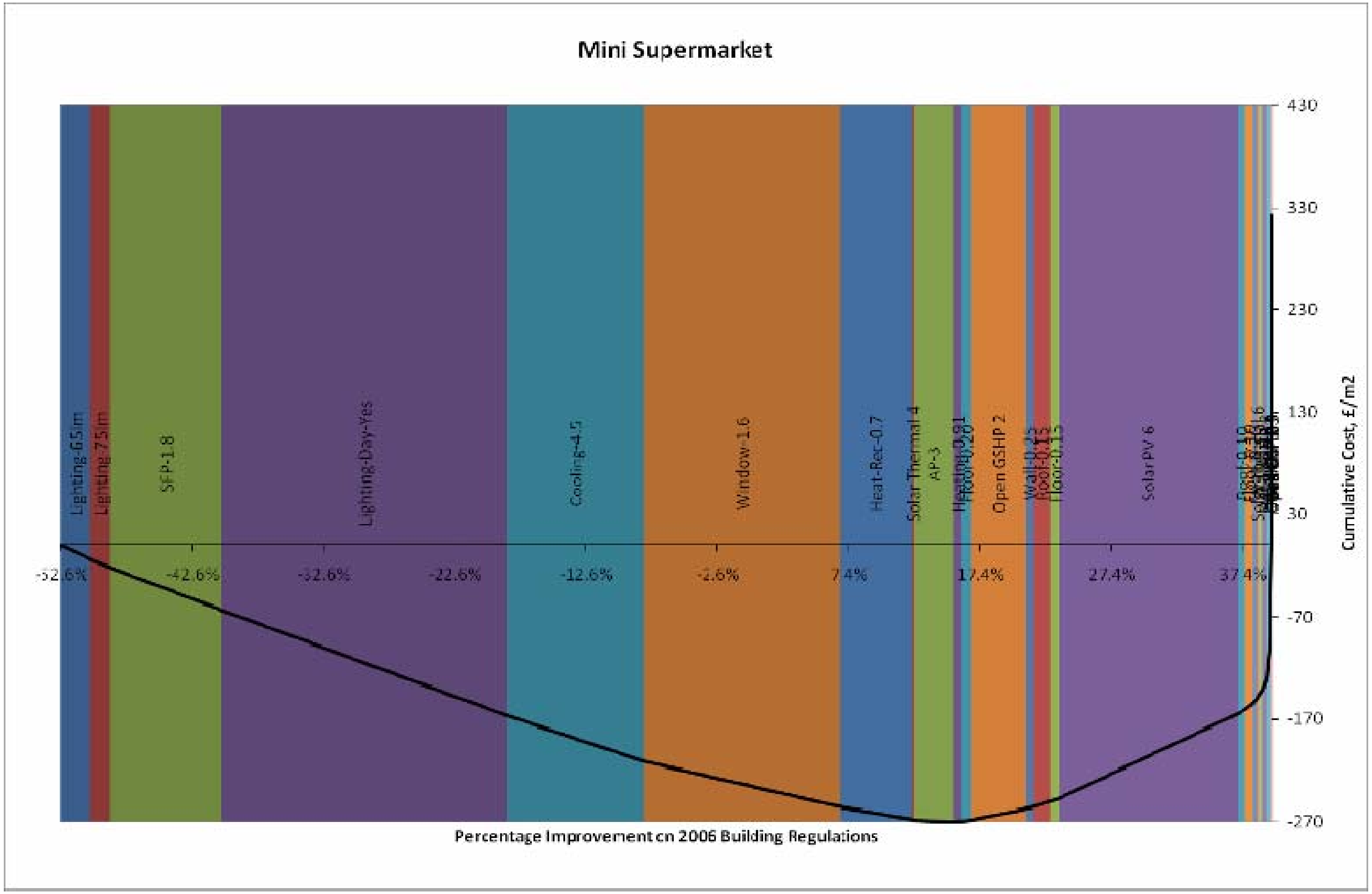

Figure B.17b: Lifecycle cost curve for Mini Supermarket

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