Response from the UK Energy Research Centre (UKERC) to the Energy and Climate Change Committee's Inquiry on Heat

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Submitted on behalf of UKERC by
Robert Sansom, Imperial College London, SW7 2AZ
Email: r.sansom10@imperial.ac.uk
Prof Nick Jenkins, Cardiff University, CF24 3AA
Email: jenkinsn6@cardiff.ac.uk
Dr Modassar Chaudry, Cardiff University, CF24 3AA
Email: chaudrym@cardiff.ac.uk
Prof Nick Eyre, University of Oxford, OX1 3QY
Email: nick.eyre@ouce.ox.ac.uk
Prof Jim Watson, UKERC, SW7 2PG
Email: jim.watson@ukerc.ac.uk

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Executive Summary

1. This document sets out the response of the UK Energy Research Centre (UKERC) to the Energy and Climate Change Committee's Inquiry on Heat.
2. The submission is under the control of Robert Sansom from Imperial College London.
3. UKERC welcomes the ECC's call for evidence on heat and concur with concerns that the Government's energy policy focus has been on the electricity sector. The risk of such a focus is that action taken in one sector does not take account of the impact on the other and the outcome may be sub-optimal.
4. We would always encourage a "whole systems approach" to energy, certainly including heat with electricity, and ideally transport as well. Such an approach is more likely to encourage consistency between sectors, avoiding perverse incentives but also it is more likely to lead to the discovery of optimal solutions.
5. In the call for evidence, the Committee makes the comment that there is disagreement concerning the un-used heat from thermal electricity generation with some arguing that this should be used through combined heat and power (CHP) systems, while others suggest optimal energy efficiency occurs through centralised electricity generation plus heat pumps at the local level.
6. Heat exhausted from large thermal generators has very little use as most of the useful energy has been extracted to produce electricity. A typical temperature of the "exhausted heat" is around 30°C which is too low for district heating systems. This requires heat to be extracted at a higher temperature, circa 90°C, but this does result in lower electricity output from the thermal generators. Typically, 7 units of heat generated by a CHP unit will result in the reduction of 1 unit of electricity output [1]. This contrasts with air source heat pumps where the ratio is 1 unit of electricity to 3 units of heat (typically).
7. Hence CHP is much more energy efficient but of course district heating system infrastructure is required. Opponents of CHP systems cite this as the major stumbling block but they ignore the electricity infrastructure cost, mainly distribution but also transmission and generation that would be required for heat pumps. They also ignore the customer based cost of the heat pumps, upgrades to home heating systems, etc. Once these costs are all included the economics for CHP are much improved [2].
8. A further point to make is that heat provided by CHP will have the lowest carbon emissions compared to other fossil fuel-based heat generation. For example, using typical values, a condensing gas boiler emits circa 210 g/kWh_t[1] and an electric heat pump circa 120g/kWh_t[2]. However, for a CHP it is circa 60g/kWh_t[3].

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[1] 190g/kWh (carbon content of natural gas) ÷ 90% (boiler efficiency)
[2] 190gkWh ÷ 55% (CCGT efficiency) ÷ 93% (transmission & distribution efficiency) ÷ 300% (heat pump efficiency)
[3] 190gkWh ÷ 55% (CCGT efficiency) ÷ 85% (heat network efficiency) ÷ 700% (thermal generation Z factor or virtual heat pump efficiency)

9. **Thus our overall opinion is that CHP (electricity and heat production) and district heating (which encompasses all forms of heat production as well as heat network and other associated infrastructure) do not receive the attention they deserve.**

10. Please note that our responses to questions 1, 2 and 9 are based on those submitted by the RAEng and IET as we share the same expert (Dr N Eyre) in this area.

UKERC Response to Questions

Question 1 - Is the government taking the right approach to reduce heat energy demand?

11. While the Government's basic principle to reduce heat demand through the Green Deal is sound, it is difficult to give a simple answer to this question given that the sector has many different stakeholders and government schemes have changed considerably in recent times. This has led to confusion among both consumers and industry regarding what is available and uncertainty as to what the long-term outcomes will be. It is unclear whether the new arrangements will prove successful in the long run.

12. When determining success it is vital that the prospective energy savings arising from Green Deal interventions are, in fact, achieved in practice and this must be continually monitored rather than relying on priori forecasts. Early indications suggest the Green Deal is not performing well, see paragraph 17.

13. It is important to stress that for long-term success and learning effects to be realised, policy stability is needed – helping to reduce risk and uncertainty. Raising and reinforcing the importance of heat to our energy system will help to reduce confusion. There is an opportunity to link this to other areas such as the roll-out of smart meters.

14. More generally, it is unfortunate that this consultation does not mention areas of heat waste. The Energy Saving Trust's recent report "At Home with Water"[4] highlights the extent to which heat is wasted through water use in households, illustrating how the subject of heat needs to be looked at in totality.

Question 2 - What progress is the government making on reducing carbon emissions from the demand for heat?

15. Government policy has been a major driver of reducing heat demand over the last decade. Since 2004, energy use in households has fallen by 25%[5], with the vast majority of this reduction being from space and water heating. The key drivers of this reduction have been the improvement of boiler efficiency due to the mandatory use of condensing boilers since 2005 and insulation programmes.

16. However, recent policy changes by the Government seem likely to have a less positive influence on reducing demand for heat. The current administration inherited major insulation programmes, Government's own fuel poverty scheme and the energy supplier obligation programmes. The former has since been discontinued (in England) and the latter reduced in scale. These have been replaced by the Green Deal which makes available loans at commercial rates which are tied to the property rather than the individual.

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[4] www.energysavingtrust.org.uk/About-us/The-Foundation/At-Home-with-Water

[5] www.ons.gov.uk/ons/rel/regional-trends/area-based-analysis/household-energy-consumption-in-england-and-wales--2005-11/art-household-energy-consumption-in-england-and-wales--2005-11.html

17. The Government's own projections indicate that this will be approximately one third as effective as the policies it replaces [3]. Moreover, take-up on the Green Deal has been initially very slow suggesting concern on the part of consumers and possibly problems relating to financing. UKERC is exploring the circumstances under which consumers will undertake energy efficient renovations in their homes, including the impact of the Green Deal[6]. The results will be published later this year.

18. The Renewable Heat Incentive (RHI), which offers financial support for renewable heat technologies, has been operational for non-domestic customers since November 2011 and is expected to be open for domestic customers in spring 2014. Reports[7] suggest that the total paid out to May 2013 has been less than £12m, which is insignificant compared with the scale of the challenge although we accept it is still early days.

19. Delays in implementation, excessive centralised bureaucracy, changes to the tariffs, the decision to cut payments to mid-size biomass users and the complexity of the scheme, as well as the relationship with other schemes, such as the Renewable Heat Premium Payment (RHPP), have contributed to complex arrangements that are poorly understood by many potential beneficiaries and overall it is no surprise that progress has been limited.

20. Ultimately, the success of government policy will depend on their ability to design schemes that are attractive to investors and customers alike and that integrate well together, for example the ability to combine Green Deals with RHIs.

21. It is also important to note that any success in improving energy efficiency measures runs the risk of 'rebound effects' whereby lower heating costs result in people maintaining higher temperatures in homes for added comfort, thus negating any possible reductions in heating demand. This has been observed in countries with high levels of thermal efficiency in buildings and, even in the UK, average household temperatures have been steadily rising since the wide-scale introduction of central heating[8]. The UKERC review [4] concluded that rebound effects are only partial in these sorts of cases and so do not negate the impacts of energy efficiency policies, but they do mean that their impacts will not be as large as many assessments predict.

Question 3 - Biomass is deemed a key fuel for heat production from both the cost and GHG perspectives. What should be done to ensure methods of calculating biomass GHG balance represent an accurate picture?

22. **We would recommend the adoption of the methodology detailed in the IEA Bioenergy LCA assessment report published in 2011 [5]. This ensures that the calculation includes all processes with significant GHG emissions, including, where relevant, upstream processes of extraction or biomass production and end of life processes**.

[6] www.ukerc.ac.uk/support/tiki-index.php?page=RF3LEnergyEfficientHomeRenovations
[7] www.businessgreen.com/bg/news/2271949/government-boosts-rhi-in-attempt-to-warm-up-renewable-heat-market
[8] www.bre.co.uk/filelibrary/pdf/rpts/fact_file_2008.pdf

23. However, a fundamental assumption is that GHG emissions produced by combustion of plant biomass are assumed to be recaptured by new growing plants. When the raw material is wood, the time needed to re-absorb the CO_2 emitted in the atmosphere can be long, depending on the source of wood. This delay can create an upfront "carbon debt" that can significantly weaken the capability of bioenergy to reduce the GHG in the atmosphere in the short to medium term [6].

24. However, this is a complex issue[9, 10] and so we suggest that more research is needed to accurately account for "carbon debt" in the calculation of biomass GHG emissions. Work on this issue is on-going within the Department of Energy and Climate Change and we hope this can be expedited to help promote sustainable sources of biomass.

Question 4 - There are sustainability guidelines for biomass, do these go far enough?

25. By spring 2014, sustainability criteria for biomass used in the UK for large and small-scale electricity and heat production will become standardised. The criteria go beyond existing EU requirements for these types of energy production from biomass. The Renewable Heat Incentive (RHI) will become the mechanism for promoting and controlling the use of biomass for heat production across domestic and non-domestic heat systems [7].

26. Currently all mandated sustainability criteria for biomass is environmentally-focused but in line with sustainable development ideals biomass energy needs to be sustainably produced and economically viable without negatively impacting other social conditions. Research has shown that social or economic systems can be de-stabilised by higher levels of income inequalities, social divide or poverty [8].

27. **Hence, we believe that the sustainability criteria for biomass do not go far enough. Social and economic impacts of biomass use remain largely unknown, although there have been calls for these types of issues to be included within mandated sustainability criteria [9].**

28. Resistance to the take-up of renewable energy is most-often based on concerns of impacts across social, economic and environmental spaces. The social acceptability of the use of biomass is likely to be higher if socio-economic impacts and issues are included alongside environmental assessments.

29. A recently published UKERC study into public values, attitudes and acceptability of energy technologies [10] found that public perceptions of biomass and biofuels are more complex than perceptions towards other renewable energy technologies, partly owing to their being less familiar and more diverse. Sustainability criteria and standards for biomass could be a means of increasing their social acceptance, making them more cost-effective and improving levels of uptake for these types of scheme.

[9] www.nnfcc.co.uk/publications/nnfcc-briefing.-bioenergy-a-sustainable-solution-to-delivering-heat-and-power-in-the-uk
[10] greenallianceblog.org.uk/2013/06/14/carbon_debt_is_not_a_reason_to_pull_the_plug_on_biomass_electricity/

Question 5 - What will the local environmental impact (for example air pollution) be from the use of heat generation in urban areas, for example CHP units?

30. We assume that this question refers specifically to heat generation technology which is eligible to receive the RHI. There are a number of local environmental impacts from heat generation in urban areas. These include fuel transport, waste management, noise and visual impact.

31. However the only RHI-eligible technology which is likely to have a local environmental impact on air pollution is biomass technology, and for this to meet the eligibility criteria for both the domestic and non-domestic RHI it must comply with the specified air quality standards (not to exceed the maximum permitted emissions limits of 30 grams per gigajoule (g/GJ) net thermal input for PM and 150 g/GJ for NO_x)[11,12].

32. We are unable to comment on how challenging this is. However, the UK has ambitious targets for biomass in order to comply with the EU renewable energy target and it is possible that despite satisfactory air quality standards, the local environment may be adversely impacted if the concentration of this technology is high. Unless the government has evidence that the local environmental impact will not be adversely affected we suggest that monitoring is undertaken to ensure that action can be taken before this becomes a problem.

Question 6 - What are the relative merits of using gas to directly provide space heating compared to centralised electricity production plus domestic heat pumps?

33. Gas is a very effective fuel for heating. It is clean, flexible and can be stored relatively cheaply enabling it to meet the very substantial peaks in demand that occur at times of cold weather. Over 80% of the homes in the UK are designed to be heated by gas and most installed gas boilers have a high capacity rating which enables homes to be heated quickly if needed. In addition gas has an existing and well proven infrastructure that has received and continues to receive substantial investment.

34. **However, gas is carbon emitting and there is limited scope for decarbonising gas for residential and commercial heating applications, i.e. via bio-methane and hydrogen injection. Hence the UK will have to reduce substantially and possibly discontinue its use of gas for heating if we are to meet the 2050 GHG emissions target.**

35. Electric heat pumps properly designed and installed also offer an effective form of heating and with grid decarbonisation carbon emissions arising from space and water heating can be reduced. However, the heat has different features compared to gas heating. It is produced

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[11] www.gov.uk/government/policies/increasing-the-use-of-low-carbon-technologies/supporting-pages/renewable-heat-incentive-rhi

[12] www.gov.uk/government/uploads/system/uploads/attachment_data/file/212089/Domestic_RHI_policy_statement.pdf

at a lower water temperature than gas boilers and upgrades to the building's radiators may be required. Heat pumps will have a lower capacity rating, typically <50% of a gas boiler and so will take longer to meet the space and water heating demands of the building. For air source heat pumps the maximum heat output will decline with external air temperature and so additional heating may be required in cold weather.

36. **It is important to note that the large-scale deployment of heat pumps will require very substantial investment in electricity generation, transmission and distribution infrastructure. Electricity demand is particularly onerous on the system as heat is sensitive to large "peaks". For example, using the DECC 2050 Pathways Calculator [11] and under credible heat pump deployment rates, peak electricity demand could double from current levels (approximately 60GW) [2] [12].**

37. This of course raises the question of what we should do with the existing gas infrastructure and consideration needs to be given to its future role. Various options were explored by UKERC earlier in March 2013 in a meeting entitled "The Future of the Gas Network"[13].

38. The workshop discussed possible future scenarios for the UK gas network and identified a number of policy issues for the UK Government and Ofgem. It noted that studies of UK decarbonisation pathways to meet the UK emissions targets have invariably suggested that the low-pressure gas mains networks should be mostly decommissioned by 2050, with heating provided by electric heat pumps, biomass boilers and district heating.

39. A number of alternative roles for gas networks in the UK energy system were also examined but it also recognised that the expectation of their decommissioning seems to have come about by accident rather than by design and so this needs to be incorporated within the UK's overall energy strategy.

40. **One of the main conclusions from the meeting was the need to establish a Gas Networks Strategy Group to examine the future role of gas networks in the UK and which we believe should be given serious consideration.**

Question 7 - Why is community heating/CHP not more common in the UK?

41. District heating was investigated in the 1970s by the Marshall Inquiry [13][14] which recommended that strategic plans should be drawn up for the future development of CHP schemes in the UK. However, by then natural gas had become readily available. This is in contrast to other parts of Europe, particularly in Denmark where over 50% of total electrical power production is from CHP [15]. Denmark rapidly deployed CHP and district heating after the 1970s' oil price crises in order to reduce its dependence on imported oil. Without access to natural gas the economics of CHP for heat production was more attractive particularly relative to imported oil.

[13] www.ukerc.ac.uk/support/0313_MP_GasNetworks

42. Gas remains the main competitive alternative to community or district heating. Where there is an existing gas infrastructure, community heating is at a competitive disadvantage due to the investment required in the heat network infrastructure. However, in contrast to gas, district heating can be decarbonised through the use of low carbon heat sources, e.g. fossil fuel CHP plant with CCS, large electric heat pumps, solar thermal, geothermal, biomass, waste. Hence, the main alternative to community heating in the future is likely to be electric heat pumps. In both cases a substantial investment in infrastructure is required to meet the increase in low carbon heat demand and when these costs are included district heating is likely to be more attractive, particularly for high density heat loads [2] [16].

43. **However, district heating networks are at a disadvantage, as they will be competing with an infrastructure that is subject to regulation and where there is a mechanism to support network investment. No such mechanism is available for heat networks and although there are a number of examples of successful private heat networks in the UK, such arrangements may not be appropriate for large-scale deployment, particularly when competing with a regulated asset. Hence consideration needs to be given to whether heat networks should be regulated in a similar way to other network infrastructure.**

44. It should also be noted that the supply of heat can be a competitive activity in the same way as gas and electricity. Just as suppliers do not need to have ownership of electrons or gas molecules to supply customers with electricity or gas, they do not need to have ownership of water molecules to supply heat.

Question 8 - What are the lock-in, costs and GHG savings from the promotion of different forms of domestic heating solution?

45. Not answered.

Question 9 - Should the government take any further any specific actions in relation to cooling?

46. The recent hot weather has reminded us that temperatures in Britain can become unpleasantly hot and humid, particularly in cities which suffer from urban heat island (UHI) effects and climate change is likely to result in greater variability and more frequent hot periods. Most significantly there is mortality associated with UHI overheating.

47. In the hot summer of 2003, more than 900 deaths were directly attributable to overheating in the UK and more than 20,000 attributable deaths occurred in Europe. It is therefore advisable to consider cooling when specifying any thermal management system. In almost all cases, a well-designed cooling system, integrated with the building structure and heating system will be more efficient than a succession of schemes added as afterthoughts to residential or office buildings.

48. The need for cooling and the efficiency with which cooling is currently delivered to buildings has been generally ignored by government and in public debate. The requirement for air conditioning inspections under the Energy Performance in Buildings Directive is largely ignored by the public sector. There has also been little consideration in designing building regulations on the impact of high insulation standards on summertime performance. For example, a small modern flat with west facing glazing left locked up during the day can easily reach 40°C because of a lack of external shading.

49. New London flats are often sold with air conditioning, no doubt reflecting buyers' expectations, but with no regulatory control on efficiency that would be imposed on a heating system. Air conditioning design can itself create a heating problem. Much of the US high energy consumption is associated with using electric resistive heating to warm up air leaving dehumidifiers. Packaged air conditioners are substantially less efficient than systems, and while some can be reversed in winter to act as a heat pump the efficiency performance is poor.

50. In many office buildings air conditioning is required to ensure a comfortable working environment. However, even in hotter climates, in residential buildings and many commercial and public buildings, it should be possible to ensure comfort without this additional cost and energy use. Effective passive cooling techniques have been known for hundreds of years in climates warmer than foreseen in the UK.

51. Key principles include improved insulation (but not internal to the walls), improved shading (to reduce solar gain), higher thermal mass (to use night-time cooling) and better ventilation; these need to become part of standard designs in refurbishment and new build, and where appropriate should be incorporated into building regulations.

52. It should also be noted that groundwater cooling is fortuitously available from under-used aquifers below many UK cities. This technology is still in its infancy but there are large-scale trials[14] that suggest further investigation is warranted.

Question 10 - Why does the RHI not seem to promote heat pumps successfully?

53. It is too early to comment, particularly as it has not yet been introduced to the domestic market.

Question 11 - How successful will the RHI be when rolled out to households?

54. Issues still persist on the level of complexity of the entire RHI administrative process, from certification (MCS, ETS), monitoring/metering equipment, and installation and correct sizing of heat pumps. A lack of trust between the wider public and energy companies was

[14] See, for example http://eprints.gla.ac.uk/82767/ (full text available on request)

highlighted in a recent UKERC report [10] on public perceptions to energy issues this could well be a barrier given that RHI payments will be made through energy companies.

55. The level of subsidy will be critical but even then there are many other factors that will need to be considered. According to a previous UKERC response[15] to the DECC consultation on the RHI (2011) it was noted a kWh based subsidy (RHI tariff) may not be enough to sway consumers given the high upfront capital costs. Although complexity of the entire RHI administrative process may deter some people, the upfront costs issues have to a degree been addressed through the Green Deal although there remain a number of serious concerns as discussed in paragraph 18.

Question 12 - Thermal storage is a potential useful method of balancing electricity/energy demand both diurnally and annually. What is government policy doing to promote thermal storage, and should it do more/different?

56. The future role of energy storage has recently been the subject of a UKERC research project[16] and the report is due to be published in Autumn 2013 and we would be delighted to send the ECC a copy of the report as soon as it is available.

57. At present other than sponsoring research, there is no action by government to support thermal storage. In fact thermal storage has declined in the UK due to the popularity of combination gas boilers which have enabled hot water storage tanks to be removed from households[17].

58. Thermal Energy Storage (TES) is a useful method for reducing peak heat consumption. District heating systems enable large thermal (hot water) energy storage systems to be installed relatively inexpensively and which can reduce carbon emissions by 10% compared with the base case without TES [17].

59. The thermal storage performance of a building can also be enhanced with the installation of phase change materials (PCM) [18]. Studies on PCM indicate that significant energy savings can be obtained when PCM are used in buildings.

60. TES combined with CHP can be used as a means for balancing electricity and heat supply networks. This method (common in Denmark) is justified if electricity is generated using renewable energy sources which are stochastic and unpredictable [19].

61. One of the benefits of district heating systems is that they provide the option to use many different forms of heat generation. As an example of such a holistic approach is the integration of Compressed Air Energy Storage (CAES) with Thermal Energy Storage. CAES and TES (hot water storage) are mature technologies and some studies suggest that CAES technology has the lowest cost compared with batteries and even pumped hydro storage

[15] www.ukerc.ac.uk/support/Inputs+to+Policy
[16] www.ukerc.ac.uk/support/tiki-index.php?page=RF3SmallThermalStorage
[17] www.bre.co.uk/filelibrary/pdf/rpts/Space_and_Water_Heating_2007.pdf

systems [20]. However, the low energy efficiency of CAES systems compared with pumped hydro has impeded its acceptance. A distinctive feature of CAES systems, compared with other energy storage technologies, is the production of a large quantity of heat during the compression stage. This feature of CAES systems can be utilised for generation and storage of heat when combined with TES. A recent study on combined CAES and TES shows that these systems have the potential to be used both as energy storage and heat source and could be a useful tool for balancing overall energy demand and supply [21].

References

[1] Lowe, R. (2011). "Combined heat and power considered as a virtual steam cycle heat pump." Energy Policy UK 39, pp 5528–5534.

[2] Sansom, R; Strbac, G. (2012). "The impact of future heat demand pathways on the economics of low carbon heating systems." BIEE – 9th Academic Conference - European Energy in a Challenging World: The impact of emerging markets. St John's College, Oxford. 19/20 September 2012.

[3] Rosenow, J.; Eyre, N. (2012). "The Green Deal and the Energy Company Obligation – will it work?" 9th BIEE Academic Conference - European Energy in a Challenging World: The impact of emerging markets. St John's College, Oxford. 19/20 September 2012.

[4] Sorrell, S. (2007). "The Rebound Effect: an assessment of the evidence for economy-wide energy savings." UKERC. London. UK.

[5] IEA Bioenergy. (2011). "Using a life cycle assessment approach to estimate the net greenhouse gas emissions of bioenergy." IEA Bioenergy: ExCo: 2011: 03.

[6] Zanchi, G.; Pena, N.; Bird, D.N. (2010). "The upfront carbon debt of bioenergy." Report for Birdlife International by Joanneum Research. www.birdlife.org/eu/pdfs/Bioenergy_Joanneum_Research.pdf

[7] DECC. (2013). "Domestic Renewable Heat Incentive: The first step to transforming the way we heat our homes." DECC. London, UK.

[8] Wilkinson, R.; Pickett, K. (2010). "The Spirit Level: Why Equality is Better for Everyone." Penguin. UK.

[9] Nuffield Council of Bioethics (NCB). (2011). "The Ethics of Biofuels." NCB. April 2011. UK.

[10] Parkhill, K.A.; Demski, C.; Butler, C.; Spence, A; Pidgeon, N. (2013). "Transforming the UK Energy System: Public Values, Attitudes and Acceptability – Synthesis Report." UKERC. London. UK. pp 12-13.

[11] DECC. (2010). "2050 Pathways Analysis." DECC. London. UK.

[12] Bagdanavicius, A.; Jenkins, N. (2013). "Power Requirements of Ground Source Heat Pumps in a Residential Area", Applied Energy 102, pp 591-600.

[13] Anon. (1976). "District heating combined with electric generation in the UK: Energy Paper Number 20." HMSO.

[14] Anon. (1979). "Combined heat and electric power generation in the UK: Energy Paper Number 35". HMSO.

[15] IEA. (2008)."Combined Heat and Power – Evaluating the benefits of greater global investment." IEA. Paris.

[16] Grant, I. A. G. *et al.* (2013). "Historical daily gas and electrical energy flows through Great Britain's transmission networks and the decarbonisation of domestic heat." Energy Policy 61, pp 301-305.

[17] Martin, M.; Thornley, P. (2013). "The potential for thermal storage to reduce the overall carbon emissions from district heating systems." Tyndall Centre for Climate Change Research. p 50.

[18] Mehling, H.; Cabeza, L.F. (2010). "Heat and cold storage with PCM." Springer. Berlin. p. 308.

[19] Chesi, A.; Ferrara, G.; Ferrari, L.; Magnani, S.; Tarani, F. (2013). "Influence of the heat storage size on the plant performance in a Smart User case study". Applied Energy (accepted).

[20] Sundararagavan, S.; Baker, E. (2012). "Evaluating energy storage technologies for wind power integration". Solar Energy. 86(9), pp 2707-17.

[21] Bagdanavicius, A.; Jenkins, N. (2013). "Exergy and Exergoeconomic analysis of a Compressed Air Energy Storage combined with a District Energy System." Energy Conversion and Management (under review).