# Abstract

Currently space heating accounts for a large portion of the world's energy demand. The majority of this heat is produced from carbon intensive fossil fuels. Ground Source Heat Pumps (GSHPs) are a technology which can be utilized to offer low carbon emissions heating/cooling and hot water supply. However, currently GSHPs are often a more expensive alternative to conventional fossil-fuel heating systems. Moreover, improperly designed GSHPs can increase operational costs and often do not provide the expected reduction in emissions. Due to the many uncertainties involved in the design of GSHP systems, designers prefer to use unnecessarily high factors of safety when choosing the size of a system, which in turn leads to high installation costs. Hence it is important to reduce these uncertainties and improve design procedures of GSHP systems in order to maximize the advantages of this technology and make it more competitive in the market. GSHP systems, and especially hybrid GSHP systems, have many degrees of freedom; there are trade-offs between the reduction in ground heat exchanger size, the size of the supplementary recharger/rejecter, reduction in building demand demand, and the control strategy. Under the current design approach in the industry each of the GSHP system components is designed separately. However, in order to optimize the tradeoffs between the different system components and to account for the uncertainty in building heating and cooling demand, we need an integrated approach that can model the system as a whole. The main objective of this thesis is to develop integrated models of GSHP systems and to test these models with case studies of existing GSHP systems in the UK, in order to demonstrate the advantage of the integrated modelling approach for design and post-occupancy performance evaluation/monitoring of GSHP systems.

This research provides the following main contributions to the design, control and maintenance of GSHP systems: (i) demonstrating the high uncertainty in building demands and the impact of this uncertainty on GSHP system design and performance and proposal of a novel approach of incorporating this uncertainty in the design and economic evaluation of full-size (i.e. non-hybrid) GSHP systems, (ii) demonstrating the added value that integrated models provide to the process of GSHP system optimization, and to system fault diagnosis in the design and/or operation stage, (iii) demonstrating the correlation and dependency of building demand (and therefore building design parameters), distributions system and GSHP system parameters; and the sensitivity of GSHP system efficiency and lifetime costs to these parameters, as well as the ability of a detailed building model integrated with a GSHP model to reduce building energy consumption and operational costs, (iv) assessment of the design and analysis advantages of a detailed and computational intensive finite element GHE model, and (v) quantification of the emission and health impact of the current GSHP portfolio in the UK and the assessment of the potential environmental/health benefits of the technology on a nationwide scale.