Renewable and Sustainable Energy Reviews 81 (2018) 895–911

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A review of energy simulation tools for the manufacturing sector

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ARTICLE INFO

Keywords:
Building Energy Modelling
Manufacturing Process Simulation
Holistic industrial energy use simulation
Co-simulation
Industry
Energy use

ABSTRACT

Manufacturing is a competitive global market and efforts to mitigate climate change are at the forefront of public perception. Current trends in manufacturing aim to reduce costs and increase sustainability without negatively affecting the yield of finished products, thus maintaining or improving profits. Effective use of energy within a manufacturing environment can help in this regard by lowering overhead costs. Significant benefit can be gained by utilising simulations in order to predict energy demand allowing companies to make effective retrofit decisions based on energy as well as other metrics such as resource use, throughput and overhead costs. Traditionally, Building Energy Modelling (BEM) and Manufacturing Process Simulation (MPS) have been used extensively in their respective fields but they remain separate and segregated which limits the simulation window used to identify energy improvements.

This review details modelling approaches and the simulation tools that have been used, or are available, in an attempt to combine BEM and MPS, or elements from each, into a holistic approach. Such an approach would be able to simulate the interdependencies of multiple layers contained within a factory from production machines, process lines and Technical Building Services (TBS) to the building shell. Thus achieving a greater perspective for identifying energy improvement measures across the entire operating spectrum and multiple, if not all, manufacturing industries. In doing so the challenges associated with incorporating BEM in manufacturing simulation are highlighted as well as gaps within the research for exploitation through future research. This paper identified requirements for the development of a holistic energy simulation tool for use in a manufacturing facility, that is capable of simulating interdependencies between different building layers and systems, and a rapid method of 3D building geometry generation from site data or existing BIM in an appropriate format for energy simulations of existing factory buildings.

1. Introduction

Against the backdrop of increasingly competitive global markets and climate change, manufacturers aim to reduce costs and increase sustainability without negatively affecting the yield of their finished products, thus maintaining or improving profits. An improvement in energy efficiency or reduction in energy use during manufacturing is an effective method of achieving both goals [1,2]. The energy use by industry accounted for 54% of delivered end-use energy globally in 2012 [3], see Fig. 1-1a, and this is predicted to have reduced slightly to 53% in 2040. Therefore, attempts at reducing energy usage within industry could have the greatest effect on reducing global end-use energy when compared with residential buildings, commercial buildings, transportation and other end-use sectors. Although the global end-use energy for industry is 54%, each country will deviate from this global mean depending on its own manufacturing activity [4]. This is illustrated in Fig. 1-1b which depicts the breakdown of 2015 United Kingdom (UK) end-use energy by sector, of which 17% accounts for industrial use [5].

By examining the UK industrial energy use, see Fig. 1-2, it is clear that a significant proportion of energy is utilised on building services (e.g. space heating and lighting) as well as manufacturing or industrial processes. As such, both should be considered together in attempts to achieve more effective energy savings within industry.

By modelling entire manufacturing facilities, a holistic approach can be taken in assessing all of the interconnected systems [6], allowing

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http://dx.doi.org/10.1016/j.rser.2017.08.063
Received 29 November 2016; Received in revised form 10 January 2017; Accepted 14 August 2017

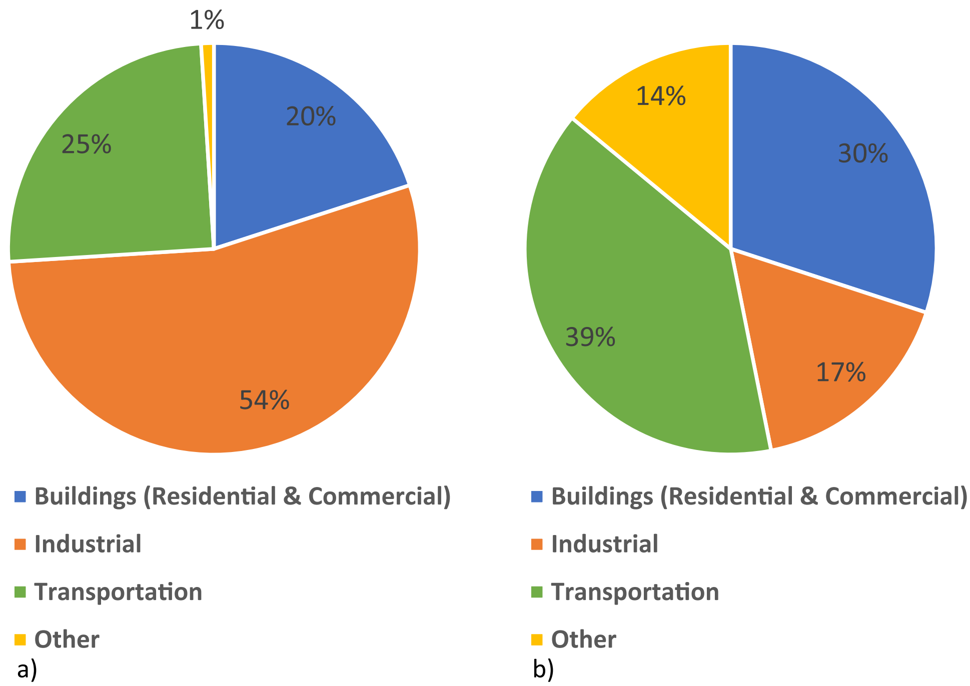

Fig. 1-1. Breakdown of a) 2012 Global End-Use Energy by Sector [3], b) 2015 UK End-Use Energy by Sector [5].

for the identification of areas, where the most potential exists for improvements in energy efficiency, throughput or both. This is applicable to existing factories, that may have undergone decades' worth of renovation, demolition and rebuilding, and new factories. In the UK it is estimated that 70% of the existing building stock from 2010 will still be utilised in 2050 [7]. This figure is for residential and commercial buildings; however, a similarly large proportion of the existing manufacturing plants would be expected to still be in use in 2050; albeit with modifications to meet changing business demands.

Building Energy Modelling (BEM) and Manufacturing Process Simulation (MPS) are mature techniques for analysis. BEM is traditionally used to analyse a thermal building envelope and is widely used for residential and commercial building assessment (e.g. DesignBuilder [8], EnergyPlus Simulation Engine [9], eQuest [10], Green Building Studio [11], International Building Physics Toolbox (IBPT) [12], Integrated Environmental Solutions (IES) Virtual Environment (VE) [13], Modelica Buildings Library [14] and Sefaira [15]). MPS is traditionally used to optimise a manufacturing process line by assessing parameters such as machine utilisation and throughput (e.g. AnyLogic [16], Arena [17], DELMIA [18], FlexSim [19], Plant Simulation [20], Simio [21] and SIMUL8 [22]). BEM application in a manufacturing facility has only begun to be applied in recent years [23,24] and traditionally MPS has not focused on energy use between manufacturing equipment, utilities or the building for the purposes of energy efficiency improvements [25,26].

A combination of elements from both techniques offer a potential solution that would allow effective retrofit or modification decisions to be made holistically within a manufacturing facility. Such a solution should aim to identify potential options to reduce energy use while maintaining or improving facility productivity. Rahimifard et al. [27] argue that considering energy use at a "plant" (BEM) or "process" (MPS) level independently does now allow manufacturers to identify how much energy is used per unit product. As such this review will address the research undertaken to date that has attempted to combine elements of BEM and MPS.

A note on terminology and definitions;

- Several modelling approaches are discussed within this paper and are defines as thus;
  - Time-driven – A modelling approach in which time is a simulation variable that is incremented at set discrete intervals and all computation is conducted at each increment.
  - Event-driven – A modelling approach in which discrete events in a sequence, such as a production line, are incremented sequentially, regardless of time between events, and all computation is conducted at each increment.
  - Continuous flow – A modelling approach that simulates a continuous time and mixed state Markov Process for a system that utilises buffers and continuous mass flow concepts, such as a production line [28].
  - Numerical techniques – A modelling approach that uses any numerical methodology other than simulation. This can include measurements, experimentation and calculation from first principles.
  - Agent driven – A modelling approach that comprises components of a whole system that are autonomous agents interacting in and with a defined environment. Agent driven modelling can be either time-driven or event-driven or a hybrid of both using an event-driven time advance [29].
  - Co-simulation – A modelling approach where each subsystem within a larger system is simulated independently using the most suitable technique. Between system simulation iterations, the inputs and outputs of each subsystem are communicated between each applicable subsystem. This is then repeated until a system equilibrium is achieved.
- This paper includes discussion and comparison of the merits of simulation software Graphical User Interfaces (GUIs), that use external simulation engines, with the simulation engines themselves. This is to highlight the limitations of using certain software configurations for future research.

1.1. Methodology

The methodology employed in this literature review was systematic in nature. Applicable literature was identified by performing keyword searches; this included previous reviews as well as standalone research. The citations of these papers were followed to identify applicable