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Extended Total Sites with Multiple Energy Carriers

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The paper presents an extension of the Total Sites methodology covering industrial, residential, service, business and agricultural customers and the incorporation of renewable energy sources, accounting for the variability on the supply and demand sides. The challenge to increase the share of renewables in the energy mix could be met by integrating solar, wind, biomass, geothermal energy as well as some types of waste with the fossil fuels. The renewables availability, the energy demands of the considered sites all vary significantly with time of the day, period of the year and location. Some are not predictable and varying very fast. Total Site CHP energy systems are optimised minimising heat waste and carbon footprint, and maximising economic viability.

1. Introduction

Renewable resources are distributed over a given area. Their availability in time is usually below 100 % varying with time and location. The customer demands for heating, cooling and power also vary significantly with time. The variations of supplies and the demands are partly predictable and some form stable patterns – *e.g.* day and night for solar energy. Availability of wind and solar generated energy can be predicted for a short period only by advanced metrological forecasts. Optimising energy systems with renewables is more complex than when using just fossil fuels. A system combining the supply and demand of the individual users may serve industrial, residential, and the service–sector customers. They could typically utilise various energy carriers and the task is to account for the variability on both the demand and supply sides. This requires applying advanced Process Integration with the time as another problem dimension. A basic methodology has been developed for batch heat integration – Time Slice and Time Average Composite Curves (Kemp and Deakin, 1989), and summarised by Klemeš *et al.* (1994). The approach has been revisited by Foo *et al.* (2008). A novel approach is to extend this methodology into renewables heat integration. Perry *et al.* (2008) investigated such Locally-Integrated Energy Sectors for a given steady state.

2. Issues and concepts

Energy demands vary among the various users and with time. Industrial sites mostly require heating from about 100°C to 400 °C and sometimes to thousands of °C, cooling from 20 °C to 50 °C, chilling in the range 0 to 10 °C, refrigeration to subzero

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temperatures. The energy demands of the service-industry and the building complexes (hotels, hospitals, schools, universities, banks, governmental complexes) are generally similar in structure to those of residential sites.

The energy sources for all users are mostly common: fossil fuels, solar irradiation, wind, biomass, hydropower, geothermal energy, ground heat or cold using heat pumps. *Energy supply and demand vary with time and location.* In the this analysis, a fixed a set of locations is assumed and the analysis focuses on the time variations. *The time variations of demands* have been subject to research in the past both in industrial and residential contexts. Residential electricity demands tend to be more volatile, while industrial ones vary less and are more predictable. The heating and air-conditioning demands are generally subject to smaller variations, bound to the ambient temperature. Using direct drives in industry eliminates generating electricity and the related losses.

Demand variations are mostly predictable with minor uncertainties in timing. The picture is slightly different among buildings, industrial sites and farms. Differences may occur in other types of building complexes – service buildings (hotels, hospitals), where the demand levels will depend on the occupancy rate and some less predictable features.

To efficiently exploit renewables it is necessary to assess their availability in time. This presents integration challenge with diverse time horizons. Biomass, as fossil fuels, can be stored ensuring continuous energy generation for weeks up to months. Wind and solar energy availability oscillates on the order of hours and minutes. The Total Site methodology needs an extension to cope with such variations.

2.1 Integration of total sites including renewables

Process Integration has been traditionally dealing with steady-state industrial processes (Linnhoff and Hindmarsh, 1983; Klemeš *et al.*, 2008). Some sites are usually run in several month campaigns (*e.g.* European sugar plants) or in batch mode, which have been successfully energy-integrated (Klemeš *et al.*, 1994). Further, industrial plants have been integrated into Total Sites (Klemeš *et al.*, 1997). Adding residential and service-building customers has been the subject of a recent work (Perry *et al.*, 2008), which indicates the significant potential for saving even more energy.

Demands are usually imposed to the energy conversion systems. Short-term fluctuations are modelled using time-differential equations. For longer-interval variations, piecewise approximations of the demands are used. An important issue when handling variability/uncertainty is predicting the exact levels of the piecewise-constant demands. Potential tools are sensitivity analysis, multi-period optimisation and chance constrained optimisation. The piecewise constant demands representation can be embedded within a total site formulation. Typical examples are winter and summer demands for residential buildings, seasonal campaigns in sugar industry; and working shift-related variations.

To cope with the variable supply and demand in the optimum energy system design, some assumptions are made: (i) The fast smaller–scale variations are typically handled by a control system; (ii) The longer-period variations as day / night for solar energy supply or peak / off-peak demands could be treated in several ways. The most widely used is to represent the supply and demand profiles by piecewise constant approximations. The availability of the renewables can also be thought of as imposed to the system and not belonging to the degrees of freedom. What can be used as a degree of freedom is the fraction of the available renewables to be harvested.

3. Integration approach

3.1 Framework

To integrate renewables and varying loads at high efficiency, a holistic approach is needed, employing storage and multi-energy-carrier techniques. The targeting should be done both in time intervals and time average. This formulation brings some potential for applying an extended methodology developed for batch processes. The first step is to identify the degrees of freedom: (i) *Load balancing*. Integrating different processes or consumers into total sites (Klemeš *et al.*, 1997; Perry *et al.*, 2008) allows exploiting the temporal displacement of the energy consumption patterns and smooth the variation of the total energy demands for improved recovery and generation efficiency; (ii) The *degree of utilisation of the available renewables* – solar, wind, biomass (including waste); (iii) *Storage of temporary excess energy* (e.g. heat) for the future use. A Total Site analysis for fixed demand and supply was presented by Perry *et al.* (2008). However, accounting for variability reveals the need for introducing energy storage. Potential storage locations are the premises of the final users and those of the larger-scale utilities. This architecture has been initially formulated for total site heat integration using for simplicity only steam as an energy carrier. For purposes of integrating between heterogeneous processes and premises, including renewables, it has become apparent that more energy carriers are generally needed.

3.2 Potential tools and techniques for handling renewables variability

Following the current state-of-the-art in Total Site Integration (Klemeš *et al.*, 1997), Batch Heat Integration (Kemp and Deakin, 1989), HEN sensitivity analysis (Kotjabasakis and Linnhoff, 1986), and including the time by Wang and Smith (1995), the current methodology applies Time Slices to the Locally Integrated Energy Sources Total Sites accounting for the variability. it is very important to optimise the energy system energy storage. If available at the given time, required capacity and at feasible cost, it could considerably increase the heat efficiency of the system. Energy storage is a demanding issue which is still waiting for a major breakthrough. The Heat Integration methodology could however provide targets which are suppose to be achieved. The more detailed description is published elsewhere (Varbanov and Klemeš, 2010)

4. Demonstration case study

4.1 Description

The demonstration case study is based on a previously publication (Perry *et al.*, 2008). Four areas are integrated into a Total Site – two industrial plants, a hotel, and a residential area ("processes"), each featuring a number of streams – hot and/or cold. The heat flow is assumed positive for cold streams and negative for hot streams. The time intervals are expressed for a 24 h cycle. The residential area has a number of solar thermal collectors for generating domestic hot water and space heating. The utilities available at the Total Site are Cooling Water 15°C to 30°C; Solar Hot Water 80 °C to 50°C; District Hot Water 75°C to 50°C; MP Steam at 220°C; LP Steam at 130°C. The storage facility uses hot water. It loses part of the stored heat and not all of it can be successfully retrieved. This involves temperature decrease as a result of cooling down.

It is assumed that the storage facility is operated continuously. The temperature decrease is neglected and only a duty loss is considered. It amounts to 30% of the stored heat. The operating temperature of the storage is assumed 75 °C.

4.2 Total Site Targeting with Time Slices

After analysing the process streams, three switching time points over the 24-hour horizon have been identified: 6 h, 17 h and 20 h. The solar collectors in the residential Process D have total area of 196.5 m^2. The average heat captured by the collectors is assumed as follows. Slice 1: 112.9 kW; Slice 2: 92.1 kW; and Slice 3: no capture.

The energy targets have been evaluated for the described Total Site, giving precedence to renewables when placing utilities. The analysis for Time Slice TS1 is shown in Figure 1. A proper judgement is needed to ensure feasibility of the utility placement. If directly matched against the Utility Use Site Composite Curve as a single utility stream, the recovered heat from the Site Source Profile and the solar capture would violate the temperature feasibility of the problem – part of the solar heat plot would lie below the Curve. Instead, the solar heating stream is split into two branches as shown in Figure 1. The right-hand solar heat segment represents the branch sent to the storage. For the whole duration of TS 1 this totals to 730.4 kWh of heat admitted to the storage.

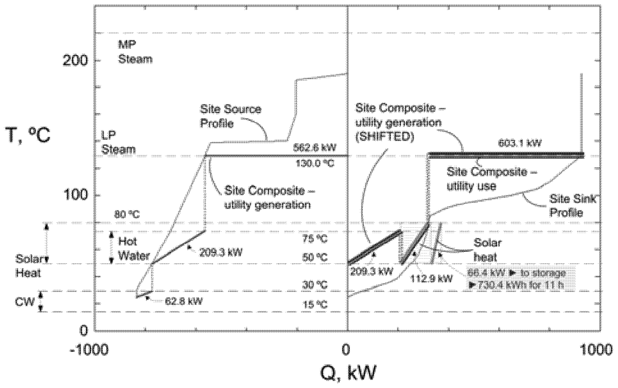

Figure 1. Time Slice 1: Site targets for solar heat capture and storage

For TS 2 the active process streams are supplemented with the heat from the storage. After the deterioration (30% loss), the heat retrieved from storage during TS 2 is 511.3 kWh. It is distributed over the Slice duration and generates a 170.4 kW hot stream running from 75°C to 50 °C, which is embedded in the Site Source Profile. The targets for TS 2 are illustrated in Figure 2. The total heat recovered from the Site Source Profile covers entirely the needs for process heating, represented by the Site Sink Profile. The excess 107.3 kW of District Hot Water and the captured solar heat (92.1 kW) are sent to the storage. The overall heat supplied to the storage during TS 2 is 501.3

Retrieved heat storage for TS3 is 350.9 kWh. For the 10 h duration 35.1 kW average heat flow is retrievable from the storage and embedded into the Site Source Profile for TS 3. The Total Site targets for TS 3 are given in Figure 3. Although no solar heat is captured during this time, the industrial processes provide some excess heat, which can potentially lead to heat storage build-up and exceed the storage capacity.

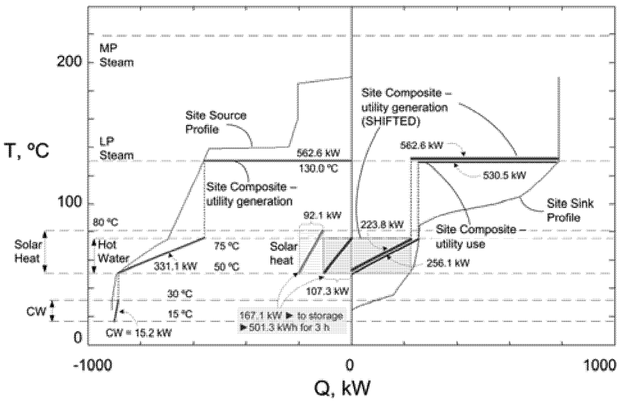

Figure 2. Time Slice 2: Site targets for solar heat capture and storage

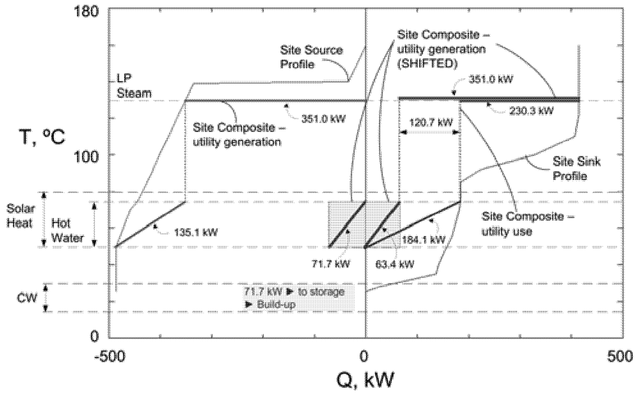

Figure 3. Time Slice 3: Site targets for solar capture and storage

4.3 Analysis of the targets

Over the short-term horizon, there is a trend of heat storage build-up and the capacity of the heat storage cannot be directly targeted. This can be resolved in several ways: (i) Finding an economically feasible use of the waste heat inside or outside the Total Site. (ii) Purging part of the hot water recovered during TS 3. This would produce a target of 730.4 kWh for the storage capacity. (iii) Performing the analysis over a longer time horizon – *e.g.* a whole month, season, or year. This would reveal the time-global needs for heat storage, whereby the heat demands may substantially increase for bad weather conditions or increased occupancy in the hotel. In such situations the build-up behaviour identified in the current analysis may be significantly reduced or disappear altogether.

5. Conclusions

Including renewables with their changing availability requires extensions of the traditional heat integration approach. The problem becomes more complicated having more dimensions. Revisiting previously developed Process Integration tools and developing them further enables solving this extended problem. The presented contribution has been a step in this direction summarising the problem and suggesting potential solutions. A demonstration case study illustrates the heat saving potential of integrating various users and using heat storage. The advanced tools based on the suggested methodology have been under development (Varbanov and Klemeš, 2010)

Acknowledgements

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References

Foo D.C.Y, Chew Y.H., Lee C.T., 2008. Minimum units targeting and network evolution for batch heat exchanger network, Applied Thermal Engineering 28(6), 2089-2099.

Kemp I. 2007, Pinch Analysis and Process Integration. A User Guide on Process Integration for the Efficient Use of Energy, Elsevier, 396 ps.

Kemp I.C., Deakin A.W., 1989. The Cascade Analysis for Energy and Process Integration of Batch Processes. Part 1: Calculation of Energy Targets, Transactions of IChemE Chem. Eng. Res. Des. 67, 495-509.

Klemeš J., Linnhoff B., Kotjabasakis E., Zhelev T.K., Gremouti I., Kaliventzeff B., Heyen G., Maréchal F., Lebon M., Puigjaner L., Espuńa A., Graells M., Santos G., Prokopakis G.J., Ashton G.J., Murphy N., Paor de A.M, Kemp I.C., 1994. Design and operation of energy efficient batch processes, Final Report, EC Brussels

Klemeš J., Dhole V.R., Raissi K., Perry S.J., Puigjaner L., 1997. Targeting and Design Methodology for Reduction of Fuel, Power and CO_2 on Total Sites, Applied Thermal Engineering 7, 993–1003.

Klemeš J, Smith R., Kim J.-K. (eds), 2008, Handbook of water and energy management in food processing. Woodhead Publishing Ltd, Cambridge, England, 1029 ps

Kotjabasakis E., Linnhoff B., 1986. Sensitivity Tables for the Design of Flexible Processes (1) - How Much Contingency in Heat Exchanger Networks is Cost-Effective? Transactions of IChemE Chem. Eng. Res. Des. 64, 197-211.

Linnhoff B., Hindmarsh E., 1983. The Pinch Design Method for Heat Exchanger Networks. Chemical Engineering Science 38, 745-763.

Perry S., Klemeš J., Bulatov I., 2008. Integrating Waste and Renewable Energy to Reduce the Carbon Footprint of Locally Integrated Energy Sectors, Energy 33(10), 1489-1497.

Varbanov P., Klemeš J., 2010, Total Sites Integrating Renewables with Extended Heat Transfer and Recovery. Heat Transfer Engineering, 31(9), 2010. doi: 10.1080/01457630903500858

Wang Y.-P, Smith R., 1995. Time Pinch Analysis, Transactions of IChemE Chem. Eng. Res. Des., 73(A8), 905-914.