Energy-oriented layout planning for production facilities

Chenqing Wang[1,*], Günther Seliger[1]

[1]Technische Universitaet Berlin, Department of Machine Tool and Factory Management, 10587 Berlin, Germany

*chenqing.wang@mf.tu-berlin.de

Abstract Due to limited resource and the rapid economic development, energy becomes the bottle neck of sustainable manufacturing. The integration of energy efficiency criteria into production system planning substantially contributes to resource productivity and thus offers an effective solution for meeting the demands of sustainable value creation. A suitable layout planning can increase the energy efficiency of production processes. The recent layout planning for production facilities, being based on material aspect, overlooks energy aspect. As an indispensable element of production, energy should be concerned within factory management including layout planning. This paper describes a sustainability concerned layout planning model, which integrates energy flow into layout planning process to optimize the productivity of resource.

1 Introduction

Due to limited earth's resource and the rapid growing population – 9.2 billion are estimated for 2050, almost 2.2 billion more than 2010 [1] – sustainable product development and sustainable production practices has been a major issue of industrial sector. Sustainable management, which is defined as a concept of creating value with the requirements for ecological compatibility and social fairness and brings them into a fair balance [2], is basically a resource productivity procedure that can benefit the society, economy and the environment.

Resource efficiency has been identified as an important indicator for sustainability. With regard to Life Cycle Management, resource consumption can be defined as the amount of material cost in the production process. Efficient consumption of raw material implies achieving the same functionality with fewer resources. Approaches to increase the productivity benefits of resources for products from production technology have been in particular implemented on the product side. Focus of observation is the resources bounded in product structure and caused emissions during the use phase. On the production side, scientific researches up to now also focus on the product bounded material resources, in which the life cycle management and new possible use phases of products are improved through the development of processes and organizational structures [3].

In the life cycle phases of product manufacturing and remanufacturing, the focus of resource efficiency moves from the material applied per unit to material used in the various production phases as part of the production processes, e.g. cooling lubricants, compressed air or hydraulic oil, and on the energy requirements of the production processes [4]. According to the research from Lawrence Livermore National Laboratory (LLNL), more than 20% of energy was lost in industrial sector in the USA in 2009 [5]. From the energy flow's point of view, in order to establish an sustainable manufacturing system, the energy-efficient work should include every energy-consumption related manufacturing phases, that is to say, every modelling, planning and production phases should be energy-efficient.

Layout planning often has a significant impact on the performance of a manufacturing or service industry system and is usually a multiple-objective problem. Neither an algorithmic nor a procedural layout planning methodology is usually effective in solving a practical design problem. It is stated that 10–30% of material handling cost can be reduced by having an effective facilities layout [6]. A sustainable layout planning should not only save the space, optimize the process for manufacturing, but also provide a solution for improving energy efficiency.

This paper will present the state of the art of life cycle based layout planning system leaning to energy efficiency and based on that a concept for energy-oriented layout planning system with the help of simulation method is proposed and explained. It is structured as follows:

Section 2 will present the state of the art of life cycle based layout planning and industrial energy efficiency. A proposed layout planning with the help of energy efficiency concept will be describes in Section 3 and the probable method to realise it and challenges will be listed in Section 4.

2 Layout planning and energy saving potentials

2.1 Life cycle based layout planning

A facility layout is an arrangement of everything needed for production of goods or delivery of services. Facilities can be broadly defined as buildings where men, material and machines come together for a stated purpose [7]. Facility layout travels through a life cycle which consists of the following phases: design, implementation, growth, maturity and obsolescence. In each life cycle phase, decisions including design, selection and evaluation of an effective layout have to be made. Designers face the facility layout problem not only when they create a new manufacturing system but also when they expand, consolidate, or modify existing systems. Even established manufacturing companies need to change the layout of departments every two or three years.

Depending on the level of the factory level, facility layout can be divided into different types [Figure 1]:

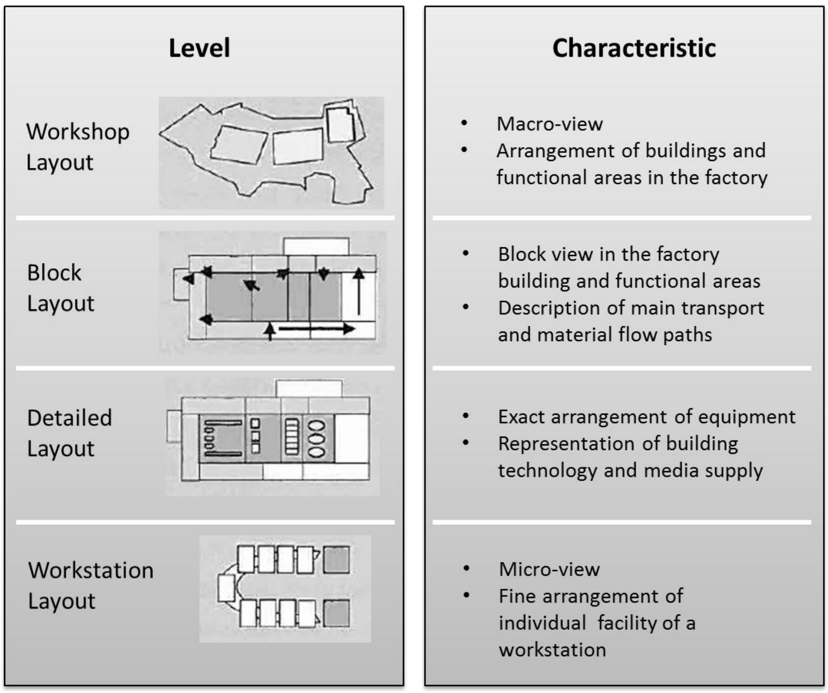

Fig.1: Types of layout [8]

Layout planning has been a vital research area for many decades. Numerous researchers have developed different layout models, most of them are either algorithmic or procedural [9]. Material flow planning and layout design can be regarded as inseparable in major planning phases. Although material flow plays a main role in the planning from block layout planning to detailed layout planning, the research of material flow, however, so far stays in a relative rough phase in detailed layout planning. Nowadays it is much based on work plan, from which the individual processing steps can be taken out. Further information regarding the material flow is not given in the work plan.

Singh and Sharma [10] analysed the recent trends in layout design and they highlighted the changes in the focus from single factor Material Handling Cost (MHC) based layout design towards concurrent layout design, which incorporate other aspects of a manufacturing system with design of a layout. Singh and Sharma have concluded that multi-attribute design approach is the emerging trend. Kettner and Schmidt [11] divide the influencing of a layout design into three parts:

- Production flow: material flow, energy flow, person flow and information flow
- Production design: organizational influences, resource, production conditions and work conditions
- Building relevant influencing factors: property-determined influencing factors, structural influencing factors and building usage.

In the energy flow sector, some influence factors which need to be significantly considered have been advised, e.g. energy types, energy consumption, types of consumption, installation system, station for energy center, substation, disposal and emergency supply.

Hence, it is evident that most of the existing models considered more material flow as the main performance factor, which has less relation with environment. With the emerging trends of multi-influencing factors, a towards ecology layout planning model, in which material flow incorporate energy efficiency is needed to fill the gap of sustainable production.

2.2 Industrial energy efficiency

Energy efficiency is used to compare energy consumption and product output. Under industrial manufacturing scope, it can be described as the maximum production output with the minimum consumption of energy. Manufactures have been interested in energy efficiency since the industrial revolution, nevertheless energy efficiency has recently become significantly more important due to both concerns over energy saving and the generally accepted link between climate change and mankind’s combustion of fossil fuels.

Muller et al. [12] suggest that in today’s factories, energy consumption data are either not available or too inaccurate to be used to inform production planning. They propose monitoring of in-process energy consumption to enable continuous improvements at an equipment level. Devoldere et al. [13] showed how that a significant part (up to 65%) of the energy was consumed in non-productive mode. Chiotellis et al. [14] identify missing information regarding energy consumption and potential in introduction energy efficiency into various production planning and control levels, and propose a framework for daily energy-aware production control based on equipment energy consumption profiles.

Industry researchers need to identify opportunities both to increase thermal energy efficiency of factories where possible, and to reduce the energy intensity of operations. The former can be achieved in many ways and an effective approach is highly context specific depending on the nature of the facility and the processes operating within. Herrman and Thiede [15] extend the simulation approach to model the energy profiles associated with each individual process within a manufacturing system. By combining process modelling with production metrics, energy metrics and current energy price, an optimized schedule can be developed.

The options for re-use of waste heat are examined using an energy analysis which accounts for the quality of the energy available. Gutowski et al. [16] describe how this may be carried out to separate the specific energy required to process material into the component used to process the material itself and the base load of the production equipment for example in the coolant pumps and the controller. Weinert [17] develops a planning system for the detailed prognosis of a production system's energy consumption with a concept of EnergyBlocks, by which a time based prediction of the amount of energy required by each machine and thus by the whole production system becomes possible. The energy researches which focus on energy awareness and simulation of a production system provide operational references for integration energy efficiency consideration into layout planning.

2.3 Layout planning with energy efficiency consideration

To realizing a sustainable layout planning, one approach is integration energy efficiency into planning process. When putting in energy efficiency objectives, the strategic aspect of the layout planning of a production area within a factory, e.g. manufacturing area, or assembly area, relates significantly to the energy flow during the production process, e.g. the input and output of energy in each production process or cell. When conducting layout planning, one should take into account the energy consumption profile of the system to be implemented. This means that an evaluation of the various alternative options for designing a layout according to its energy efficiency must take place. Such an evaluation is only possible when the data concerning the consumption behaviour of the individual equipment is available. During the design phase of the layout, the planner can evaluate, by using an energy database the various alternatives for each production system and decide the optimal system configuration.

On the operational level, an approach includes developing models of the considered production area that also address its energy flow. The generic approach is applied for determining the exact energy requirements and output of a production cell when producing a predetermined volume of products in a predetermined production sequence. The first step for the planner is to design the production sequence by deciding on the production processes and the handling and transport operations. In a given system this entails determining the way the products travel through the system, while when designing a new system, the layout and material flow need also to be designed.

3 Simulation supported layout planning towards energy efficiency: concept

Based on the integration of energy consideration into planning steps, an approach for energy-oriented layout planning is proposed. Energy flow plays a main role in layout planning. With the help of this approach it is possible for the production system to reach an energy-efficient state during layout planning.

This approach starts with a principle consideration that each production facilities has its energy demand, including energy environment requirements and various energy consumption, e.g. electricity, compressed air, and its energy output, e.g. the thermal exhausting and the energy bounded on products. This energy I/O in each production processes is the basic for an energy-efficient layout planning, when it can be designed to reach an energy-equivalence state between different facilities. From energy efficiency point of view, a sustainable facility layout is minimizing energy loss during production. Thus the re-utilization or a suitable arrangement of energy output from one production facility to another directly or with the help of special equipment, e.g. energy storage, will be meaningful for improving energy efficiency of a production system.

Currently no research for energy-oriented layout planning is known to the authors which considers using simulation as a tool in providing monitoring energy flow and layout planning for production systems. Based on the result from the literature study and the opportunities given by the simulation technology nowadays, a concept for an energy-oriented layout planning method is proposed [Figure 2].

4 Work plan and challenges

The proposed concept is just in the early phase of development. There are a lot more information needs to be found and lots of more research need to be done. Anyhow this concept will be developed and tested.

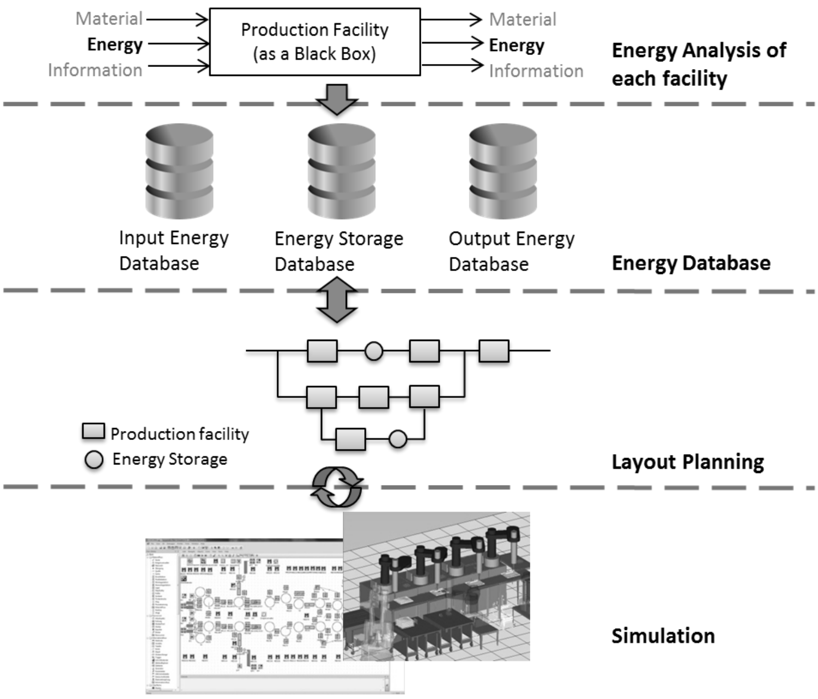

Fig.2: Proposed concept of energy-oriented layout planning for production facilities

The development will starts with monitoring energy I/O of production cells/equipments. After the awareness of energy consumption and losses during one facility, which can be divided into manufacturing, assembly and transportation, a widely used energy database can be established, which involves basically energy input database (electricity, heat, hydraulic, pneumatics, etc.), energy storage database (energy harvesting, energy storage methods, energy conversion efficiency, etc.) and energy output database (heat losses, vibrations, etc.). The utilization analysis of energy loss contributes also to the energy-oriented layout planning, i.e. which and how the energy output from one facility can be used for others. From that, an energy based facility layout can be designed with integration of energy analysis [Figure 3].

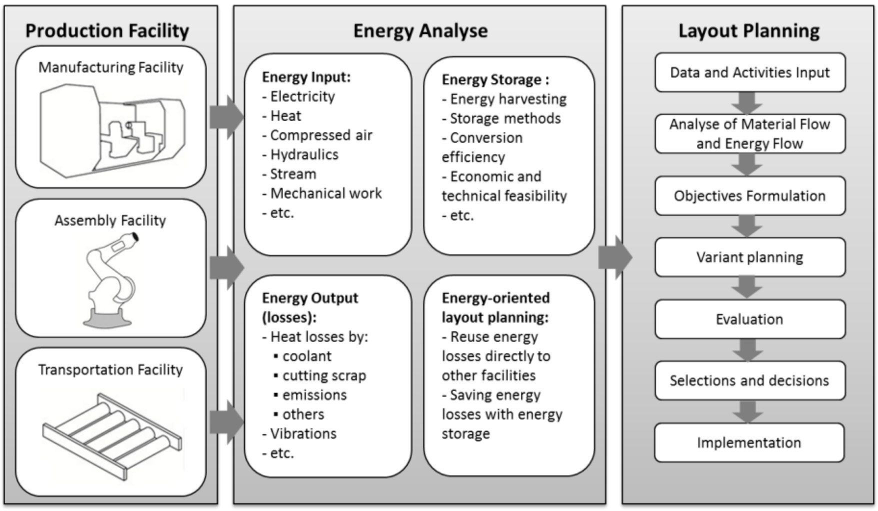

Fig.3: Approach for methodology for energy-oriented facility layout

However, there are some challenges that authors have been identified during the early phase of the project and need to overcome. Some of the challenges are:

1) A global accepted benchmarking for energy-efficient production system is lack, which will surely take much more time to give a definition for that.
2) Nowadays methods for in-process energy aware method are not totally well developed, which need a lot of concentrating.
3) When using energy storage as a connection between facilities, the energy efficiency of production system is mostly depended on the transfer efficiency in energy storage.

5 Conclusion and outlook

This paper introduces a layout design model which explicitly takes energy efficiency into consideration in order to minimize energy losses in production system. Required information and potentials for improving facility layout planning are investigated. Derived from this, a simulation supported energy-oriented layout planning for production facilities with the help of energy storage is proposed and the probable methodology is also suggested. The proposed concept is just in the early phase of development and need for more refinement. A lot of literatures have been reviewed to establish the state of the art of this area and some of it is presented in this paper. It seems the gap is there and a lot of potential in this area to be expand for bridging the gap. The proposed concept will be developed and the outcome of this research will then be published.

6 References

[1] <http://www.destatis.de/jetspeed/portal/cms/Sites/destatis/Internet/DE/Presse/pm/2009/07/PD09__261__124.psml>, (Accessed 23.01.2011).

[2] VDI-Richtlinien 4070, Sustainable management in small and medium-sized enterprises – Guidance notes for sustainable management, Beuth Verlag, 2006.

[3] Seliger, G., Sustainability in Manufacturing. Springer, Berlin Heidelberg New York, 2007.

[4] Weinert, N., Chiotellis, S., Seliger, G., Concept for Energy-Aware Production Planning based on Energy Blocks. 7th Global Conference on Sustainable Manufacturing, Madras, 2009, pp. 75-80.

[5] <https://flowcharts.llnl.gov>, (Accessed 07.04.2011).

[6] Tompkins, J. A., Facilities planning. 4th Edition, New Jersey: Wiley, 2010.

[7] Heragu, S. S., Facilities Design, iUniverse, 2006.

[8] Grundig, C.-G., Fabrikplanung: Planungssystematik – Methoden - Anwendungen, Carl Hanser Verlag, 2009.

[9] T. Yang, C. Kuo, A hierarchical AHP/DEA methodology for the facilities layout design problem, European Journal of Operational Research, No. 147, 2003, pp. 128–136.

[10] Singh, S.P.; Sharma, R.R.K., A review of different approaches to the facility layout problem. The International Jounal of Advanced Manufacturing Technolpgy, No, 30, 2006, pp. 425–433.

[11] Kettner, H.; Schmidt, J.; Greim, H.-R., Leitfaden der Systematischen Fabrikplanung. Carl Hanser, 1984.

[12] Müller, E.; Strauch, J.; Engelmann, J., Energieeffizienz als Zielgröße in der Fabrikplanung - Energieeffizienzorientierte Planung von Produktionsanlagen am Beispiel der Automobilindustrie. wt Werkstattstechnik online, Vol. 98, No. 7/8, 2008, pp. 634 - 639.

[13] Devoldere, T.; Dewulf, W., Deprez, W.; Duflou, B.: Improvement Potential for Energy Consumption in Discrete Part Production Machines. 14th CIRP International Conference on Life Cycle Engineering (LCE), Tokyo, Japan, 2007, pp. 311-316.

[14] Chiotellis S., Weinert N., Seliger G., Energy-aware Production Planning and Control, 16th CIRP International Conference on Life Cycle Engineering, Cairo, Egypt, 2009.

[15] Herrmann, C.; Thiede, S., Increasing energy efficiency in manufacturing companies through process chain simulation. Global Conference on Sustainable Product Development and Life Cycle Engineering VI, Pusan, Korea, 2008, pp. 52 - 57.

[16] Gutowski, T.; Dahmus, J.; Thiriez, A., Electrical Energy Requirements for Manufacturing Processes. 13th CIRP International Conference on Life Cycle Engineering (LCE), Leuven, Belgium, 2006, pp. 623 - 629.
[17] Weinert, N., Vorgehensweise für Planung und Betrieb energieeffizienter Produktionssysteme, Dissertation, Berlin, 2010.