TOWARDS ZERO ENERGY INDUSTRIAL HALLS — SIMULATION AND OPTIMIZATION WITH INTEGRATED DESIGN APPROACH

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ABSTRACT

Net-zero energy building (NZEB) is thought to be the building of choice, but in practice, is also synonym to high investment cost. It is, therefore, very important to investigate if the amount of the additional capital investment could be recouped from the energy saving (or generation).

The investigation is particularly meaningful for industrial halls for the great energy saving potential (with respect to the high energy demand) and the ready energy generation possibility (due to favourable building geometry). In this paper, an integrated design approach will take into consideration parameters from the demand side to the generation side. Building energy performance simulation and optimization will be deployed to search for design solutions that are maximized for energy production capability and minimized for additional capital investment.

Keywords: industrial halls, energy consumption, energy generation, NZEB, energy performance simulation, integrated design approach

INTRODUCTION

The industrial sector is one of the heaviest consumers of energy. In the United States, the sector consumed 32% of the total energy consumption in 2009 (LLNL, 2010), while in Europe, this sector consumed 24% in 2009 (Eurostat, 2011). Some of the energy from this amount is consumed in the manufacturing processes, while much of the rest is spent in lighting and space conditioning. Industrial halls, which are mainly single floor structures, maintain a relatively high roof-to-floor area ratio as compared to other types of buildings. Thermal comfort is seldom a concern for industrial halls, in which space conditioning (heating and ventilation) is provided to maintain the building within a reasonable or legally allowable temperature range. By contrast, saving in energy consumption for space conditioning and that for lighting is a big issue since even the modest percentage reduction in energy consumption could be translated into a large absolute monetary sum.

With relatively loose requirement in space conditioning, and comparatively high internal heat gain; the approach in industrial hall design is quite different from that of office building. In fact, what poses to be an energy efficient design for multi-storey office buildings might not be appropriate for single floor halls.

Moreover, the comparatively simple building geometry and construction method of industrial halls, as compared to office building, allow the investigation of energy demand for space conditioning to be limited to a few number of demand side parameters (e.g. insulation value of walls), in which, change in values in some of the parameters affects the overall energy demand significantly.

Furthermore, single floor structures allow energy saving measures, such as daylighting through skylight, to be applied to the whole building area, as opposed to only the area of the top floor as in multi-floor buildings. Investigating the benefit of daylighting, and the corresponding impact on ventilation and heating energy is crucial.

In addition, the vast rooftop of industrial halls, with practically no commercial value otherwise, opens up opportunities in deploying renewable energy generation systems such as photovoltaic (PV). The generation capacity will hopefully supplement the deficit in energy demand that is already much reduced with the various energy saving measures. In fact, the Netherlands has a target to cover 14% of its final energy consumption with renewable energy. However, only 3.2% came from renewable source by 2008 (EEP, 2012).

However, all these energy saving or energy generation measures might not work to the benefit of one another. An example will be the conflicting interest of skylight and PV, in which both take up space of the same rooftop. Will the added generation capacity of PV compensates the lost energy saving potential of skylight? When the building is subject to strong solar irradiance, skylight might nevertheless introduce unwanted heat gain, whereas PV might harness good amount of solar power. On the other hand, on an overcast day, skylight might bring in some amount of daylight, whereas PV might yield no power at all. To complicate the matter further, whether the additional heat gain or loss are welcomed is also depending on the building envelope performance, in which insulation plays an important role. The interaction, and thus the aggregated effect, of all of the components of a building could only be evaluated with dynamic hour-by-hour computational building energy performance simulation.

In this paper, an integrated design approach will be adopted, in which different energy saving and generation measures will be weighed against each other to lower the total energy consumption if not to increase the energy generation. Optimization, based on this integrated design model, will help identify design options that maximize energy production (towards the ultimate goal of achieving net-zero energy building or even energy producing building) and minimize capital investment.

To demonstrate the unique nature of industrial halls, this paper will present a case study for a typical warehouse (type of industrial halls that is most common in the Netherlands). The optimized design solutions (evaluated for the energy performance and the capital investment) will be compared to that of a baseline building prescribed by ASHRAE standard 90.1 (ASHRAE, 2007a).

This paper presents some of the results of an on-going project "Sustainable Energy Producing Steel Frame Industrial Halls", which also studies other operation energy related aspects.

SIMULATION AND OPTIMIZATION FOR INDUSTRIAL HALLS

The Case Study

The case study includes a hypothetical building, which represents a typical rectangular shape industrial hall in Amsterdam, the Netherlands. The baseline building is set up according to the requirement specified in ASHRAE standard 90.1 with few noted exceptions, to be discussed in later section, in which the requirement for office buildings are not applicable to industrial halls.

The hypothetical building measures 100m x 40m x 6m. The process load of a typical warehouse is assumed to be 5 W/m^2 according to CIBSE Guide F (CIBSE, 2004). Fluorescent lighting with a lighting power density (LPD) of 9 W/m^2 is assigned according to ASHRAE standard 90.1.

The workers are assumed to perform light work. For an industrial hall kind of environment, current guideline (ARAB, 2006) recommends that the temperature of the space has to be maintained under 30°C to protect workers from heat stress and heating has to be provided only if the space drops below 18°C during occupied hours. Occupancy schedule is highly varying. For freight forwarding, logistics, or distribution industries, a two-shift work schedule is quite common. A Monday to Saturday work week, from 6 AM till 10 PM, is assumed. Moreover, the occupant density can only be considered on a case-by-case basis. A highly automated logistics warehouse will be less dense than a shipping centre. Nonetheless, a conservative occupant density of 5 persons per 1000 m^2 is assumed.

The building is built with steel cladding on a steel frame. The baseline building is assigned with insulation according to ASHRAE standard 90.1 mandatory provisions; the insulation for the wall and the roof requires a minimum resistance value of R_{SI} 2.3 and R_{SI} 3.3 respectively. Ventilation rate at 0.55 L/s-m^2 is adopted according to ASHARE standard 62.1 (ASHRAE, 2007b).

Steel frame construction is in general quite airtight and infiltration is mainly due to opening of doors, which is particularly the case for warehouses. Infiltration rate basically depends on wind velocity, wind direction, temperature differential between inside and outside. Infiltration rate is evaluated dynamically in the simulation by assuming a constant opening of a 0.1m by 3m gap on the entrance side (assumed to be facing south).

Certain aspects of daylighting are discussed in the standard, but no value is prescribed to specify or to recommend the amount of daylighting; therefore, no daylighting is assumed for the baseline building. The building is located in Amsterdam, the Netherlands, which is classified as ASHRAE climate zone 5 (ASHRAE, 2007a) with a warm summer and a cold but not severe winter.

Demand side design parameters

The building might not be optimally designed in terms of consuming the lowest energy; if it is designed according to the default values as prescribed by the standard. *Table 1* lists the demand side design parameters that are to be investigated in this study and presents the ranges of values for each parameter. These values are within practical range; that is, no custom made construction is necessary to implement any of these specifications. Any configuration based on possible combination of these values can be readily built. Values assigned for the baseline building are highlighted in bold.

Table 1
Demand Side Design Parameters

PARAMETERS	DESIGN RANGES
Resistance of roof insulation (R_{SI})	1.0 – **3.3** – 4.5
Resistance of wall insulation (R_{SI})	1.0 – **2.3** – 4.5
Daylighting (as % of roof area)	**0** – 15%

Lighting is a major energy consumer in buildings. Daylighting (through translucent skylight) is an effective means to lessen the reliance on artificial lighting that is dimmed with sensor control switch. The saving in energy for lighting will be somewhat offset by the additional cooling load due to heat gain during the day and heating load due to heat loss during the night particularly in the winter. The exact benefit of daylighting can be evaluated only after a thorough study by considering the impact on HVAC.

Supply side design parameters

Heat is released from processes, lighting fixtures, and occupants. In practice, forced ventilation with heat recovery is a common system for industrial halls in a moderate climate, in which the halls can be efficiently cooled by drawing in ambient air at a lower temperature. Addition to fans that fulfill minimum ventilation rate of outdoor air, muliple fans with a total rated power of 4.2 kW are possible to draw in an extra 21,600 L/s (the selection is in the mid range with more efficient fans rated at power of 1 kW to fans rated at 14 kW, per 10,000 L/s of flow. TWF, 2010). The fans are controled by feedback controller, which moderate the fan output to maintain the space at the temperature setpoint.

Transpired solar collector (TSC) could be a possible and effective alternative for heating, in which outdoor air is heated up as it is drawn through the perforated metal wall cavity of the collector that is installed on the south facing wall to take advantage of the free solar energy. The coverage of TSC is indicated in *Table 2*. The only energy consumption will be that of the fans, which draw in and distribute the heated air.

Table 2
Supply Side Design Parameters

PARAMETERS	DESIGN RANGES
TSC coverage (as % of south wall)	0 – 100%

There are times that forced ventilation cannot effectively cool down the building due to high outdoor air temperature. In such case, supplemental cooling is provided by precooling the outdoor air with air-to-air chiller with a constant COP of 2.5.

During early morning or late evening hours, or whenever solar irradiance is not strong enough to heat the air through TSC, local heating with hanging infrared gas radiators will ensure the space to be kept at the required temperature. Radiators are the only elecments that consume gas rather than electricity; this fact is significant in future work, when carbon emission reduction is the goal instead of just energy saving and generation.

Generation side design parameters

Commonly deployed monocrystalline type PV panels rated at 158 W_P/m^2 are to be considered in this project. The total generation capacity is largely depending on the optimal amount of PV panels that can be installed on the finite roof area. The taller the panels and the tighter the gap between rows of panels will on one hand increase the amount of surface area of PV, but on the other hand induce unwanted shading casted by the row of PV in front.

The optimal amount of PV to be designed will therefore a variable depending on the tilt angle and the height of PV, and the number of rows of PV. The design ranges are presented in *Table 3*.

Table 3
Generation Side Design Parameters

PARAMETERS	DESIGN RANGES
PV height (m)	0.5 – 1.5
Gap between PV rows (m)	1.5 – 9.5
PV tilt angle	36° – 56°

In fact, as discussed in the introduction, the most optimal combination of PV and daylighting (skylight) to be installed can only be investigated through simulation that considers the shading effect and the conflicting roles between different energy saving and generation measures.

Energy Performance Analysis

The building energy performance simulation program TRNSYS is used to perform the energy analysis for energy consumption due to cooling and heating, and energy generation with PV. Energy performance by the hour is evaluated and aggregated for the year. The baseline building model is created according to the specification just discussed. For each alternative design solution, energy performance is evaluated for a new combination of values within the range for each of the studied design parameters.

DAYSIM is used to evaluate the illuminance level on the work surface at each of the hour due to daylighting, at different locations inside the building and for different configurations of halls under investigation. Based on the illuminance level (a conservative illuminace level of 500 lx is assumed based on a mix of tasks suggested in CEN, 2002), lighting energy consumption is then calculated by a proprietary program written in MATLAB according to the dimmable lighting characteristics suggested by Rubinstein et al. (2010).

The net energy production will be the energy generation minus the sum of energy consumption of cooling, heating, and lighting. The design solutions can be considered as feasible contenders or alternatives to the baseline building if they exhibit energy production (or at least, come with lower energy consumption).

Optimization

Optimization is deployed to search for the optimized design solutions. With seven design parameters, there could be hundreds of thousands of different configurations. A complete search through all the configurations is computational intensive. With appropriate algorithms, optimization can search for the optimized design solutions without the need of covering the whole design space.

MODEFRONTIER is selected as the platform of optimization for its vast selection of optimization algorithms, and its flexible connectivity to energy performance simulation and post-processing tools, namely, TRNSYS, DAYSIM and MATLAB in this case study. For each simulation, MODEFRONTIER will base on the configuration and prepare simulation files for each tool. Out of the many available algorithms in MODEFRONTIER, MOGA (multi-objective genetic algorithm) is chosen as the optimization algorithm.

The objectives are to maximize net energy production (or at least, energy consumption saving, which is explained in the previous section), and to minimize the additional capital investment, which will be descibed in the next section.

An initial search space of 50 configurations is generated with Latin Hypercube sampling (LHS). As the optimization progresses through generations, MOGA will move to a more likely search space. Deviation of the current search space from the previous one depends on the mutation setting, which has to strike a balance between fast convergence and consideration of all possibilities.

The optimization converged at the last few generations without further improvement. The optimization is set to stop after 30 generations.

Capital investment

Parameters of selected design options from demand side to generation side have been described in previous sections. Each of these design options has a significant impact on the net energy production by affecting one or more of the domains of cooling, heating, lighting, and energy generation. The choice of design options also affects the capital investment. *Table 4* presents the unit installation cost for each of the design options. The cost information is based on literature and correspondence with the industrial partners. The values are both time sensitive and local situation dependent.

Table 4
Unit cost of design options

DESIGN OPTIONS	UNIT COST (€)
Insulation portion (per R_{SI}-m^2)	6
Steel portion (per m^2)	14
Skylight (per m^2)	450
PV (per kW_P)	2,100
TSC (per m^2)	70

Roof and wall are assumed to be steel sandwich panel that is composed of a steel portion and an insulation portion. In reality, sandwich panels are sold in pieces; the portion prices are regression estimates based on actual installed products. One of the optimization objectives is to minimize the capital investment based on configurations of different combinations of design options. For example, the installation of PV will reduce the possible amount of skylight, which in turn, will reduce the amount of steel sandwich panel to be installed.

In this paper, the interest is not on the total investment cost of the building, but rather, the additional capital investment necessary to implement those energy saving and generation measures. There will be no additional capital investment for the ASHRAE baseline building, which is taken as the reference.

RESULTS AND DISCUSSION

Optimization process searches through 1,500 configurations (i.e. 30 generations of 50 samples). *Figure 1* presents all configurations (with different combinations of values of the aforementioned design parameters) that have been studied.

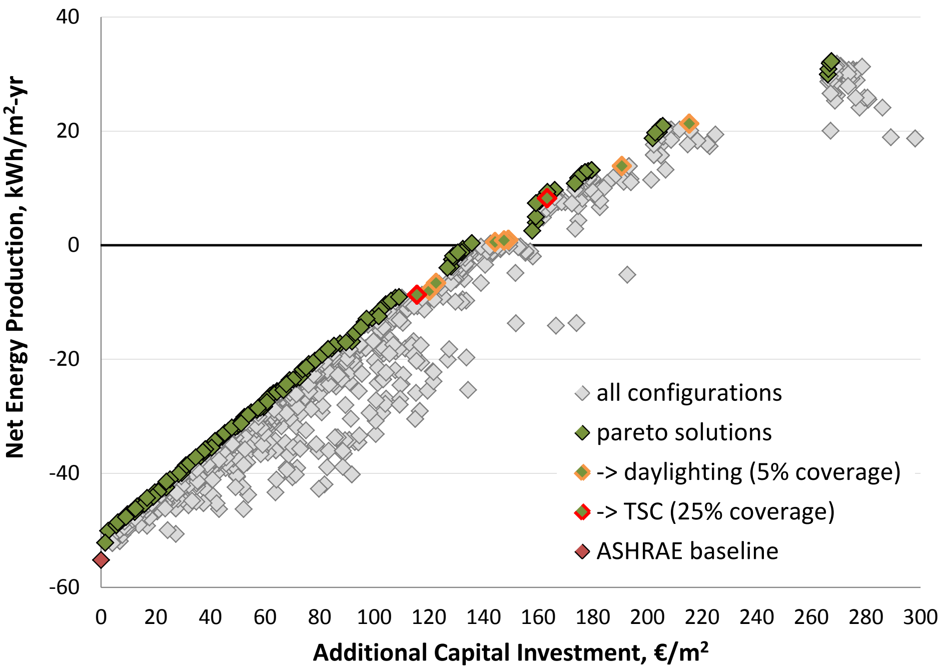

Figure 1 Design solutions obtained by optimization with varying amount of insulation, skylight, TSC, and PV installation

Each of the configurations is represented by a grey diamond, which presents the corresponding additional capital investment and net energy production capability of that configuration.

The pareto solutions, which also known as trade-off solutions, are represented by the green diamonds. There will be no higher energy production solution without an increase in additional capital investment among these pareto solutions. Selection among these solutions is a matter of trade-off decision between the desired energy production capability and the amount of committable additional capital investment.

All pareto solutions are presented in *Figure 2*. Each parallel line represents a design solution of a different combination of values of the five design parameters (tilt angles, heights, and gaps of PV could be presented in terms of the resulting power rating of the design PV system in kW peak). The green area indicates that no design solution present in the respective ranges of the design parameters.

Insulation

From *Figure 2*, it can be obeserved that the insulation values for wall range from a minimum of R_{SI} 1.0, to a maximum of R_{SI} 2.0 (with an average of R_{SI} 1.2), which implies that wall insulation has little impact on energy consumption. By lowering wall insulation than that of the ASHRAE baseline value, the capital investment reduced. On the other hand, roof, a sizable horizontal area that is more than twice as large as walls' surface area, is subject to greater influence of solar irradiance and other external factors. Among the pareto solutions, roof insulation covers the whole range of values being studied, from R_{SI} 1.0 to R_{SI} 4.5, such that in tandem with daylighting, TSC and PV installation, yields the optimized results.

ASHRAE standard specifies R_{SI} 3.3 for the roof. Design solutions with roof insulation values greater than R_{SI} 3.3 are highlighted in purple lines (the purple area grey out the other solutions). The results do support the notion that extra amount of insulation helps reducing energy consumption. For the most net energy production solution, the roof insulation is R_{SI} 4.5. Neighbouring solutions exhibit slightly less energy production but cost almost the same, since the cost of extra insulation is minimal as compared to PV installations (for high energy production solutions), whereas the relative benefit is also marginal.

However, for solutions of lower PV capacity (where both the net energy production and additional capital investment are no longer dominated by PV installation), other energy saving measures might also provide the same amount of benefit as extra amount of roof insulation for the same capital investment. Therefore, for design solutions of lower installed PV capacity, extra insulation might not be the most cost effective option for a certain amount of additional capital investment. The pareto solutions offer a variety of possible configurations that could achieve the desire net energy production / additional capital investment combinations.

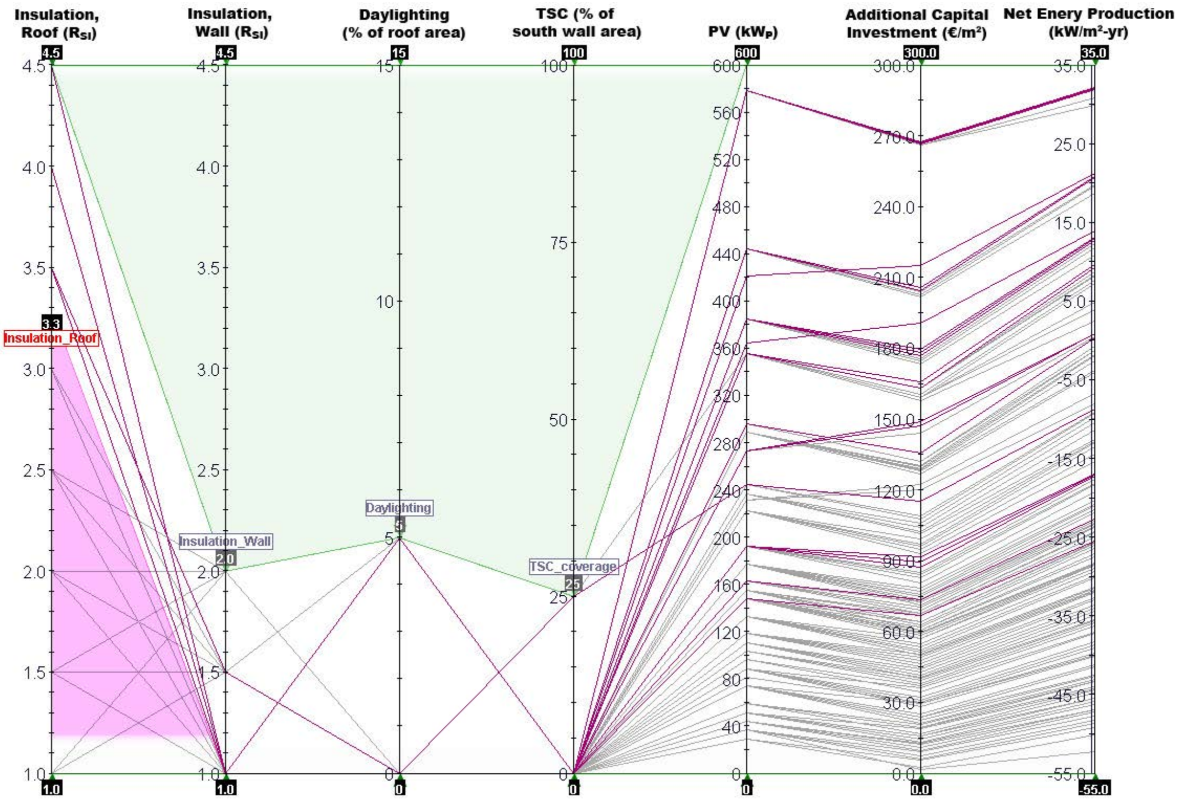

Figure 2 Parallel coordinates plot for all of the pareto solutions; solutions with roof insulation values greater than R_{SI} 3.3 are highlighted in purple lines

Daylighting and TSC

Daylighting with skylight can lower the energy consumption for lighting, while TSC can lower the energy consumption for heating. For the same amount of capital investment, it is thus necessary to investigate if the installation of PV system generates more or less the amount of energy being saved by skylight and TSC.

Roof with skylight covering none to 15% of the roof area is being investigated. Pareto solutions that incorporate skylight are marked in green diamonds with orange outline in *Figure 1*. It is found that the marginal energy saving due to additional daylight does not yield comparable energy production per unit of additional capital investment; and thus all pareto solutions that consider daylighting cover only 5% of the roof area with skylight. For the same reason of cost effectiveness, a maximum of 25% of the south wall is covered by TSC for a number of pareto solutions that are marked in green diamonds with red outline. In those solutions with either daylighting or TSC, PV systems ranging from a capacity of 245 kW_P to 422 kW_P are considered (as contrasted to pareto solutions with tightly packed PV system of 579 kW_P).

Many of the pareto solutions are neighbouring to one another in close proximity and displaying similar energy and cost characteristics. *Table 6* presents two neighbouring solutions that are differed by the amount of skylight.

Table 6
Two neighbouring solutions with different amount of skylight

DAYLIGHTING	ENERGY (kWh/m^2-yr) COOLING/ HEATING	LIGHTING	GENERATION	NET ENERGY PRODUCTION (kWh/m^2-yr)	ADDITIONAL CAPITAL INVESTMENT (€/m^2)
0%	8.8	45.1	74.6	**20.9**	**205.7**
5%	12.1	37.3	70.6	**21.3**	**215.3**

When skylight covers 5% of the roof, cooling and heating energy consumption increased by 3.3 kWh/m^2-yr, while lighting energy consumption decreased by 7.8 kWh/m^2-yr. With that 5% of the roof area taken up by the skylight, less amount of PV can be installed, and thus resulted in a decrease in the amount of energy being generated. However, the energy saving through daylighting does complensate the loss in energy generation, and thus, results in a slight increase in net energy production, which is accompanied by an small increase in additional capital investment.

PV installation

PV installation is being considered in all of the pareto solutions and the installed capacity is ranging from 30 kW_P to 579 kW_P. Those capacities are the result of different combinations of PV heights and gaps between PV rows. The optimal tight angle is found to be 36° as opposed to 52°, which is the theoretical optimal angle for Amsterdam in which the most solar energy could be received on a single row of panels. Because of the shading effect, PV installation at higher tilt angle (as compared to that of the optimal tilt angle) will yield lesser total output when rows of panels are tightly packed.

Basically, energy generation is linearly proportional to the amount of PV being installed (at optimal configurations of title angle, height, and gap); whereas energy saving due to insulation, daylighting, and TSC is of diminishing returns. The energy saving measures, after reaching a certain amount, provide insignificant marginal saving. Therefore, the pareto solutions follow the same linearity as PV energy generation.

PV installation is the only energy saving and generation measure that has a lifespan assumed to be shorter than the building. Usually, a life-cycle of 20 years is assumed for PV systems. In the current investigation of capital investment, the factor of life-cycle is not taken into consideration. However, if cost-benefit is the subject of interest, life-cycle plays an important role and will be discussed in the future work section.

Design solutions

As mentioned, each of the green diamonds on *Figure 1* represents a pareto solution. Neighbouring pareto solutions provide very similar energy and cost performance and arrive at those performance with different configurations. Previous discussion just demostrates how the trading of lesser amount of PV with 5% daylighting provides almost the same energy production capability at very similar costs. In general, *Figure 1* only shows how net energy production is related to additional capital investment for the pareto solutions; whereas *Figure 2* only helps to identify performance trends of each design parameters. Information is lacked in evaluating if a certain investment is worthwhile to commit. In fact, the amount of capital investment affects the decision-making process greatly; since after all, the availability and also the cost-benefit of the financial resource is the determining factor.

Table 7 presents three distinctly different design solutions, namely, the solution that costs the least additional capital investment, the net-zero energy solution, and the one that yield the most net energy production; and stacks them against the baseline building configuration. Also presented in the table is the percentage of energy saving over ASHRAE baseline building.

Table 7
Energy production capability and additional capital investment of three distinct design solutions as compared to the ASHRAE baseline building

SOLUTIONS	ADDITIONAL CAPITAL INVESTMENT (€/m^2)	ENERGY CONSUMPTION (kWh/m^2-yr)	ENERGY GENERATION (kWh/m^2-yr)	NET ENERGY PRODUCTION (kWh/m^2-yr)	ENERGY SAVING OVER BASELINE (%)
ASHRAE Baseline	-	55.2	-	-55.2	-
Least Additional Capital Investment	1.6	59.4	7.2	-52.2	5.4%
Net-Zero Energy	**135.8**	**53.9**	**54.2**	**0.4**	**100.7%**
Most Net Energy Production	267.4	53.5	85.8	32.2	158.3%

From the results, it is found that a net-zero energy industrial hall is indeed possible and comes at an additional capital investment of €543,200 for the case study hall. The net-zero energy hall save 210 MWh each year over the ASHRAE baseline building, which in monetary terms equal to €18,850 per year (at €0.0896/kWh for the Netherlands. Assume no feed-in tariff, that is, the electricity selling price is equal to the purchasing price; EEP, 2012).

The above saving implies a simple payback period of almost 29 years, which is 9 more years beyond what is assumed for the life of the PV panels. In other words, if PV panels do fail or reduce in efficiency in 20 years, the building operators will be bearing the additional cost with no or little return. A review of the most net energy production solution comes to similar conclusion that the additional capital investment cannot be recouped with energy saving / production (simple payback period of 34 years).

On the other hand, even though the least additional capital investment solution realizes only a small amount of energy saving of 5.4% as compared to the baseline building, the additional capital investment of €6,400 can be recouped in a mere 6 years. After that, the building operators in fact receive positive cash flow from the investment.

This least additional capital investment solution proposes a minimum amount of insulation with just a small array of PV (rated at 37 kW_P). A closer look into the solution reveals that the PV installation costs an extra €19.4/m^2 while generates 7.2 kWh/m^2-yr. At the same time, the reduced amount of insulation over the ASHRAE baseline building brings a cost saving of €17.8/m^2 while induces extra energy consumption of 4.2 kWh/m^2-yr. The net result is that this solution requires minimal upfront cost, saves energy in the long run, and bring positive cash flow to the building operators.

A simple payback period of 20 years and the assumption that PV systems cease to operate at the end of the life cycle imply, in a simplified sense, that the investment bears no financial burden nor yields any economic benefit to the building operators. Quite a number of design solutions do have a simple payback period of 20 years. Those solutions have an average roof insulation of R_{SI} 2.0, wall insulation of R_{SI} 1.0, and PV capacity of 105 kW_P; and post an average energy saving of 35% over the ASHRAE baseline building. In other words, at no cost (in simple terms) to the building operators, industrial halls could be built to cut energy consumption by more than a third over current practice.

Limitation of the investigation

Simple payback period does provide quick estimate of the feasibility of the investment. However, it fails to provide a meaningful interpretation if the simple payback period extends beyond the life cycle of the investment, as in the cases for those high energy production solutions (and net-zero energy solution). In fact, the worthiness of the investment can only be determined with a life-cycle cost-benefit analysis, which is beyond the scope of this paper. The analysis involves the consideration of energy bills that would have to be paid without the investment (opportunity cost), the net energy cost to be paid (or earned) as a result of the investment, the annualized cost of the investment, and the numerous economic factors (Lee et al., 2011).

Moreover, environmental impact of energy is more dependent on the sources of the energy rather than the amount of energy. A carbon based investigation will more adequately reflect the environmental impact of the design solutions.

CONCLUSION

From the discussion and the demonstration of applying optimization in searching for the design solutions that are maximized for energy production capability and minimized for additional capital investment, it can be concluded that some design solutions that are high in energy production capability are not economically feasible, while some design solutions that cost virtually nothing in the long run post significant energy saving over the ASHRAE baseline building.

Optimization is an automated and systematic way to search through the design space for optimized design solutions. By applying optimization to simulation models that are based on integrated design approach, design solutions that are both energy and cost effective can be identified. In fact, in a single parameter consideration, for example, that of insulation, extra amount always exhibits some benefits, and it is difficult to evaluate if one energy saving and generation measure is performing better than the other measures. With this integrated design approach, design options that are not as energy or cost effective will be eliminated from the choices.

With findings from this paper, significant energy saving for industrial halls is no longer a remote dream.

Future work

Future study that evaluates carbon emission due to building operation and annualized expense / profit of the energy saving and generation measures will allow better comparison among design solutions in both environmental and economic sense. Only with carbon emission reduction prediction and actual cost projection of NZEB (that has simple payback period beyond the life cycle), incentive policy that promotes energy conservation can then be developed accordingly.

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