E3S Web of Conferences **362**, 11006 (2022) https://doi.org/10.1051/e3sconf/202236211006
BuildSim Nordic 2022

Optimization of Thermal Comfort and Energy Consumption in Bangladesh Ready-Made Garment Factories: An Approach towards the Path to Net Zero Energy Buildings

Md Ashikur Rahman Joarder[1*], Monir Hossain[1], Aaron J.E. Bach[2], Jean P. Palutikof[2], Fahim Tonmoy[3]
[1] Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh
[2] Cities Research Institute, Griffith University, Australia
[3] BMT Commercial pty, Brisbane, Australia

* *Corresponding author: ashikj2000@gmail.com*

Abstract

RMG workers in Bangladesh are facing scorching heat due to regional climatic conditions and increasing temperatures due to climate change. This research investigates the indoor thermal condition of a ready-made garment (RMG) factory and develops strategies to improve the comfort of workers. Energy optimization is carried out and design features are identified (e.g. window, shading and skylight configurations) that achieve the best energy performance. Eight simulation steps are also carried out to accomplish the process towards the path to net zero energy building (NZEB). Simulation analysis is carried out to measure energy use intensity (EUI) over the year for the base case building. By changing various features, a further seven steps of simulation are carried out to reduce the EUI value and turn it into zero energy building. The EUI value is gradually decreased at each step. The research shows that nearly 750,000 kWh energy can be saved per year in the case RMG factory. The incorporation of photovoltaic (PV) panels can harvest approximately 40,000 kWh over the year.

Introduction

Ready-made garment (RMG) factories in Bangladesh have been heavily criticized for their working conditions (Joarder and Iqbal, 2015). More than 80% of the export earnings of Bangladesh come from the RMG sector (IFC. 2011) and about four million people are involved in this industry. In the factories, workers are engaged in sewing, ironing, packing, tailoring, operating machines and other labour-intensive activities. Due to the nature of their work and the heat generated from machinery, the indoor environment of the factories is often uncomfortable and workers suffer a range of health problems that affect the individual as well as the overall productivity of the factory. Heat stress is a major health risk for RMG workers, and is expected to worsen in the future due to global warming. Due to the current environmental situation, energy saving has become the leading driver in the modern research approach (Bojic et al., 2013). By having an effective architectural design, the energy consumption from heating or air conditioning systems could be reduced significantly (Kalmár and Csiha, 2006). A comfortable environment can be achieved by removing generated heat by effective natural and/or artificial ventilation systems. In recent times, to ensure workers' comfort and productivity, the construction of fully air-conditioned factory buildings is getting popular among the owners and management of RMG factories in Bangladesh. Electricity-based carbon-intensive air conditioning systems can result in a significant amount of energy consumption. On the other hand, passive or hybrid ventilation systems require less energy to operate and at the same time have less impact on the environment, carbon emissions and climate change.

This research addresses the growing threat to worker health and productivity from heat stress that may be caused by climate change and seeks to identify sustainable cooling strategies that will not add to the burden of greenhouse gas emissions. It explores low-to moderate-cost sustainable strategies to ensure workers' comfort and reduce energy consumption. It presents a comparison between thermal parameters for the evaluation of thermal comfort between different ventilation strategies. EnergyPlus™ is used to provide the necessary framework to explore the effectiveness of the proposed interventions.

A model of a case steel-structured RMG building that is fully air-conditioned is first optimized for the target parameters of thermal comfort and energy consumption. Then, a configuration of an environment-friendly RMG factory is formed as an approach towards the path to net zero energy building (NZEB) by incorporating some additional passive features, e.g. controlling window configurations, providing natural ventilation, controlling shading configurations, reducing artificial lighting load, reducing cooling load, and controlling skylight configurations.

The findings of this study demonstrate that optimum thermal comfort inside RMG factories can be achieved by passive means in the tropical climatic context, i.e. Bangladesh. To achieve an NZEB, solar energy needs to be integrated.

Case study for base case modelling

A single storied, constructed with steel and brick, RMG building located in northwest Dhaka (Figure 1) is selected for the investigation. The factory undertakes garment manufacture from cutting through sewing and ironing to packing. A physical survey was conducted to measure the existing configurations and collect the climate data (Table 1) that is required for simulation analysis. The selected building is an 864-square meter factory building with a pitched roof. The building is north facing (Figure 1: top) towards the access road. The roof is made of metal sheet adjacent to a truss frame structure (Figure 1: bottom). The North facade of the factory has two large gates (6 meters x 2.5 meters) made of steel. During working hours, these two gates remain closed for security purposes. So, for simulation modelling, the north facade of the base case was assumed with no opening. Rhinoceros and Grasshopper are used to prepare the base case model.

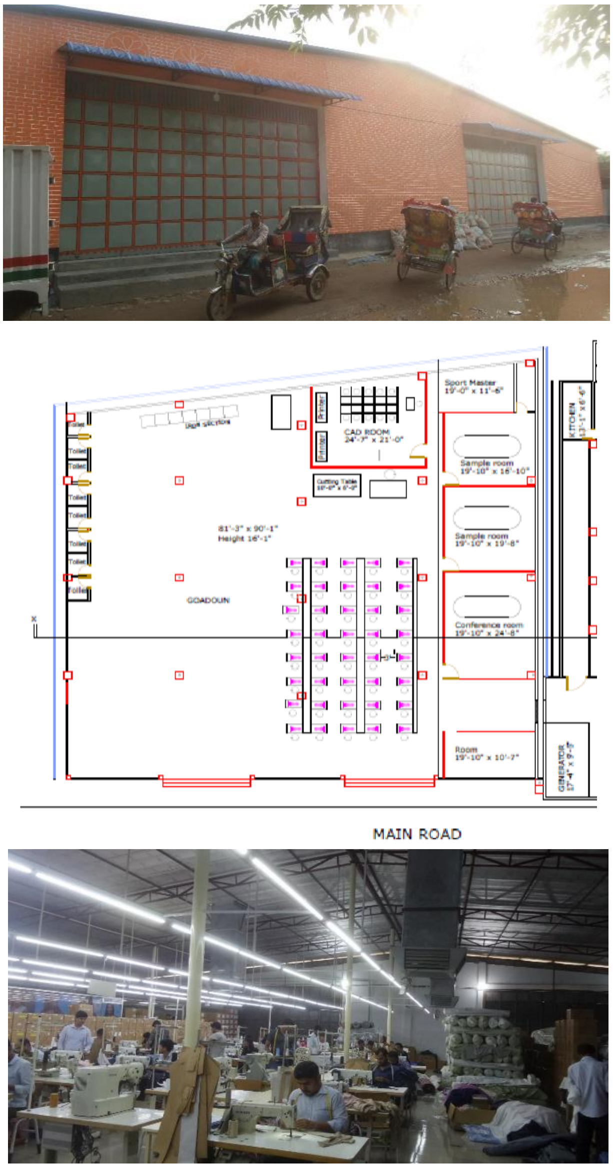


Figure 1: North side view of the selected building (top), floor plan (middle) and inside view of the RMG factory (bottom).

Methods

An abstract geometry of the model is used for simulations in this research. A detailed model is not required for this study. For energy simulation, the space needs to be classified as a zone. Although in the base case model there are no windows and skylights, in the Grasshopper script these need to be specified. Window wall ratio (WWR) and skylight roof ratio are used in this model. The range of the ratio can be adjusted with sliders. There are four main phases of this research as explained below.

In the first phase, the base case three-dimensional model is prepared considering the collected data from the physical survey. Rhinoceros, Grasshopper and ClimateStudio software and plugins are used to prepare the model. The model is controlled with the Grasshopper script. In this script, the workflow can be divided into four parts. Part A is the components for developing the building geometry (floor, wall, roof, window, shading and skylight). The geometry is connected to components in Part B for energy modelling. In this part, material selection for individual elements of the building, zone settings, adiabatic and boundary condition settings are incorporated. Part C is the component for optimization. Part D is the component for data output and visualization.

In the second phase, optimization for energy consumption is carried out. Around 200 plus simulations are conducted to find the optimized design variables. By using the Pareto Front Algorithm, the best combination is identified.

Table 1: Indoor and outdoor mean maximum temperature (T_{max}) and mean minimum relative humidity (RH_{min}) between 08:00 and 18:00 on the days the factory was operating in 2021.

	Indoor	**Outdoor**
January (n=308 hours over 28 days)		
T_{max} (°C)	28.6	24.5
RH_{min} (%)	44.2	50.3
March (n=264 hours over 24 days)		
T_{max} (°C)	29.6	33.3
RH_{min} (%)	59.9	38.8
September (n=286 hours over 26 days)		
T_{max} (°C)	30.1*	32.6
RH_{min} (%)	62.4*	64.3
All of 2021 (n=3234 hours over 294 days)		
T_{max} (°C)	30.9^	30.6
RH_{min} (%)	58.7^	55.9

**30 hours of missing data not included*
^ 39 hours of missing data not included

In the third phase, the simulation for thermal comfort is carried out. Three options (Op1- base case, Op2- energy-optimized, and Op3- energy optimized with changing materials) are prepared for the predicted percentage of dissatisfied (PPD) and predicted mean vote (PMV) analysis. By comparing the three results, the best option is identified as complying with both the American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE) and Bangladeshi standards (BNBC, 2020). To achieve sustainable and green design, performance simulations are often used to verify these criteria and modify the design. The conventional approach of manual trial-and-error is too time-consuming to be practical (Jahangir et al., 2014).

In the fourth phase, the path to net zero analysis is conducted. For this, an eight-step process is identified and initiated. At each step (except Step 1), the base case building is modified and the site EUI value is calculated through simulation. In Step 8, PV panels are provided to harvest energy to achieve the net zero energy goal.

Optimization of energy consumption

High-energy performance buildings can save primary energy and reduce CO_2 emissions. The EU energy policy in the buildings sector, including technical solutions and legal procedures, aims to improve the energy performance of buildings and guarantee human comfort (Tronchin and Tarabusi, 2013). In this section, simulation analysis is carried out to find out optimized values of nine design variables (WWR-North, WWR-East, WWR-South, WWR-West, Shading Depth-North, Shading Depth-East, Shading Depth-South, Shading Depth-West, Skylight) in terms of energy performance metrics (EUI and CO2 emissions).

First, the base model is modified and the nine design variables are incorporated (Table 2). The selected variables have their range sliders in the script so that the best configuration can be identified by parametric analysis.

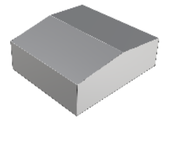
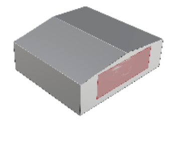
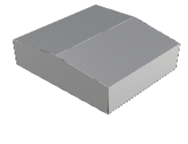
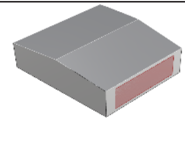
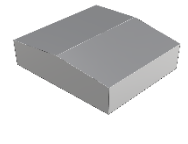
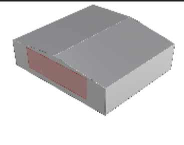
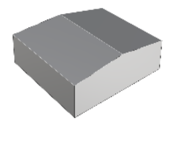
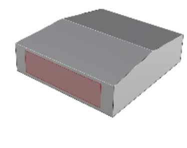
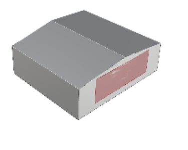
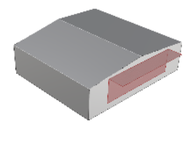
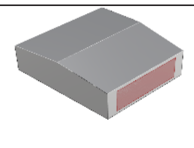
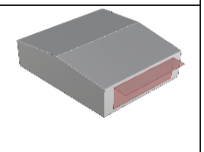
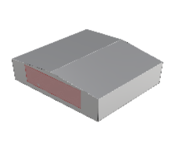
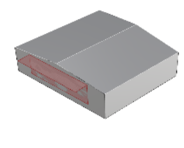
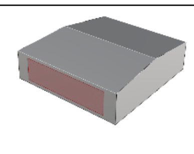
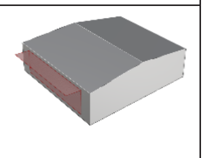
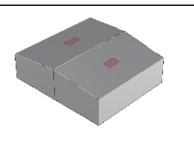
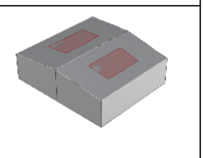
Second, the zone settings in the Grasshopper script are updated (e.g. equipment load, lighting load, cooling load, humidity, temperature, air speed and materials) using the physical data collected from site visits. The indoor space is considered non-air-conditioned while conducting this simulation. The climate data file (.epw) is also attached to the script.

Third, Octopus is connected with two sets of variables (the design variables and performance metrics).

Finally, through the Pareto Front interface, by setting population size and generation number, the optimization process is run. In this research, over 200 iterations are completed. The Pareto Front algorithm compares these results and identifies the optimized option for the best energy result (Table 3). The identified values will be used later for the path to net zero and thermal comfort analyses. The identified EUI and CO_2 emissions for the best energy case are 56 kWh/(m^{2}yr) and 46 kgCO_2e/(m^{2}yr) respectively.

Figure 2 presents the optimization of energy consumption. Among the 200-plus simulations, the Pareto Front identifies the optimal solution. The yellow circle indicates the Pareto Frontier.

Table 2: Design variables and ranges for simulation analysis.

	Variables	Minimum	Maximum
1	WWR-North	 No windows	 Full-wall windows
2	WWR-East	 No windows	 Full-wall windows
3	WWR-South	 No windows	 Full-wall windows
4	WWR-West	 No windows	 Full-wall windows
5	Shading Depth-North	 No shading	 2.0 m
6	Shading Depth-East	 No shading	 2.0 m
7	Shading Depth-South	 No shading	 2.0 m
8	Shading Depth-West	 No shading	 2.0 m
9	Skylight	 2%	 20%

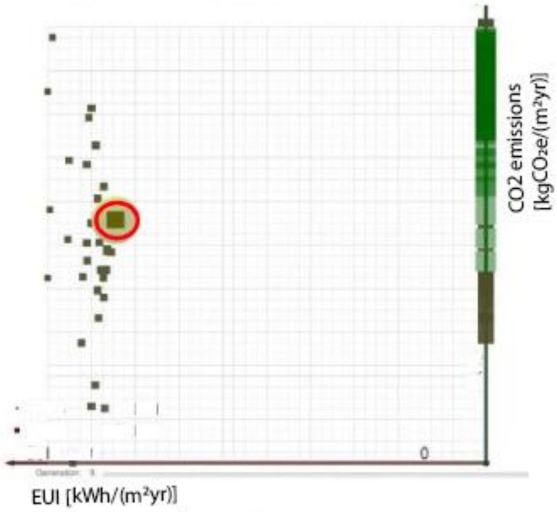


Figure 2: Pareto Font analysis for energy optimization.

Table 3 shows the optimization results and the values of the independent variables (Joarder et al., 2022). It will be used later for the thermal comfort and the path to net zero analyses.

Table 3: Optimization results for energy consumption

Design Variables	Optimized design parameters for energy consumption
WWR-North	40 %
WWR-East	4 %
WWR-South	24 %
WWR-West	34 %
Shading Depth-North	1.86 m
Shading Depth- East	0.95 m
Shading Depth -South	0.09 m
Shading Depth -West	0.39 m
Skylight	10 %

Simulation for thermal comfort analysis

By understanding the thermal behaviour of existing factory buildings, owners can improve the indoor environmental quality to increase their production (Sayem et al, 2011). In this research, to measure thermal comfort of case building, PPD and PMV simulations are carried out with existing variables (Op1- base case). Later, two more options (Op2- energy-optimized and Op3- energy optimized with changing materials) are analysed with modified variables (Table 3). By using Rhinoceros, Grasshopper and ClimateStudio, 3D models and spatial-comfort-analysis scripts are prepared. The values of the design variables shown in Table 3 are used for modelling. In the case of base case, the values of these variables are set to '0' (zero). The thermal properties of the building materials considered in the model are as follows: U-values in W/m^{2}K for the roof, wall, floor, window and skylight are 0.40, 3.69, 5.62, 5.84 and 2.60 respectively. The solar heat gain coefficient for the window is 0.25 and for the skylight is 0.30. Radiance glass material is used in the window where visible transmittance is 0.6. Radiance opaque materials are used for interior wall, ceiling and floor where reflectance are 0.5, 0.8 and 0.2 respectively. For skylight, radiance translucent material is used where diffuse reflectance is 0.21 and specular reflectance is 0.2.

The following parameters are considered as input before running the simulation: June 21 and 12.00 AM (summer equinox) is set as time zone, the weather data file in epw format, people density 0.05/m^2, metabolic rate 1.2 m^2, occupancy schedule 9:00 am to 5;00 pm weekdays, equipment power density 10 W/m^2, lighting power density 10 W/m^2, illuminance target 300 lux, heating and cooling both checkboxes are kept off, hourly air changes 3, infiltration 0.5, airmass flow coefficient 0.001 kg/s, 300 mm concrete with 80 mm insulation and 80 mm screed for the roof (for option 3 only). PPD result that appeared in the script is the average value of 232 sensor points (Figure 3, left). PMV values are also derived for 232 sensor points. The lowest (negative) and highest (positive) values are identified to declare the final PMV result. The results graph and values are shown in the right portion of the script (Figure 3, right).

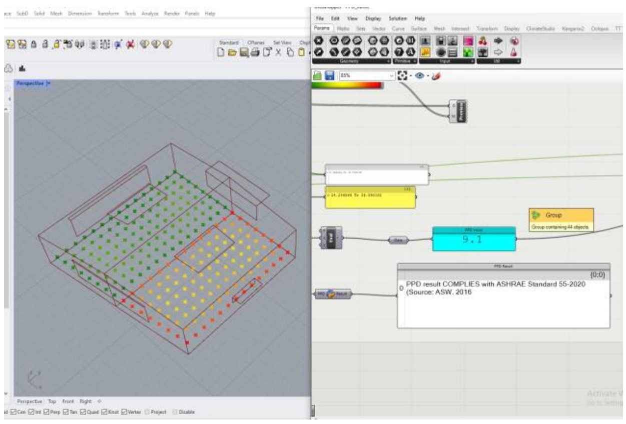


Figure 3: Rhinoceros model and Grasshopper script for PPD analysis

In Op1, the PPD results were very high (70%) which is unacceptable. In Op2, the PPD results were again quite high (34.4%) which is also unacceptable. Option 3 generated the best PPD result (9.1%) (Figure 4). This complies with both the ASHRAE and Bangladeshi (BNBC, 2020) standards. On the other hand, PMV results are found -1.92 to 2.90 for Op1, -0.16 to 1.78 for Op2, and -0.04 to 0.63 for Op3. Although ASHRAE standard ranges for PMV is -0.5 to 0.5, in the case of Bangladesh, -1.0 to 1.0 also indicates a thermal comfort range. The value only complies with Op3. Thus, Op3 is recommended for RMG factory buildings in the context of Bangladesh to get the best performance for thermal comfort.

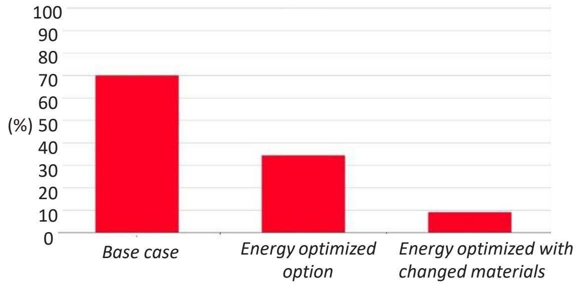


Figure 4: PPD results for the base case, energy-optimized option and energy-optimized with changing materials

Simulation for path to net zero analysis

A basic definition states that a NZEB is the one that reduces the energy requirement of a building using passive design strategies and energy-efficient systems. Also, it should be able to generate the required electricity from renewable energy sources to meet the remaining energy needs (Gupta, 2017). With the appropriate use of technology, it is anticipated that the energy consumption in the building sector can be reduced to about 30% to 80% (Gupta, 2017). In this research, eight steps are conducted towards the path to net zero analysis. The target is to reduce energy consumption gradually. If the value of energy consumption does not drop to zero, further steps are taken. In contrast, if zero can be achieved by fewer than eight steps, the process could be stopped. Figure 5 shows the model and Grasshopper script for the path to net zero analysis.

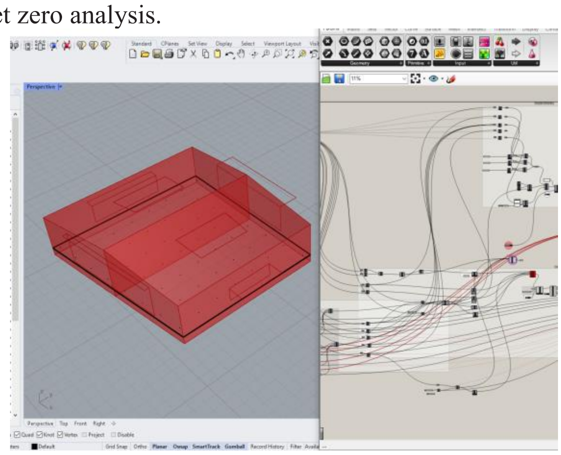


Figure 5: Rhinoceros and Grasshopper interface showing the RMG model and script for the path to net zero analysis.

Step-1: Base case analysis

In Step-1, the Grasshopper script is prepared for the Path to net zero analysis. CS energy model (e+), a ClimateStudio-based simulation engine is used to run the process. The left side of the script contains the information associated with modelling (e.g. size and direction of windows, depth of shadings and size of skylight). The middle portion of the script represents different types of settings (e.g. zone, boundary condition, input of local weather data, run button and energy results) and the right side of the script contains a representative graph of the simulation outcome (e.g. graph of monthly energy consumption, track of path to net zero results, site EUI history and energy harvest history). In the base case, no windows, shading or skylights are used in simulation. The values of these variables are kept '0' to represent the real scenario. The equipment load, lighting load, metabolic rate, people density, air speed, cooling load, fan energy, material properties and other information are required for this simulation analysis. Data are as the same as in the section: 'Simulation for thermal comfort analyses'. The simulation results found a yearly total of 675,400 kWh/yr of energy is consumed, which is high for this small size building. The site EUI value per area is found at 3142 kWh/(m^{2}yr) (Table 4). To achieve net zero, further steps need to be carried out. Figure 6 (Top) shows the graph of EUI results for the individual month (January to December). The graph shows, as expected, that the cooling load is comparatively higher for the summer months (May to July) and lower for the winter months (November to February).

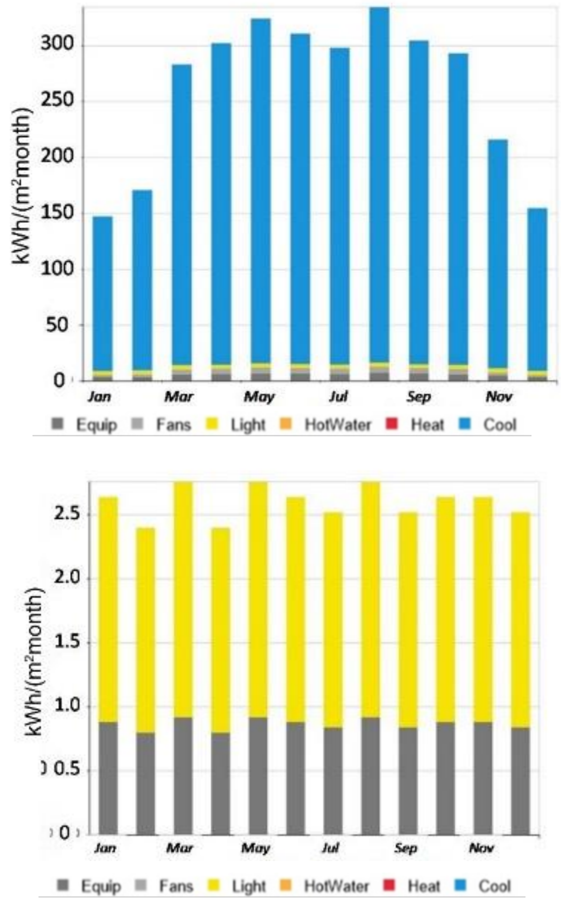


Figure 6: EUI results for base case (top), EUI results after completion of eight steps (bottom)

Step-2: Controlling window configuration

As windows have a large-scale impact on daylighting and thermal comfort depending on their sizes, orientations and shading configurations, as well as on the energy consumption of buildings, it is necessary to optimize window design for maximum benefit (Aman, 2017). The low glazing ratios at the south and west walls are the main reason why EUI is reduced (Aman et al., 2021). In Step-2, the model is updated with an increasing window-to-wall ratio for all (north, south, east and west) orientations. The window configurations of this simulation study are as follows: WWR-North is 40%, WWR-South is 24%, WWR-East is 4% and WWR-West is 34% (the optimized results are presented in Table 3). After completion of the simulation process, the EUI result was 650776 kWh/yr (Table 4). The results indicate that, by controlling window configurations, 24624 kWh/yr of energy can be saved (Table 4). On the other hand, the site EUI value per area was 3032 kWh/(m^2yr) (Table 4) which also indicates, that 110 kWh/(m^2yr) energy can save per square meter (comparing the result of Step-1) by incorporating these four window variables.

Step-3: Providing natural ventilation

In this step, simulation is run considering the building is natural-ventilated. The inputs are specified in the Grasshopper script to update the model are as follows: natural ventilation 'on', hourly air exchanges 1.6 ACH, buoyancy driven flow 'on', indoor mean maximum temperature 30.9 ^{o}C, outdoor mean maximum temperature (T_{max}) 30.6 ^{o}C, indoor mean minimum relative humidity (RH_{min}) 58.7%, outdoor mean minimum relative humidity 55.9%, infiltration 0.5 ACH. T_{max} and RH_{min}, values are taken from physical survey data (Table 1). After completion of the simulation, the yearly EUI value is 639533 kWh/yr (slightly lower than the value of Step-2) and the value is still too high. Yearly energy saving and site EUI value per area are 11243 kWh/yr and 2983 kWh/(m2yr) respectively (Table 4).

Step-4: Controlling shading configurations

Shading devices protect against direct solar radiation entering the space. They also keep the façades away from extra heat gain. In this step, shading devices are added to the model and the simulation is run. Optimized value for shading-depth in individual directions is important because extra depth can be an obstacle to daylight entering into the space. In this simulation, optimized values for shading-depth (Shading-North 1.86m, Shading-South 0.95m, Shading-East 0.09m and Shading-West 0.39m) are used (Table 3). Other variables and parameters for simulation are kept unchanged. When the simulation is carried out, the results are that the yearly EUI value (635216 kWh/yr) is slightly decreased from the previous step. Energy Saving value (4317 kWh/yr) and per area site EUI value [2963 kWh/(m^2yr)] both are also decreased from the previous step (Table 4).

Step-5: Reducing lighting load

In Step-5, artificial lighting loads are deducted from the process of simulation analysis. Usually, the working schedule for RMG workers counts (from 8.00 AM to 6.00 PM) 10 hours during the daytime (including lunch and other breaks). In Dhaka's context, there is plenty of outdoor daylight available during these hours. Proper window design can welcome this amount of daylight to enter into the space. In this step, the Grasshopper script has been slightly modified by turning 'off' the artificial lighting. Simulation results found that the yearly EUI value is 570131 kWh/yr, the energy-saving value is 65085 kWh/yr and the site EUI value per area is 2674 kWh/(m^2yr) (Table 4).

Step-6: Reducing cooling load

In Step-6 the factory is considered as a non-air-conditioned building. The highest number of energy consumption causes by the cooling load (Figure 6, Top). In this step, the simulation process is run by turning off the cooling load option in the Grasshopper script. Since windows are incorporated, a natural ventilation system is active and electric ceiling fans are provided, an active cooling system can be omitted in this simulation. After completion of the simulation, the result is found that the EUI value (39865 kWh/yr) is significantly decreased (Table 4). On the other hand, the energy-saving value is sharply increased (530266 kWh/yr) where the yearly site EUI value is found at 176.8 kWh/(m^2yr) (Figure 7).

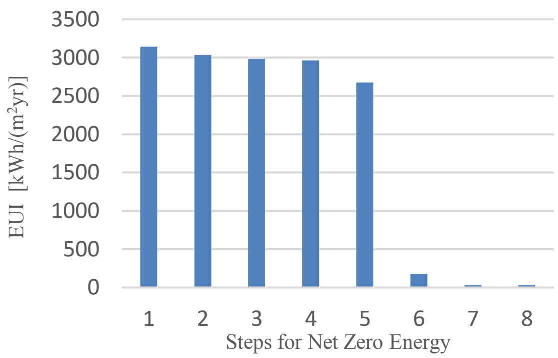


Figure 7: Graph of site EUI history

Step-7: Controlling skylight configuration

Step-7 proposes a skylight on the roof of the case building and the changes are adopted in the Grasshopper script. In the previous script, the skylight value was set to zero (0) on the range slider component. During this simulation, the skylight value is set at 10% (the optimal value found in the energy optimization) (Table 3). After this simulation, the yearly EUI is found to be 7035 kWh/yr (Table 4) while it was 39865 kWh/yr in Step-6. The analysis indicates that by controlling skylight configurations 32830 kWh/yr energy can be saved and the site EUI value can be reduced to a value of 31.2 kWh/(m^2yr) (Table 3).

Step-8: Photovoltaic panel incorporation

In Step-8, Photovoltaic (PV) panels on the roof are introduced. PV seems to be technically the easiest way to get the zero energy balance, as the recent, sharp drop in PV prices makes it competitive even with active solar thermal collectors, and building materials in general (Adinolfi et al., 2014). In Grasshopper, an additional script for PV panel setup is connected to the previous script. With the help of ClimateStudio PV components (e.g. run CS PV model and load CS PV result), the additional script is prepared. On the right side of the script, the result of the simulation appears and a graph

 https://doi.org/10.1051/e3sconf/202236211006

presents the PV energy harvest history. After PV incorporation, the EUI is found to be -40206 kWh/yr (Table 4) while it was 7035 kWh/yr at the previous step (Step-7). The analysis indicates that, by incorporating PV panels, 47241 kWh/yr of energy can be saved (Figure 8).

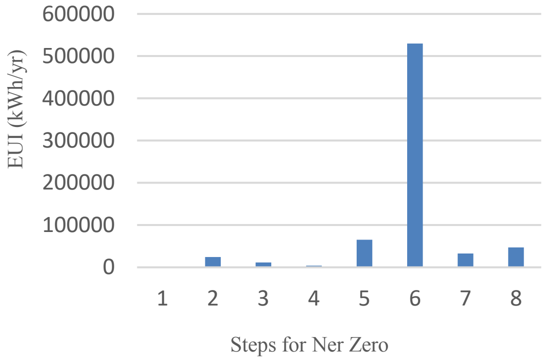


Figure 8: Graph of energy saving history

To summarize the results across all steps of the path to net zero simulation, the EUI value is high (675400 kWh/yr) in Step-1 compared to Step 8 (-40206 kWh/yr) (Figure 9). Thus, the path to net zero has been accomplished. The negative EUI value indicates there is no consumption of energy by this building. In contrast, the building can produce additional energy through its PV panels. Figure 7 shows the yearly energy consumption per unit area for all the steps. In Step-7, the values found were 31.2 kWh/(m^{2}yr) compared to 3142 kWh/(m^{2}yr) in Step-1. Table 4 and Figure 8 present the amount of energy saving at each step.

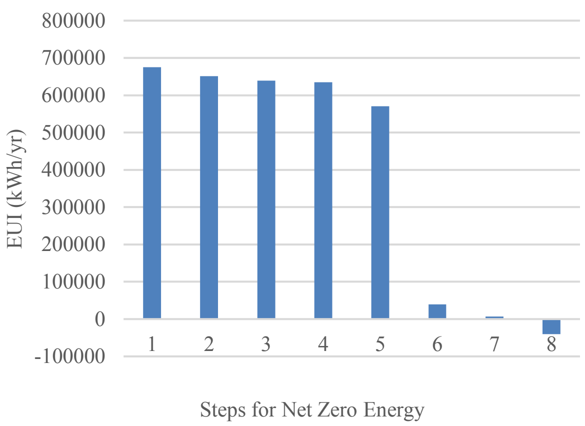


Figure 9: Graph of path to net zero history

The highest amount (530266 kWh/yr) of energy-saving occurred in Step-6. In this step, the air conditioning load which contributes a significant amount of energy consumption is omitted. If a passive cooling system is considered at the design stage, dependency on air conditioning can be reduced. The second highest energy saving is found at Step-5 and the third-highest saving at Step-7. Reducing the lighting load and providing plenty of natural light into the space through a skylight can contribute a significant amount of energy saving.

Table 4: Summary of the eight steps for path to net zero analysis

Steps for path to net zero	**Site EUI history [kWh/(m^{2}yr)]**	**Energy saving [kWh/yr]**	**Path to net zero history [kWh/yr]**
Step-1: Base case analysis	3142	0	675400
Step-2: Controlling window configurations	3032	24624	650776
Step-3: Providing natural ventilation	2983	11243	639533
Step-4: Controlling shading configuration	2963	4317	635216
Step-5: Reducing lighting loads	2674	65085	570131
Step-6: Reducing cooling loads	176.8	530266	39865
Step-7: Controlling skylight configurations	31.2	32830	7035
Step-8: PV panel incorporation	31.2	47241	- 40206

Conclusion

The global increase in demand for energy has generated pressure on saving energy. Consequently, energy-efficient buildings are an important factor related to the energy issue (Jahangir et al., 2014). This research conducts an optimization of energy performance and identifies the optimized value of nine design variables (WWR-North 40%, WWR-East 10%, WWR South 24%, WWR-West 10%, Shading-North 1.35m, Shading-East 1.58m, Shading-South 1.63m, Shading-West 1.55m and Skylight 10%). These features can be followed as strategies for designing sustainable RMG buildings in the context of Bangladesh. Thermal comfort analysis is also carried out in this research. Three options are explored for PMV and PPD analysis (the base case, energy-optimized option and energy-optimized with material changed option). Option 3 gave the best PMV and PPD results (-0.04 to 0.63 and 9.1% respectively). This research also conducts the path to net zero analysis with eight steps. The analysis showed that the yearly EUI value is decreased in kWh/yr in the following sequence: 675400, 650776, 639533, 635216, 570131, 39865, 7035 and finally -40206. The research recommends that the path to net zero analysis should be performed during the design stage of the building. Controlling window configurations, providing natural ventilation, controlling shading configurations, reducing the artificial lighting load, reducing the cooling load, controlling skylight configurations, and incorporating PV panels are suggested as strategies to design a zero energy RMG building in the context of Bangladesh.

Acknowledgement

This work is part of the project "Managing heat stress among Bangladesh ready-made clothing industry workers" funded by Wellcome under the Our Planet Our Health Programme. This work has been carried out in the Department of Architecture, BUET. The authors gratefully acknowledge the support and facilities provided by BUET.

References

Adinolfi, G., Graditi, G. and Scognamiglio, A. (2014). Smart photovoltaics in net zero energy buildings and clusters: a technological path towards the smart city. 29th European Photovoltaic Solar Energy Conference and Exhibition. 22 – 26, Sep 2014. Amsterdam, Niederland.

Aman, J., Tabassum, N., Hopfenblatt, J., Kim, J., B., and Haque, M., O. (2021). "Optimizing Container Housing Units for Informal Settlements- A Parametric Simulation and Visualization Workflow for Architectural Resilience." In 26th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA), Hong Kong.

Aman, J. (2017). Impact of windows for daylighting on thermal comfort in architecture design studios in Dhaka. A dissertation submitted to the Department of Architecture, Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh in partial fulfillment of the requirements for the degree of 'Masters of Architecture'.

Bojic, M., Patou-Parvedyb, A. and Boyer, H. (2012). Optimization of thermal comfort in building through envelope design. International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems, ECOS 2012, Perigia: Italy.

EAC. (2009). Energy Management Study on Abony Textile Limited and Abony Knitwear Limited, Hamayatpur, Savar, Dhaka. Energy Audit Cell, Ministry of Energy and Mineral Resources, BD.

Fang, Y. (2017). Optimization of Daylighting and Energy Performance Using Parametric Design, Simulation Modeling, and Genetic Algorithms. A dissertation submitted to the Graduate Faculty of North Carolina State University in partial fulfillment of the requirements for the degree of Ph.D. in Design.

Gligor, V. (2004). Luminous Environment and Productivity at Workplaces. Thesis (Licentiate). Espoo: Helsinki University of Technology.

Godiawala, P., Anand, N., and Patel, J.M. (2014). Sky lighting - A solution to reducing energy consumption in Apparel Sector. International Journal of Scientific and Research Publications, 4(4).

Hossain, M. and Ahmed, K. S. (2013). Illumination Conditions and Visual Comfort in Production Spaces of Ready-Made Garments Factories in Dhaka. IACSIT International Journal of Engineering and Technology, 5(5).

Hussain, M. (2018). Impact of thermal environment on occupational health at readymade garments buildings in Bangladesh. a thesis submitted to fulfill 'Masters of Architecture degree.

Gupta, M. (2017). A path towards net zero energy buildings. International Journal of Research in Engineering & Technology (IJRET). 5 (2): 5-14.

IFC. (2011). Ready-made Garments: Challenges in Implementing a Sector Strategy. Dhaka: Bangladesh International Finance Corporation.

Jahangir, A, Islam, M.A. and Biswas, B.K.. (2014). Energy simulation to estimate building energy consumption using EnergyPlus. International Conference on Mechanical, Industrial and Energy Engineering. Khulna, Bangladesh.

Joarder, M.A.R. and Iqbal, M.N. (2015). "Green Daylit Industry for Dhaka: An evaluation of Integrated Skylights and Solar Panels for RMG Factory Buildings". Proceedinsg of 48th the International Institute of Engineers and Researchers (IIER) International Conference, Spain, Barcelona, 11th December 2015:15-20.

Joarder, M.A.R., Hossain, M.M., Bach, A.J.E., Palutikof, J.P. and Tonmoy, F. (2022). "Optimization of Daylighting and Energy Performance in Bangladesh Ready-Made Garment Factories: Use of Parametric Design, Simulation Modeling, and Genetic Algorithms". 5th Building Simulation Applications Conference (BSA 2022), Bozen-Bolzano (South Tyrol, Italy) June, 29th – July, 1st 2022.

Kalmár, F. and Csiha, A. (2006). Interrelation between glazed surfaces, building structure and thermal comfort. The 23rd PLEA - The conference on Passive and low energy architecture, Geneva, Switzerland, 6-8 September.

Sayem, A., Ahmad, H. and Hayat, T. (2011). Indoor thermal condition of factory building in Bangladesh. Journal of Architecture and Built Environment. 38 (2): 55-62.

Tronchin, L., and Tarabusi,V. (2013). Energy Performance of Building and Thermal Comfort: a comparison. Recent Researches in Environmental and Geological Sciences. DIENCA – CIARM, University of Bologna, Italy.

Zohir, S.C. and Majumder, P. (2008). Garment Workers in Bangladesh: Economic, Social and Health Condition. Dhaka: Bangladesh Institute of Development Studies.