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Energy-Efficient Design Optimization of a Building Envelope using DOE-2

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Abstract: ***This paper focuses on various design parameters targeted to improve building considering numerous variable such as efficient energy measures, cost effective parameters, indoor & outdoor comfort, environmental problems based on seasonal variations etc. The reported data deals with various optimization parameters of the building envelope located at the GIET University campus, Gunupur, Odisha. The research focuses on optimal choices of cost, energy consumption and efficiency measures. The data analyzed provide qualitative information on optimal cost, energy efficiency solutions, renewable energy production onsite and energy saving potential. This work is intended for optimizing the energy performance of building using Energy Plus and Open studio which is a simulation-based optimization methodology which links the data related to the building optimization model targeting towards net zero energy building.***

Keywords: ***Building, Energy, Optimization, DOE-2, Energy plus***

I. INTRODUCTION

Creating energy efficient building is a challenging task and net zero energy refers to total energy produced is equal to energy consumed in that particular building on yearly basis[1]. These building overall contribute less green house gases compared to non zero energy buildings. Traditional buildings consume total 40% of the total fossil fuels in all over the world and are significant contributors of green house gases. The zero energy consumption principle is viewed as a means of reducing carbon emissions and reduction in the use of fossil fuels. High initial costs, particularly with respect to green buildings, discouraging Indian customers, and energy efficient and eco friendly appliances remain accessible only in moderately small quantity in the market. Indian architects too remain divided on both the necessity and economic feasibility of the idea. But wide research of these zones in building technology can be proved as more economical. This requires a systematic approach to balance energy efficiency and conservation against renewable energy generation. Several types of software's were used including Energy plus based simulation, Google sketch up and Open Studio. This optimized building provides comfortable indoor conditions with low energy consumption compared to regular home, cost optimization and environmental protection by reducing carbon emissions [2]. The proposed methodology identifies the various parameters.

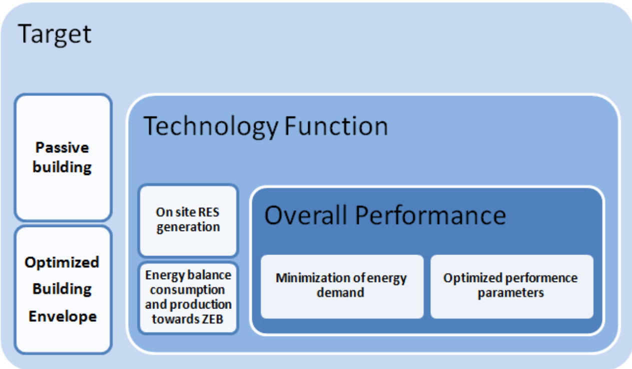

Figure 1: Building strategy

A. Heat transfer in building

- **Conduction:** The heat transfer rate by conduction can be expressed by the relation

$$Q = -kA\frac{\partial T}{\partial x}$$

Where:

Q: heat transfer rate.

T: temperature.

X: distance.

K: substantial thermal conduction

*A:*heat path zone.

- **Convection:** Transfer of heat occurs when a liquid/liquid flow touching a warm body in Convection process.

Newton's cooling law defines the impact of convection and is given by

$$Q = H\,A\,(T_S - T_\infty)$$

Where:

Q: heat transfer rate.

A: external zone.

T_S: partition (external) temperature.

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$T\infty$: liquid temperature.

H [W/m2.K]: convection heat transfer constant.

- **Contamination:**

Thermal contamination energy transported through the electromagnetic waves given by [1]

$$Qs = AI\Theta$$

Where
A= zone of the window in m^2
I = (W/m^2)heat flow contamination of sun density
Θ = beam contamination gain factor

II. OBJECTIVES OF THE PROPOSED SYSTEM

- To test the modeling approach, this study first carries out a virtual experiment of a building model in college campus, where it is possible to compare the outcomes of energy consumption from our reduced order model to the outcomes from a higher order simulation approach
- The proposed methodology uses a reduced order simulation approach to achieve a reliable and tractable dynamic modeling framework in a single platform taking in to consideration of various factors like Integration of renewable, HVAC design and optimization and energy simulation parameters [3].
- To evaluate variance of cost and energy efficiency measures of the project
- To compare optimized and initial parameters.

III. DESCRIPTION OF THE PROJECT SOFTWARE

Energy Plus is an optimization program specially designed to find the user selected designed parameters to minimize the objective function like peak energy demand and annual energy usage. It allows coupling of any simulation with text based I/O by modifying the configuration file without the requirement of modifications in code. This software has an open interface with the simulation program side and minimization algorithm side which runs either on GUI or as a console application. It can easily couple to the program like Open Studio. Energy plus software based on DOE 2 optimization. After modeling, the basic building block in the mentioned software in which we simulate the initial model tan into account by using the optimized algorithm where sequential approach is considered which takes a few minutes to evaluate the various building performance parameters. The derived mathematical model is to find effective and reduced energy consumption of building blocks like thermal analysis of windows, partitions, roof and ventilation system.

IV. CONCEPTS RELATED TO THE BUILDING OPTIMIZATION

For the work presented in this paper we used Energy Plus 9.0.1 which is an simulation based optimization tool developed by US Department of Energy's (DOE) Building Technologies Office. Energy Plus based DOE-2; a sequential search technique is used for optimal building design. The sequential search is based on various parameters like partition type, ceiling type, window glass type, roof substantial. The resulted optimum design will describe the values, which are chosen for the optimization criteria like energy demand (electricity consumption, heating, cooling,), comfort parameters validating the used optimization method laying a path towards Energy efficient Building. Losses related to heat in building envelope includes (roof ceiling, windows mounts and specific floor), as well as ventilation system.

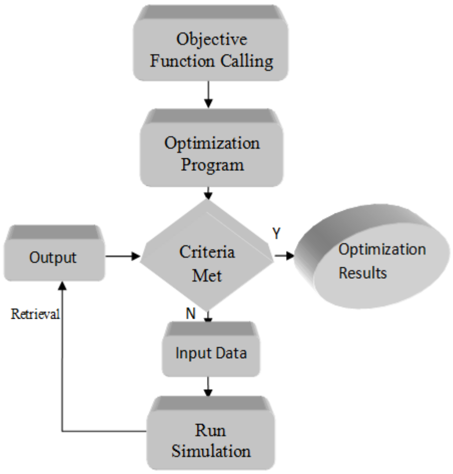

Figure 2 Optimization strategy

V. METHODOLOGY

The air circulation in the room, heat and mass transfer of the building is based on air circulation unit and air ducts which include [4]:

a. Heat transformation based on various parameters including the slab substantial, roof structure, thermal analysis of ceiling, partitions and windows.

b. Solar contamination transmission and conduction through window glazing.

c. Internal and external climatic condition with respect to the person's availability in the room and their body temperatures are considered.

d. Heat dissipation through the lightning equipment, occupants and other substantial's inside the room

Table I: Properties of window mount

Window mount	Thermal conductivity	Specific heat capacity [J/chg.]	Density [kg/m^3]
Steel	16	490	7820

A. Model of heat transfer through windows mount:

Energy balance equation is expressed as

$$P_{frame} C_{pframe} V_{frame} \frac{dT_{frame}}{dT} = \frac{1}{\frac{1}{h_{inside}} + \frac{l_{frame}}{2.k_{frame}}} A_{frame}(T_{indoor} - T_{frame}) -$$

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$$\frac{1}{\frac{1}{h_{outside}}+\frac{l_{frame}}{2.k_{frame}}}A_{frame}(T_{frmae}-T_{so,frame})$$

Where:

P_{frame}: density of mount [kg/m^3].

Cp_{frame}: specific heat capacity of mount [J/chg.].

V_{frame}: mount volume [m^3].

$T_{so,\,frame}$: mount solar air temperature [˚C]

By rewriting the above equation we get

$$T_{frame} = \int\{ \frac{1}{\frac{1}{h_{inside}}+\frac{l_{frame}}{2.K_{frame}}}A_{frame}(T_{indoor}-T_{frame}) - \frac{1}{\frac{1}{h_{outside}}+\frac{l_{frame}}{2.k_{frame}}}A_{frame}(T_{frame}-T_{so,frame}) \}P_{frame}.C_{P_{frame}}.V_{frame}$$

Building envelope heat transformation can be defined as

$$Q_{envelope} = \frac{1}{\frac{1}{h_{inside}}+\frac{l_1}{2.k_1}}A_1\,(T_1-T_{indoor}) + \frac{1}{\frac{1}{h_{inside}}+\frac{l_{frame}}{2.k_{frame}}}A_{frame}\,(T_{frame}-T_{indoor}) + \frac{1}{\frac{1}{h_{inside}}+\frac{l_{roof}}{2.k_{roof}}}A_{roof}\,(T_{roof}-T_{indoor})$$

H_{inside} [W/m^2.K]: constant of the heat transfer

l_1 [m]: first layer thickness

k_1 [W/make]: first layer inside thermal conduction

A_1 [m^2]: first layer zone

T_1 [˚C]: first layer temperature

L_{frame} [m]: window mount thickness

K_{frame} [W/make]:window mount thermal conduction

A_{frame} [m^2]: window mount zone

T_{frame} [˚C]: window mounts temperature

L_{roof} [m]: concrete first layers thickness

[w/m]: Concrete layer thermal conductivity

A_{roof} [m^2]: concrete layer zone referred to roof

T_{roof} [˚C]: first concrete layer under roof temperature

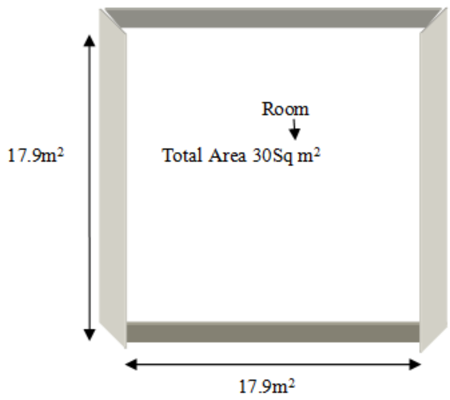

Figure 3 Roof Envelope

Dimensions of a virtual building envelope

Length=17.9m^2 and Breadth=17.9m^2

Zone= length × breadth given by 30m^2

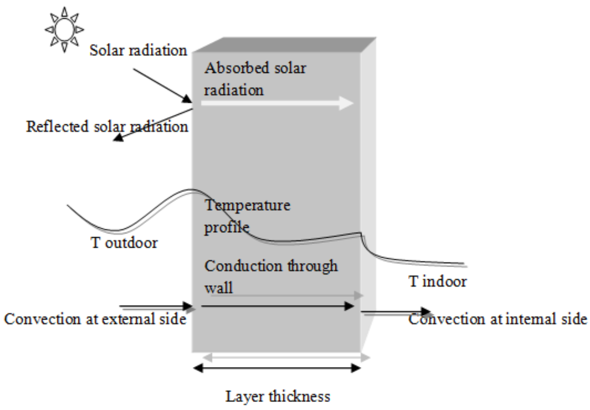

Figure 4 Heat transfer through external partition

B. Modeling transfer of heat through roof:

Roofs energy balance equation is expressed in terms of

$$P_{roof}.C_{P_{roof}}.V_{roof}.\frac{dT_{roof}}{dt} = \frac{1}{\frac{1}{h_{inside}}+\frac{l_{roof}}{2.K_{roof}}}A_{roof}(T_{indoor}-T_{roof}) - \frac{1}{\frac{1}{h_{outside}}+\frac{l_{roof}}{2.K_{roof}}}A_{roof}(T_{roof}-T_{out,roof})$$

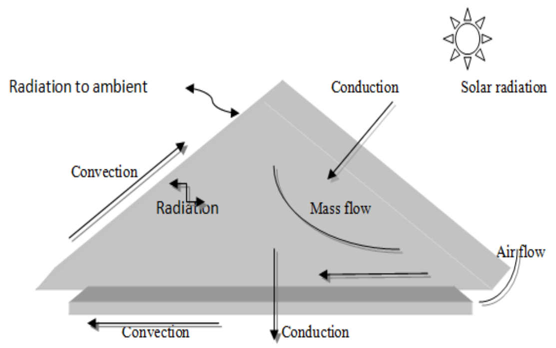

Figure 5 Heat transfer mechanism in the roof

Where:

P_{roof} [kg/m^3]: concrete layer density

Cp_{roof} [J/chg.]: specific heat capacity of concrete layer of roof.

V_{roof} [m^3]: volume of concrete layer of roof.

$T_{out,roof}$ [C]: roof temperature

By rewriting the mentioned equation, $Troof$ can be defined as

$$T_{roof} = \int \left(\frac{ \frac{1}{\frac{1}{h_{inside}} + \frac{l_{roof}}{2.K_{roof}}} A_{roof}\left(T_{indoor} - T_{roof}\right) - \frac{1}{\frac{1}{h_{outside}} + \frac{l_{roof}}{2.K_{roof}}} A_{roof}\left(T_{roof} - T_{so,roof}\right) }{ P_{roof} . C_{P_{roof}} . V_{roof} } \right)$$

VI. OPTIMIZATION METHODOLOGY

Energy Plus Software founded on DOE-2 software, customs for instance by orientation intended for thermal building energy simulations .DOE-2 simulates the heating and cooling loads and energy practice of samples/climate models. It replicas building heating, cooling, appliances, lighting and domestic hot water requests.DOE-2 building loads are basic and used in a sequential manner as input for energy supply systems. DOE-2 and Energy Plus simulation both compute the energy use of the building. Two commonly used building energy simulation engines, Energy Plus and DOE-2, can differ significantly in their controls of window heating load, heat transfer algorithms used in detailed window models of DOE -2 provide recommended changes to make the calculations more precise. We estimate that up to 82% of the observed differences can be resolved through the chosen optimization tool [5]. The DOE-2 model based on fenestration chapter of the 2006 ASHRAE Handbook. Energy Plus and DOE-2 use the same algorithm for the natural convection, but there are alterations in the calculation of forced convection. For building exteriors, the forced convection constant varies with the wind velocity near the surface [6]. In Energy Plus and DOE-2, the wind velocity near each surface is calculated from the weather station. In DOE-2, this near-surface wind velocity is used to calculate the forced convection constant for every surface except windows .The interior contamination algorithms in DOE-2 use basically dissimilar heat balance methods, and it is not practical to change DOE-2 to calculate the surface temperatures required to perform similar irradiative exchange calculations[7]. Energy Plus employs a method called “Script F” contamination matrix to estimate the net contamination exchange for each surface within that zone.

VII. RESULT AND DISCUSSION

	Area [m2]
Total Building Area	30.15
Net Conditioned Building Area	30.15
Unconditioned Building Area	0

Figure 6 Building Area

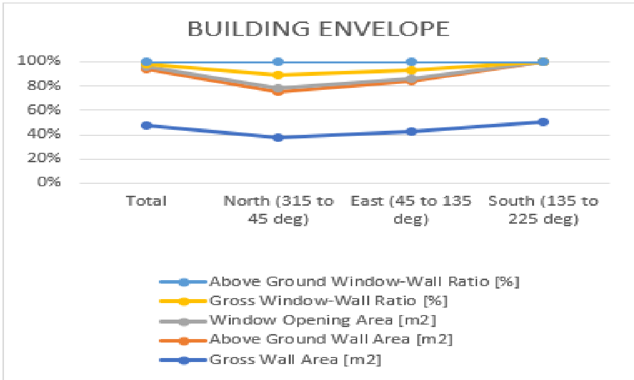

Figure 7 Building Envelope

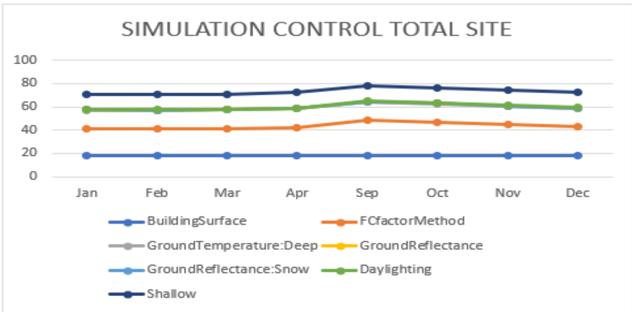

Figure 8 Control of Total site

	Location Name	Latitude {N+/S-Deg}	Longitude {E+/W-Deg}	Time Zone Number {GMT+/-}
1	Bhubaneshwar Orissa IND ISHRAE WMO#=429710	20.25	85.83	5.5

Figure 9 location data

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Report: Envelope SummaryC375:F396
For: **Entire Facility**
Timestamp: **2019-07-29 21:42:35**
Opaque Exterior

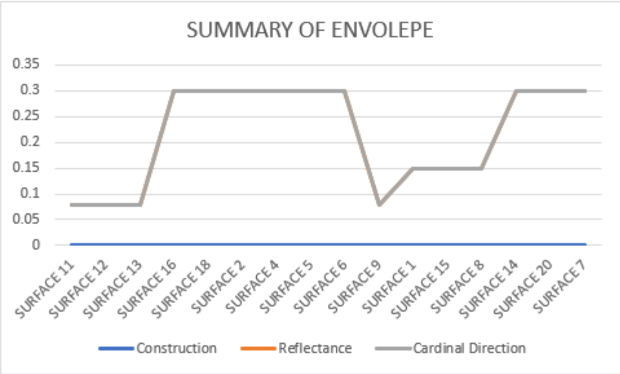

Figure 10 Envelope summary

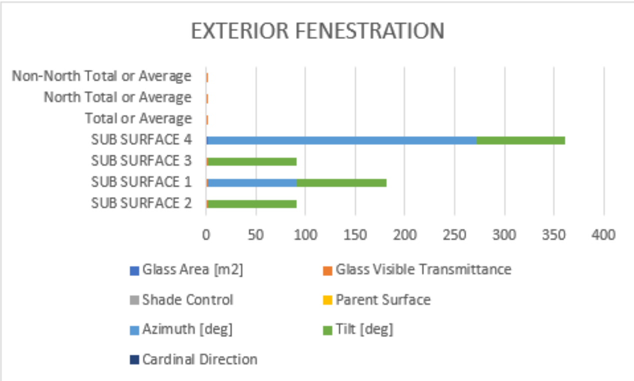

Figure 11 Envelope Fenestration

Report: **Object Count Summary**
For: **Entire Facility**
Timestamp: **2019-07-29 21:42:35**

	Total	Outdoors
Wall	10	10
Floor	3	3
Roof	3	3
Internal Mass	2	0
Window	4	4
Door	2	2

Figure 12 Object count

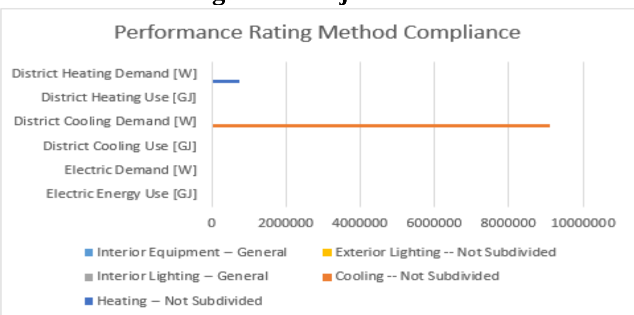

Figure 13 Performance rating

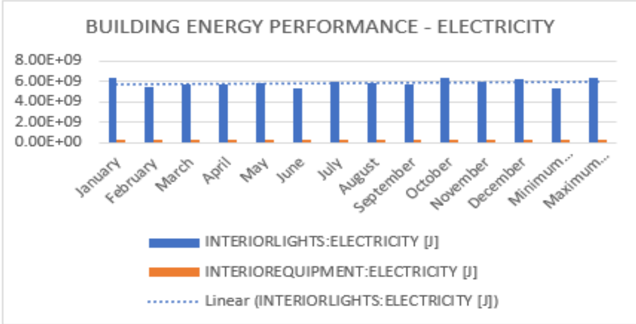

Figure 14 Building energy performance

Sizing Period Design Days

	Maximum Dry Bulb (F)	Daily Temperature Range (R)	Humidity Value	Humidity Type	Wind Speed (mph)	Wind Direction
BHUBNESHWAR ANN CLG .4% CONDNS DB=>MWB	101.3	17.1	79.7	Wetbulb [F]	11.86	180.0
BHUBNESHWAR ANN CLG .4% CONDNS DB=>MWB 1	101.3	17.1	79.7	Wetbulb [F]	11.86	180.0
BHUBNESHWAR ANN CLG .4% CONDNS DP=>MDB	88.34	17.1	82.94	Dewpoint [F]	11.86	180.0
BHUBNESHWAR ANN CLG .4% CONDNS DP=>MDB 1	88.34	17.1	82.94	Dewpoint [F]	11.86	180.0
BHUBNESHWAR ANN CLG .4% CONDNS ENTH=>MDB	94.28	17.1	41.7	Enthalpy [Btu/lb]	11.86	180.0
BHUBNESHWAR ANN CLG .4% CONDNS ENTH=>MDB 1	94.28	17.1	41.7	Enthalpy [Btu/lb]	11.86	180.0
BHUBNESHWAR ANN CLG .4% CONDNS WB=>MDB	93.2	17.1	84.74	Wetbulb [F]	11.86	180.0
BHUBNESHWAR ANN CLG .4% CONDNS WB=>MDB 1	93.2	17.1	84.74	Wetbulb [F]	11.86	180.0

Figure 15 weather data

Envelope

Base Surface Constructions

Construction	Net Area (ft^2)	Surface Count	R Value (ft^2*h*R/Btu)
ASHRAE 189.1-2009 ExtRoof IEAD ClimateZone 1	169	2	19.96
ASHRAE 189.1-2009 ExtRoof IEAD ClimateZone 2-5	156	1	24.73
ASHRAE 189.1-2009 ExtWall Mass ClimateZone 1	575	6	2.90
ASHRAE 189.1-2009 ExtWall Mass ClimateZone 4	433	4	11.08

Figure 16 envelope construction

Sub Surface Constructions

Construction	Area (ft^2)	Surface Count	U-Factor (Btu/ft^2*h*R)
ASHRAE 189.1-2009 ExtWindow ClimateZone 1	44	4	
Exterior Door	40	2	

WWR & Skylight Ratio

Description	Total (%)	North (%)	East (%)	South (%)	West (%)
Gross Window Wall Ratio	4.06	7.7	4.08	0.0	4.49
Gross Window-Wall Ratio (Conditioned)	4.06	7.7	4.08	0.0	4.49
Skylight-Roof Ratio	0.0				

Figure 17 dimension ratio

Space Type Breakdown

Space Type Breakdown - view table

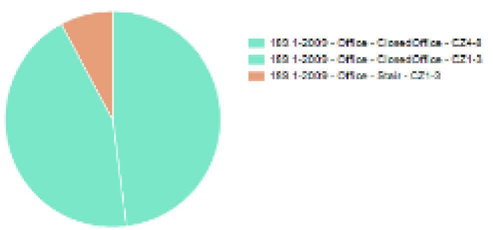

Figure 18 spaces

Temperature (Table values represent hours spent in each temperature range)

Zone	Unmet Htg (hr)	Unmet Htg - Occ (hr)	< 56 (F)	56-61 (F)	61-66 (F)	66-68 (F)	68-70 (F)	70-72 (F)	72-74 (F)	74-76 (F)	76-78 (F)	78-83 (F)	83-88 (F)	>= 88 (F)	Unmet Clg (hr)	Unmet Clg - Occ (hr)	Mean Temp (F)
NORMAL ROOM	0	0	0	1	47	68	375	343	391	4570	504	2461	0	0	0	0	75.9 (F)

Humidity (Table values represent hours spent in each Humidity range)

Zone	< 30 (%)	30-35 (%)	35-40 (%)	40-45 (%)	45-50 (%)	50-55 (%)	55-60 (%)	60-65 (%)	65-70 (%)	70-75 (%)	75-80 (%)	>= 80 (%)	Mean Relative Humidity (%)
NORMAL ROOM	4	12	60	205	288	319	362	601	740	736	822	4611	78.0 (%)

Figure 19 Zone Temperature

Schedule Overview

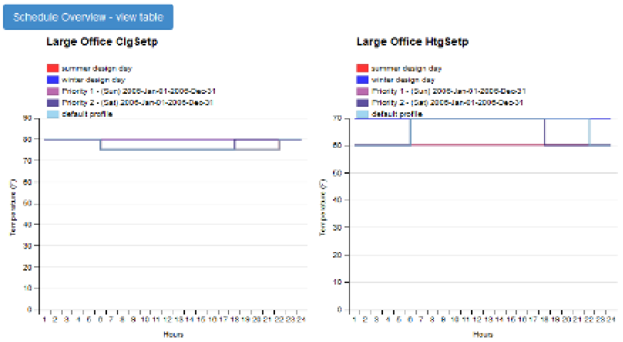

Figure 20 Designed Schedules

VIII. CONCLUSION

This Paper presents sequential search optimization method applied to a virtual building to establish characteristics of optimal building design laying path towards energy efficient building. The analyzed optimization results introduced a novel method that is able to implement the encapsulating concept through a holistic optimization process providing fast and detailed analysis on the building -Envelope and increase in the energy efficiency by various heat transfer modeling of buildings roof, window, HVAC system by using Energy plus.

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