# POLITECNICO DI MILANO

Faculty of Architecture, Urban Design and Building Construction

*Master of Science*

*in Building and Architectural Engineering*

# A machine learning based tool for heating needs forecasting in Campus Leonardo buildings

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# ABSTRACT

According to studies done by the IEA (International Energy Agency), buildings constitute to 40 percent of the total primary energy consumption around the world. The fact that 90 percent of our time (human beings) are spent indoors (schools, university, offices), it becomes imperative for us to look at the energy utilization of buildings in terms of efficiency and production. Hence, using the European energy signature as a benchmark and Politecnico Di Milano, Leonardo campus as a case study, we will be looking into the heating energy needs of different building applications. This study involves introducing an additional variable for analysis i.e solar irradiance (Wh/m$^2$) to the existing dry bulb temperature (°C) in the European energy signature. This improvement would help us understand how energy needs of buildings change with respect to Irradiance.With this in mind we have predicted future heating energy needs of the buildings taking different boundary conditions in mind. Here, it was realized that using this additional variable we have an obtained a co-efficient of determination of 0,95 which gives us the good insight of the model we have developed. This method of analysis being adaptable, makes it a good tool for future analysis and forecasting of heating energy needs in buildings.

# ACKNOWLEDGEMENT

I would like to thank my professors at Politecnico di Milano who gave me so much support to strive towards excellence. Professor Mario Motta and Professor Rossano with their experience and guidance have really helped me towards achieving such a level of research.

The support of my parents in the journey has been immense. My girlfriend Irene who I met in Milan has also been a sign of support through thick and thin.

The competitiveness in Politecnico di Milano has brought a side of me which makes me happy and very curious to learn more. I have also through my studies in Politecnico pushed myself to become a “Certified LEED green associate” and will be writing my “WELL AP” examination in the month of January. This drive to succeed and do more is all because of the atmosphere inculcated in me thanks to the professors and the university.

Hopefully if everything goes as planned, i will move forward to do a PhD in this topic in Politecnico di Milano in the future.

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# NOMENCLATURE

- T_ext – External Dry Bulb Temperature (°C)
- Irr – Solar Irradiance ($Wh/m^2$)
- Q_dot - Heat Transfer at The District Heating Substation (kWh)
- $R^2$ - Coefficient of Determination (-)

# 1 INTRODUCTION

As we know with the introduction of the Paris climate accord in 2015, all major economies in the world and countries have come to a common understanding that there is a serious need to reduce carbon emissions by controlling the amount of emission in terms of buildings and other $co_2$ emitting sources.

While we look at emitting sources, buildings account for 39% in the United States of America, which means the rest of the world also in the needs to reduce its carbon footprint to mitigate the problem of global warming and climate change which is damaging the world's supply chain and the ecosystem.

The world is loaded with so much information that we have a new phrase we use called "in the world of information overload". We have come to a stage where we need to start monitoring the information on various walks of life. With the understanding of the energy consumptions of buildings we can truly move towards more sustainable and economical design of machinery and energy systems to make emission less damaging. It is very difficult to understand that the world was introduced to the industrial revolution in the 19th century and the world was introduced to the world wide web in 1991. Even though we have so much information lying around we have never pushed ourselves to analyze our data more closely to understand the trend of energy consumption and to work towards a more sustainable future considering moderate design rather than peak design, which involves over producing heating and cooling needs that accounts for a very high carbon footprint for buildings.

We need to understand that office buildings and universities are spaces where maximum ages 6-60-year-old individuals spend most of their time in the year and we need to look at the situation very closely to make sure these places of occupancy are designed in the most efficient and sustainable method. To make this work we must make sure the energy for heating and cooling is supplied to building for maximum IEQ (indoor environment quality) which according to LEED design includes indoor air quality[1]. For this to be possible it is very necessary to investigate trends of energy consumption and high precision tracking of data must be made a very high priority.[2]

Looking at the need for this intervention, this study has investigated different methods of analysis. With the European Energy Standard[3][4], it has been possible to understand that there can be a linear relation between the energy demand of the building and the external dry-bulb temperature, which can be in-accurate. We need to understand that in commercial buildings and schools the occupancy time is the biggest factor of energy consumption in the building.

Looking at the aspect of single and multi-variable regression models, Mohammad Mottahendi and team [5][6] have highlighted that the shape and the orientation of the building can have a high impact on the analysis results. The study involved a linear regression between the energy consumption(kWh) and the design scenario of the building. To improve the accuracy of the analysis they also looked at other aspects which are highlighted in the table below.

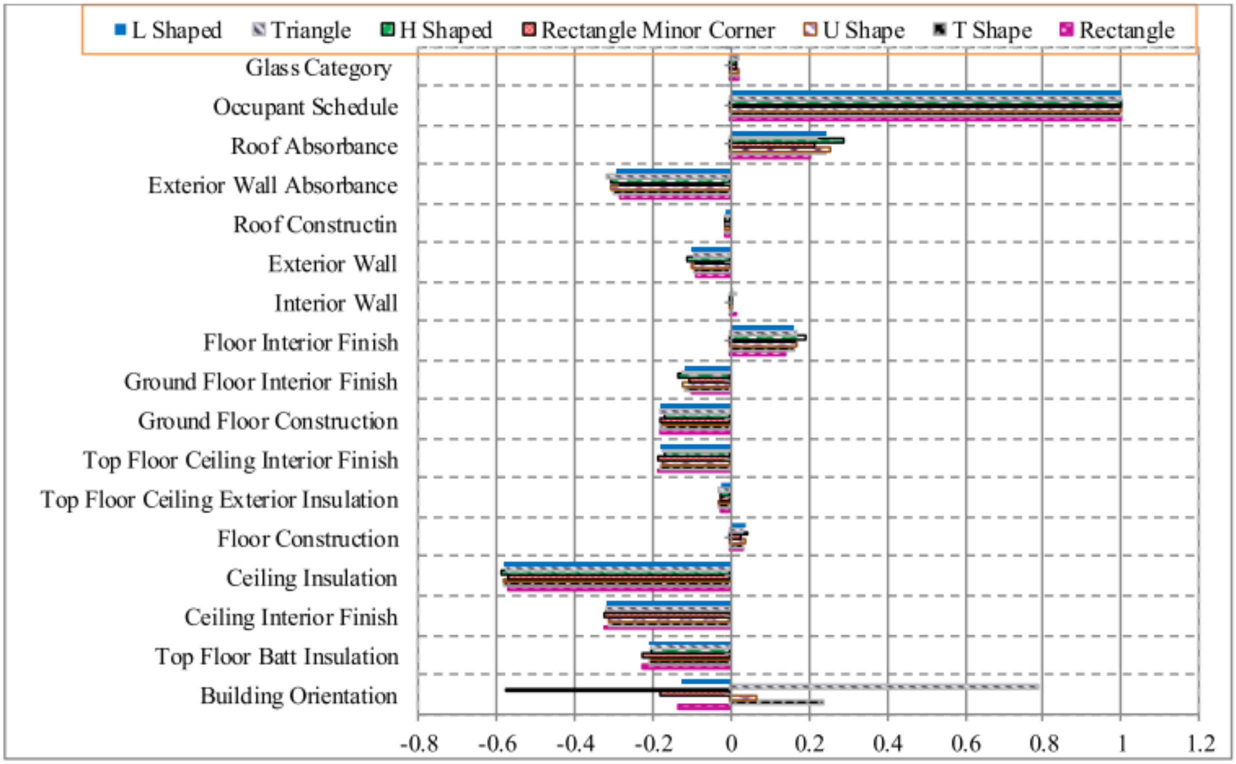


FIGURE 1 - EFFECT OF BUILDING PARAMETERS IN THE ANNUAL CONSUMPTION THE BUILDING[5]

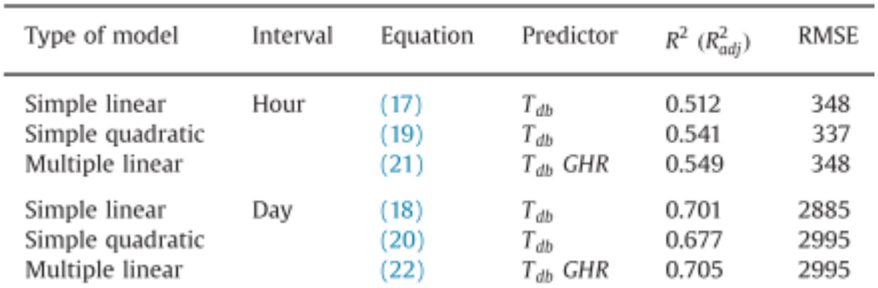
This method of analysis was done to improve the accuracy and sensitivity of the analysis. Through this analysis they envision an improved method of pre-design of buildings.

Looking ahead, it was investigated through this literature review done by Giovanni Tardioli which involved comparing various data driven methods to understand building energy consumption at the urban level as it involves high quantum of data [7]. He in this study has also identified that smart metering in buildings has improved the possibility of checking and assessing data. The study also talks about how data used in a timely fashion can improve the data tracking without reducing the integrity of the data. He has also compared the different approaches of the evaluation of data.

He talks about the white box-based approach which involves analysis of smaller stock of the building producing BEMs (building energy models) in detail, it also helps in deep energy conservation methods for deep retrofits.

He has looked at the grey box method of analysis which involves principles of physics and data driven approaches. Finally, he spoke about the black box method of analysis which is the method that has been adopted in this thesis which helps in predicting and forecasting the energy use. The popular methods that he has been highlighted are single regression, multi-regression models, decision trees and so on. The method adopted in analysis is completely based on the data available.

Moving ahead from the best methods to be used for black box analysis, Nelson Fumo using residential energy consumption as a source of data used regression analysis as a method [8][9]. He found that dry bulb temperature plays an important part in the residential energy consumption. In the study it is highlighted that time-steps chosen wisely can also determine the accuracy of the model. In this paper, he has again highlighted that smart metering in households could be a very good way forward to understand energy consumption. He in this study has looked at the aspect of how linear and multiple regression model's accuracy change with time-steps.[10]



| Type of model | Interval | Equation | Predictor | $R^2$ ($R^2_{adj}$) | RMSE |
|---|---|---|---|---|---|
| Simple linear | Hour | (17) | $T_{db}$ | 0.512 | 348 |
| Simple quadratic | | (19) | $T_{db}$ | 0.541 | 337 |
| Multiple linear | | (21) | $T_{db}$ $GHR$ | 0.549 | 348 |
| Simple linear | Day | (18) | $T_{db}$ | 0.701 | 2885 |
| Simple quadratic | | (20) | $T_{db}$ | 0.677 | 2995 |
| Multiple linear | | (22) | $T_{db}$ $GHR$ | 0.705 | 2995 |

FIGURE 2 - COMPARISON OF REGRESSION MODELS[8]

Based on the studies and takeaways from the bibliographic research done, the thesis will follow the following references as guidelines.

# 2 EUROPEAN ENERGY SIGNATURE

According to “*consumo energetico globale e definizione dei metodi di valutazione energetica*” (overall energy use and definition of energy ratings).

Energy assessment of buildings is done for the following reasons:

- compliance with respect to building regulations expressed in terms of a limitation of energy use or a related quantity;
- transparency in commercial operations through the energy certification and/or display of a level of energy performance (energy performance certification);
- monitoring of the energy efficiency of the building and its technical building systems;
- helping in planning retrofit measures, through prediction of energy savings which would result from various actions.

This standard specifies a general framework for the assessment of overall energy use of a building, and the calculation of energy ratings in terms of primary energy, co2 emissions or parameters defined by national energy policy. Separate standards calculate the energy use of services within a building (heating, cooling, hot water, ventilation, lighting) and produce results that are used here in combination to show overall energy use. This assessment is not limited to the building alone but considers the wider environmental impact of the energy supply chain.

Two principal types of energy ratings for buildings are proposed:

- calculated energy rating;
- measured energy rating.

The differences in the way these two ratings are obtained, they cannot be directly compared. However, the difference between the two ratings for the same building can be used to assess the cumulative effects of actual construction, systems and operating conditions versus standard ones and the contribution of energy uses not included in the calculated energy rating.

Heating and cooling energy use is correlated to climatic data over a suitable period. Plotting for several time periods the average heating or cooling power versus average external temperature allows a fast detection of malfunctions and provides useful information on the building energy performance.

This monitoring method assumes constant internal temperature, and that external temperature is the most influential parameter. It is useful in buildings with stable internal gains and relatively low passive solar gains.

Energy use for heating and cooling, as well as an average external temperature or accumulated temperature difference is recorded at regular intervals. These intervals can be as small as one hour, but for manual monitoring, a week is often used. The average external temperature can also be obtained from a neighboring meteorological station. Average power is obtained by dividing the energy use by the duration of the time interval between successive records.

The average energy demand (phi) is plotted versus the average external temperature or degree-days. For the heating season, lines are drawn through the dots measured during the heating season (heating on, cooling off), the cooling season (cooling on, heating off) and intermediate season (both off) using a linear regression.

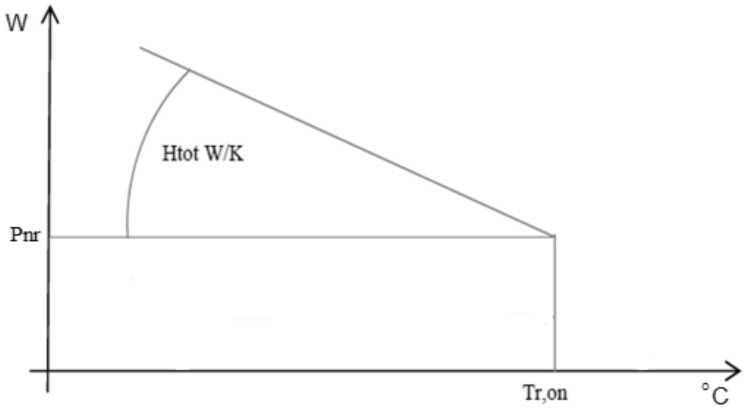


FIGURE 3 - ENERGY SIGNATURE X AXIS (T_EXT) (°C) VS Y AXIS (Q_DOT) (W)

- $\Phi$ is the average energy demand between two successive records.
- $\Phi_0$ energy demand at 0*c
- $\Phi_b$ base energy demand, not dependent on external temperature (e.g. For system loss and hot water)
- $\Theta_l$ heating limit external temperature
- $\Theta_e$ external average temperature between two successive records

The line drawn outside the heating (or cooling) season has in general a nearly-zero slope and represents the system loss and energy for services other than heating and cooling (e.g. Hot water). The line drawn during the heating (or cooling) season is characterized by an energy demand $\phi_0$ at 0°C and a slope h.

$$\Phi = \varphi_0 - h * \theta_e$$

- $\Phi$ is the average energy demand between two successive records.
- $\Theta_e$ external average temperature between two successive records
- $H = (\varphi_0 - \Phi_b)/\theta\_L$

But as highlighted above there is a constraint that this method is useful in buildings with stable internal gains and relatively low passive solar gains.

The main aim of this thesis is to develop a numerical relationship for the energy demand (kWh) to consider high solar gains (i) and other control variables which is considered in the building energy rate balance.

# 3 BUILDING ENERGY BALANCE

When we talk about buildings it is very important to understand the energy balance of the system to understand the effect of internal and external factors affecting the heating and cooling needs.[11]

The first consideration that is made is, the building is an open system which means the building is considered as a system in which mass or energy can be lost to or gained from the environment.

The hypothesis considered is:

$$\frac{dE_{cv}}{dt} = \sum \emptyset_X^{in} + \sum \Pi_{\mathrm{x}}^{1}$$

Where:

- $E_{cv}$ is the quantity x in a control volume per unit time 't'. [x/s]
- $\emptyset_X^{in}$ is sum of flows of the quantity x through the control surface.
- $\Pi_{\mathrm{x}}^{1}$ is the sum of production or consumptions of the quantity x inside the control volume.

So, when we consider our test case the building. The building gains and loses energy through its functioning and needs to be taken in account for analysis of the heating and cooling demands.

The energy is gained or lost by:

- Occupants in the building $q_{dot\_p}$.
- Heat transfer through the envelope by transmission ($q_{dot\_t}$)
- Heat transfer through openings by ventilation. ($q_{dot\_v}$)
- Heat gain by solar energy ($q_{dot\_sol}$)
- Heat gain by electrical equipment in the room ($q_{dot\_eqp}$)
- Heat gain by mechanical heating and cooling systems ($q_{dot\_app}$)

When we consider the control volume i.e the building and our hypothesis becomes:

$$\frac{dX_{cv}}{dt} = q_{dot\_p} + q_{dot\_t} + q_{dot\_v} + q_{dot\_sol} + q_{dot\_eqp} + q_{dot\_app}$$

But, the energy gained has two additional components, the sensible heat component and the latent heat component.

- $Q_{dot\_p}$ the occupants produce both latent and sensible heat
- $Q_{dot_}$v, $q_{dot\_eqp}$ ,$q_{dot\_app}$ also includes a latent component in terms of water vapor in addition to the sensible heat component

For further analysis we do consider a steady state condition where the building is assumed to be at its set point condition which assumes that $\frac{dX_{cv}}{dt}$ is 0.

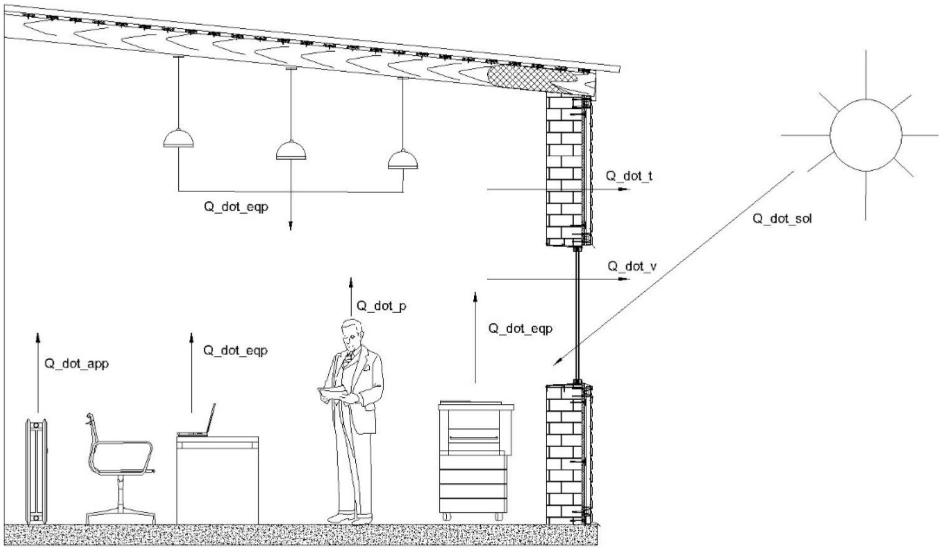


FIGURE 4 - SCHEMATICS OF THE ENERGY RATE BALANCE OF A TYPICAL ROOM CONSIDERING MAJOR EQUIPMENT.

The sign convention considered is (+) for the all the gains in the room and (-) for all the losses. Now, looking at the above equation the gains and loses can be sub-divided into sensible and latent gains/losses:

- $-\,q_{\mathbf{dot\_sensible}} = - q_{dot\_v\_sensible} + q_{dot\_p\_sensible} + q_{dot\_eqp\_sensible} - q_{dot\_t} - q_{dot\_sol}$
- $-\,q_{\mathbf{dot\_latent}} = - q_{dot\_v\_latent} + q_{dot\_p\_latent} + q_{dot\_eqp\_latent}$

With this following equation we try to understand the total $q_{dot\_eqp}$ which according the european energy standard is a linear regression between the $Q_{dot\_Eqp}$ (Energy Demand Of The Building(kWh)) and the $T_{ext}$ (External Dry Bulb Temperature (°C)).

This thesis will be looking into how the european energy standard can be improved by looking at other factors affecting the hvac system ($q_{dot\_app}$) in the building.

$Q_{dot\_app}$ is a combination of $q_{\_dot\_sensible}$ and $q_{\_dot\_latent}$. It will consider both the components. Based on these details the sizing and type of mechanical system will be determine.

# 4 SCOPE OF IMPROVEMENT

As highlighted in the introduction using the research done and the existing European energy signature method as a basic guideline, this study has pushed a little further by looking at the aspect of how the heating needs of the building can be affected by the solar irradiance as an additional variable. From this we can understand that, this thesis study will follow the method of multiple variable regression as compared to the approach carried out by the European energy standard method.[12]

When we look at the methodology carried in out in the residential buildings[8], the study was done to understand the energy consumption (electrical)of the residential building, which will be changed to the aspect of the heating energy needs here.

The study done based on the shapes of the buildings used as a parameter[5] in the study has been altered in terms of the application of the building in this thesis. The orientation of the building and application of the buildings has been used as a source of interpreting the data. The building under-consideration here are purely administrative building (building-1), classroom + offices (building-14), classrooms + libraries (building 11), classrooms + laboratories (building 5). The orientation of the buildings will also play an important role in data analysis process.

The black box method of analysis is used in this thesis because of the lack of data available. The main aim of this thesis is to develop a simplified and simple parametric equation for forecasting and predicting the future energy needs for the Leonardo campus of Politecnico di Milano.

# 5 METHODOLOGY

It was planned to use Un-Supervised Machine Learning (K-means Clustering) as a tool of analysis.

Unsupervised machine learning is typically tasked with finding relationships within data. There are no training examples used in this process. Instead, the system is given a set data and tasked with finding patterns and correlations therein.

K Means Algorithm represents each cluster by a single mean vector which is methodology used in this analysis. This method of analysis is called as clustering analysis. Cluster analysis or clustering is the task of grouping a set of objects in such a way that objects in the same group (called a cluster) are more similar (in some sense) to each other than to those in other groups (clusters). It is a main task of exploratory data mining and a common technique for statistical data analysis, used in many fields like in machine learning. Data mining is the process of discovering patterns in large data sets involving methods at the intersection of machine learning, statistics and data base systems.

Given a set of points, the k-medians algorithm attempts to create k disjoint cluster that minimize the following equation. This means that the center of each cluster center minimizes this objective function

$$Q\left(\{\pi_j\}_j^k\right) = \sum_{j=1}^{k} \sum \left\| x - c_j \right\|_1$$

This minimized by the geometric median

$$\arg\min(y \in R^n) \sum_{i=1}^{m} \left\| x_i - y \right\|_2$$

The k-medians approach to clustering data attempts to minimize the 1-norm distances between each point and its closest cluster center. This minimization of distances is obtained by setting the center of each cluster to be the median of all points in that cluster.

PCA (Principle component analysis), which is a statistical procedure that uses an orthogonal transformation$< u, v > = < Tu, Tv >$ to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components.

This transformation is defined in such a way that the first principal component has the largest possible variance (that is, accounts for as much of the variability in the data as possible), and each succeeding component in turn has the highest variance possible under the constraint that it is orthogonal to the preceding components. PCA is sensitive to the relative scaling of the original variables.

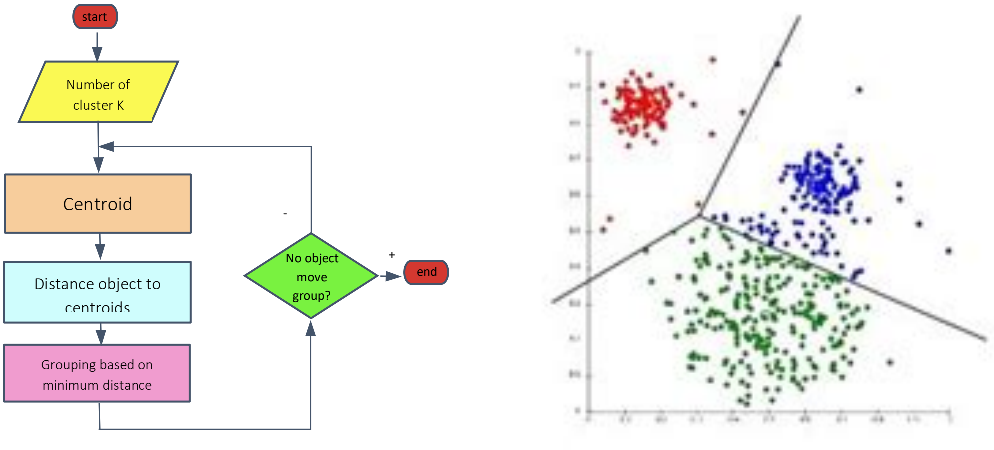


FIGURE 5 – K MEANS CLUSTERING PROCESS(SOURCE: HTTPS://WWW.LINKEDIN.COM/PULSE/FACEBOOK-GRAPH-DATA-ANALYSIS-POPULAR-FAN-PAGES-USING-KMEANS-ALI-KHAN)

The three-cluster formed during the linear analysis were

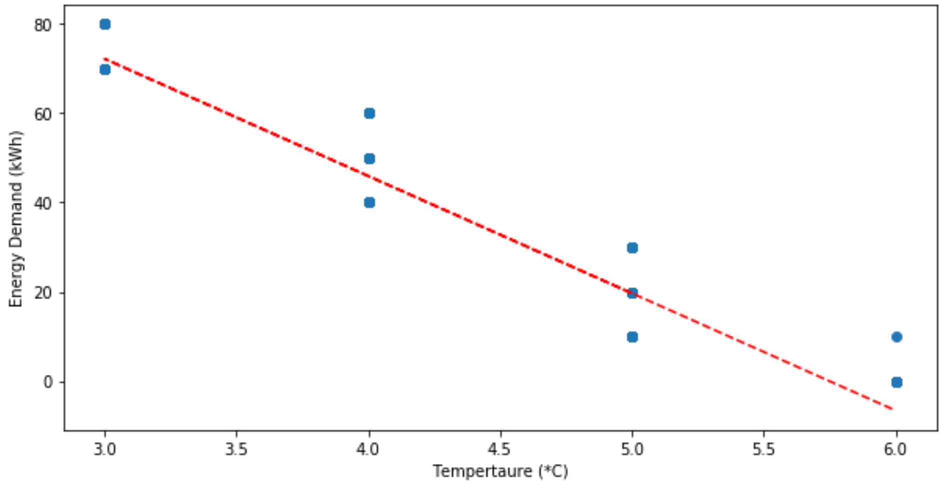


FIGURE 6 - CLUSTER 0

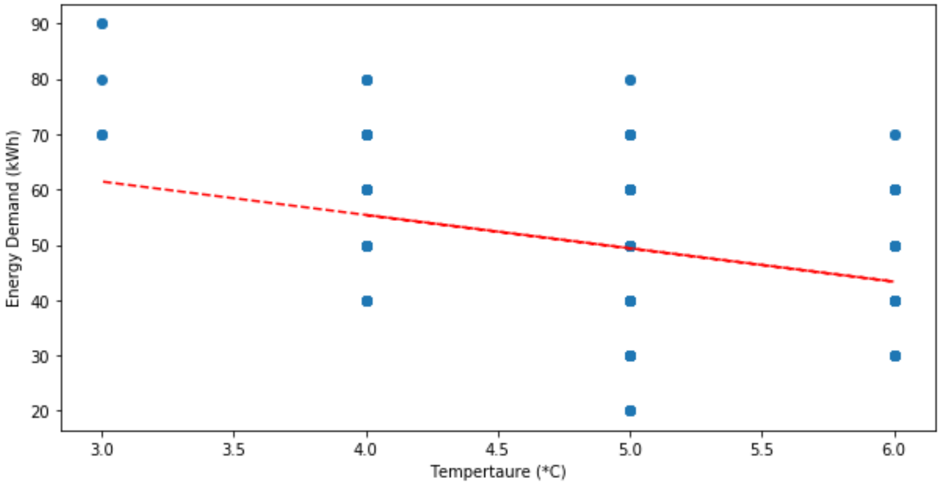


FIGURE 7 - CLUSTER 1

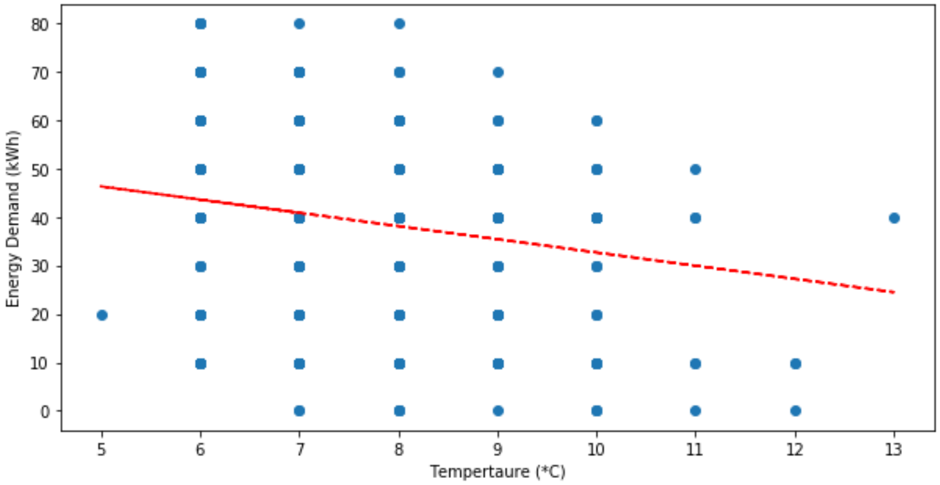


FIGURE 8 - CLUSTER 2

The sets of clusters above show no linear co-relation which is a reason why another method of analysis was adopted. The method adopted for further analysis was considering a supervised machine learning technique.

# MULTIPLE VARIABLE REGRESSION

The main purpose of the to look at the machine learning techniques was to understand how the European energy signature could be improved in terms of its accuracy. Since, the European energy signature mainly involved a linear regression model involving one dependent variable i.e. external dry-bulb temperature (®C) and the independent variable the heating energy need (kWh). But, in this study we have used a multiple regression model which involved two dependent variables i.e external dry bulb temperature (®C) and solar irradiance (Wh/m$^2$).

Below we will see, how this method of regression is adopted. The application used for data analysis is the curve fitting toolbox in matlab[13]. This method uses the least squares while data fitting.

This thesis study is making use of the supervised machine learning technique because it is very important to know on what basis and assumptions, the machine learning algorithm is functioning. But this is not the case in terms of un-supervised machine learning

When we look at the method used in the european energy signature method. The method used is a single variable linear regression model considering that, the heating energy needs of the building φ is completely dependent on only the $T_{ext}$ (external dry bulb temperature) as an independent variable.

To improve the machine learning technique, we will use a three-dimensional space considering that energy demand φ is dependent on two or more independent variables.

The hypothesis considered in this method

$$h_\theta(x) = \theta^T * x = \theta_0 * x_0 + \theta_1 * x_1 + \theta_2 * x_2 \dots\dots\dots\dots \theta_n * x_n$$

Where:

- $h_\theta(x)$ is the dependent variable
- $x_1$ $x_2$ $x_n$ are the independent variables used to determine $h_\theta(x)$.
- $x_0 = 1$
- $\theta_1$ $\theta_2$ $\theta_3$ $\theta_4$ are the parameters
- m number of independent variables

Since $(n \geq 1)$:

$$J(\theta) = \frac{1}{2m} * \sum_{i=1}^{m} (h_\theta(x^i) - y^i)^\wedge 2$$

Where:

- $J(\theta)$ is the least square distance to determine the $\theta_0$ $\theta_1$ $\theta_2$ also known as the cost function.

After calculating the cost function, we will calculate $\theta_0$ $\theta_1$ $\theta_2$ using the method gradient decent.[14]

The algorithm used will be:

This will be repeated (simultaneously updating $\theta_j$ for j = 0,1,2 …n)

$$\theta_j = \theta_j - \alpha \frac{1}{m} * \sum_{i=1}^{m} (h_\theta(x^i) - y^i) x^i$$

The interpretation of the above equation will be:

$$\theta_0 = \theta_0 - \alpha \frac{1}{m} * \sum_{i=1}^{m} (h_\theta(x^i) - y^i) * x_0^i$$

$$\theta_1 = \theta_1 - \alpha \frac{1}{m} * \sum_{i=1}^{m} (h_\theta(x^i) - y^i) * x_1^i$$

$$\theta_2 = \theta_2 - \alpha \frac{1}{m} * \sum_{i=1}^{m} (h_\theta(x^i) - y^i) * x_2^i$$

Here:

- $\alpha$ is defined as the learning rate of the algorithm

Gradient decent can be defined as a first-order optimization algorithm. To find a local minimum of a function using gradient descent, one takes steps proportional to the negative of the gradient (or of the approximate gradient) of the function at the current point.

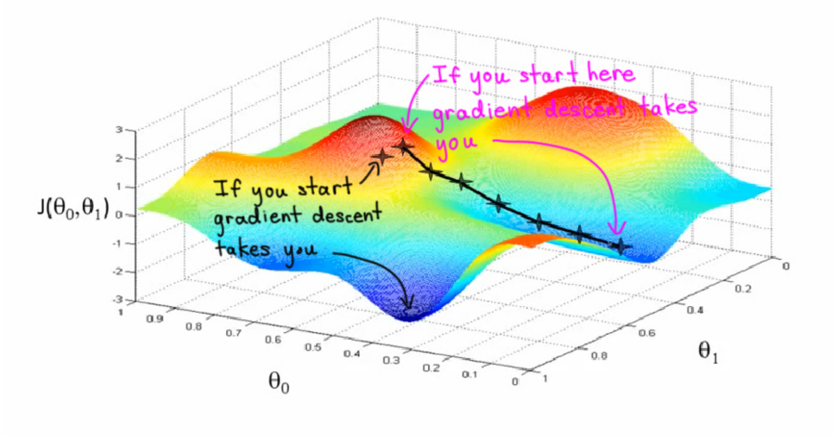


FIGURE 9 - GRADIENT DECENT METHODOLOGY. (IMAGE COURTESY OF ANDREW NG)

A cost function is a mathematical formula used to use to chart how a mathematical function will change at different output levels. In other words, it estimates the total production given a specific quantity produced.

But, for this algorithm to work efficiently it is very important to understand that the order of magnitude of the dependent and independent variables should be well defined before the algorithm is executed.

The method used in the **thesis to feature scale** is mean normalization method which is done by:

$$\mathrm{X_n} = (\mathrm{X_n} - \mathrm{M_n})/\mathrm{S_n}$$

Where:

- $x_n$ is the dependent or independent variable taken in consideration
- $\mu_n$ is the average value of $x_n$
- $s_n$ is the standard deviation of the data-set.
- $0.5 \leq x_n \leq -0.5$ , $-0.5 \leq x_n \leq 0.5$

**Feature scaling** is a method used to standardize the range of independent variables or features of data. In data processing, it is also known as data normalization and is generally performed during the data preprocessing step.

## Correlation co-efficient (calculation method)

Step 1: the elements in the data set are converted to standard units.

Step 2: call the results $x_i^*$, $y_i^*$, $z_i^*$ to do this for x, subtract the mean of x from each x value, then divide each deviation by the standard deviation. About 95% of the resulting values will lie between -2 and 2. The mean of the new variable, x*, will be zero, and the standard deviation will be 1.

Step 3: multiply corresponding values of the standardized $x_i^*$, $y_i^*$, $z_i^*$….

Step 4: the average of the products computed in step 3. That is the correlation.

When there is high variance along x axis with respect to y:

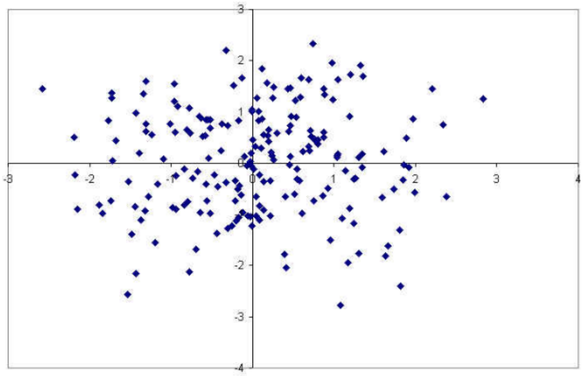


FIGURE 10 -VERY LOW CO-RELATION

When there is moderate variance along x axis with respect to y:

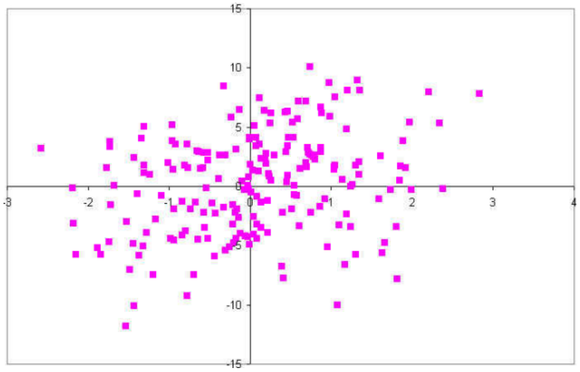


FIGURE 11 - MODERATE CO-RELATION

When there is low variance along x axis with respect to y:

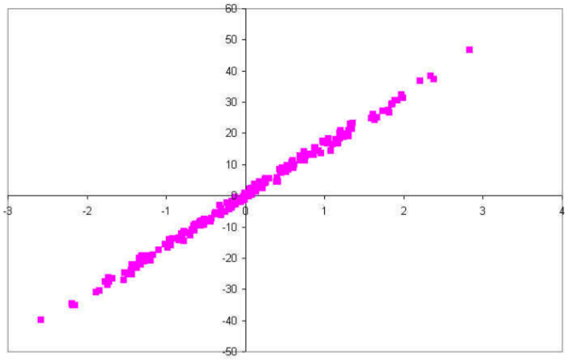


FIGURE 12 - HIGH CO-RELATION

Based on the methodology stated above, the data which needs to be trained and analysed are uploaded on the curvefitting toolbox. The next section will highlight how the data is trained and interpreted.

# ANALYSIS STEPS

The following methodology was carried to make sure all the data provided by “Commissione Energia” (Milano, n.d.) is exported onto excel for further analysis.

The step carried out are as follows.

- The data is collected from the data base, i.e external temperature(t_ext)(°C), solar irradiance(irr) (Wh/m2), energy demand of the building(kWh).
- The data-base has expressed the data as
  - Rad_deng – irradiance – y
  - Trg_g_tmpesterna_tt919 – external temperature – x
  - Sct_building number_misprimario_energia- energy demand – z
- The data for the above is available in different time steps, hence when the evaluation is done, a daily time-step is considered.
- once the data is collected, a compilation of data is done group the three variables.
- The data exported from the online portal is for heating season of 2016-17 and 2017-18, the heating season considered is 1st November 2016 to 25th March 2017 and 1st Novemeber 2017 to 25th March 2018.

| Duration | T_ext (*c) | Irr (Wh/m$^2$) | Q_dot (kWh) |
|---|---|---|---|
| Wednesday, November 1, 2017 | 10.01 | 875.98 | 80.00 |
| Thursday, November 2, 2017 | 11.13 | 978.34 | 1270.00 |
| Friday, November 3, 2017 | 12.07 | 836.98 | 1610.00 |

TABLE 1 - EXAMPLE OF DATA COMPILATION OF MICROSOFT EXCEL

- The data once compiled will be analyzed on MATLAB 2019 by converting the table into arrays using a simple code to separate the for individual analysis.

```
A=table2array(vs2018allcalculationss24)
X_bui5_new_temp_17_18 = a(:,1);
Y_bui5_new_irr_17_18= a(:,2);
Z_bui5_new_qdot_17_18 = a(:,3);
```

- The array is then used in an application of matlab 2019 called the curved filling tool where the data is inserted into a 3-dimension data drop box.

- The main aim of doing two seasons is to understand if a prediction done in 2016-17 is close to the values of 2017-18, which will be a good barometer to understand if the hypothesis considered is successful or not for forecasting energy demand.

With the initial study done taking all data into consideration, it is important to understand the redundancies in the model.

The following steps were taken to improve the models:

- Removing q_dot (kwh) values which are related to weekends.
- Eliminating q_dot(kwh) when the system is off.
- Using the q_dot (kwh) values between 0600 to 1800hrs as the working hours of the system, which corresponds to the peak working hours of the buildings under consideration.
- Understanding the days of inactivity (holidays and low heating(q_dot) values) of the sub-station.

# 6 CAMPUS LEONARDO DISTRICT HEATING SYSTEM

## 6.1 GENERAL DESCRIPTION

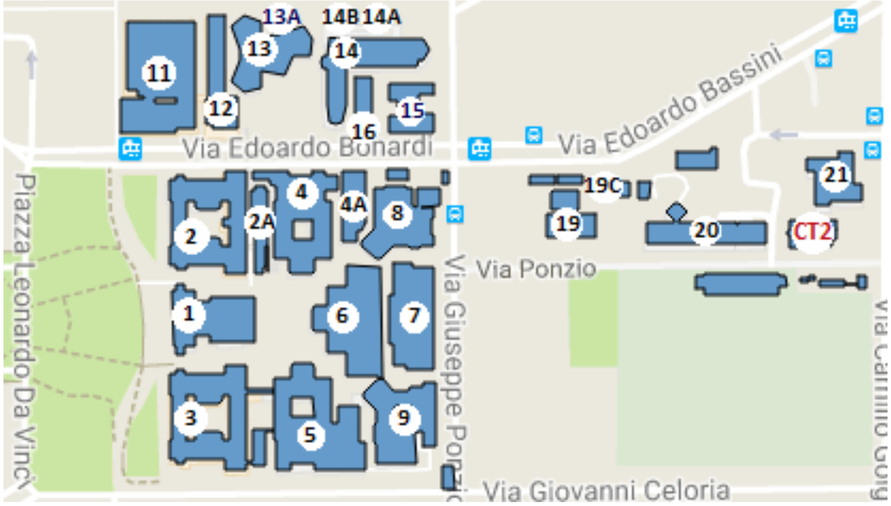


FIGURE 13 - LAYOUT OF POLITECNICO DI MILANO

Based on the layout of the substation, in the analysis, it was realised that orienatation and application of the buildings would play an important part in the process of forecasting future energy needs of the buildings. The application of the buildings have played a major role in determining the change in correlation.

The general details of the buildings in Politecnico Di Milano are as follows:

| S.No | Building No | Locality | Campus | Net. Contact Surface (m$^2$) | Heated volume (m$^3$) |
|---|---|---|---|---|---|
| 1 | Edificio 1 | Milano | Piazza Leonardo da Vinci 32 | 6768 | 48.52 |
| 2 | Edificio 2 | Milano | Piazza Leonardo da Vinci 32 | 10380 | 39.56 |
| 3 | Edificio 2A | Milano | Piazza Leonardo da Vinci 32 | 2299 | 4.29 |
| 4 | Edificio 3 | Milano | Piazza Leonardo da Vinci 32 | 10532 | 37.783 |
| 5 | Edificio 4 | Milano | Piazza Leonardo da Vinci 32 | 7875 | 33.143 |
| 6 | Edificio 4A | Milano | Piazza Leonardo da Vinci 32 | 2709 | 20.803 |
| 7 | Edificio 5 | Milano | Piazza Leonardo da Vinci 32 | 9842 | 44.369 |
| 8 | Edificio 6 | Milano | Piazza Leonardo da Vinci 32 | 8505 | 45.426 |
| 9 | Edificio 7 | Milano | Piazza Leonardo da Vinci 32 | 4855 | 30.109 |

| | | | | | |
|---|---|---|---|---|---|
| 10 | Edificio 8 | Milano | Piazza Leonardo da Vinci 32 | 5300 | 44.975 |
| 11 | Edificio 9 | Milano | Piazza Leonardo da Vinci 32 | 5820 | 29.672 |
| 12 | Edificio 9A | Milano | Piazza Leonardo da Vinci 32 | 92 | 0.392 |
| 13 | Edificio 10 | Milano | Piazza Leonardo da Vinci 32 | 74 | 0.325 |
| 14 | Edificio CT1 | Milano | Piazza Leonardo da Vinci 32 | 105 | |
| | | | Total | 75156 | 379.367 |

| S.No | Building No | Locality | Campus | Net. Contact Surface ($m^2$) | Heated volume ($m^3$) |
|---|---|---|---|---|---|
| 15 | Edificio 11 | Milano | Via Bonardi | 14350 | 55.405 |
| 16 | Edificio 12 | Milano | Via Bonardi | 5500 | 23.386 |
| 17 | Edificio 13 | Milano | Via Bonardi | 5045 | 31.615 |
| 18 | Edificio 13A | Milano | Via Bonardi | 480 | 2.013 |
| 19 | Edificio 14 | Milano | Via Bonardi | 13482 | 76.188 |
| 20 | Edificio 14A | Milano | Via Bonardi | 816 | 7.788 |
| 21 | Edificio 14B | Milano | Via Bonardi | 579 | 2.468 |
| 22 | Edificio 15 | Milano | Via Bonardi | 3261 | 10.666 |
| 23 | Edificio 16 | Milano | Via Bonardi | 839 | 4.648 |
| 24 | Edificio 18 | Milano | Via Bonardi | 182 | 0.841 |
| | | | Total | 44534 | 215.018 |

TABLE 2 - GENERAL DETAILS OF BUILDINGS IN POLITECNICO DI MILANO (LEONARDO CAMPUS)

Looking at the aspect of the generation sub-system, the combined heat and power plant is used in Politecnico Di Milano. Generation of electricity and useful heat jointly, especially the utilization of the steam left over from electricity generation for heating.

Cogeneration is a more efficient use of fuel because otherwise wasted heat from electricity generation is put to some productive use.

Combined heat and power (chp)[15] plants recover otherwise wasted thermalenergy for heating. The cogeneration system is usuallydesigned for base load. Additional load is supplemented by using boilers.

## DETAILS AND SPECIFICATIONS [16]

FIGURE 14 - JENBACHER TYPE 6 GAS ENGINE

## ENGINE SPECIFICATION

- Fuel – natural gas
- Engine type – 1 x j612
- Electrical output – 1457 kW
- Thermal output – 1536 kW

## TECHNICAL FEATURES

- Four valve cylinder head
- Heat recovery - flexible arrangement of heat exchanger, two stage oil plate heat exchangers on demand
- Air / fuel mixture charging - fuel gas and combustion air are mixed at low pressure before entering the turbocharger
- Pre-combustion chamber, the ignition energy of the spark plug is amplified in the pre-combustion chamber.

## 6.2 ANALYSED BUILDINGS

Looking at the aspects highlighted in the tables, the study has taken orientation and application as a benchmark for building analysis.

Looking at the aspect of orientation and application, building 1, building 5, building 11 and building 14 were chosen. The diversity in application will be a good gateway to understand how the corelation changes.

The buildings taken in to consideration are as specified and described in the following pages.

## 6.2.1 BUILDING 1

FIGURE 15 - BUILDING 1 - POLITECNICO DI MILANO (COURTESY GOOGLE)

- Orientation – West facing
- Envelope Surface – 6768 $m^2$

**Edificio 1 (Main Administration Building)** – largely involved with the administration of the leonardo campus. The occupancy mainly involves offices and reduced density of human occupancy and movement. This building will be a contrast with other buildings when internal gains, internal and external conduction are taken into consideration.

## 6.2.2 BUILDING 5

FIGURE 16 - BUILDING 5 (COURTESY GOOGLE MAPS)

- Classrooms orientations – North and West
- Envelope Surface – 9842 m$^2$

**Edificio 5 (Class-rooms and Civil and Structural lab)** – this building hosts students for classes and studios. But, in the underground area a wide range of activities involving labs and experimental areas where research is done. Since, there is such a diversity in function of the building it was very interesting to study how the energy demand would be as compared to the other building in consideration.

### 6.2.3 BUILDING 11

FIGURE 17 - BUILDING 11 ARCHITECTURAL BUILDING (COURTESY GOOGLE MAPS)

- Classrooms orientations – North and West
- Library - South
- Envelope Surface – 14350 m$^2$

**Edificio 11 (Main Architecture building)** – combined with classrooms and the architecture library, since there are large corridors and large working spaces, there is a high quantity of internal conduction and convection through the doors, relatively high amount of natural ventilation which will make the primary energy demand (sub-district energy demand) relatively high in winter. To maintain the ambient temperature in the library taking in account the air changes per hour will make this study very interesting.

### 6.2.4 BUILDING 14

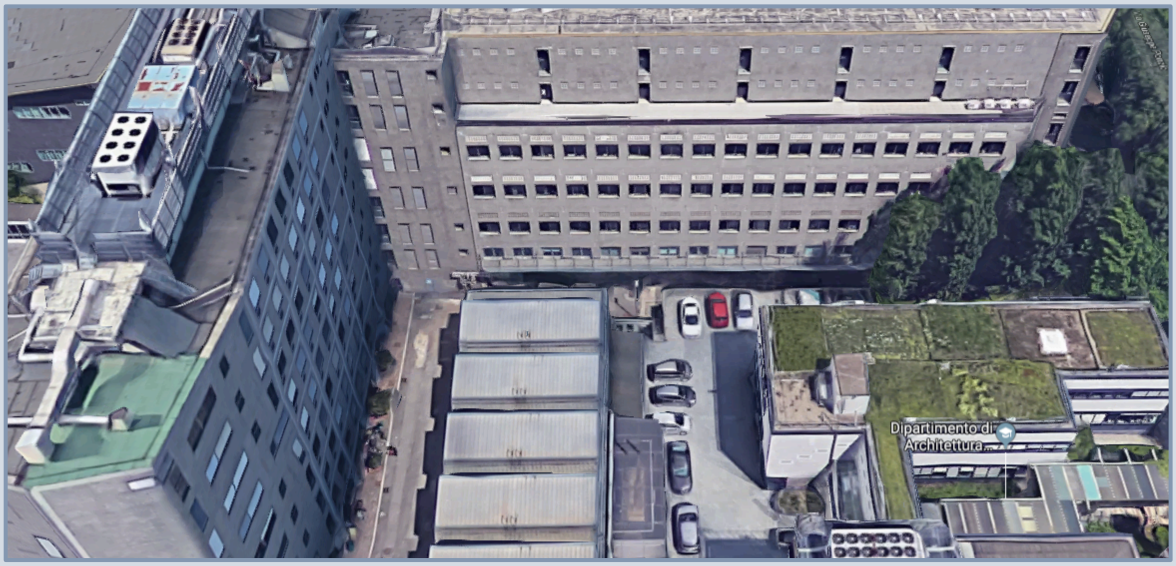


FIGURE 18 - BUILDING 14 NAVE (COURTESY GOOGLE EARTH)

- Offices orientation – west
- Classrooms orientations – north
- Corridors – south
- Envelope Surface – 13482 $m^2$

**<u>Edificio 14 (Nave)</u>** – a combination of offices and classrooms. The study done on this building will very effective as we will understand the effect of high internal gains and relatively high ventilation rate in the in the classrooms. The ventilation rate and the internal gains will make the analysis interesting.

# 7 ANALYSIS AND RESULTS

Here we look at the aspect how the Temperature and Solar Irrdaiance changes, when we look at the time period of 2016-17 and 2017-18. It is important to look at this aspect because change in these two variables can considerabily change the correlation between the heat transfer at the district substation and the dependent variables i.e external dry bulb temperature and solar irradaiance.

Through this analysis we will see how the correlation and the coefficient of dertermination changes with respect to the application of the building. The time-step taken into consideration in this section is a daily time-step. The analysis has also looked at how the working hours in the building (06:00 to 18:00 hrs) determines the functioning of the system. There is a comparison done based on the heating cycle with and without holidays and weekends.

## 7.1 TEMPERATURE ANALYSIS

- T_ext_2016-17 – external dry bulb temperature for the heating season of 2016-17
- T_ext_2017-18 – external dry bulb temperature for the heating season of 2017-18

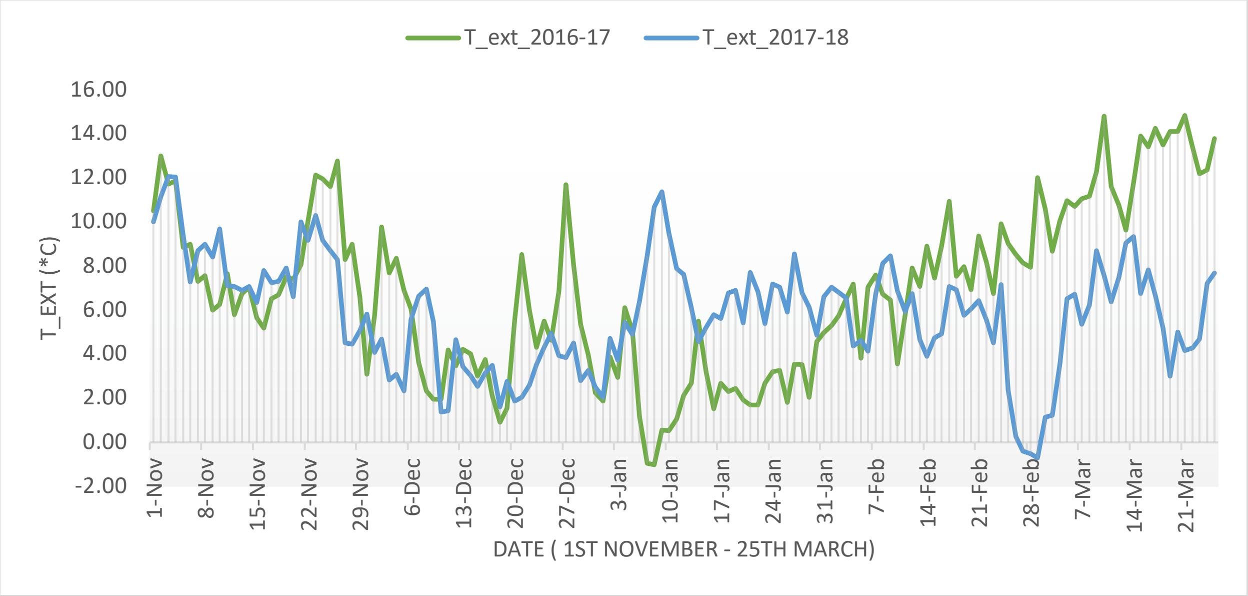


FIGURE 19 - TEMPERATURE ANALYSIS (2016-17 VS 2017-18)

As depicted in the graphical representation for the heating periods of 2016-17 and 2017-18 for the city of Milano, there seems to be a very high deviation in months of January and February. There is a divergence in temperature in the month of march which means there is a reason of investigation because it would create a change in the perception of the design of the model in terms of the $r^2$.

## 7.2 IRRADIATION ANALYSIS

- Irr_2016-17 – the solar irradiance (direct solar radiation) in 2016-17 (wh/$m^2$)
- Irr_typical – the solar irradiance (direct solar radiation) for the typical season (wh/$m^2$)
- Irr_2017-18 – the solar irradiance (direct solar radiation) in 2017-18 (wh/$m^2$)

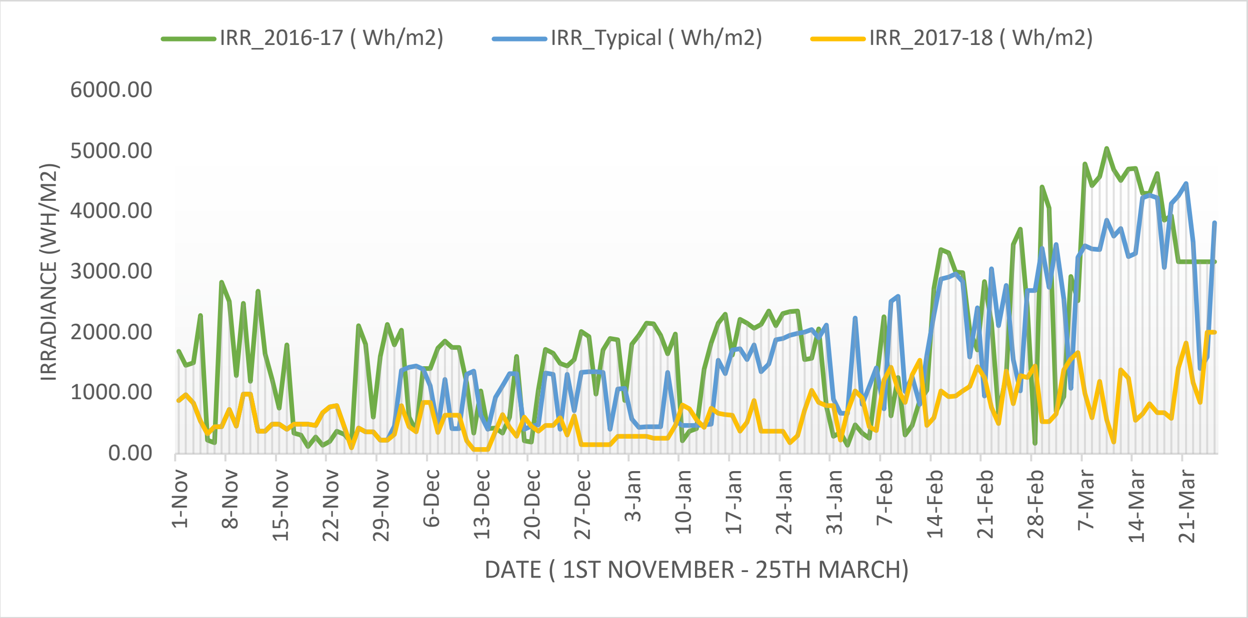


FIGURE 20 - ANALYSIS OF THE SOLAR IRRADIANCE (2016-17 VS TYPICAL VS 2017-18)

As per data depicted for the city of Milano above , it is understood that the total daily irradiance received by the sensor shows a higher intensity in the 2016-17 as compared to the 2017-18. This will also play a pivotal role in determining the effectiveness and the accuracy of the model.

The typical irradiance (wh/m2) was introduced to understand the how the trend of the irradiance changes in a typical year. Since there was a large change in the 2016-17 and 2017-18, there was a requirement to check the accuracy of the calculation.

## 7.3 CORRELATION ANALYSIS BETWEEN TEMPERATURE (ºC), SOLAR IRRADIANCE (WH/M2) AND HEAT TRANSFER AT THE DISTRICT HEATING SUBSTATION (KWH)

### 7.3.1 CONSIDERING ALL DAYS OF THE WEEK AS A TIME-STEP

- X axis - T_ext – external dry bulb temperature (°C)
- Y axis – Irr – solar irradiance (Wh/m2)
- Z axis - q_dot – heat transfer at the district heating substation (kWh)

#### 7.3.1.1. BUILDING 1 (2016-17)

This study involved understanding how the heating demand of the building (kwh) in relation with the exterior dry bulb temperature(*c) and the solar irradiance (w.h/$m^2$). Through this analysis it is found that there is a reduced $r^2$ = 0.66 which is depicted in the figure below

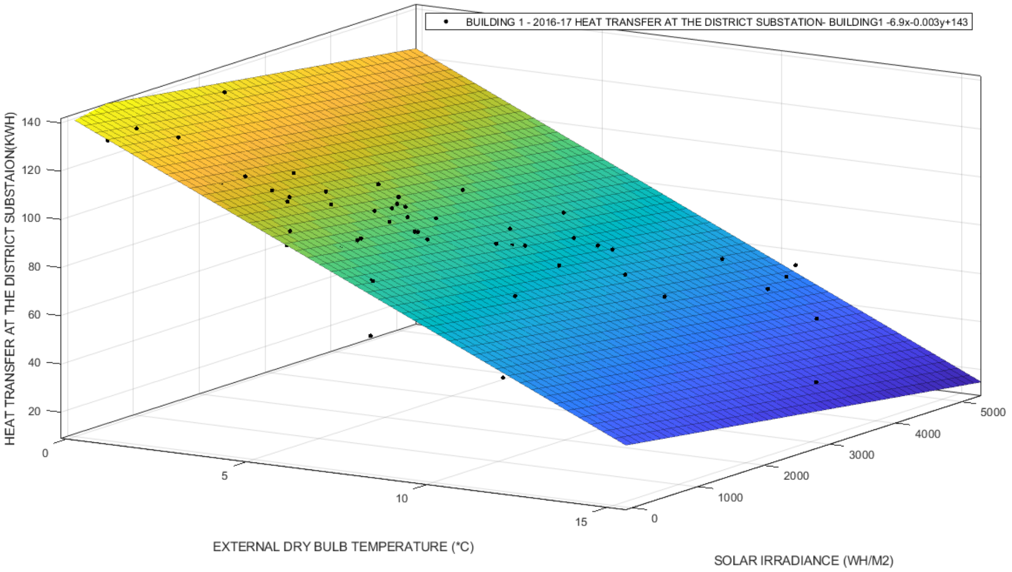


FIGURE 21 - BUILDING 1 - 2016-17 - ALL ON – XYZ

In figure 21, we see that there are a few points which seem to be displaced and there is a requirement to have a closer investigation in term of the data analysis. A closer study will be carried to understand why there is such a variance in the data. A closer study can be carried in terms of the on-off cycle and the analysis period.

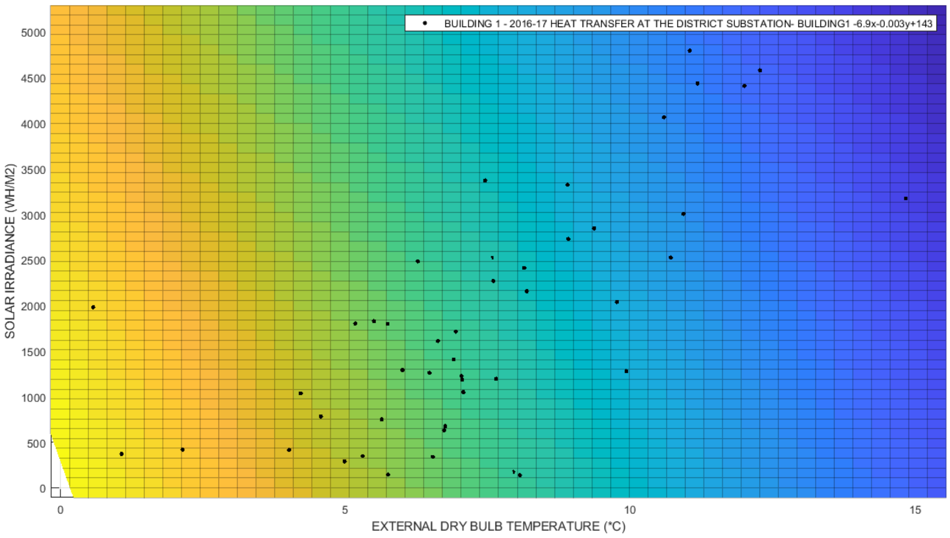


FIGURE 22 - BUILDING 1 - 2016-17 - ALL ON - XY

In figure 22, it was very important to understand the relation of the external dry bulb temperature and the irradiance even though we are looking their relation in terms of the energy demand of the building. Through this depiction, to a certain limit a relation between for irradiance and temperature can be made for a certain energy demand.

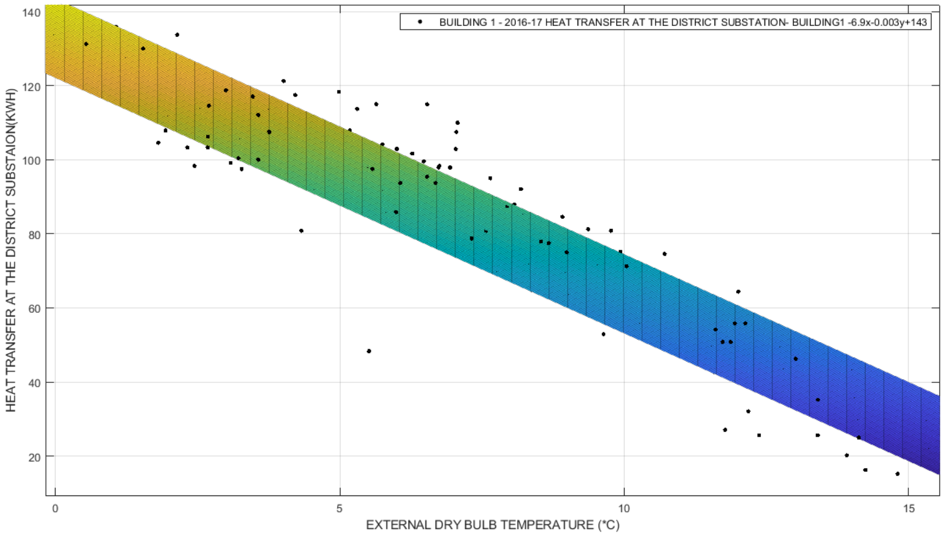


FIGURE 23 - BUILDING 1 - 2016-17 - ALL ON - XZ

In figure 23, it was very important to understand the relation of the external temperature and the energy demand. We can also understand that there is very important correlation between how the external dry bulb temperature can highly affect the heating demand of a building.

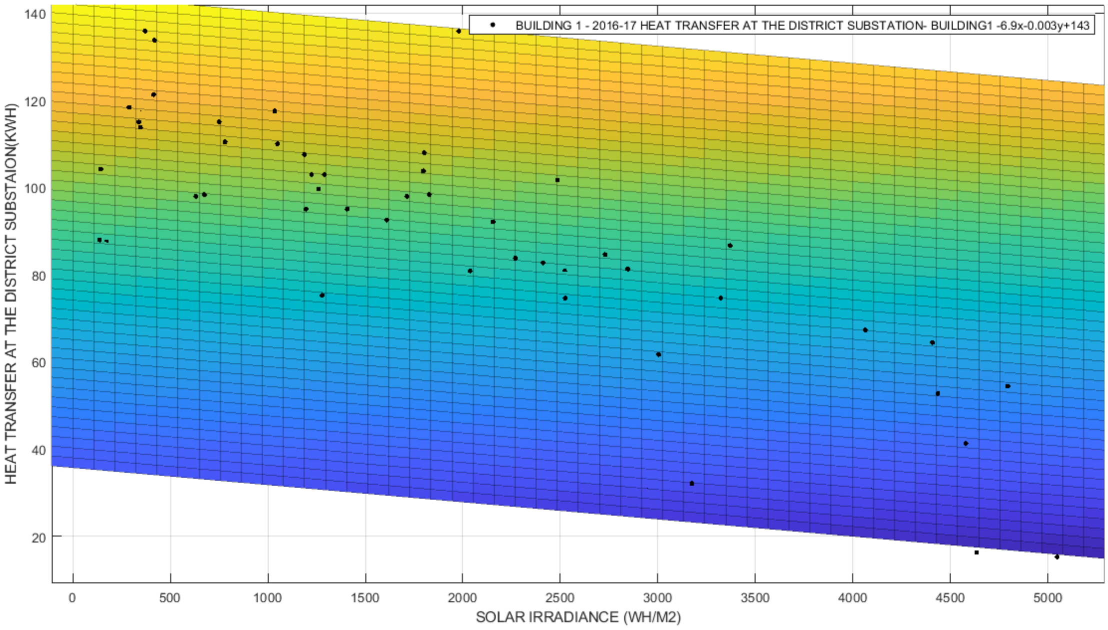


FIGURE 24 - BUILDING 1 - 2016-17 - ALL ON YZ

Similarly, in figure 24, for the irradiance, it is important to know that it can change the external dry bulb temperature, which eventually means that there is correlation with the energy demand of the building.

### 7.3.1.2. BUILDING 1 (2017-18)

Similarly, a similar study was done for the heating season of 2017-18 and there is lower $r^2$ of 0.47.

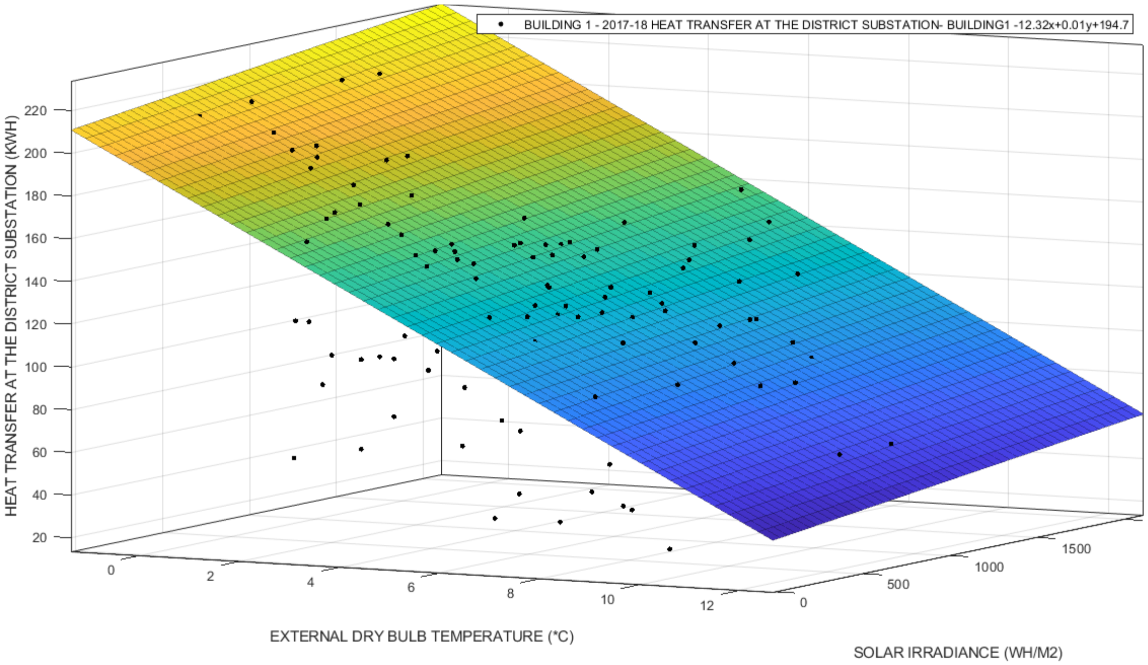


FIGURE 25 - BUILDING 1 - 2017-18 - ALL ON - XYZ

In figure 25, we see that there are a few points which seem to be displaced and there is a requirement to have a closer investigation in term of the data analysis. A closer study will be carried to understand why there is such a variance in the data. A closer study can be carried in terms of the on-off cycle and the analysis period.

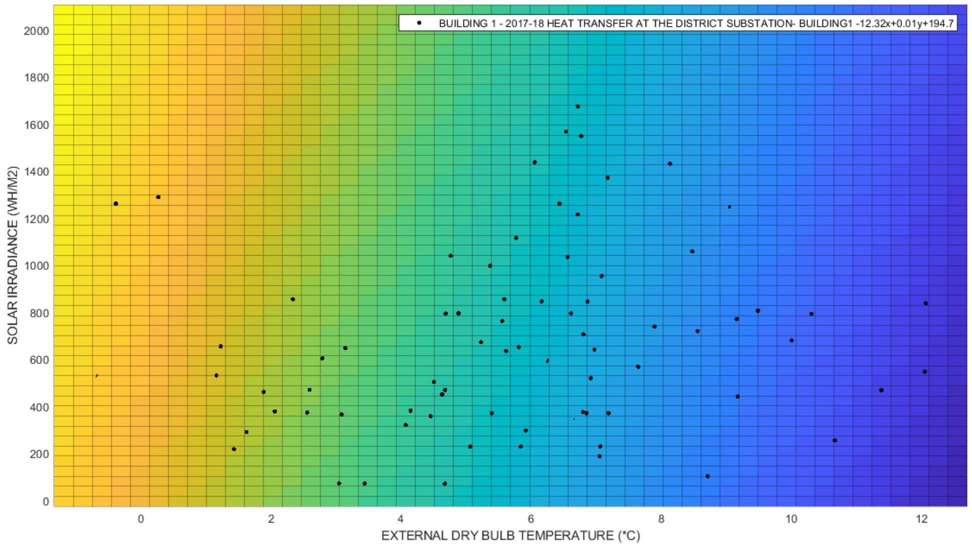


FIGURE 26 - BUILDING 1 - 2017-18 - ALL ON - XY

In figure 26, it was very important to understand the relation of the external dry bulb temperature and the irradiance even though we are looking their relation in terms of the energy demand of the building. Through this depiction, to a certain limit a relation between for irradiance and temperature can be made for a certain energy demand.

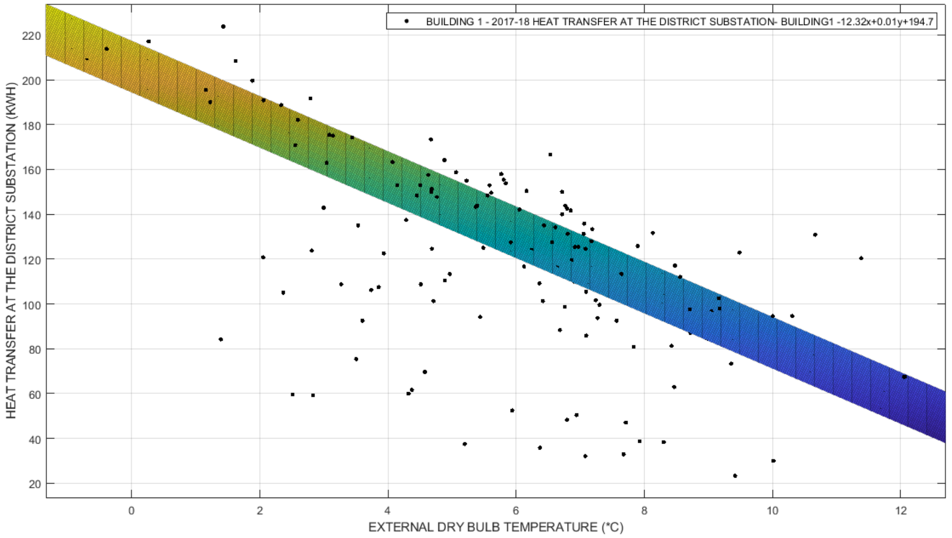


FIGURE 27 - BUILDING 1 - 2017-18 - ALL ON – XZ

Similarly, in figure 27, for the irradiance, it is important to know that it can change the external dry bulb temperature, which eventually means that there is correlation with the energy demand of the building.

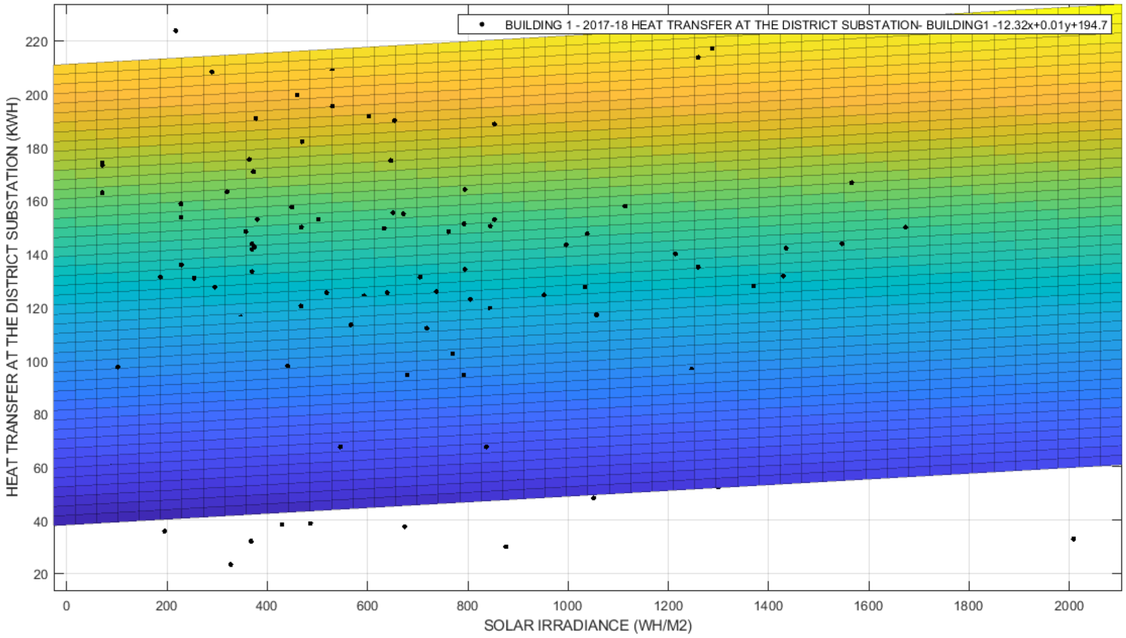


FIGURE 28 - BUILDING 1 - 2017-18 - ALL ON - YZ

Similarly, in figure 28, for the irradiance, it is important to know that it can change the external dry bulb temperature, which eventually means that there is correlation with the energy demand of the building.

### 7.3.1.3. BUILDING 5 (2016-17)

Here from a building study we understand that the building has the civil and structural labs which involve maintaining a controlled environment for experimental purposes. The building has a few lecture halls. Due to the following factors we see a very high $r^2$ of 0.87.

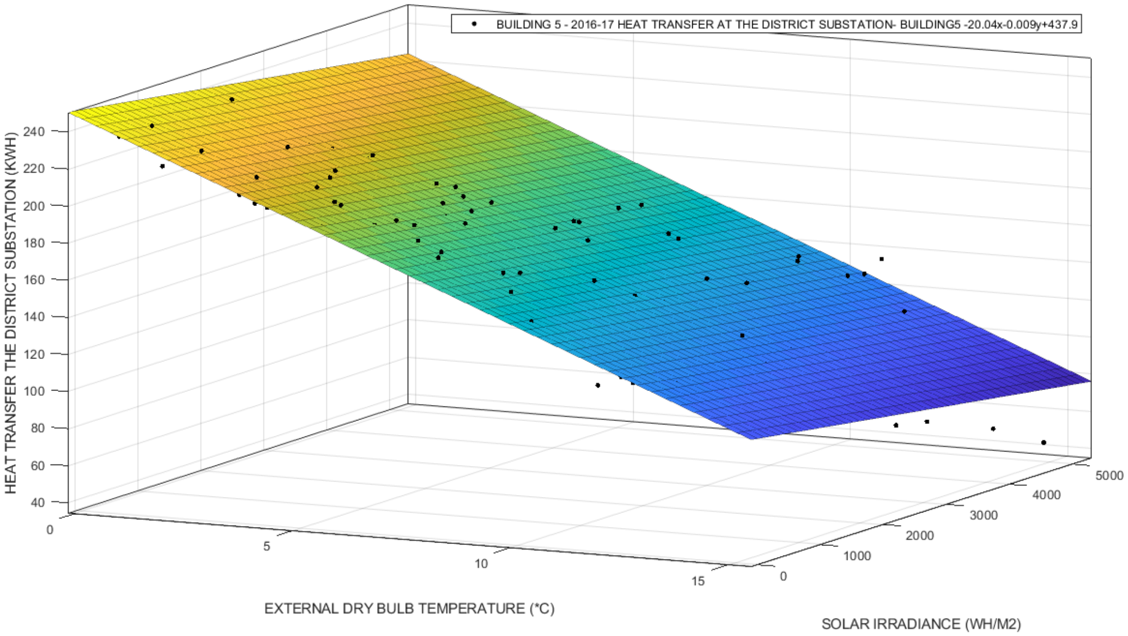


FIGURE 29 - BUILDING 5 - 2016-17 - ALL ON - XYZ

In figure 29, we see that there are a few points which seem to be displaced and there is a requirement to have a closer investigation in term of the data analysis. A closer study will be carried to understand why there is such a variance in the data. A closer study can be carried in terms of the on-off cycle and the analysis period.

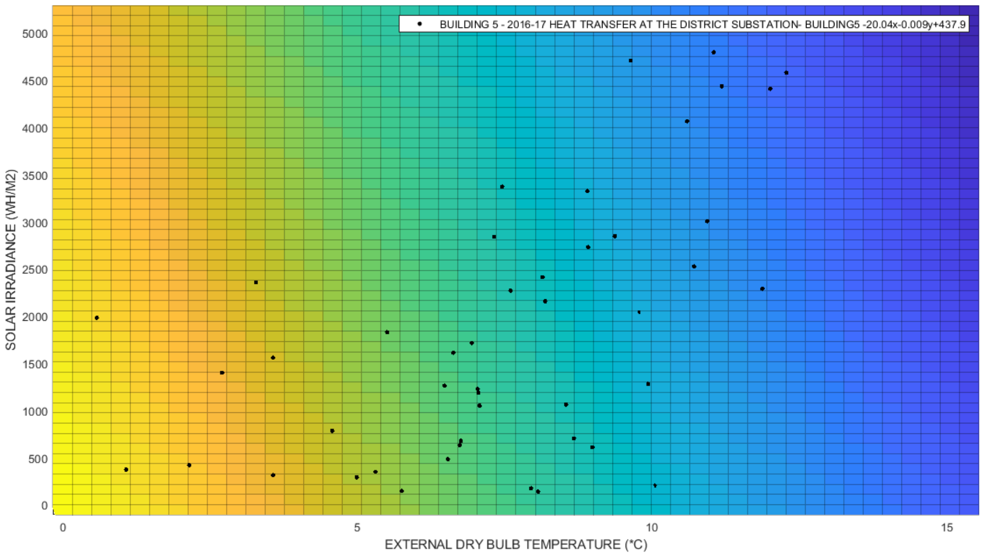


FIGURE 30 - BUILDING 5 - 2016-17 - ALL ON - XY

In figure 30, we see that there are a few points which seem to be displaced and there is a requirement to have a closer investigation in term of the data analysis. A closer study will be carried to understand why there is such a variance in the data. A closer study can be carried in terms of the on-off cycle and the analysis period.

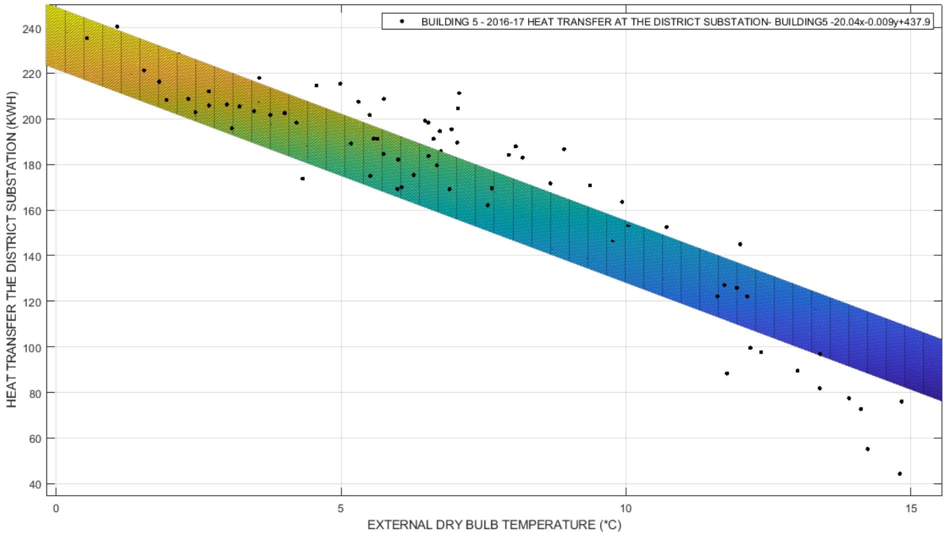


FIGURE 31 - BUILDING 5 - 2016-17 - ALL ON - XZ

In figure 31, it was very important to understand the relation of the external temperature and the energy demand. We can also understand that there is very important correlation between how the external dry bulb temperature can highly affect the heating demand of a building.

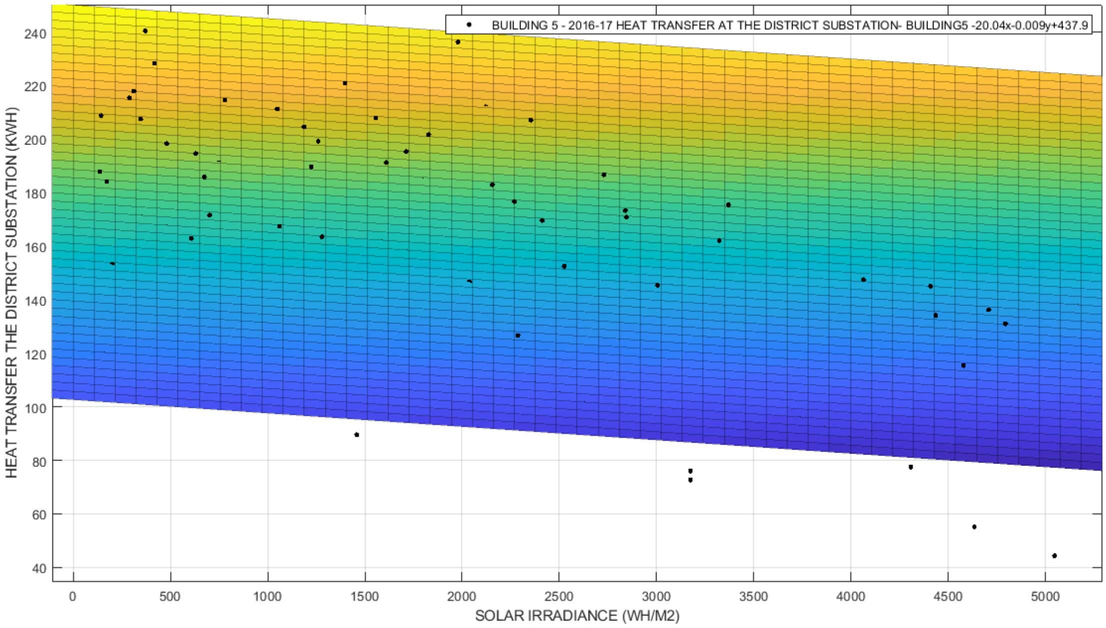


FIGURE 32 - BUILDING 5 - 2016-17 - ALL ON – YZ

Similarly, in figure 32, for the irradiance, it is important to know that it can change the external dry bulb temperature, which eventually means that there is correlation with the energy demand of the building.

### 7.3.1.4. BUILDING 5 (2017-18)

A reduced $r^2$ of 0.41 is noticed in terms of the model.

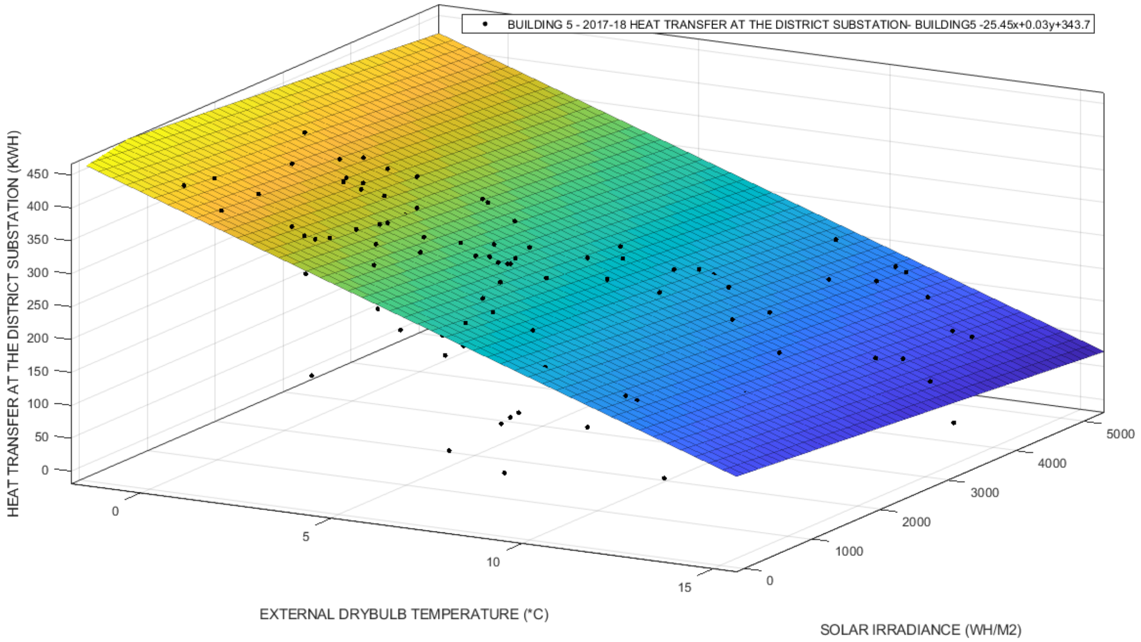


FIGURE 33 - BUILDING 5 – 2017-18 ALL ON - XYZ

In figure 33, we see that there are a few points which seem to be displaced and there is a requirement to have a closer investigation in term of the data analysis. A closer study will be carried to understand why there is such a variance in the data. A closer study can be carried in terms of the on-off cycle and the analysis period.

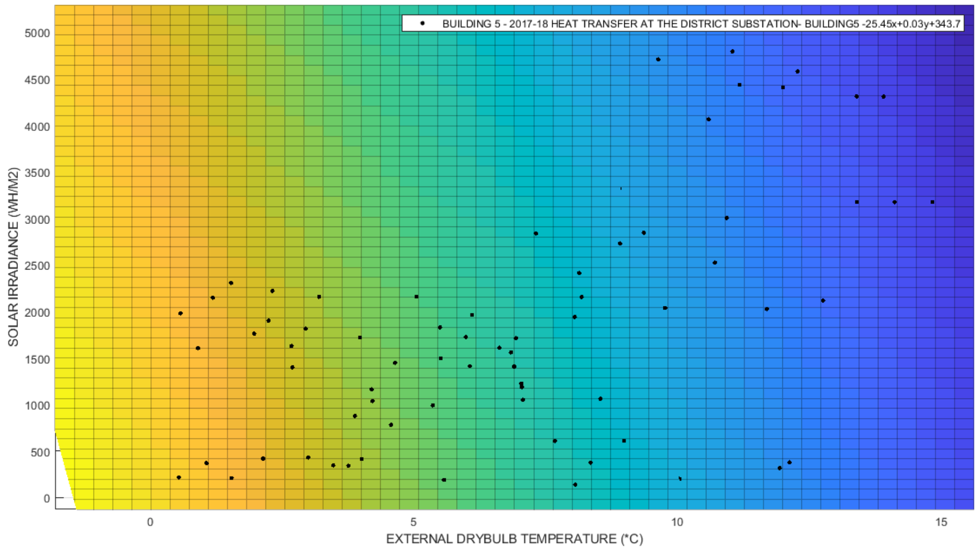


FIGURE 34 - BUILDING 5 – 2017-18 ALL ON – XY

In figure 34, it was very important to understand the relation of the external dry bulb temperature and the irradiance even though we are looking their relation in terms of the energy demand of the building. Through this depiction, to a certain limit a relation between for irradiance and temperature can be made for a certain energy demand.

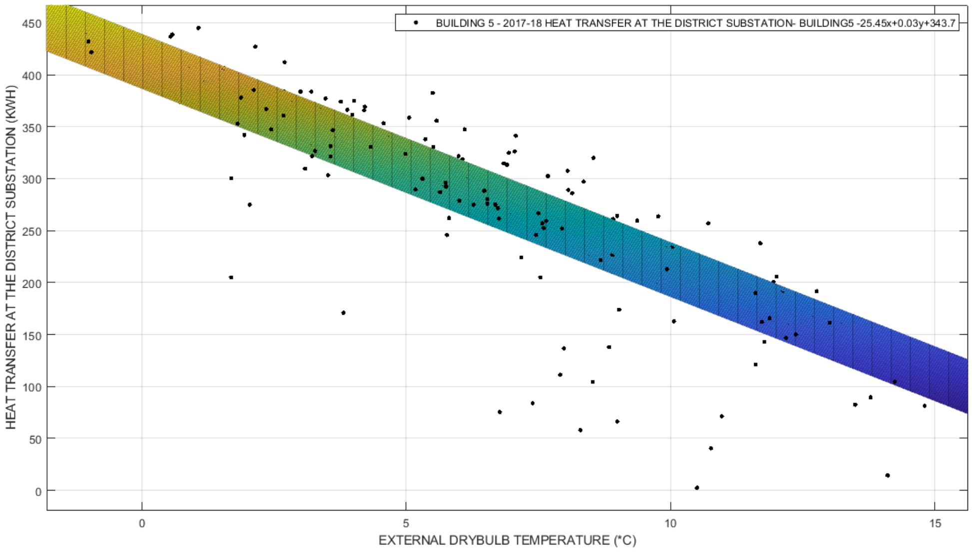


FIGURE 35 - BUILDING 5 – 2017-18 ALL ON – XZ

In figure 35, it was very important to understand the relation of the external temperature and the energy demand. We can also understand that there is very important correlation between how the external dry bulb temperature can highly affect the heating demand of a building.

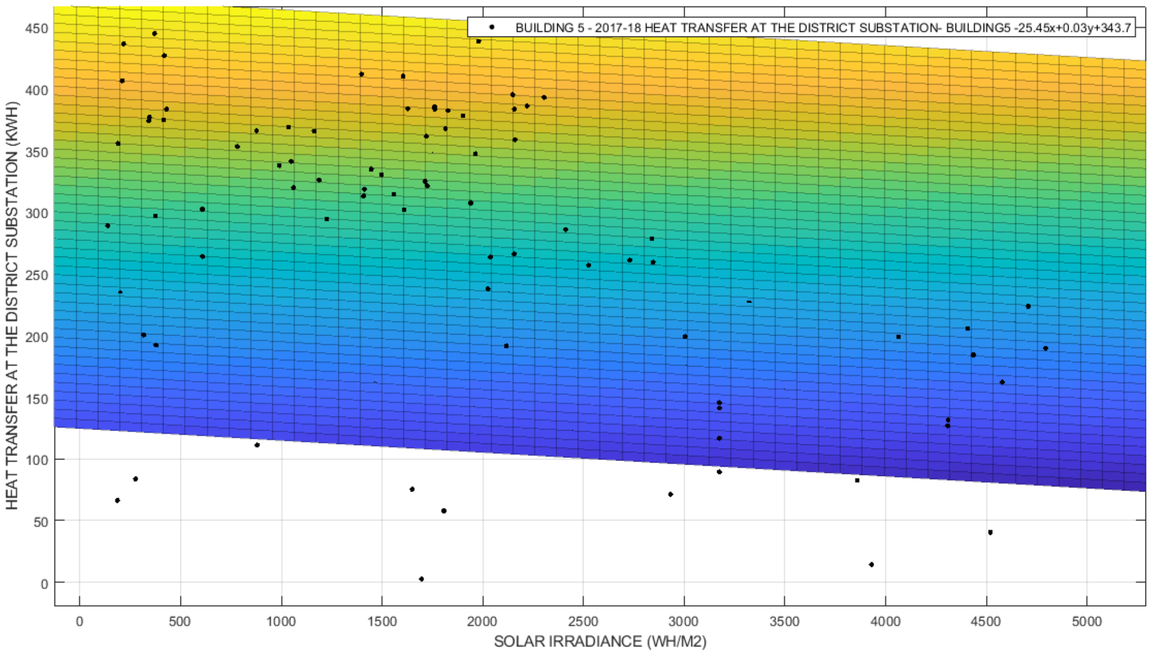


FIGURE 36 - BUILDING 5 – 2017-18 ALL ON – YZ

Similarly, in figure 36, for the irradiance, it is important to know that it can change the external dry bulb temperature, which eventually means that there is correlation with the energy demand of the building.

### 7.3.1.5. BUILDING 11 (2016-17)

This building being for a mixed-use building in terms of application that involves larger flux of students as it consists of lecture halls, design rooms, study areas and the library. The $r^2$ value of the building is relatively high at 0.76.

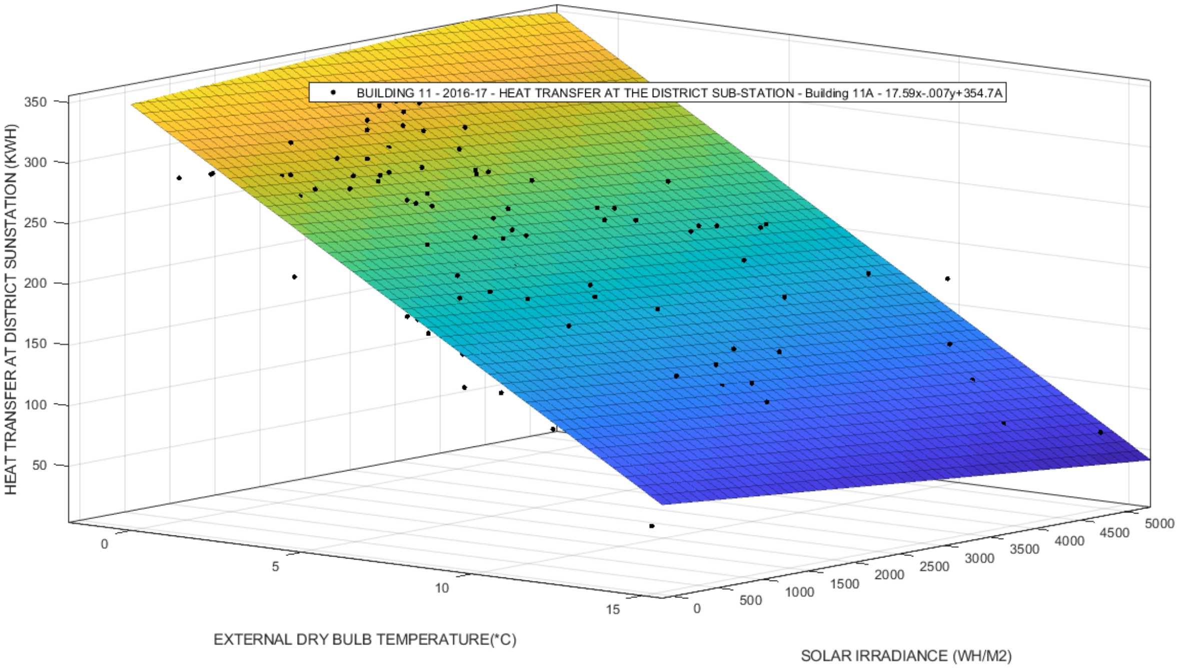


FIGURE 37 - BUILDING 11 - 2016-17 - ALL ON - XYZ

In figure 37, we see that there are a few points which seem to be displaced and there is a requirement to have a closer investigation in term of the data analysis. A closer study will be carried to understand why there is such a variance in the data. A closer study can be carried in terms of the on-off cycle and the analysis period.

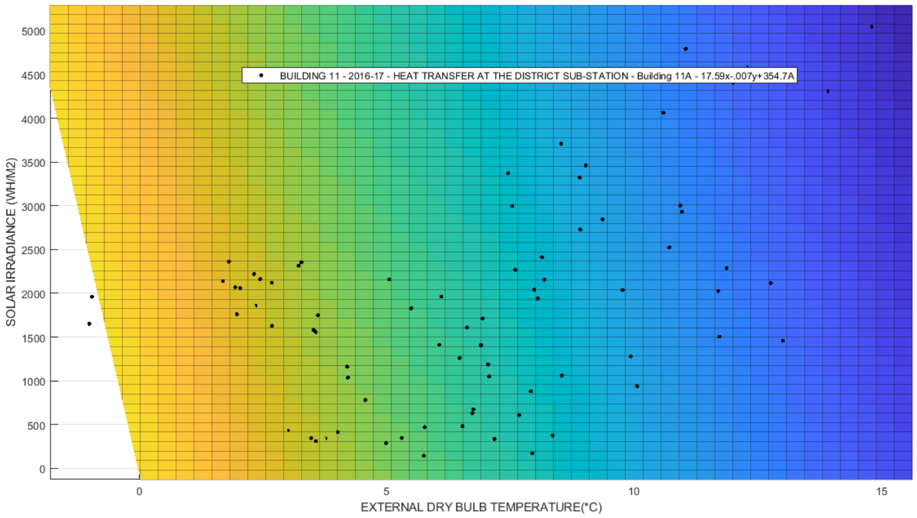


FIGURE 38 - BUILDING 11 - 2016-17 - ALL ON – XY

In figure 38, it was very important to understand the relation of the external dry bulb temperature and the irradiance even though we are looking their relation in terms of the energy demand of the building. Through this depiction, to a certain limit a relation between for irradiance and temperature can be made for a certain energy demand.

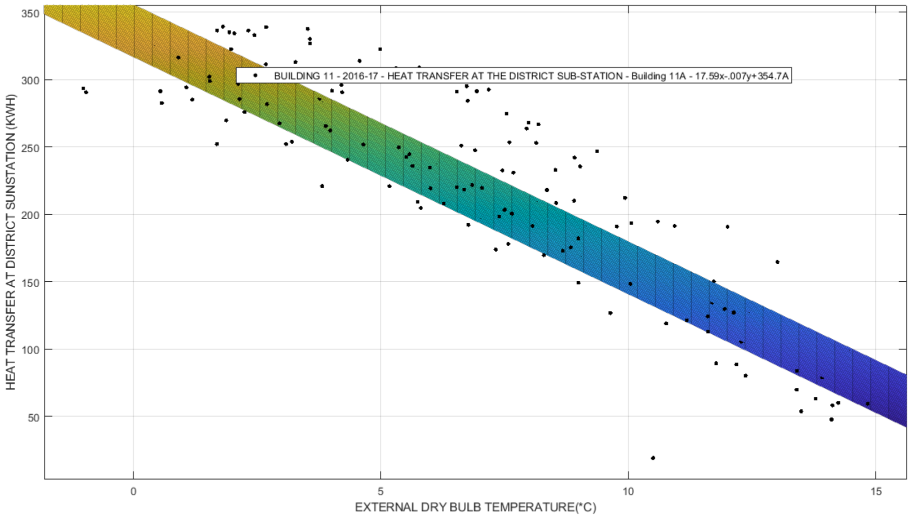


FIGURE 39 - BUILDING 11 - 2016-17 - ALL ON – XZ

In figure 39, it was very important to understand the relation of the external temperature and the energy demand. We can also understand that there is very important correlation between how the external dry bulb temperature can highly affect the heating demand of a building.

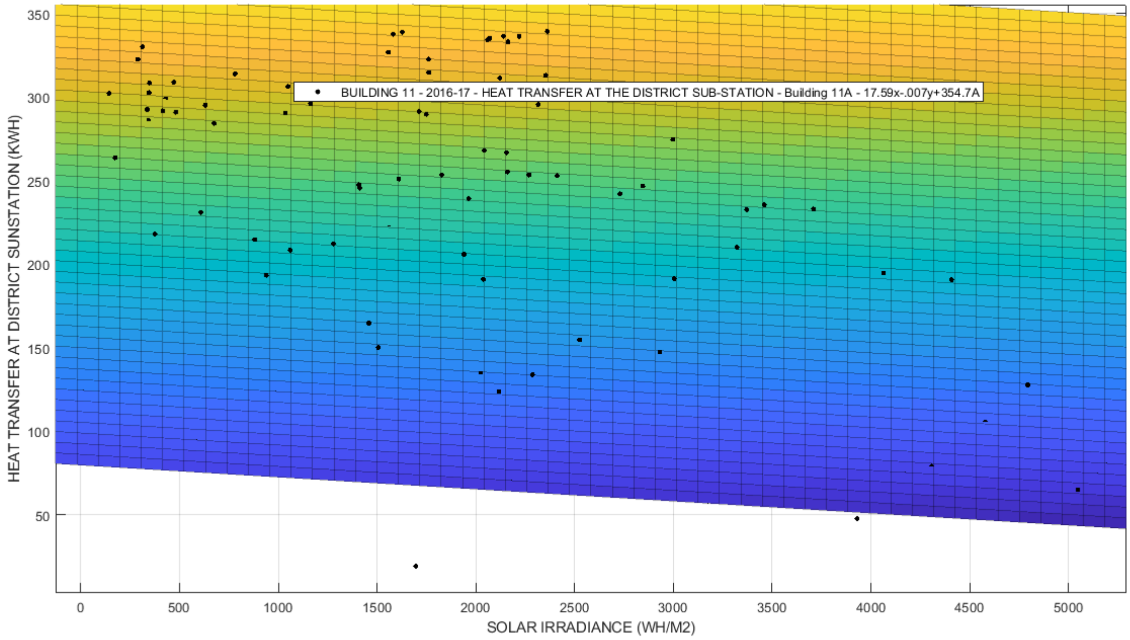


FIGURE 40 - BUILDING 11 - 2016-17 - ALL ON – YZ

Similarly, in figure 40, for the irradiance, it is important to know that it can change the external dry bulb temperature, which eventually means that there is correlation with the energy demand of the building.

### 7.3.1.6. BUILDING 11 (2017-18)

Similarly, to building no 1 there is reduced $r^2$ 0.61

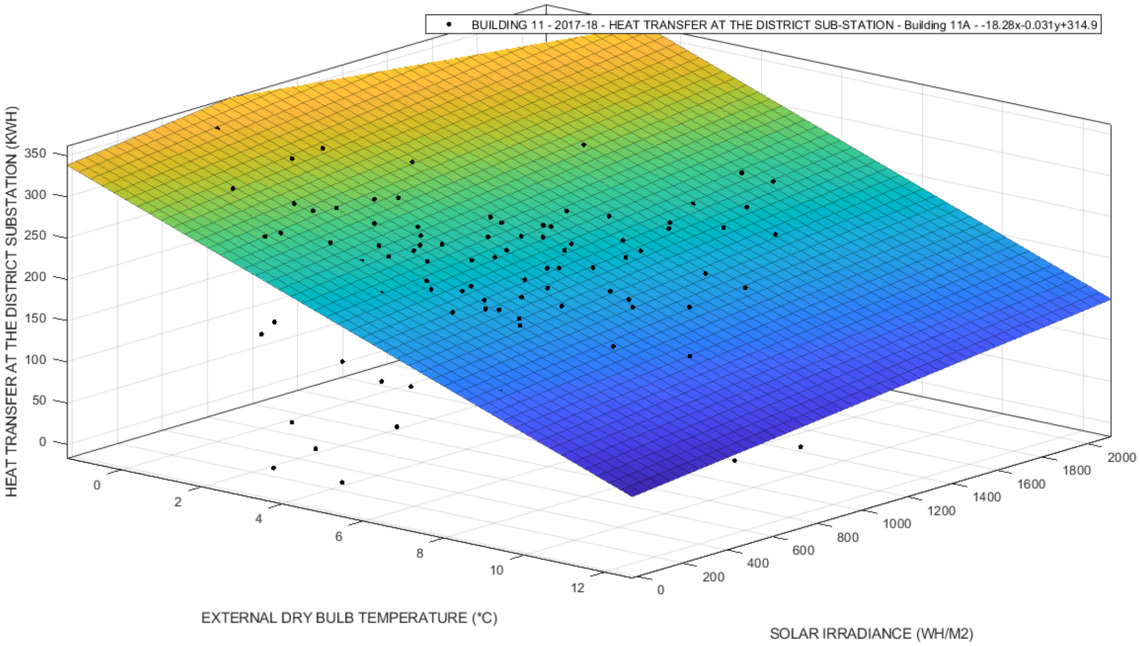


FIGURE 41 - BUILDING 11 – 2017-18 ALL ON - XYZ

In figure 41, we see that there are a few points which seem to be displaced and there is a requirement to have a closer investigation in term of the data analysis. A closer study will be carried to understand why there is such a variance in the data. A closer study can be carried in terms of the on-off cycle and the analysis period.

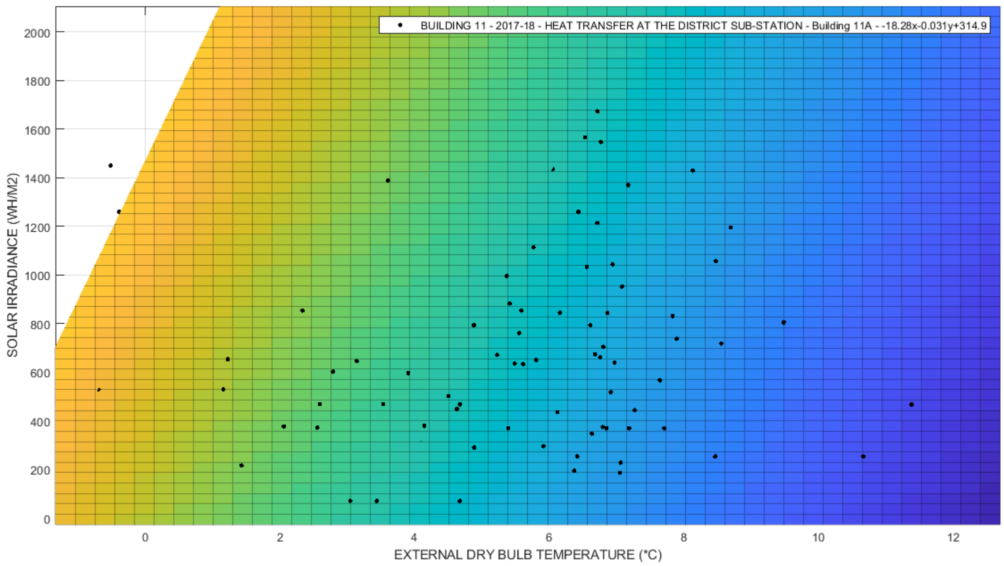


FIGURE 42 - BUILDING 11 – 2017-18 ALL ON – XY

In figure 42, it was very important to understand the relation of the external dry bulb temperature and the irradiance even though we are looking their relation in terms of the energy demand of the building. Through this depiction, to a certain limit a relation between for irradiance and temperature can be made for a certain energy demand.

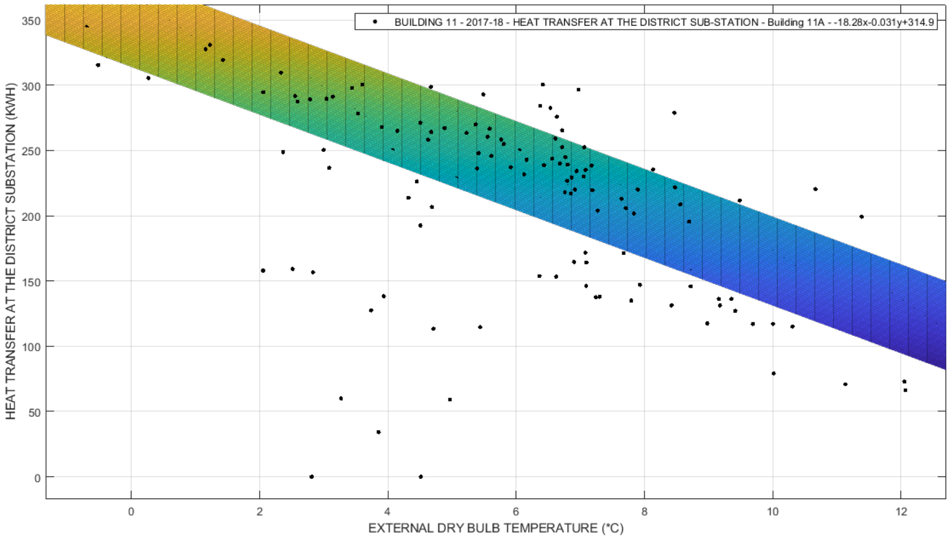


FIGURE 43 - BUILDING 11 – 2017-18 ALL ON - XZ

In figure 43, it was very important to understand the relation of the external temperature and the energy demand. We can also understand that there is very important correlation between how the external dry bulb temperature can highly affect the heating demand of a building.

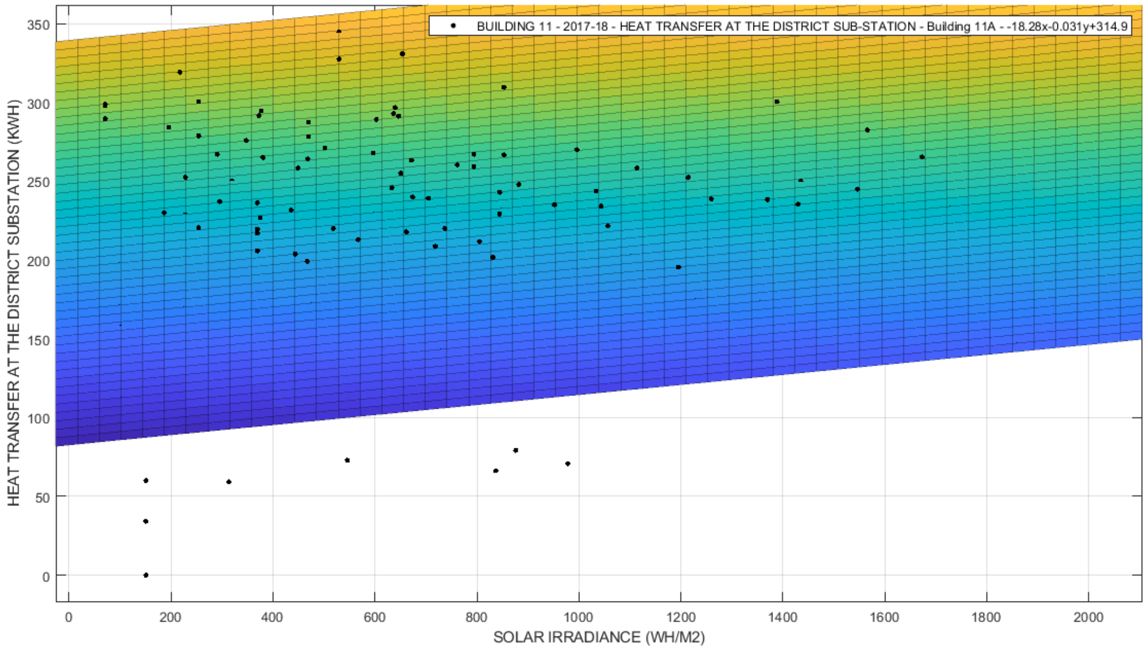


FIGURE 44 - BUILDING 11 – 2017-18 ALL ON - YZ

Similarly, in figure 44, for the irradiance, it is important to know that it can change the external dry bulb temperature, which eventually means that there is correlation with the energy demand of the building.

### 7.3.1.7. BUILDING 14 (2016-17)

The building has more lecture halls and class-rooms which has less student flux, but more stationery student involved in terms of class timings. Due to that there is a low r$^2$ of 0.64

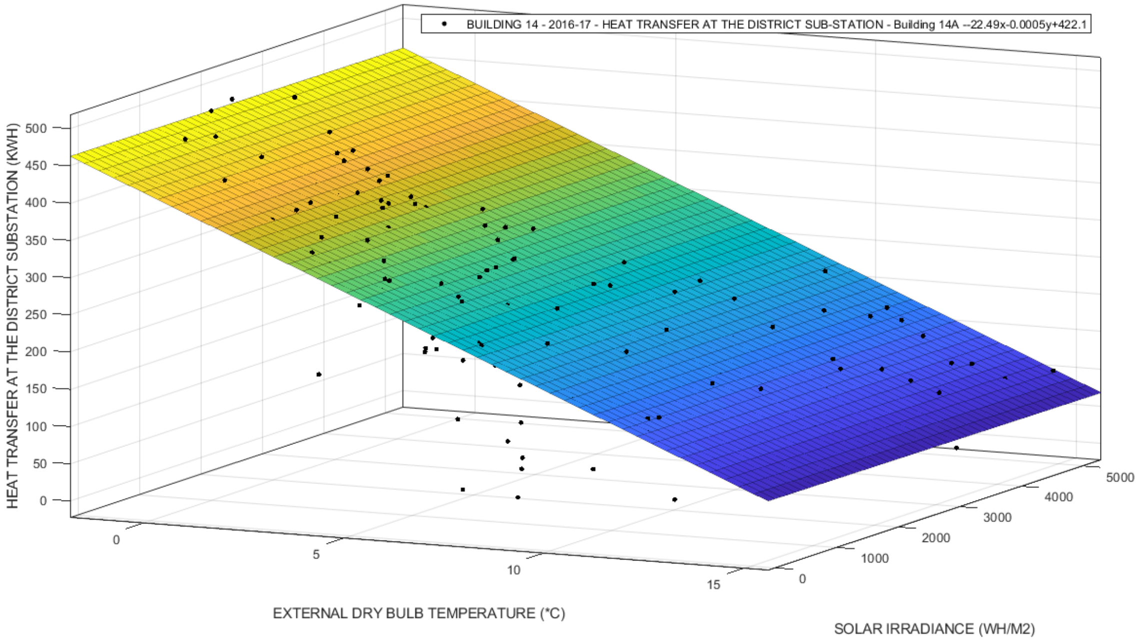


FIGURE 45 - BUILDING 14 - 2016-17 - ALL ON – XYZ

In figure 45, we see that there are a few points which seem to be displaced and there is a requirement to have a closer investigation in term of the data analysis. A closer study will be carried to understand why there is such a variance in the data. A closer study can be carried in terms of the on-off cycle and the analysis period.

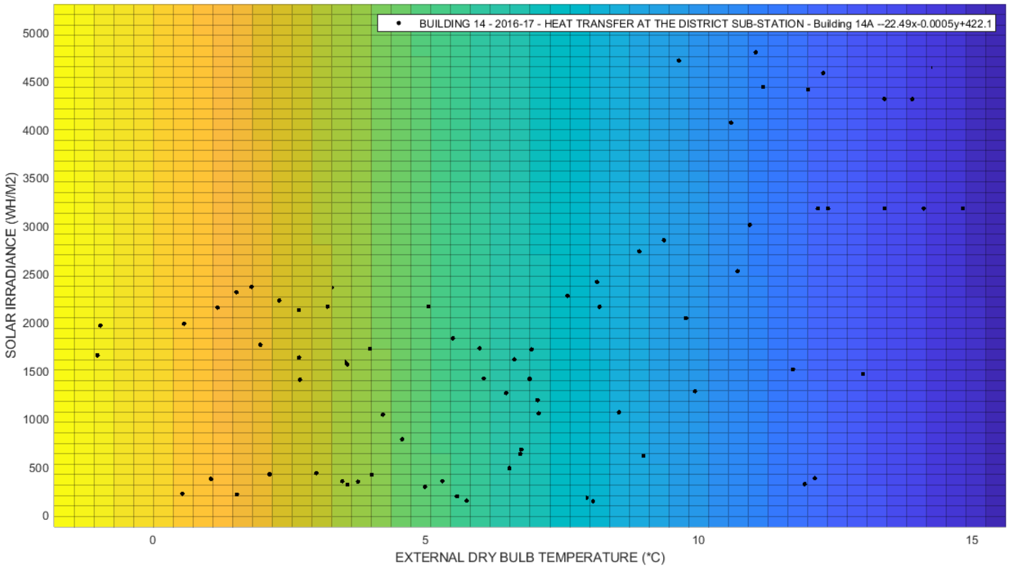


FIGURE 46 - BUILDING 14 - 2016-17 - ALL ON – XY

In figure 46, it was very important to understand the relation of the external dry bulb temperature and the irradiance even though we are looking their relation in terms of the energy demand of the building. Through this depiction, to a certain limit a relation between for irradiance and temperature can be made for a certain energy demand.

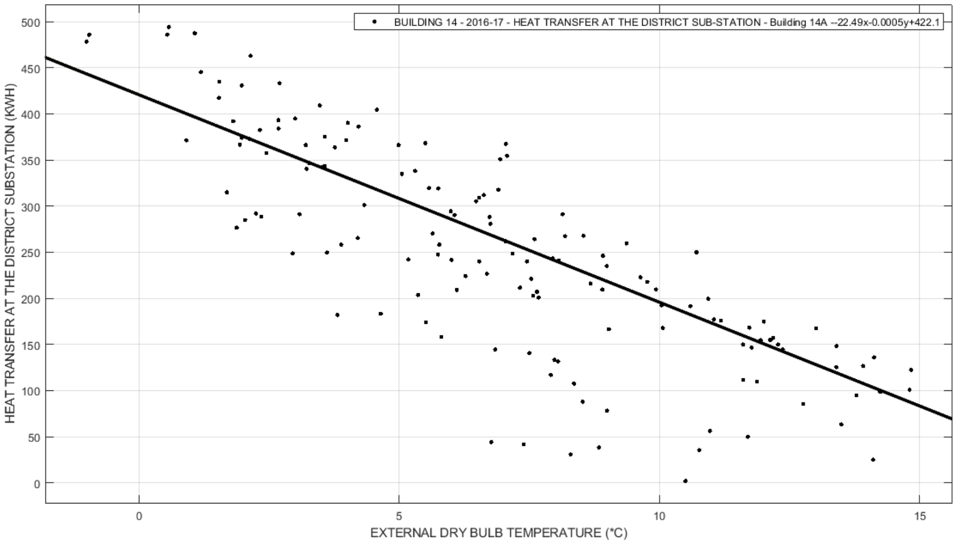


FIGURE 47 - BUILDING 14 - 2016-17 - ALL ON – XZ

In figure 47, it was very important to understand the relation of the external temperature and the energy demand. We can also understand that there is very important correlation between how the external dry bulb temperature can highly affect the heating demand of a building.

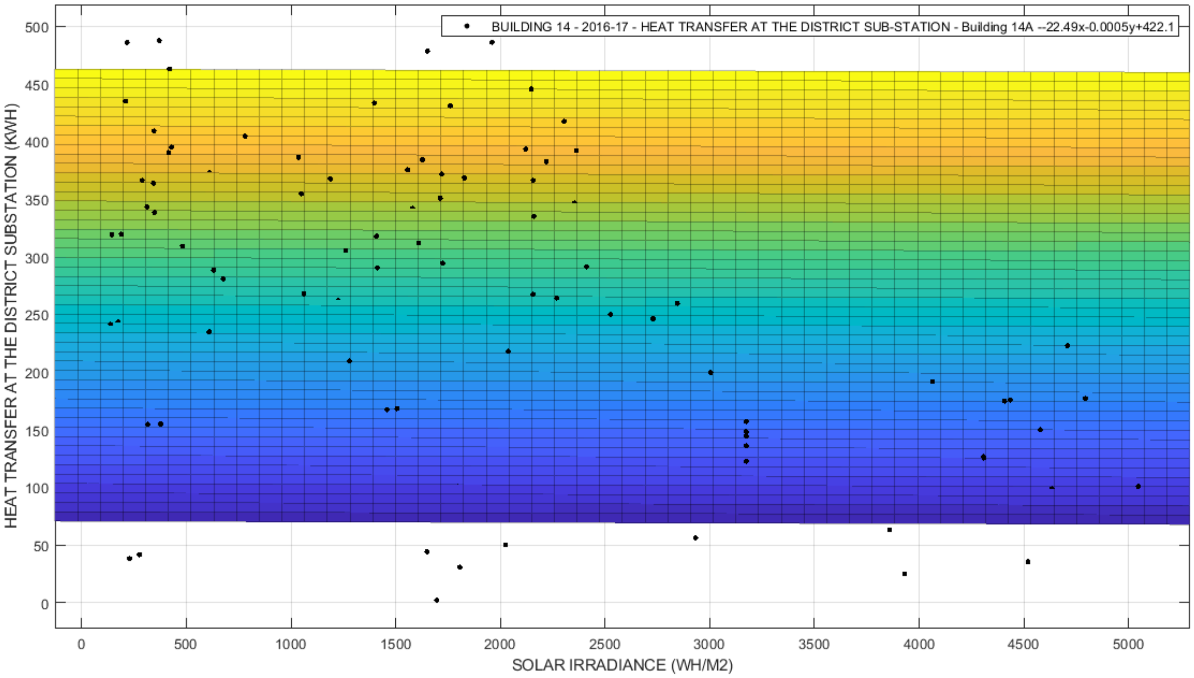


FIGURE 48 - BUILDING 14 - 2016-17 - ALL ON - YZ

Similarly, in figure 48, for the irradiance, it is important to know that it can change the external dry bulb temperature, which eventually means that there is correlation with the energy demand of the building.

### 7.3.1.8. BUILDING 14 (2017-18)

Due to high fluctuations in data readings there is a very low $r^2$ of 0.25 noticed.

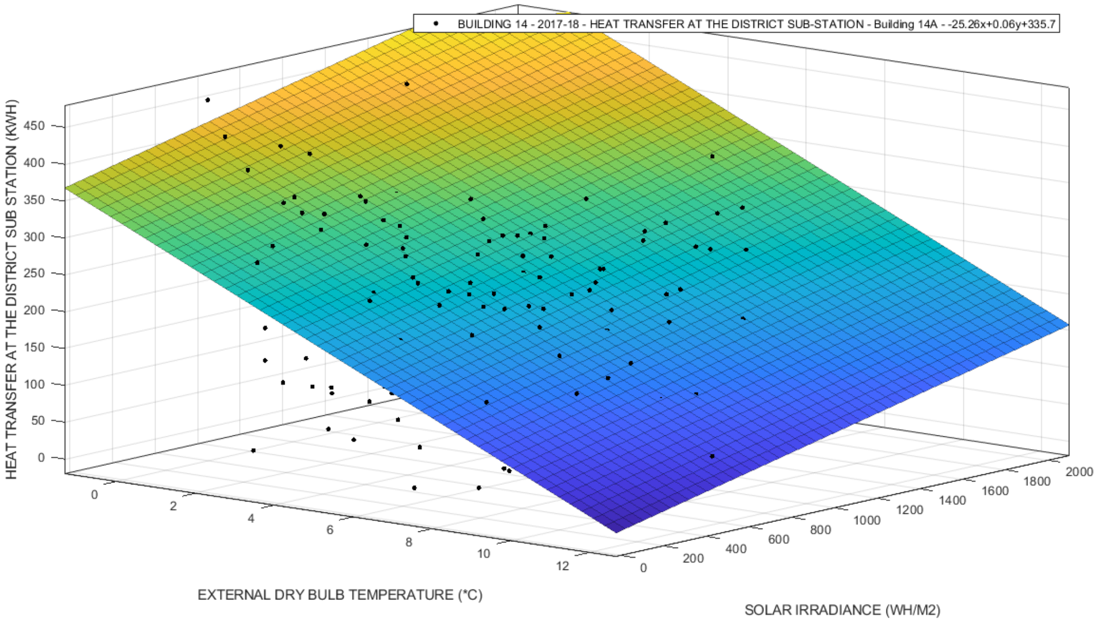


FIGURE 49 - BUILDING 14 – 2017-18 ALL ON – XYZ

In figure 49, we see that there are a few points which seem to be displaced and there is a requirement to have a closer investigation in term of the data analysis. A closer study will be carried to understand why there is such a variance in the data. A closer study can be carried in terms of the on-off cycle and the analysis period.

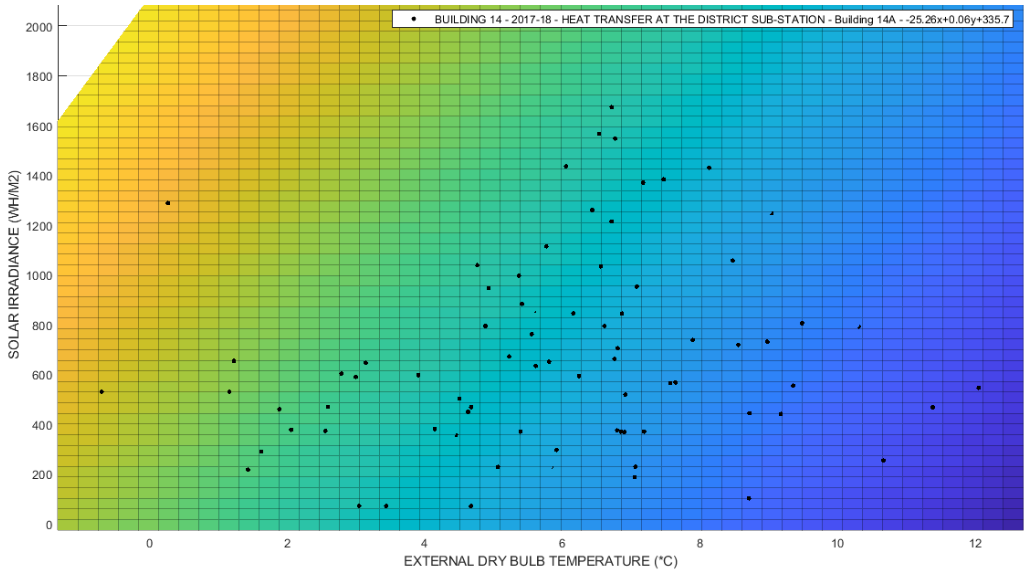


FIGURE 50 - BUILDING 14 – 2017-18 ALL ON – XY

In figure 50, it was very important to understand the relation of the external dry bulb temperature and the irradiance even though we are looking their relation in terms of the energy demand of the building. Through this depiction, to a certain limit a relation between for irradiance and temperature can be made for a certain energy demand.

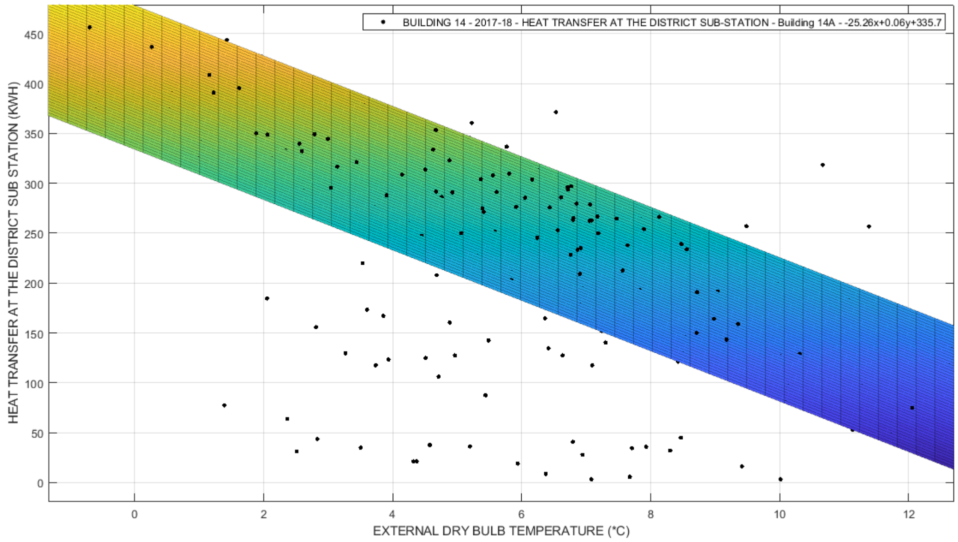


FIGURE 51 - BUILDING 14 – 2017-18 ALL ON – XZ

In figure 51, it was very important to understand the relation of the external temperature and the energy demand. We can also understand that there is very important correlation between how the external dry bulb temperature can highly affect the heating demand of a building.

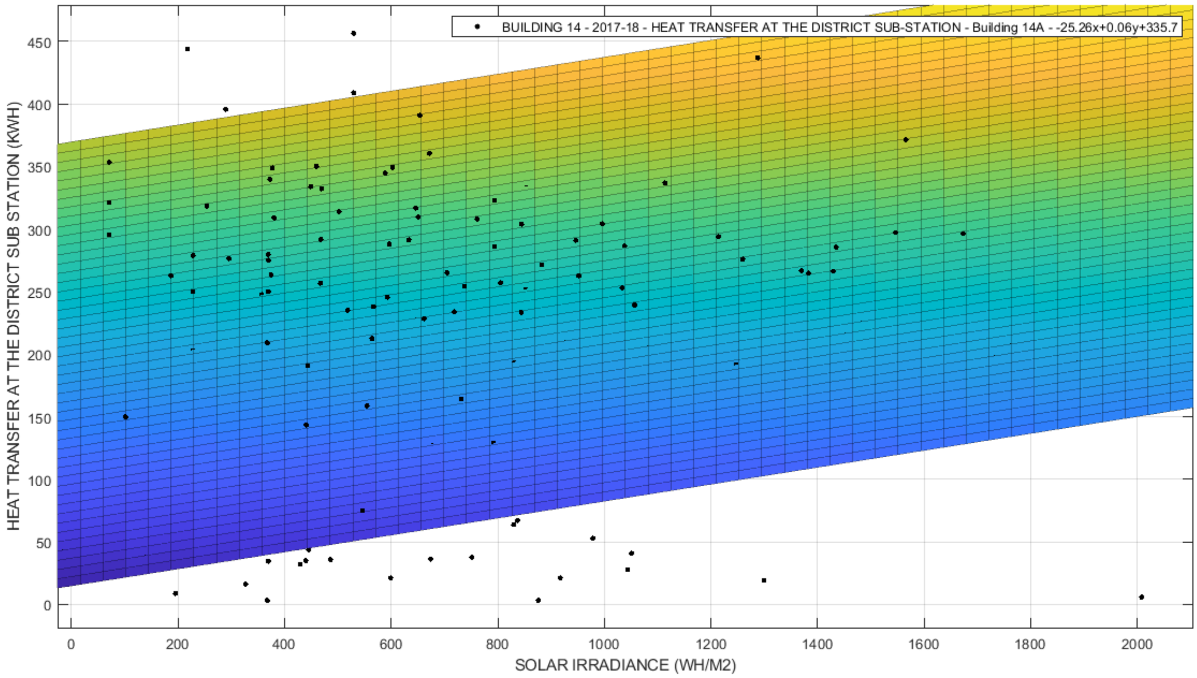


FIGURE 52 - BUILDING 14 – 2017-18 ALL ON – YZ

Similarly, in figure 52, for the irradiance, it is important to know that it can change the external dry bulb temperature, which eventually means that there is correlation with the energy demand of the building.

From this initial study, it is understood that there needs to be a closer look into the functioning of the sub-station functioning. It is imperative to understand the on and off cycles of the system and the periods where the heating system seems to function poorly in terms of calibration. A study needs to be done to understand if the weekends also determine if the model is correct or not.

The study also draws an interesting fact that the orientation of the building also determines the consistency of the model that been developed.

From the above analysis, we find that the outliers are the cause of reduced correlation. We thus need to find what would be reasons for these points to go out of position.

So, in the section we will look at how the changing the time step and the days of analysis will change the outcome of the correlation.

## 7.3.2. CONSIDERING NO WEEKENDS, HOLIDAYS AND 06:00 HRS TO 18:00 HRS AS A TIME-STEP

### 7.3.2.1. BUILDING 1 (2016-17)

After considering the working time as 6 am to 6 pm and neglecting all holidays and weekend, there has been a significant improvement in $r^2$ to 0.98.

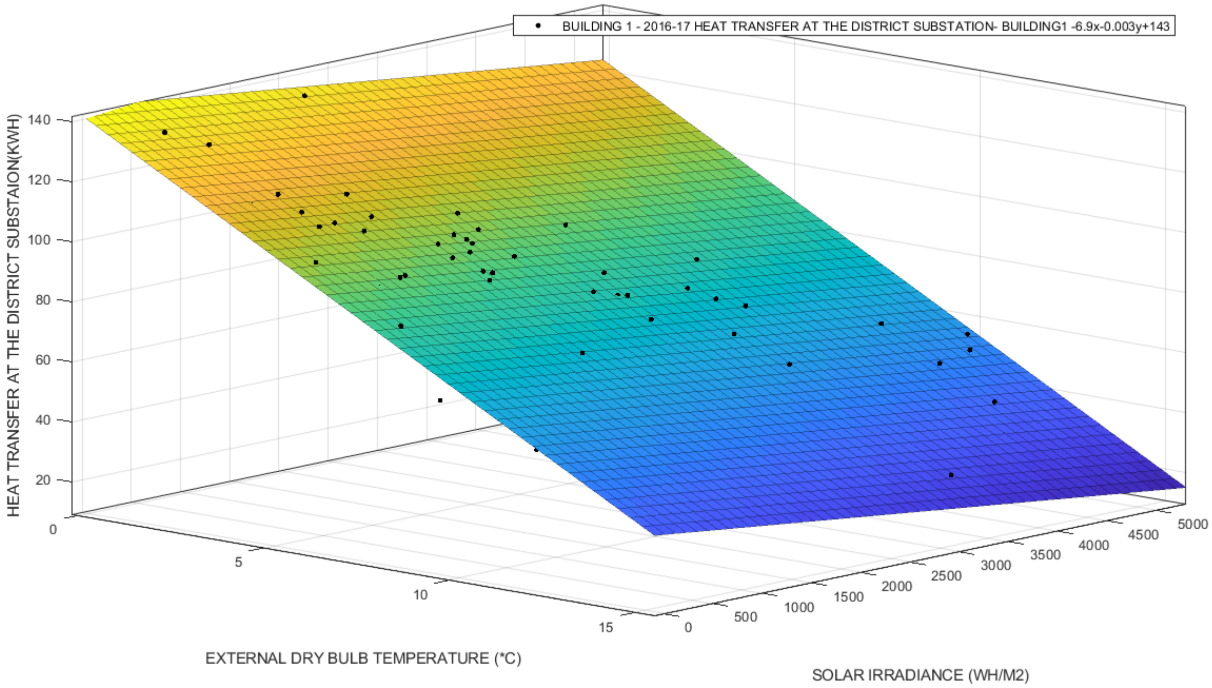


FIGURE 53 - BUILDING 1 - 2016-17 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS - XYZ

In figure 53, we see that there are a few points which seem to be displaced and there is a requirement to have a closer investigation in term of the data analysis. A closer study will be carried to understand why there is such a variance in the data. A closer study can be carried in terms of the on-off cycle and the analysis period.

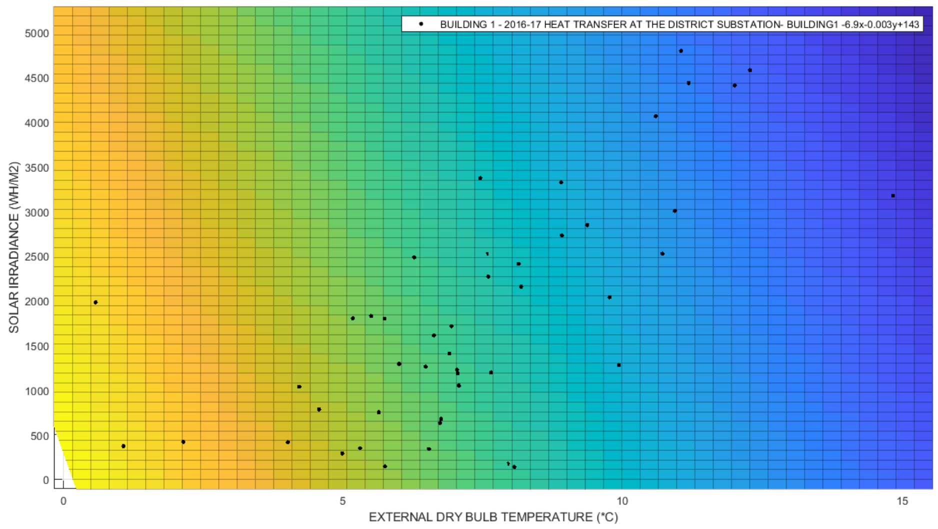


FIGURE 54 - BUILDING 1 - 2016-17 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS - XY

In figure 54, it was very important to understand the relation of the external dry bulb temperature and the irradiance even though we are looking their relation in terms of the energy demand of the building. Through this depiction, to a certain limit a relation between for irradiance and temperature can be made for a certain energy demand.

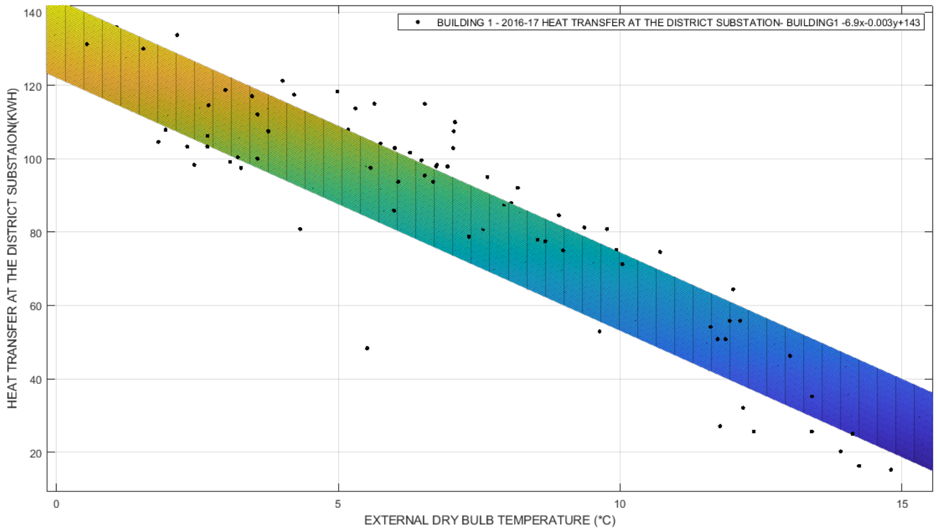


FIGURE 55 - BUILDING 1 - 2016-17 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS - XZ

In figure 55, it was very important to understand the relation of the external temperature and the energy demand. We can also understand that there is very important correlation between how the external dry bulb temperature can highly affect the heating demand of a building.

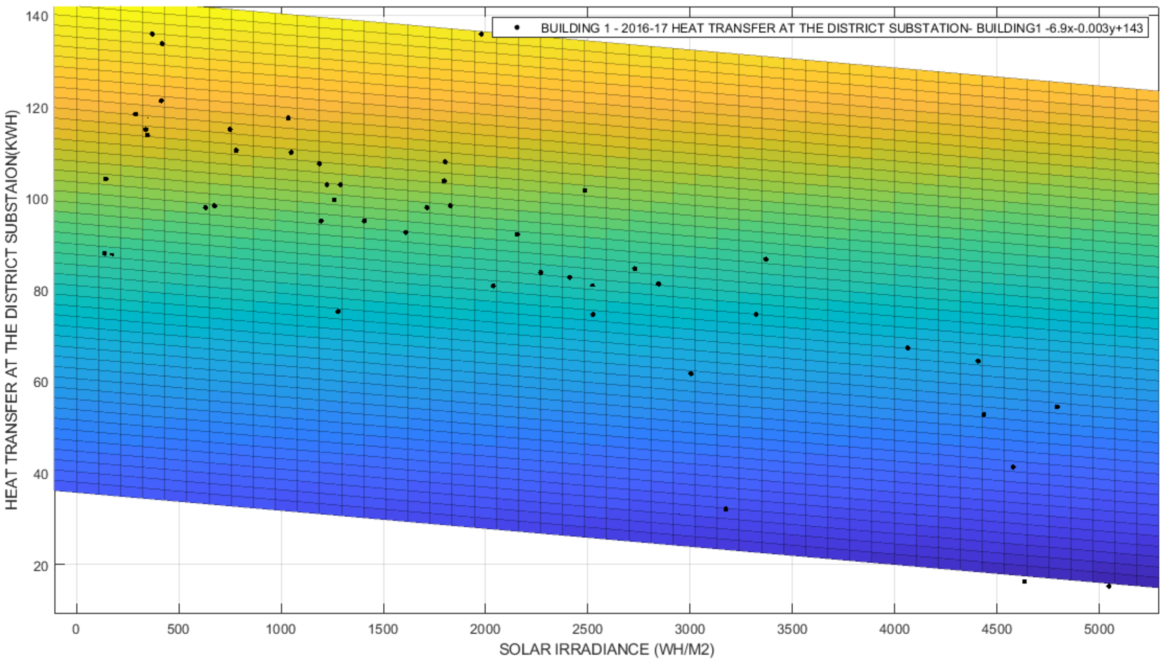


FIGURE 56 - BUILDING 1 - 2016-17 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS - YZ

Similarly, in figure 56, for the irradiance, it is important to know that it can change the external dry bulb temperature, which eventually means that there is correlation with the energy demand of the building.

### 7.3.2.2. BUILDING 1 (2017-18)

After further investigation, it was noticed that there has been a significant change in the $r^2$ value for this time-period. The $r^2$ 0.76 which is moderate improvement from the previous analysis

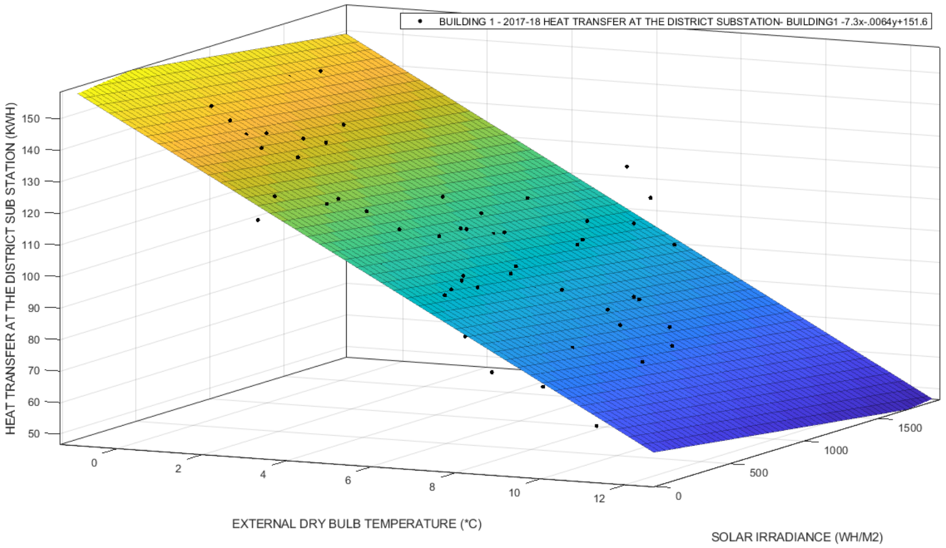


FIGURE 57 - BUILDING 1 - 2017-18 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS- XYZ

In figure 57, we see that there are a few points which seem to be displaced and there is a requirement to have a closer investigation in term of the data analysis. A closer study will be carried to understand why there is such a variance in the data. A closer study can be carried in terms of the on-off cycle and the analysis period.

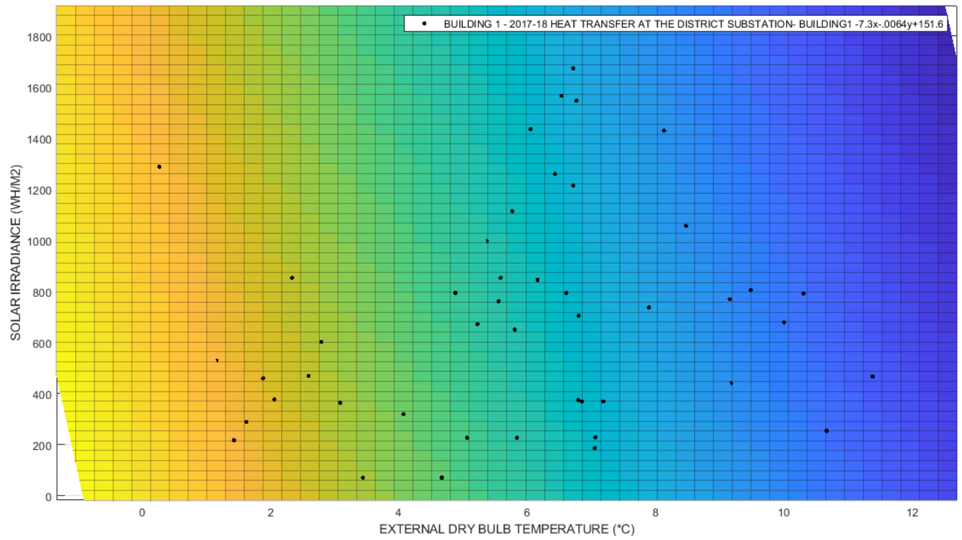


FIGURE 58 - BUILDING 1 - 2017-18 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS- XY

In figure 58, it was very important to understand the relation of the external dry bulb temperature and the irradiance even though we are looking their relation in terms of the energy demand of the building. Through this depiction, to a certain limit a relation between for irradiance and temperature can be made for a certain energy demand.

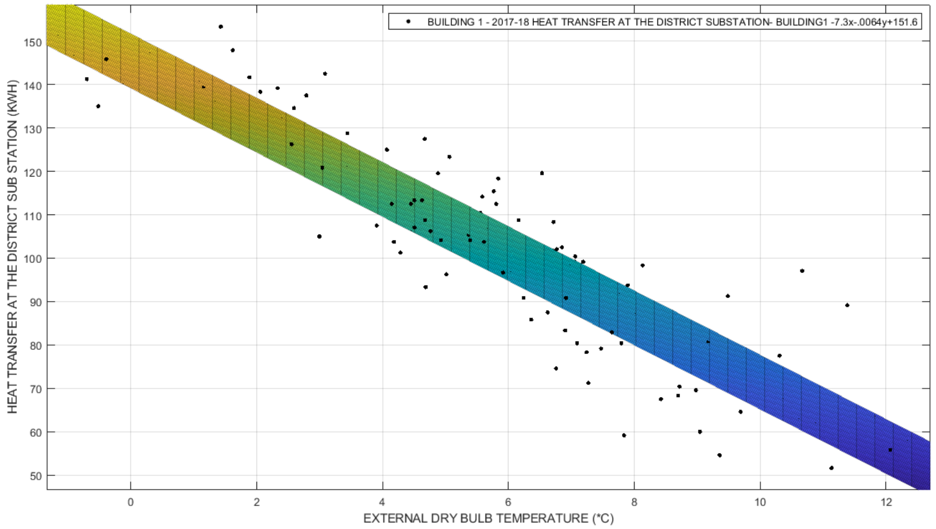


FIGURE 59 - BUILDING 1 - 2017-18 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS- XZ

In figure 59, it was very important to understand the relation of the external temperature and the energy demand. We can also understand that there is very important correlation between how the external dry bulb temperature can highly affect the heating demand of a building.

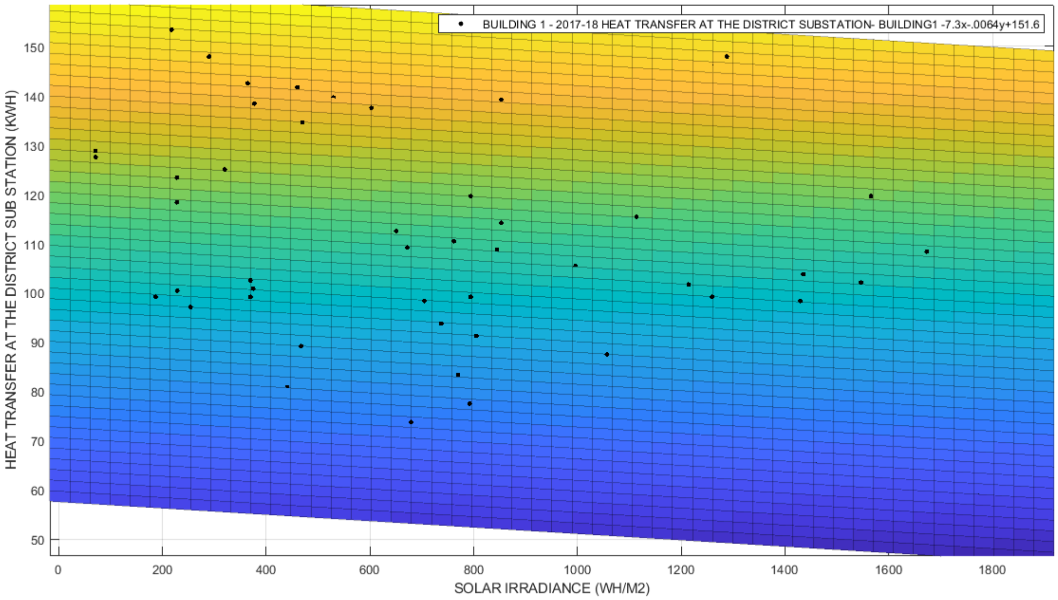


FIGURE 60 - BUILDING 1 - 2017-18 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS- YZ

Similarly, in figure 60, for the irradiance, it is important to know that it can change the external dry bulb temperature, which eventually means that there is correlation with the energy demand of the building.

### 7.3.2.3. BUILDING 5 (2016-17)

After considering the working time as 6 am to 6 pm and neglecting all holidays and weekend, there has been a significant improvement in $r^2$ to 0.88

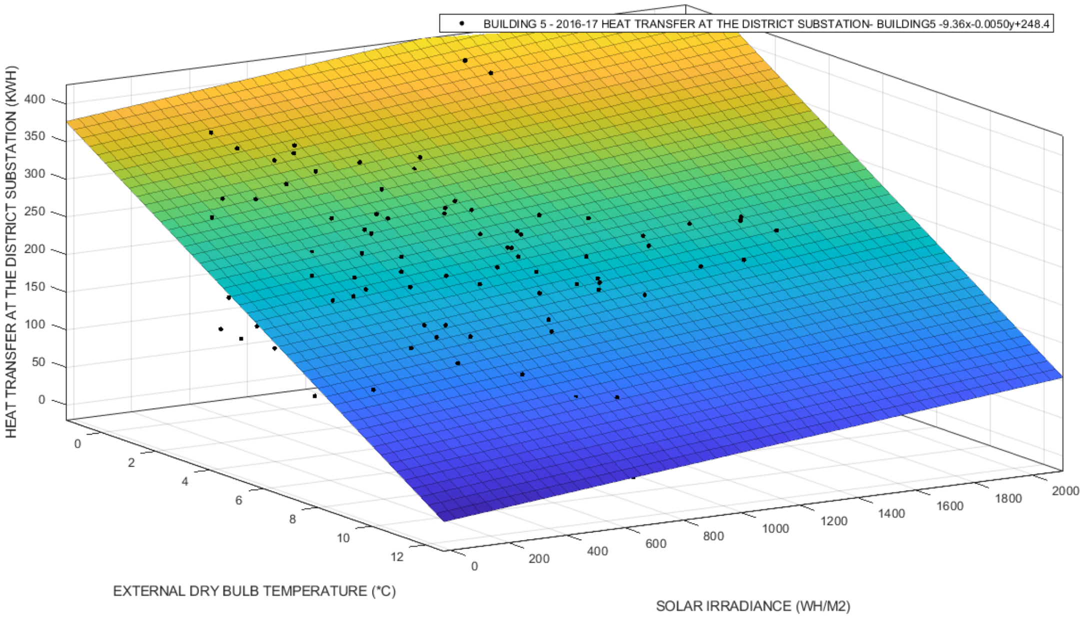


FIGURE 61 - BUILDING 5 - 2016-17 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS- XYZ

In figure 61, we see that there are a few points which seem to be displaced and there is a requirement to have a closer investigation in term of the data analysis. A closer study will be carried to understand why there is such a variance in the data. A closer study can be carried in terms of the on-off cycle and the analysis period.

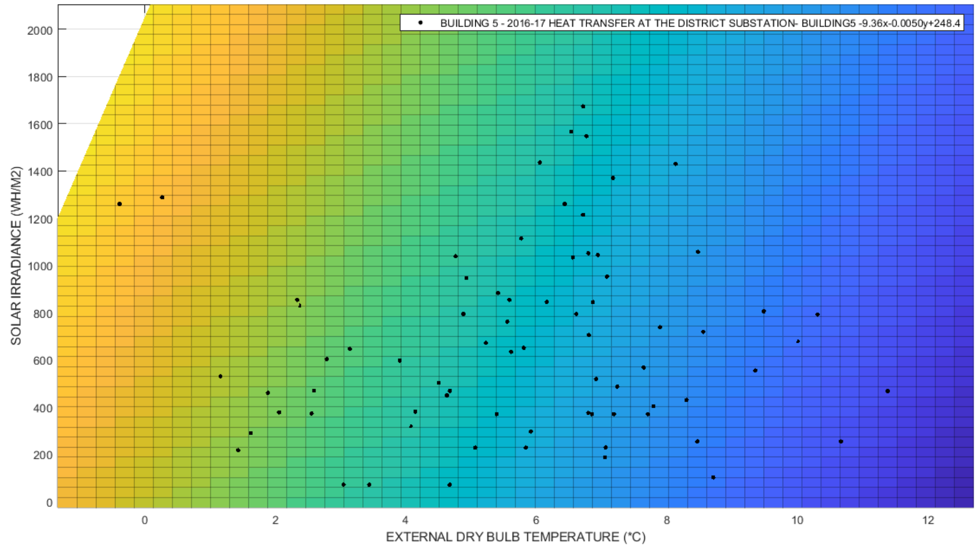


FIGURE 62 - BUILDING 5 - 2016-17 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS- XY

In figure 62, it was very important to understand the relation of the external dry bulb temperature and the irradiance even though we are looking their relation in terms of the energy demand of the building. Through this depiction, to a certain limit a relation between for irradiance and temperature can be made for a certain energy demand.

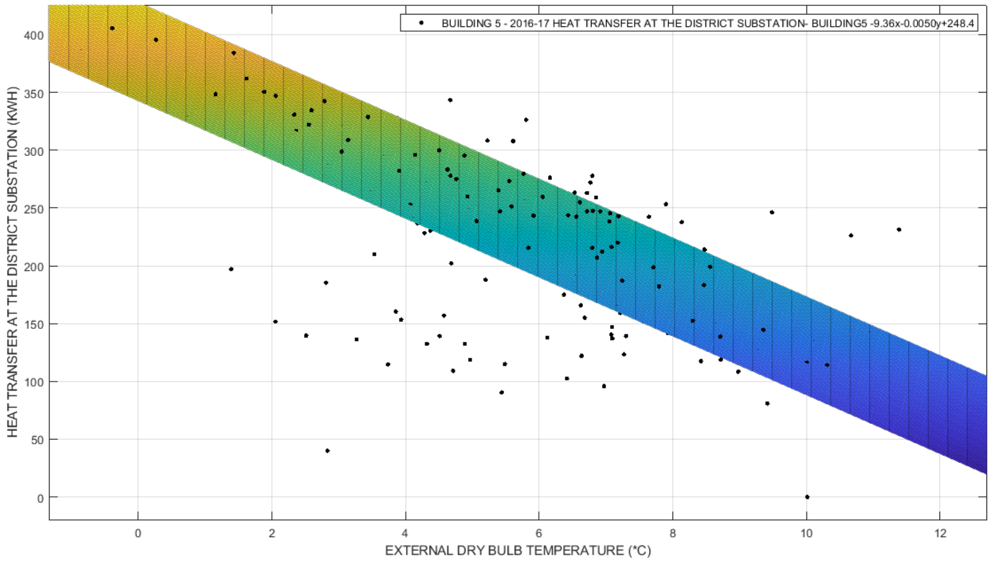


FIGURE 63 - BUILDING 5 - 2016-17 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS- XZ

In figure 63, it was very important to understand the relation of the external temperature and the energy demand. We can also understand that there is very important correlation between how the external dry bulb temperature can highly affect the heating demand of a building.

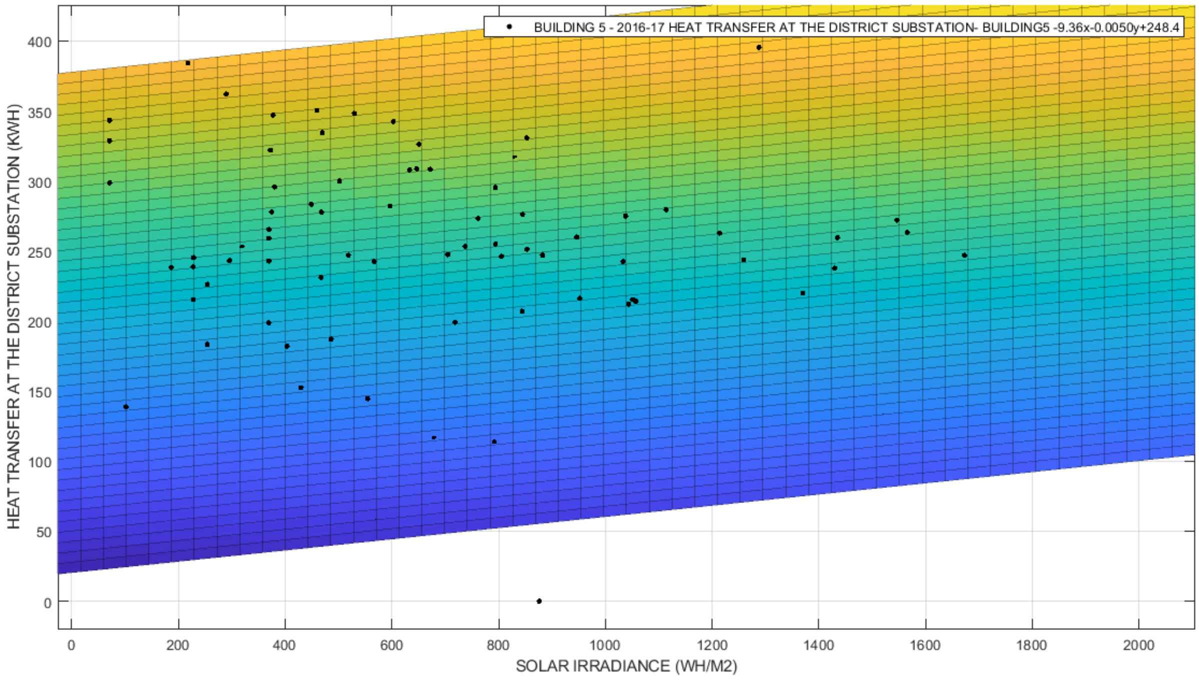


FIGURE 64 - BUILDING 5 - 2016-17 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS- YZ

Similarly, in figure 64, for the irradiance, it is important to know that it can change the external dry bulb temperature, which eventually means that there is correlation with the energy demand of the building.

### 7.3.2.4. BUILDING 5 (2017-18)

After further investigation, it was noticed that there has been a significant change in the $r^2$ value for this time-period. The $r^2$ 0.58 which is moderate improvement from the previous analysis.

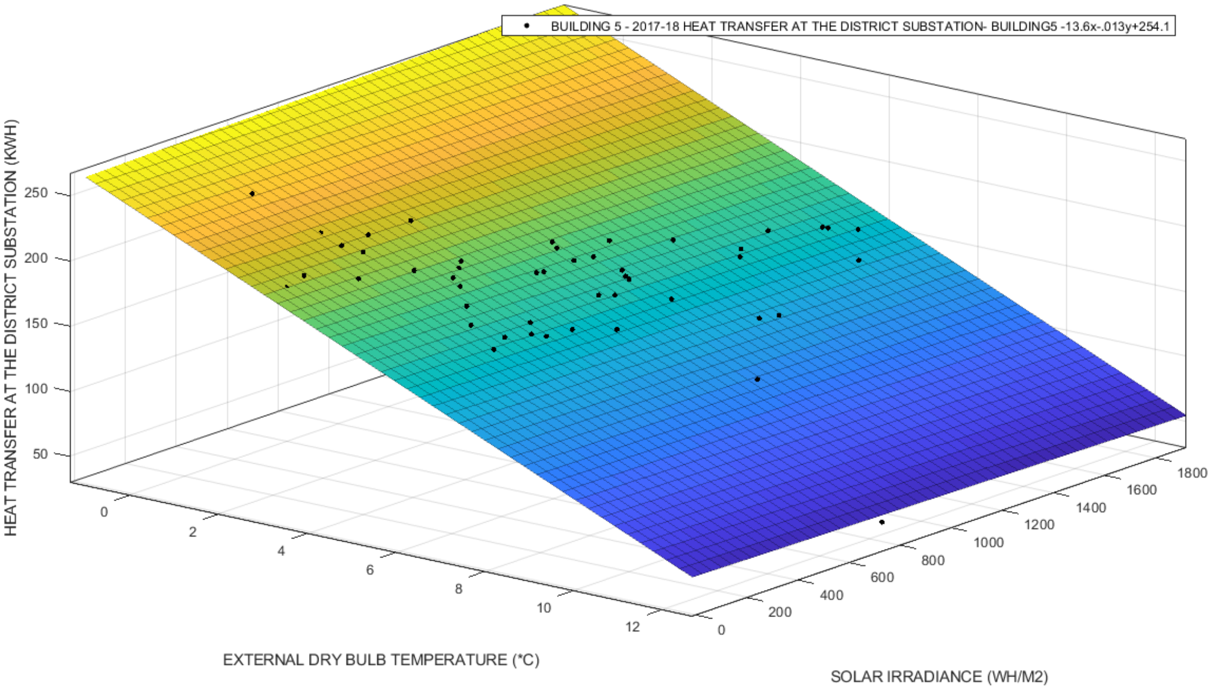


FIGURE 65 - BUILDING 5 - 2017-18 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS - XYZ

In figure 65, we see that there are a few points which seem to be displaced and there is a requirement to have a closer investigation in term of the data analysis. A closer study will be carried to understand why there is such a variance in the data. A closer study can be carried in terms of the on-off cycle and the analysis period.

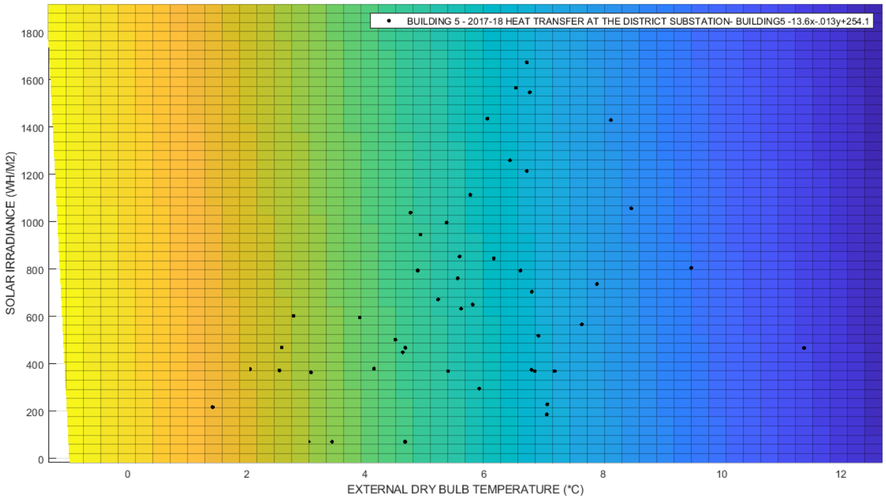


FIGURE66 - BUILDING 5 - 2017-18 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS - XY

In figure 66, it was very important to understand the relation of the external dry bulb temperature and the irradiance even though we are looking their relation in terms of the energy demand of the building. Through this depiction, to a certain limit a relation between for irradiance and temperature can be made for a certain energy demand.

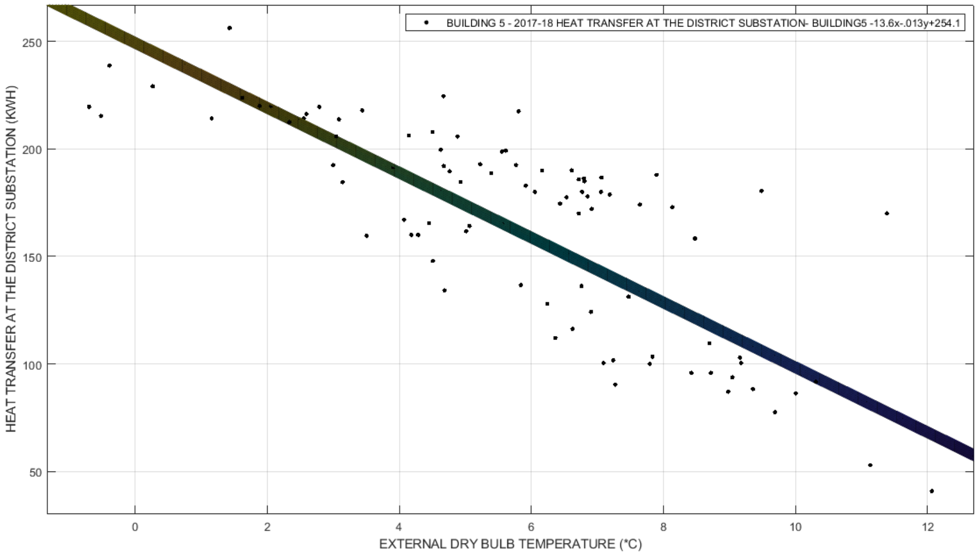


FIGURE67 - BUILDING 5 - 2017-18 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS - XZ

In figure 67, it was very important to understand the relation of the external temperature and the energy demand. We can also understand that there is very important correlation between how the external dry bulb temperature can highly affect the heating demand of a building.

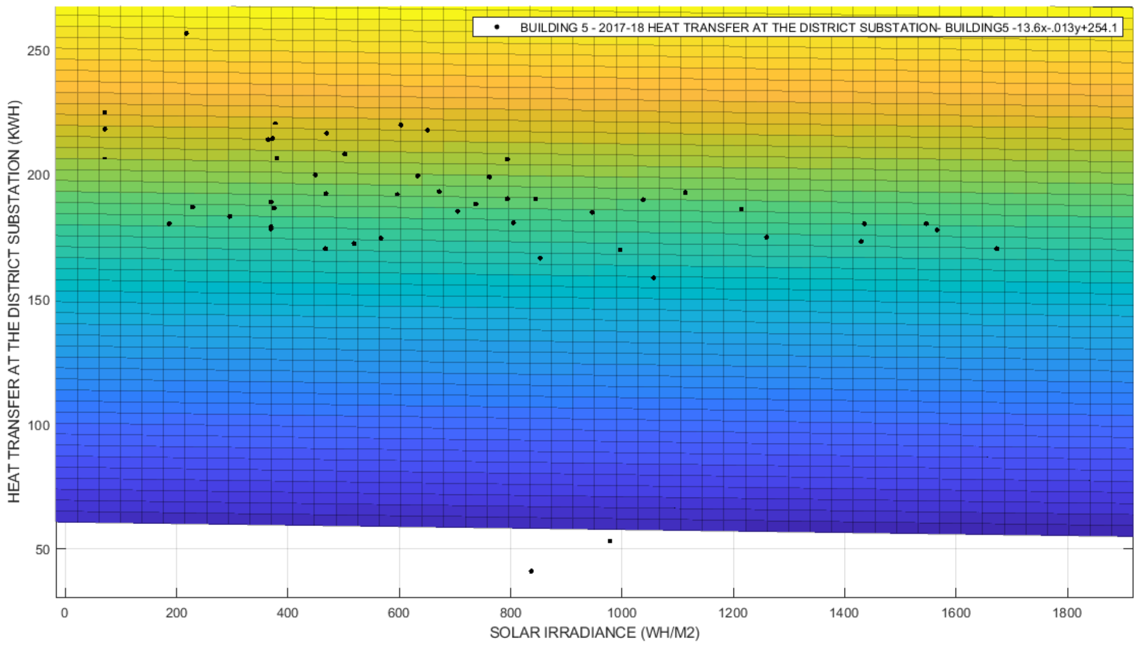


FIGURE68 - BUILDING 5 - 2017-18 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS - YZ

Similarly, in figure 68, for the irradiance, it is important to know that it can change the external dry bulb temperature, which eventually means that there is correlation with the energy demand of the building.

### 7.3.2.5. BUILDING 11 (2016-17)

After considering the working time as 6 am to 6 pm and neglecting all holidays and weekend, there has been a significant improvement in $r^2$ to 0.97

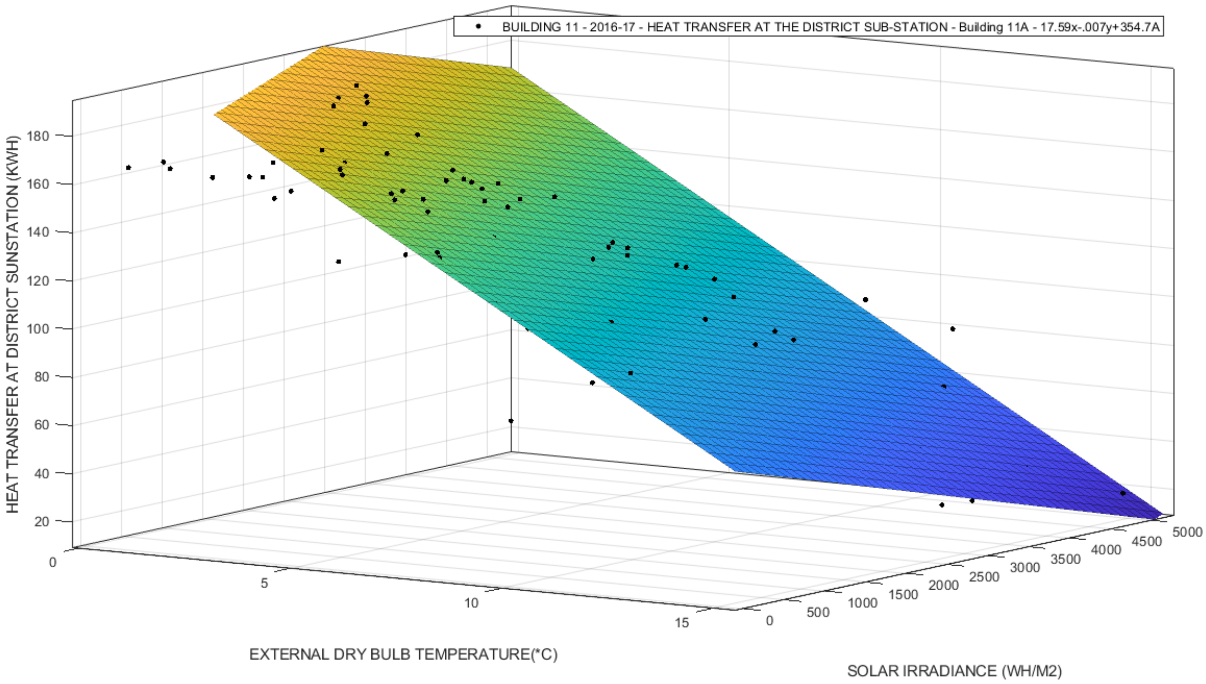


FIGURE 69 - BUILDING 11 - 2016-17 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS - XYZ

In figure 69, we see that there are a few points which seem to be displaced and there is a requirement to have a closer investigation in term of the data analysis. A closer study will be carried to understand why there is such a variance in the data. A closer study can be carried in terms of the on-off cycle and the analysis period.

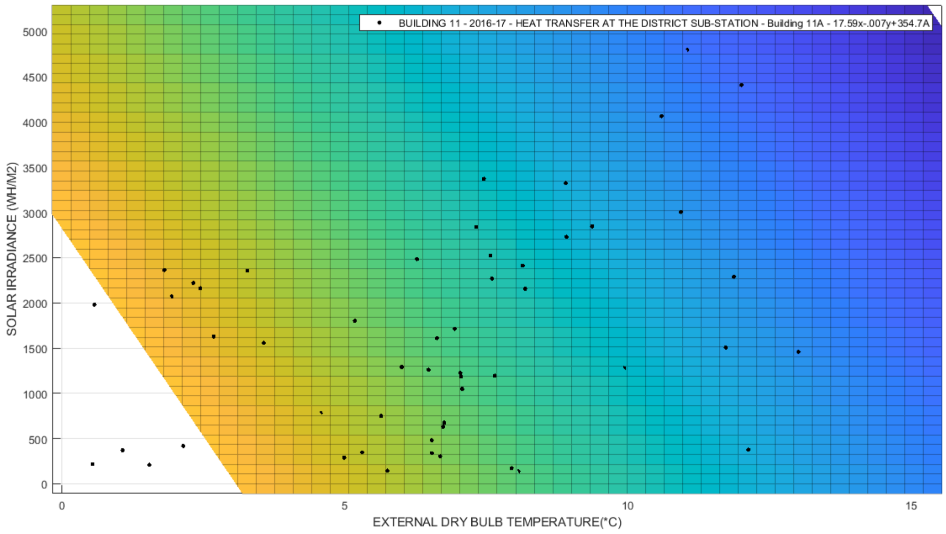


FIGURE 70 - BUILDING 11 - 2016-17 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS - XY

In figure 70, it was very important to understand the relation of the external dry bulb temperature and the irradiance even though we are looking their relation in terms of the energy demand of the building. Through this depiction, to a certain limit a relation between for irradiance and temperature can be made for a certain energy demand.

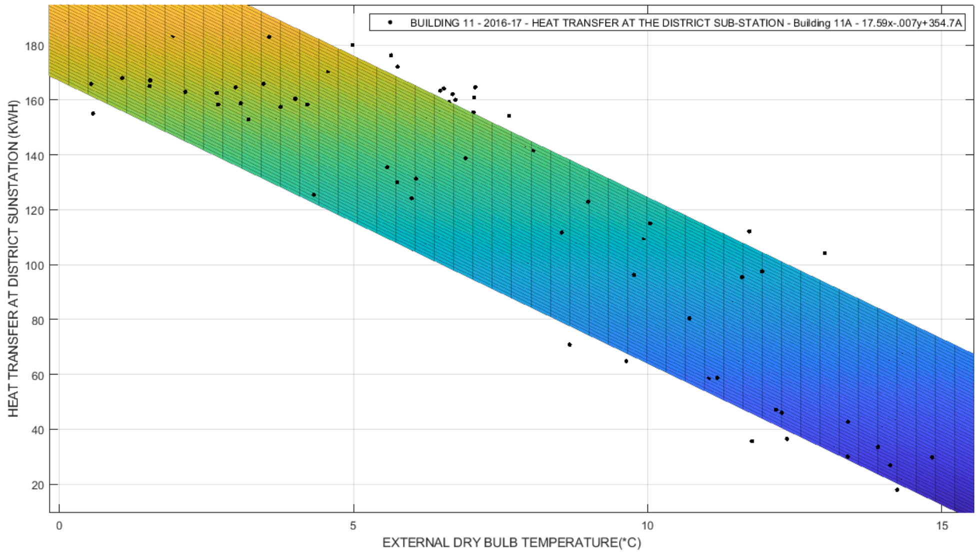


FIGURE 71 - BUILDING 11 - 2016-17 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS - XZ

In figure 71, it was very important to understand the relation of the external temperature and the energy demand. We can also understand that there is very important correlation between how the external dry bulb temperature can highly affect the heating demand of a building.

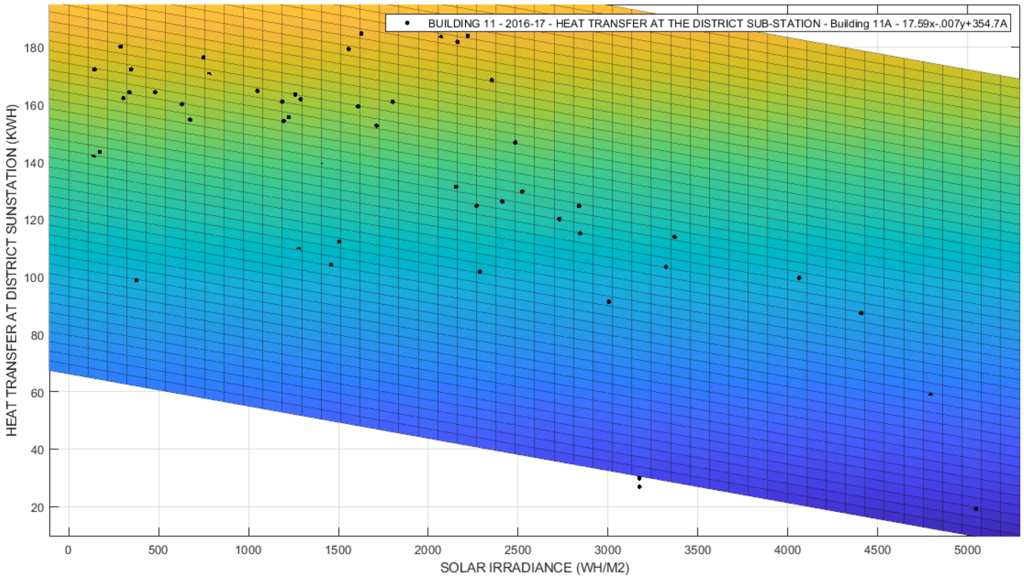


FIGURE 72 - BUILDING 11 - 2016-17 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS - YZ

Similarly, in figure 72, for the irradiance, it is important to know that it can change the external dry bulb temperature, which eventually means that there is correlation with the energy demand of the building.

### 7.3.2.6. BUILDING 11 (2017-18)

After further investigation, it was noticed that there has been a significant change in the $r^2$ value for this time-period. The $r^2$ 0.67 which is moderate improvement from the previous analysis.

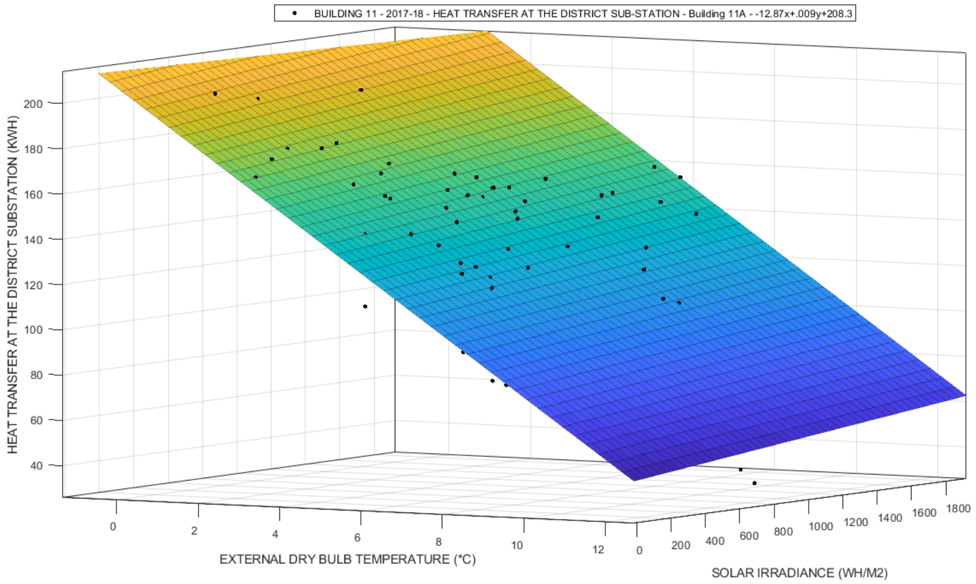


FIGURE 73 - BUILDING 11 - 2017-18 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS - XYZ

In figure 73, we see that there are a few points which seem to be displaced and there is a requirement to have a closer investigation in term of the data analysis. A closer study will be carried to understand why there is such a variance in the data. A closer study can be carried in terms of the on-off cycle and the analysis period.

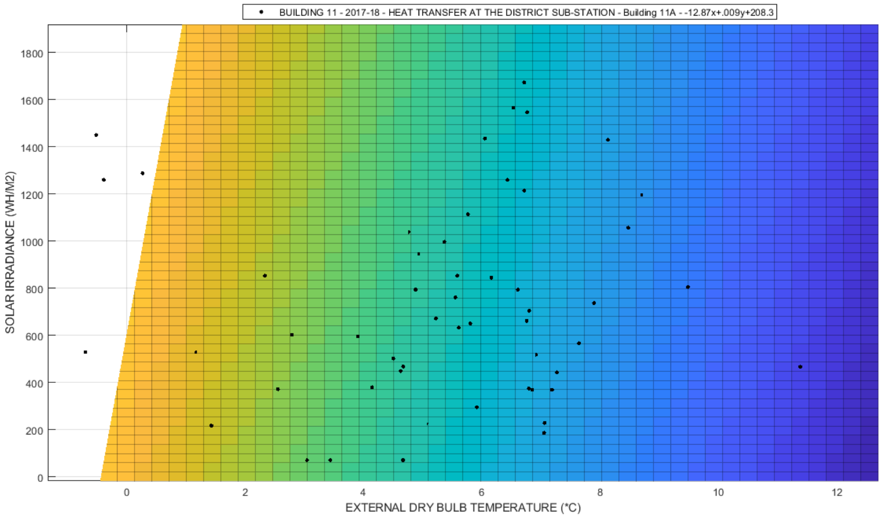


FIGURE 74 - BUILDING 11 - 2017-18 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS - XY

In figure 74, it was very important to understand the relation of the external dry bulb temperature and the irradiance even though we are looking their relation in terms of the energy demand of the building. Through this depiction, to a certain limit a relation between for irradiance and temperature can be made for a certain energy demand.

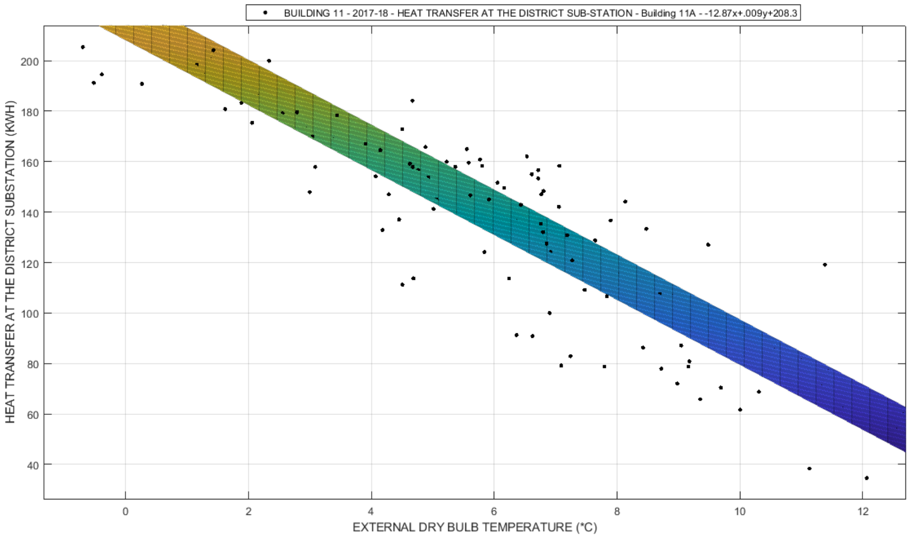


FIGURE 75 - BUILDING 11 - 2017-18 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS - XZ

In figure 75, it was very important to understand the relation of the external temperature and the energy demand. We can also understand that there is very important correlation between how the external dry bulb temperature can highly affect the heating demand of a building.

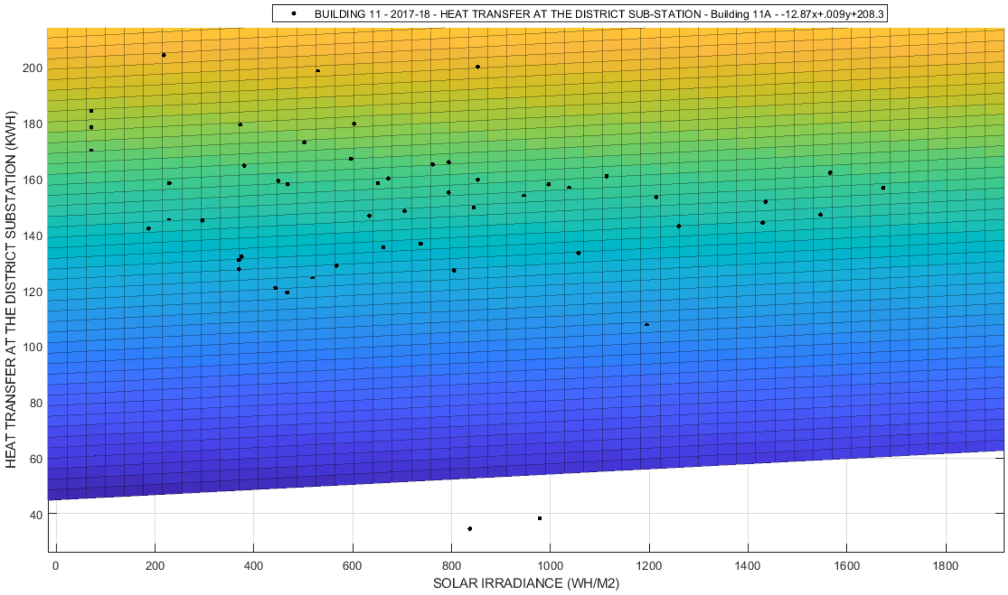


FIGURE 76 - BUILDING 11 - 2017-18 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS - YZ

Similarly, in figure 76, for the irradiance, it is important to know that it can change the external dry bulb temperature, which eventually means that there is correlation with the energy demand of the building.

#### 7.3.2.7. BUILDING 14 (2016-17)

After considering the working time as 6 am to 6 pm and neglecting all holidays and weekend, there has been a significant improvement in $r^2$ to 0.98.

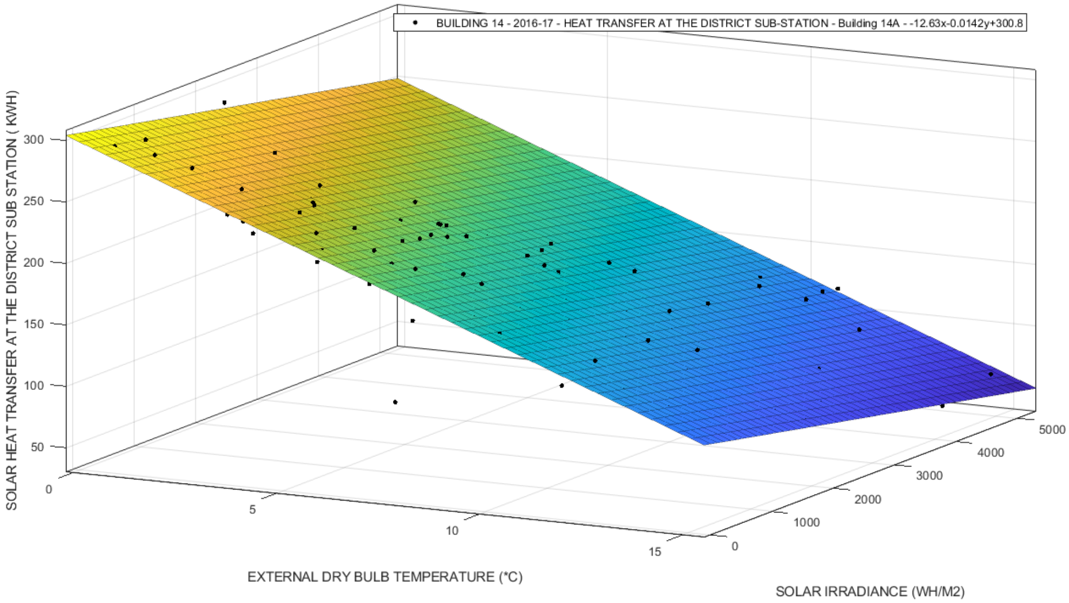


FIGURE 77 - BUILDING 14 - 2016-17 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS - XYZ

In figure 77, we see that there are a few points which seem to be displaced and there is a requirement to have a closer investigation in term of the data analysis. A closer study will be carried to understand why there is such a variance in the data. A closer study can be carried in terms of the on-off cycle and the analysis period.

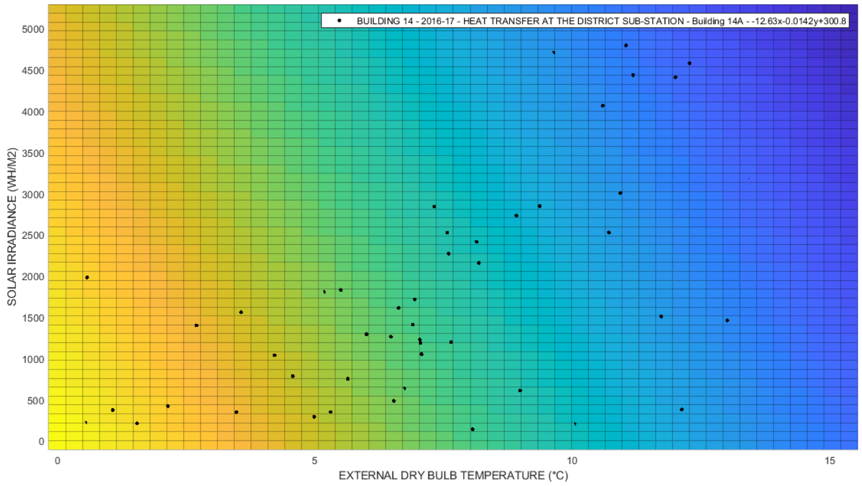


FIGURE 78 - BUILDING 14 - 2016-17 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS - XY

In figure 78, it was very important to understand the relation of the external dry bulb temperature and the irradiance even though we are looking their relation in terms of the energy demand of the building. Through this depiction, to a certain limit a relation between for irradiance and temperature can be made for a certain energy demand.

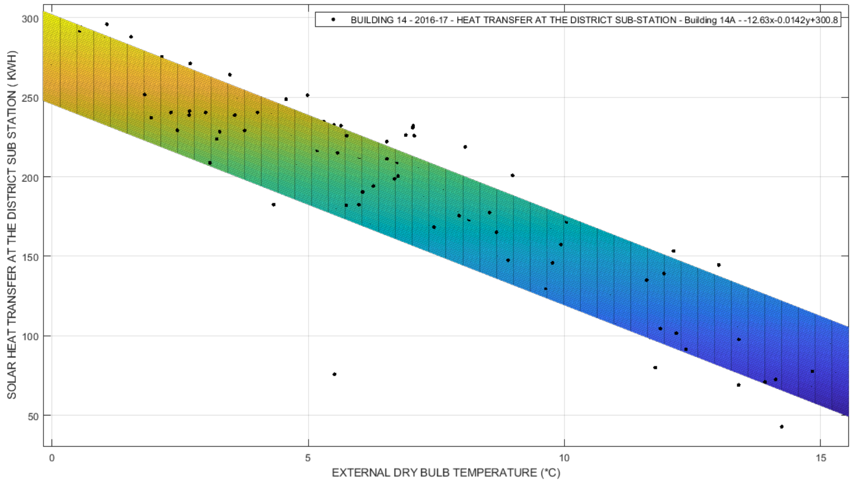


FIGURE 79 - BUILDING 14 - 2016-17 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS - XZ

In figure 79, it was very important to understand the relation of the external temperature and the energy demand. We can also understand that there is very important correlation between how the external dry bulb temperature can highly affect the heating demand of a building.

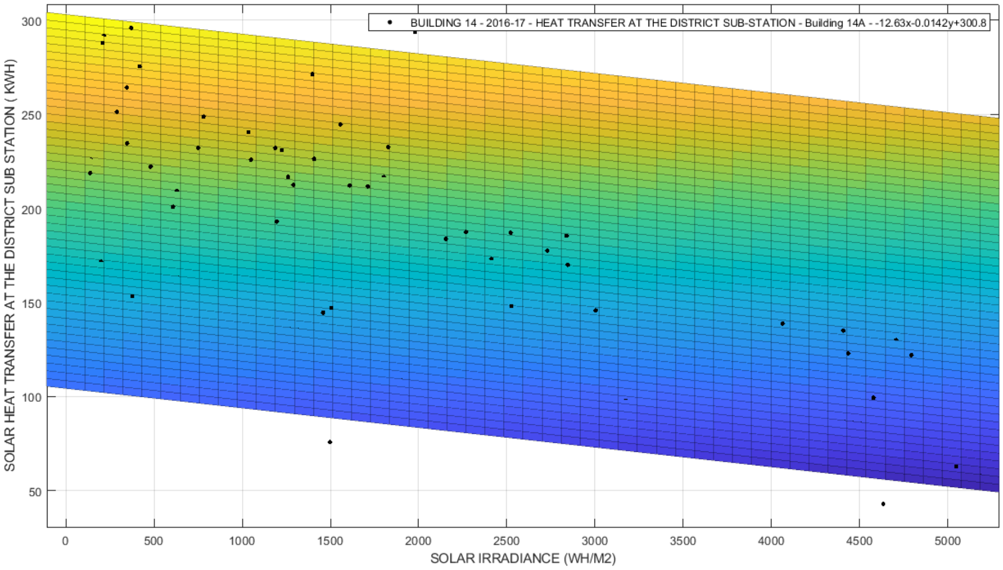


FIGURE 80 - BUILDING 14 - 2016-17 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS - YZ

Similarly, in figure 80, for the irradiance, it is important to know that it can change the external dry bulb temperature, which eventually means that there is correlation with the energy demand of the building.

### 7.3.2.8. BUILDING 14 (2017-18)

After further investigation, it was noticed that there has been a significant change in the $r^2$ value for this time-period. The $r^2$ is 0.66 which is moderate improvement from the previous analysis.

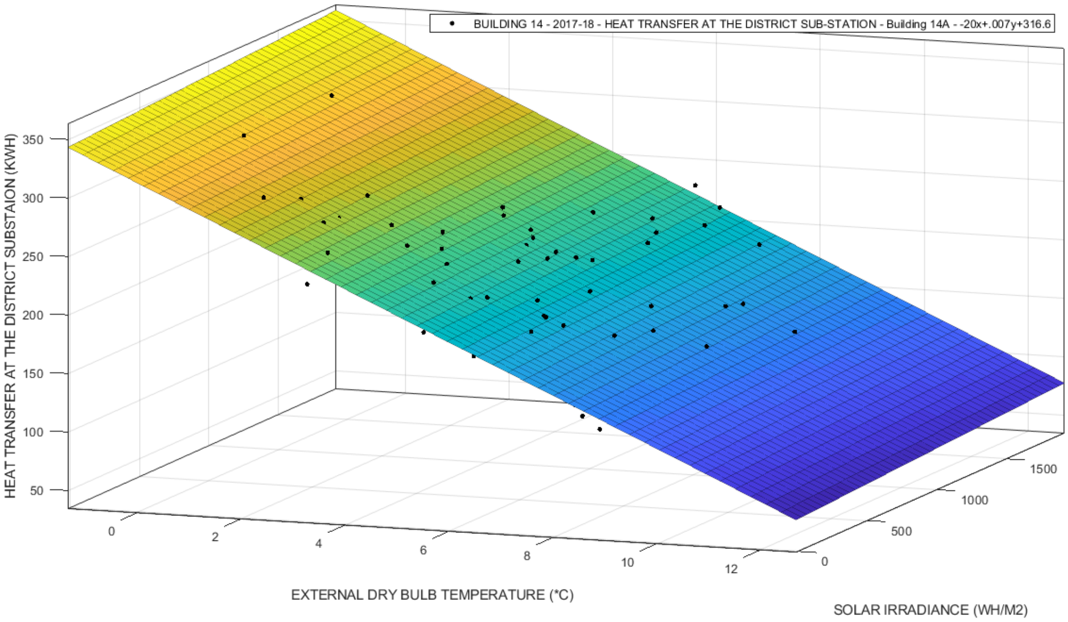


FIGURE 81 - BUILDING 14 - 2017-18 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS - XYZ

In figure 81, we see that there are a few points which seem to be displaced and there is a requirement to have a closer investigation in term of the data analysis. A closer study will be carried to understand why there is such a variance in the data. A closer study can be carried in terms of the on-off cycle and the analysis period.

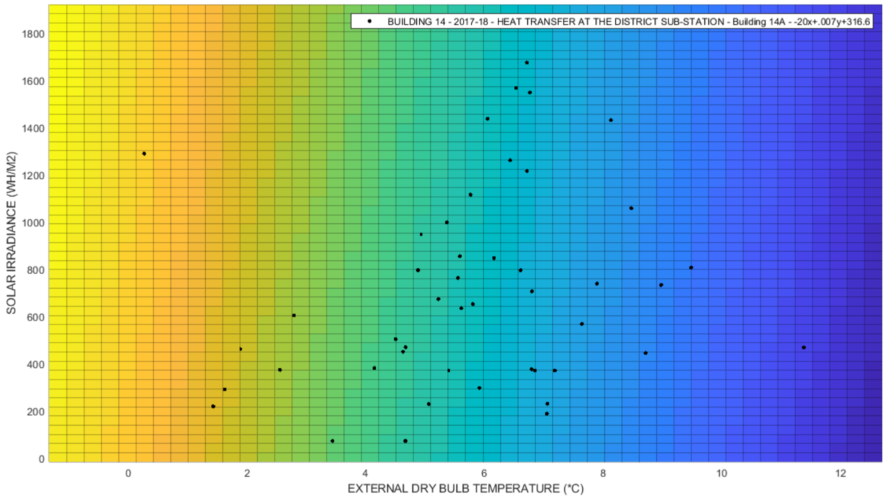


FIGURE 82 - BUILDING 14 - 2017-18 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS - XY

In figure 82, it was very important to understand the relation of the external dry bulb temperature and the irradiance even though we are looking their relation in terms of the energy demand of the building. Through this depiction, to a certain limit a relation between for irradiance and temperature can be made for a certain energy demand.

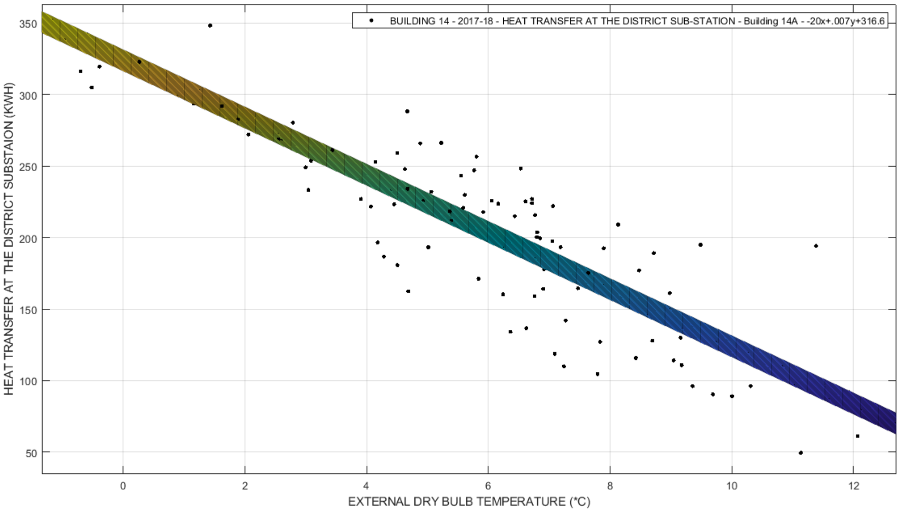


FIGURE 83 - BUILDING 14 - 2017-18 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS - XZ

In figure 83, it was very important to understand the relation of the external temperature and the energy demand. We can also understand that there is very important correlation between how the external dry bulb temperature can highly affect the heating demand of a building.

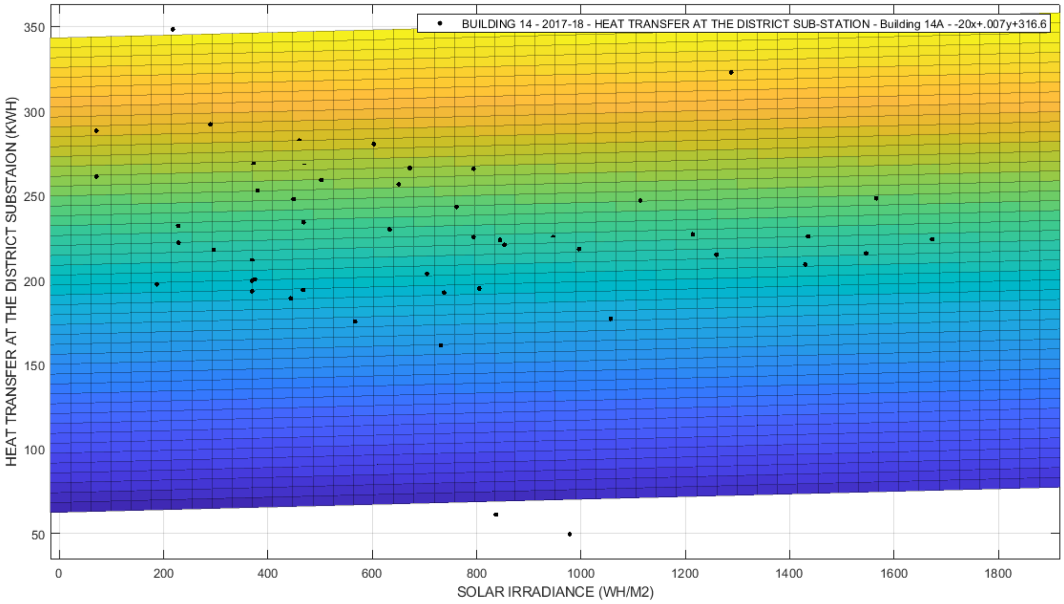


FIGURE 84 - BUILDING 14 - 2017-18 – NO WEEKENDS AND HOLIDAYS 0600:1800 HRS - YZ

Similarly, in figure 84, for the irradiance, it is important to know that it can change the external dry bulb temperature, which eventually means that there is correlation with the energy demand of the building.

## 7.3.3. ANALYSIS SUMMARY

The standard equation used for the analysis is $f(x, y) = A * x + B * y + C$ where x and y are the dependent variables. X is the external dry bulb temperature (*c) and y is the solar irradiance (Wh/m2)

| Name | $R^2$ (2016- 17) | $R^2$ (2016- 17) _new | Equation (2016-17) | Equation (2016-17) _ new |
|---|---|---|---|---|
| Building 1 | 0.66 | 0.98 | -220x – 0.12y+4440 | -6.9x-0.003y+143 |
| Building 5 | 0.87 | 0.88 | -481x-.23y+10520 | -9.36x-0.0050y+248.4 |
| Building 11 | 0.76 | 0.97 | -406.8x-.20y+8579 | -10.27x-.011y+226.3 |
| Building 14 | 0.64 | 0.98 | -570.2x-.02y+10610 | -12.36x-0.0142y+300.8 |

TABLE 3 - ANALYSIS SUMMERY 2017-18

$R^2$ (2016- 17) -the coefficient of determination for the year 2016-17 with holidays and weekends. The whole is considered for evaluation

$R^2$ (2016- 17) _new - the coefficient of determination for the year 2016-17 without holidays and weekends. Only 0600-1800 hrs is considered.

Equation (2016-17) – correlation equation for the year 2016-17 with holidays and weekends. The whole is considered for evaluation

Equation (2016-17) _ new- correlation equation for the year 2016-17 without holidays and weekends. Only 0600-1800 hrs is considered.

| Name | $R^2$ (2017- 18) | $R^2$ (2017- 18) _new | Equation (2017-18) | Equation (2017-18) _ new |
|---|---|---|---|---|
| Building 1 | 0.47 | 0.76 | -273.8x +0.25y +4481 | -7.3x-.0064y+151.6 |
| Building 5 | 0.41 | 0.58 | -539.4x+.77y+7856 | -13.6x-.013y+254.1 |
| Building 11 | 0.61 | 0.67 | -437.4x+.301+7788 | -12.35x+.008y+207 |
| Building 14 | .25 | 0.67 | -543.8x + 1.467+7533 | -18.35x+.0002y+315.5 |

TABLE 4 - ANALYSIS SUMMERY 2017-18

$R^2$ (2017- 18) -the coefficient of determination for the year 2017-18 with holidays and weekends. The whole is considered for evaluation

$R^2$ (2017- 18) _new - the coefficient of determination for the year 2017-18 without holidays and weekends. Only 0600-1800 hrs is considered.

Equation (2017-18) – correlation equation for the year 2017-18 with holidays and weekends. The whole is considered for evaluation

Equation (2017-18) _ new- correlation equation for the year 2017-18 without holidays and weekends. Only 0600-1800 hrs is considered.

The tables above clearly explain how the data and the equations have change and improved with the interventions planned. After understanding the data, it is going to inserted with respect to the 2017-18 temperature and irradiance to see how it effects the data analysis and if it holds good.

Since we understand how the data changes based on application of the building, orienatation and time-step. In the next section we will see how the equations for the year 2016-17 for each building with the no weekends, holidays considered and a working time of 06:00 hrs to 18:00 hrs. This will give us a good insight of how well our prediction works.

## 7.3.4. PREDICTED VS ACTUAL RESULTS

This section talks about the monthly data of the year 2017-18 is used to check if our forecasting using the 2016-17 data is okay for future forecasting.

Here, the comparison of the heat transfer at the district heating substation is looked at and there is reasonably high r^2 value which is promising. This shows that there is relatively high correlation **where the equations are used** as a predicting tool. The methodology considered was to use the equation developed using the data of 2016-17 where **x is the external dry bulb temperature(*c) and y is the solar-irradiance (Wh/m2)**.

Once the equation was developed, the same equation was used with the x and y data of 2017-18 in ordered to get the predicted (2017-18) values. Once the values were calculated an average monthly value is calculated and compared to the actual 2017-18 values. This is a good way to see if the data is a good predictive tool.

Based on this assumption, the table below clearly explains that the data analysis and assumptions are accurate. The boundary condition considered is 0600 – 1800 hrs working hours, 1-hour time step and no holidays and weekends are considered.

The tables and graphs represent the following:

- Actual 2017-18 (kWh) – Actual Heat Transfer at the district Substation for the year 2017-18
- Predicted 2017-18 (kWh) – Predicted Heat Transfer at the district Substation for the year 2017-18.

### *BUILDING 1*

.

The equation used for prediction is **-6.9x-0.003y+143**

| Month | Actual 2017-2018 (kWh) | Predicted (2017-18) (kWh) |
|---|---|---|
| November | 82.06 | 85.79 |
| December | 134.11 | 120.27 |
| January | 100.02 | 92.38 |
| Feb | 110.58 | 103.74 |
| March | 96.41 | 103.37 |

TABLE 5 - HEAT TRANSFER AT THE DISTRICT HEATING SUBSTATION (KWH) ACTUAL VS PREDICTED (2017-18) - BUILDING 1

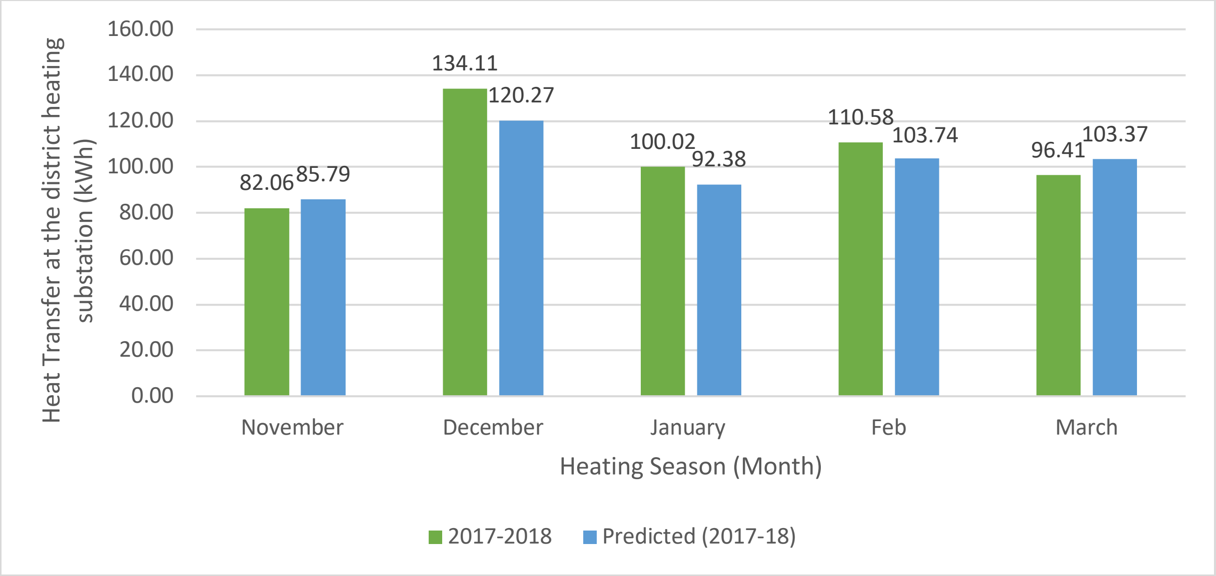


FIGURE 85 - HEAT TRANSFER AT THE DISTRICT HEATING SUBSTATION (KWH)ACTUAL VS PREDICTED (2017-18) - BUILDING 1

Looking at the graphical representation of the heat transfer at the district heating substation, the monthly predicted values for the january, february and march have a very close relationship between the actual and predicted values. November and december have a little divergence because of the change in the weather pattern in the input parameters.

To further understand the accuracy of the prediction a regression model with a 3d chart has been developed.

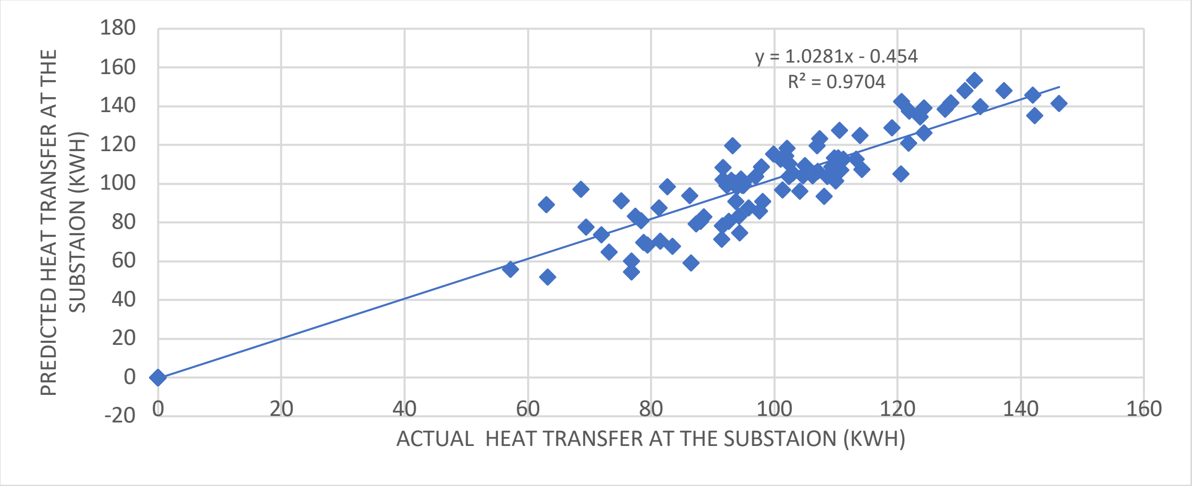


FIGURE 86 - ACTUAL VS PREDICTED HEAT TRANSFER LINEAR REGRESSION MODEL - BUILDING 1

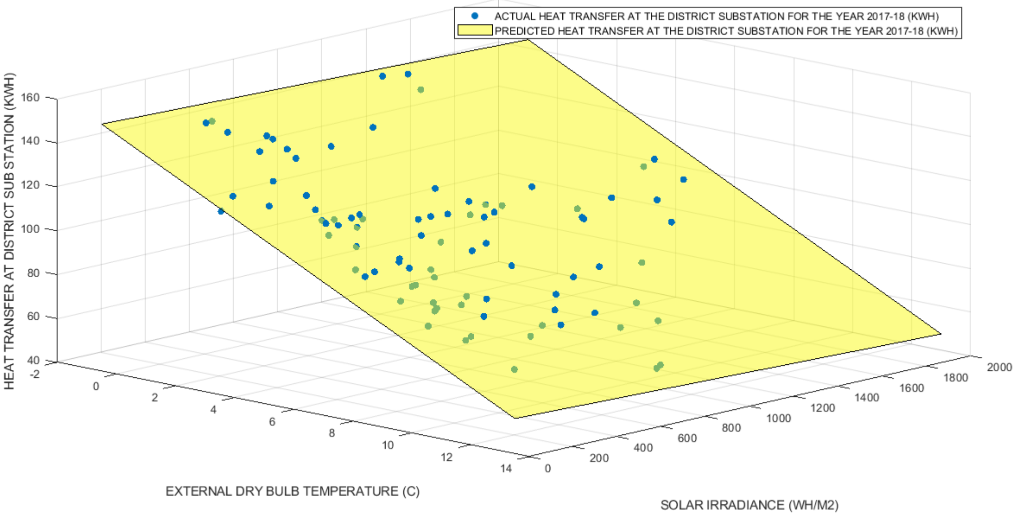


FIGURE 87 - ACTUAL VS PREDICTED HEAT TRANSFER AT THE DISTRICT SUBSTATION – XYZ

The above representation in figure 87 represents the actual heat transfer at the district substation represented in the blue scatter and the plane in yellow represents the predicted heat transfer considering the equation **-6.9x-0.003y+143.** It was important to understand the representation to see how accurate the prediction is.

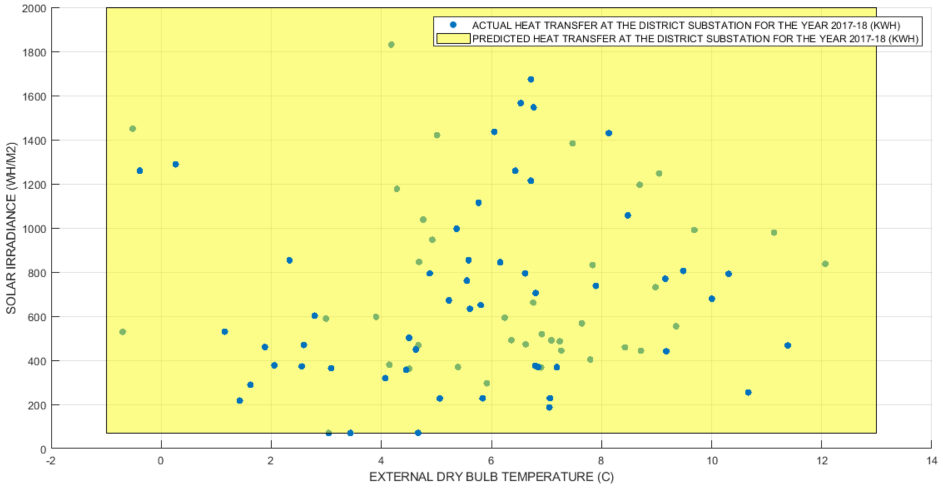


FIGURE 88 - ACTUAL VS PREDICTED HEAT TRANSFER AT THE DISTRICT SUBSTATION - XY

In addition to the 3d representation, in scatter in figure 88 highlights how the dry bulb temperature and solar irradiance relate to each for a fixed heat transfer at the district sub-station. This plot helps us understand the data analysis deeper and more presisely.

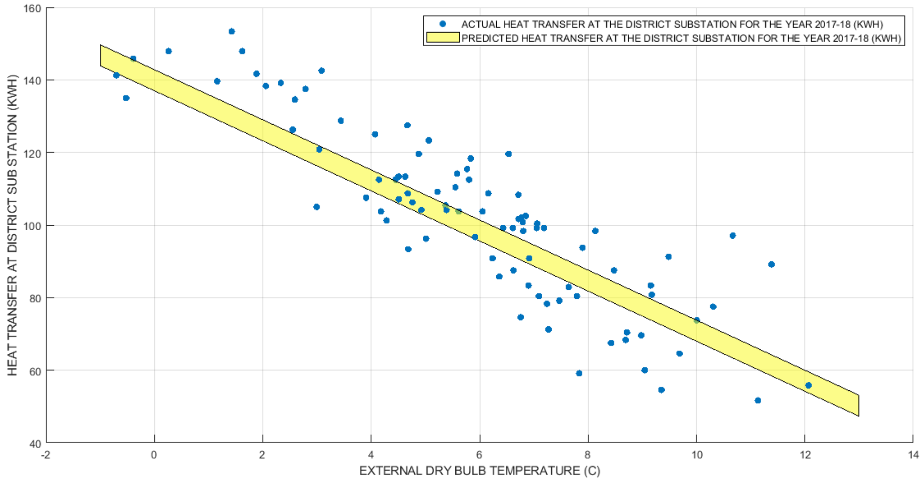


FIGURE 89 - ACTUAL VS PREDICTED HEAT TRANSFER AT THE DISTRICT SUBSTATION - XZ

Like figure 88, the scatter in figure 89 helps us look at the heat transfer at the sub-station with respect to the dry-bulb temperature. This data is with respect to the corresponding solar irradiance.

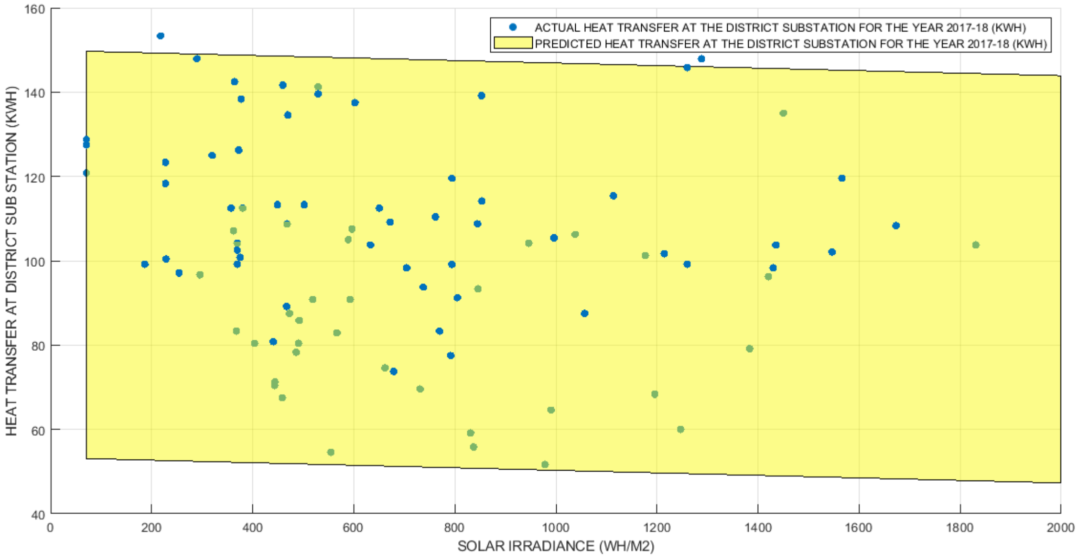


FIGURE 90 - ACTUAL VS PREDICTED HEAT TRANSFER AT THE DISTRICT SUBSTATION – YZ

Like figure 88 and 89, the scatter in figure 90 helps us look at the heat transfer at the sub-station with respect to the solar irradiance. This data is with respect to the corresponding dry bulb temperature.

To understand the how precise and how accurate this model is to predict future demand this regression model shows that the predicted vs actual heat transfer at the district substation for the administrative block is on the higher side because of the very controlled occupancy rate of the building. The orientation also plays a very big role in the high $r^2$ of 0.97.

Building 1 being an admistrative building has less uncertainties as compared to the other buildings under consideration because of the occupancy rate of the building. The occupancy of the building and the time of peak usage is very predictable. Hence there is less uncertainity in terms of the heat transfer.

### *BUILDING 5*

The equation used for prediction is **-9.36x-0.0050y+248.**

| Month | Actual 2017-2018 (kWh) | Predicted (2017-18) (kWh) |
|---|---|---|
| November | 104.31 | 170.27 |
| December | 207.63 | 216.91 |
| January | 186.74 | 181.24 |
| Feb | 193.48 | 194.28 |
| March | 153.61 | 193.65 |

TABLE 6 - HEAT TRANSFER AT THE DISTRICT HEATING SUBSTATION (KWH)ACTUAL VS PREDICTED (2017-18) - BUILDING 5

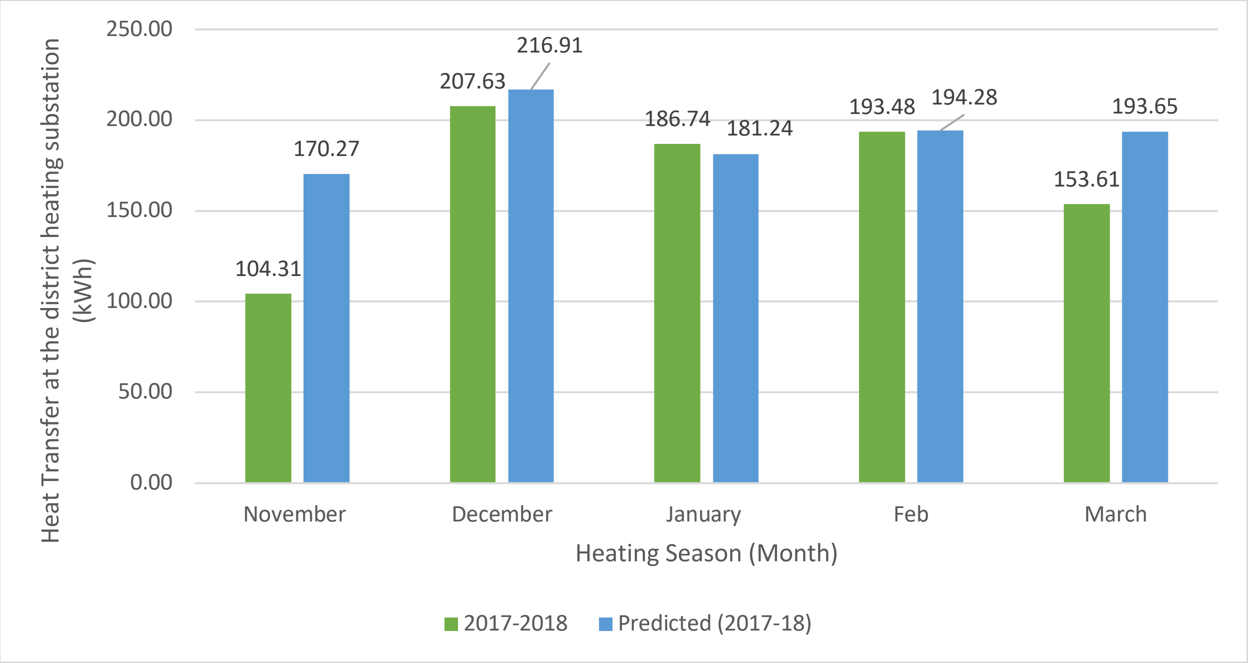


FIGURE 91 - HEAT TRANSFER AT THE DISTRICT HEATING SUBSTATION (KWH)ACTUAL VS PREDICTED (2017-18) - BUILDING 5

Looking at the graphical representation of the heat transfer at the district heating substation, the monthly predicted values for the january, february and march have a very close relationship between the actual and predicted values. November and december have a little divergence because of the change in the weather pattern in the input parameters.

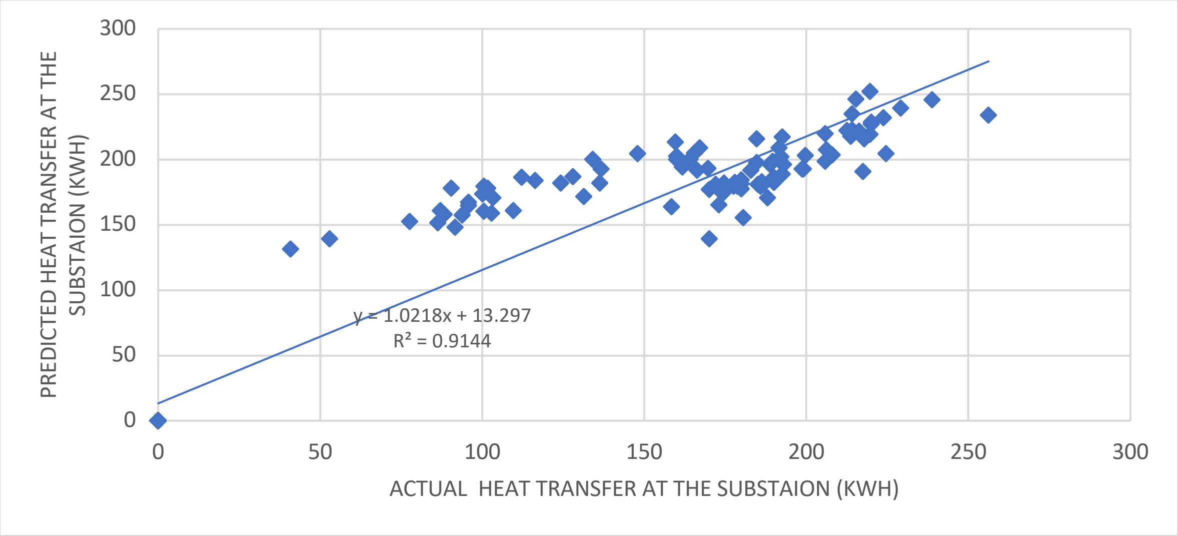


FIGURE 92 - ACTUAL VS PREDICTED HEAT TRANSFER LINEAR REGRESSION MODEL - BUILDING 5

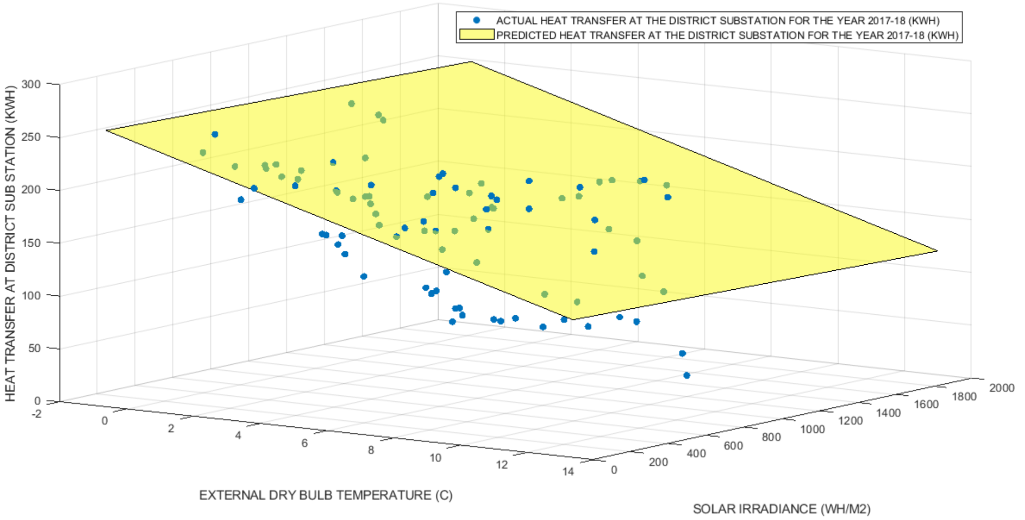


FIGURE 93 - ACTUAL VS PREDICTED HEAT TRANSFER AT THE DISTRICT SUBSTATION – XYZ

The above representation in figure 93 represents the actual heat transfer at the district substation represented in the blue scatter and the plane in yellow represents the predicted heat transfer considering the equation -9.36x-0.0050y+248. It was important to understand the representation to see how accurate the prediction is.

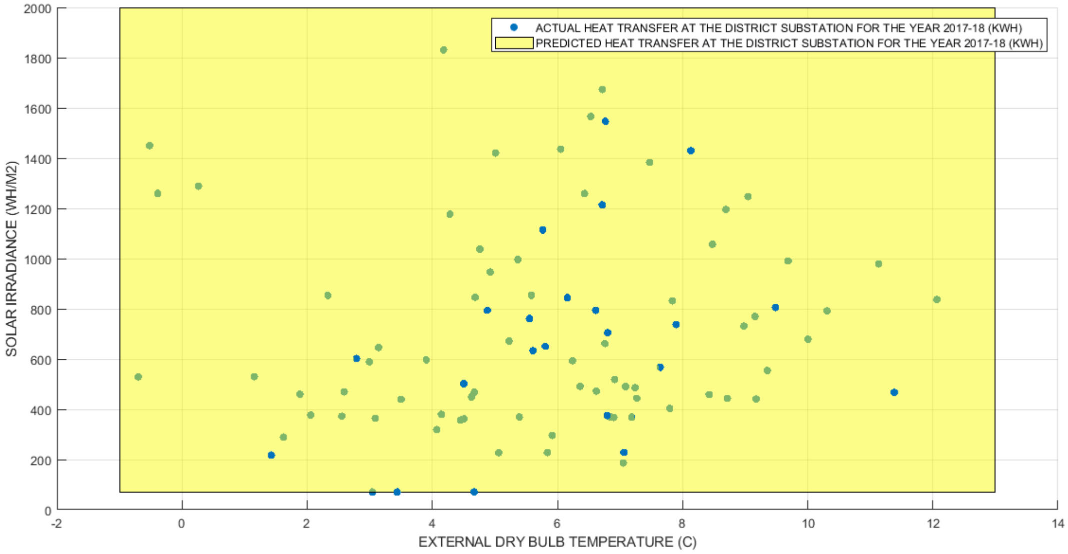


FIGURE 94 - ACTUAL VS PREDICTED HEAT TRANSFER AT THE DISTRICT SUBSTATION - XY

In addition to the 3d representation, in scatter in figure 94 highlights how the dry bulb temperature and solar irradiance relate to each for a fixed heat transfer at the district sub-station. This plot helps us understand the data analysis deeper and more presisely.

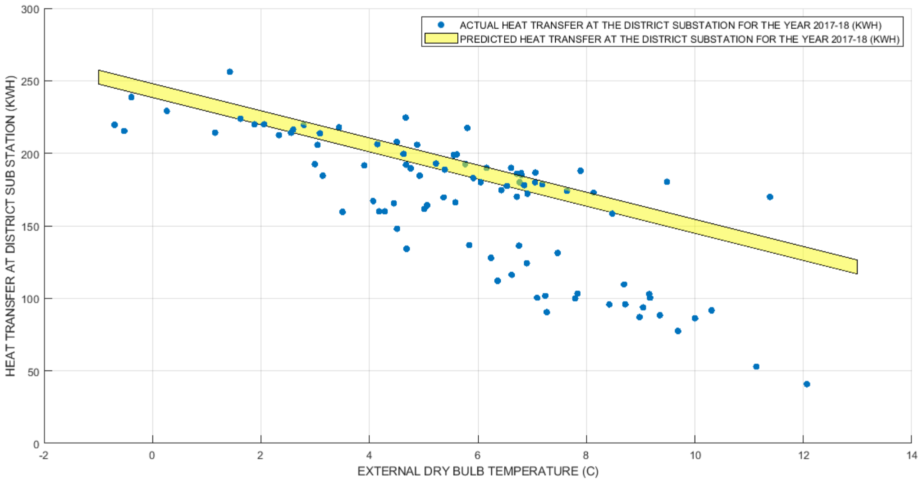


FIGURE 95 - ACTUAL VS PREDICTED HEAT TRANSFER AT THE DISTRICT SUBSTATION – XZ

Like figure 94, the scatter in figure 95 helps us look at the heat transfer at the sub-station with respect to the dry-bulb temperature. This data is with respect to the corresponding solar irradiance.

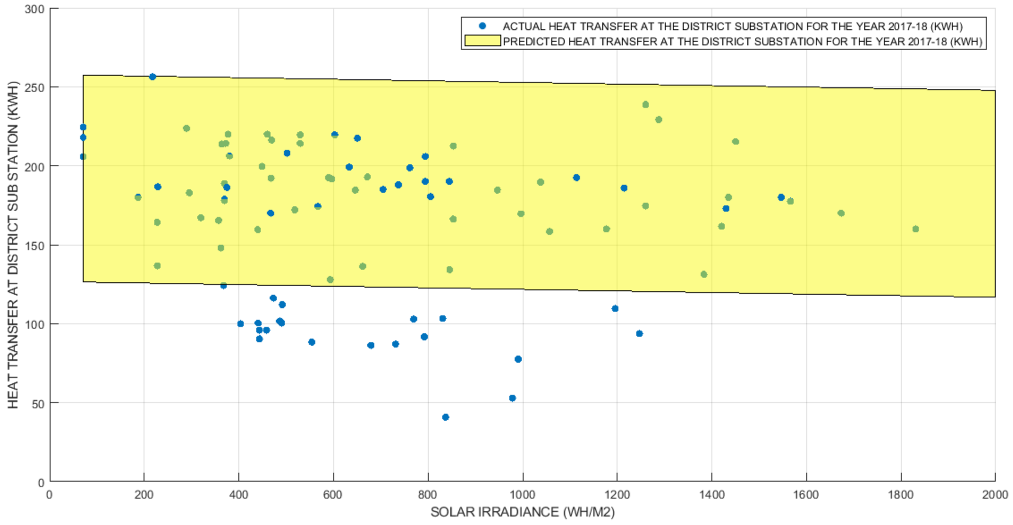


FIGURE 96 - ACTUAL VS PREDICTED HEAT TRANSFER AT THE DISTRICT SUBSTATION - YZ

Like figure 94 and 95, the scatter in figure 96 helps us look at the heat transfer at the sub-station with respect to the solar irradiance. This data is with respect to the corresponding dry bulb temperature.

Building no 5 is more unpredictable as compared to the administrative block because it involves occupancy by students which is more unpredictable. But the fact that there is a civil and structural lab within the building has a very high demand of a controlled heating environment. The $r^2$ of 0.91 show that the value that is predicted to through the multiple regression model is relatively accurate.

In building 5 it is very important to realise that, this building contains classrooms, offices and laboratories. This makes the space conditioning more controlled in this building because of the research activities carried out.

### *BUILDING 11*

The equation used for prediction is **-10.27x-.011y+226.3**

| Month | Actual 2017-2018 (kWh) | Predicted (2017-18) (kWh) |
|---|---|---|
| November | 87.18 | 137.48 |
| December | 177.41 | 190.02 |
| January | 140.54 | 149.62 |
| Feb | 160.69 | 161.82 |
| March | 137.78 | 160.38 |

TABLE 7 - HEAT TRANSFER AT THE DISTRICT HEATING SUBSTATION (KWH)ACTUAL VS PREDICTED (2017-18) - BUILDING 11

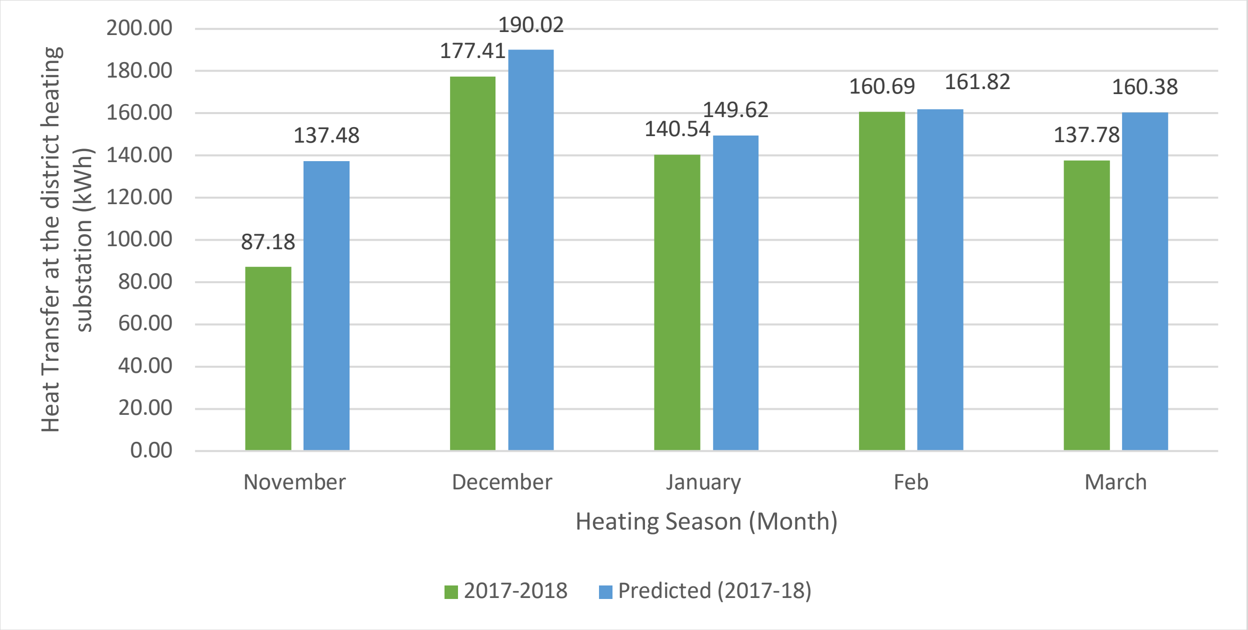


FIGURE 97 - HEAT TRANSFER AT THE DISTRICT HEATING SUBSTATION (KWH)ACTUAL VS PREDICTED (2017-18) - BUILDING 11

Looking at the graphical representation of the heat transfer at the district heating substation, the monthly predicted values for the january, february and march have a very close relationship between the actual and predicted values. November and december have a little divergence because of the change in the weather pattern in the input parameters.

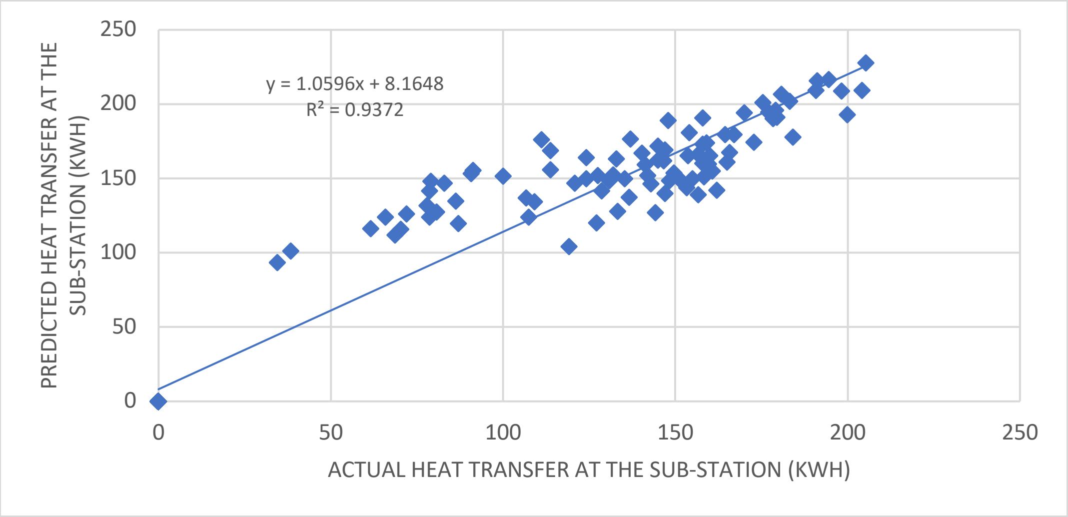


FIGURE 98 - ACTUAL VS PREDICTED HEAT TRANSFER LINEAR REGRESSION MODEL - BUILDING 11

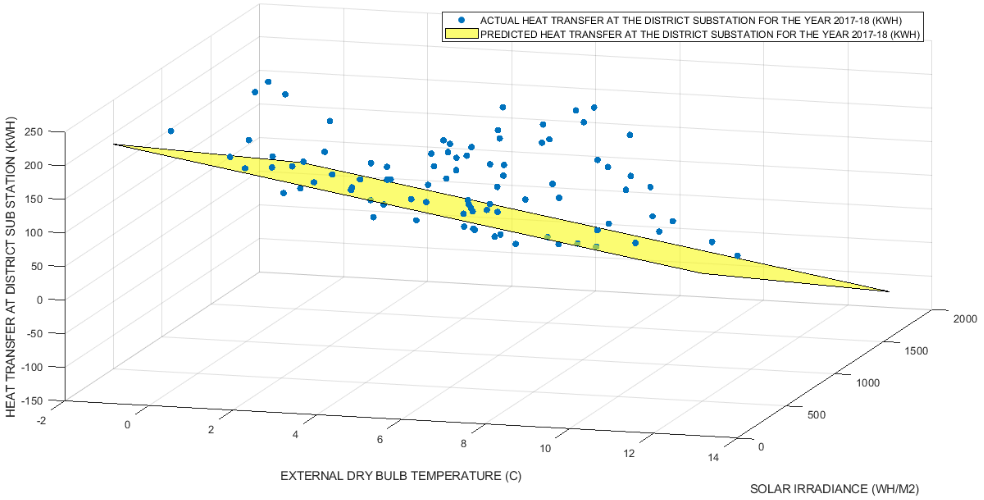


FIGURE 99 - ACTUAL VS PREDICTED HEAT TRANSFER - BUILDING 11 – XYZ

The above representation in figure 99 represents the actual heat transfer at the district substation represented in the blue scatter and the plane in yellow represents the predicted heat transfer considering the equation **-10.27x-.011y+226.3**. It was important to understand the representation to see how accurate the prediction is.

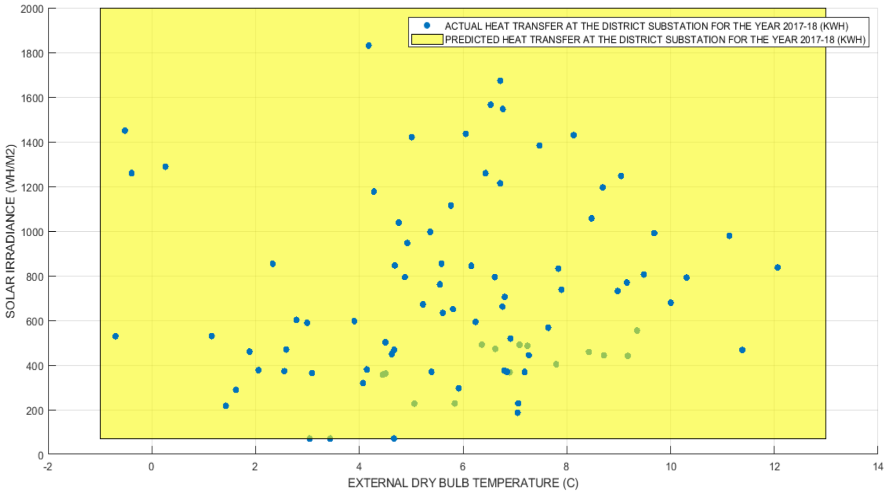


FIGURE 100 - ACTUAL VS PREDICTED HEAT TRANSFER - BUILDING 11 - XY

In addition to the 3d representation, in scatter in figure 100 highlights how the dry bulb temperature and solar irradiance relate to each for a fixed heat transfer at the district sub-station. This plot helps us understand the data analysis deeper and more presisely.

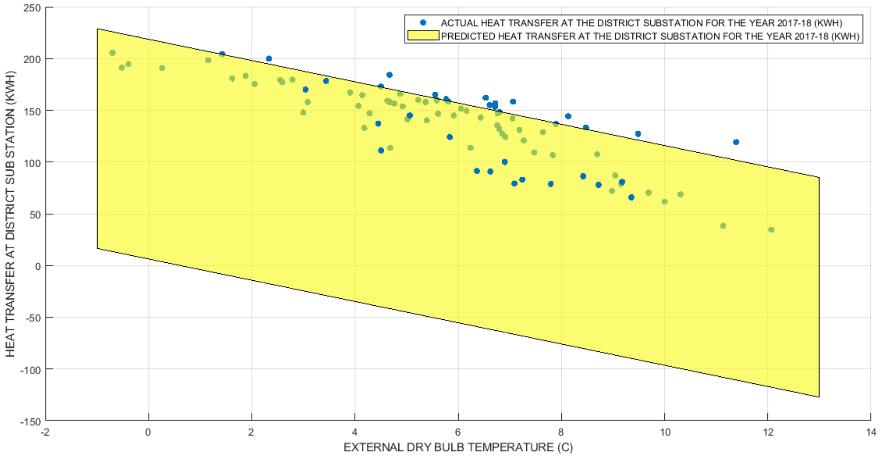


FIGURE 101 - ACTUAL VS PREDICTED HEAT TRANSFER - BUILDING 11 - XZ

Like figure 100, the scatter in figure 101 helps us look at the heat transfer at the sub-station with respect to the dry-bulb temperature. This data is with respect to the corresponding solar irradiance

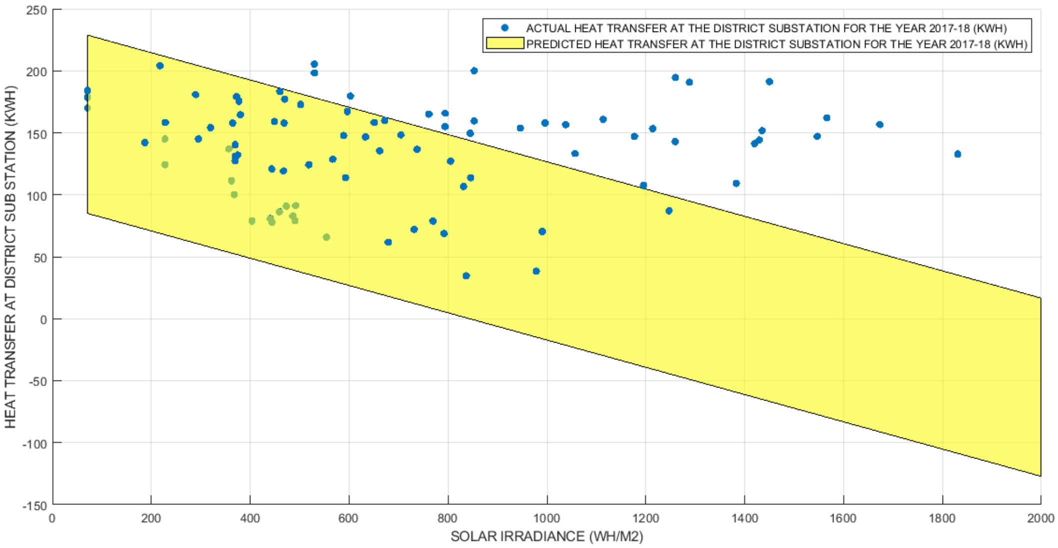


FIGURE 102 - ACTUAL VS PREDICTED HEAT TRANSFER - BUILDING 11 - YZ

Like figure 100 and 101, the scatter in figure 102 helps us look at the heat transfer at the substation with respect to the solar irradiance. This data is with respect to the corresponding dry bulb temperature.

Since this building is more of architectural studio and library area, it is very important to understand that the heating needs of the buildings is more predictable because of the constant occupancy of the library. A $r^2$ value of 0.93 with respect to the actual value shows that the equation used is reliable and can be used for future predictions.

### *BUILDING 14*

The equation used for prediction is **-12.36x-0.0142y+300.8**

| Month | Actual 2017-2018 (kWh) | Predicted (2017-18) (kWh) |
|---|---|---|
| November | 133.89 | 193.36 |
| December | 268.84 | 256.77 |
| January | 213.14 | 208.00 |
| Feb | 240.40 | 222.31 |
| March | 196.87 | 220.45 |

TABLE 8 - HEAT TRANSFER AT THE DISTRICT HEATING SUBSTATION (KWH)ACTUAL VS PREDICTED (2017-18) - BUILDING 14

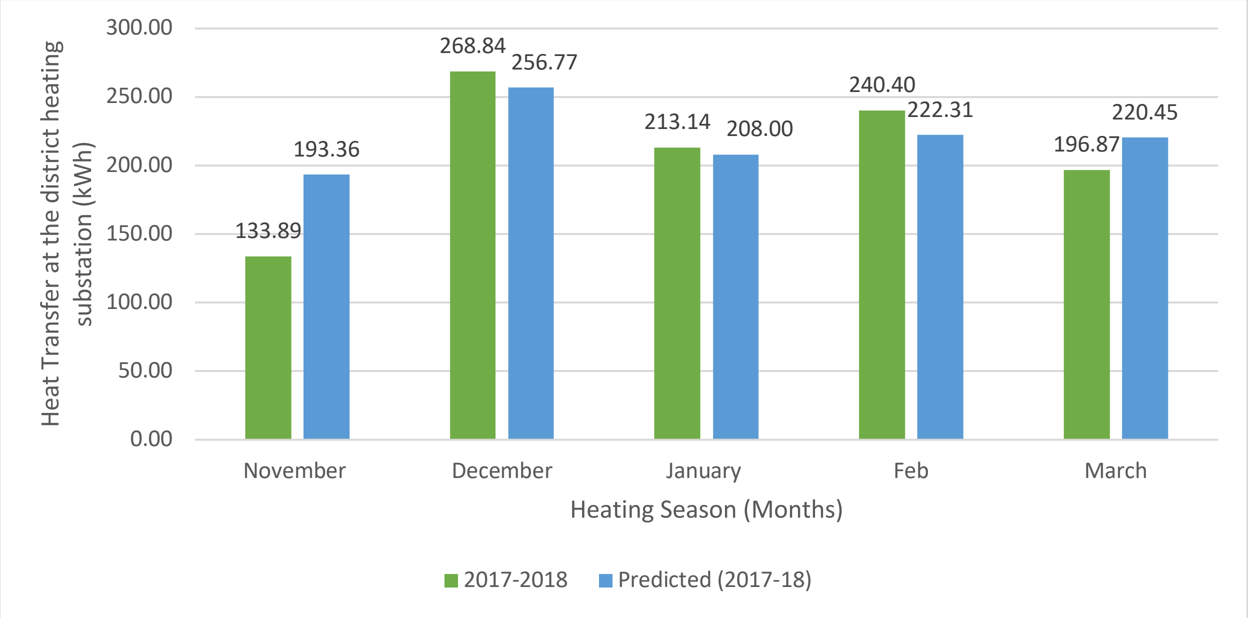


FIGURE 103 - HEAT TRANSFER AT THE DISTRICT HEATING SUBSTATION (KWH)ACTUAL VS PREDICTED (2017-18) - BUILDING 14

Looking at the graphical representation of the heat transfer at the district heating substation, the monthly predicted values for the january, february and march have a very close relationship between the actual and predicted values. November and december have a little divergence because of the change in the weather pattern in the input parameters.

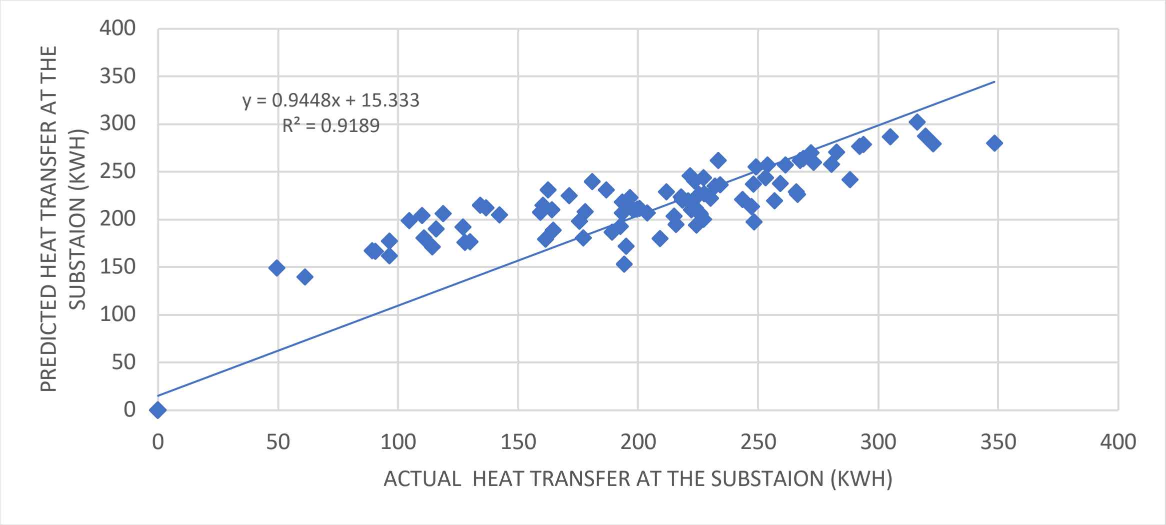


FIGURE 104 - ACTUAL VS PREDICTED HEAT TRANSFER LINEAR REGRESSION MODEL - BUILDING 14

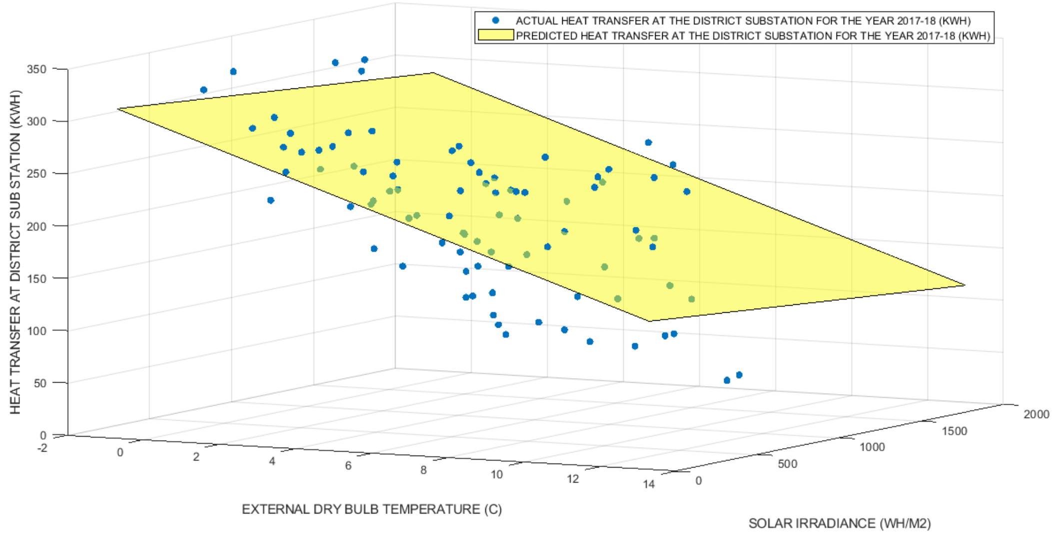


FIGURE 105 - ACTUAL VS PREDICTED HEAT TRANSFER - BUILDING 14-XYZ

The above representation in figure 105 represents the actual heat transfer at the district substation represented in the blue scatter and the plane in yellow represents the predicted heat transfer considering the equation **-12.36x-0.0142y+300.8**. It was important to understand the representation to see how accurate the prediction is.

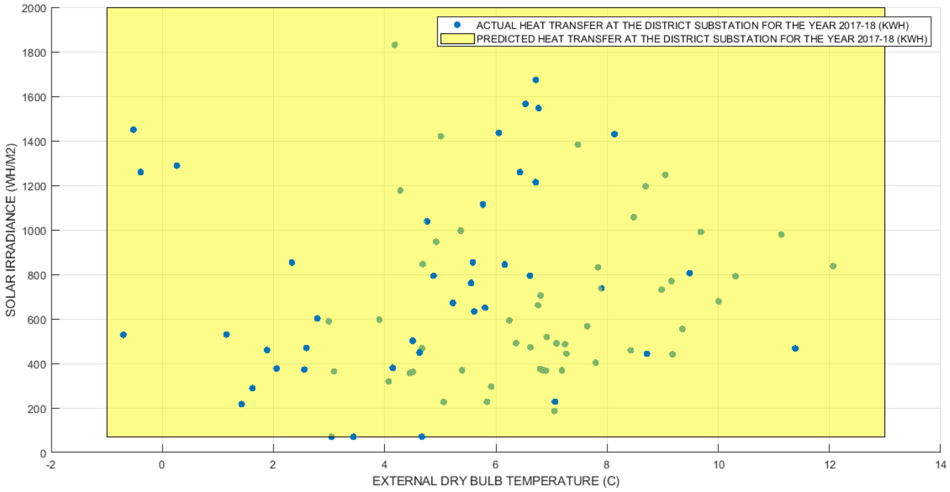


FIGURE 106 - ACTUAL VS PREDICTED HEAT TRANSFER - BUILDING 14 - XY

In addition to the 3d representation, in scatter in figure 106 highlights how the dry bulb temperature and solar irradiance relate to each for a fixed heat transfer at the district sub-station. This plot helps us understand the data analysis deeper and more presisely.

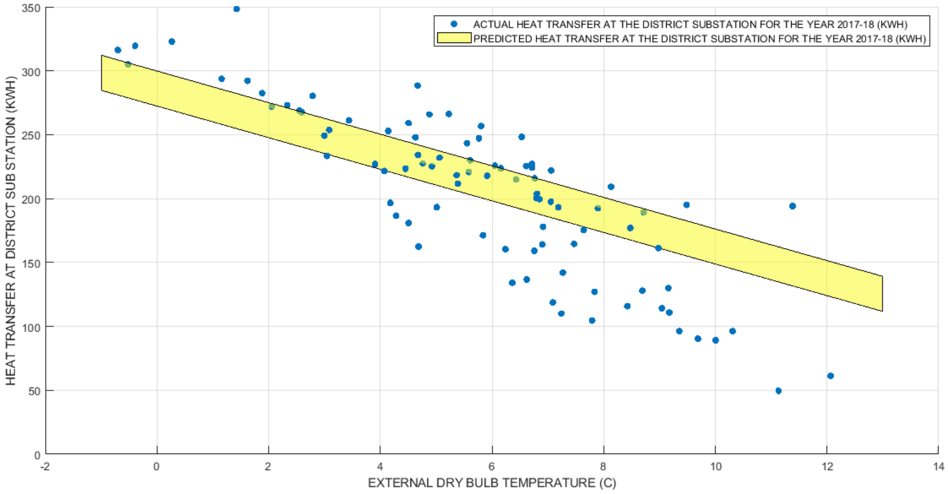


FIGURE 107 - ACTUAL VS PREDICTED HEAT TRANSFER - BUILDING 14 - XZ

Like figure 106, the scatter in figure 107 helps us look at the heat transfer at the sub-station with respect to the dry-bulb temperature. This data is with respect to the corresponding solar irradiance.

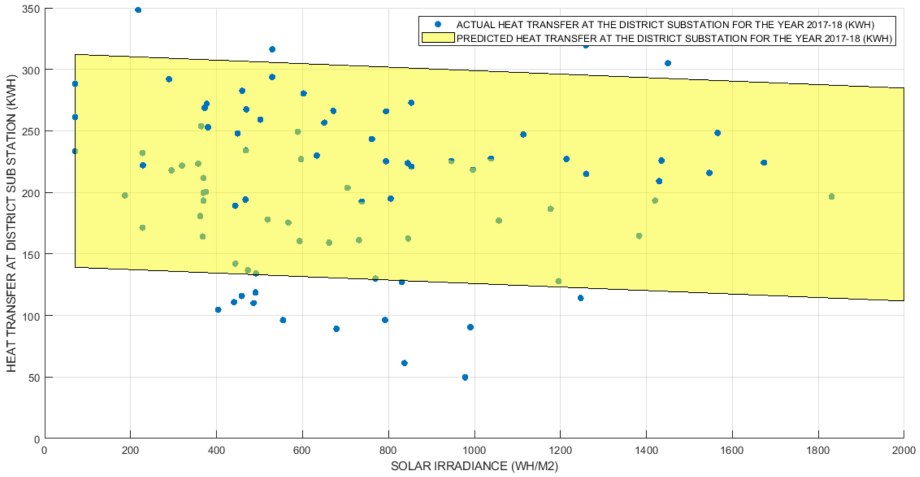


FIGURE 108 - ACTUAL VS PREDICTED HEAT TRANSFER - BUILDING 14 - YZ

Like figure 106 and 107, the scatter in figure 108 helps us look at the heat transfer at the sub-station with respect to the solar irradiance. This data is with respect to the corresponding dry bulb temperature.

When the analysis came down to building 14 the nave, it was important to understand the diversity of the building and the orientation of the building was going to make the prediction of data more unpredictable. The equation used for predicting the data with respect to the actual 2017-18 heat transfer at the district substation shows that there is a relatively a good co-relation which is shown in the $r^2$ of 0.91.

Building 14 is very diverse as it includes classrooms, offices, study areas. This inturn will create an uncertainity due to occupancy and occupancy time. Since, it this building involves large occupancy rates, the need of pre-contioning the building is very important. Since class rooms are heated for maximum occupancy, there is more unpredictability in the heat transfer.

# 8 CONCLUSION

The above study was done in order to understand how the European energy standard could be improved in order to work out a simplified equation using supervised machine learning which involved a multiple variable regression to predict and forecast future energy needs for different buildings (orientation, applications).

Looking at Politecnico di Milano as a case study it was important to understand the with the data available from “Commissione Energia” (Milano, n.d.), the online portal where the data regarding the building heating needs information, external dry bulb temperature and the solar radiation data was obtained needed to be interpreted. After data analysis using different timesteps and assumptions in terms of days to be considered and working hours.

It was concluded that a daily timestep was a good way for forecasting energy needs. With the daily time step, it is considered that optimum working time is 0600hrs to 1800 hrs because it’s important to look at that aspect of preconditioning the building prior to occupancy. Since 0800hrs is the starting time during the winter cycle of the university and because of this it was important to look at the trend of energy consumption of the buildings under consideration.

Moving further in the analysis it was also concluded that, orientation and application of the building also changed the correlation of the data. The application of building 5 which is basically a laboratory and classroom building had a lower correlation because of the uncertainty provided by its application.

The main takeaway from this analysis process, we find that the occupancy time and the holidays taken into considerations can truly change the functioning of the system as Lagunas in the data analysis can be found easily when this data is not considered.

Since the study involved different buildings with a wide range of application, this study can be put into different application like office building application, schools and public libraries because the equations developed are adaptable and very useful for energy needs forecasting.

Looking at this study, we can look at future precdiction by introducing more variables to make the study more accurate and practical. Human interaction in this study hasn’t been considered. Appliances and other sensible heat sources need to be considered for future studies.

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