Amplification of comfort and the air quality with green roof in cities

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Abstract

Since the last few decades the world population has been increasing in a faster rate. With the increasing population, the needs of the people have also increased. Because of that more people have lean towards to move to the cities in search of facilities. The demand for dwellings in the cities has increased. To accommodate this demand, more buildings have been constructed, changing the previous arrangement of the cities. The cities have turned into a compacted space with less vegetation and greenery. Yet again the pervious lands in the urban space have changed to impervious surfaces making the urban climate to be changed peculiarly in terms of temperature and air quality. The more the urban space has become industrialized, the more the air has been contaminated. There are other environmental issues together with the changes for the cities. Due to the increment of artificial surfaces the temperatures of the cities have been increased than the country side allowing the heat island effect to take place making the energy demands of the cities to be high. For these climatic problems the researchers have identified green roofs as a sustainable solution.

This research mainly focuses on augmentation of air quality and on reduction of heat island effect, with the replacement of existing flat slabs in the Colombo city in Sri Lanka, with green roofs. A well compacted city area was chosen in the Colombo district. The measurements were taken in terms of temperature, humidity and CO_2 in the chosen city. Different special places were chosen for the measurements. The obtained measurements are observed for the identification of the best remedy. With that the expected increment of air quality and expected reduction of the temperatures are modeled with the replacement of existing flat slabs in the area with green roofs. From the results it's evident that the green roofs can play a major role in enhancing air quality and reducing heat island effect making people to live in cities comfortably and healthily.

Key Words:CO_2, city, temperature, humidity, green roofs

1. Introduction

Urban areas represent a location where a large and ever increasing number of people live and where an unequal share of natural resources including fossil fuels are used. With this imbalance many comprehensive environmental problems have occurred in modern cities such as urban heat island, effect air pollution, deterioration of life expectancy etc. (C.S.B. Grimmond, 2002)

Urban heating causes many problems for the inhabitants of cities and areas, in particular those with a tropical environment. Urban heating could deteriorate our living environment, increase energy consumption, elevate ground-level ozone and even increase mortality rates. Three billion people (48% of the world population) living in urban areas are directly exposed to urban heating problems and more people will be vulnerable to these problems as the number of people living in urban areas is expected to grow to five billion by 2030. (Rizwan Ahmed Memon, 2009)

Urban heating is not the only problem that should be addressed but, air pollution taken place,in most major cities across the world is also another environmental problem. With that some researchers have focused on the role of urban vegetation in the formation and degradation of air pollutants in cities. (David J. Nowak, 2006) In a typical urban environment, the population is exposed to about 200 air pollutants or classes of air pollutants. The concentrations of each pollutant are functions of the emission rates of the pollutant, atmospheric chemistry, meteorology and local terrain, among other factors. The concentration levels of each of these pollutants therefore vary with time and location. (Pierre Sicard, 2000)

Within this identified pollutants, carbon dioxide play a major role since it's a greenhouse gas. The urban carbon cycle has its own driving forces, significantly different from those of natural ecosystems. Humans and automobile activity produced more than 80% input of CO_2 into the urban environment (Koerner, B, 2002), and motor vehicles are significant sources of air pollution emissions. The pollutants, when released into the atmosphere, pose a direct and serious hazard to living organisms in general, and to humans, in particular.(Pearson, R.L, 2000)Moreover, CO_2 is site and time dependent and it is related to weather conditions. In the last few years, much attention has been focused on the increase of air pollutants. In general, pollutants are released at ground level and their upward movement is restricted because of tall buildings. Therefore, pollutants frequently cause adverse effects on the environment quality of urban areas.(Loretta Gratani, 2004)

Installing green roofs is now widely considered as an effective strategy to solve these problems. Green roofs can mitigate the urban heat island (UHI) effect, purify water and air, improve the energy efficiency of buildings, reduce storm water runoff, increase biodiversity, as well as elongate the life span of roofs. (Chi Feng, 2010)With that this research focuses on reducing urban carbon dioxide concentration and the temperature with the installation of green roofs on the existing flat roofs slabs in the Colombo city. A highly vegetated area and a canopy in the city center were chosen. The temperature, humidity and carbon dioxide were measured in the chosen places for 8 hours..

2. Objectives

- The main objective of this research is to measure the carbon dioxide variation in the city of Colombo with implementation of green roofs in the existing flat roofs slabs.
- The second objective is to verify the urban heat island effect in the Colombo city with the measured temperature values.

3. Method

The field measurements were carried out to evaluate the difference of CO_2 concentration together with the temperature different at two locations: one in the middle of a canopy and the other is near open space with lot of greenery. The distance between two sites, is 2.53km. Temperature, humidity, time and CO_2 concentration measurements were taken in two selected places for 8 hours that is from 9.30am to 4.30pm. The time period was chosen because before 8.00am and after 4.30pm the trees and grasslands were shaded from the sunlight and photosynthesis process was stopped. (Jian-feng Li, 2010)The research was carried out to investigate the effect of green roof on the surrounding CO_2concentration and to verify the temperature reduction of the city with the implementation of green roofs.

3.1.Site Description

The study was carried out in the city of Colombo, Sri Lanka. It was possible to differentiate the two selected places, one as a place with lot of greenery and the other as a place in the canopy layer, surrounded with lot of high rise buildings. Bambalapitiya was chosen as the middle of the canopy and the Viharamahadevi Park was chosen as the place with greenery. Bambalapitiya is a junction with lot of high rise buildings and the width of the main road which passes through these high rise buildings is 9m. In the morning and in the evening the traffic density is high inBambalapitiya junction. Google earth images of these two sites are sown in the figure 1 and 2.

Figure 1: Google Earth Images of Bambalapitiya

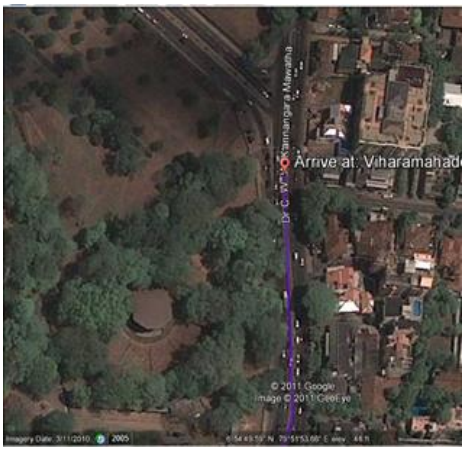

Figure 2: Google Earth Images of Viharamahadevi Park

Colombo features a tropical rainforest climate under the Köppen climate classification. Colombo's climate is fairly temperate all throughout the year. The average total year rainfall is 2238mm; the average minimum air temperature in the coldest months (January and February) is 23°Cand the average maximum air temperature in the hottest month (April) 31 °C. Most of the total rainfall is distributed in period is from June to August and from September to October. The city is characterized by constant speed's wind during the year 3.3 ms^{-1} (Data provided by the Meteorological Department of Sri Lanka1995–2003).

4. Theory

For the analysis of data the Pearson Correlation, Regression analysis, standard deviation and mean were used.

4.1. Pearson Correlation

In statistics, the Pearson product-moment correlation coefficient (sometimes referred to as the PPMCC or PCCs, and typically denoted by *r*) is a measure of the correlation(linear dependence) between two variables *X* and *Y*, giving a value between +1 and −1 inclusive. It is widely used in the sciences as a measure of the strength of linear dependence between two variables. The correlation coefficient is sometimes called "Pearson's *r*."Pearson's correlation coefficient($\rho x, y$)between two variables x and y is defined as the covariance of the two variables divided by the product of their standard deviations. The equation is shown below.

$$\rho x, y = cov(x, y)/\sigma x \sigma y \quad \text{——————} \quad (1)$$

A value of 1 for the correlation coefficient implies that a linear equation describes the relationship between *X* and *Y* perfectly, with all data points lying on a line for which *Y* increases as *X* increases. A value of −1 implies that all data points lie on a line for which *Y* decreases as *X* increases. A value of 0 implies that there is no linear correlation between the variables. (David M.Levin, 2006)

4.2.Regression Analysis

In statistics, regression analysis includes many techniques for modeling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables. R^2 in regression analysis, also known as the coefficient of determination is a commonly used statistic to evaluate model fit. R-square is 1 minus the ratio of residual variability. When the variability of the residual values around the regression line relative to the overall variability is small, the predictions from the regression equation are good.

$$R^2 = 1 - \left(\frac{SSerr}{SStot}\right) \quad \text{——————} \quad (2)$$

In the equation 2, R^2 represent the coefficient of determination, SSerr represent the residual sum of square and SStot represents total sum of squares.Once a regression model has been constructed, it may be important to confirm the goodness of fit of the model and the statistical significance of the estimated parameters. Commonly used checks of goodness of fit include the R-squared, analyses of the pattern of residuals and hypothesis testing. Statistical significance can be checked by an F-test of the overall fit, followed by t-tests of individual parameters.(David M.Levin, 2009)

4.3.Standard Deviation and Mean

Standard deviation is a widely used measure of variability or diversity used in statistics and probability theory. It shows how much variation or "dispersion" there is from the average (mean, or expected value). A low standard deviation indicates that the data points tend to be very close to the mean, whereas high standard deviation indicates that the data points are spread out over a large range of values.The standard deviation of a statistical population, data set, or probability distribution is the square root of its variance. In mathematics and statistics, the arithmetic mean, often referred to as simply the mean or average when the context is clear, is a method to derive the central tendency of a sample space. (David M.Levin, 2009)

5. Results and Discussion

The three variables of the experiment were assumed as time, temperature and humidity. The following figure 3 shows the variation of CO_2levelwith the time in the two different places. From the graph it's evident that from 12:15pm to 3:15pm the CO_2level at Viharamahadevi Park is lesser than the Bambalapitiya junction. From 11:00pm to 12:00pm there's not much difference in the level ofCO_2in the two places.

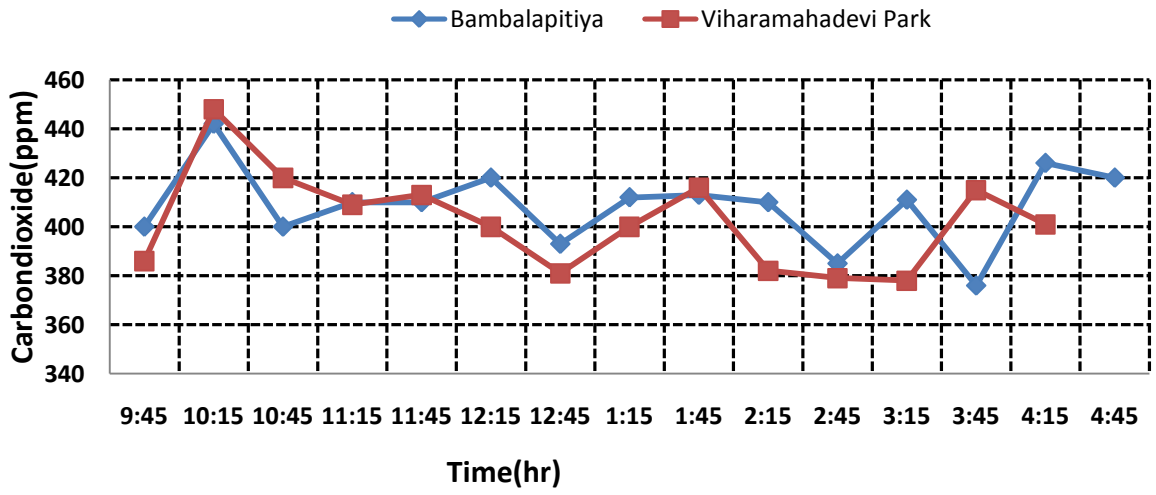

Figure 3: Variation of CO2 with time

Pearson correlation coefficient from 10:00am to 12:30pm for $CO_2$and time is -0.22 which reveals that with the time the CO_2level is reducing from 10:00am to 12:30pm. But the Perason correlation coefficient from 1:00pm to 4:30pm for $CO_2$and time at Viharamahadevi Park is 0.17 which is a positive value. This reveals during 1:00pm to 4:30pm period CO_2levels are increasing. This identification can be related with the photosynthesis phenomenon of trees and grasses. As shown in the figure 4 the flux levels are increasing in the time period of 7:00am to 12:00pm and reducing from 12:00pm to 5:00pm. So it can be stated that with the photosynthesis the CO_2levels are reducing in the city in the morning until noon.(Jian-feng Li, 2010)

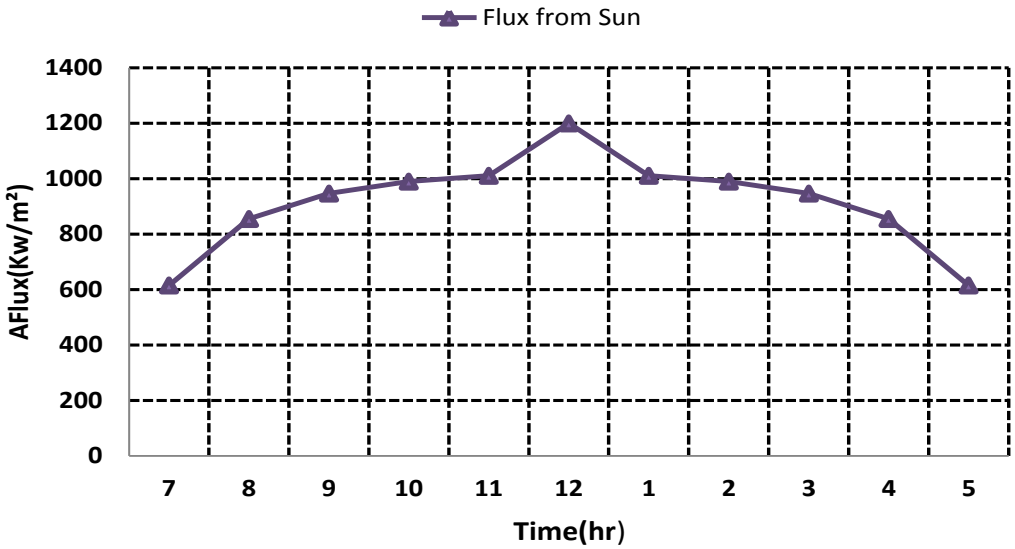

Figure 4: Variation of Flux from the sun with time

The table 1 shows the analysis results of the data set. There BTem, BHum, BCO_2 represent, temperature, humidity, and Carbon dioxide levels at Bambalapitiya. And VTem, VHum, VCO_2 represent,thesame variables mentioned above at Viharamahadevi Park.The maximum CO_2 occurred at Bamabalapitiya was 442ppm and it occurred at 10:15pm. This was because the traffic congestion was high at that time. The mean CO_2 level was 408ppm and standard deviation was 16.326 at Bambalapitiya. The mean CO_2level was 402ppm and standard deviation was 19.9at Viharamahadevi Park. This shows that at ViharamahadeviPark lower CO_2level was maintained compared to Bambalapitiya.

When considered temperature the minimum temperature at Bambalapitiya was 29.8^0C and at Viharamahadevi Park the minimum temperature was 29.4^0C. This reveals that throughout the day time a minimum temperature was given in the site with lot of greenery. The minimum CO_2 level at Bambalapitiyawas 376ppm and the minimum CO_2 levelat Viharamahadevi Park was 378ppm. The minimum levels of CO_2 occurred after 3:00pm in both places. This yet again reveals that throughout the day a minimum CO_2level was recorded at the site with lot of greenery.The maximum temperature level of

33.3°C occurred at Bambalapitiya. The mean temperature at Bamabalapitiya was 31.36 °C where the standard deviation was 0.3118. At Viharamahadevi Par the mean temperature was 31.2 °C where the standard deviation was 0.28. This shows that a lower temperature was maintained at Viharamadevi Park compared to Bambalapititya. When taking readings the places with tree shadings were omitted.

Table 1: Statistical analysis for the whole data set

	N	Minimum	Maximum	Mean		Std.Deviaiton	Variance	Skewness	
	Statistic	Statistic	Statistic	Statistic	Std.Error	Statistic	Statistic	Statistic	Std.Error
BTem	15	29.8	33.3	31.36	0.3118	1.2076	0.11	0.58	-1.502
BHum	15	62	71	65.687	0.7957	3.0817	0.338	0.58	-1.344
BCO2	15	376	442	408.53	4.215	16.326	-0.123	0.58	0.683
VTem	14	29.4	32.8	31.207	0.2841	1.063	-0.333	0.597	0.923
VHum	14	60	73	67.271	1.1937	4.4664	0.065	0.597	-1.401
VCO2	14	378	448	402	5.338	19.973	0.703	0.597	0.541

The figure 5 reveals the identifications for the temperature variation, from the above data set. From the figure it's clear that at Viharamahadevi Park a lower temperature was maintained after 2:15pm. This different has caused due to the impervious layers that exists in the city center. This yet again shows the existence of heat islandeffect; the temperature increment in the city compared to the rural, in the congested cities.

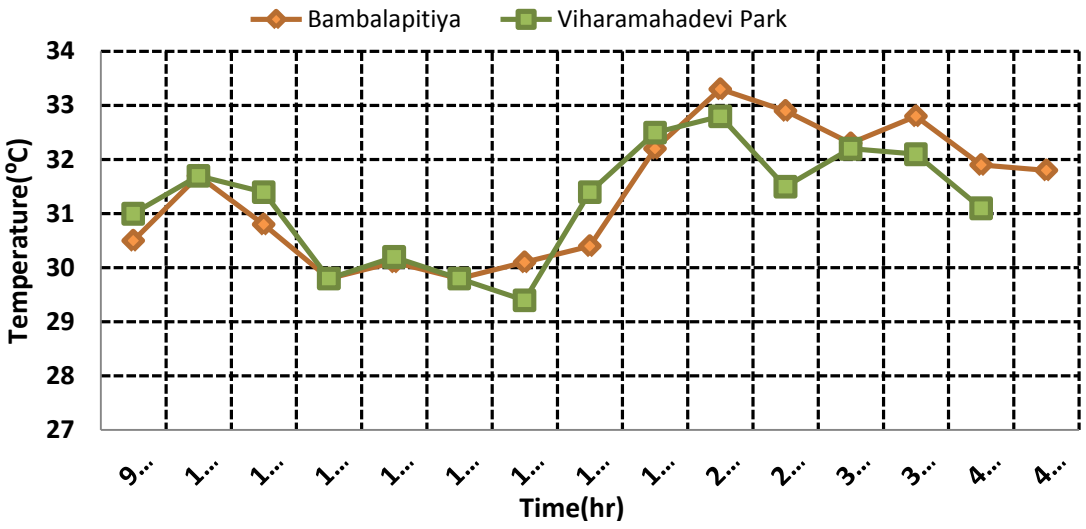

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Figure 5: The temperature variation with time

correlation obtained from the regression analysisfor the three variables assumed, can be related as in equation 3 and 4 for the two different places. With the help of this equationthe CO_2levels at Bambalapitiya and Viharamahadevi Park can be predicted.

$$BCO2 = -0.107BTime - 1.375BTem + 0.262BHum \quad \text{——————} \quad (3)$$

$$VCO2 = -2.946VTim + 13.545VTem + 2.774VHum \quad \text{——————} \quad (4)$$

The R^2; coefficient determination for the three variables identified at Bambalapitiya was 0.024and for Viharamahadevi Park R^2 is 0.522. This shows that CO_2 levels at Viharamahadevi Park have a considerable relationship with the three variables than at Bambalapitiya. This again shows the importance of existence of trees and grass lands to reduce CO_2 levels in a city. The normality test was performed to prove that the regression analysis can be applied to the data set. The residuals are normally distributed and it's shown in the figure 6 and 7.

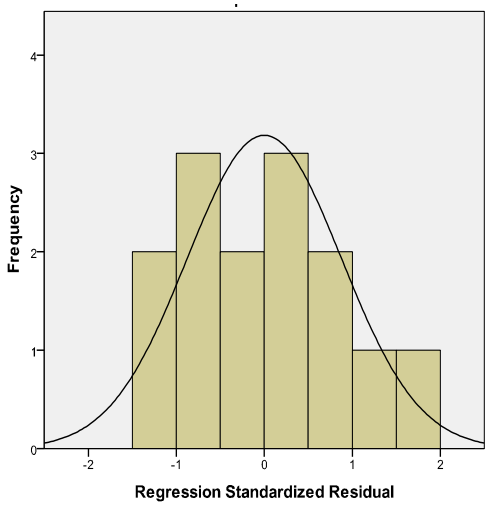

Figure 6: Regression Standardized Residual Histogram for Viharamahadevi Park

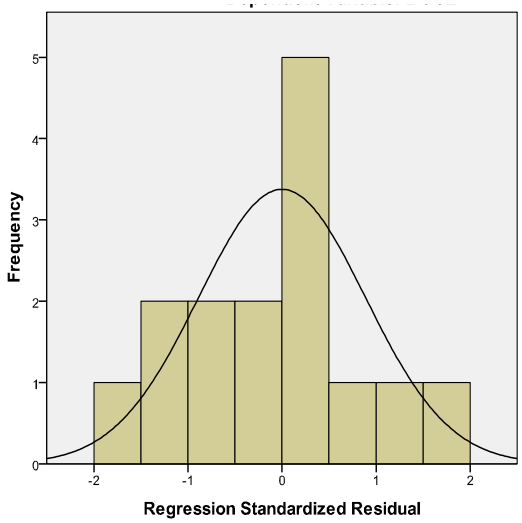

Figure 7: Regression Standardized Residual Histogram for Bambalapititya

6. Conclusion

Greenery in the cities is reducing with the expansion of the cities. With the depletion of greenery the cities are facing problems such as heat island effect, pollution of air, storm water runoff, deterioration of life expectancy etc. With that the need to investigate the importance of greenery in the cities is unavoidable. The experiment was carried out to measure the CO2 variation with the existence of grasslands and trees compared to a city junction. The measurements were taken with respect to humidity, temperature and CO_2. The data set was analyzed with using Regression analysis, Pearson correlation and

with use of mean, median and standard deviation. From the results it was proven that with the existence of grass lands and trees the CO_2 levels are reducing at the day time and hence the purification of air is taking place.Yet again the research reveals the gravity of depletion of trees in the developing cities. If all the land areas with greenery are replaced with impervious layers the severity of the problem of air pollution will be much higher. But with all that the development is unavoidable. The land area is limited and the space that can be kept for grasslands and parks are limited.As a solution for the limited space the city can be improved with greenery with use of green roofs. With that the importance of implementing green roofs as the roof top is revealed.

References

C.S.B. Grimmond, T.S. King, F.D. Cropley, D.J. Nowak, C. Souch (2002) "Local-scale fluxes of carbon dioxide in urban environments methodological challenges and results from Chicago"

Rizwan Ahmed Memon, Dennis Y.C. Leung, Chun-Ho Liu (2009) "An investigation of urban heat island intensity (UHII) as an indicator of urban heating" *Department of Mechanical Engineering, The University of Hong Kong, Hong Kong, China*

David J. Nowak_, Daniel E. Crane, Jack C. Stevens (2006) "Air pollution removal by urban trees and shrubs in the United States" *USDA Forest Service, Northeastern Research Station, 5 Moon Library, SUNY-ESF, Syracuse, NY 13210 USA*

Pierre Sicard, Olivia Lesne, Nicolas Alexandre, Antoine Mangin, RémyCollomp(2000)"Air quality trends and potential health effects and development of an aggregate risk index" *ACRI-ST, 260 route du Pin Montard, BP 234, 06904 Sophia AntipolisCedex, France*.

Koerner, B., Klopatek, J.(2002) "Anthropogenic and natural CO2 emission sources in an arid urban environment" *Environmental Pollution 116, 45–51.*

Pearson, R.L., Wachtel H., Ebi, K.L., (2000)"Distance-weighted traffic density in proximity to a home is a risk factor to leukemia and other childhood cancers"*Journal of Air and Waste Management Association 50, 175–180.*

Loretta Gratani_, Laura Varone(2004) "Daily and seasonal variation of CO2 in the city of Rome in relationship with the traffic volume"*Department of Plant Biology, University of Rome, ''La Sapienza'' P.le A. Moro 5, 00185 Rome, Italy*

Chi Feng, QinglinMeng, Yufeng Zhang (2010)"Theoretical and experimental analysis of the energy balance of extensive green roofs" *Building Environment and Energy Laboratory (BEEL), State Key Laboratory of Subtropical Building Science, South China University of Technology, Wushan, Guangzhou, PR China*

Jian-feng Li, Onyx W.H. Wai, Y.S. Li, Jie-min Zhan, Y. Alexander Ho, James Li, Eddie Lam (2010) "Effect of green roof on ambient CO2 concentration" *Department of Applied Mechanics and Engineering, Sun Yat-sen University, Guangzhou, China*

David M.Levin, Pimophy C.,Krehveil, Mark L.Beremson, P.K.Vishanathan(2009) Bussiness Statistics *Fourth Eddition*