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# OPTIMUM STREET LAYOUT OR CONFIGURATION FOR MINIMIZING ENERGY DEMAND IN BERLIN

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*Abstract*— **The paper aims to make suggestions in terms of ideal street layout or configuration for the city of Berlin in order to minimize the overall energy demand. The methodology followed is background study of related topics, benchmarking the parameters considered, simulation of different factors using Energy Builder software and recommendations through outcomes and simulation results. By drawing the relationship between urban form, building design and energy usage, it is easier to estimate the desired street layouts based on two important climatic parameters: wind direction and sun. Energy demands for various typologies have been calculated by considering different street widths and floor area ration (FAR) of the buildings.**

*Keywords*— **Street Layout, Street Configuration, Energy Demand, Urban Form**

## I. INTRODUCTION

### *A.* Methodology

The research goes through a number of reports and journals that discuss the urban form and its effect on energy consumption inside households. The most important parameters are considered for benchmarking and for simulating to real life Berlin based parameters (for example the main wind direction in the city).

The simulation focuses on wind and sun effect on street orientation and the effect of those two parameters on other parameters like floor area ratio and street width. The paper aims at providing the reader with conclusions on the best parameters for street orientation that will help save energy consumption inside households.

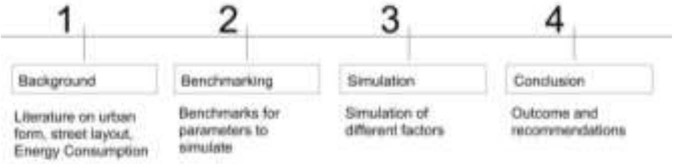


Fig. 1. Methodology steps of the research paper; done by authors

### *B.* Literature Review

- Ye Kang Ko (2013) Urban form and residential energy use: A review of design principles and empirical findings

- Ye Kang Ko (2012), The Energy Impact of Urban Form: An Approach to Morphologically Evaluating the Energy Performance of Neighborhoods

In Ko's paper, she discussed the effects of urban form on the residential energy consumption. The paper collected and gathered information, empirical evidence, and outcomes of simulations and compared them against each other. It focused on housing type and size, density, community layout and greenery effect on energy consumption inside home.

The paper gave a holistic outlook on most of the previous research outcomes done before and provided guidelines for future research on the subject apart from giving recommendation to what is needed to strengthen the research on the relationship between residential energy consumption and urban form.

Ko's more detailed PhD on the energy impact of urban form also provided a more detailed description of the impact of urban form both on the microclimate and residential energy demand with a huge load of simulation and empirical evidence that served as a validation for years of work of researchers that provided theoretical framework before this research was produced.

Ko also focused on the policy implementations of doing such simulations and research and providing very valuable avant-garde implications to planning practices and planning methods in different contexts. The study uses many simulation techniques and three-dimensional urban GIS models derived from Light Detection and Ranging (LiDAR) data.

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## II. BACKGROUND INFORMATION

Urban form is mostly associated with energy use in the outdoor climate with a number of researches to support that, yet there is not enough research that support the effect of urban form on building energy use. This paper focuses on exactly that highlighting on the effect of street grid and orientation on reduction of building energy use.

The research paper tries to measure how much the urban form, specially the street has on the residential energy consumption focusing on the street orientation and street configuration crisscrossing different benchmarks based parameters to reach the optimal street orientation and configuration to save residential energy consumption.

The research takes Berlin as a case study with its long and cold winters, during which a lot of energy is consumed in heating up houses. The research tries to experiment with the ties of street layout and heat consumption inside Berlin. The outcome of the research is to see the effects of urban form (especially street layout) on the energy demand and how can through some changes in these configurations it is possible to provide a less energy demand and consumption inside households. Do doing so, the paper would serve as a methodological framework backed with empirical evidence to help planners design a more energy saving urban forms and also affect a better micro urban climate.

### *A.* Urban form and buildings energy consumption

Urban form elements that affect building energy consumption include density, house sizes and types, community layout and greenery.

[10] and from a large number of researches, studies and simulation they did, their outcomes concluded that energy consumption is highly affected by building design by a factor of 2.5xs and this effects the system efficiency by factor of 2 times, and in turn is affected by occupant behavior by a factor of 2 times.

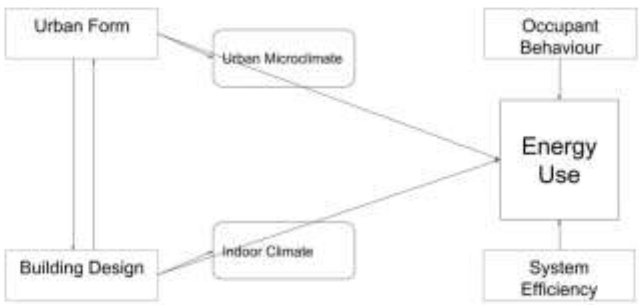



Fig 2. Effect of different factors on energy use; done by authors based on [11]

The urban form affects the microclimate which affects energy use and indoor heating and cooling. Building energy use can be explained as a function of urban form, building design, energy system efficiency, and occupant behavior [11].

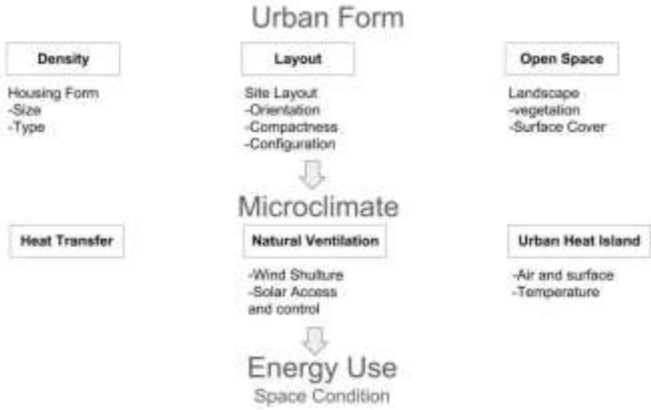



Fig 3. Effect of urban form on energy use; done by authors based on [2]

### *B.* Street Layout

Street layout and configuration have many shapes and plans, mostly affected by the urban planning or urban design paradigms and schools. Street configuration have often been tied to accessibility, transportation and urban life. (Haldmen) 2011 talked about how the streets can affect how people live. But also, street configuration has a huge effect on energy consumption and micro urban climate.

### *C.* Street Layout and Urban life

The role that streets layout plays in urban life, (Haldmen, 2011) mentioned the streets as a function that "determines...how the people shall live, how they shall travel to and fro, how they shall work and play." he also mentioned that the street layout has "a direct influence upon the character of the home and its surroundings, upon the safety, comfort and convenience of the people, and upon the efficiency of government and the public service."

It can be observed that different street layouts were produced in different place around the world. In hotter climate like for example medieval Cairo, streets were narrow to compact the heat during days, which resulted in both more micro-climate thermal comfort and also indoor thermal comfort. Those kinds of street layout affected the environment as much as they affected the daily lives of people living in them and their activities and social lives. Thus, street layouts affect the environment, accessibility and social life.

### *D.* Street Layout and Energy Consumption

The effect and relationship between street layout and residential energy use has been a very controversial topic between researchers mainly due to the lack of research on the topic. Buildings energy consumption can be explained as a function of urban form, user's behavior and the efficiency of the energy systems [11].

Building energy consumption exceeds industrial and transportation figures in the US and EU [12]. Changing the orientation in London from South to West can increase space heating energy by 16% in passive solar houses and by 9% in conventional homes [13].

Street orientation is also mainly responsible for orientation of the housing unit [14]. And because in urban setting building coverage is maximized; buildings modification of orientation on land is possible but rarely happens. Appropriate street orientation can allow sun to get into households thus minimizing heat consumption or can allow wind to go over buildings not through them which will also help in reducing heating consumption. Thus, tying street orientation and configuration is a must to reach the optimum energy saving method [5].

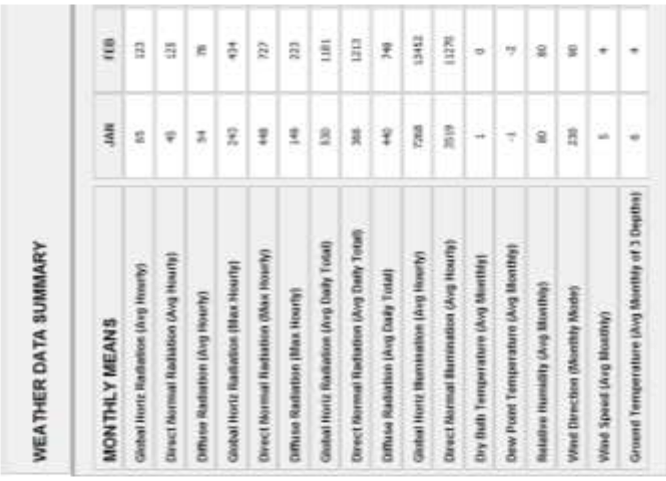
## III. SIMULATION

To try to find the optimal configuration of street layout, the research first started with street orientation trying to figure out what factors affect street orientation; Sun and Wind were mentioned as huge factors of street orientation as both affect the consumption of energy inside buildings heavily [2].

The research then took the best outcomes generated from both simulation of wind and sun and ran them across other street configuration parameters like street width and floor area ratio to reach the optimum energy saving solution.

### *A.* Location

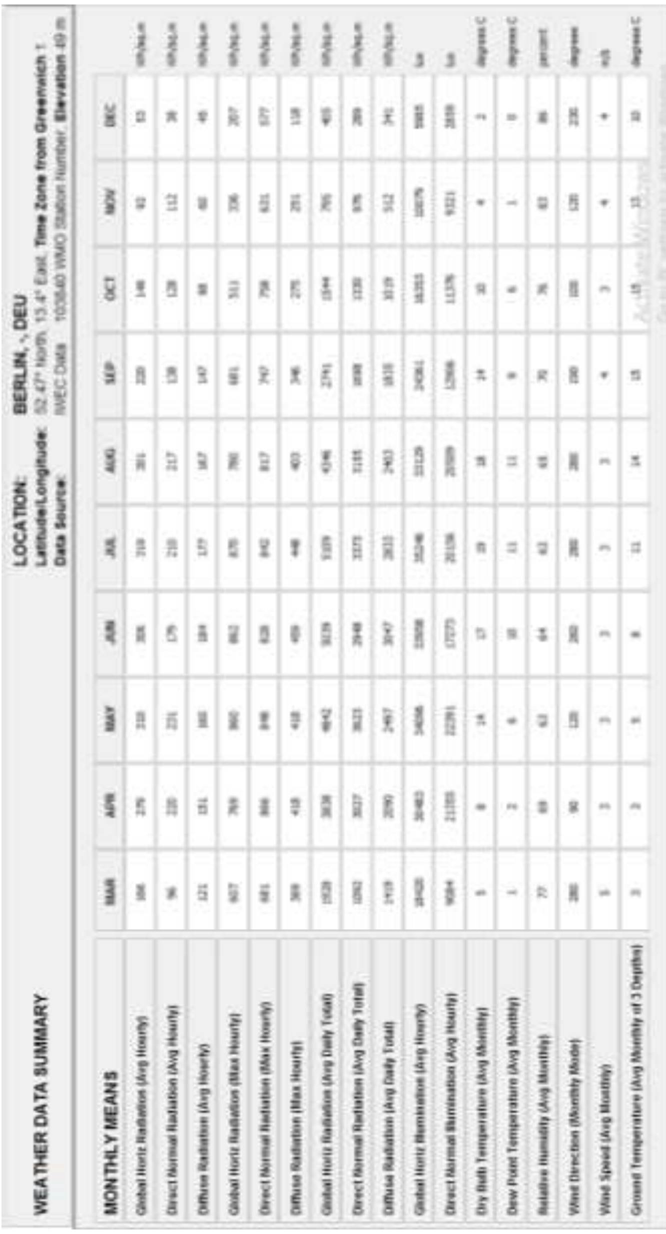
The simulations were conducted in Berlin (Germany's capital), and looking at its temperature average, we find the city has a very cold weather in winter, with strong wind, rain and snowfall, making the energy consumption of heating very high across households [7].



WEATHER DATA SUMMARY

| MONTHLY MEANS | JAN | FEB |
|---|---|---|
| Global Horiz Radiation (Avg Hourly) | [illegible] | [illegible] |
| Direct Normal Radiation (Avg Hourly) | [illegible] | [illegible] |
| Diffuse Radiation (Avg Hourly) | [illegible] | [illegible] |
| Global Horiz Radiation (Max Hourly) | [illegible] | [illegible] |
| Direct Normal Radiation (Max Hourly) | [illegible] | [illegible] |
| Diffuse Radiation (Max Hourly) | [illegible] | [illegible] |
| Global Horiz Radiation (Avg Daily Total) | [illegible] | [illegible] |
| Direct Normal Radiation (Avg Daily Total) | [illegible] | [illegible] |
| Diffuse Radiation (Avg Daily Total) | [illegible] | [illegible] |
| Global Horiz Illumination (Avg Hourly) | [illegible] | [illegible] |
| Direct Normal Illumination (Avg Hourly) | [illegible] | [illegible] |
| Dry Bulb Temperature (Avg Monthly) | [illegible] | [illegible] |
| Dew Point Temperature (Avg Monthly) | [illegible] | [illegible] |
| Relative Humidity (Avg Monthly) | [illegible] | [illegible] |
| Wind Direction (Monthly Mode) | [illegible] | [illegible] |
| Wind Speed (Avg Monthly) | [illegible] | [illegible] |
| Ground Temperature (Avg Monthly of 3 Depths) | [illegible] | [illegible] |

Fig 4 Part 1. Weather file for Berlin; Source: Climate Consultant



WEATHER DATA SUMMARY

LOCATION: BERLIN, -, DEU
Latitude/Longitude: 52.47° North, 13.4° East, Time Zone from Greenwich 1
Data Source: IWEC Data 103840 WMO Station Number, Elevation 49 m

| MONTHLY MEANS | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Global Horiz Radiation (Avg Hourly) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | Wh/sq.m |
| Direct Normal Radiation (Avg Hourly) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | Wh/sq.m |
| Diffuse Radiation (Avg Hourly) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | Wh/sq.m |
| Global Horiz Radiation (Max Hourly) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | Wh/sq.m |
| Direct Normal Radiation (Max Hourly) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | Wh/sq.m |
| Diffuse Radiation (Max Hourly) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | Wh/sq.m |
| Global Horiz Radiation (Avg Daily Total) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | Wh/sq.m |
| Direct Normal Radiation (Avg Daily Total) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | Wh/sq.m |
| Diffuse Radiation (Avg Daily Total) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | Wh/sq.m |
| Global Horiz Illumination (Avg Hourly) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | lux |
| Direct Normal Illumination (Avg Hourly) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | lux |
| Dry Bulb Temperature (Avg Monthly) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | degrees C |
| Dew Point Temperature (Avg Monthly) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | degrees C |
| Relative Humidity (Avg Monthly) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | percent |
| Wind Direction (Monthly Mode) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | degrees |
| Wind Speed (Avg Monthly) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | m/s |
| Ground Temperature (Avg Monthly of 3 Depths) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | degrees C |

Fig 4 Part 2. Weather file for Berlin; Source: Climate Consultant

### *B.* Street Orientation Simulations

Since Berlin (The case study) is designated by cold and windy winter, the need for more sun to reduce the energy demand and to avoid the effects of strong cold wind is a must to reduce energy demand.

### *C. Wind*

Proper street orientation can reduce the effect of extreme weather; for example. if the street can protect against cold wind it will decrease the energy required for heating thus decrease energy consumption [2]. If the orientation of the street is parallel to the wind, the wind will go through the walls and if the street orientation is perpendicular to the wind flow the air flow will go above the building, thus decrease the intensity of cold wind (Givoni 1998). According to Meteoblue website, the main direction of wind in Berlin are South West (SW) to North East (NE) and West to East(WE) winds, thus in order to fight those winds, streets must be designed perpendicular to those two main wind directions.

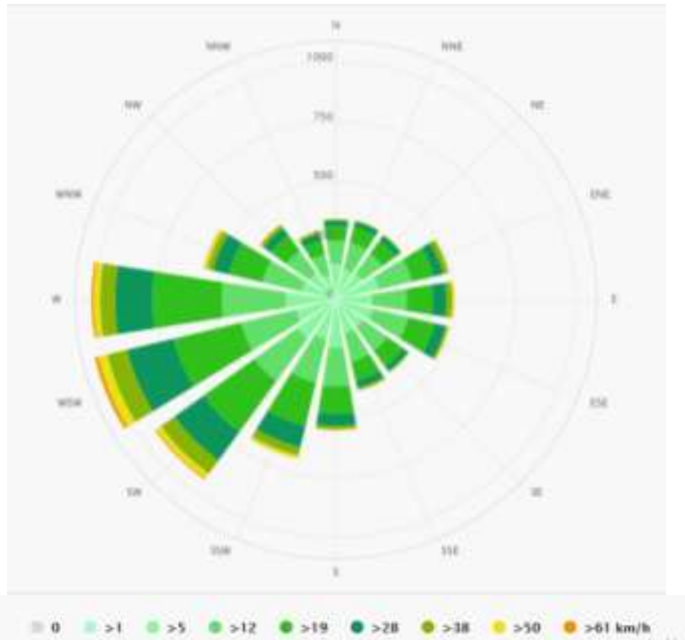



Fig 5. Wind rose Berlin [7]

*C1.* ***Option 1-Street orientation North West (NW) - South East (SE)***

The first major wind direction is South West (SW) to North East (NE), thus the street is designed perpendicular to this direction which is North West (NW) - South East (SE), and the buildings will be parallel to the street meaning facing the same direction.

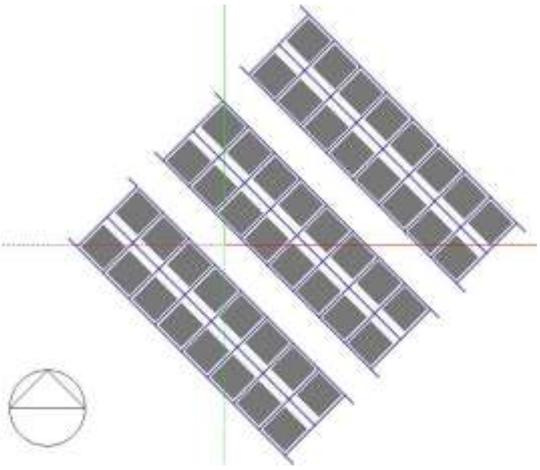


Fig 6. Street Direction (NW) - (SE)
Source: Author (Design Builder Software)

**Outcome**

The total energy demand was 141.65 kWh/m2 and the total primary energy demand is 237.04 kWh/m2, the lighting was at 18.82 kWh/m2, heating at 98.90 kWh/m2 and cooling at 23.93 kWh/m2.

*C2.* ***Option 2-Street orientation North (N)***

Challenging another major wind direction which is South (S) to East (E) by simulating a street that is perpendicular to it facing the North South (N-S) direction.

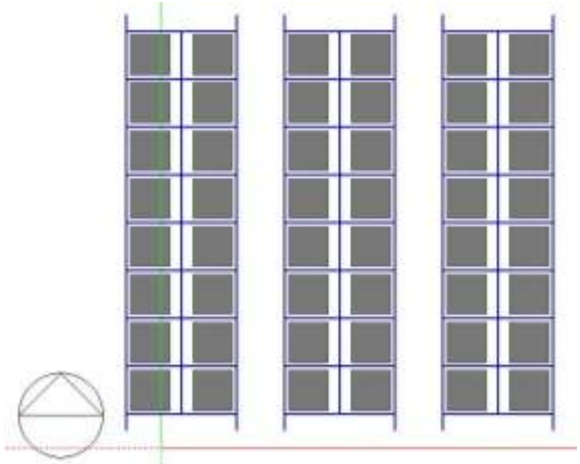


Fig 7. Street Direction (N-S)
Source: Author (Design Builder Software)

**Outcome**

The total energy demand was 145.10 kWh/m2 and the primary energy demand is 244.19 kWh/m2, the lighting was at 18.82 kWh/m2, heating at 98.90 kWh/m2 and cooling at 23.93 kWh/m2.

*C3.* ***Overall outcome***

Comparing the two directions together, not much difference can be seen, but Berlin has severe cold weather in winters and most of the energy is consumed on heating. Then the cooling consumption in option 1 is less than option 2 which makes the direction of the street (NW) to (SE) better for reducing energy consumption.

*D.* ***Sun***

In colder weathers like Berlin, heating is considered the biggest concern when it comes to energy consumption, this is essential for buildings to face the sun to receive most of the sunlight for less energy consumption inside.

*D1.* ***Option 3 – Street Orientation East-West (E-W)***

East–West street orientation that allows North–South lots and this accommodates more South facing facades and more sun receiving buildings.

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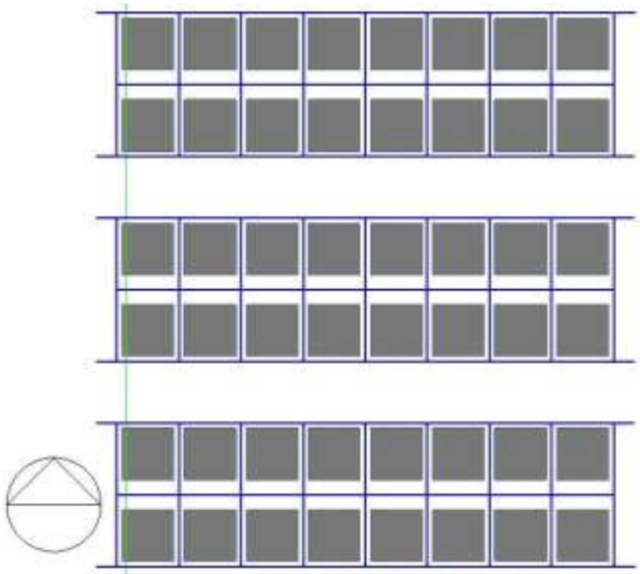

Fig 8. East-West (E-W) street direction
Source: Author (Design Builder Software)

**Outcome**
The total energy demand was 136.55 kWh/m2 and the total primary energy demand is 225.97 kWh/m2, the lighting was at 18.81 kWh/m2, heating at 96.67 kWh/m2 and cooling at 21.07 kWh/m2.

*D2. **Option 4 – Street Orientation 20 degree East of South***

[15] argued that the optimal street orientation is 20 east of south; he believed that it could decrease the house peak heating load in winter by 24–70% on a windy day, thus the next simulation tries to see if this argument is true to Berlin.

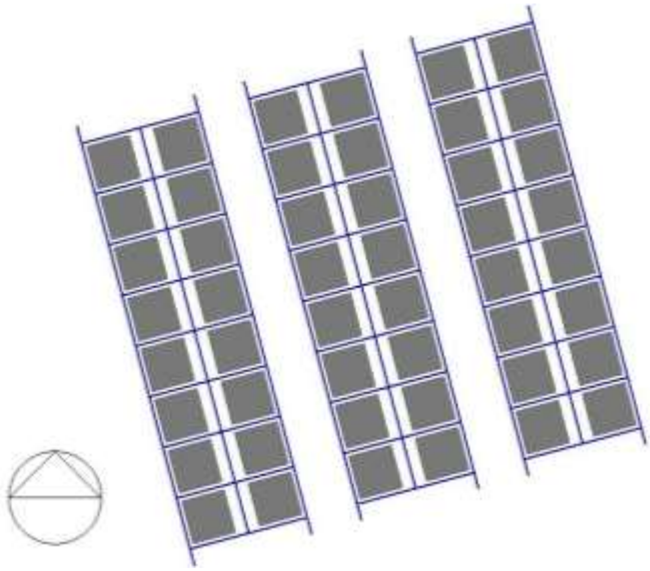

Fig 9. 20 degrees East-South (E-S) direction
Source: Author (Design Builder Software)

**Outcome**
The total energy demand was 144.91 kWh/m2 and the total primary energy demand is 244.10 kWh/m2, the lighting was at 18.79 kWh/m2, heating at 100.33 kWh/m2 and cooling at 25.79 kWh/m2.

*D3. **Overall Outcome***

The total energy demand and the primary energy demand is better in option 3, and also the heating, heating demand is less, meaning that the sun plays an important role in energy consumption. Berlin a city with average rainfall and long winters; directing a building to face the sun can save a lot in energy demand and consumption.

Now that that the simulations showed which options are the best of the four, next step is taking those options and experimenting them with more inputs that has to do more with street configuration. Option 1 being the best of the simulation based on wind direction and option 3 being the best of simulations based on sun direction will be tested with other street configuration parameters like different street width and floor area ratio.

*E. **Street Configuration Simulations***

E1. **Type 1A**
Taking the optimal street direction which is (NW) best proven to fight the cold wind, allowing the wind to fly over the buildings and not throw them and seeing what the effect of that on a street of 8 meter width and floor area ratio of 0.6.

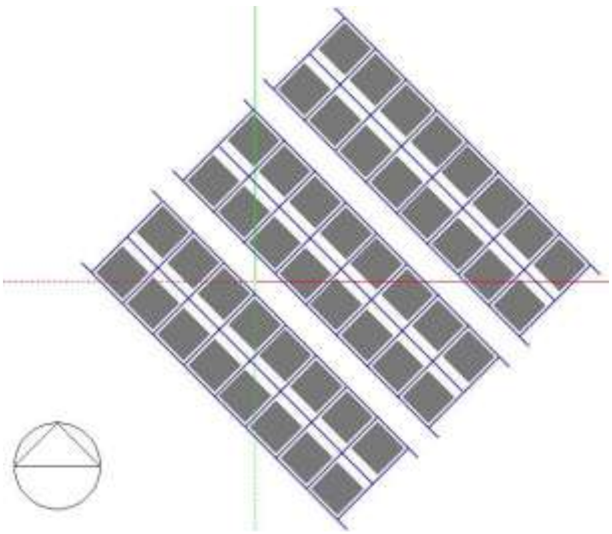

Fig 10. Street direction North-West (N-W) to South-East (S-E) with street width 8m and FAR 0.6.
Source: Author (Design Builder Software)

**Outcome**
The total energy demand was 141.66 kWh/m2 and the total primary energy demand is 236.52 kWh/m2, the lighting was at

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18.9 kWh/m2, heating at 99.23 kWh/m2 and cooling at 23.56 kWh/m2.

E2. **Type 1B**

Taking the same direction (NW) and experimenting with a different street width, this time 16m street.

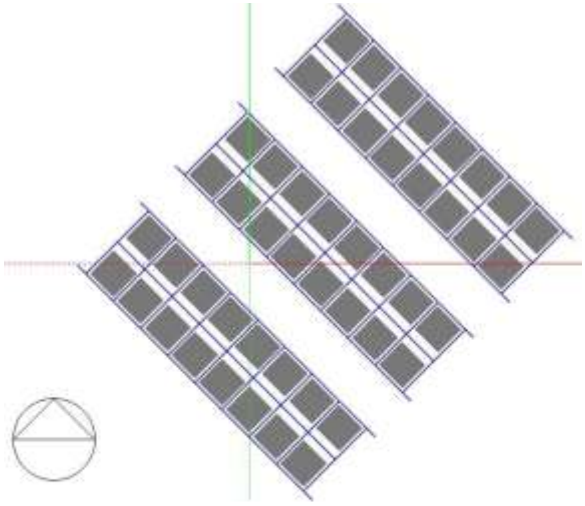

Fig 11. Street direction North-West (N-W) to South-East (S-E) with street width 16m and FAR 0.6.
Source: Author (Design Builder Software)

**Outcome**

The total energy demand was 141.66 kWh/m2 and the total primary energy demand is 237.48 kWh/m2, the lighting was at 18.81 kWh/m2, heating at 98.72 kWh/m2 and cooling at 24.15 kWh/m2.

E3. **Type 1C**

Same street direction (NW) to (SE) and a street width of 16m with a different floor area ratio of 0.4.

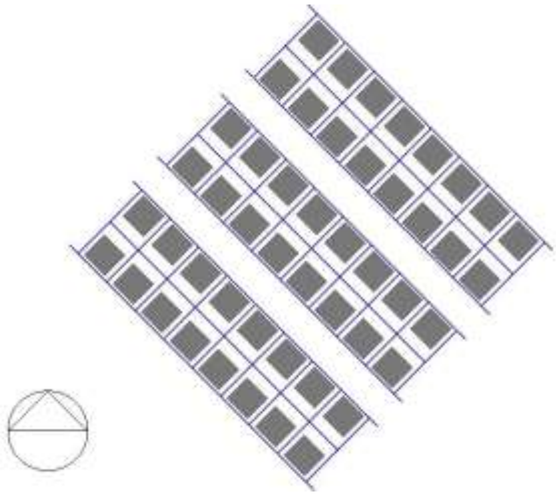

Fig 12. Street direction North-West (N-W) to South-East (S-E) with street width 16m and FAR 0.4.
Source: Author (Design Builder Software)

**Outcome**

The total energy demand was 141.19 kWh/m2 and the primary energy demand is 245.07 kWh/m2, the lighting was at 17.51 kWh/m2, heating at 93.95 kWh/m2 and cooling at 29.73 kWh/m2.

E4. **Type 3A**

Taking the best street direction that was produced out of simulating best street directions according to sunlight direction which in this case we got the street direction of east west for optimum residential energy saving methods, it was first tried with 8m wide street and floor area ratio of 0.6.

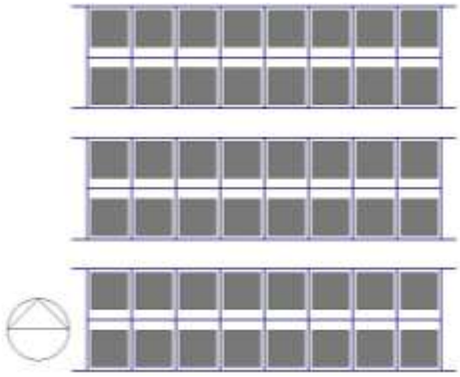

Fig 13. Street direction East (E) with street width 8m and FAR 0.6.
Source: Author (Design Builder Software)

**Outcome**

The total energy demand was 136.56 kWh/m2 and the primary energy demand is 225.45 kWh/m2, the lighting was at 18.88 kWh/m2, heating at 96.96 kWh/m2 and cooling at 20.71 kWh/m2.

E5. **Type 3B**

The same east direction that proved to be the best for sunlight street direction is tested with a street of 16 meter width and a floor area ratio of 0.6.

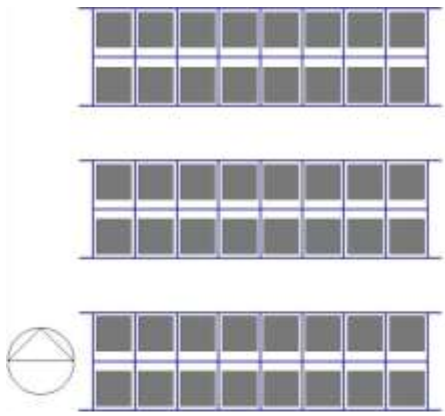

Fig 14. East street orientation with street width 16m and FAR 0.6.
Source: Author (Design Builder Software)

**Outcome**
The total energy demand was 136.61 kWh/m2 and the primary energy demand is 226.44 kWh/m2, the lighting was at 18.80 kWh/m2, heating at 96.51 kWh/m2 and cooling at 21.29 kWh/m2.

E6. **Type 3C**
Type 3C experiments with the same street direction (east-west) and street width of 8 meter and floor area ratio of 0.4.

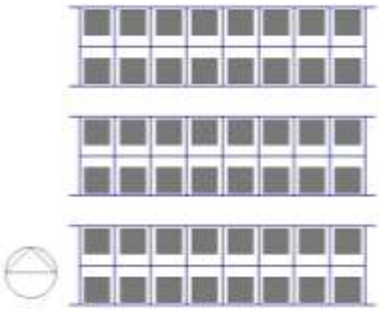

Fig 15. East street orientation with street width 8m and FAR 0.4.
Source: Author (Design Builder Software)

**Outcome**
The total energy demand was 137.19 kWh/m2 and the primary energy demand is 236.03 kWh/m2, the lighting was at 17.5 kWh/m2, heating at 92.38 kWh/m2 and cooling at 27.30 kWh/m2.

E7. **Overall Outcome**
Comparing the different parameters of street width and floor area ratio, option 3A and 3B are saving on energy demand.

## IV. CONCLUSION AND DISCUSSION

Comparing all the previous simulations together we find that the simulations that come from the east street direction perform better overall type 3 and 3A, which is an indication of the fact that sunlight plays a more significant role in saving energy than the wind direction. Also, a floor area ratio of 0.6 performs better than 0.4. The street width of 8 meters seems to be giving better numbers than that of a street width of 16 meters in smaller ratios than the sun.

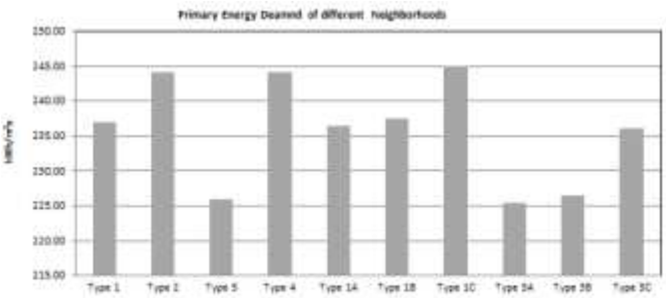

Fig 16. Energy performance for all the simulations
Source: Author (Design Builder Software)

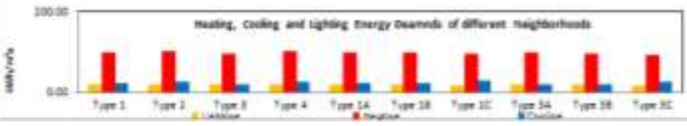

Fig 17. Heating, cooling and lighting demand for all the simulations
Source: Author (Design Builder Software)

**Outcomes of the study**
1. In comparing the sun based simulation (type 2,3) and the wind based simulation (type 1,2) it is found that more sun is more effective than less wind, implying that sun plays a huge role in less energy heating consumption and thus less total energy demand.

2. Street orientation plays a bigger role in consuming energy than the street configuration parameters.

3. The differences within street width 8m and 16m is not that big in the simulations done with optimum sun and wind directions.

4. Floor area ratio 0.4 And 0.6 also don't affect energy consumption highly.

5. These kind of simulations for orientation and street configuration should be done before the design of streets in towns to ensure optimum energy consumption.

6. Although heating played a strong role in determining energy consumption in Berlin; in hotter weathers, cooling will play a bigger role in measuring energy consumption.

Although the simulations have given an overall view on best street orientation and street configuration (street layout); this study is still specific to Berlin weather conditions and may be applicable to other somehow similar weather conditions around Europe. Thus, every city is required do this sort of research to figure out the street configuration best for minimizing energy demand.

The paper has tried to establish the connection between street layout and energy demand; yet, some more simulations and research must be conducted in the future on that subject since the research on urban form and energy demand with simulations and empirical evidence is not much.

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