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Impact of Floor Area Ratio (FAR) on Energy Consumption at Meso Scale in China: Case Study of Ningbo

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Abstract

In any urban planning and design project, Floor Area Ratio (FAR) of the site is a debatable factor across various stakeholders. China's increase of FAR for residential areas is one of the most remarkable cases of change of FAR in recent decades. China's urban residential projects have shifted away from low storey single-standing residential units to mid-storey mass housing projects and towards contemporary high-rise residential compounds. The changes in FAR are often very significant and is multiplied over the past few decades. In this study, FAR calculation of a meso-scale residential project located in the City of Ningbo (immediate inner city area) is put in place to shape the argument of renewable energy production and pathways towards energy use reductions. This study first elaborates on energy and policy implications of FAR. The study will then explore one example of a residential compound, based on four models of FAR (at 1, 2.5, 3 and 4). A comparison study is conducted using Eco-Tect software. All four models are analysed using their differences in heights and density. While FAR 1 is not suitable for the context of China (i.e. very low), FAR 3 and 4 are also considered to be high for energy-use reductions but are current practices. This paper argues these scenarios and concludes with impacts of FAR for energy production and reduction at meso scale.

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Keywords: Floor Area Ration (FAR); China; Residential Units; Energy; Solar.

1. Introduction

Metropolitan cities in china have experienced and are still experiencing rapid economic growth and urbanization. This has led to the expansion of built up areas. Many cities doubled their built up areas between 1990 and 2000, this is set to further increase by 60% in 2030. This translates to over 250 million persons urbanizing in the next 25 years [1]. This rapid change has occurred in the atmosphere of very high energy prices and the established linkage between Greenhouse gas emissions and climate change [2]. These discoveries make the study of urban form and policy quite imperative, as urbanization and suburbanization has very close links to how built up areas expand, leading to high energy use and volume of greenhouse gas emissions [1]. It is worth pointing out that energy consumption has not been the primary motivator for spatial planning particularly in china. This has been led by (i) rapid rural migration (ii) increased living

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standard (iii) restructuring of the economy in response to integration in the global market and the conversion of very high-density city cores to modern central business districts (iv) change in transportation system from public to private (v) relocation of industries to economic zones[3][4]. These rationales, lack the motivation of energy in spatial planning, let alone its relationships to urban form. However, research by various authors on these energy inter-linkages and the aforementioned climate change issues, particularly in China is motivation for this study. This study takes a brief but insightful look into urban form and spatial planning with a development in Ningbo china as a case study. The testing of various Floor-Area-Ratios (FAR) will provide an overview of energy efficiency in housing layouts which is directly relevant to the context of applied energy in the built environment. This study investigates a number of urban forms and their impact on energy consumption at various FARs.

2. Energy and Policy Implications of FAR

China's large population makes the optimal use of land a necessity, this is most crucial when considering the existing energy cost, scarcity of arable land and backlog of environmental pollution. The right level of land consumption per capita has generally been determined by the supply of land, local economic conditions and preference to consumers [1]. Land has seldom been selected because of its geographical positioning to possibly save energy in China. In addition, national and local regulation has a strong and determining impact in land availability, allocation and structure. As an example Density is controlled in the suburbs by minimum lot sizes and set back rules and restrictions on the height of buildings are used for the similar purposes. Generally building height restrictions are often made for aesthetics purposes as in the case with Washington DC, where no building can be taller than the US capitol. However, they serve other purposes which this studies highlights. They are used to limit densities due to environmental and congestion issues, save arable land and often over looked have significant impact on how passive cooling and heating approaches. They can augment wind directions in urban canyons, allow or block daylighting, provide shade etc. these modifications bring s the discussion of FAR to the fore front [1] [5][6][7][8]. The aforementioned principles of density and energy management can be regulated through FAR. FAR is calculated by dividing the a buildings usable floor area by the site or land parcel which it sits. This study uses FAR as a key tool for analyzing the energy impact of urban form and a reflection on it policy implications.

Many researchers now subscribe to the notion urban form and its effects on energy. One of the first to theorize this was Steadman [9] who addressed the energy implications of large scale urban form. He focused on high density formation in Line and Blob positioning, concluding that high density growth along a linear platform would be more energy efficient than centralized dense growth. This would increase the prospects of passive solar gains, natural lighting and local food production [9]. Publication by Newman and Kenworthy [10] focus on the correlation of urban density and gasoline use, which formed the bases of future studies of urban form and energy demand though London School of Economics suggest that these studies debatable conclusion [10][11]. For instance the argument of compact versus dispersed urban form has long been debated by Holden [6] and Mindali [12] recommending density as equivalent to energy efficiency with its negative impact on natural lighting, solar gains and ventilation [6] [12] [13].

These varied conclusion and debates has led to the development of software's used in the urban form and spatial and analysis [11]. Which have improved the analysis of wind flow, solar calculations and associated energy demand and consumption calculations [14] [15]. Yannas [16] observed 40% heat savings during his comparative study of apartments and detached housing. The study theoretically concludes that buildings with FAR 2.5 might represent the optimum density in neighbourhood dvelopment [16]. Capuleto and Shaviv [17] were able to show that even at relatively high built density, the FAR of around 1.6 to 1.8

was possible to maintain solar access to all building within a neighbourhood [17] [18]. Thereafter, building Layouts by Compagnon [19], Montervon et al [20] were conducted across Swiss cities where the effects of urban development on solar collectors were assessed. This provided the evidence to the possible consequences of urban planning guidelines on solar access. Arboit et al [18] studied the solar potential of low density urban form in Argentina, using 32 sample urban blocks and augmenting parameters such as street width glazing and trees. The conclusion was that solar energy could offset as much a 34% of heat energy demand. The author also emphasised the importance of orientation and shape of city blocks. These examples in literature give the energy-oriented importance of urban form, which China has yet to embrace, possibly due to other reasons such as rapid urbanization, linked to rapid economic improvement. This has led to the average increase of FAR in china over the years. London School of Economics further concludes that China is using land even more sparingly than before with little concern over possibility of optimizing thermal comfort and energy consumption through FAR and urban form design. In conclusion, there is a major impact on FAR on land and energy consumption. This study takes a brief look at the energy implications of urban form in Ningbo China in the form.

3. Methodology

The ideology of this research is based on spatial placement of building blocks and their impact on energy consumption on a neighbourhood level (Meso). LSE's report [11] looks at the impact of spatial planning and building materials on maintaining thermal comfort. This was done through the analysis of heat energy demand of five European cities. Similarly, this study looks at configuration of buildings in Ningbo, China. This research aims to find out which spatial configuration would best fit this location in terms of energy design. This approach is based on using FAR of the site. As identified earlier, FAR of 1.5 to 2.5 has been identified as the most energy efficient in spatial planning. This was similarly verified in [11]; and this study aims to look at it from a Chinese perspective, where rapid urbanization and increasing population adds to the spatial planning conundrum. However the full extent of the energy implications has not been fully investigated on a meso level, in particularly the cooling implications. Higher FARs of 3 and 4 are tested to model the current practice of development in most urban redevelopment cases in China.

Firstly, four configurations were modelled which utilized FAR 1, 2.5, 3 and 4 (fig. 1). Apart from FAR 4, all adjustments were made in the form of useful floor area. This was either reduced or increased to achieve the required FAR. A maximum of 30 floors is considered due to the rules and regulations for building height in such urban areas. For the FAR 4, additional buildings were allocated to meet the FAR. All parameters apart from those pertaining to form were also kept constant including climate. The climate was simulated to the nearest weather station near Ningbo at Dinghai. The simulation utilises Autodesk EcoTect 2011 and simulates indirect solar radiation which affects heat gains and losses of the urban blocks. From this the average heat and cooling demand per m^2 of usable floor area is obtained and analysed. Also wall construction materials are constant through all models and technological specifications in terms of appliances and various energy supplies were set aside. EcoTect is best used for early stage design analysis. Thus, relative differences is the focus of this study It also responds well to design changes which is ideal in this study. By utilizing these variables it becomes possible to compare heat or cooling demands across all configurations. Also, it should be noted that due to the simplification of analysis, heating and cooling energy should be seen as being relative values. This means that real energy heating and cooling energy demands may be quite different to the predicted values, and heating and cooling demand here is a just a direct difference between urban for in terms and FAR (Majorly height). The major parameter to be observed through this study is the indirect solar radiation which is solar radiation incident upon building walls.

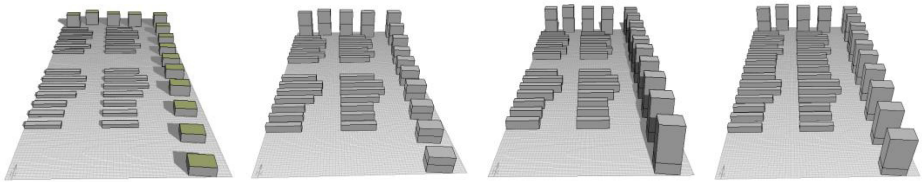

Fig. 1. (a) FAR 1 model; (b) FAR 2.5 model; (c) FAR3 model; (d) FAR 4 model

FAR 1	Low rise units: 3 Floors High rise units: 10 – 15 Floors
FAR 2.5	Low rise units: 6 Floors High rise units: 15 – 30 Floors
FAR 3	Low rise units: 6 Floors High rise units: 25 Floors
FAR 4	Low rise units: 6 Floors High rise units: 30 Floors Increased density by additional 4 Low rise units

4. *Results and Discussions*

The Indirect solar radiation was used to bring out important results from the analysis. Figure 3 shows that FAR 4 has a large amount of indirect solar radiation incident upon the walls of the all the buildings. FAR 1 has the least radiation, likely due to reduction of height of both low-rise and high-rise buildings as shown in Figure 1(a). Indirect solar radiation was used for this analysis, as this indicates the solar gains incident upon the walls of development. Direct solar radiation in EcoTect is interpreted as radiation that accesses the internal areas of a building. Indirect solar radiation allows us to understand how much radiation in terms of energy the building materials absorb. It should be noted that the indirect solar energy incident is divided by the total usable floor area of the development. Though computation is per m^2 the result indicates that there is higher radiation coverage as FAR increases, possibly due to increased surface coverage. Another observation is that FAR 2.5 and 3 have similar irradiation irrespective of the increased number of floors in FAR 3. This could mean that a difference of 0.5 FAR is not significant enough to make a significant difference in building envelope energy consumption. The Degree day comparative analysis further shows that FAR 4 has the highest heat gains but also the highest losses which supersede the gains. Alternatively, FAR 1 has the lowest heat gains and the lowest losses, signifying the possible impact of

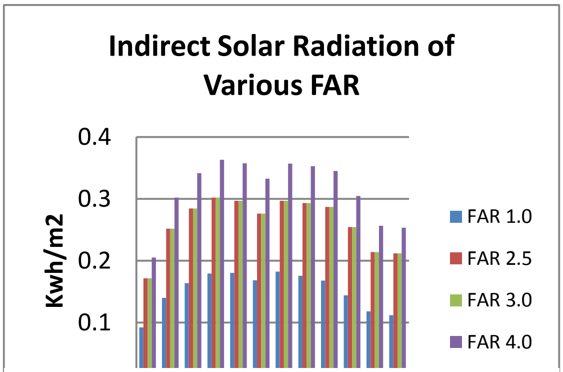

Figure 2: Indirect Solar Radiation for Various FAR

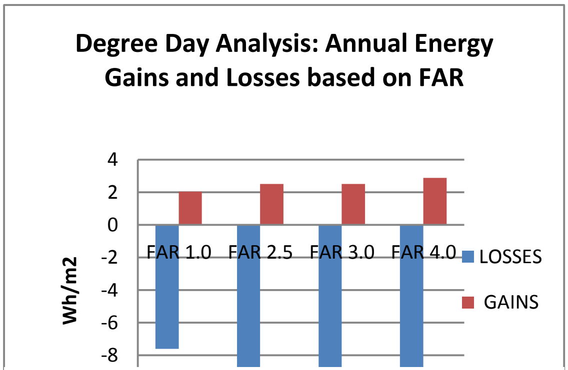

Figure 3: Annual Energy gains and Losses based on FAR

height and density, in heat gains and losses. It suggests that climate may play a significant role in these losses. From a renewable energy perspective this also gives an idea as to the type of development that would optimize solar thermal and PV panels within a neighbourhood. Further investigation was made on the components of the losses and gains, to identify what exactly is attributing to these values.

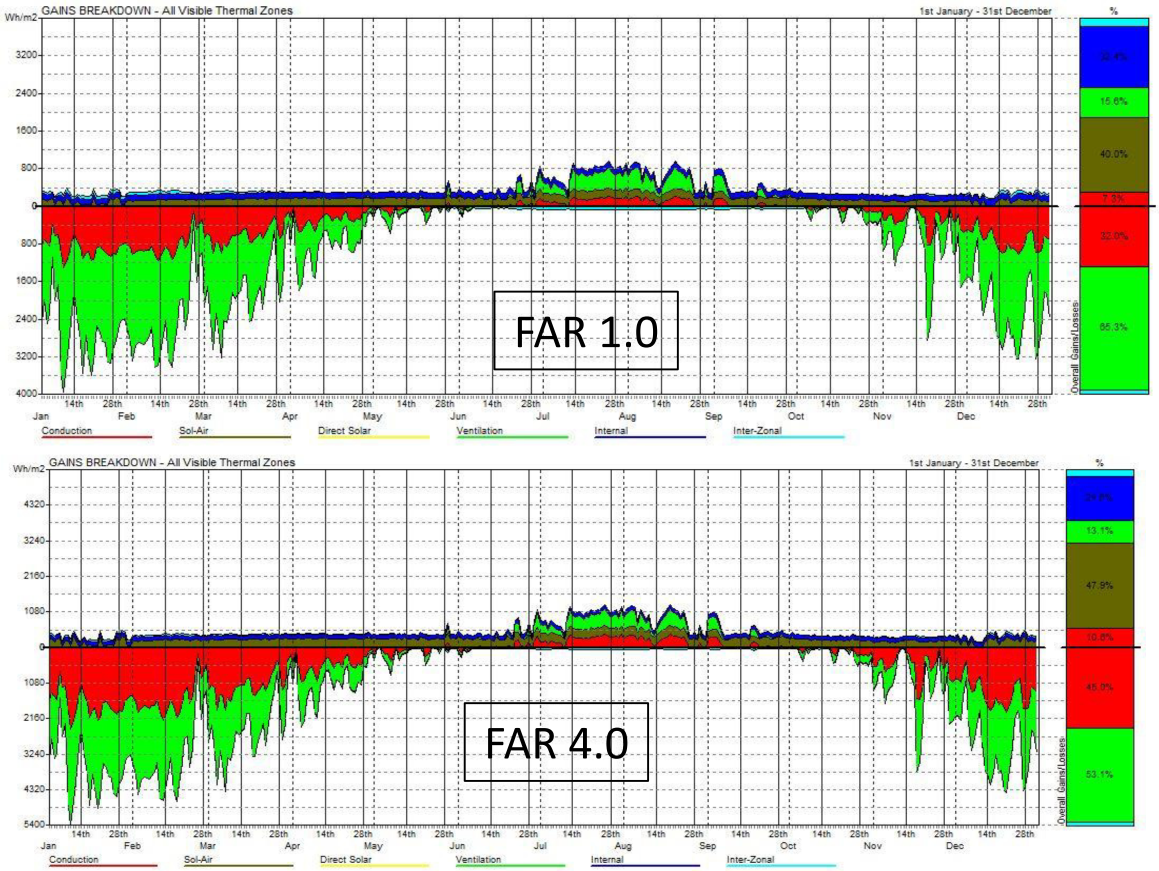

Fig. 4. Passive Building Energy Gains and Losses Breakdown

The comparative figure 4 shows that FAR 4 has higher ventilation and conduction losses compared to 1. This provides some evidence of the impact of height on the fabric losses and when coupled with Ningbo subtropical monsoon climate, the results become understandable. To further confirm these inferences from results, a new FAR model was developed, which reduced height from 30 to 25 floors on the high rise and increased density of low-rise buildings by adding more blocks (see fig.5).

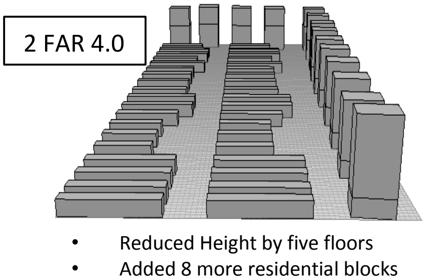

Figure 5: Second FAR 4 model

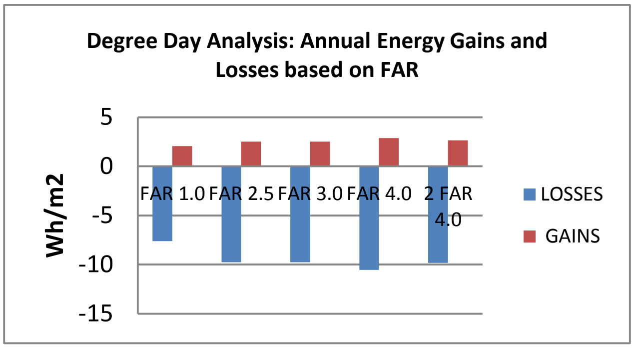

Figure 6: Degree Day Analysis: Annual Energy gains and Losses based on FAR

The results show that though the gains of 2FAR 4 reduces by 7% the losses also reduces by 8%. Essentially, higher buildings provide for more losses and less heat gain. Hence, a city such as Ningbo may benefit from building heights that reduces ventilation thus reducing thermal losses. Especially, when buildings require heating for 7 months on the year. This would undoubtedly affect energy use and associated costs (environmental and financial).

FAR 4 can be observed to provide the most thermal gains in terms of indirect solar radiation but also the most losses, leading to more energy being spent on heating than cooling. Literature above has highlighted the energy savings in heating but has not fully looked at the cumulative differences when development is compared. Fig. 1 indicates that FAR 1 would actually save more energy. However this would not be practical in highly urbanizing nations such as china which is driven by economic and minimal land use directives.

3. Conclusion

Essentially, climate of Ningbo has a strong role to play in energy consumption of this region. This would imply the strong contextual nature of FAR. Thus, energy characteristics of FAR would vary amongst continents and countries. Further investigation would need to be done to understand its impact. Secondly, there is clear relationship between FAR, energy production and consumption; wider surface areas and higher buildings allow for more indirect solar radiation which is linked to higher gains. However, if the buildings are too short this would affect radiation coverage and also productivity of solar energy technologies such as solar facades. Furthermore FAR of 2.5 and 3 provided a safe middle ground between FAR 1 (which though energy efficient is not suitable for the Chinese population or the economy) and FAR 4 (which addresses land use and economic issues but has high energy losses). The 0.5 FAR variable needs to be investigated further but current results indicate that when using FAR, an 0.5 addition would bear no significant loss but would have business and economic advantages by increasing usable floor area. Floor reduction as in the case of FAR comparison showed reduction in losses by reducing the floor number by 5 floors. This could imply that an optimum height can be gauged in terms of energy, in order words the higher the building the more losses. This would be a good precursor in developing policies and strategies for land use using FAR

FAR 4 also shows great affinity for renewable energy production and to a certain degree a good level of passive heating for buildings as compared to the other FARs. Ideally a balance has to be achieved to optimize solar energy production and passive design. Further studies, will look at higher intervals of FAR in order validate the 0.5 FAR theory. Another investigation involves the combination FAR with solar energy production to optimize not only energy consumption but also energy production. Ultimately, it is up to the developer working with existing laws on height an FAR to find which design best suites a specific development at specific location. This research also shows that the understanding and the utilization of FAR could be a strong tool in energy and urban planning. It also, shows that FAR is viable Indicator to use as a bench mark in passive energy design for the Built Environment and as a policy implementation guideline and strategy.

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Biography

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