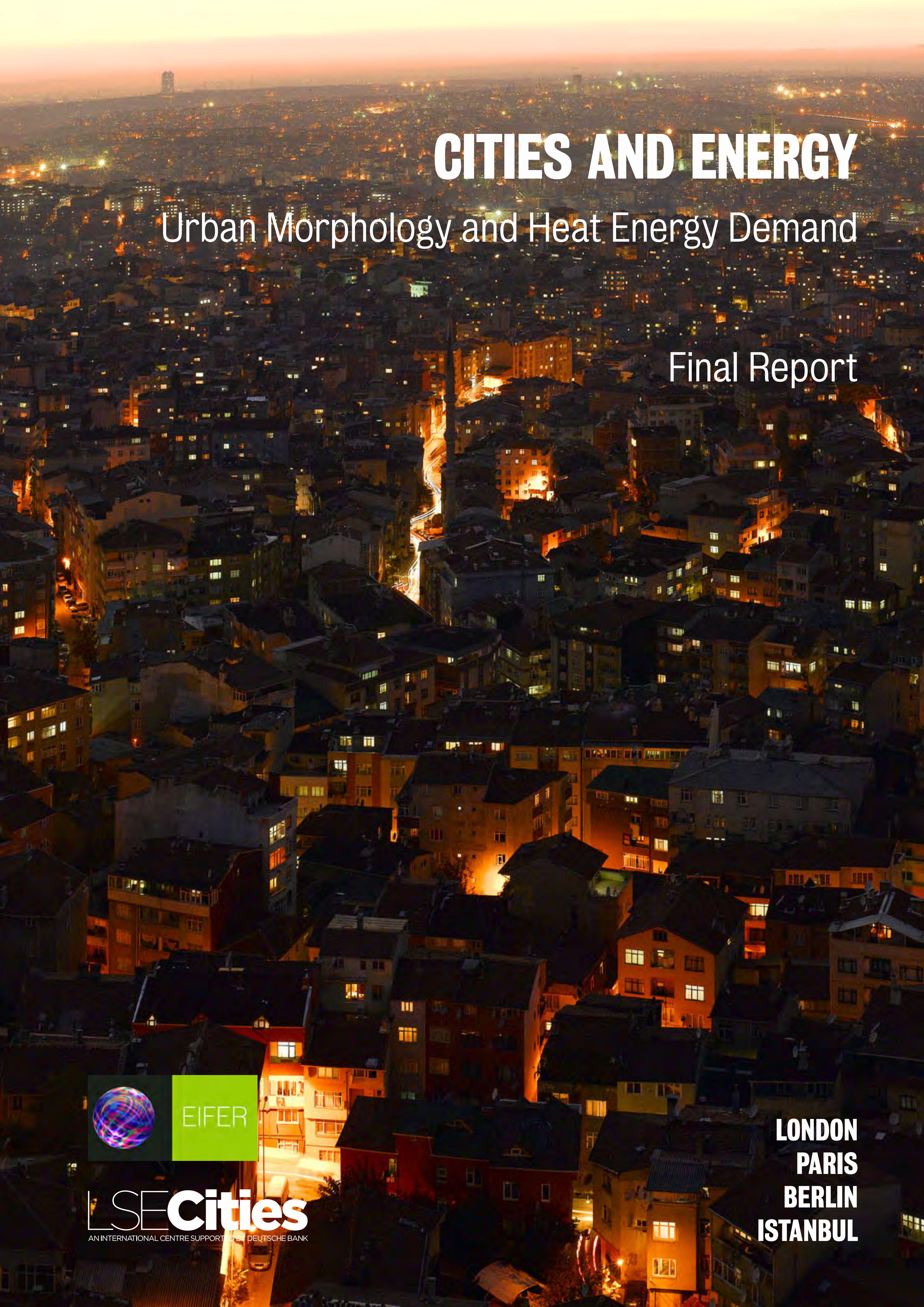
# CITIES AND ENERGY

## Urban Morphology and Heat Energy Demand

Final Report



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## Urban Morphology and Heat Energy Demand

## Final Report

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LSE Cities is an international centre at the London School of Economics and Political Science that carries out research, education and outreach activities in London and abroad. Its mission is to study how people and cities interact in a rapidly urbanising world, focussing on how the design of cities impacts on society, culture and the environment.

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The European Institute for Energy Research is a European Economic Interest Group set up by Electricité de France (EDF) and the University of Karlsruhe (KIT - Karlsruhe Insitute of Technology). Its mission is to develop or improve efficient innovative energy technologies as well as tools and approaches for sustainable development.

left
Berlin-Mitte: typical urban block building typology
*Anja Schlamann*

cover
Istsanbul by night
*Cemal Emden*

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# EXECUTIVE SUMMARY

It has long been known that buildings represent a large proportion of global energy demand. Approximately 40 per cent of energy end-use in the developed world takes place in buildings, compared to a figure of 20 per cent in the developing world – the latter still a highly significant amount (Pérez-Lombard et al 2008). In 2004, this resulted in global emissions of 8.6 GtCO2e (Levine et al 2007) or approximately 33 per cent of all energy-related greenhouse gas emissions and 17.6 per cent of all anthropogenic greenhouse gas emissions (Rogner et al 2007). In some cities, the dominance of buildings in relation to energy demand is even more pronounced. In the case of London, the energy used in buildings amounts to almost 70 per cent of the city's total energy demand (UN-Habitat 2008), resulting in a similar share of carbon emissions (Mayor of London 2010). In Berlin, building energy use is slightly lower at about 56 per cent, but it still far exceeds transport- and industry-related energy demand (UN-Habitat 2008). The building sector is thus the most significant contributor to carbon emissions in the global North, but it has also been highlighted as a sector with the scope and opportunity for significant improvement.

The report 'Urban Morphology and Heat Energy Demand', by LSE Cities at the London School of Economics and Political Science and the European Institute for Energy Research (EIFER) at Karlsruhe Institute of Technology, focuses on heat energy efficiencies created by the spatial configuration of cities. Of all energy used in buildings, energy for space heating represents the greatest demand. In Europe, approximately 70 per cent of energy use in residential buildings is heating related (WBCSD 2009). In principle, three types of intervention could play equally important roles in reducing heat-energy demand: behavioural adjustments, technological advancement and design considerations. For the overall energy consumption in non-domestic buildings, Baker and Steemers (2000) suggest that these three factors together could account for variations in energy demand by a factor of 10 (2, 2, and 2.5, respectively). To fully explain the up to twenty-fold variation observed for the energy demand of buildings, Ratti et al (2005a) consider whether urban geometry might be the missing factor. In this study we address this question by focusing exclusively on theoretical heat-energy demand (excluding space cooling and air conditioning) related to design issues at their most fundamental level: building design and urban form. The theoretical results of this study suggest that urban morphology-induced heat energy efficiency is significant and can lead to differences in heat-energy demand by up to a factor of six. Compact and tall building types were found to have the greatest heat-energy efficiency at the neighbourhood scale, while detached housing was found to have the lowest.

At the building scale, a number of studies on heat-energy demand have questioned the commonly held view that more compact building types, such as apartment blocks, outperform small-scale, individual building units such as detached, single-family housing. These results may initially seem surprising, given the basic physical relationship between heat-energy demand and the function of surface-to-volume ratio or massing of buildings in reducing heat loss. However, they can be better explained when the more complex trade-offs between the solar heat gains and the surface heat losses of different urban forms are considered. Indeed, this is now well understood at the level of the individual building. The tools have recently become available to move this research up to the scale of the urban block and neighbourhood.

With the exception of isolated studies looking at the thermal performance of blocks consisting of some of Martin's (1967) archetypal building forms, there has apparently not been a study of the thermal performance of general urban morphology types. Perhaps closest to a general study was the work conducted by APUR (2007) and the CSTB (Salat 2009) into the thermal performance of the Parisian building stock. Though this study was comprehensive, its methodology was based on the classification of buildings by age and not form, making the findings very specific to Paris and, by weak affiliation, other major French cities. Arboit's (2008) study on the city of Mendoza was a good example of the practical application and value of research into the thermal performance of general urban morphology types, though again results were specific to low-density buildings in an arid climate. Apart from work developing the tools and techniques for this field, studies into morphology and thermal performance have been disparate and specific in nature, often concentrating on one sector of a city, a subset of urban form, or the effects of a particular morphological parameter.

City planners and policy makers do not differentiate the urban fabric by geometric values, but rather by neighbourhood qualities and building types. There is still a lack of a larger body of literature on the general categorisation of urban morphology types in modern European cities, and by extension, a knowledge gap as to the effect of urban morphology type on building heat energy demand. This report aims to fill this knowledge gap.

## RESEARCH APPROACH

For the empirical basis of this investigation, the five most dominant building configurations were identified in each of the four largest European cities: London, Paris, Berlin and Istanbul. From each of these cities, the five selected building types were sampled five times at a scale of 500 by 500 metres. For each sample, basic information on the footprint/position, distribution and height of all buildings was extracted and represented as a digitised 3D model. From each of the 20 sets of five 'real' morphology samples, five idealised samples were created, based on the most generic features of the building configurations. These samples allow a 'purification' of the morphological characteristics of the dominant urban forms which, in the real samples, mostly coexist with other forms that might interfere or distort the heat-energy demand analysis results.

In the first stage of the project, the heat energy demand of all the samples was modelled so that the average annual heat energy demand per square metre could be determined. Modelling used a reduced set of parameters, where all non-morphological factors impacting on heat energy demand such as the insulation factor (u-value), façade details, building age and materials were kept constant. Climatic conditions for all samples were fixed to those of Paris. Orientations of all real building configurations were kept, while idealised configurations were adjusted to a north-south or east-west axis. Results allowed an investigation, at the neighbourhood scale, into effects on heat energy demand of different morphology types and macro morphological parameters: building density; surface-to-volume ratio; building height and surface coverage of buildings. Because of these simplifications, results should be interpreted as indicators of the relative difference between the heat energy demands of different morphology types, and not as absolute values to be compared to real building heat energy consumption. It should be noted that heat energy demand represents the first stage before an end or primary energy demand assessment, and thus ignores electrical appliances, hot water or means of energy generation and distribution.

In the second stage of the project, the effects of wall insulation, window u-value with glazing ratio, and climate were investigated. In particular, the extents to which insulation levels can mitigate some of the negative effects of morphology on heat energy demand are analysed. The report concludes with a summary of the key findings, a discussion of how these findings may inform city planning and policy, and a listing of potential next steps and future work.

Below follows an introduction to the building typologies that were identified in each of the four cities, after which an overview of the headline results is given.

## Building typologies compared

The selection of the 100 sample areas in the four case study cities was made using the following methodology. The initial process of scanning for the most prevalent building morphologies was undertaken using a qualitative method, which relied largely on conversations with experts in local typologies, architectural styles and urban neighbourhoods. Scanning made use of extensive literature and satellite mapping programmes such as Google Earth and Microsoft Bing Maps.

**Overall, similar building configurations were identified in all four cities which, at the same time, feature some unique building types.** Building configurations were analysed to identify five broad categories in each of the four cities. Across the cities, four common configurations dominated: detached housing, high-rise apartments, slab housing, and compact urban blocks. Unique building types included London's terraces and Berlin's row housing, which shared some similarities. The regular urban blocks of Paris featured a lower density version of the city's archetype compact urban block, and the gecekondu of Istanbul displayed a form of low rise urban housing typology that emerged as a result of the city's organic growth. Furthermore, a separate category was formed for detached multi-unit apartment buildings in Berlin and for the newer apartments in Istanbul - a dense but modern housing type which is prevalent across the city.

**Compact urban blocks combine the highest building densities with low surface-to-volume ratios and high surface coverage.** Density here is referred to as Floor Area Ratio (FAR), defined as the ratio of the sum of the areas of all building floors to that of the sample area (500 by 500 metres in this study). The building densities of compact urban blocks typically ranged between FAR 1.5 and 2.5. The most significant exception was Paris, where this value ranged between FAR 4 and 5.2. Lower density levels of compact urban blocks were observed in Istanbul and London, with FARs between 1 and 1.3. Surface-to-volume ratios of compact urban blocks are relatively low and typically in the region of 0.25, reaching as low as 0.1 in Paris. The building coverage ratio, often just referred to as coverage, is defined as the ratio of the sum of the building footprint areas to that of the sample area. Compact urban blocks generally occupy the same coverage ratio band of between 50 and 75 per cent, with very little observable increase in density with higher coverage. The idealised samples displayed the same overall patterns in all four cities.

**Detached housing combines the lowest building densities with high surface-to-volume ratios and low surface coverage.** Unsurprisingly, detached housing in all four cities featured by far the lowest building densities, with typical FARs of below 0.5. The highest density values for detached housing were observed in Paris, with one example displaying FAR 0.8, while Berlin's samples were all in the region of 0.2. Surface-to-volume ratios are mostly above 0.3, with several cases in Berlin exceeding 0.4. Surface coverage is usually between 10 and 20 per cent, rising as high as 30 per cent in Paris. Again, the idealised samples displayed the same overall patterns.

**High-rise apartments and slab housing share a potential for low surface coverage and a wide range of building densities and surface-to-volume ratios.** The overall pattern for high-rise apartments and slab housing within and across the four cities was less clear. This was probably compounded by the fact that these configurations were the least likely to exist in their pure form within the 500 by 500 metre sample areas. For both, density typically varied, with FAR between 0.6 and 1.7 and a tendency toward higher densities for high rise compared to slab housing. Coverage of both configurations ranged from 10 to 20 per cent - similar to that of detached housing. Idealised samples tended to have a higher FAR and lower coverage outliers than the real samples, indicating the lack of purity of the morphologies in the real samples.

**Terrace housing in London combines relatively low density with relatively low surface coverage and a range of surface-to-volume ratios while row housing in Berlin has slightly lower surface coverage at same density levels with little surface-to-volume variation.** London's dominant urban form of terrace housing and Berlin's row housing typically featured a density of FAR 0.5 to 1. However their coverage differed, ranging between 20 and 30 per cent in London compared to 15 and 22 per cent in Berlin. Both their idealised samples featured similar values.

**Gecekondu in Istanbul and regular urban blocks in Paris feature wide spread densities and surface coverage values.** Although at different absolute levels, both configurations shared results showing a wide range of different density and coverage values. Gecekondu density ranged from FAR 0.4 to 1.8 with coverage from 25 to 42 per cent. Regular urban blocks in Paris were significantly denser, ranging from FARs 1.8 to 3.4 and coverage between 15 and 35 per cent, with some scattered higher coverage outliers from Istanbul. The idealised samples displayed the averages of these values in both cases.

**Density is achieved either through increasing the average building height or overall surface coverage, but rarely simultaneously.** While density can be seen to increase steadily up to a FAR of approximately 1, between FAR 1 and 1.5 there appears to be a bifurcation of the data points. Past this point, the morphology types appear to either follow a path of fast height increase with increasing density, or one of very little height increase with increasing density. It is the high-rise apartment and slab housing formations which tend to follow the former path, with the regular urban blocks of Paris, the modern apartments of Istanbul and the compact urban blocks of all cities following the latter. This alludes to a mutual exclusivity in design choices (as regulated for by the planning laws in all four cities): if one wishes to increase density, one can either build upwards or increase the surface coverage of the building. The data suggests that these two strategies are seldom attempted in unison. Only detached housing does not feature in this bifurcation, combining lowest densities with the lowest average height of fewer than 2.5 floors in all cities.

A comprehensive visualization of the key spatial variables used in this report is facilitated by the 'Spacemate' diagram developed by Berghauser Pont and Haupt (2005). Besides the three parameters already introduced – floor area ratio, surface coverage and building height – the diagram uses the open space ratio, which is the ratio between the un-built area and the gross floor area of any given site. Some key insights are summarized below.

## HEADLINE RESULTS

**Urban morphology matters: A large variation of up to a factor of six was identified for the heat-energy demands of different urban morphologies.** Heat energy demand is measured in kWh per square metre per year but is henceforth quoted in the abbreviated form of kWh for convenience. As highlighted above, these are theoretical energy values only comparable across the results of the modelling undertaking as part of this study. They cannot be compared to the real energy performances of buildings. The distribution of heat demand in all 100 samples in the four cities followed a standard normal distribution with an average of 103 kWh. The highest heat energy demand of 194kWh was calculated for the gecekondu in Istanbul, while the lowest value, at about 30 kWh, was identified for an area of compact urban blocks in Paris. The distribution of the 20 idealised samples tended towards lower energy efficiency than the real samples, with an average heat energy demand of 119 kWh, although with a much wider range of between 60 and 238 kWh. The best performing samples in this case included a mix of high-rise apartments, slab housing and the compact urban blocks.

## Building typology and energy

**Compact urban blocks consistently perform best, detached housing worst.** The majority of compact urban blocks displayed a heat energy demand of less than 100 kWh and, in the case of Paris, even below

50 kWh. The exception was compact urban blocks in Istanbul, which were in the medium range of 100 to 150 kWh. Idealised samples of the compact urban block had a heat energy demand of below 120 kWh, and in the case of Paris and Berlin, below 85 kWh. However, and as discussed below, several idealised samples of high-rise apartments and slab housing had even lower heat energy demands at levels as low as 60 and 67 kWh respectively. Across all cities, none of the detached housing samples achieved heat energy demands below 110 kWh, while most featured performances in the real samples in the region of 150 kWh.

**High-rise apartments and slab housing can potentially perform very well**. With the exception of London slab housing and Berlin high rise apartments, all idealised samples of these morphology types showed heat energy demands of less than 80 kWh. The real samples of high rise apartments seemed to underperform due to the fact that they rarely exist in a pure form within the 500 by 500 metre sample areas. The same phenomenon was observed for slab housing, particularly in the case of London and Paris, where real samples tended to generate heat energy demands as high as 150 kWh, while idealising the samples pushed this value down to 105 and 80 kWh respectively.

**Building typologies show a diversity of performance results.** Urban morphologies that featured the most diverse energy performances included the gecekondu in Istanbul, with heat energy demands ranging between 100 and 200 kWh, apartment buildings in Berlin ranging between 90 to 170 kWh, and slab housing in Paris and London ranging between 60 to 150 kWh and 85 to 150 kWh respectively. While the performance ranges of the real samples of slab housing again reflect the result of a mixing-in of other configurations, the variations of other morphologies showed the diversity of performance that is inherent even in areas following similar urban design principles. Terrace housing in London performed relatively poorly, with performance averaging 110 kWh. Row housing in Berlin was only slightly better, with a range of between 75 and 95 kWh.

## Building density and energy

**Density was found to be a good indicator of heat energy demand.** This variable was found to best fit a logarithmic relationship, with heat energy demand decreasing with increasing density. With a correlation coefficient of 0.77, this relationship was seen to be strong.

**The impact of increasing densities is greatest at the lowest density levels.** Those morphologies with the lowest densities (under FAR of 0.5) display a heat-energy demand of at least 100 kWh rising to almost 200 kWh, but it is here where the impact of increasing density levels is greatest. At the same time, efficiency levels of less than 50 kWh are common only above FAR 4, although samples in Paris and Berlin seem to suggest similar efficiencies at densities as low as FAR 1. The overall pattern of all 20 idealised samples is similar but re-emphasises the potential of some typologies - high-rise apartments and slab housing - to achieve the maximum energy performance across all samples at a building density in the region of FAR 1. In these cases heat-energy demand is as low as 50 kWh.

**Minimum building density appears to guarantee the maximum heat-energy demand.** For all samples with a density of above FAR 1.5, heat energy demand was significantly below 100 kWh (with only two exceptions, both in Istanbul). All morphologies at density levels above FAR 4 have performances that vary between 30 and 50 kWh.

**Greatest variation in energy demand was found at a density of FAR 1.** Energy demand here ranged from 50 to 150 kWh. It is at this point that other urban form-related factors appear to become more significant. In areas of lower density, these ranges become slightly smaller, while increases in density appear to significantly reduce heat energy demand ranges.

## Surface-to-volume ratio and energy

**Surface-to-volume ratio was found to be a good indicator of heat energy demand.** This variable was found to best fit a linear relationship, with heat energy demand increasing with increasing surface-to-volume ratio. With a correlation coefficient of 0.80 this relationship was seen to be strong.

**Increasing surface-to-volume ratio increases the range of energy demand in buildings.** These variations in heat energy demand at similar surface-to-volume ratios hint at the trade-off between surface heat losses and solar gains, which both scale positively with building surface area. At a ratio of 0.15 the range in energy performance is only 35 to 80 kWh, while at a ratio of 0.4 this increases to a range of nearly 110 to 200 kWh.

## Average building height and energy

**Average building height was found to be the best indicator of heat energy demand.** This variable was found to best fit a logarithmic relationship, with heat energy demand decreasing with increasing height. With a correlation coefficient of 0.88 this relationship was seen to be the strongest of all the tested variables.

**The average building height of the four cities was a good indicator of its heat energy performance.** Paris demonstrates the greatest average heights, with over half of the morphologies sampled having more than 6 floors. Conversely, London demonstrates the lowest average heights, with more than half having fewer than 4 floors. A corresponding difference in heat energy demand is seen, with Parisian compact urban blocks achieving only 30 kWh while the equivalent morphology in London achieves 70 kWh at its lowest.

### Surface coverage and energy

**Surface coverage ratio was found to have very little correlation with heat energy demand.** This variable was found to loosely fit a linear relationship, with heat energy demand increasing with decreasing surface coverage. With a correlation coefficient of 0.40 this variable was seen to be very weakly linked with heat energy demand.

**Good heat energy performance can be achieved with a wide range of coverage options.** Good thermal performance can be seen at low coverage ratios in high rise apartments, and at high coverage ratios in compact urban blocks. This demonstrates the wide range of coverage options that exist for thermally efficient morphology types. Heat energy demands below 100 kWh were common for high-rise and slab housing typologies with surface coverage of below 20 per cent. Similar performances are achieved in compact urban blocks and row housing with coverage of above 50 per cent.

**High-rise and slab housing offer a unique combination of low surface coverage and energy efficiency.** Energy demand below 100 kWh is also common for high-rise and slab housing typologies with surface coverage of below 20 per cent. Again, a particular strong combination of low surface coverage and energy demand emerges based on the analysis for the idealised samples of these two building configurations.

## EFFECT OF INSULATION, GLAZING RATIO AND CLIMATE

**Insulating a building with a high initial heat energy demand will result in a greater absolute energy saving.** Insulating walls should result in greater absolute energy saving if the original through-wall energy losses (and thus heat energy demand) are high. Modelling results showed that insulating a building which has higher initial heat energy demands results in a greater absolute reduction in that heat energy demand. The Parisian compact urban block has a heat energy demand of 97 kWh with a wall u-value of 2, reducing to 37 kWh when the u-value is reduced to 0.5 - a net energy saving of 60 kWh. However, Berlin detached housing shows a heat energy demand of 393 kWh at the high u-value of 2, reducing to 118 kWh at the low u-value of 0.5 - a much greater net saving of 275 kWh. Of course, there will be more wall area to insulate per unit volume in detached housing, so this will be more expensive and include higher embedded energy. Future work ranking the cost-benefit of insulation for different morphology types would be a useful next step.

**More linear building forms such as row housing, slab housing and terraced housing show the highest critical window u-values.** Different morphology types have different critical window u-values: the u-value above which increasing the glazing ratio would result in increased thermal losses. It was shown that the compact urban block and detached housing often have similar critical window u-values. This seems to imply that the compactness of the building form is not in itself an important factor in determining critical u-value. It seems likely that a morphology's solar cross-section relative to its volume is a more important indicator of the critical window u-value.

**In the absence of the effects that changing latitude may have, the effect of climate is but a scaling one.** The colder the climate the greater the heat energy demand of the buildings. With a maximum 4°difference between the latitudes of London (52°), Paris (49°) and Berlin (53°), the effect of latitude is justifiably small. However, with Istanbul at a latitude of 41°, the effects of the angle of the sun may have a noticeable impact on the overshadowing of buildings. The sun will be higher in the sky and thus shadows will generally be shorter. Further investigation would be required to quantify this. A brief description of the climatic conditions of the four selected cities is presented in chapter 5.3.

## PROVISIONAL POLICY IMPLICATIONS

In summary, the preliminary results of this study seem to suggest that urban morphology-induced heat energy efficiency is either achieved by higher building densities, as in all the cases of compact urban blocks or by taller buildings, which in turn allow for building densities as low as a FAR of 1. It is at that density level that the diversity of urban morphologies, as well as heat energy demands, are greatest.

Given the limitations that were applied to this investigation, it is difficult to derive any direct policy implications at this point. However, emerging areas of policy influence could include the following, which will have to be tested in the follow-up research:

- Prioritize mid to high-density urban typologies
- Avoid detached housing particularly in an urban context where there are alternatives
- Building height could be used as an indicator for morphology-induced heat energy demand in cities
- Set a minimum density standard of FAR 1
- Set a maximum surface-to-volume ratios of 0.2
- Make solar studies a prerequisite for planning evaluation

# 1 INTRODUCTION

Cities around the world are at the epicentre of a global shift of populations from rural to urban areas. In 2007, for the first time in human history, the number of global urban dwellers outnumbered those living in rural settings. The latest UN estimates suggest that this trend is likely to lead to a total of 6.3 billion urban residents by 2050 - approximately 70 per cent of the predicted global population (UN DESA 2010). As the world becomes increasingly urban, questions regarding the shape, size, density and distribution of the city have become ever more complex and politicised. This urban dawn, whilst presenting many problems, also offers a unique opportunity for more sustainable development patterns through recalibration of the relationship between economic prosperity, social equity, resource efficiency and environmental protection.

Efforts to recalibrate will include a strategy to tackle ever increasing energy demand, currently only satisfied by a dramatic overconsumption of non-renewable resources. It is in this context that cities and energy will have a defining role to play in any attempt to address this global environmental crisis. In many instances, today's cities have become the pinnacle of a 'brown' economy, featuring vast, energy-intensive urban agglomerations that are hardly recognisable as a 'city', with defining features of shared public space, infrastructure and service provision. At their best, however, cities can deliver energy efficiency coupled with major socio-economic benefits. They can produce physical proximities, significantly reducing the need for motorised travel; benefit from scaling effects for infrastructure provision; and feature a built environment with a greater regard for energy efficiency due to their compaction, massing and spatial organisation.

This report on 'Cities and Energy' by LSE Cities at the London School of Economics and Political Science and the European Institute for Energy Research (EIFER) at the Karlsruhe Institute of Technology, focuses on energy efficiency induced by the spatial configuration of cities and specifically explores the relationship between urban morphology and heat energy demand.

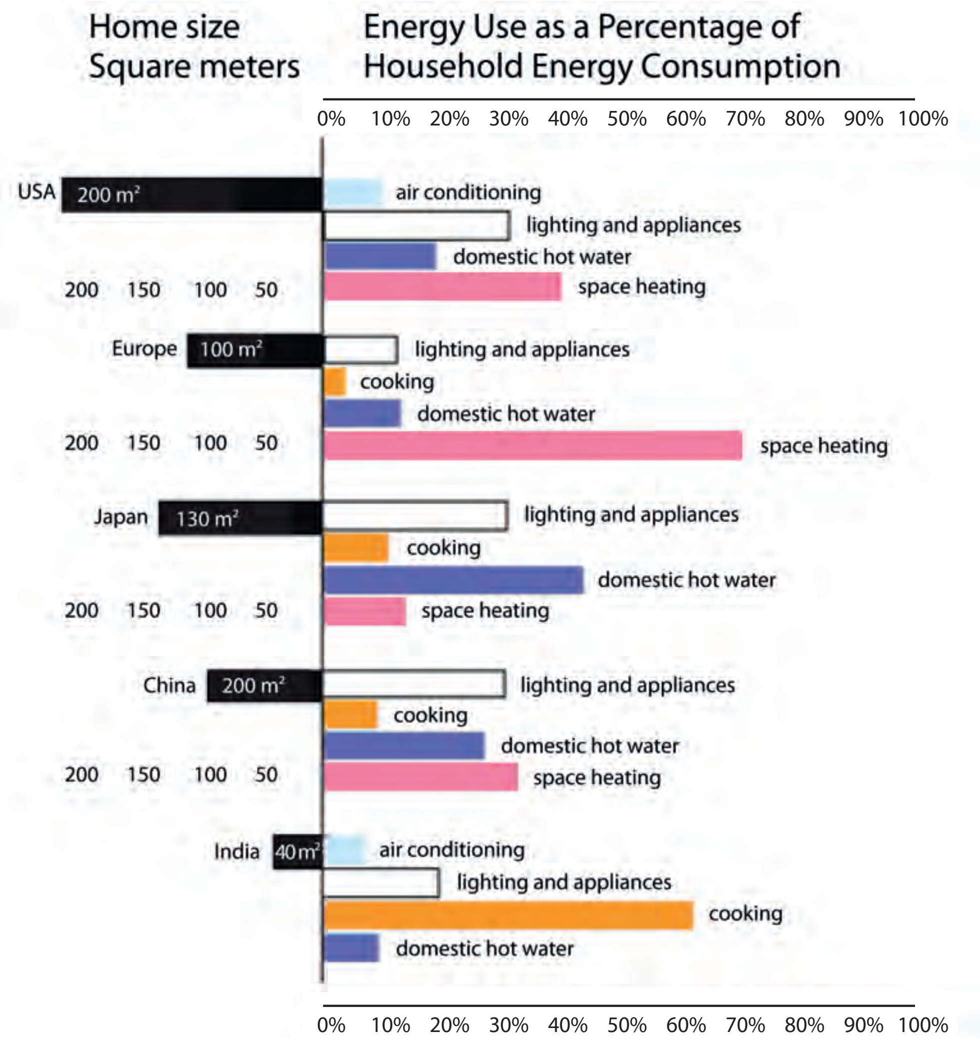
## 1.1 BUILDINGS AND HEAT ENERGY DEMAND

Buildings concentrate a large proportion of global energy demand. Approximately 40 per cent of energy end-use in the developed world and 20 per cent in the developing world takes place in buildings (Pérez-Lombard and others 2008). In 2004, building-related energy use resulted in global emissions of 8.6 GtCO2 e/yr (Levine and others 2007), or approximately 33 per cent of all energy-related greenhouse gas emissions and 17.6 per cent of all anthropogenic greenhouse gas emissions (Rogner and others 2007). Within cities, the dominance of building-related energy demand is even more pronounced. In the case of London, energy demand for buildings amounts to almost 70 per cent of the city's total energy demand (UN-Habitat 2008), with a similar share of carbon emissions (Mayor of London 2010). In Berlin, building energy use is slightly lower at about 56 per cent, but still far exceeds transport- and industry-related energy demand (UN-Habitat 2008). Major factors influencing levels of energy consumption in buildings include climate, urban context (or morphology), building design, systems efficiency and occupant behaviour (Baker and Steemers 2000). Often, these factors are interrelated, for example building design can easily affect behaviour. Baker and Steemers (2000) estimated that building physics could have a factor 2.5 effect, systems and occupant behaviour each a factor 2 effect, and a later study by Salat (2009) found that, for Paris, morphology could have as much as a factor 1.8 effect. These numbers are context-specific but clearly they are powerful levers with which to reduce energy demand; each one alone having the potential to cut by half the energy used in buildings. This is all the more pertinent when one considers that, based on current policy commitments, overall energy demand from buildings will increase by between 31 and 37 per cent of 2008 levels by 2035 (IEA 2010).

Of all energy used in buildings, energy for space heating amounts to the largest share in cold and temperate climates. In Europe, approximately 70 per cent of energy use in residential buildings is related to space heating (WBCSD 2009). Although at a lower overall percentage, space heating also features highest among all building-related energy uses in contexts as diverse as the US and China. The only exceptions are hot and tropical climates with limited heat energy demand (see graph on this page). Besides climatic conditions, human behaviour related to the climate control of buildings has a big impact. Thermal comfort levels within buildings typically range from 18 to 26 degrees Celsius (Baker and Steemers 2000) and small changes within that range can have significant impacts on the overall heat energy demand.

Global trends suggest that the overall demand for heat energy in residential buildings is set to rise. Changing patterns of occupancy in the global north, with a sharp rise of one-person households and increasing personal living space, is a critical factor. The average size per dwelling in EU-15 countries has increased from 84 square metres in 1985 to 89.5 square metres in 2001 (UN-Habitat 2008), while the total population residing in single person dwellings has increased from 11 per cent in 1998 to 14.3 per cent in 2009 (Eurostat SILC) . Increasingly, heating demands in developing cities that experience cold winters will play a significant role in future energy demand, as dwellings increase in size and thermal comfort expectations rise.

Today, the challenges related to the prospect of further increasing heat energy demands are well understood and, in the last decade, policy makers have begun to address the issue of energy efficiency. A vast range of policy directives concerning the energy efficiency of buildings has been initiated, with the European Energy Performance of Buildings Directive (EPBD) among the more prominent examples. As outlined above, a significant part of the effort towards increasing the heat energy efficiency of buildings can be addressed through optimising their design and configurations both individually and in relation to each other.




**Residential energy consumption and home size in selected regions**

*Source: World Business Council for Sustainable Development (WBCSD), 2009.*

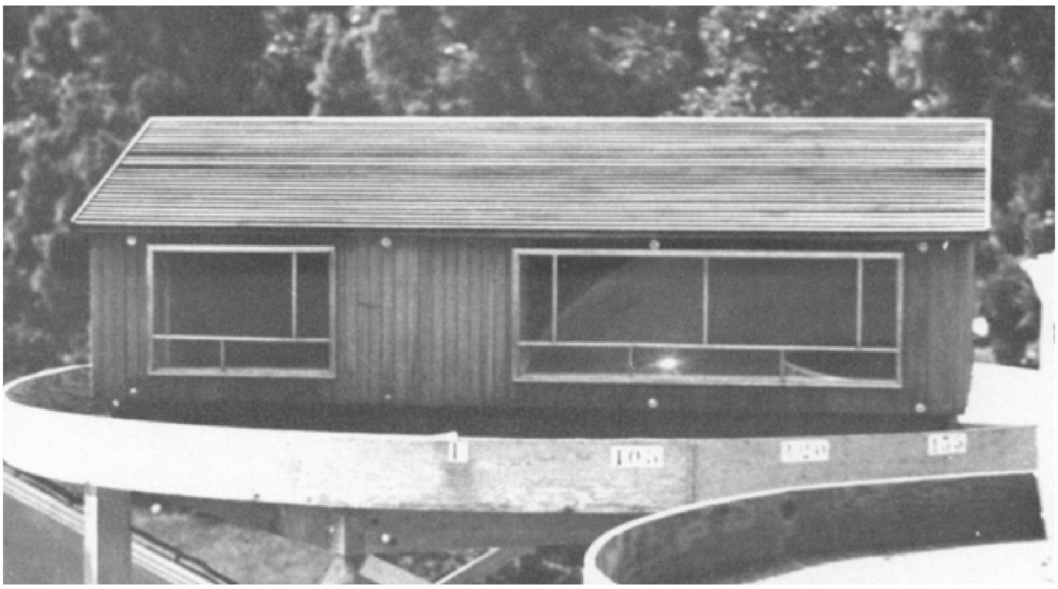
## 1.2 STATE OF RESEARCH

### Pioneering work at the macro and micro level

The dawn of environmentalism and concerns regarding resource depletion, together with the oil crisis in the 1970s, brought with them the beginnings of a discourse on building form and energy consumption.

At the macro scale, urban form was investigated through large-scale observable parameters such as density and shape. Steadman (1979) was one of the first to theorise the energy implications of large-scale urban form. He concentrated on the different energy use implications as a result of the formation of high-density urban fabric in either 'line' or 'blob' formations. His conclusions were that high-density growth along linear transport infrastructure would be more efficient than centralised dense growth. Increasing the possibility of passive solar gains, natural lighting, ventilation and local food production were seen as benefits of this kind of urban footprint. After the publication of Newman and Kenworthy's (1989) iconic study showing the high correlation between urban density and gasoline use, the macro level implications of urban density on transport energy use were increasingly accepted. These early findings formed the basis for many future studies on the effects of morphology on energy demand, though more recent literature is less certain of its conclusions. Some generally subscribe to the concept of 'density equals efficiency' (Holden 2004; Mindali 2004) whilst others are more wary to jump to this conclusion, citing the negative impacts of density on natural light, solar gains and ventilation as important trade-off factors (Hui 2001), and the possibility that the relationship between density and efficiency may not be causal (Larivière and Lafrance 1999; Steemers 2003).

At the micro scale - the level of the individual building - predictions of energy demand were made through geometric approximations of building form and basic scientific principles (Olgyay and Olgyay 1963), supported and calibrated by experimental results. Notably, Olgyay (1967) at Princeton University constructed a scale model of a building on a turntable to investigate the effect of orientation on solar heating. At around the same time, Martin (1967, 1972), March and Trace (1969), and others at Cambridge University were investigating the relationships between surface coverage, building height, building depth and density to understand the equivalent levels of day lighting. They selected simplified urban types based on archetypal building forms in order to compare their performance (Martin 1967). The attractiveness of these generic forms lay in their simple and repeatable characteristics, thus eliminating the complexities found in real urban sites. These archetype samples were very influential and were reused in many subsequent studies. The desire to practically apply the learning from such work led Baker and Steemers to develop the 'lighting and thermal' (LT) method (Baker and Steemers 2000, 1995; Baker 1996; Roaf 1992). The LT method



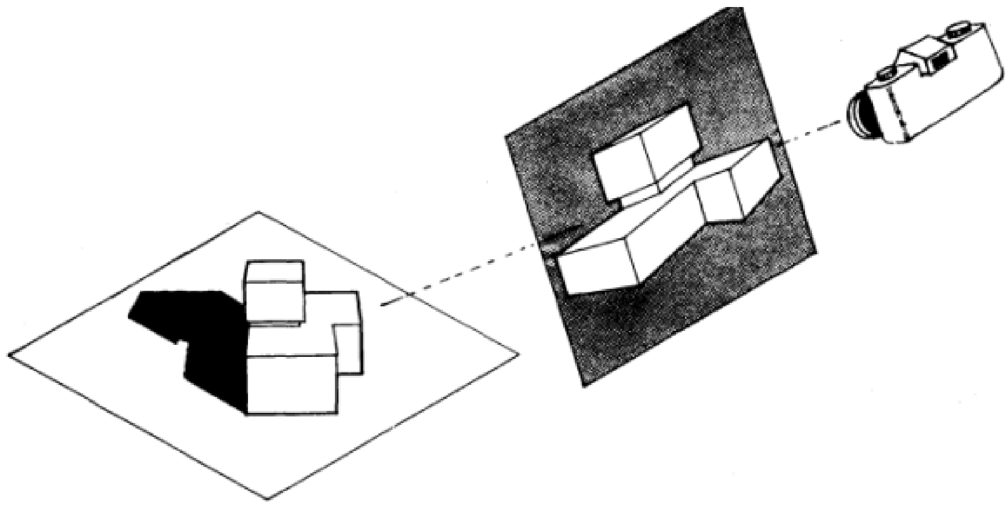
Experiments at Princeton University: Test model used for analysing the impact of orientation on heat-energy demand in buildings.
*Olgyay 1967*

involves differentiating between passive and non-passive zones within the building. Passive zones are defined as those with a depth (distance from an exterior wall) normally twice the floor to ceiling height, therefore having potential access to passive lighting, heating, cooling and ventilation. Active zones are all those that are unable to take advantage of passive systems and require the 'active' use of energy to provide lighting, heating, cooling and ventilation. Through performing a series of simple calculations on these zones, an instructive estimate of the building's lighting, heating and cooling energy demand can be derived from a building's solar heat gains, internal heat gains and ambient outdoor temperature. By striking a balance between over simplicity and over complexity, the LT method became a useful design tool for architects. The overriding message implied by using this method is 'avoid deep plan' buildings (Baker 1996).

With a few notable exceptions this earlier work was limited to studies on small numbers of easily obtainable parameters. This polarised research between the macro and micro scales of understanding: those at the city level, and those at building level. However, using an innovative photographic technique, a device known as a heliodon and groups of building models, Knowles (1974) was able to calculate solar cross-sections for entire neighbourhoods, thus pioneering research into the effects of passive solar heating at this hitherto unobserved morphological scale. This work led to the concept of the 'solar envelope'; a surface defined as the maximum limits of a buildable volume or 'solar volume' on a given site such that the new structure does not obstruct the hours of solar access onto adjacent sites and buildings. This concept was later used to inform solar access guidelines for urban blocks in order to maximize their passive heating and lighting potential. Gupta (1984) elaborated upon this technique, using it to compare the pavilion, row and court archetypal building forms (Martin 1967) against their thermal performance in a hot climate. Distance between buildings, orientation and form were all shown to be significant factors in thermal performance. Furthermore, while the pavilion performed well as an individual unit, its performance dropped very significantly when analysed in block formation, clearly demonstrating the importance of morphology analysis at a scale above that of the individual building.

## New computer-based analysis

The introduction of computers had a profound impact on the field of urban morphological research, particularly at the neighbourhood scale where significant macro scale data is difficult to obtain and sufficient micro scale data (principally data that defines building form) becomes too labour-intensive to manually collect and analyse when scaled beyond the plots of one or two buildings. With computer automation, more complex geometries could be explored and calculations could be rapidly repeated for many buildings in order to expand the analysis to the neighbourhood scale.

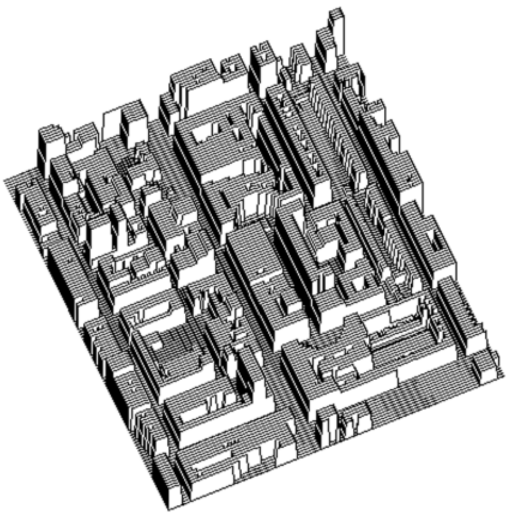


Photographic method for calculating the sunlit area
*Gupta 1984*

For this to be useful, new data to feed such models was required. Fortunately, in a parallel vein of research, computers were revolutionising the collection and analysis of geographical information. Availability of satellite and high altitude camera imagery, and the creation of a satellite global positioning system (GPS) provided plentiful raw data. Analysis of this data was enabled by the development of geographic information systems (GIS) software. While some imaging can be applied directly to observe macro effects such as heat islands (Quattrochi and Luvall 1997), more information can be extracted through appropriate processing techniques. Webster (1996) was one of the first to develop image texture analysis techniques for urban morphology research, showing that urban density data could be extracted from satellite imagery. Richens (1997) took this work still further by incorporating image processing techniques and a digital elevation model (DEM), a tool previously used by geographers to overlay three dimensional topographical features onto two dimensional images, producing something akin to a 3-D figure ground drawing and allowing the previously manual LT method (Baker and Steemers 2000) to be automated.

Still at the level of the individual building, Steadman et al. (2000) conducted a comprehensive categorisation of non-domestic building stock (NDBS) with the primary aim of creating a database of building form to be used for energy analysis. From a survey of 3350 buildings in four English towns, classification criteria focused on the building's external envelope - already known to be highly significant in energy demand calculations. In a follow-up study, this data was used to create the UK 'national nondomestic buildings energy and emissions model' (N-DEEM) (Pout 2000). By combining NDBS built form statistics with other data sources such as energy use statistics, surveys and planning records, building energy demand was broken down by activity and end use. This data was then used to analyse various mitigation options and produce a cost abatement curve in order to inform government energy policy. As well as showing that space heating is by far the largest energy end use in non-commercial buildings, results indicated that the retrofitting of cavity wall insulation and the replacement of florescent bulbs should be amongst the first improvements implemented, both providing net financial benefit whilst reducing carbon emissions. Unfortunately this assessment does not include morphological characteristics of buildings and only uses mean figures for energy use per square metre. This study could be an opportunity to integrate them.

The numerical modelling tools to investigating the neighbourhood scale were further honed by Ratti and Richens (1999) with the addition of new functions that could calculate built form statistics from the DEM; including surface coverage, average built height, sky view factors and shadows. In addition, demonstrations of how they could be used in other areas of research were

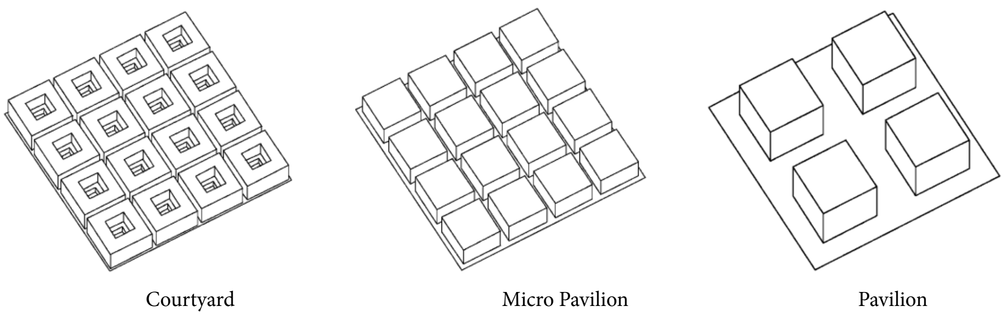


Left
Thermal and areal imaging
*Quattrochi and Luvall 1997*

Right
GIS and Digital elevation models [DEM]
*Richens 1997*

provided; for example wind flow and pollution dispersal. Martin's (1967) archetypal building forms were once again examined, though this time bringing to bear new computer modelling tools to compare their thermal suitability for an arid climate (Ratti, Raydan and Steemers 2003). Results encouragingly agreed with centuries of intuitive local design knowledge with the Arabic vernacular courtyard form proving to be the most suitable. At the same time, by incorporating tools to calculate and display the solar volume for any given plot, Capeluto and Shaviv (2001) were able to demonstrate that even at relatively high built densities - Floor Area Ratios (FARs) of around 1.6 to 1.8 - it was possible to maintain solar access rights to all buildings in a neighbourhood. Developing his original work, Knowles (2003) showed how the architectural form of buildings could be optimised to allow such solar access.

From 2000 onwards, various refinements were made to solar radiation modelling tools in order that they more accurately reflect reality. Improvements allowing models to take account of shading and inter-reflection between buildings, anisotropic sky lighting and greater surface detail were implemented (Mardaljevic and Rylatt 2003; Robinson 2006). Most importantly however, models were optimised to become radically more scalable given the finite availability of computing resources (Mardaljevic and Rylatt 2003; Robinson and Stone 2004). Compagnon (2004), Montervon and others (2004) demonstrated the usefulness of such inherent scalability by conducting some of the first analyses on the neighbourhood scale, comparing building layouts with respect to daylight effects across three Swiss cities. Potential uses were postulated including quantifying the impact of new urban developments on existing buildings or solar collectors, and assessing the possible consequences of urban planning guidelines on solar access before implementation. A comprehensive appraisal of the potential of such tools was given by Ratti and Richens (2004).




Building form and environmental performance: archetypes, analysis and an arid climate.
*Ratti, Raydan and Steemers 2003*

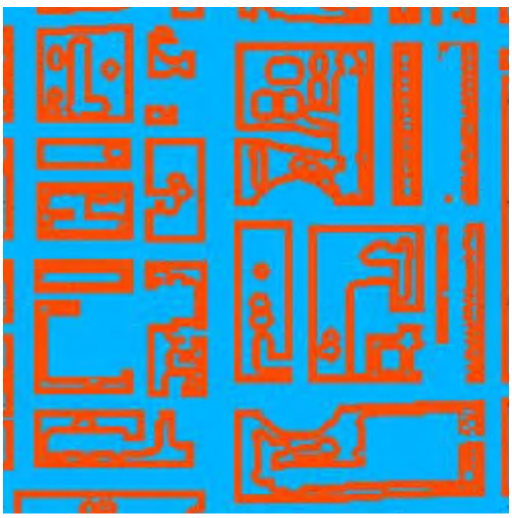
Marrakech satellite image
*Ratti, Raydan and Steemers 2003*

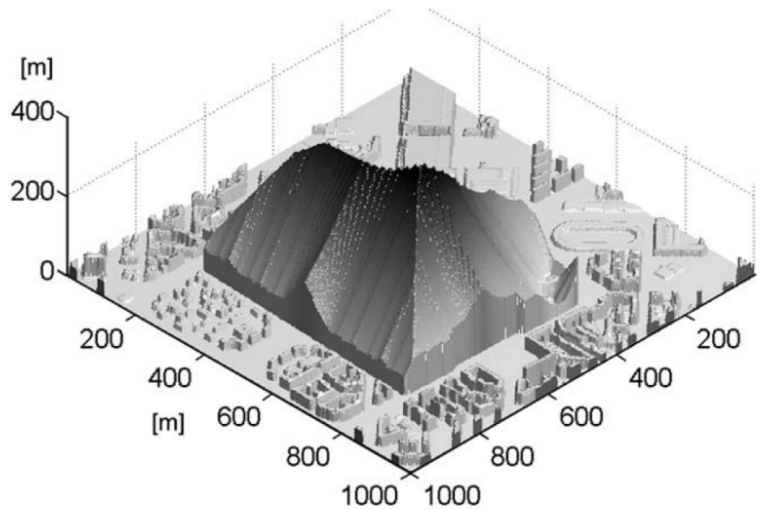
With the introduction of the concept of 'isosolar surfaces' by Ratti and Morello (2005), urban solar radiation modelling tools reached a situation largely resembling the state of the art (at the time of writing). A further improvement on the concept of the solar envelope, isosolar surfaces are 3-D surfaces linking all areas that will receive the same amount of solar energy. In a modelling tool, this value can be viewed as a series of concentric layers of graduating levels of received solar energy. The more accurate representation of solar gain offered by isosolar surfaces was a major improvement on the initial solar envelope concept which did not take into account the sun's angle of incidence or intensity. Morello and Ratti (2009) later made isosolar surface calculations more extensible and demonstrated their usefulness as a planning tool through calculating the maximum buildable volume of the Milan Trade Fair development site for a given allowable solar obstruction angle. An overview of the methods for calculating the solar envelope and its potential uses for policy guidance is given by Sarkar (2009). He concludes that while it is a useful tool for formulating a planning guidance system, this system would be specific to an urban district. It is, therefore, most suitable for identifying low energy morphologies at the level of the urban block.

While advanced solar gain modelling tools were now available, the link between this and actual building energy demand was still only an empirical one. In their paper, "Energy consumption and urban texture", Ratti, Baker and Steemers (2005) sought to bridge the divide between the older analogue methods of calculating building energy demand, and these new computer modelling tools. By integrating algorithms (Richens 1997) that performed the LT method (Baker and Steemers 2000) and incorporating parameters to approximate factors such as occupant behaviour, systems efficiency and insulation standards (U-values), Ratti et al (2005) were able to automate the calculation of building energy demand at the hitherto impracticable neighbourhood scale. Initial trials on morphology samples taken from London, Toulouse and Berlin showed that the surface to volume ratio, contrary to some expectation, did not fully describe energy consumption. The ratio of passive to non-passive zones was shown to be a better indicator, with non-passive zones consuming approximately twice as much energy as unobstructed passive zones. Though this had the effect of weakening the relationship between energy consumption and urban morphology, variances as large as 10 per cent were still observed as a result of morphology differences between Toulouse and Berlin. This is still a very significant potential energy saving, and justified future work towards optimizing urban morphology for reduced energy demand. Given the significance of the effects of glazing ratios on solar gains, the authors noted that this tool could be used to help optimise this ratio for a given urban situation. For example, glazing ratio should be greater in built up areas where availability of natural light is scarce, and lower in open areas where there may be a risk of overheating in summer.

left
Passive zone detection on DEM
*Ratti 2005*

right
Buildable solar volume
*Morello and Ratti 2009*





## Contemporary studies

Several other recent studies have focused on using passive solar radiation for lighting and heating. As in this study, they were conducted in a context where most research has produced evidence that increased solar gain is associated with reduced built densities, while at the same time leading to greater heat losses. For passive solar house standards, Steemers (2003) highlights a 22% increase in heating energy for a 30° obstruction of a south-facing façade compared with an unobstructed façade. At the same time he refers to Yannas (1994), who found 40% higher heat savings when comparing apartments with detached housing and concludes that building densities with a theoretical FAR of 2.5 might represent the optimum density for reducing heat-energy demand.

Cheng et al (2006) studied the impact of randomness in the plot layout and height of buildings at high urban densities. By independently varying the randomness of the positional and height parameters in their model, they concluded that randomness in both the vertical and horizontal dimension is beneficial for increasing overall solar access to buildings and surrounding space, with a difference factor of 3 being observed in some cases. This is contrary to the belief held by some that increasing urban density will always lead to a deterioration in the immediate environment with respect to solar access.

Atelier Parisien d'Urbanisme (APUR), a French urbanism research group, carried out a project looking at the energy efficiency of the Parisian building stock, investigating 96,000 buildings (APUR 2007). Buildings were grouped into archetypal blocks and classified by age, with inhabitant behaviour and urban form investigated independently for their effects on heat energy demand and green house gas emissions. The detailed emissions and building age map data resulting from this study were used to guide policy. Interestingly, the results showed that from the beginning of the 1800s, building insulation performance gradually worsened until the first oil crisis in 1975. Thereafter, implementation of thermal regulations produced a steady increase in performance through to the modern day. Policy advice duly recommended a focus on pre-1975 buildings for retrofit.

Following up this study, Salat (2009) combined these results with morphological data collected by the Centre Scientifique et Technique du Batiment (CSTB) to conclude that, due to morphology alone, modernist urban form consumes 1.8 times more energy for heating than contemporary or traditional Parisian urban blocks. Echoing Ratti et al's (2005) conclusion, it was suggested that this was due to the higher passive volumes observed in traditional architecture (90 per cent) as compared to the modernist forms (82 per cent).

Arboit et al (2008) conducted a study to assess the solar potential of low-density urban environments in Mendoza, Argentina. They took 32 samples of urban blocks from the low-density residential areas of the city and then parameterised the building form and that of the surrounding environment, including factors such as building glazing, trees and street width. They showed that through the implementation of a series of improvements on existing building stock - mainly through upgraded energy conservation and increased size of north facing windows (Mendoza is in the southern hemisphere) - solar energy could be used to offset as much as 34 per cent of the existing heat energy demand. Through statistical analysis of the variables investigated, the authors concluded that the benefits provided by urban forests during the summer largely outweigh the loss of solar resource caused by overshadowing from the trees' leafless branches during winter. Furthermore, the shape and orientation of city blocks is an important variable in their ability to passively absorb useful solar energy. It was noted that architects in many places around the world still pay little attention to this. In an extension to this study, Arboit et al (2010) carried out further work towards finding easy-to-use statistical indicators of solar resource.

Kämpf et al (2010) performed multi-objective evolutionary optimisation of building form parameters for terrace flat roof, slab sloped roof and terrace court formations. For each of these, the parameters optimised were the height of building facades and the height and orientation of their roofs. Built volume and solar gains were set as the objective functions, giving rise to a Pareto front showing the trade-off between built volume and potential solar gains. Basel, Switzerland was selected as the case study site. Results showed that terrace court formation was the most optimal in all trade-off cases.

Okeil (2010) performed a comparison on three types of urban form, described as linear, block and residential solar block (RSB). The RSB formation was a new and optimised building form alleged to be able to maximise the passive solar heating of building facades without overshadowing neighbouring buildings. The forms were compared in simulations of insolation, airflow and urban heat island effects. In a model simulated at 48 degrees latitude, the RSB was found to perform best in these categories.

## Knowledge gaps

As shown above, at the building scale, a number of studies on heat-energy demand have called into question the generally accepted view that more compact building types, such as apartment blocks, outperform small-scale, individual building units most commonly represented by detached, single-family housing (Newton et al, 2000; Utley and Shorrock, 2008). Upon initial inspection these results may seem surprising given the basic physical relationship between heat-energy demand and the function of surface-to-volume ratio or massing of buildings in reducing heat loss. However, they can be better understood when the more complex trade-offs between the solar heat gains and the surface heat losses of different urban forms are considered. Indeed, this is now well understood at the level of the individual building. The tools have recently become available to move this research up to the scale of the urban block and neighbourhood.

Apart from isolated studies examining the thermal performance of blocks consisting of some of Martin's (1967) archetypal building forms, there is a general lack of studies on the thermal performance of urban morphology types. Perhaps closest to a general study was the work conducted by APUR (2007) and the CSTB (Salat 2009) into the thermal performance of the Parisian building stock. Though this study was comprehensive, its methodology was based on the classification of buildings by age and not form, making the findings very specific to Paris and, by weak affiliation, other major French cities. Arboit's (2008) study on the city of Mendoza was a good example of the practical application and value of this research field, though again, results were specific to low-density buildings in an arid climate. Apart from the work developing the tools and techniques for this field, studies into morphology and thermal performance have been disparate and specific in nature, often concentrating on one sector of a city (e.g. Arboit and others 2008), a subset of urban form (e.g. Okeil 2010) or the effects of a particular morphological parameter (e.g. Cheng and others 2006).

City planners and policy makers do not differentiate the urban fabric by geometric values, but rather by neighbourhood qualities and building types. There is still lacking a large body of literature on the general categorisation of urban morphology types in modern European cities and, by extension, a knowledge gap as to the effect of urban morphology type on building heat energy demand.

## 1.3 AIMS

This study by LSE Cities and EIFER aims to fill the knowledge gap highlighted in the literature review, taking the established discourse on heat-energy demand and building typologies to the next, larger scale and allowing an exploration of trade-offs and scaling effects at the neighbourhood level that have thus far been overlooked. The following underlying research hypothesis serves as the basis for this investigation:

> *The basic configuration of buildings in cities (urban morphology) at the neighbourhood level significantly impacts on heat-energy demand, with more compact urban morphologies displaying far greater heat-energy efficiency than suburban and modernist building configurations such as residential towers and slab housing.*

To investigate this, the archetypal morphologies of four major European cities were analysed and categorised to create generic idealised morphology types. These morphology types were then computer-modelled in order to compare their thermal performance for passive solar heat gains. This allowed an investigation of trade-offs between design, density and energy demand at the neighbourhood level.

Alongside the overall research framework, the following questions were addressed:

- What is the relationship between the most basic spatial characteristics such as gross floor area ratio, surface-to-volume ratio and surface coverage for the selected samples?
- What is the average annual heat energy demand per square metre for each of the real and the idealised morphology samples?
- What patterns emerge regarding the heat energy demand of similar building typologies across the four different cities?
- What are the variations of heat-energy demand within similar, and between different categories of urban morphologies?

This work is intended to inform urban planning policy and provide a basis for future investigation of city dynamics. The categorisation of urban fabric types and subsequent analysis of their thermal performance will provide a metric for other European cities to use as a policy guidance tool.

Below
High rise apartment in Istanbul.
*Emden Cemal*

## 1.4 METHODOLOGY

As an empirical basis for this investigation, 25 different building configurations were identified in each of the four largest European cities: London, Paris, Berlin and Istanbul. Although climatic conditions in these cities differ significantly, all four have cold winters typically requiring some considerations of heat-energy provisions. More importantly, the selection of these cities ensures that a wide range of different building types is covered, as they represent diverse national building cultures that over centuries have resulted in clear differences in building organisations.

The urban patterns observed in European cities have mostly emerged over the last 150 years with little or no regard for heat energy demand. The majority of their urban building stock was designed and constructed at a time when a range of other factors determined the shape of the city; when energy was mostly cheap and global warming was not an issue. Some building configurations rely entirely on technical, energy intensive heating systems where designed-in passive heating and ventilation aids are largely absent. However, whether the morphological impact on heat energy demand was considered at the design stage or not, today's diversity of existing building stock in European cities allows for a far-reaching comparative analysis.

From the four cities, five different urban morphological types primarily catering for residential use were identified. For each of the five types (and in each of the cities), a 500 by 500 metre sample was chosen to isolate and represent the urban fabric as homogenously as possible. In addition to these 'real' samples, 'idealised' samples were constructed for each of the tissue types. These idealised samples were essentially a purification of the real samples; an artificial recreation of the characteristics of the fabric under investigation. This was necessary because, at a scale of 500 by 500 metres, individual fabric types do not exist in isolation without considerable interference from others.

Each of the 100 samples of 500 by 500 metres was represented by a 3D digital model for which the basic information on the footprint/position, distribution and height of all buildings was included. Information on the footprint and height of building was retrieved from official GIS documents. Where the information on building height was missing (as in the case of Berlin and Istanbul), it was extracted from a perspective aerial view published by Bing Maps. The project was executed in two stages. In the first stage, all parameters apart from those pertaining to form were fixed, including the climatic conditions (for which the Paris sample was adopted throughout). The real and idealised samples were run through a simulation that modelled solar heat gains and building surface heat losses. From this, the average annual heat energy demand per square metre of indoor floor space was calculated. Results allowed an investigation, at the neighbourhood scale, into effects on heat energy demand of different morphology types and macro morphological parameters: building density, surface-to-volume ratio and height and surface coverage. During this stage, the following caveats should be highlighted:

- Non-morphological factors impacting on heat energy demand, such as the insulation factor (U-value), façade details, building age and materials are all kept constant;
- Possible effects of parks, green space and waterways as well as different building uses are not considered;
- All 100 real and 20 idealised samples are tested for the climatic conditions of Paris;
- Orientations of all real building configurations are kept, while idealised samples are adjusted to a north-south or east-west axis.

In the second stage of the project, the effects of wall insulation, window U-value and glazing ratio, and climate were investigated. In particular, the extent to which insulations levels can mitigate some of the negative effects of morphology on heat energy demand are analysed.

It should be noted that since all the results are based on the simplifications above, there is enormous potential for further follow-up research, in particular related to orientation, façade details, building age and materials. Critically, this will require a better understanding of the embedded energy efficiencies that accompany higher insulation standards and the extent to which lower morphological efficiencies can be compensated for by higher insulation standards.

London
Terraced Housing
*Google Earth*

Paris
Compact Urban Block
*Google Earth*

Berlin
Regular Urban Block
*Google Earth*

Istanbul
Modern Apartment
*Google Earth*




# 2 URBAN MORPHOLOGY ANALYSIS

The focus of this research report on Cities and Energy is to better understand the impacts of urban morphology on the heat energy demand of residential buildings. Therefore, before moving to the energy-related analysis, a brief introduction of urban morphology is given, followed by a description of the empirical analysis and categorisation of the urban morphology types.

## 2.1 DEFINITIONS

The following three principles of morphological analysis were devised by the International Seminar on Urban Form (ISUF), and are used as the basis of our analysis (Moudon 1997):

1. Urban form is defined by three fundamental physical elements: buildings and their related open spaces, plots or lots and streets.
2. Urban form can be understood at different levels of resolution. Commonly, four are recognized, corresponding to the building/lot, the street/block, the city and the region.
3. Urban form can only be understood historically since the elements of which it is comprised undergo continuous transformation and replacement.

The analysis of physical form typically focuses on the plot and street patterns, building typology, the general urban syntax and the interrelations of these elements.

In urban planning and architecture there is a long history of studying "typologie". This usually amounts to the study of the shape of buildings, the dimensions of the interiors and their outward features. There is also a body of literature assessing these types in relation to the urban fabric, the streets and spaces in-between and upon which an understanding of the morphology of the city has been based. The relationship between building typology and urban morphology has been somewhat contested (Caniggia and Maffei 1987; Conzen 1960), but it is recognised that although distinguishable they are also often inseparable. An example of this is in Paris, where the regulations of the *Ancien Regime* dictated building type but, in so doing, also set the parameters of the open spaces left between buildings, with street width and building height forming a morphological relationship. More generally, the predominance of one building type does often lend a consistent and recognisable street pattern of repeating plot size and shape, blocks of standardised dimensions and consistency in street width - what one might call a neighbourhood. This homogenous urban fabric, with defining features and recognisable character, is the urban morphology referred to in this report. The following definitions apply throughout the report:

**Urban morphology** is the spatial structure and form of a metropolitan area, city, town or neighbourhood and its constituent parts.

**Building type or typology** describes the form and function of individual buildings.

**Building category** is a broader classification of building types.

**Building configuration** is the arrangement of height, volume, footprint shape and size of individual buildings and their relationship to each other.

**Surface coverage** is the ratio of the land covered by buildings and the total surface of a given area.

**Building density** or **floor area ratio (FAR)** is the ratio between the total floor area of the buildings and the land area of the total land area analysed.

**Surface-to-volume ratio** is ratio of the envelope of a building (external facades and roof) to the entire volume of that building [sqm/cbm].

**Height** of buildings is measured by 'number of storeys'

While most of these descriptors of urban form are based on parameters used to characterise individual buildings, it is important to stress that aggregate values covering a larger area with the same indicator can acquire different qualities that no longer allows for direct comparison at the building level. In turn, they become exclusive larger-scale, urban morphology indicators that need to cut across a minimum number of buildings.

Right
Kartal, Istanbul.
*IMP*

## 2.2 ESTABLISHING THE EMPIRICAL BASIS

### City selection

The first phase of the 'Cities and Energy' project focuses exclusively on Europe. Besides the pragmatic considerations of data collection, this regional selection is helpful in ensuring a focus on building heat- related energy demands rather than cooling. Across the continent, colder temperatures during the winter season require considerable heat-energy related considerations, even in Southern European countries. Furthermore, given Europe's long tradition in city building with pronounced regional building cultures, it is also a context that features a diverse range of different building typologies, adding to the range of different urban morphologies that can be analysed as part of this study. Within Europe, four cities were selected using the following selection criteria:

- The city must be large enough to ensure a wide range of building typologies.
- The city must be built in a variety of topographical configurations.
- The cities must represent a wide variety of European cultures and building styles.
- There must be sufficient availability of building data and city information to conduct the study.

Based on the above, the four cities selected were London, Paris, Berlin and Istanbul. Not only are these the four largest European cities but they are all characterised by particular models of urban development, bringing together the building cultures of the United Kingdom, France, Germany and Turkey.

### Initial scanning and identification of main building typologies

Following the selection of case study cities, an initial scanning of residential building types and urban morphologies was conducted. The first component of this process utilised a qualitative approach, relying largely on conversations with experts knowledgeable about local architectural styles, building compositions and urban neighbourhoods.

The second component made use of existing literature and the increasing availability of visual documentations of urban territories, including Google Earth and Streetview as well as Microsoft Bing Bird View. Exploring each city via the satellite imagery then allowed the selection of the typologies which were most distinct from a morphological point of view.

Both scanning components informed the choice of the 5 most dominant building typologies featured in each city.

## Selection of urban morphology samples

For each dominant building typology, five urban morphology samples were identified in each of the four case study cities. This selection made use of the cataloguing of samples in the previous phase and selected the most homogenous and representative samples for each building type within each city. Priority was given to selecting diverse morphological arrangements within the same broad building typology. All samples were recorded at a scale of 500 by 500 metres, framed to isolate a single and homogenous urban fabric ideally consisting of a single building type (though this was not always possible). For each of the five morphology types in each of the four cities, five real relevant samples of the city's fabric were chosen to give a total of 100 real samples.

## Construction of idealised urban morphology samples

In addition to using 'real' urban morphology samples as they exist in the four cities, idealised samples were constructed to inform the investigation. This was critical to allow a 'purifying' of the real samples, which at a scale of 500 by 500 metres rarely exist in isolation without interference from other building types and stratified modifications of the original shape of the buildings. In other words, the idealised samples are the distilled and refined morphologies.

The process of creating the idealised samples began by identifying the most basic features of the housing type and reproducing them in the simplest possible way. These were:

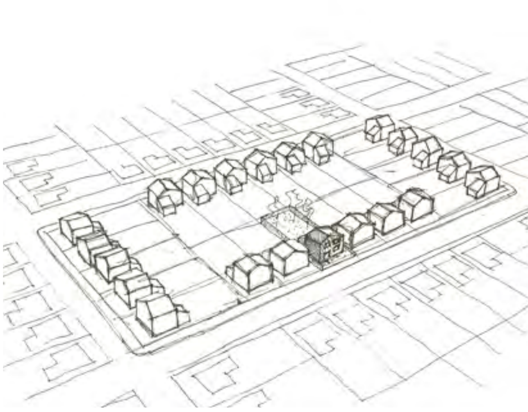
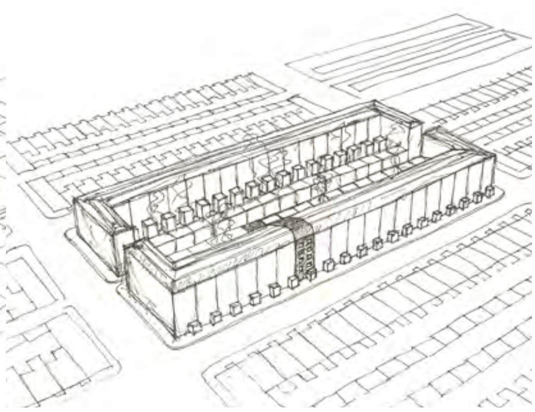
- building type (size, volume and shape of the single unit);
- number of floors;
- plot shape and proportion;
- alignments;
- street layout/pattern;
- street width;
- street/ façade proportion;
- aggregation principles of parts;
- size, volume, shape and proportions of blocks (the aggregation of the single units);
- built-up density;
- coverage ratio.

An emphasis on accuracy in volumetric spatial configuration was included as it is the most important factor in the energy consumption simulation. The methodology to build the idealized samples was based on averages of the main parameters taken from the selected real samples. A single detached housing unit, for example, has been calculated using the average area of every building from each of the five samples for that type. Likewise the number of units comprising the ideal sample has been calculated as the average number from the five selected real examples. The height of the buildings has been set using a similar calculation.

While applying these analytical approaches to control the accuracy of each formal factor in the re-modelling of the idealized sample, the visualization of the 'image' of the type, its form and shape were also important. The idealized samples had to 'look like' the real samples. Still, the idealisation of samples leads to a loss of information on the typologies and de-contextualizes them from their environment - but with the specific purpose of looking just at the impact of their shapes and volumes. In particular, having to decide on a specific orientation of these samples can have significant consequences for energy demands. Additional future research outlined in the last section can address this concern. For each of the five morphology types in each of the four cities, one idealised sample was created from the five real samples of the city's fabric to give a total of 20 ideal morphology samples.

1

It is worth a cautionary note that the selection of urban morphology types was a subjective process. Types were categorised according to how people would generally classify buildings and not on any statistical grouping or cluster analysis of built form parameters. Inevitably, there are some ambiguous cases and categorisation is not an exact science.

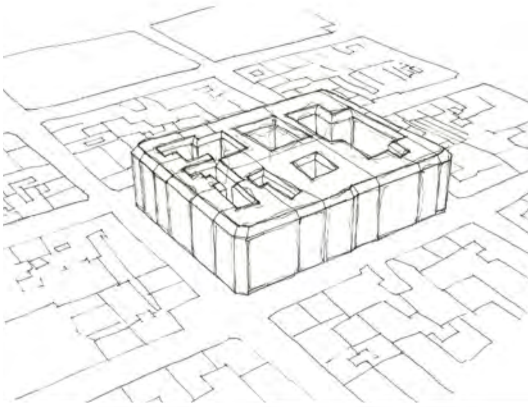
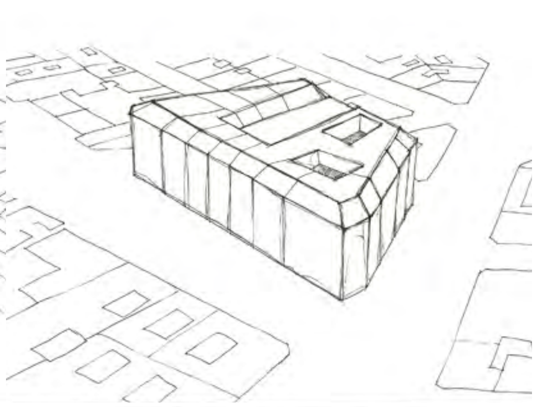
Left

Sketch of London Detached Housing idealised sample.

Right

Sketch of London Compact Urban Block idealised sample.

*Guido Robazza*

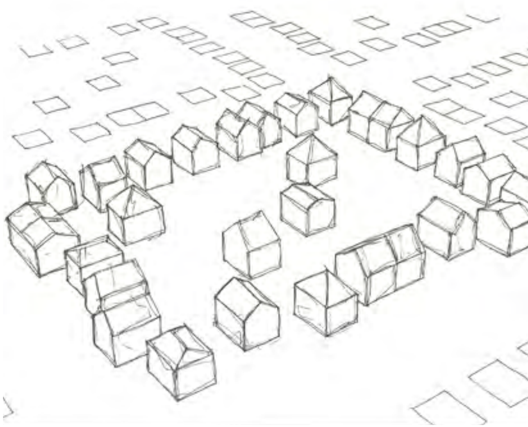
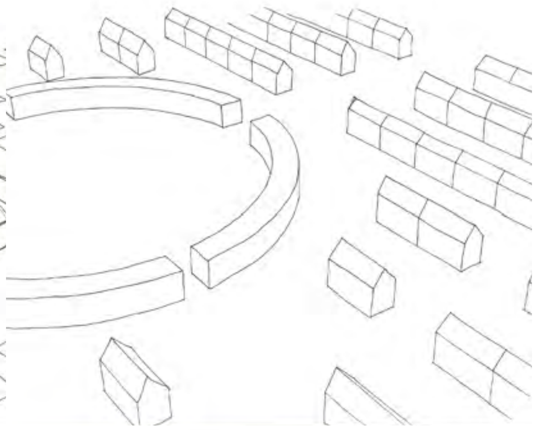
Left

Sketch of Paris Regular Urban Block idealised sample.

Right

Sketch of Paris Compact Urban Block idealised sample.

*Guido Robazza*

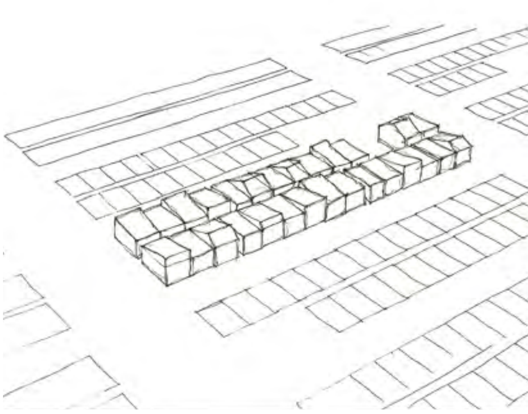
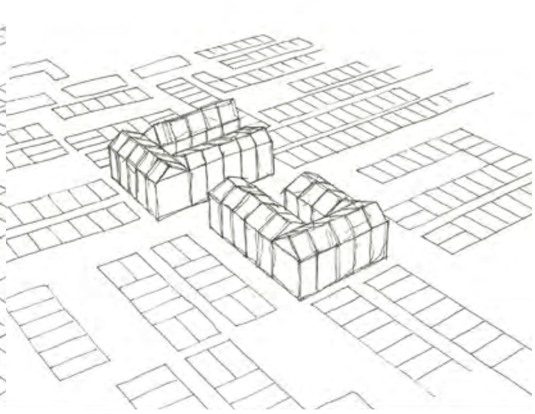
Left

Sketch of Berlin Apartment Building idealised sample.

Right

Sketch of Berlin Row Housing idealised sample.

*Guido Robazza*

Left

Sketch of Istanbul Gecekondu idealised sample.

Right

Sketch of Istanbul Compact Urban Block idealised sample.

*Guido Robazza*

## 2.3 CASE STUDY CITIES

Population levels in European cities have stabilised after a long period of rapid growth and decline. Urban centres with 100,000 inhabitants have remained stable between 1991 and 2001, and those with populations of 5 million or more have increased at an average rate of 1.4% annually (UN-Habitat 2008). Below is a short introduction to the four case study cities.

### London

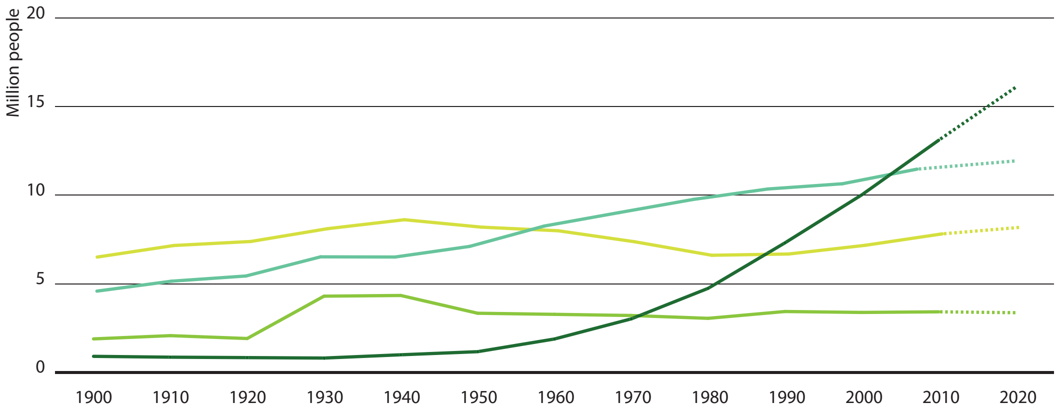
London is a city celebrated for its diversity and dynamism, evident as much in the built environment as in its citizenry. Originally a tale of two cities - the City of London and the City of Westminster - they eventually amalgamated, enveloping rural villages such as Chelsea and Highbury. The resulting city is defined by village districts of relatively low density in an overall polycentric formation. Fire and war were the instigators of the defining urban restructuring of the 17th and 20th centuries, and radical planning programs such as the post-war greenbelt policy ensured the city did not suffer exponential outward growth. The resulting fabric is a patchwork of historical and contemporary development, lying cheek by jowl, with no discernable historical centre and possessing a grain as complex as the city's labyrinthine history. Much of the historic housing stock still exists today, with large swathes of Regency, Georgian and Victorian urban blocks and terraced housing. London's success has brought with it some of the world's highest land values, with restrictive conservation and planning laws preserving many of these older typologies rather than allowing them to be replaced with higher density ones.

The post-war housing crisis saw the cityscape alter, with the addition of large tower blocks and slab housing estates. These modernist plans were implemented in the 1950's at a time when land was available in the aftermath of the war and London's population was peaking at over eight million. The creation of satellite towns and changing aspirations led to a subsequent emptying out of the city over the following decades, often referred to as the doughnut effect, whereby large numbers began leaving London in search of a more 'garden' lifestyle.

London, despite the current downturn of the markets, is still enjoying an urban renaissance. Its efforts in the 1980's and 1990's to establish itself as the financial centre of Europe and to re-launch itself as a post-industrial city are typified in the re-development of the old Docklands into a new financial centre, Canary Wharf. Now well established as Europe's global city, and with a rising population, it has managed to re-invent itself as an international centre with an urban fabric to mirror this success. Under the strong governmental guidance of the London Plan and strengthened city governance generally, London has embraced new building typologies into its fabric with many of them, such as apartments and industrial conversions, in a more European style. With the 2012 Olympic Park development under way and the project for the renewal of the Thames Gateway, London's physical transformation is an ongoing project.

### Paris

Paris - '*capital of the nineteenth century*' - was at that time in the throes of unprecedented political turmoil. Much of the Paris we see




**Population over time in selected cities**

All figures refer to the administrative area of each city. The dotted lines represent projections

*Source: LSE Cities Research*

today was constructed during these uncertain times, predominantly during the reign of Napoleon Bonaparte in the Second Empire.  Paris underwent a massive restructuring program under Baron Haussmann, who redesigned the city to include wide boulevards and apartment block as opposed to the organic tangled Paris of before. This typological revolution created the unique homogeneity of building types evident in Paris today. The apartment block, the dominant motif of Paris and subsequently of other French cities, was not however the imagining of Haussmann. The dawn of the modern banking system and the speculators it generated initiated the city block apartment building, with shared courtyards, some 100 years prior to Haussmann. These speculative developments began to create density which was deemed excessive, and in order to balance the ratio of public and private space, the *Ancien Regime* passed a set of regulations which would determine the style of development in Paris for the next three hundred years – a set of regulations only abolished in the 1950s. The height of buildings determined the street width and a set amount of public space per floor of block was stipulated. These regulations have created a city whose morphology is set according to the typology, a uniformity and harmony unique to Paris. Paris was the first city whose space was conceived of at the level of the city block rather than simply at the scale of the plot of land, and has been hugely influential in cities all over the world.

Post war development marked a departure from the *Ancien Regime,* with the removal of the old fortifications and land equivalent to one quarter of Paris becoming available for development. The combination of the removal of the stringent planning regulations, the appetite for modernization, and post-war housing shortages resulted in a new dawn in Paris' building stock. A new urbanism for Paris began, with amenities previously difficult to provide in the existing fabric developed on this band of newly available land. Cite Universitairé, modernized hospitals and a ring road motorway, the peripherique, were built. The business district of La Défense was developed and led to the construction of individual tower blocks built separately by different developers through the latter part of the 20th century. In the greater Paris region a larger plurality of typologies exists, some pre-dating the restructuring of the nineteenth century. This mix includes timber framed detached houses as well as large areas of slab housing or tower blocks from the post war 'habitation à loyer modéré' project. These suburbs of Paris, known as the banlieue, were built in the post-war years in response to housing shortages and in order to decant those from bidonville (slums). However, many of these areas have been in steady decline and much of the prospective development in Paris is nowadays directed at unifying the core city with its surroundings.

## Berlin

Berlin has had a number of re-configurations, necessitated by its past. It is a capital city whose character has not continuously been shaped by national power, resulting in a uniquely Germanic horizontal power structure across cities nationally. Its relatively stable population post WWII in comparison to other major European cities, and a planning culture which has emphasised open and recreational spaces (which now occupy 45% of the city's total space), has created a low density city. The reason why Berlin is not included as a global city is often explained by the peculiarities and interruptions in German history that have prevented the kind of centrality we see in London and Paris. However the partition, crisis and decay which loomed over the city for nearly a century have now been superseded by a new excitement for the city. The low occupation of many buildings and low rent values has given rise to an international and creative citizenry, with creative industries forming a large section of the economy.

Each of the governments based in Berlin — the 1871 German Empire, the Weimar Republic, Nazi Germany, East Germany, and now the reunified Germany — initiated ambitious construction programs, each with its own distinctive character. During the Empire, the industrial revolution caused massive growth in cities across Germany and in Berlin led to the construction of vast areas of the city's typical 5-storey, perimeter block developments. With the establishment of the Weimer Republic just before 1920, the boundary of Berlin was re-drawn to include dozens of suburban cities and towns that had developed around it. Some of these settlements were Siedlungen - planned low rise housing estates often designed by prominent architects. They were and still are a successful feature of the Berlin landscape. However, a large proportion of Berlin's present urban fabric reflects developments caused by destruction and upheaval following WWII. With huge swathes of the city completely destroyed and Berlin at the centre of the power sharing agreement between the Allies, it was torn into four territories of occupation, mirroring that of the country as a whole. The style of re-development in the east and west of the city became synonymous with the ideology governing it, and in the types produced we see overtly political urban morphologies. Stalinallee, a grand reconstruction project in East Berlin, was built in the socialist classicist style, a large development of shops and apartments of the same size. Aside from the larger re-construction projects, the communist housing estates or Plattenbau (categorised here as slab housing) were constructed to solve the post war housing shortages and still prevail all over the east side of the city. At the same time as the construction of Stalinallee, across the wall in the completely obliterated Hansaviertel district of West Berlin, development of a starkly different nature was occurring. The 1958 Interbau competition saw the most famous international architects of the time showcasing the latest in modern architecture, often symbolic of the free market liberalism of the West.

Unification and the shift of power again from Bonn to Berlin left the city unstitched. Subsequent developments have sought to amend this and it is debatable how successful they have been. The city has remained polycentric, multifaceted and un-precious in its approach to re-making itself. The result is a fascinating cityscape and a very unique style of urbanisation.

## Istanbul

Istanbul is a city not only of seven hills but of two continents. Straddling Europe and Asia, it has served both western and eastern civilizations, having been the capital of both the Ottoman and Roman Empires as Constantinople before being renamed Istanbul in 1930. The city's cultural mix is reflected in its form, and many of the built religious relics from its long history remain. The Byzantine period gave the peninsular a form relating more to cultural and religious symbolism than utilitarian needs. The form of the historic city today is a palimpsest of all the cultures of the conquering nations of the past. From the 19th century onwards, much of the new development adopted a Eurocentric baroque style with a general phasing out of Ottoman style types. At this time the city walls of Galata were demolished and the transformation of Istanbul outside of its historical confines began.

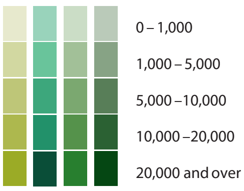
However, in 1923 came the decision that Ankara become the capital of Turkey. Istanbul saw a massive decline in its population and did not reach the level of one million again until the 1950s. Since then, the population has increased twelve-fold, creating a city of new typologies, new densities and new urban geographies. Rapid urbanisation brought with it the challenge of combining integrated planning with a careful consideration of both the city's traditional delicate urban grain and the natural resources that have been supplying the city throughout its long history, including its busy waterways. The construction of two bridges across the Bosporus provided an opportunity to further integrate the two continents, but also allowed for an unprecedented intensity of residential development – both informal and formal. This massive growth in the later part of the 20th century has been concentrated mainly on the Anatolian (Asian) side. The typologies of the growth are extreme in their variation. A regular street layout dominates the Pangalti district, whilst the formerly Greek area of Tarlabasi is chaotic in form. The informal settlements of the gecekondu, established due to the scale of migration to the city, tend to hug the industrial areas, whilst the more established post-gecekondu neighbourhoods are closer to the historical centre. The construction of the bridges not only allowed the city to expand further, but caused a new kind of urbanism in Istanbul. The pretty and conserved hills of Anatolia gave rise to a suburbanization by the wealthy, with new developments of commuter settlements along the highways into Anatolia similar to those found in California. The spreading of Istanbul away from its centre has led to infrastructure problems and the city government is now seeking a remedy to this style of urbanization. The speed of change in Istanbul over the past fifty years, against a backdrop of the city's history which spans over two thousand years, has created an astonishing built landscape with many complexities that have yet to be fully understood.

## Urban densities compared

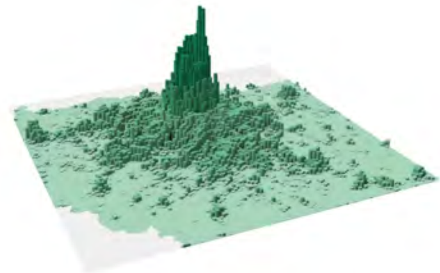
Among the most basic spatial characteristics of cities that allow for simple comparison is the distribution of different densities across the metropolitan region. The urban density illustrated below shows the number of people living in each square kilometre of a 100 x 100 km urban area for the four case study cities. Density is largely driven by the location of public transport and other infrastructure and topographical constraints, as well as by each city's inherited traditions of urban planning and development. While high density is sometimes associated with poor and overcrowded urban environments, it can also enable a higher quality of life and reduce the environmental impact of cities by facilitating walking and cycling. In so doing, high density urban areas can enhance a city's vitality and make the provision of public transport and other amenities more viable.

The four cities demonstrate a range of different density patterns – from the very high densities in the centres of Istanbul and Paris, to the much lower density development patterns of Berlin and London. Taken within a 10 km radius of the city centres, Istanbul shows the highest average density levels of the four cities, with approximately 20,000 people per square kilometre. In stark contrast Berlin, the lowest average density city, has only 6,500 people/km$^2$. Istanbul also shows the highest peak density of 77,000 people/km$^2$ - more than four times the London maximum.

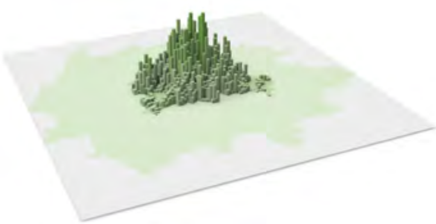
**Population Density (people/km$^2$)**



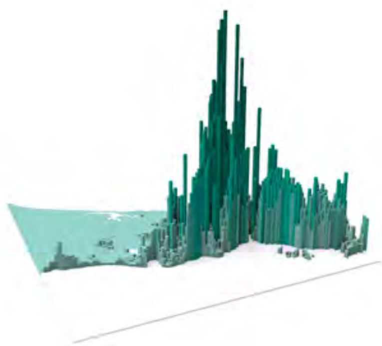

**London**



**Paris**



**Berlin**



**Istanbul**

**London**

London is the least densely populated city amongst the four case studies. Its peak density remains far below 20,000 people/km$^2$. Greater London's average is about 4,500 people/km$^2$.

*Source: LSE Cities 2010*

**Paris**

Paris is the second most densely populated city of the case studies with densities reaching the highest 40,600 people/km$^2$ at the centre of the city, with an averages within a radius of 10 Km of about 13,300 people/km$^2$.

*Source: LSE Cities 2010*

**Berlin**

Berlin is only slightly denser than London reaching a peak of about 24,200 people/km$^2$. Still, it is considered a compact city that has escaped extensive suburbanisation due to its particular history.

*Source: LSE Cities 2010*

**Istanbul**

Istanbul is by far the densest amongst the selected cities with an average density within a radius of 10 Km of about 20,100 people/km$^2$.The European side of the city features the highest density levels with peaks of almost 80,000 people/km$^2$.

*Source: LSE Cities 2010*

## 2.4 BUILDING TYPOLOGIES

This section introduces the results of the selection process for the most prominent building typologies within each city. These range from detached housing, post-war high rise, terraced housing and compact urban block in all cities to the informally constructed gecekondu in Istanbul. The categories for each city vary slightly according to context-specific history and their architectural style. The differences are most pronounced for the historical urban fabrics in the centre, whilst more recent developments, often towards the periphery, tend to be more generic in style and form. Haussmann's boulevards and apartment blocks of Paris are not comparable to any other urban types in this study, just as London's terraced housing has no equivalent in Paris, Berlin or Istanbul. However, the more recent types such as 'slab housing' and 'tower block' display very similar characteristics across all four cities.

### LONDON

Detached Housing

High Rise Apartment

### PARIS

Detached Housing

High Rise Apartment

### BERLIN

Detached Housing

Apartment Building

### ISTANBUL

Detached Housing

High Rise Apartment

**Slab Housing**

**Terraced Housing**

**Compact Urban Block**

**Slab Housing**

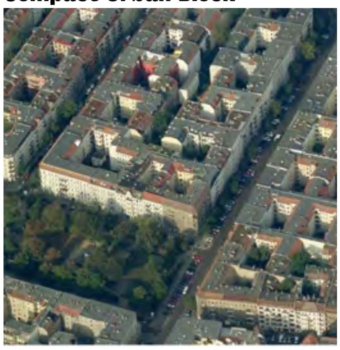
**Regular Urban Block**

**Compact Urban Block**

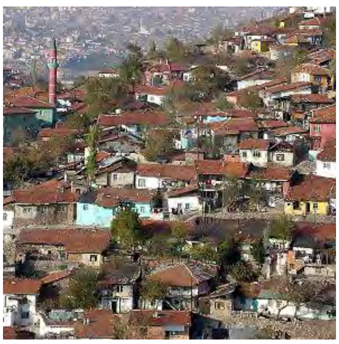
**Slab Housing**

**Row Housing**

**Compact Urban Block**



**Gecekondu**



**Modern Apartment**

**Compact Urban Block**

## Figure grounds

This section presents the figure grounds for each of the 500 by 500 metre urban morphology samples dominated by the building typologies described above. While the previous building type overview highlighted overall commonalities, the actual urban morphology samples in each city differ greatly. In Paris for example, unlike in London and Berlin, there are two types of dense core city fabrics. In Istanbul, the gecekondu and its successor, the post-gecekondu, feature relatively organic urban forms which have no equivalent in the other cities.

### LONDON

**Detached Housing***

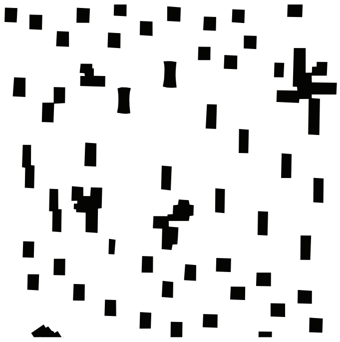
**High Rise Apartment**

* Semi-detached housing has been put in the same category for this study as detached housing. Both are presented under 'Detached' housing.

### PARIS

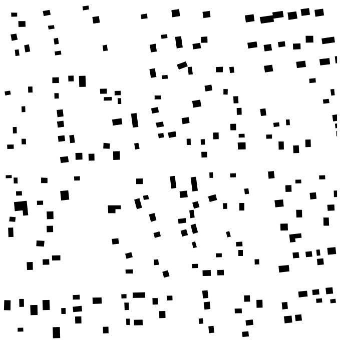
**Detached Housing**

**High Rise Apartment**

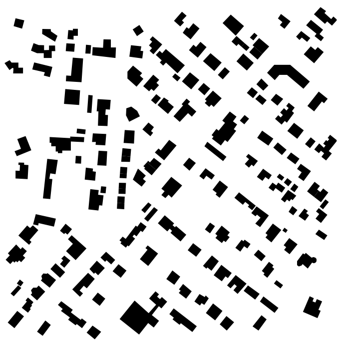


### BERLIN

**Detached Housing**

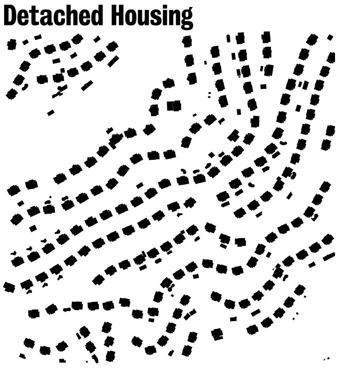


**Apartment Building**



### ISTANBUL

**Detached Housing**

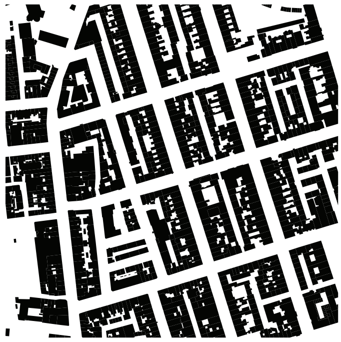


**High Rise Apartment**

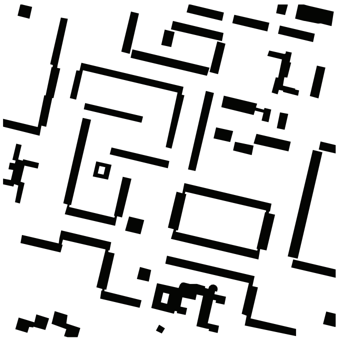
Slab Housing

Terraced Housing

Compact Urban Block

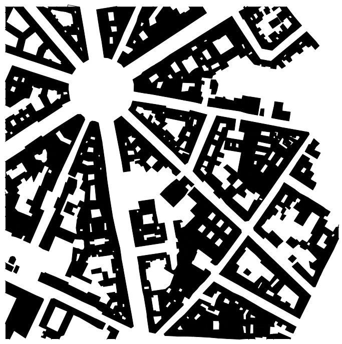


Slab Housing



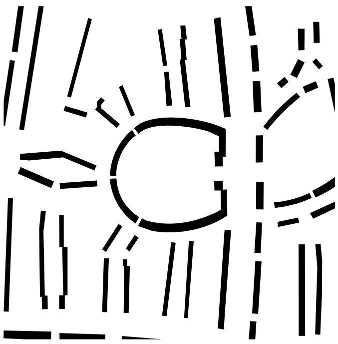
Regular Urban Block

Compact Urban Block

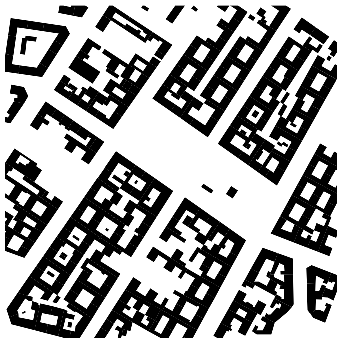


Slab Housing

Row Housing



Compact Urban Block



Gecekondu

Modern Apartment

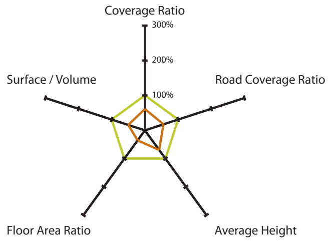
Compact Urban Block

## Numeric Comparison

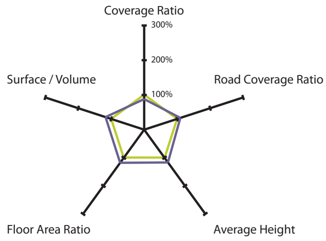
The diagrams below introduce numeric values used to describe the urban form of each of the urban morphology samples. These measurements include building coverage, average height, floor area ratio, surface-to-volume ratio and road coverage. The individual values below are presented relative to averages across all five samples within their four respective cities. The shape of the diagram allows for immediate recognition of the most relevant differences between each morphology sample. All detached housing samples have similar shapes, with Paris having a somewhat higher road coverage ratio and London a higher average height. Not surprisingly, detached housing has consistently low values for all measures. Compact urban blocks have high values across all cities.

## LONDON

### Detached Housing

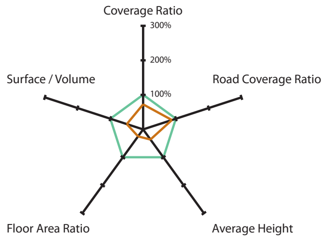



### High Rise Apartment

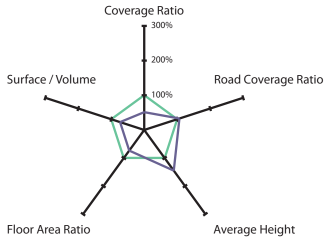



## PARIS

### Detached Housing

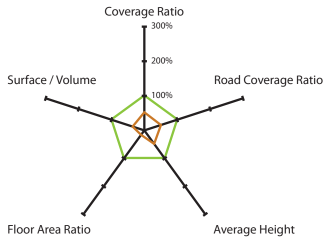



### High Rise Apartment

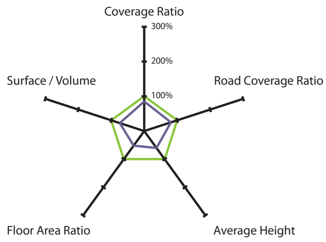



## BERLIN

### Detached Housing

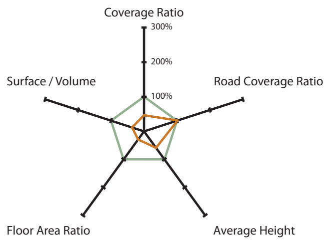



### Apartment Building

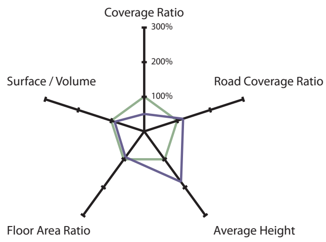



## ISTANBUL

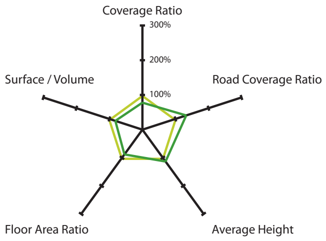
### Detached Housing



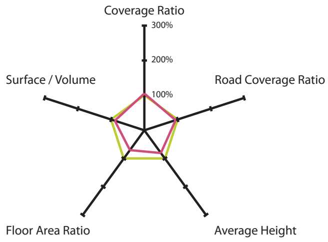

### High Rise Apartment



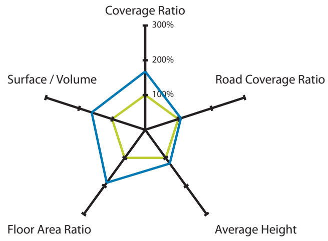
## Slab Housing



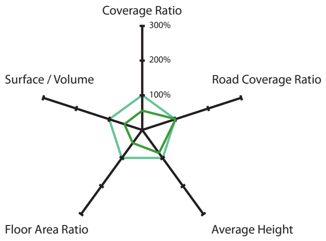

## Terraced Housing



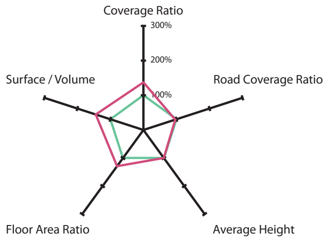

## Compact Urban Block



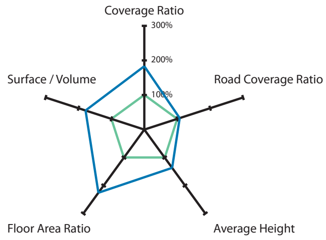

## Slab Housing




## Regular Urban Block




## Compact Urban Block

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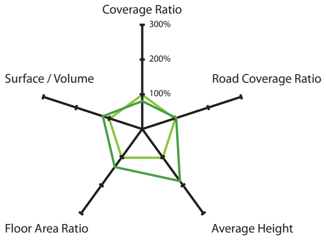
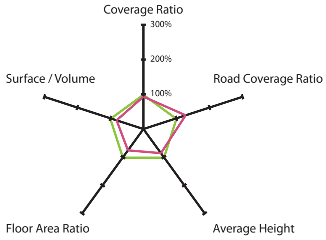



## Row Housing

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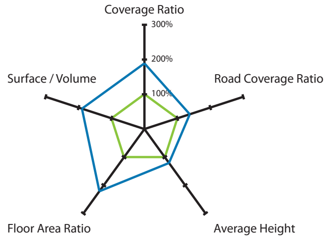
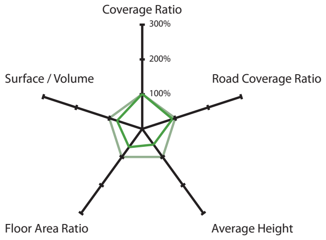
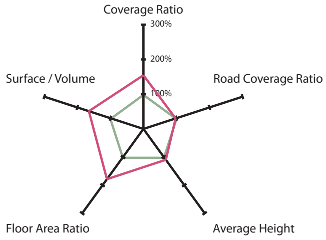


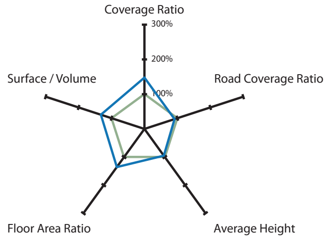

## Gecekondu




## Modern Apartment




## Compact Urban Block

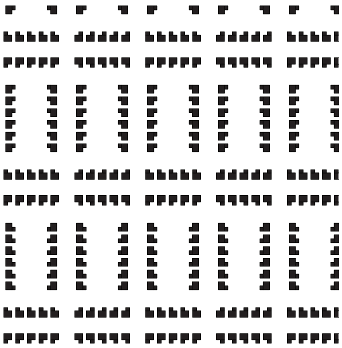


## The idealised samples

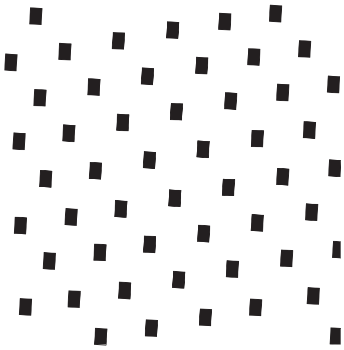
This section introduces the figure grounds of the idealised samples that were prepared for each of the prominent building typologies. These idealised samples express the key aspects of the real morphology samples, without any untypical or unnecessary features that might distort the results of the simulation. Averages for footprint, heights, volumes and plot layout were used in the construction of the idealised samples, but beyond these formulaic calculations, hand drawings were made in an intuitive application of the data because staying true to the 'type' as well as the data was important. Not only are the elevations and volumes correct, but the idealised versions also look and feel like the original morphology samples. These samples of 500 x 500metres are the beginnings of a morphology catalogue, ranging from the main historical European tissues to more recent urbanization which characterizes the processes of development in our cities. This purification of types allows accurate and meaningful comparisons to be made between them.

**LONDON**

Detached Housing

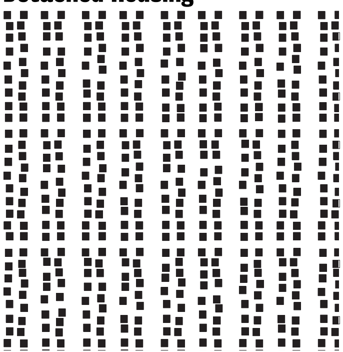


High Rise Apartment

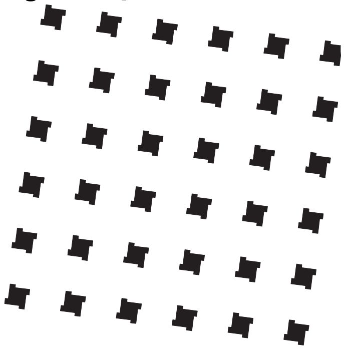


**PARIS**

Detached Housing

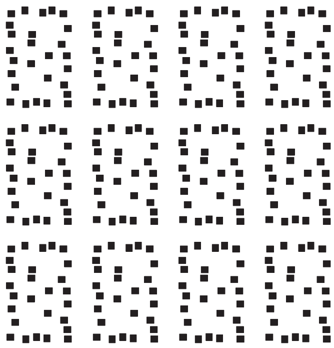


High Rise Apartment

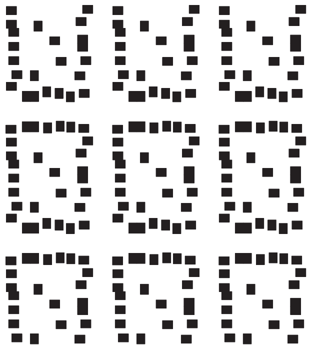


**BERLIN**

Detached Housing

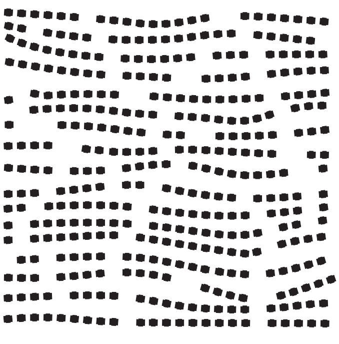


Apartment Building

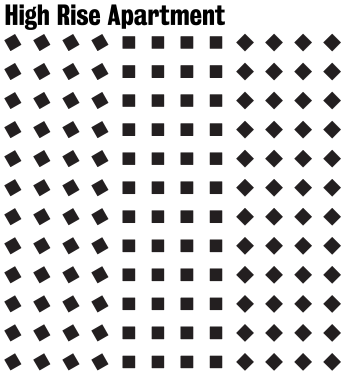


**ISTANBUL**

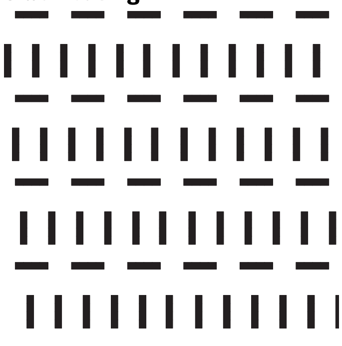
Detached Housing



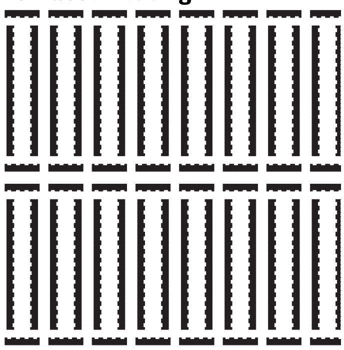
High Rise Apartment



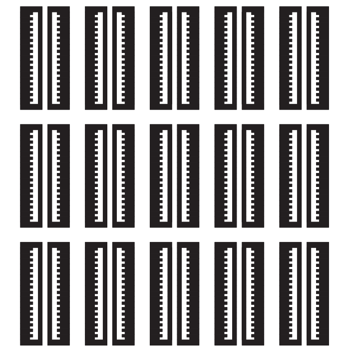
Slab Housing



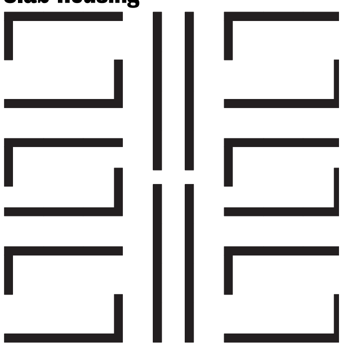
Terraced Housing



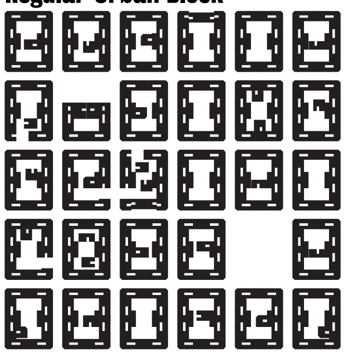
Compact Urban Block



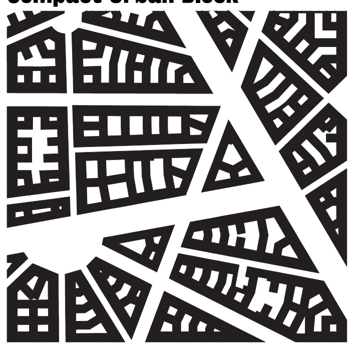
Slab Housing



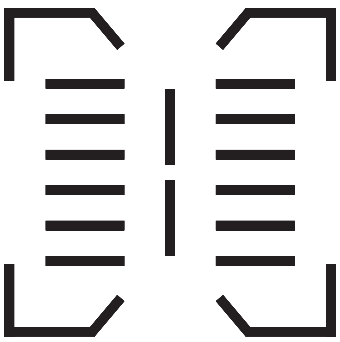
Regular Urban Block



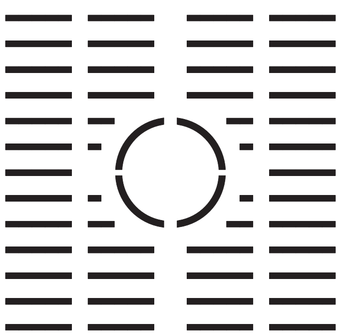
Compact Urban Block



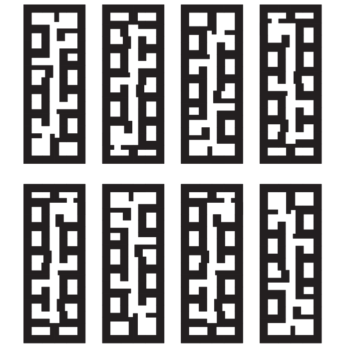
Slab Housing



Row Housing

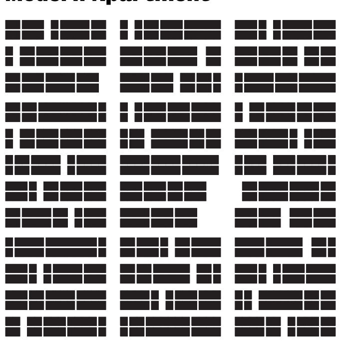


Compact Urban Block

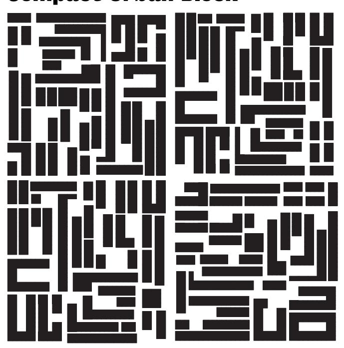


Gecekondu

Modern Apartment



Compact Urban Block



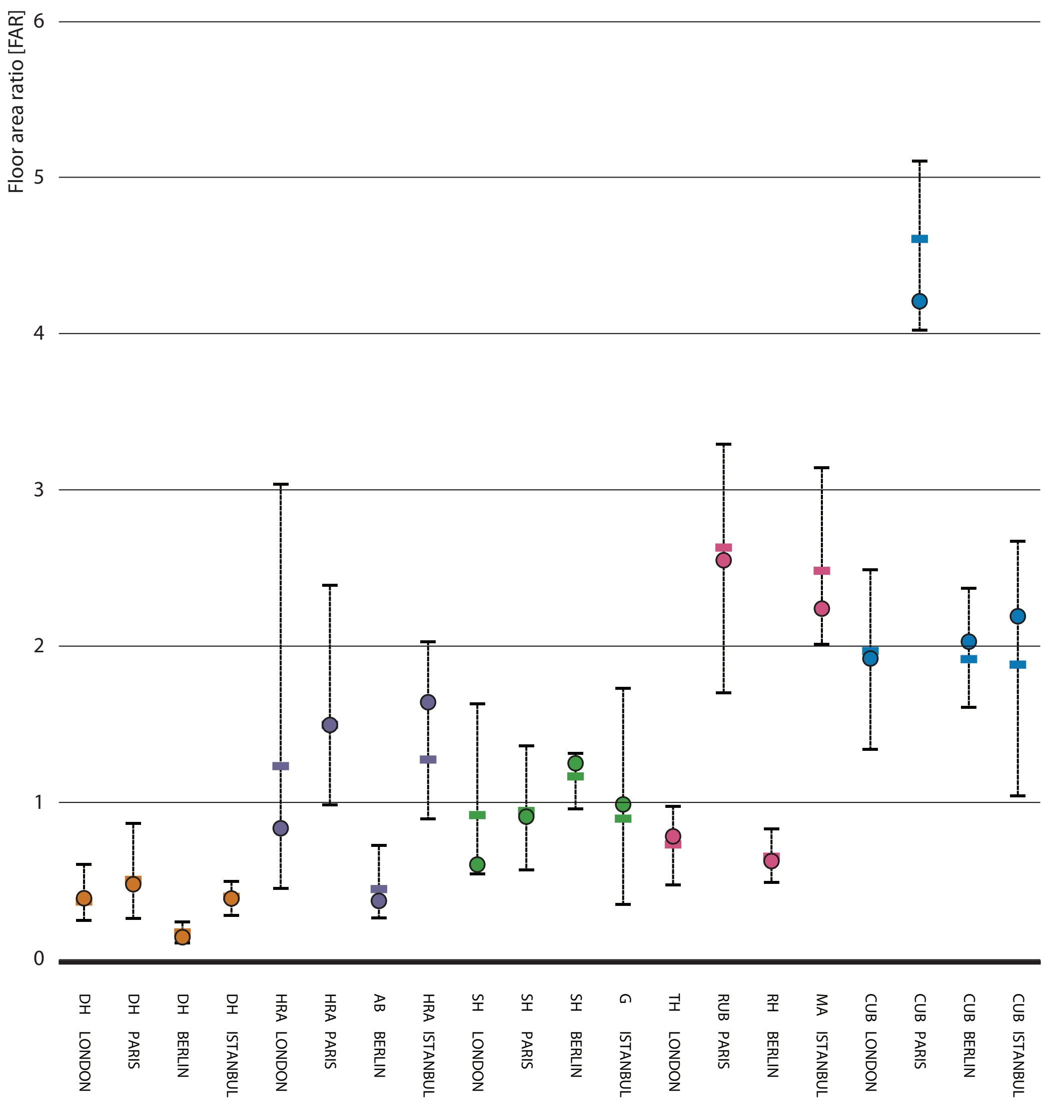
London
Terraced Housing
*Jason Hawkes*

## 2.5 KEY RELATIONSHIPS

This section compares the different morphology types against the macro built form parameters of building density, surface coverage ratio, average built height and surface-to-volume ratio. For all graphs, density was chosen as the control variable against which to compare the others. Overall it can be seen that surface coverage and height correlate positively with density, while surface-to-volume ratio correlates negatively. For both height and surface-to-volume ratio there appears to be a critical density beyond which further increases in density have a much reduced effect. In all graphs morphology types are generally aggregated with their own kind, though exceptions do exist. For each variable a discussion of the overall data trends, exceptions and potential reasons for these are given. All typologies were also compared using the 'Spacemate' diagram of Berghauser Pont, and Haupt (2004), which illustrates the key relationships between four key characteristics of urban form.

### Building typology and density

This section displays density against building typology for each of the four case study cities. Across all cities, detached housing consistently has the lowest average densities of between FAR 0.1 and 0.9, although Berlin occupies the lowest part of this range and Paris the highest. Paris shows the highest average density of FAR 4.6 in its compact urban block, which is much higher than the next densest city, Istanbul, which has a maximum average density of FAR 2.5 in its modern apartment typology.

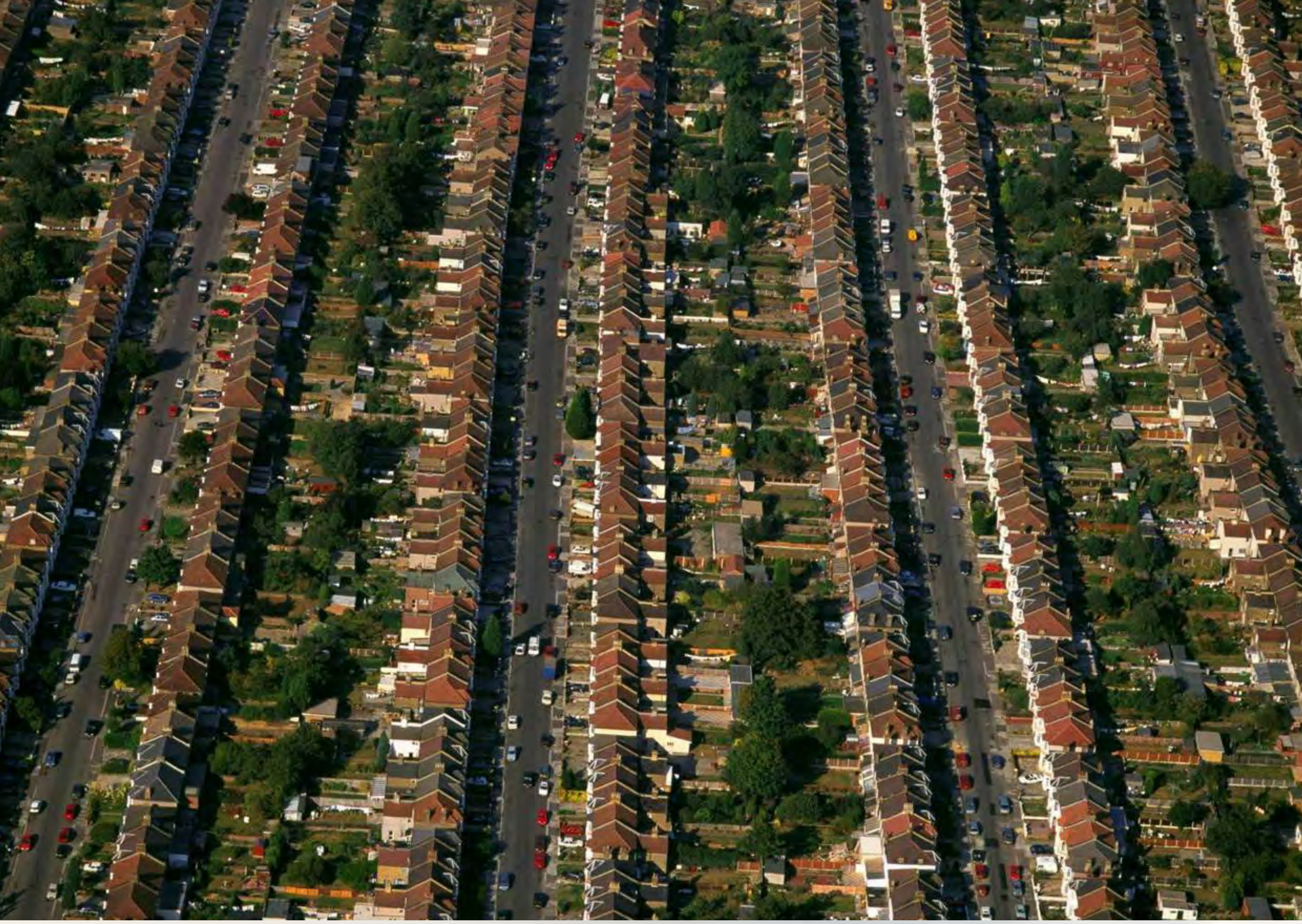



**Building typology and density**
Heat energy demand ranges (maximum - minimum - average) by building typology for the four cities

Average Value
Ideal Sample Value
CUB - Compact Urban Block
MA - Modern Apartment
RH - Row Housing
RUB - Regular Urban Block
TH - Terraced Housing
SH - Slab Housing
HRA - High Rise Apartment
AB - Apartment Building
DH - Detached Housing

*Source: LSE Cities and EIFER Research*

Istanbul
High Rise Apartment
*Ali Taptık*

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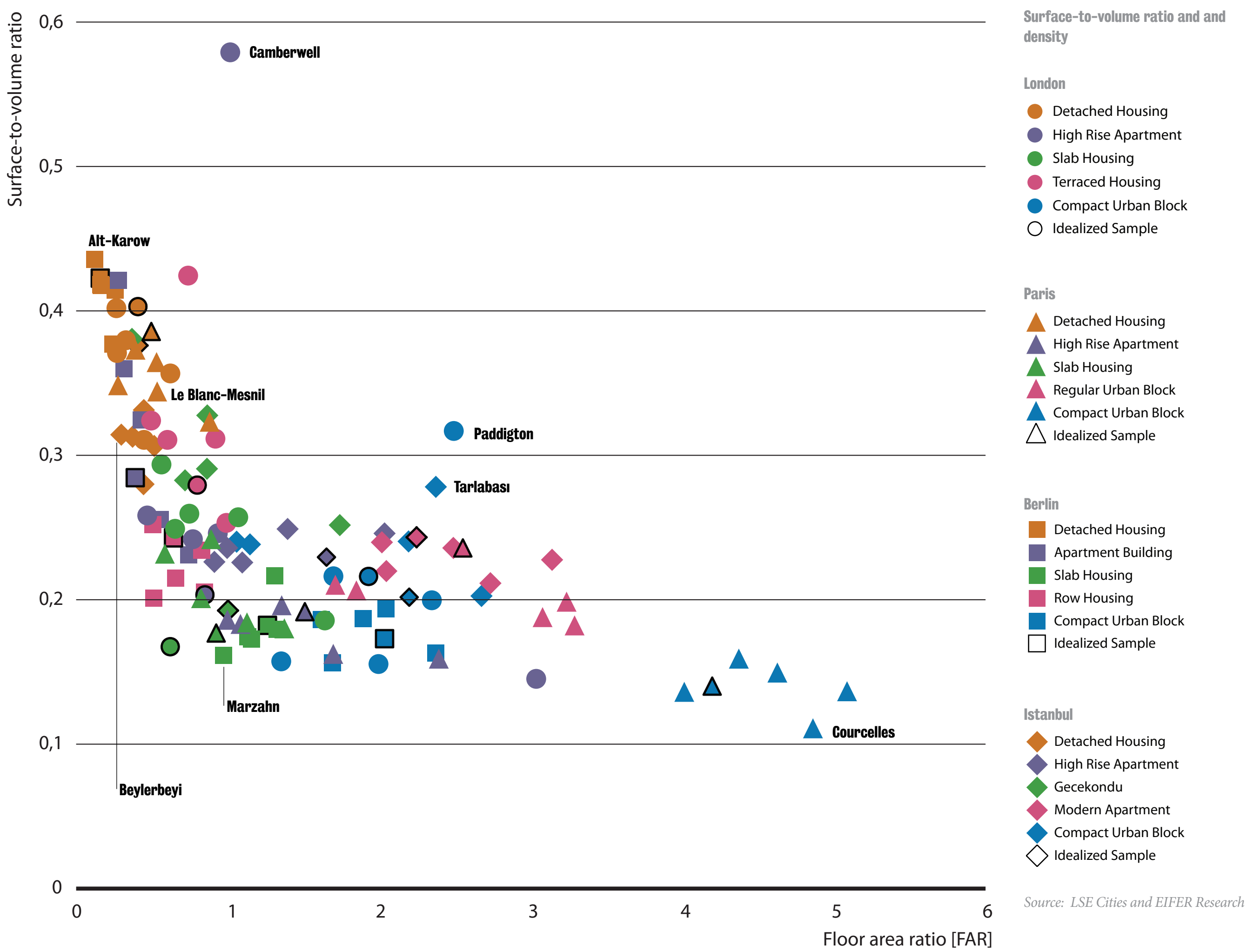
## Surface-to-volume ratio and density

This section shows the relationship between surface-to-volume ratio and building density. Surface-to-volume ratio is defined as the total external surface area of the building divided by the volume of that building. A negative correlation between surface-to-volume ratio and building density exists in all cities up to a FAR of 1. Past this density, the surface-to-volume ratio seems to be relatively constant at between 1.5 and 2.5 in all cities. A likely reason for this is the need to allow for day lighting even as density increases. This requires buildings to be more elongated as density increases, to ensure a maximum building depth of 8 to 10 metres in residential buildings (about 12 to 14 metres for offices). The exception to this trend is Paris, where a slight continual decrease in surface-to-volume ratio is apparent with increasing density – a likely effect of the extreme densities to which the compact urban block form has been taken here.

While the same general pattern is apparent in all cities, London shows the greatest divergence. Here, at a density of around 0.5, surface-to-volume ratio differences as large as 3.5 can be seen. Berlin shows the tightest adherence to the general trend, while Paris and Istanbul show similar ranges of surface-to-volume ratio. By taking the density of the compact urban block to the extreme of FAR 5, Paris achieves the lowest surface-to-volume ratios of between 0.15 and 0.1.

The upper end of the surface-to-volume ratio scale is consistently dominated by detached housing, while the lower end can seemingly constitute the entirety of the remaining morphology types. The different morphology types are well aggregated, with a few exceptions.




*Source: LSE Cities and EIFER Research*

London shows a considerably larger amount of mixing of all morphology types except detached housing. All idealised samples appear to be representative of their morphology types, with little departure from the general trend or their localised groupings.

Of the extreme cases displayed below Camberwell in London is the absolute outlier, with a surface-to-volume ratio of 0.57 at FAR 1.01 - higher even than the detached housing configurations which range between 0.31 and 0.43 in the extreme cases in Istanbul, Paris and Berlin. These occur at density levels of between FAR 0.11 and 0.52. Extremely low surface-to-volume ratios of between 0.11 to 0.16 are observable in the case of Paris' compact urban block, with Courcelles at a density of FAR 4.88 and Berlin's slab housing in Marzahn at a density of only FAR 0.96.

**Extreme samples: surface-to-volume ratio and density**

## London

**Paddigton**
Compact Urban Block 03
S/V 0.31; FAR 2.49

**Camberwell**
High Rise Apartment 05
S/V 0.57; FAR 1.01

## Paris

**Le Blanc-Mesnil**
Detached Housing 04
S/V 0.34; FAR 0.52

**Courcelles**
Compact Urban Block 03
S/V 0.11; FAR 4.88

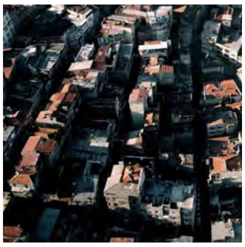
## Berlin

**Alt-Karow**
Detached Housing 05
S/V 0.43; FAR 0.11

**Marzahn**
Slab Housing 03
S/V 0.16; FAR 0.96

## Istanbul

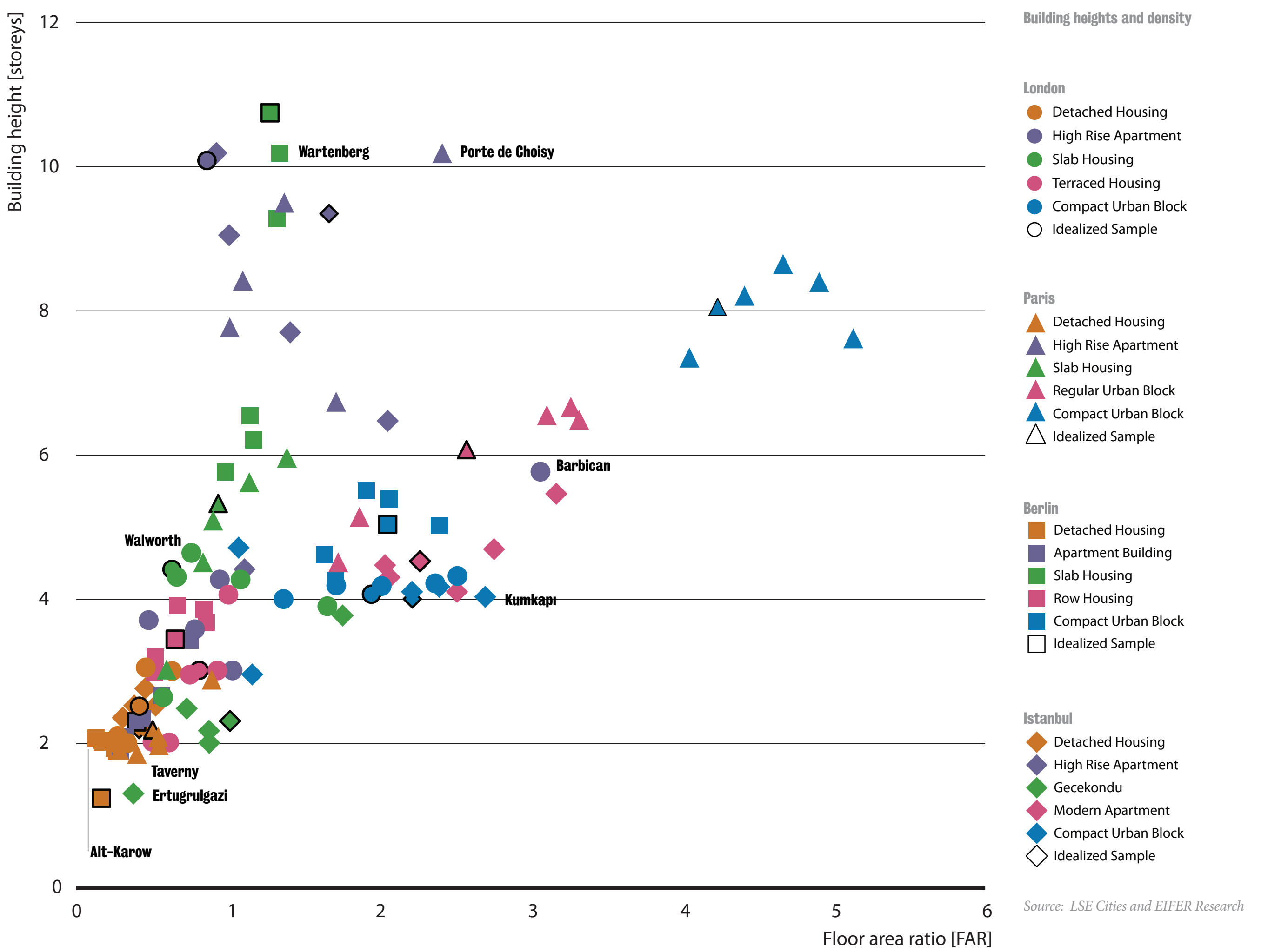
**Beylerbeyi**
Detached Housing 04
S/V 0.31; FAR 0.28



**Tarlabası**
Compact Urban Block 02
S/V 0.27; FAR 2.37

## Average building height and density

This section shows the relationship between average building height and building density. In general a positive correlation between building height and density can be seen. In all cities except London, what might be described as a bifurcation of the data seems to occur at density of between FAR 1 and 1.5. At this point, the morphology types appear to either follow a path of fast height increase with increasing density, or one of very little height increase with increasing density. It is the high rise apartment and slab housing formations which tend to follow the former path, with the regular urban blocks of Paris, the modern apartments of Istanbul and the compact urban blocks of all cities following the latter. This alludes to a mutual exclusivity in design choices – if one wishes to increase density, one can either build upwards or increase the surface coverage of the building. The data suggests that these two strategies are seldom attempted in unison. Only detached housing does not feature in this bifurcation, showing almost without exception the lowest densities and heights in all cities. The mentioned bifurcation could also be a consequence of planning controls put in place to avoid the kinds of effects caused by the uncontrolled proliferation of high-rise buildings. Either an absolute limit is set on building height or, if buildings are made taller, they must by law be set further apart (so to decrease surface coverage). If both height and surface coverage are increased together, this results in excessive overshadowing and poor day lighting in the lower floors. These effects were studied by Martin (1972) and March (1969) in their work on land use and built forms.




*Source: LSE Cities and EIFER Research*

Paris demonstrates by far the highest built form of all the cities, exceeding 8 storeys in many cases – a reflection of the high rise, high-density planning of Haussmann. Istanbul and Berlin show midrange, very similar height profiles, with the exception that Istanbul reaches the same heights as Berlin at much higher densities. Contrasting starkly with Paris, London demonstrates the lowest built form of all the cities, rapidly levelling off at 4 storeys in all morphology types except detached housing – a clear manifestation of the height restrictions which have been incorporated into the London Plan.

Outlying morphology samples tend to be of the high rise apartment type, showing broad scattering on both axes in all cities except Berlin. In the case of London, the outlying high rise apartment sample was taken in Barbican - part of the London financial district and thus sporting some of the highest examples of built form in the city. The idealised sample of the London high rise apartment is shown to have a much higher average built height than the real samples. This is because the high rise building type is rarely found in a 500 by 500 metre area without significant mixing in of other building types. In the real samples, these invasive building types act to reduce the average built height of the sample area. With these typologies removed from the ideal samples, the average built height of the ideal samples more closely reflects that of the high rise apartment in question. For all other morphology types the idealised samples were seen to be representative of the real samples.

Extreme samples: building heights and density

## London

**Walworth**
Slab Housing 02
Height 4.63; FAR 0.73

**Barbican**
High Rise Apartment 04
Height 5.76; FAR 3.04

## Paris

**Taverny**
Detached Housing 03
Height 1.84; FAR 0.38

**Porte de Choisy**
High Rise Apartment 05
Height 10.18; FAR 2.39

## Berlin

**Alt-Karow**
Detached Housing 05
Height 2.06; FAR 0.11

**Wartenberg**
Slab Housing 04
Height 10.18; FAR 1.32

## Istanbul

**Ertugrulgazi**
Gecekondu 03
Height 1.29; FAR 0.35

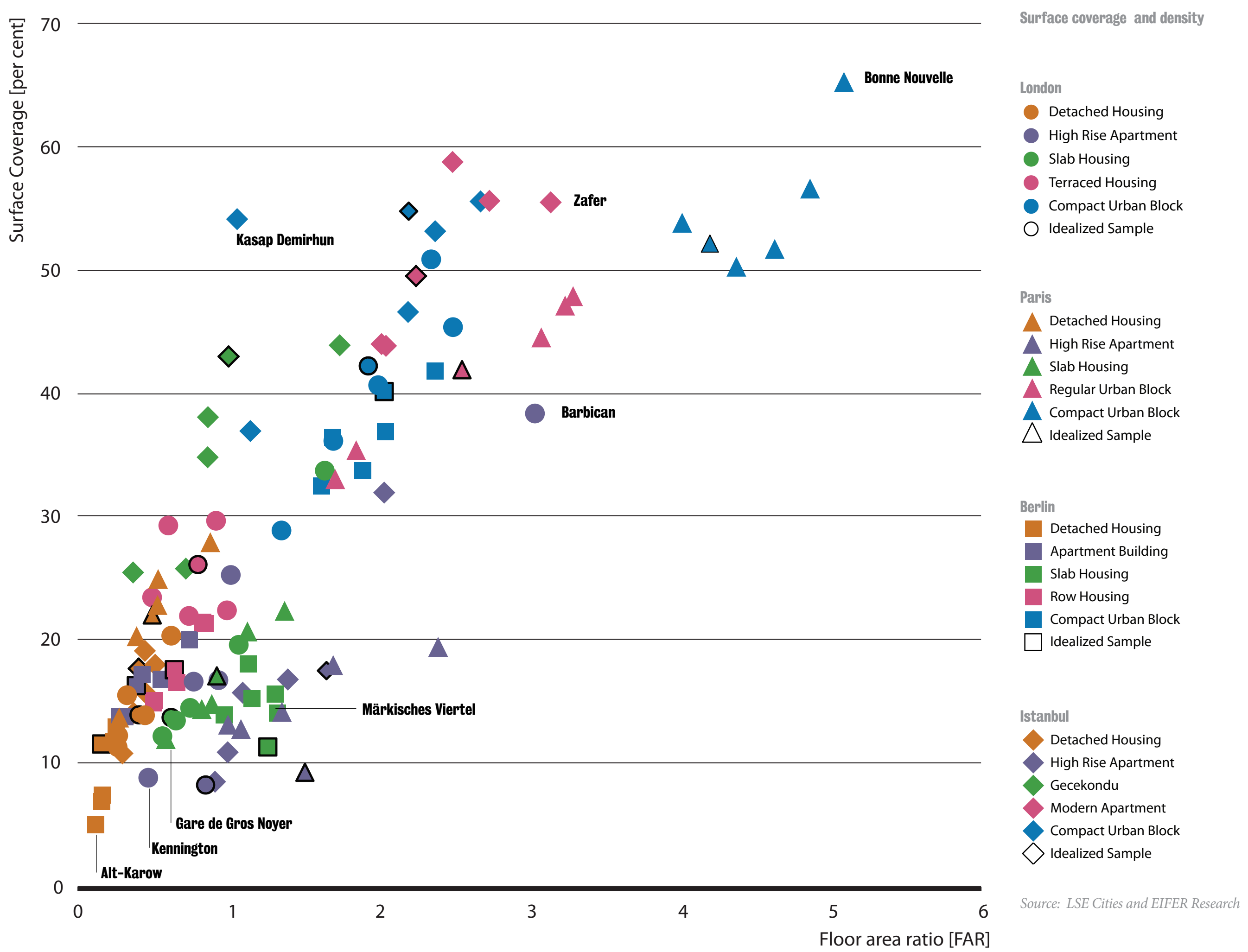
**Kumkapı**
Compact Urban Block 04
Height 4.02; FAR 2.67

## Surface coverage and density

This section shows the relationship between surface coverage and building density. Surface coverage is defined as the total surface covered by buildings divided by the total sample area. A positive correlation between surface coverage and building density is observed in all cities. This general relationship also holds for the pattern within each of the main building categories. There are two obvious exceptions to this trend: terraced housing in London and slab housing in Berlin, where no clear relationship between building density and surface coverage emerges.

The four cities differ particularly at the upper ends of both scales, with Paris showing by far the highest densities with a FAR more than 5, coupled with a surface coverage above 0.6. This is followed by Istanbul with density values of up to FAR 3.2 and a coverage ratio just below 0.6. Both the analysed areas in London (with the exception of the Barbican) and Berlin remain below a FAR of 2.5 and a surface coverage of 0.5. The density-coverage relationship follows a steeper trend in Istanbul and London compared to Paris in Berlin. The two latter cities seem to increase their building density to a lesser extent not by covering a larger surface area but by building upwards. London and Berlin show a tighter relationship between the two variables, while Paris and Istanbul have greater variations around the same general trend.

The different typologies seem well aggregated, with samples of the same type showing broadly similar density and surface coverage ranges. Not surprisingly, compact urban blocks are the densest building structures in all cities except




*Source: LSE Cities and EIFER Research*

for Istanbul, where they are outperformed by modern apartment buildings. Similarly, detached housing features particularly low densities in all four cities, although in some instances they have higher surface coverage than several high rise apartment configurations. Large variations within each building category can be observed for the compact urban block in London, the regular urban block in Paris, as well as the gecekondu and compact urban block in Istanbul. Istanbul leans towards higher floor coverage ratios and Berlin towards lower ones. The diversity of different building configurations is greatest at a building density of around FAR 1 and a floor coverage ratio of 0.2 across all four cities.

The idealised samples display near average values within each of the building categories, validating the methodology that was chosen to generate these 'purified' samples of urban morphology. The exceptions are those building configurations that rarely exist without mixing with other configurations or open land in the real samples. This explains the tendency for idealised samples of high rise apartments in London and Paris to differ from the real examples, with lower coverage ratios but similar floor area ratio. Likewise, slab housing in Berlin and gecekondu configurations in Istanbul slightly diverge from the averages of their respective real samples.

Extreme samples: surface coverage and density

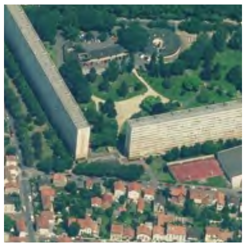
## London

**Kennington**
High Rise Apartment 01
SC 9; FAR 0.45

**Barbican**
High Rise Apartment 04
SC 39; FAR 3.04

## Paris

**Bonne Nouvelle**
Compact Urban Block 02
SC 65; FAR 5.10



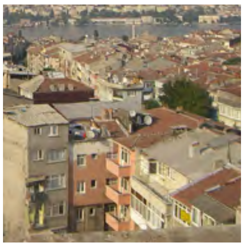
**Gare de Gros Noyer**
Slab Housing 02
SC 12; FAR 0.57

## Berlin

**Alt-Karow**
Detached Housing 05
SC 5; FAR 0.11

**Märkisches Viertel**
Slab Housing 04
SC 14; FAR 1.32

## Istanbul



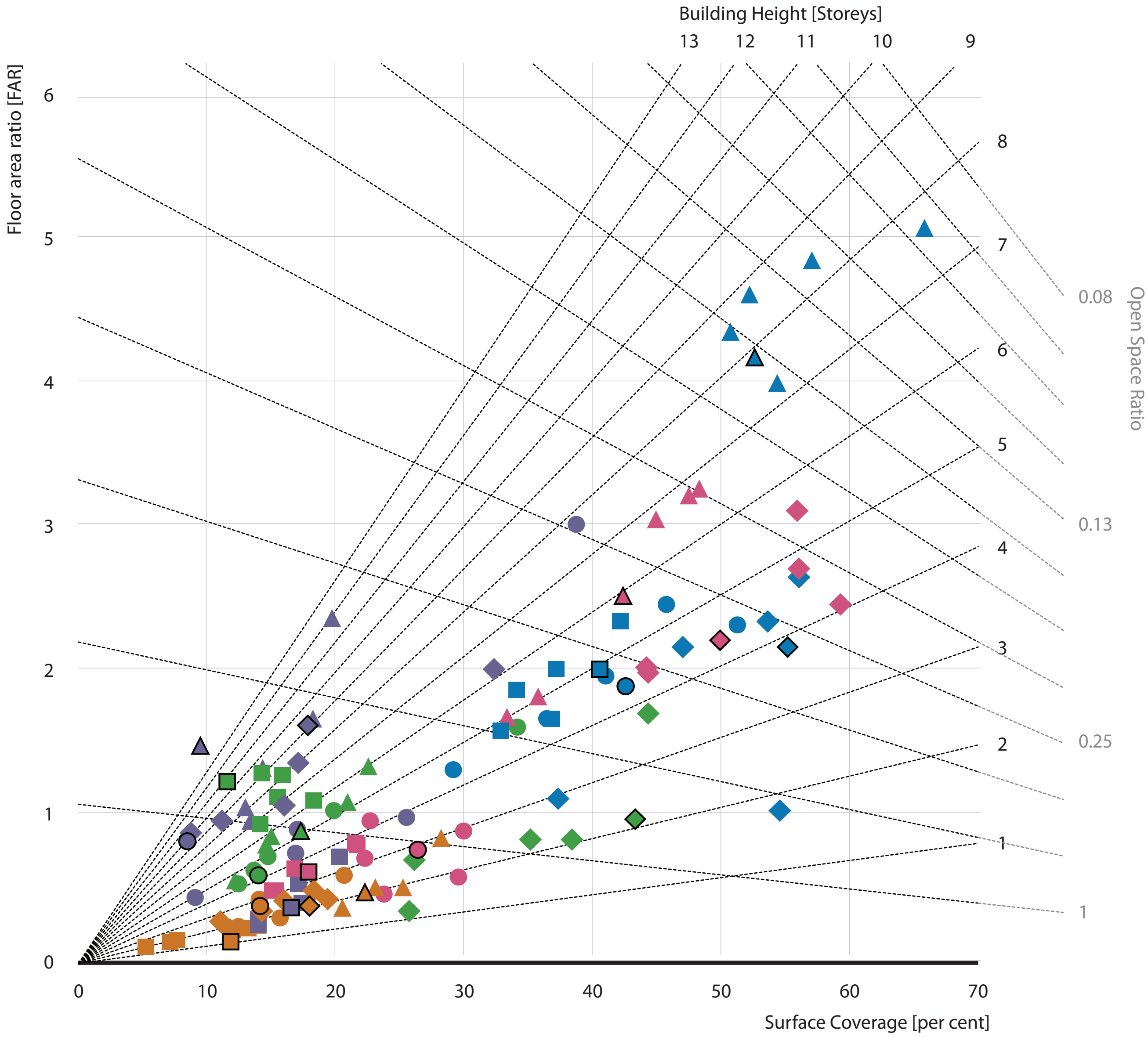
**Kasap Demirhun**
Compact Urban Block 03
SC 54; FAR 1.04

**Zafer**
Modern Apartment 01
SC 55; FAR 3.14

## The Spacemate Diagramm

A comprehensive visualization of the key spatial variables used in this report is facilitated by the 'Spacemate' diagram developed by Berghauser Pont and Haupt (2005). Besides the three parameters which were already introduced – floor area ratio, surface coverage and building height – the diagram uses the open space ratio, which is the ratio between the un-built area and the gross floor area of any given site. Some key insights are summarized below.

The diagram clearly positions the two typological extremes of detached housing and compact urban blocks. The former is characterized across all cities by density levels typically below FAR 0.5, surface coverage below 30 per cent, a building height around two storeys and an open space index above 1. The latter - compact urban blocks - have two clusters. The first around density levels of FAR 2, a surface coverage between 30 and 60 per cent and building heights typically between 4 and 6 storeys while the second cluster, which only includes Parisian blocks, achieves significantly higher density levels of FAR 4 to 5.2, mainly due to taller buildings which feature average heights of between 7 and 9 storeys. Modernist urban form, such as slab housing and high rise apartments combine relatively low surface coverage and



density with greater building heights and open space ratios. City specific typologies such as London's terrace housing also feature relatively low density levels between FAR 0.5 and 1, surface coverage between 20 and 30 per cent and an open space ratio around 1. They rarely exceed a building height above 4 storeys, while Istanbul's gecekondu is only slightly denser but has significantly higher surface coverage.

Spacemate diagram of sample morphologies

London
- Detached Housing
- High Rise Apartment
- Slab Housing
- Terraced Housing
- Compact Urban Block
- Idealized Sample

Paris
- Detached Housing
- High Rise Apartment
- Slab Housing
- Regular Urban Block
- Compact Urban Block
- Idealized Sample

Berlin
- Detached Housing
- Apartment Building
- Slab Housing
- Row Housing
- Compact Urban Block
- Idealized Sample

Istanbul
- Detached Housing
- High Rise Apartment
- Gecekondu
- Modern Apartment
- Compact Urban Block
- Idealized Sample

*Source: LSE Cities and EIFER Research*

# 3 HEAT ENERGY DEMAND

## 3.1 OVERVIEW

This chapter describes the analysis of the urban morphology samples introduced in the previous chapter in terms of heat-energy demand. Heat-energy demand is the theoretical deficit of heat energy required by a building to maintain thermal comfort levels in response to its climatic context (here thermal comfort is set as a minimum of 19°C). If we assume that variables such as insulation, climatic conditions and social preferences are constant and ignore other technical differences, the physical dimensions of the buildings and the syntax of the urban fabric come to the fore, with their effects isolated and quantifiable at the scale of the urban block. Using this approach it has been possible to understand the energy performance of an urban type solely in relation to its spatial (volumetric and relational) configuration. Due to the constant reference scenario, this performance data can be comparatively analysed.

## 3.2 DETAILED METHODOLOGY

The energy demand model used for this study follows the principles of an engineering-based, bottom up model (Swan and Ugursal, 2009). The modelling of theoretical heat-energy demands for each of the morphology samples was conducted in two stages. For the first stage, all parameters apart from those pertaining to form were fixed, including the climatic conditions. The simulation then modelled solar heat gains and building surface heat losses. From this, the average annual heat-energy demand per $m^2$ of indoor floor space was calculated for each sample. In the second stage, the effects of wall insulation, window U-value and glazing ratio, and climate were analysed.

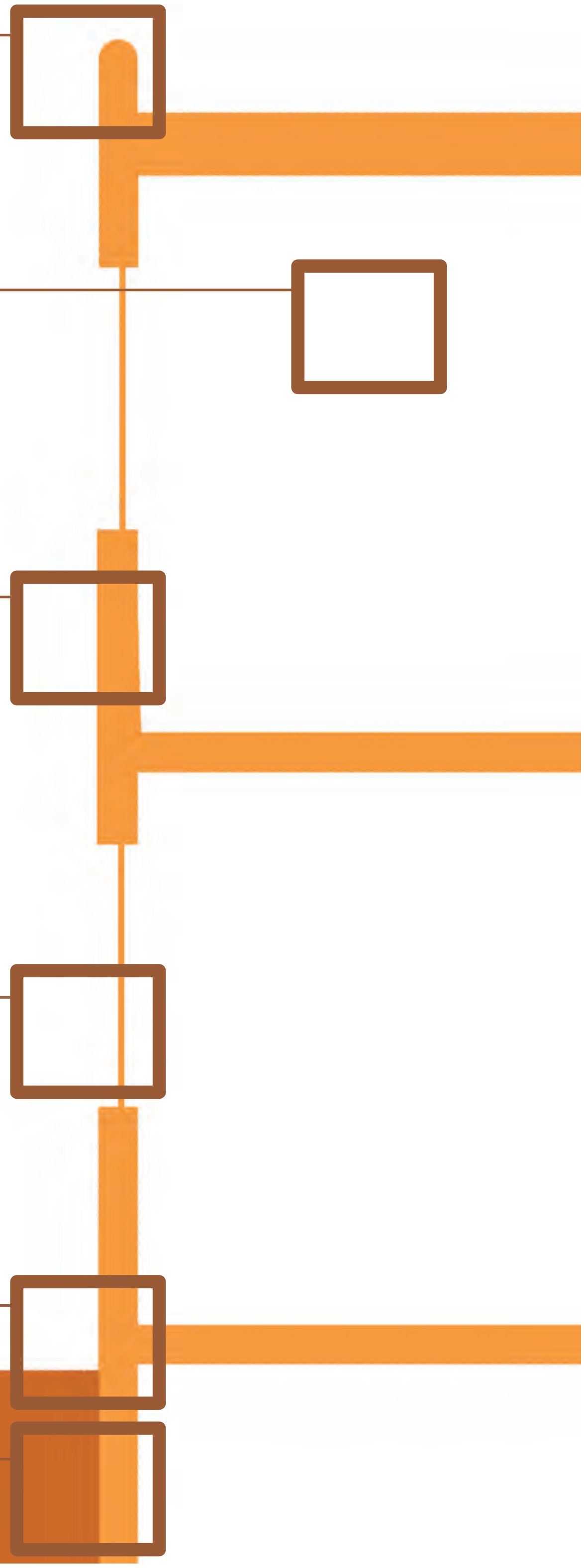
In order to draw direct comparisons between typologies and heat demand, a scenario was created and applied to all simulations. For the climatic conditions the case of Paris was selected for all scenarios, and values referring to building construction were kept constant throughout. The technological specifications of buildings in terms of appliance variations and variations in energy supply were set aside. A formula based on end-user heat energy demand would not measure the morphological impact, as end-use heat energy demand becomes distorted by social variables. By setting all social and technical variables constant, the only changing variable is the urban typology itself. The effect of the physical dimensions of buildings, their arrangement and layout at a larger scale becomes, in effect, measurable. Using this arrangement, it is possible to measure and compare heat energy demand across different building typologies at the scale of the urban block. It should be noted that, due to the simplifications of the heat energy demand model and the fixing of parameters for all but those pertaining to building form, heat energy demand results should be interpreted as being of only relative value. This is to say that real building heat energy demands may be quite different to the predicted values, and that the heat energy demands calculated here only reflect the relative differences between heat energy demands that are a direct result of morphological variables.

The heat energy assessment calculation outlined below is modelled through GIS (Geographic Information System) software, thus allowing for the creation and testing of three dimensional building models. Urban morphological factors affecting heat energy demand, including exposure to sun radiation, the spatial and physical dimensions of buildings and their environmental context, were incorporated. This enabled the calculation of the heat energy demand of multiple buildings so that it could be analysed at the scale of the urban block. Given that average monthly temperatures in all four selected cities were below 26°C, this energy assessment focused only on heat energy demand rather than energy for cooling. While this is clearly a simplification, as temperatures do exceed 26 °C on individual days, the project objective in this case was to specifically understand the effect of morphology and heat energy demand. However, it is recognised that future work would indeed add value by understanding the trade-offs between heat energy demand and cooling energy demand. It should also be noted that water heating was considered a separate issue to space heating, and was thus not considered in this study.

### Definitions

The demand for heat energy in buildings is a direct consequence of the surrounding climatic conditions, the energy performance of the building and the behaviour of the occupier. The thermal comfort level of an interior is affected by energy losses and gains, and the heat energy demand amounts to the deficit of heat energy required to achieve accepted thermal comfort levels.

## MODEL ASSUMPTIONS



**Roof**

Roof geometry = not considered
U-value = same as external wall value below

**Room**

Inner temperature = 19°C
Habitable surface = 80%
Ventilation = 0.5 $h^{-1}$
Night heating coeficcient = 0.95
Thermal capacity air = 0.34 $W/m^3K$
Internal gains =23 $kWh/m^2$ a.
Average store height = 3 m

**External wall**

U-value = 1.15 $W/m^2K$

**Environment**

Vertical solar radiation = 410 $kWh/m^2$
Heating degree hours = 67425 K

**Window**

Glazing of facade = 40%
U-value = 2.8 $W/m^2K$
Frame = 15% of window area
Shadowing devices = no

**Thermal bridges**

Area x 0.05 W/m2K

**Cellar**

Excluded
Reduction factor = 0.6

Energy losses occur via the building envelope, when outdoor temperature drops below a reference indoor temperature. These losses derive from the envelope itself, its openings, thermal bridges and losses amassed by ventilation.

Energy gains are generated by solar radiation entering through transparent parts of the building, warming the air of the interior. Gains are also a result of building use: the associated heat generated from either the occupiers themselves or by appliances within the building.

**The main variable: outdoor temperature**

The main variable in assessing the primary heat energy demand is the outdoor air temperature in relation to the chosen constant indoor temperature which, for this enquiry, has been set to a constant of 19ºC. The heating period is measured according to average annual city air temperatures, measured either hourly, daily or monthly. These are described here as heating degree hours ($H^{DH}$) or heating degree days ($H^{DD}$), depending on the chosen unit. They are a measure of how many degrees Celsius and for how long ($t^{Hp}$) the outside air temperature ($T^{ex}$) is lower than the set reference indoor temperature ($T^{in}$):

$$H^{DD} = \Sigma\, (T^{in}\text{-}T^{ex})\, t^{Hp}$$

The primary heat energy demand ($D^{H}$) is therefore calculated as the difference between heat losses ($L^{tot}$) and heat gains ($G^{tot}$):

$$D^{H}= H^{tot} - G^{tot}$$

The heat losses are defined as the sum of the losses during the heating period through the building envelope ($L^{HT}$) and the ventilation ($L^{HV}$):

$$L^{tot} = \Sigma\, (T^{in}\text{-}T^{ex})\, t^{Hp}\, (L^{HT} + L^{HV})$$

The heat gains are defined as the sum of the gains during the heating period from the incoming solar radiation ($G^{Sun}$) and the internal gains from dwellers and appliance use ($G^{Int}$), lowered by their real usage factor ($\eta$):

$$G^{tot} = \Sigma\, \eta\, (G^{Sun}+G^{Int})\, t^{Hp}$$

**Energy losses: transmission**

$$L^{HT} = \Sigma\, (U_i\, A_i\,) + L^{HTb}$$

Heat transmission losses ($L^{HT}$) are expressed as the sum of the losses through the façade (wall and openings), and the heat losses of thermal bridges ($L^{HTb}$). The façade losses are expressed as the thermal conductivity of the building materials ($U_i$) multiplied by the surface area exposed to the environment ($A_i$). The thermal conductivity of the building material ($U_i$) has not been assessed in this work, but set as a constant listed with all the other parameter values in the previous section.

The thermal bridge losses are expressed as the length of the edges of the building's main form ($l_i$) multiplied by their thermal conductivity coefficient ($\psi_i$):

$$L^{HTb} = \Sigma\, l_i\, \psi_i$$

This method of assessing losses associated with thermal bridges usually leads to an overestimation in buildings with higher insulation standards. A simple correction factor accounted for this. Assuming a certain construction standard, the heat losses through the thermal bridges can be assessed as the average ($U_i$) value of the façade construction increased by 0.05 W/m²k . Therefore, the formula becomes:

$$L^{HT} =\Sigma\, (U_i\, A_i\,) + 0{,}05\, A_i$$

In this study, transmitting wall surfaces are assessed by GIS software. Profiling by means of layering data sets in GIS allows an enriched mapping and configuring of the three dimensional information. Footprint data from cadastral plans, along with building height data can be used to generate further values such as volume and floor space (assuming an average storey height of 3m). Using the ESRI-ArcInfo geographic system for the analysis of building information, external and adjacent walls can be differentiated. This allows walls that have no contact with the exterior to be removed from the assessment. These should not affect the building envelope's performance as the temperature between adjacent walls is assumed as the same as internal temperatures (therefore no energy is exchanged).

**Energy heat losses: ventilation**

$$L^{HV} = \rho^{A}\, c^{A}\, \nu\, V_i$$

Ventilation losses are identified as the volume of air ($V_i$) exchanged in units over time ($\nu$), considering its density at a standard temperature and pressure within a room, and defining its thermal capacity as 0.34 Wh/m³ k. The air exchange rate in buildings depends firstly on how the occupants of the space interact with the permeation of the building, and secondly on the technical ventilation appliances, if any exist. Ventilation can therefore vary widely, but the value of 0.5 cycles per hour has been applied here as a reasonable average. $\rho$ is the air density at standard temperature and pressure (0° celcius and 101.3 kPa, respectively) = 1.29 kg/m$^3$, and *c* is the specific thermal capacity of air = 0.279 Wh/kgK.

It is not necessary - or indeed standard practice - to heat a building in its entirety, therefore the 'volume' does not refer to the net volume but rather the volume excluding the volume of inner walls, staircases or other uninhabited rooms. The correction value for both the volume and the related floor space has been set to 0.8 of the total, but this is a value that is adjusted to the size and use typology of the building.

**Energy gaining: inner gaining**

$G^{Int} = q_{i,a} A_i$

The value ($q_{i,a}$) is set according to the German and French standard of 22 kWh/m$^2$ of inhabitable floor-space area ($A_i$). Inhabitable floor-space area is considered to be 80 per cent of the total area – as for the volume within the ventilation losses assessment. A precise assessment of the internal gains depends on the appliances utilised in the building and their usage time. This is a social variable depending on occupancy and has therefore been set as a constant.

**Energy gaining: solar gaining**

$G^{Sun} = \Sigma I_i^{Sp} \, \Sigma F_i^{Wf} \, F_i^{Ss} \, F_i^{Sh} \, g_i \, A_i$

The total gain from solar radiation is defined as the incident solar radiation ($I_i^{Sp}$) during the heating period on the different facades of a building. The incident solar radiation has to be defined for each façade separately, and depends on a number of factors:

- orientation of a façade and the relative incident radiation energy ($I_i^{Sp}$);
- the area of transparent elements of a façade ($A_i$), lowered by the properties of the glazing and resulting transmittance of radiation energy ($g_i$);
- the fraction of area occupied by the frame ($F_i^{Wf}$);
- possible horizontal shading installations ($F_i^{Sh}$) and the shading of outstanding objects ($F_i^{Ss}$).

In the first instance, solar radiation acting on a vertical surface according to the geographical position must be considered. This quantity has to be taken from the building energy consumption assessment directives in a particular state, or

Below
Paris
*© Kolor 2010*

from other data sources. Subsequently, the solar radiation which actually enters a room is quantified according to the proportion of the window frame related to the total window area ($F_i^{Wf} = 0.85$). The physical properties of glass do not allow the transmission of all incident radiation, firstly because the angle of incidence of the radiation is seldom perpendicular, and secondly because glass is never fully transparent due to aging or dust ($g_i = 0.5$). Shadowing generated by other volumes in the vicinity of the building must also be considered a major factor influencing accessibility to solar energy within the urban tissue ($F_i^{Sh}$). These values amount to a rigorous assessment of the solar radiation for each façade within their typological context and scale. Horizontal shadowing devices should also be considered, though for simplicity we have assumed that they have not been installed ($F_i^{Ss} = 1.0$).

### Cooling

In the same way that the heating period is defined as the period when the exterior temperature drops below that of the interior (which is a constant 19ºC), the cooling period is defined as the period when the outdoor temperature rises above 26ºC. For the sites of analysis here, the monthly average temperatures do not exceed 25ºC and therefore cooling is not considered in the calculations. Of course there is demand in the summer months for cooling energy but this has been categorised at the latitude of the sample cities as a consumer preference (linked to affluence and other social factors) rather than a utility, and as such is not considered in this study.

### Solar radiation

When using this formulated method for assessing energy gains from solar radiation, the main variables are the incidence angle of the facades of the building and the shadowing from surrounding objects during the heating period. Due to the chosen scale of the analysis, the urban morphology itself plays the dominant role in the results; the main factors affecting solar heat gain are the size of surrounding buildings, the street width and the spatial arrangement of open spaces between buildings.

Using GIS software, a comprehensive analysis of incoming solar radiation for each chosen typology has been made. The cadastral data, enriched with the height data of the typologies, was transformed into 50cm x 50cm grids. With the urban typologies represented as digital elevation


**Direct solar radiation [Wh/m²]**

- 0 - 30.000
- 40.000 - 60.000
- 70.000 - 90.000
- 100.000 - 100.000
- 200.000 - 200.000
- 300.000 - 200.000
- 300.000 - 200.000
- 300.000 - 200.000

*Source: LSE Cities and EIFER Research*


**Diffuse solar radiation [Wh/m²]**

- 260 - 15.000
- 16.000 - 30.000
- 31.000 - 45.000
- 46.000 - 60.000
- 61.000 - 75.000
- 76.000 - 90.000
- 91.000 - 110.000

*Source: LSE Cities and EIFER Research*

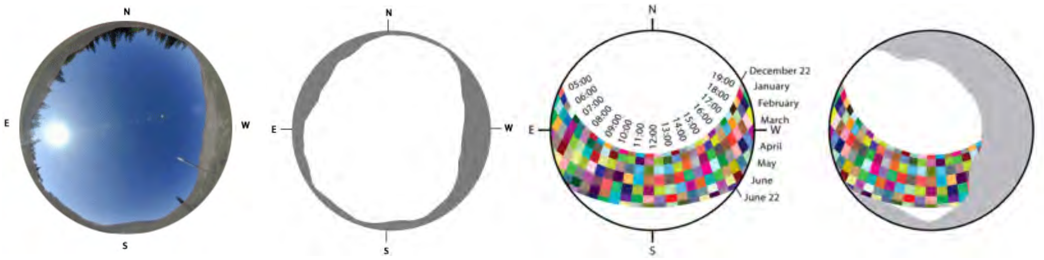

**Hours of direct radiaiton [h/m²]**

- 0 - 250
- 251 - 500
- 501 - 750
- 751 - 1.000
- 1.010 - 1.250
- 1.260 - 1.500
- 1.510 - 1.750
- 1.760 - 2.000
- 2.010 - 2.250

*Source: LSE Cities and EIFER Research*

**Schematic representation of the calculation for the direct solar radiation in a certain location.**

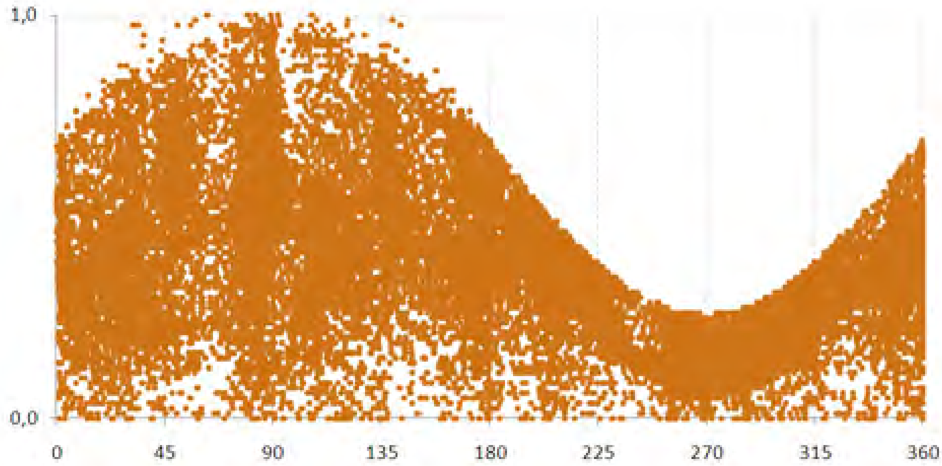
First a view-shed is calculated. This represents the visible parts of the sky, seen from a point location into all sky directions. The direct solar radiation is calculated by considering the sun track in the sky during a given period. Then, duration and total solar radiation are calculated.




**Duration of solar radiation**

Coefficient distribution according to the case-study Paris. Each point represents the coefficient value for a facade line segment for the chosen 25 typologies of Paris. To notice the deviation from a normal sinusoidal linear function of the calculated coefficient.

*Source: LSE Cities and EIFER Research*




**Hours of direct radiaiton Coefficient [0-1]**

- 0,0 - 0,2
- 0,2 - 0,4
- 0,4 - 0,6
- 0,6 - 0,8
- 0,8 - 1,0

*Source: LSE Cities and EIFER Research*

models (DEMs), the incident solar radiation was quantifiable at each grid point.

During the considered heating period, the penetration rate of solar radiation in the urban tissue is based on the analysis of the sun trajectory at 0.5 hour intervals during the day, aggregated to 14 day averages. Diffuse solar radiation, direct solar radiation and their durations are considered. The outputs of the calculation model are interpolated with the exposed surfaces of each building and normalised to a coefficient ranging between 0 and 1 (see right of page). This is multiplied by the vertical incident solar radiation value of a south facing (due to the latitude of the four case-study cities) exposed façade, resulting in a definitive value for the solar radiation of each façade. Amongst the constant parameters for all sample cities is the vertical incident solar radiation of a south facing exposed façade. All presented results refer to cumulative values for the chosen heating period.

**Critical review of the heat energy demand modelling**

As outlined in Erhorn (2007), when modelling energy consumption of real buildings, a major question for the modeller is the fair balance of the complexity and comprehensiveness of the model on the one hand, and the available quality of input data and the use of the model results on the other. When assessing energy consumption for buildings, the quality of the input data is still a major problem and often underestimated. This requires frequent revisions of dynamic models when applied to real cases and when aiming to assess the real energy consumption.

This problem is even more accentuated at the neighbourhood or city-wide level. Here, the input data is an even greater problem and is often not available, requiring various advanced statistical methods to generate datasets. As a consequence more simplified models are often used, which lead to less exhaustive but at least more reliable results.

For this study, which included a dataset of around 30 million square metres in total, a static model was chosen to calculate the annual heat energy demand as a theoretic value. It does not aim to produce real energy consumption values. Instead, the central question was about the relative effect of urban morphology on heat energy demand from a purely comparative perspective across the 120 samples, a task for which a static model offers a suitable level of simplicity. No doubt, a model that takes into consideration the monthly or hourly climate approach following EN ISO 13790 would give more detailed results and could easily be integrated as part of follow-up research, where a range of different questions could be analysed in more detail.

A further constraint on interpreting the results from common modelling approaches is the choice of a base scenario, which includes a range of building parameters set at constant. The aim of standardizing values that in the real samples are actually quite different simply helps with comparisons of the calculated heat demand across the different case studies. The values were chosen based on a subjective assessment of average between performance data for historical and modern buildings, while reflecting the main characteristics of the sample.

For example, the ventilation ratio is closer to a mechanical ventilation standard. Generally, the distortion is much more accentuated in older buildings, where air tightness is not ensured and the ventilation ratio can vary by up to a factor of two in older or low standard buildings. This is the case for the traditional urban block, whereas in modern tower blocks, higher losses might be caused by higher exposure to winds, leading to higher penetration. In such contexts, the behavioural attitudes of residents and the availability of mechanical ventilation can considerably impact on the final results.

Furthermore, the method to assess thermal bridges was simplified, as the same construction standard was assumed across all samples. The effect of losses through thermal bridges was set as 5 per cent over the total losses of the facade, while the actual heat dispersion caused by thermal bridges can be twice as high.

Also, glazing ratios need to be considered more carefully. Most buildings have a glazed surface which covers between 20 to 25 per cent of the facade surface, reaching peak levels of 35-40 per cent in normal stone or concrete buildings. In the heat demand assessment, this leads to a higher impact of the heat gains through solar radiation. Having chosen a U-value which represents double glazing standard, the effect on heat loss is still noticeable, but if the standard were set to passive house or low-consumption house standard, glazing could be increased further for access to daylight, while heat losses would be minimized.

Right
London
*Philipp Rode*

## 3.3 HEAT ENERGY DEMAND OVERVIEW

# Real samples

This section displays the average heat energy demand per square metre of floor space for a selection of the real samples. The results have been displayed through a colour heat map, so that both form and heat energy demand can be represented. The difference between detached housing and denser building typologies is well defined, and it can be seen that both form and size play a major role. It can also be seen, particularly in the gecekondu of Istanbul, that buildings with fewer shared walls, for example solitary buildings or those on the end of rows, tend to have a poorer thermal performance than those in the middle of a row. For taller building forms the most important factor may be overshadowing from adjacent buildings. In the Paris regular urban block in particular, one can see that buildings in the interior of the square blocks tend to fare worse than those at the edges.

### LONDON

#### Detached Housing*


#### High Rise Apartment


**Primary heat energy demand [kWh/m²/year]**

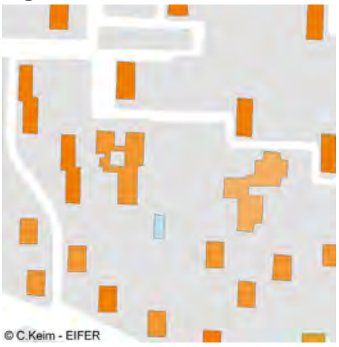
- < 50
- 51 - 75
- 76 - 100
- 101 - 125
- 126 - 150
- 151 - 175
- 176 - 200
- 201 - 225
- 226 - 250
- 251 - 275
- > 275

* Semi-detached housing has been put in the same category for this study as detached housing. Both are presented under 'Detached' housing.

### PARIS

#### Detached Housing


#### High Rise Apartment




### BERLIN

#### Detached Housing


#### Apartment Building


### ISTANBUL

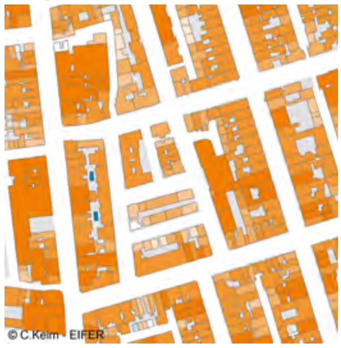
#### Detached Housing


#### High Rise Apartment

**Slab Housing**


**Terraced Housing**


**Compact Urban Block**




**Slab Housing**


**Regular Urban Block**


**Compact Urban Block**

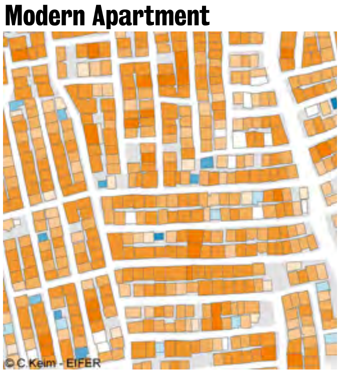

**Slab Housing**


**Row Housing**

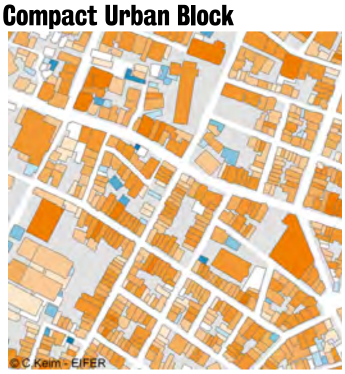

**Compact Urban Block**


**Gecekondu**


**Modern Apartment**




**Compact Urban Block**

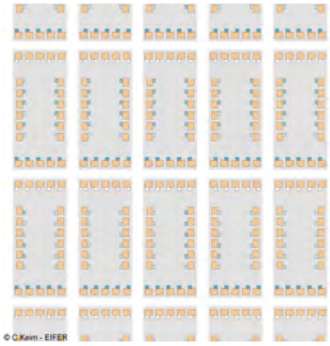


## Idealised samples

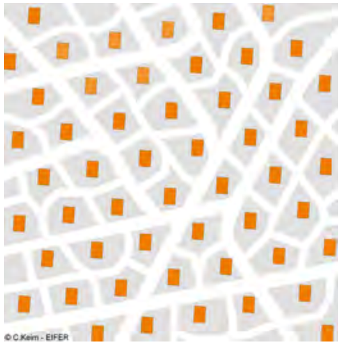
This section displays the average heat energy demand per square metre of floor space for the idealised samples. The physical proportions and spatial arrangement of the buildings mimic the real samples, with the additional advantage that invasive morphology types have been removed. As such, the more homogeneous typologies such as detached or terraced houses are within similar results ranges as the real samples. More modern typologies such as slab housing show, in some cases, massively exaggerated performances relative to their respective real samples. This is chiefly due to the removal of the low rise, low density building types which were diluting the overall performance of the sample area. Standardisation of building orientations will also have had an impact. Overall, these results show that a building's energy performance is dependant not only upon its own design, but also upon the design and position of the buildings in its immediate surroundings.

### LONDON

**Detached Housing**



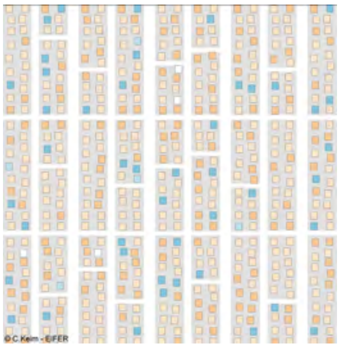

**High Rise Apartment**





### PARIS

**Detached Housing**

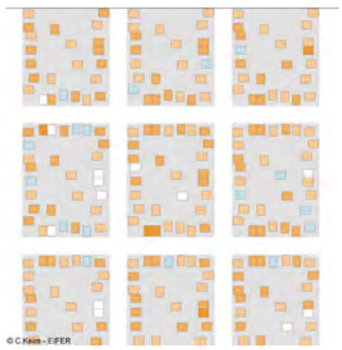



**High Rise Apartment**


### BERLIN

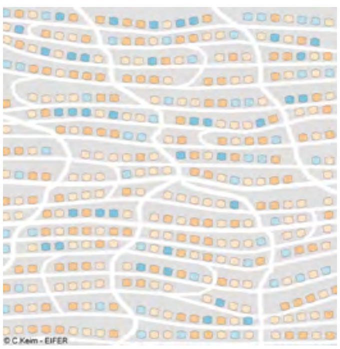
**Detached Housing**


**Apartment Building**

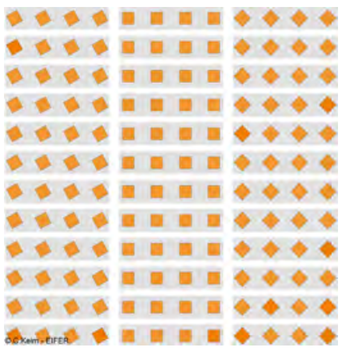



### ISTANBUL

**Detached Housing**

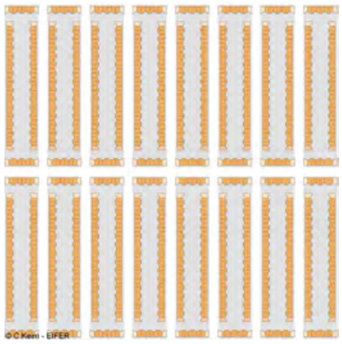



**High Rise Apartment**

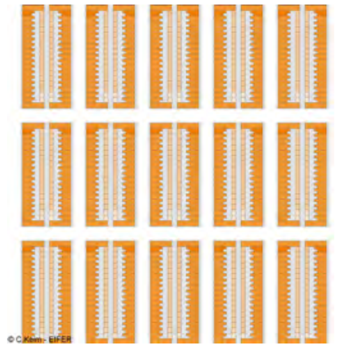


### Slab Housing

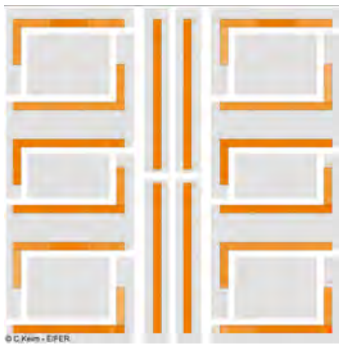

### Terraced Housing



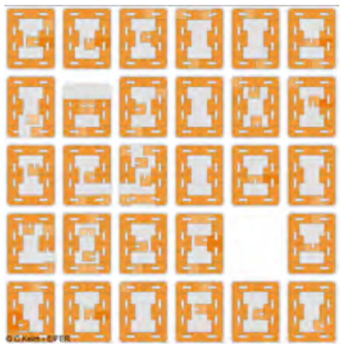

### Compact Urban Block



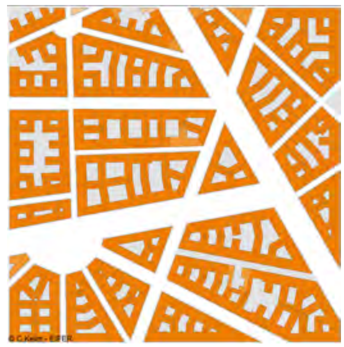

### Slab Housing




### Regular Urban Block

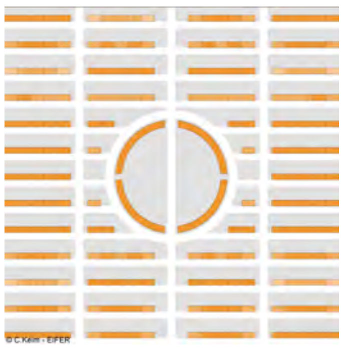



### Compact Urban Block

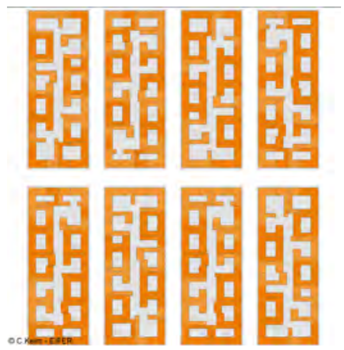



### Slab Housing

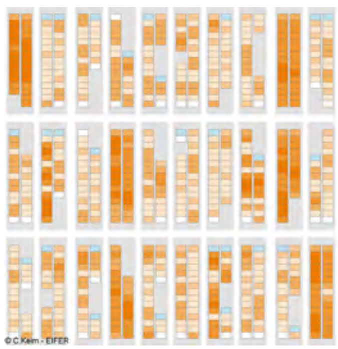

### Row Housing




### Compact Urban Block

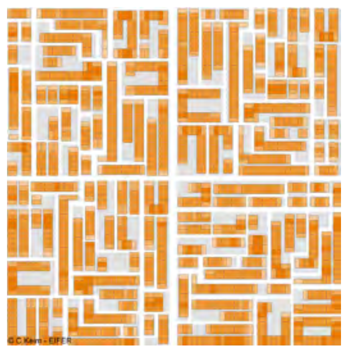



### Gecekondu




### Modern Apartment

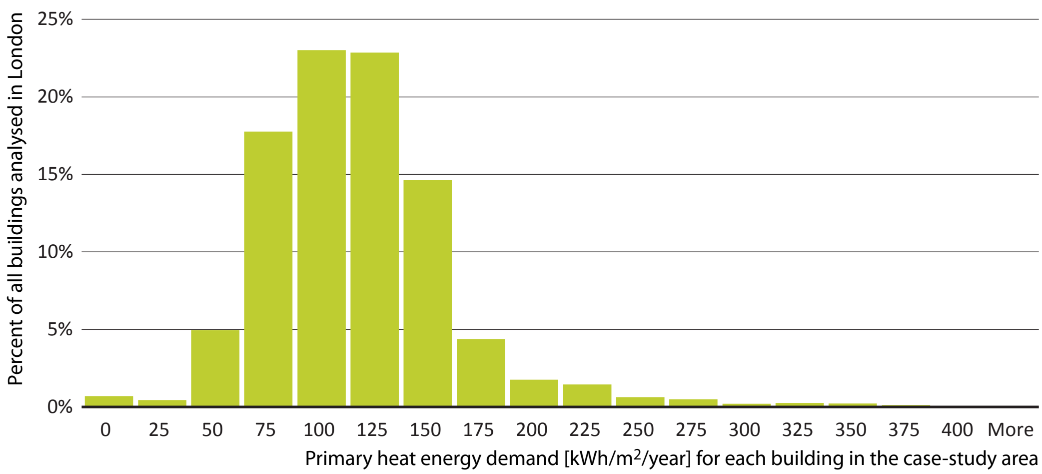

### Compact Urban Block



## 3.4 DISTRIBUTION OF BUILDINGS WITH DIFFERENT HEAT ENERGY DEMAND

This section displays the frequency distributions of heat energy demand in each of the four case study cities. Results include all real samples. All four cities display a predominance of buildings featuring a heat energy demand of between 50 and 150 kWh. Paris is notable for having the strongest representation at the lowest heat energy demand of 50 kWh. Berlin, Paris and to a small extent Istanbul show secondary and even tertiary peaks within their frequency distributions, suggesting some discretisation of building design.

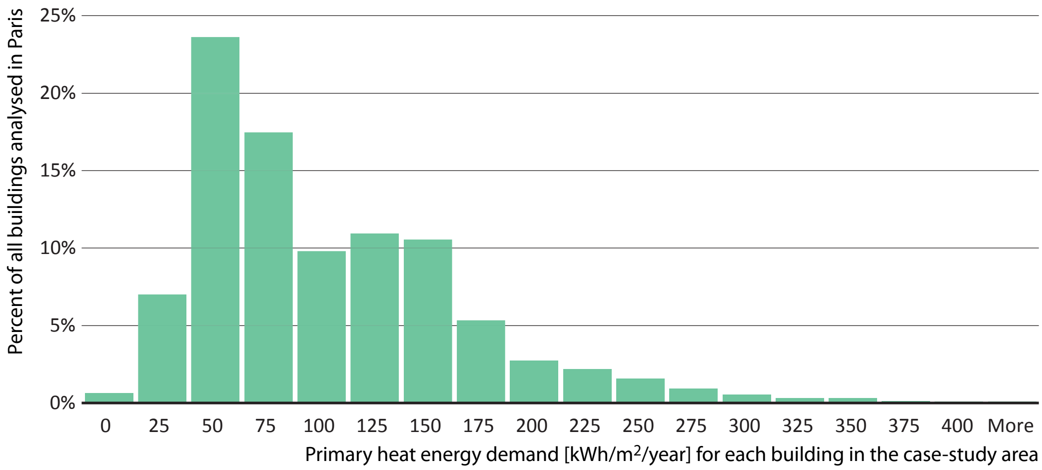
Right
Istanbul
High Rise Apartment
*Ali Taptik*




### London

**Distribution of buildings by primary heat energy demand per m² floor-space.**

*Source: LSE Cities and EIFER Research*




### Paris

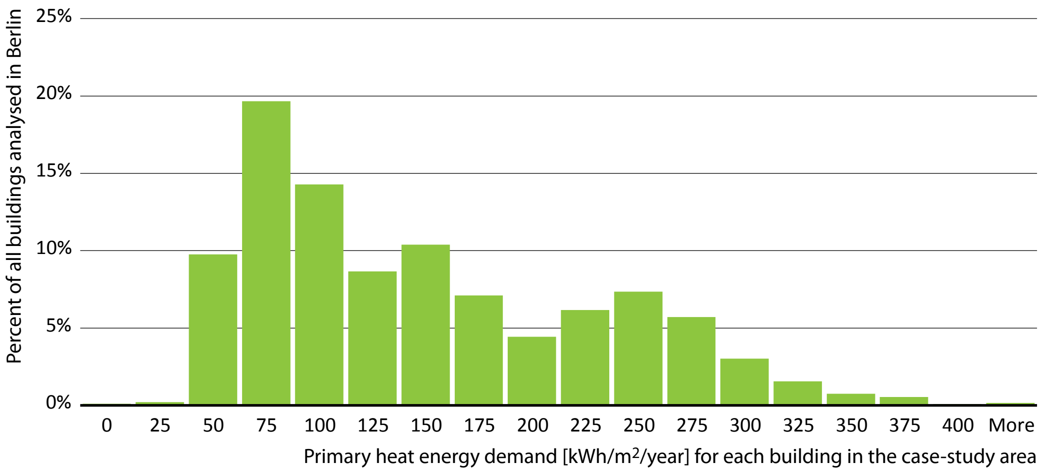
**Distribution of buildings by primary heat energy demand per m² floor-space.**

*Source: LSE Cities and EIFER Research*

**Berlin**

**Distribution of buildings by primary heat energy demand per m² floor-space.**

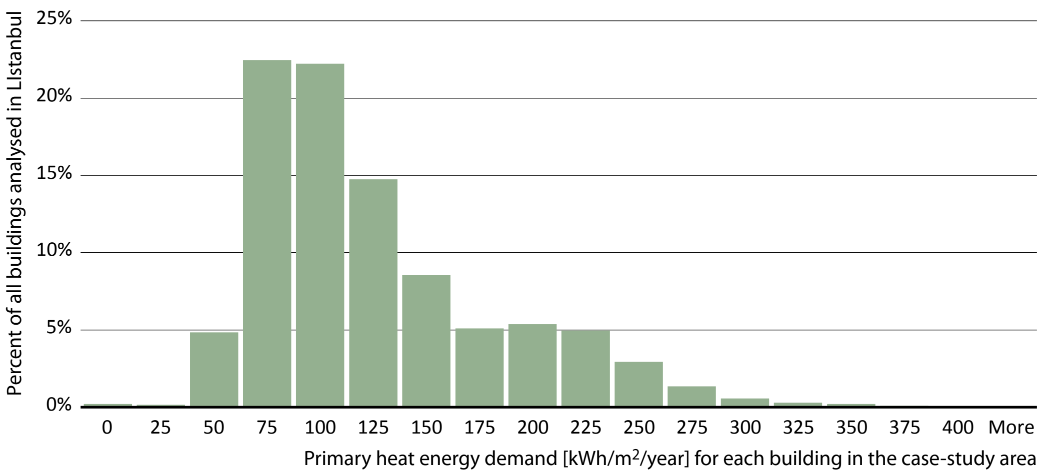
*Source: LSE Cities and EIFER Research*




**Istanbul**

**Distribution of buildings by primary heat energy demand per m² floor-space.**

*Source: LSE Cities and EIFER Research*



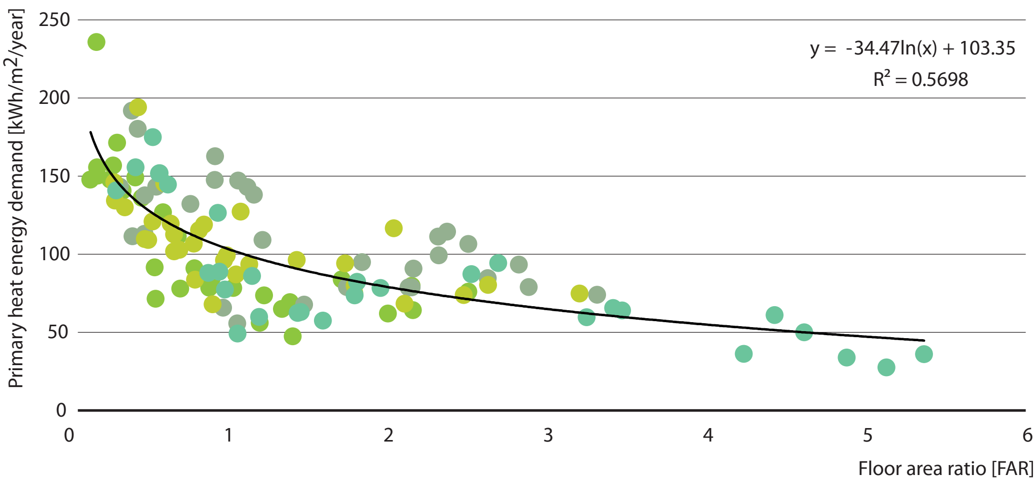
# 4 URBAN MORPHOLOGY AND HEAT ENERGY DEMAND

This chapter analyses the relationship between the headline results for heat-energy demand, calculated by the modelling exercise, and four spatial characteristics - building density (Floor Area Ratio), surface-to-volume ratio, surface coverage of buildings and average building height - that describe the different samples of urban morphology as introduced in chapter 2. Overall, the hypothesis that different building morphologies feature distinctively different energy demands and that higher density building configurations lead to greater heat-energy efficiency is confirmed. The ratio between the least and best performing sample is greater than factor six, emphasising the importance of gaining a better understanding of design-related impacts on heat-energy demands.

The average building height, building density and surface-to-volume ratio were found to be good indicators for heat energy efficiency, each correlating well with the heat energy demand.

## 4.1 DATA RELATIONSHIPS AND CORRELATIONS

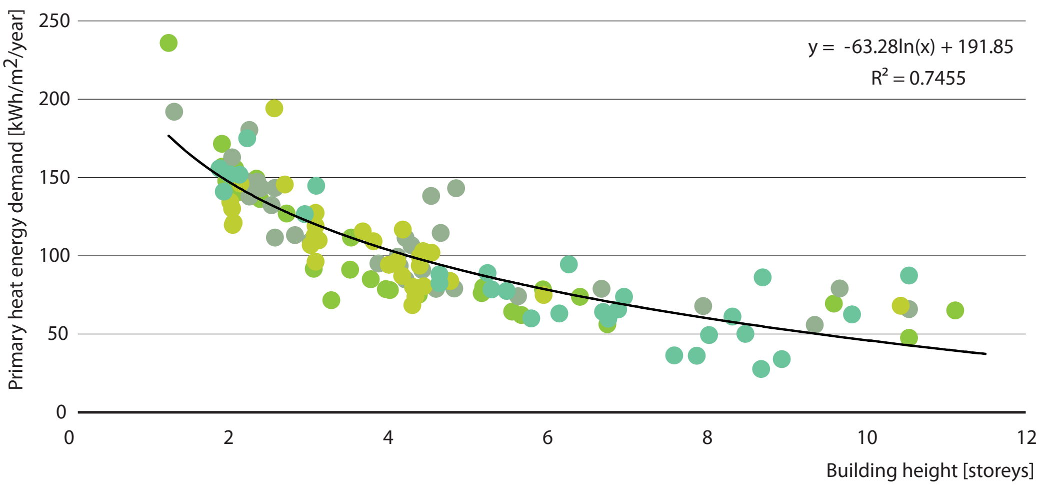
This section introduces the overall data relationships and correlations which have been observed between each of the four morphological variables and heat energy demand. The intention is to give the reader an empirical sense of the way in which heat energy demand behaves in relation to the variables, whilst providing a quantitative indicator of how well they correlate with heat energy demand. It represents a simple statistical analysis which, because it is based on adding up all morphologies across the four cities, analyses a sample that in reality does not exist in one place. Building density, average built height and surface-to-volume ratio are all found to be good indicators of heat energy demand. As can be seen from the graphs, density, height and coverage all showed negative correlations, whilst surface-to-volume ratio showed a positive correlation.




Density and and heat energy demand



*Source: LSE Cities and EIFER Research*




Building height and heat energy demand



*Source: LSE Cities and EIFER Research*

Surface-to-volume ratio and coverage were approximated as linear relationships, and height and density by logarithmic relationships.

The four graphs displayed below plot all morphology samples for their heat energy demand against each of the morphological variables respectively. As the variables actually represent highly complex real-world built environments that are also highly interdependent – for example, one expects to see an increase in building height with an increase in building density – it would be difficult to fit this data to an analytical model based on building physics. The next best alternative is to empirically map the data to a function which best approximates the observed trend. A certain amount of judgement was required here. As such, only simple data models were used, with each variable being tested for goodness of fit to an exponential, reciprocal, linear, logarithmic, and power-law relationship. The best fitting - the one with the highest $R^2$ (coefficient of determination) - was chosen. Displayed on the graphs are the trend lines, with accompanying equations for the chosen data relationships.

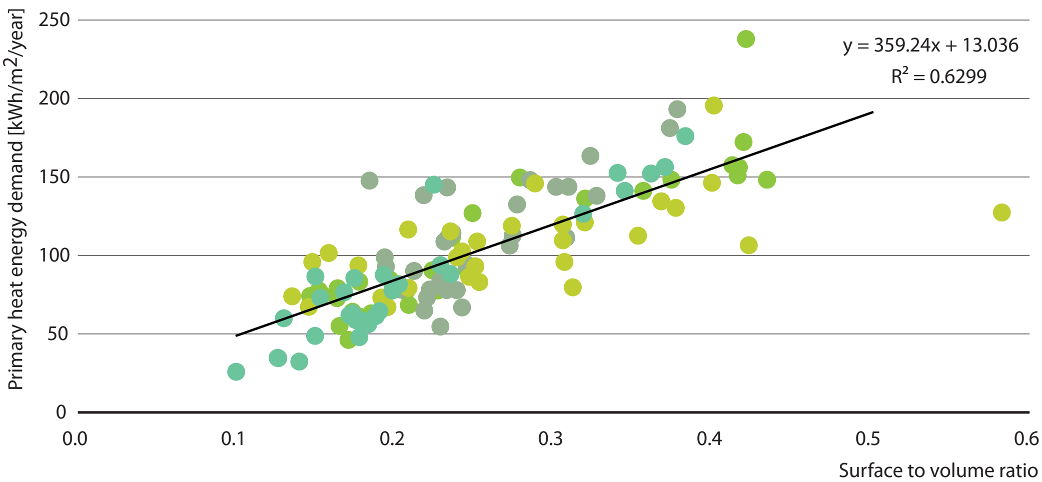
The correlation coefficients are first presented in aggregate over all samples and then broken down by city and by morphology type. Morphology types which were unique to only one city were omitted as, with so few data points, related results would not be statistically significant. The Pearson correlation formula was used to calculate these values. Though there are no hard rules, a coefficient above 0.8 is usually considered to be a strong correlation, while anything below 0.5 is a weak one.

Across the cities, density showed very strong correlation with heat energy demand in Berlin and Istanbul, though a significantly weaker one in Paris and London. The same trend is also noticed with respect to surface-to-volume ratio. Average

**Surface to volume ratio and and heat energy demand**

- London
- Paris
- Berlin
- Istanbul

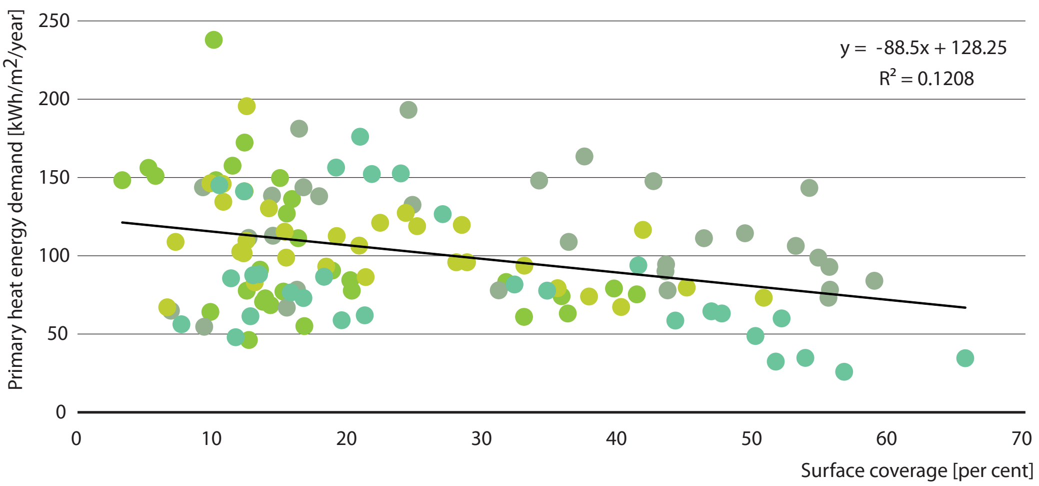
*Source: LSE Cities and EIFER Research*




**Surface coverage and and heat energy demand**

- London
- Paris
- Berlin
- Istanbul

*Source: LSE Cities and EIFER Research*



built height is shown to be a consistently good indicator, with the highest correlation coefficient above 0.86 across all samples. Here, London, with a coefficient of 0.73, is the only outlier. Surface coverage can be seen to be the least correlated variable, with a coefficient of 0.35 across all samples.

Across the morphology types, most striking is the fact that detached housing, unlike any of the other types tested, shows almost no correlation between density and heat energy demand. Additionally, for a typically low rise urban form, detached housing shows its highest correlation with height. High rise apartment and compact urban blocks show high correlation with density, though unlike the compact urban block which also correlates well with height, the high rise apartment shows only a weak link with this latter variable. A weak link with surface-to-volume ratio and practically no correlation with coverage are shown by all types except the high rise apartment. Here, a lower than average correlation with surface-to-volume ratio seems to be compensated for by a weak correlation with coverage.

## 4.2 BUILDING TYPOLOGY

This section displays the results for heat energy demand against building types in each of the four cities. Maximum, minimum and average heat energy demand for each of the real samples and the ideal samples are plotted. Building typology is confirmed as a strong predictor for heat energy demand for detached housing and compact urban blocks.

Across all cities, not one sample of detached housing achieves a heat-energy demand of less than 110 kWh per square metre per year, while many feature values in the region of 150 kWh. On the other end of the scale are compact urban blocks which are mostly well below 100 kWh, and in the case of Paris even below 50 kWh. The performance of all other building typologies is less consistent. In Paris, all high rise apartment samples display energy demands of less than 100 kWh. In London this figure ranges between 80 and 130 kWh, while in Berlin, high rise apartments range between 90 and 170 kWh. Interestingly, terrace housing in London performs relatively poorly, with an average heat energy demand in the region of 110 kWh. Row housing

| | Density | Surface to Volume | Building Height | Surface Coverage |
|---|---|---|---|---|
| Compact Urban Block | -0.80 | 0.69 | -0.80 | -0.24 |
| Detached Housing | -0.36 | 0.62 | -0.70 | -0.13 |
| High Rise Apartment | -0.94 | 0.44 | -0.54 | -0.50 |
| Slab Housing | -0.76 | 0.64 | -0.86 | -0.21 |
| All samples | -0.75 | 0.79 | -0.86 | -0.35 |

**Correlations by Typology**
Main parameters interpolated with heat energy demand by typology

*Source: LSE Cities and EIFER Research*

| | Density | Surface to Volume | Building Height | Surface Coverage |
|---|---|---|---|---|
| London | -0.70 | 0.63 | -0.73 | -0.46 |
| Paris | -0.84 | 0.93 | -0.88 | -0.51 |
| Berlin | -0.86 | 0.90 | -0.90 | -0.49 |
| Istanbul | -0.65 | 0.70 | -0.86 | -0.16 |
| All samples | -0.75 | 0.79 | -0.86 | -0.35 |

**Correlations by City**
Main parameters interpolated with heat energy demand by city

*Source: LSE Cities and EIFER Research*

in Berlin is slightly better, with an average of 80 kWh. Building typologies that feature the most diverse energy performances include the gecekondu in Istanbul, ranging from 100 to 200 kWh; apartment buildings in Berlin with 90 to 170 kWh; and slab housing in Paris and London with 60 to 150 kWh and 85 to 150 kWh respectively.

While the ranges of the real samples of slab housing typologies are again a likely consequence of a mixing-in of other configurations, the variations of all other typologies more accurately mirror the diverse performance of areas following similar urban design principles. Looking at performance across the four cities, Istanbul shows the greatest variation both between and within morphology types, with its detached housing, high rise apartment, gecekondu and compact urban block showing amongst the greatest ranges of real samples taken in any of the cities. Conversely, London and Paris exhibit smaller performance ranges between building types. In both these cities, only the slab housing type has a greater than 50 kWh variation between its maximum and minimum heat energy demand values in the real samples.

Performance of the idealised samples generally follows the pattern outlined above. However, there are some important differences. Nine of the idealised samples exhibit heat energy demands greater than their respective real ranges. In some cases this is likely to be because of the removal of invasive morphology types in the real samples, but this does not explain all such situations. If one views the real samples of detached housing, it is apparent that there is little mixing in of other morphology types. In such cases, it may be that the ordering of such samples into regular patterns negatively affects solar gains, or that the orientations chosen for the simulation of the ideal samples were not optimal. To know the answer conclusively would require further experimentation. Conversely, the idealised samples of high rise apartments seem to outperform real samples in London. This, however, can be explained by the fact that the real building type rarely exists in a pure form within an urban area of 500 by 500 metres in London.

**Building typology and heat energy demand**

Heat energy demand ranges (maximum - minimum - average) by building typology for the four cities

Average Value

Ideal Sample Value

CUB - Compact Urban Block

MA - Modern Apartment

RH - Row Housing

RUB - Regular Urban Block

TH - Terraced Housing

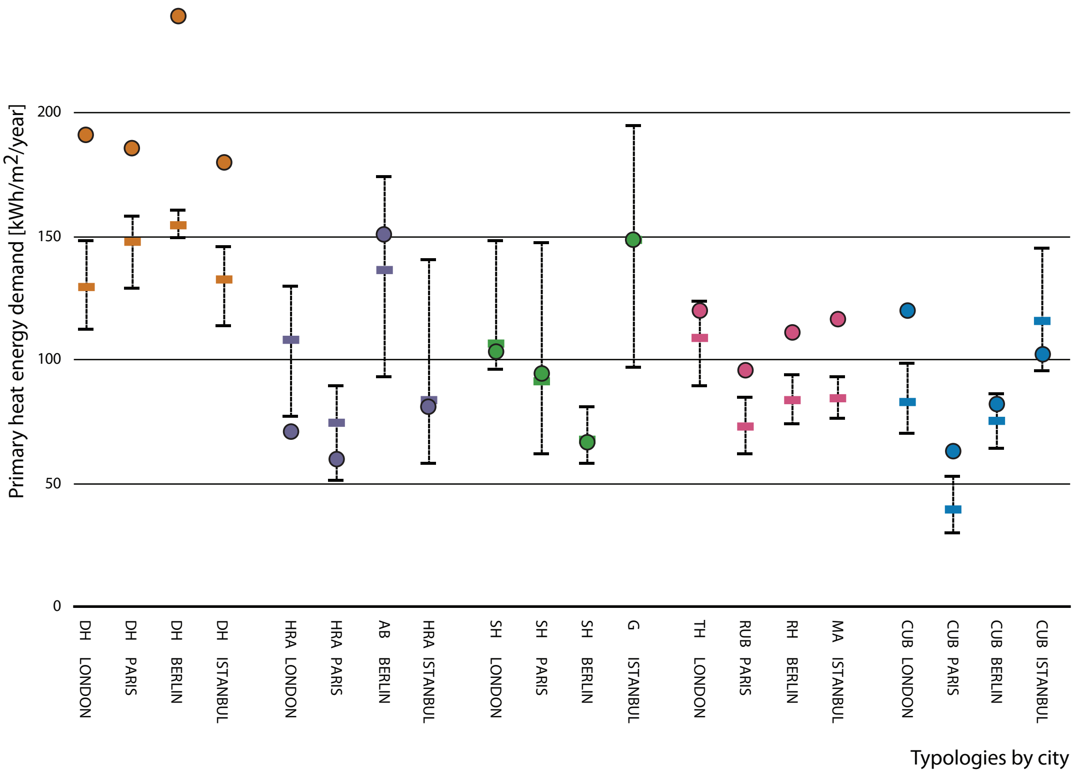
SH - Slab Housing

HRA - High Rise Apartment

AB - Apartment Building

DH - Detached Housing

*Source: LSE Cities and EIFER Research*

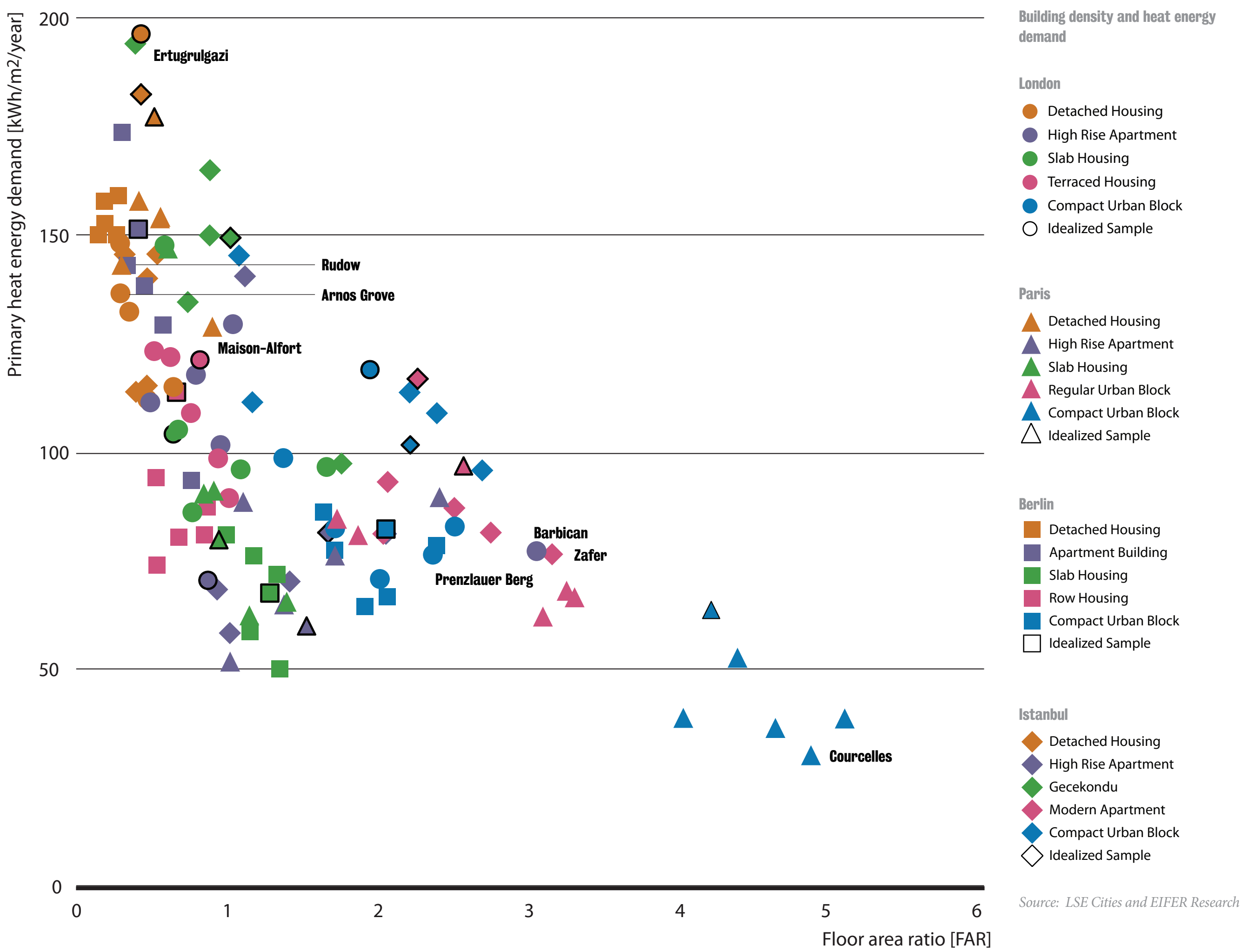


## 4.3 BUILDING DENSITY

This section displays the results for heat energy demand against building density. Overall, it can be concluded that there exists a strong negative correlation between the two, supporting the hypothesis that greater density leads to greater heat-energy efficiency. At the lowest densities of less than FAR 0.5, heat energy demand congregates at around 150 kWh per square metre per year, whereas at the highest densities of greater than FAR 2, heat energy demand is grouped at around 100 kWh. This relationship, however, seems to be significant only for building densities of below FAR 1. Above this value, only Paris shows some significant additional heat-energy efficiency gains with further increases in building densities. Here, the compact urban block is taken to almost twice the density of the other cities, achieving efficiencies of 50 kWh or less in many cases.

While all the cities show clear negative correlation between heat energy demand and density, Istanbul appears to show the weakest link. This is apparent when viewing the graph below and when looking at the calculated correlation figures in section 4.1. As can be seen in detail in section 4.2, this is related to Istanbul's building types exhibiting much greater performance ranges than those of the other cities.

The performance of the idealised samples shows that, on average, areas with densities of just above FAR 1 perform just as well as those above FAR 4. Indeed, some of the highest energy efficiencies of the idealised samples are achieved at densities of between FAR 1 and 1.5. The overall pattern of all 20 idealised samples re-emphasises the potential of some morphologies - in particular modernist buildings such as high rise apartments and slab housing - to achieve good energy efficiency at a building density of around FAR 1.




*Source: LSE Cities and EIFER Research*

The greatest variations in heat energy demands at similar building density levels can be observed in the region of FAR 1, where performances range from 50 to 150 kWh. This is where other urban form-related factors appear to matter most. Towards lower densities, these ranges become a little less, while an increase in density significantly reduces the diversity in heat energy demands. All morphologies at densities above FAR 4 only vary between 30 and 50 kWh.

With regards to the real samples, several extreme cases stand out and are introduced in greater detail below. As already mentioned, the highest heat energy demand was observed for the low-density gecekondu of Ertugrulgazi in Istanbul. With FAR 0.35, this neighbourhood features a theoretical heat energy demand of 194 kWh. On the other hand, the compact urban block area of Courcelles in Paris not only features the second highest density of all samples, with FAR 4.88, but also the lowest heat energy demand of only 29.8 kWh. High density areas in the other cities such as Prenzlauer Berg in Berlin, the Barbican in London and Zafer in Istanbul associate densities of between FAR 2.4 and 3.1 with heat energy demands ranging from 76 to 78 kWh. All low density areas displayed below have a heat energy demand above 128 kWh.

Extreme cases: density and heat energy demand

## London

**Arnos Grove**
Detached Housing 04
FAR 0.25; HED 136.65

**Barbican**
High Rise Apartment 04
FAR 3.04; HED 77.05

## Paris

**Maison-Alfort**
Detached Housing 05
FAR 0.87; HED 128.90

**Courcelles**
Compact Urban Block 03
FAR 4.88; HED 29.83

## Berlin

**Rudow**
Apartment Building 05
FAR 0.41; HED 138.41

**Prenzlauer Berg**
Compact Urban Block 04
FAR 2.37; HED 78.36

## Istanbul

**Ertugrulgazi**
Gecekondu 03
FAR 0.35; HED 194.36

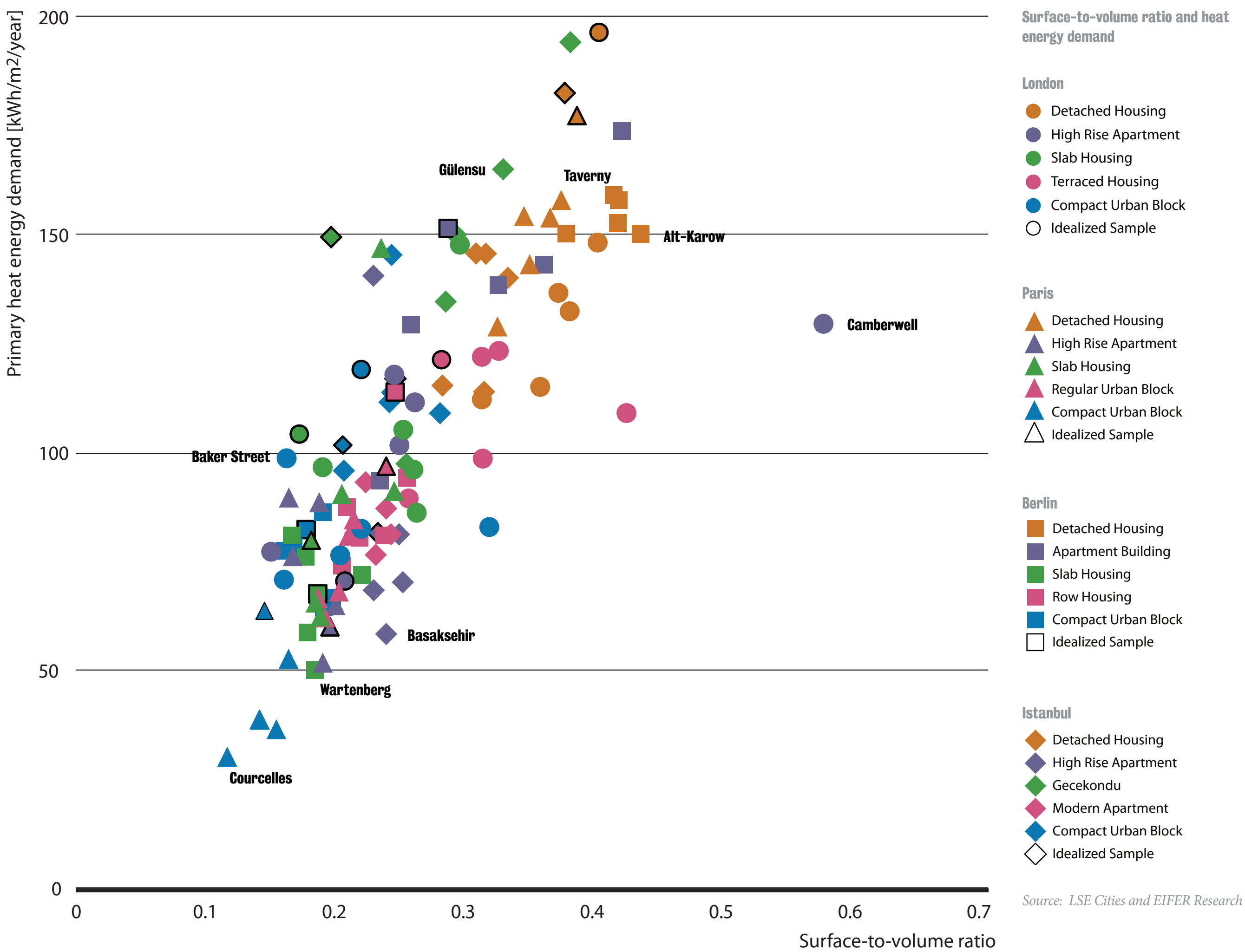
**Zafer**
Modern Apartment 01
FAR 3.15; HED 76.29

## 4.4 SURFACE-TO-VOLUME RATIO

This section displays the results for heat energy demand against building surface-to-volume ratio. As expected, a strong positive correlation exists between the two. Across all four cities and for most building typologies, larger building surfaces relative to their volumes result in higher heat energy demand. Across the four cities, surface-to-volume ratios of below 0.3 seem to ensure heat energy demand levels of lower than 150 kWh per square metre per year, and below 0.2 of less than 100 kWh.

The positive correlation is visibly strongest in Paris and Berlin, a trend which is also evidenced in the higher correlation coefficients presented in section 4.1: 0.93 and 0.90, as compared to 0.70 and 0.63 for Istanbul and London respectively. Istanbul features surface-to-volume ratios clustered between 0.2 and 0.3, with strong variations of heat energy demands at the same ratios. It is also in Istanbul where related correlations within each building typology are weakest. London seems to follow the linear relationship but with a greater variance in heat energy demand.

Across all cities, the higher surface-to-volume ratio of the detached housing type corresponds with its low performance. Conversely, the compact urban block and high rise apartment perform best and have some of the lowest surface-to-volume ratios. Of all the forms, slab housing and the gecekondu show the greatest diversity of surface-to-volume ratio, perhaps reflecting their greater diversity in design. However, even within these types, the positive correlation between surface-to-volume ratio and heat energy demand is apparent.




*Source: LSE Cities and EIFER Research*

These variations in heat energy demand at similar surface-to-volume ratios hint at the trade-off between surface heat losses and solar gains, which both scale positively with building surface area. The point at which the losses outweigh the gains is determined chiefly by a building's design and its surrounding morphology. A more detailed discussion of this trade-off and how it may be managed through appropriate choice of wall insulation, window U-value and glazing ratio is given in chapter 5.

Idealised samples are generally representative of their real morphology type samples, although there are some extreme cases. Idealised samples of detached housing in all cities show similar surface-to-volume ratios but much higher heat energy demands than the real samples. For the idealised samples of slab housing in London and Istanbul the opposite is true. Here the idealised samples show representative heat energy demands but disproportionately low surface-to-volume ratios.

The extreme examples displayed below share many similarities with the extreme areas with regards to density. Worth noting is the low surface-to-volume ratio of the slab housing area of Wartenberg in Berlin, with a heat energy demand similar to that of the compact urban block in Berlin.

Extreme Cases: surface-to-volume ratio and heat energy demand.

### London

**Camberwell**
High Rise Apartment 05
S/V 0.58; HED 129.55

**Baker Street**
Compact Urban Block 04
S/V 0.15; HED 70.59

### Paris

**Taverny**
Detached Housing 03
S/V 0.37; HED 158.09

**Courcelles**
Compact Urban Block 03
S/V 0.11; HED 29.83

### Berlin

**Alt-Karow**
Detached Housing 05
S/V 0.42; HED 152.79

**Wartenberg**
Slab Housing 05
S/V 0.16; HED 80.75

### Istanbul

**Gülensu**
Gecekondu 05
S/V 0.33; HED 149.51

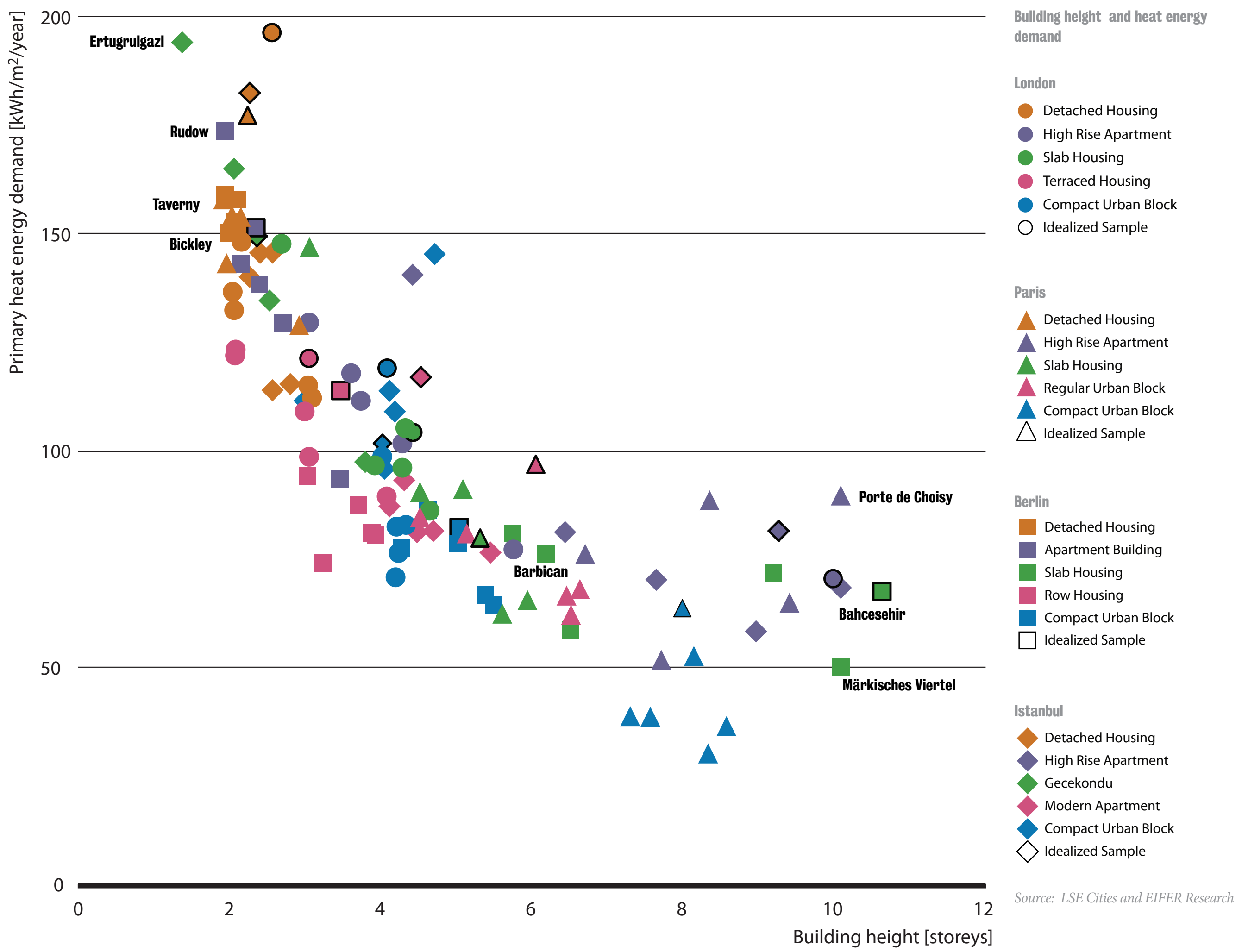
**Basaksehir**
High Rise Apartment 03
S/V 0.22; HED 140.56

## 4.5 BUILDING HEIGHT

This section displays the results for heat energy demand against average building height. There is a clear, strong negative correlation between average built height and heat energy demand. Indeed, of all the variables displayed in this chapter, height showed the strongest correlation with heat energy demand. Above a height of 4 storeys the variation in heat energy demand becomes considerably smaller, suggesting diminishing energy efficiency returns with increased built height beyond this point. In Berlin, for example, there seems to be no significant difference in the heat energy demands of buildings between the heights of 4 and 10 storeys – all average around 70 kWh per square metre.

Of all the cities Paris demonstrates the greatest average heights, with more than half of the morphologies sampled being greater than 6 storeys. Conversely London demonstrates the lowest average heights, with more than half lying below 4 storeys. A corresponding difference in heat energy demand is seen with Parisian compact urban blocks achieving only 30 kWh, while the equivalent morphology in London only achieves 70 kWh at its lowest. Berlin and Istanbul both show a wide spread of building heights with well correlated trends. Interestingly, Istanbul's compact urban block shows an abnormal diversity of heat energy demands, resulting in it being away from the main trend line.

The typologies are generally well aggregated, with detached housing, the lowest rise of the morphology types, showing the greatest heat energy demands of 150 kWh at a height of 2 storeys. At the other end of the scale, high rise apartments in Istanbul and Paris, and slab housing in Berlin, show heat energy demands of around 70 kWh at a height of 10 storeys.




*Source: LSE Cities and EIFER Research*

Idealised samples are generally representative of their morphology types with two notable extreme cases of high rise apartments in London and Paris. Here, the replacement of invasive morphology types with more high rise apartments greatly increased the average built height.

The three tallest areas across all samples include areas in all cities but London. With a similar average height of just above 10 storeys, Porte de Choisy in Paris, Maerkisches Viertel in Berlin and Bahcesehir in Istanbul feature heat energy demands ranging from 49.8 kWh in Berlin to 89.5kWh in Paris. Once again, it is slab housing typology in Berlin that performs relatively strongly. With an average height of just over half these extreme cases, London's tallest sample, the Barbican, still is with 77 kWh more heat energy efficient than the highest sample in Paris.

At the other end of the scale, low rise areas tend to be detached housing typologies with an average height of 1.39 to 2.09 storeys and a heat energy demand ranging between 148 kWh to 195 kWh. The most heat energy efficient low rise extreme is Bickley in London, while the geckondu of Ertugrulgazi in Istanbul is once again the least energy efficient and the lowest in terms of average number of storeys.

**Extreme samples: building heights and heat energy demand.**

### London

**Bickley**
Detached Housing 02
Height 2.09; HED 148.29

**Barbican**
High Rise Apartment 04
Height 5.76; HED 77.08

### Paris

**Taverny**
Detached Housing 03
Height 1.84; HED 158.09

**Porte de Choisy**
High Rise Apartment 05
Height 10.18; HED 89.51

### Berlin

**Rudow**
Apartment Building 03
Height 1.87; HED 173.89

**Märkisches Viertel**
Slab Housing 04
Height 10.18; HED 49.79

### Istanbul

**Ertugrulgazi**
Gecekondu 03
Height 1.29; HED 194.36

**Bahcesehir**
High Rise Apartment 02
Height 10.18; HED 68.12

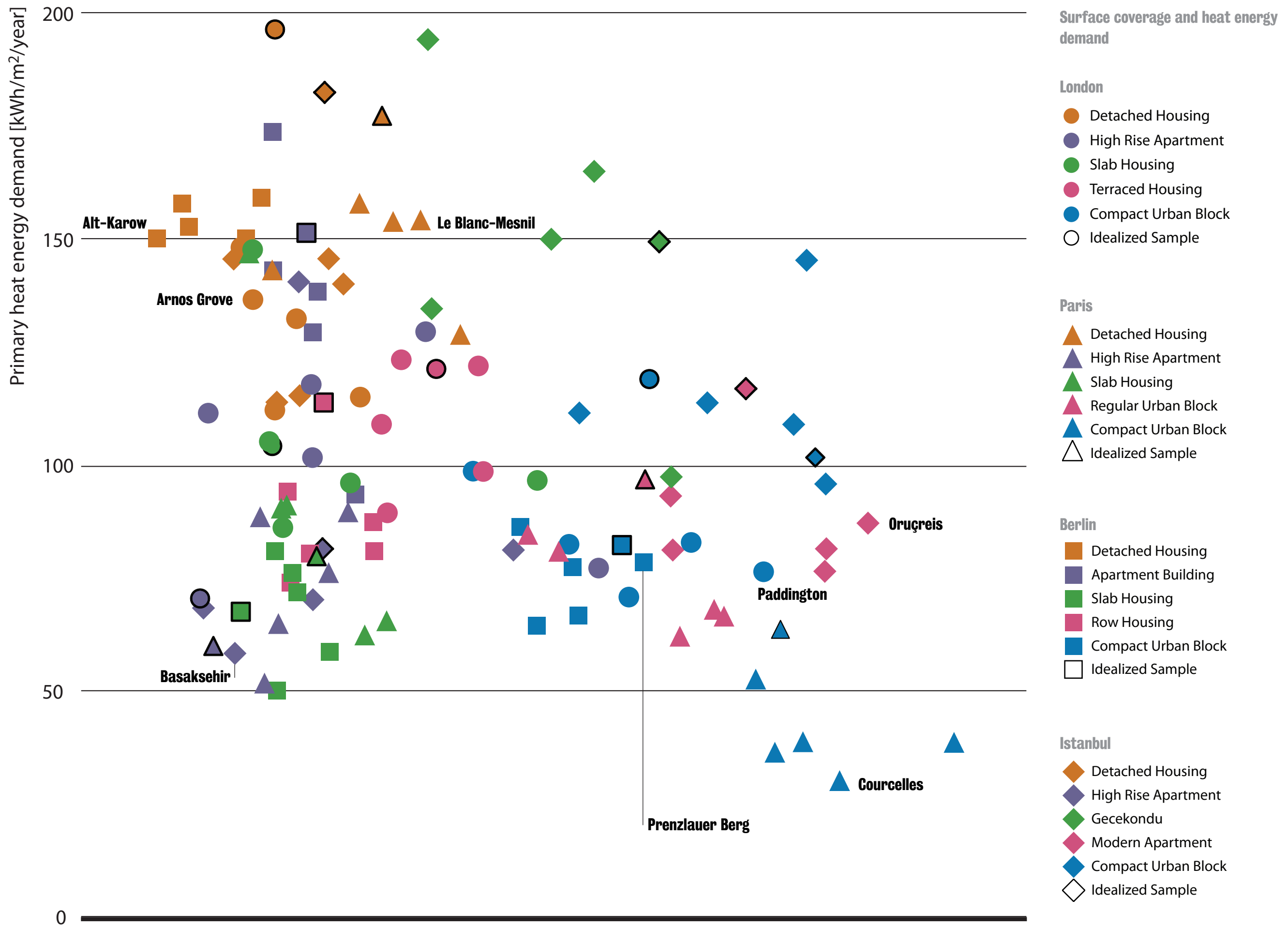
## 4.6 SURFACE COVERAGE

This section displays the results for heat energy demand against the surface coverage ratio of buildings. Although there is a negative correlation with surface coverage, it is a relatively weak one. This is evidenced both in the graphs below and through the low correlation coefficients shown in section 4.2.

As surface coverage increases, the likelihood of buildings interacting with each other, either through overshadowing (thus reducing solar heat gains) or through wall sharing (thus reducing building surface heat losses) increases. As surface coverage decreases the opposite will also be true, but only up to the point where buildings are so widely spaced that they no longer interact significantly. Beyond this point, a further reduction in surface coverage should not in itself affect heat energy demand. Any variation seen beyond this is therefore more likely to be caused by other built form parameters. This may help to explain why the diversity of heat energy demand increases significantly below coverage ratios of 30 per cent.

At surface coverage above 30 per cent, energy demands of all samples in London, Paris and Berlin are below 100 kWh, suggesting a certain probability for energy efficiency of related morphologies. Only Istanbul shows continued wide variation of heat energy demands above this value.

Good thermal performance can be seen at low coverage ratios in high rise apartments, and at high coverage ratios in compact urban blocks. This demonstrates the wide range of coverage options that exist for thermally efficient




*Source: LSE Cities and EIFER Research*

morphology types. However, one must be aware of the trade-offs: in the case of the high rise apartment and compact urban block, both of similar height, the lower coverage of the high rise apartment also means that it has a lower density (see spider diagrams in chapter 2).

The extreme samples of surface coverage below not only highlight that there is little consistency between this spatial indicator and heat energy demand, but also the diversity of typologies at each end of the coverage scale. Across the low coverage outliers of Alt-Karow in Berlin, Arnos Grove in London and Basaksehir in Istanbul, which range in building coverage from 5 to 12 per cent, different detached housing formations as well as high rise apartments result in heat energy demands ranging from 58 to 150 kWh.

At the high coverage end, Prenzlauer Berg in Berlin, Paddington in London, Courcelles in Paris and Orucreis in Istanbul feature building coverages ranging from 42 to 59 per cent and a somewhat lower range of heat energy demands from 29.8 to 87 kWh. Interestingly, but consistent with the overall finding that there is little causality between heat energy demand and surface coverage, it is Orucreis, with the highest coverage of the top four extremes, but the lowest heat energy efficiency of the four.

Extreme Cases: surface coverage and heat energy demand

## London

**Arnos Grove**
Detached Housing 04
SC 12; HED 136.65

**Paddington**
Compact Urban Block 03
SC 46; HED 82.72

## Paris

**Le Blanc-Mesnil**
Detached Housing 04
SC 25; HED 154.39

**Courcelles**
Compact Urban Block 03
SC 57; HED 29.83

## Berlin

**Alt-Karow**
Detached Housing 05
SC 5; HED 150.17

**Prenzlauer Berg**
Compact Urban Block 04
SC 42; HED 78.37

## Istanbul

**Oruçreis**
Modern Apartment 04
SC 59 HED 86.99

**Basaksehir**
High Rise Apartment 05
SC 11; HED 58.07

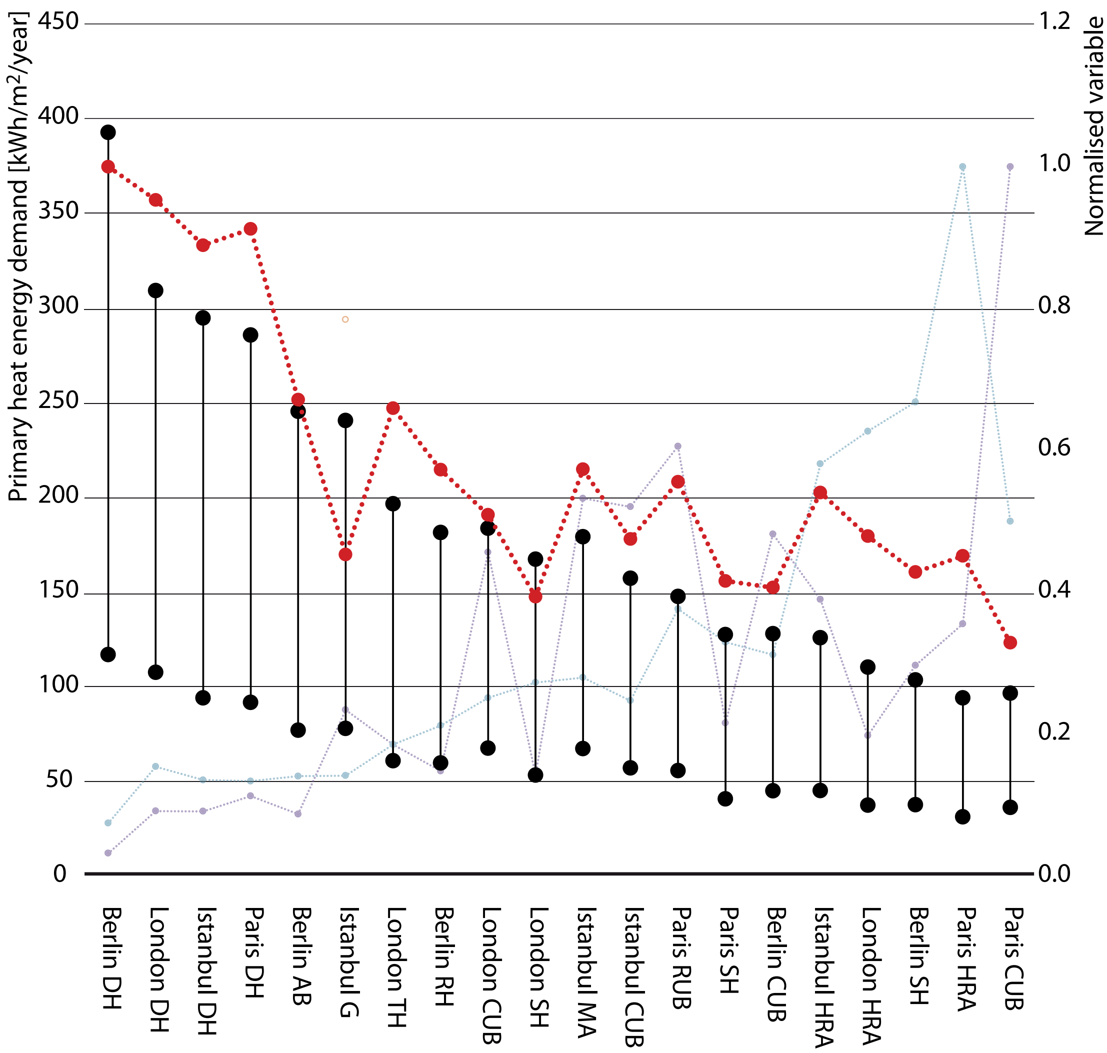
# 5 INSULATION AND CLIMATE

This chapter analyses insulation, glazing and climate parameters in order to quantify their effect on building heat energy demand. The question of how different morphology types react to changes in these parameters and how their negative impacts could be most efficiently mitigated were investigated. The presiding logic that building types with higher surface-to-volume ratio would stand to benefit the most from an increase in their wall insulation standards was proved. The concept of critical window U-values was introduced and found for the different morphology types. The theory that urban forms with greater solar corrections relative to their volumes have higher critical U-values was examined.

## 5.1 INSULATION STANDARDS

This section considers the effect of changing insulation standards (represented by wall U-values) on heat energy demand. U-values are defined as the amount of heat energy which can pass through a material per its thickness and the temperature difference across it, and is measured in Watts/[squaremeter kelvin]. In other words, a high U-value implies bad insulation and a low U-value good insulation. Up to this point, all building heat energy demands have been calculated with the wall U-values held constant so that only the effect of building form on heat energy demand could be seen.

The graph below shows the effect of changing the wall U-values between two arbitrarily chosen (though realistic) fixed values of 0.5 W/m²K and 2 W/m²K. The limits of the bars on the graph




**U-value and heat energy demand ranges**

Maximum and minimum U-Values and heat energy demand ranges for idealized samples and key spatial indicators by typology.

*Source: LSE Cities and EIFER Research*

represent the respective performances of the morphology types at these values. The heat energy demand of the morphology types at these high and low U-values illustrates the respective impact of wall insulation on their thermal efficiency.

What is immediately noticeable is that the higher the heat energy demand of the morphology types, the greater the energy demand range is between the high and low U-values. This can be understood through the relationship between heat energy demand and surface-to-volume ratio. Heat lost through the facades of a building is proportional to the surface area of the building, and a building's heat storage capacity is proportional to its volume. It therefore follows that, with all other variables held constant, surface-to-volume ratio should be proportional to its heat energy demand per unit volume, or the close equivalent used in our simulations, per unit of interior floor space. As shown above, a building with a higher surface-to-volume ratio will have a higher heat energy demand than one with a lower surface-to-volume ratio. Insulating a building (reducing its wall U-value) will reduce the heat lost through its surface so that the total heat saved is proportional to the surface area of the building and the change in U-value. Again, if this saved heat is put into specific terms - heat saved per unit volume - it is obvious that a building with a higher surface-to-volume ratio will make a greater specific heat saving than one with a low surface-to-volume ratio. Therefore, insulating buildings which have higher initial heat energy demands will result in a greater reduction in heat energy demand.

To test this relationship, the morphology types in the graph below were placed in order of the difference between the heat energy demands at the high and low U-values. The three correlating parameters of density, height and surface-to-volume ratio were normalised and plotted on the secondary axis. It can clearly be seen that there is a strong correlation between size of this range and the surface-to-volume ratio. This shows the importance of surface-to-volume ratio in determining the effectiveness of wall insulation. It is, however, not a perfect correlation and this can be accounted for in the differences in solar gain experienced by the different forms.

Certain typologies, for example the Istanbul high rise apartment, show relatively high surface-to-volume ratios for their performance ranges. Others, for example the Istanbul gecekondu, show relatively larger ranges for their surface to volume ratios. This seems to indicate that good solar design can create better performing morphology types at similar surface-to-volume ratios.

Morphology types such as detached housing, Berlin apartment blocks, Istanbul gecekondu and London terrace housing stand to benefit the most from improvements in their wall insulation. Types with lower surface-to-volume ratio, such as the compact urban block and high rise apartment, would stand to benefit the least from the same improvements in insulation. This knowledge should inform decisions on prioritising retrofitting according to building type.

Below
Berlin, Regular Urban Block.
*Bing Maps - Microsoft Corporation*

## 5.2 GLAZING RATIO AND WINDOW INSULATION

This section demonstrates the effect of changing two parameters – window insulation (window U-value) and glazing ratio – on heat energy demand. The glazing ratio represents the proportion of the building covered in windows, so that a ratio of one would be a building with facades made entirely of glass and a ratio of zero a building with no windows. As the glazing ratio is increased heat loss through windows, which is usually much greater than that which is lost through walls, increases. But solar heat gains through the windows also increase. The balance of the two is dependent on the window U-value - the rate at which heat is lost through the windows. As examples, the graphs for two of the morphology types are shown here, though the graphs for all the morphology types can be found in Appendix C. Not considered here is the risk of overheating buildings when increasing the glazing ratio beyond a certain point.

Given the relationship described above, there can exist a window U-value above which any further increase in glazing ratio would result in a net energy loss through the windows and thus an increase in heat energy demand. Conversely, below this U-value, any further increase in glazing ratio would result in net solar gains and thus a reduction in heat energy demand. The point at which this critical U-value is reached is dependent on the form of the building and the surrounding morphology. For example, a building which presents a larger solar cross-section and has little overshadowing from neighbouring buildings will receive more sunlight than a building in shadow

**Paris Detached Housing**

| U-value \ Glazing ratio | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
|---|---|---|---|---|---|---|---|---|
| 2.0 | 180 | 168 | 155 | 142 | 128 | 113 | 98 | 82 |
| 2.2 | 181 | 171 | 161 | 149 | 138 | 125 | 112 | 98 |
| 2.4 | 183 | 175 | 166 | 157 | 147 | 137 | 126 | 114 |
| 2.6 | 185 | 179 | 172 | 165 | 157 | 148 | 139 | 130 |
| 2.8 | 187 | 182 | 177 | 172 | 166 | 160 | 153 | 146 |
| 3.0 | 189 | 186 | 183 | 179 | 176 | 171 | 167 | 162 |
| 3.2 | 190 | 190 | 189 | 187 | 185 | 183 | 180 | 177 |
| 3.4 | 192 | 193 | 194 | 194 | 194 | 194 | 194 | 193 |
| 3.6 | 194 | 197 | 200 | 202 | 204 | 205 | 207 | 208 |

**Effect of changing window insulation (u-value) and glazing ratio on heat energy demand**

Lower HED
Medium HED
Higher HED

*Source: LSE Cities and EIFER Research*

**Paris Compact Urban Block**

| U-value \ Glazing ratio | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
|---|---|---|---|---|---|---|---|---|
| 2.0 | 61 | 58 | 55 | 52 | 48 | 45 | 41 | 37 |
| 2.2 | 62 | 60 | 57 | 55 | 52 | 49 | 46 | 43 |
| 2.4 | 63 | 61 | 59 | 57 | 55 | 53 | 51 | 49 |
| 2.6 | 63 | 62 | 61 | 60 | 59 | 58 | 56 | 55 |
| 2.8 | 64 | 64 | 63 | 63 | 62 | 62 | 61 | 60 |
| 3.0 | 65 | 65 | 65 | 66 | 66 | 66 | 66 | 66 |
| 3.2 | 65 | 67 | 67 | 68 | 69 | 70 | 71 | 72 |
| 3.4 | 66 | 68 | 70 | 71 | 73 | 74 | 76 | 77 |
| 3.6 | 67 | 69 | 72 | 74 | 76 | 78 | 81 | 83 |

or presenting a lower cross-section. With more sunlight available to be absorbed through the windows as solar heat gains, such a building could sustain greater heat conduction loss rates (i.e. greater window U-values) through the windows before making a net energy loss. This building would therefore have a higher 'critical U-value' than a building which receives less sunlight.

In the Paris compact urban block it can be seen that above the U-value of 2.8, increasing the glazing ratio results in an increased heat energy demand. Conversely at this value and below, increasing the glazing ratio results in reduced heat energy demand. Therefore for this morphology type, the critical U-value is approximately 2.8. Likewise for Paris detached housing, the critical U-value is reached at approximately 3.2.

The graph below shows the critical window U-values for the idealised samples of urban morphology. Interestingly, compact urban block and detached housing often have similar critical window U-values, which seems to imply that the compactness of the building form is not in itself an important factor in its determination. Rather, more linear building forms such as row housing, slab housing and terraced housing show the highest critical U-values. From this it seems likely that the cross section of a morphology relative to its volume is a more important indicator.

**Critical window U-Value for the idealised samples by typology**

CUB - Compact Urban Block

MA - Modern Apartment

RH - Row Housing

RUB - Regular Urban Block

TH - Terraced Housing

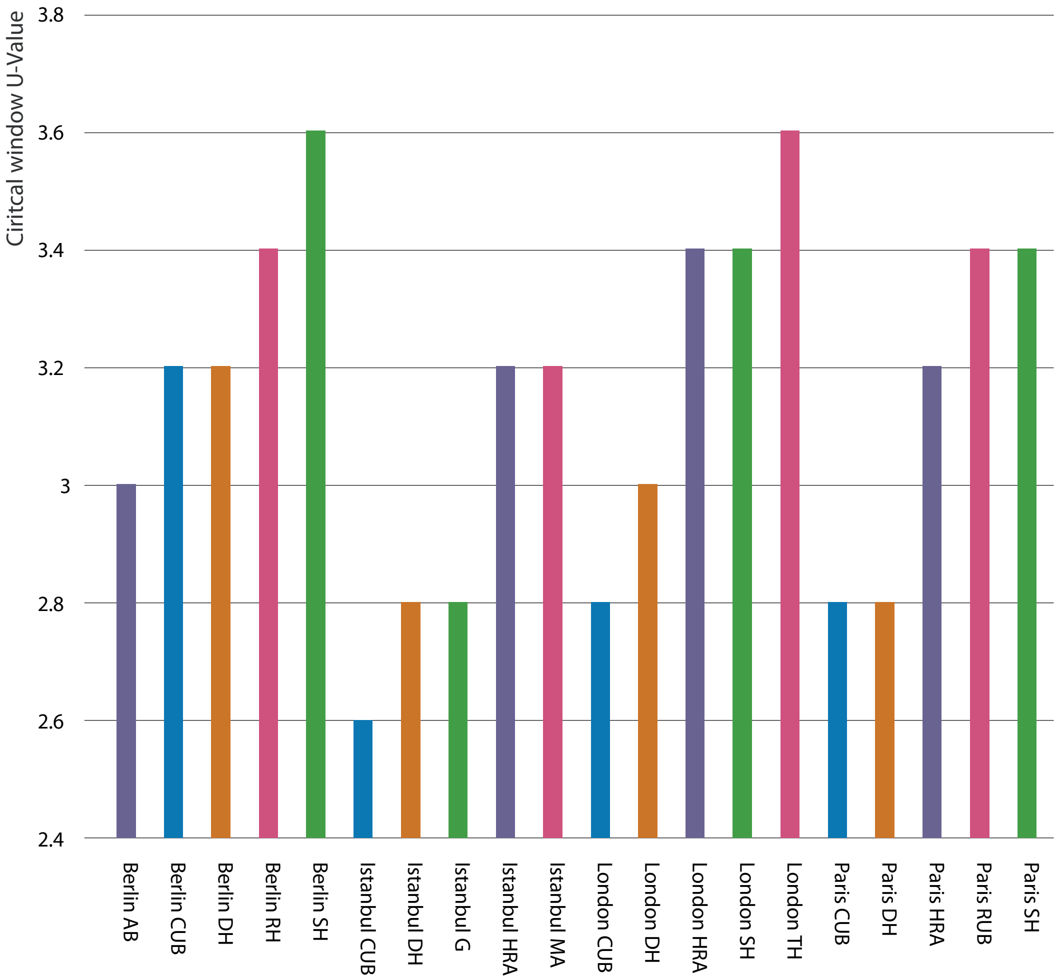
SH - Slab Housing

HRA - High Rise Apartment

AB - Apartment Building

DH - Detached Housing

*Source: LSE Cities and EIFER Research*



## 5.3 CLIMATIC CONDITIONS

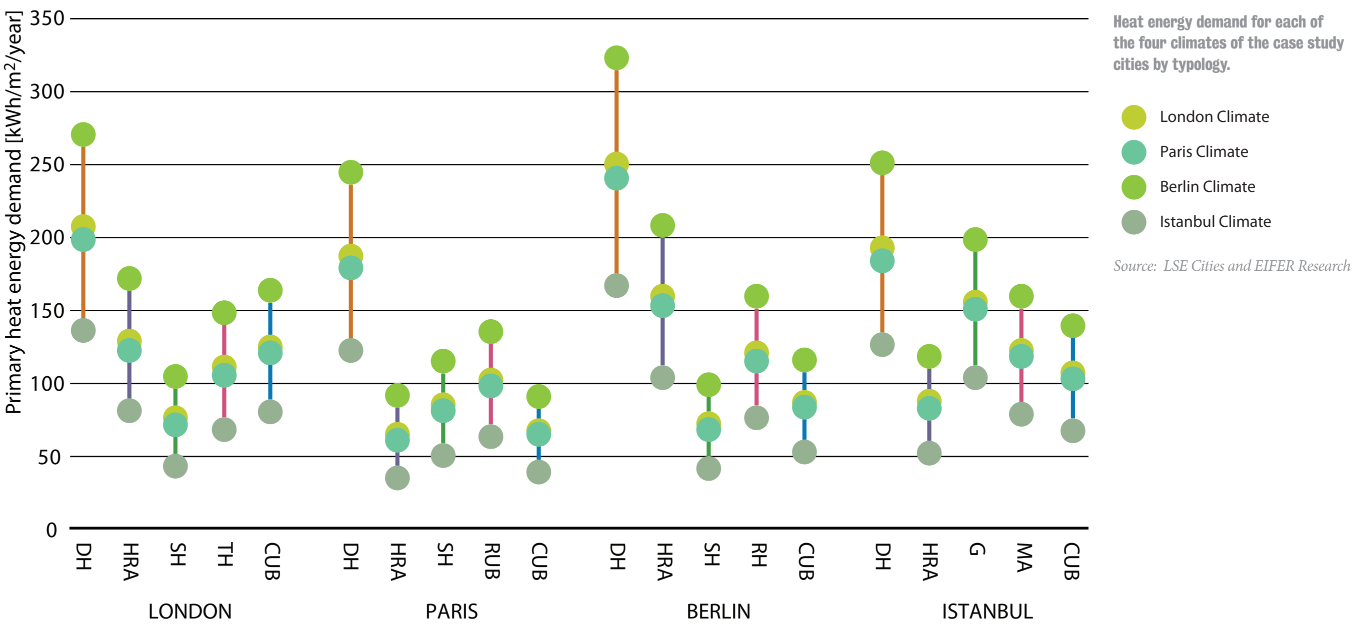
This study has, up to this point, been modelled using the climatic conditions of Paris. However, it is important to understand the effect that climate has on heat energy demand. Below follows a discussion on expanding the parameters related to climatic conditions.

The energy simulation was run again for each of the morphological samples and for the climatic conditions of each of the case study cities. To achieve this, the average monthly temperatures and the amount of sunlight received by south facing facades were changed according to the values of each city. The angle of the sun was still maintained at the values of Paris. This was justified as the latitude of London (52˚), Paris (49˚) and Berlin (53˚) only differed by a maximum of 4˚. This difference in the angle of latitude corresponds to the same difference in the angle of the sun and was therefore considered small enough to be insignificant. However in the case of Istanbul, lying at a latitude of 41˚, the effects of the angle of the sun are likely to have a noticeable impact on the overshadowing of buildings and therefore on the solar gains of different typologies and their heat energy demands. To quantify this difference, additional modelling would be necessary.

The first graph opposite demonstrates the impact of latitude on the amount of solar radiation received on both a horizontal surface and a vertical surface for each of the months of the year. During the winter months the sun lies low on the horizon so that vertical surfaces receive more light than they do in summer – the opposite being true for horizontal surfaces. This effect is exaggerated the further north one travels. As demand for heating is highest during the winter months, it is the light collected on the vertical facades of a building which has the greatest impact on heating energy demand.

The second graph opposite shows the average monthly temperatures for each of the case study cities. As one would expect due to their proximity, Paris and London show very similar temperature profiles, with summers on average reaching 18˚C and winters reaching 6˚C. In summer Istanbul is significantly warmer than all other cities, reaching as high as 25˚C on average. However come winter, temperatures drop to levels similar to London and Paris. Berlin, while showing similar summer temperatures to Paris and London, has the coldest winters with temperatures reaching as low as 0˚C on average.

The final graph opposite shows the results of the modelling of the morphology samples for




Heat energy demand for each of the four climates of the case study cities by typology.

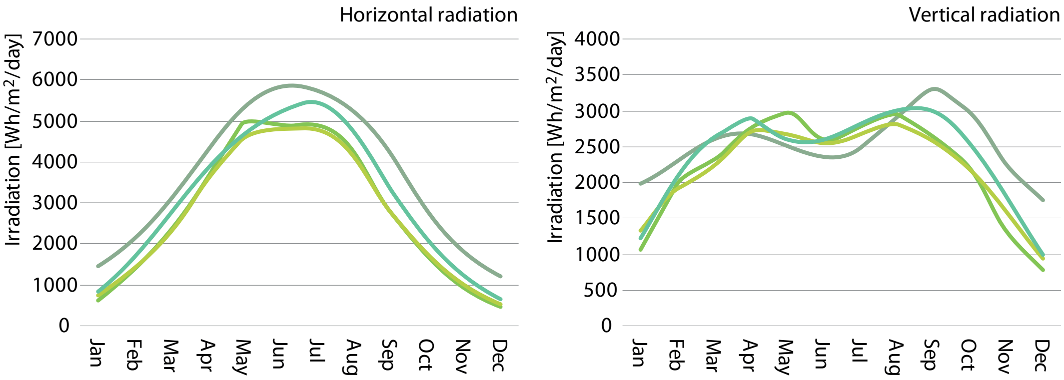
*Source: LSE Cities and EIFER Research*

different climates. Displayed on the graph is the heat energy demand for each of the morphology types (by city) for each of the four climates in the case study cities. The graph shows that, in the absence of any effect that the angle of the sun may have (which as previously stated are small), the effect of climate is but a scaling one: the colder the temperature, the greater the heat energy demand. Heat energy is seen to increase in order of the coldness of the city's winter, with Berlin, the coldest, having the highest heat energy demand. Overall, climate clearly has a very significant impact on heat energy demand, with morphology types showing as much as a 50 per cent reduction in heat energy demand between the Berlin and the Istanbul climate.

**Vertical solar radiation for a south exposed facade for each of the case study cities during the specific heating period.**

- London
- Paris
- Berlin
- Istanbul

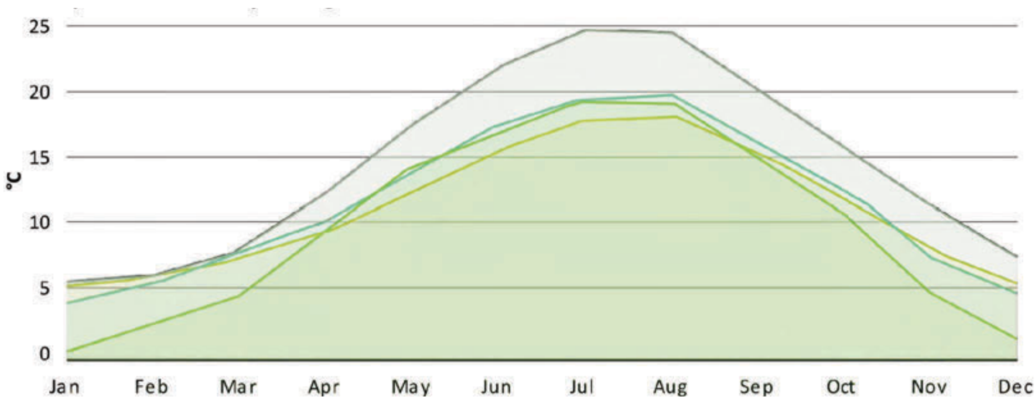
*Source: PVGIS © European Communities, 2001-2008*




**Temperatures during the year**
**Monthly average of 24h days (°C)**

- London
- Paris
- Berlin
- Istanbul

*Source: PVGIS © European Communities, 2001-2008*




**Number of days heating is required**

Heating Degree Days to keep internal temperature at 19°C.

*Source: PVGIS © European Communities, 2001-2008*

| LONDON | PARIS | BERLIN | ISTANBUL | |
|---|---|---|---|---|
| 10.267 | 11.086 | 13.987 | 9.970 | Jan |
| 9.504 | 9.792 | 12.024 | 9.288 | Feb |
| 8.779 | 8.258 | 10.862 | 8.184 | Mar |
| 6.984 | 6.336 | 6.912 | 4.824 | Apr |
| 4.836 | 3.571 | 3.497 | - | May |
| - | - | - | - | Jun |
| - | - | - | - | Jul |
| - | - | - | - | Aug |
| - | - | - | - | Sep |
| 5.059 | 4.613 | 6.175 | 2.232 | Oct |
| 7.848 | 8.352 | 10.224 | 5.616 | Nov |
| 10.118 | 10.714 | 13.318 | 8.556 | Dec |
| 63.396 | 62.722 | 76.999 | 48.670 | Total |

# 6 IMPLICATIONS AND FUTURE INVESTIGATION

This section summarises the overall findings of this study and then interprets, where possible, the practical implications of the findings in terms of city planning and policy guidance.

## 6.1 SUMMARY OF FINDINGS

### Morphology

The initial morphology analysis (detailed in section 2) featured some of the fundamental relationships of urban form, as well as a more specific introduction to the built environments in the four case study cities. A positive correlation between surface coverage and density was observed, though exceptions – such as the outlying slab housing of Berlin and terraced housing of London – existed. Height was also shown to correlate strongly with density, though a divergence of data points was observed at a density of between FAR 1 and 1.5. From this point the built form seemed to follow one of two diverging trends: a path of fast height increase with increasing density, or one of very little height increase with increasing density. High rise apartment and slab housing formations tended to follow the former path, with the regular urban blocks of Paris, the modern apartments of Istanbul and the compact urban blocks of all cities following the latter. This alludes to the obvious mutual exclusivity in design choices: if one wishes to increase density, one can either build upwards or increase the surface coverage of the building. The data suggests that these two strategies are seldom attempted concurrently. Only detached housing did not feature in this bifurcation, showing almost without exception the lowest densities and heights in all cities.

Surface-to-volume ratio and density were shown to correlate negatively, though this trend only seemed to be significant up to a density of FAR 1. At densities greater than this, no significant increase in surface-to-volume ratio was apparent in the majority of the analyzed samples. Paris was the only exception to this general trend. Here, surface-to-volume ratio continuesd to decrease – but at a significantly smaller gradient – as density increased above FAR 1. In all cities, detached housing dominated the upper end of the scales of both surface-to-volume ratio and density. The lower end of this scale was occupied by the remaining morphology types, depending on their particular localized architectural styles.

### Heat energy demand and built form parameters

Building density, average built height and surface-to-volume ratio were all found to be good indicators of heat energy demand, with correlation coefficients of 0.77, 0.88 and 0.80 respectively. Surface coverage showed almost no correlation, with a coefficient of only 0.40. Density, height and coverage all showed negative correlations while surface-to-volume ratio showed a positive correlation. Surface-to-volume ratio and coverage were approximated as linear relationships; height and density by logarithmic relationships. It could be argued that there is not a statistically significant difference between the three strongest correlating variables. However, it is worth noting that height, an easily measurable parameter, had the highest correlation with heat energy demand. This correlation pattern was largely echoed when broken down by the individual morphology types, although it was interesting to note that detached housing showed very little correlation, if any, between building density and heat energy demand. It should, however, be remembered that these results are based only on the examination of four European cities.

When broken down by typology it became obvious that detached housing was the worst performing morphology type with regards to heat energy demand. This was true in every city except Istanbul, where the gekecondu showed slightly higher heat energy demand on average. Conversely, the compact urban block was seen to perform best in Paris, London and Berlin (with one minor exception), though again not in Istanbul. Here the local type of modern apartment performed the best. It is likely that Istanbul being the exception is a consequence of its very different historical and cultural past – the morphology types could not be easily classified with western European types. The ratio between the best performing typology (compact urban block) and the worst performing (detached housing) was approximately 3.

In many cases the ideal samples performed worse than their real counterparts. To some extent this can be explained by the removal of other morphology types which normally coexist in the real urban fabric but which may have different heat energy demands. However, in the case of detached housing, the idealized samples consistently performed very much worse than the real samples. This could not be explained by the removal of unwanted morphology types, as the detached housing samples were very homogenous with little invasion of other types. It was postulated that this may therefore be due to the regular patterns used for the idealized samples in contrast with the more organic growth of the real samples, or the way in which they were oriented. This requires further investigation if it is to be resolved.

Density showed a strong correlation, with a steep reduction in heat energy demand as density increased up to approximately FAR 1. Beyond this point, heat energy demand seemed to level out and thus become less of a function of density – samples of between FAR 1 and 4 seemed to perform almost as well as each other. Istanbul again showed the weakest correlation between density and heat energy demand. Slab housing and high rise apartments both showed good heat energy performances at the relatively low densities of FAR 1.

Surface-to-volume ratio showed a strong correlation with heat energy demand, with ratios of below 0.2 appearing to ensure a good thermal performance of less than 100 kWh. The worst performing typology, detached housing, was also shown to be the one with the highest surface-to-volume ratio. In other morphology types, variations in heat energy demand at similar surface-to-volume ratios hint at the trade-off between surface heat losses and solar gains, which both scale positively with building surface area.

Surface coverage showed a weak negative correlation with heat energy demand. The diversity of heat energy demand can be seen to increase significantly below coverage of 30 per cent. It was postulated that this could be due to a lack of interaction between buildings as they get further away from each other at low coverage ratios. As surface coverage increases, the likelihood of buildings interacting with each other, either through overshadowing (thus reducing solar heat gains), or through wall sharing (thus reducing building surface heat losses), increases. As surface coverage decreases the opposite will also be true, but only up to the point where buildings are so widely spaced that they no longer interact. Beyond this point, a further reduction in surface coverage should not in itself affect heat energy demand and any variation is more likely to be caused by other built form parameters. At coverage above 30 per cent, energy demands of all samples in London, Paris and Berlin are below 100 kWh, suggesting a certain probability of energy efficiency of related morphologies. Good thermal performance can be seen at low coverage ratios in high rise apartments, and at high coverage ratios in compact urban blocks. This demonstrates the wide range of coverage options that exist for thermally efficient morphology types.

Berlin
Apartment Building
*Bing Maps*

## Effect of insulation, glazing ratio and climate

Increasing the U-value of the walls in the most susceptible morphology type - detached housing - from 0.5 to 2.0 was shown to increase heat energy demand by more than 200 per cent in some cases. This is clearly very significant. It was argued that buildings with higher surface-to-volume ratios would stand to gain more from an increase in the insulation value of their walls. It was also argued that the heat energy demand of a building should be closely linked to its surface-to-volume ratio. Modelling results duly showed that insulating a building which has a higher initial heat energy demands results in a greater absolute reduction in heat energy demand. Certain typologies, for example the Istanbul high rise apartment, show relatively high surface-to-volume ratios for such good performance values. This better performance can only be accounted for by increased solar gains: good solar design can create better performing morphology types at similar surface-to-volume ratios.

The impact of changing both the glazing ratio and window U-value was modelled. It was shown that a 'critical window U-value' could exist - the U-value above which increasing the glazing ratio results in increased thermal losses. It was shown that the compact urban block and detached housing often have similar critical window U-values. This seems to imply that the compactness of the building form is not in itself an important factor in critical U-value determination. Rather, more linear building forms such as row housing, slab housing and terraced housing show the highest critical U-values. From this it seems likely that a morphology's solar cross-section relative to its volume is a more important indicator of critical window U-value.

While the results were modelled based on the climate of Paris as a control, results for the idealized samples were recalculated and compared for the climate of each of the case study cities. Results showed that, in the absence of the effects that changing latitude (i.e. the angle of incidence of the sun) may have, the effect of climate is but a scaling one – the colder the climate, the greater the heat energy demand of the buildings. With a maximum of 4˚ difference between the latitudes of London (52˚), Paris (49˚) and Berlin (53˚), the effect of latitude is justifiably small. However, with Istanbul, lying at latitude of 41˚, the effects of the angle of the sun are likely to have a noticeable impact on the overshadowing of buildings – the sun will be higher in the sky and thus shadows will generally be shorter. Further investigation would be required to quantify this.

London
Compact Urban Block
*Bing Maps*

## 6.2 POLICY IMPLICATIONS

In summary, the preliminary results of this study seem to suggest that urban morphology-induced heat energy efficiency is either achieved by higher building densities, as in all the cases of compact urban blocks, or by taller buildings that in turn allow for building densities as low as a FAR of 1. It is at that density level that the diversity of urban morphologies, as well as heat energy demands, is greatest.

Considering the far reaching limitations that were applied to this investigation, it is difficult to derive any direct policy implications at this point. However, emerging areas of policy influence could include the following which will have to be tested in the follow-up research:

- Prioritize mid- to high-density urban typologies;
- Avoid detached housing, particularly in an urban context where there are alternatives;
- Building height could be used as an indicator for morphology-induced heat energy demand in cities;
- Set a minimum density standard of FAR 1;
- Set a maximum surface-to-volume ratios of 0.2;
- Make solar studies a prerequisite for planning evaluation.

## 6.3 FUTURE INVESTIGATION

Several potential future investigations are proposed:

**Cooling energy demand and additional case study cities.** Due to the northerly latitudes of the case study cities cooling energy demand was not considered. However it is a fact that even in London, urban heat island effects combined with the hottest summer days often push temperatures into a range where active cooling is required in buildings. Considering cooling energy demand and thus how morphology effects can be traded to minimize the combined heating and cooling energy demand of buildings, would be a useful next step. This extension could be enhanced by including case study cities in more southerly latitudes, or even tropical cities, in order to extend the reach of the findings.

**Latitude and orientation.** This study has not considered changes in the angle of the sun caused by differences in latitude. While this was argued to be small for London, Berlin and Paris, it could be significant for Istanbul. Improving the energy demand model by incorporating latitude of the city would make it more accurate. Furthermore, additional test simulations could be carried out to understand the typologies' 'sensitivity' to different orientations to sunlight. For example, the much poorer performances of the idealized samples of detached housing compared to their real counterpart have yet to be fully understood. It is suggested that an understanding of the impact of different plot patterns and the orientations of idealized samples could shed light on this.

**City-wide analysis.** This study has focused on the effects of morphology at the scale of the urban block – here sampled at 500 by 500 metres. It would be of great interest to expand the analysis beyond the 25 samples in each city and explore the possibility of creating metropolitan-wide heat-energy demand models. A standard value of heat energy demand would be associated with each of the key building typologies and combined with geographical information on the distribution of those building typologies within each city.

**Widen the city and morphology sample base.** For this study, urban morphologies of four cities were included, but this does not represent the comprehensive catalogue of European building types. Including more cities and their morphologies, and analysing the effect of other morphological parameters, such as street width, would be an important part of any future work.

**Deepen morphological analysis.** The parameters used to analyse morphologies (density, surface-to-volume, surface coverage and building height) are mainly related to the building- and not to the neighbourhood-scale analysis. A deeper investigation could analyse parameters such as solar obstruction and buffering through juxtaposed walls and present this in a quantifiable way. For example, solar obstruction would identify what percentage of the buildings envelope is obstructed from solar access due to the neighbouring effect.

**Urban design and microclimate.** This study has mainly been concerned with the form of buildings, the larger- scale urban morphology they inform and related consequences for heat energy demand. However, it is well known that urban form also has a very significant impact on microclimatic conditions, for example urban heat islands, city thermal mass and wind. Modelling, for example, the effect of open spaces, such as parks and squares, on the microclimate and therefore on the heating and cooling energy demand of buildings would help tie together two directly related research fields.

**Population density and behaviour.** This study has only been concerned with the per-floor-space heat energy demand of buildings. However, different buildings have different uses and are occupied by different social groups. Understanding the usage and occupancy of such buildings would help to place the morphology types classified in this study in a social context. Furthermore, this would enable a linking between energy-saving projects, such as insulation retrofitting, and the social goals of investing in deprived areas. From this data additional metrics, for example energy use per-capita or a measure of the social benefit of energy use, could be created for each morphology type. The study could be further augmented through investigations into the impact of morphology types on other important energy and social factors, for example transport or wellbeing.  Linking these findings with the findings of this report would allow some rudimentary social cost-benefit analysis of the different morphology types.

**Retrofit priorities of different building types.** Insulation was shown to have a significant impact on heat energy demand. If retrofitting of insulation in pre-existing building stock is to be carried out, a priority ordering of that stock in terms of cost-benefit would be needed. This study has already highlighted that some designs are thermally less efficient than others. Whether this can be effectively mitigated through increased insulation standards would depend on the cost of installing such insulation against the energy savings which would result. Aligning the results of such a study to generic morphology types could potentially allow local authorities to estimate their retrofitting needs more quickly. Such a study would be a logical continuation of this work and would also investigate the embedded energy demands of higher insulation standards. However, it should be noted that older building stock is generally less homogeneous than modern buildings, thus the categorisation of older building stock and drawing any general conclusions would have to be done with great caution.

**Retrofitting costs and benefits.** As an addition to the above, the benefits of passive solar design and new-build should be weighed against the costs of retrofitting existing building stock. It could be that certain building stocks are more cheaply replaced than retrofitted.

**Glazing ratios and window U-values balance.** Glazing ratios and window U-values were shown to have a very significant impact on the heat energy demands of buildings. Furthermore, it was shown that there exists a 'critical window U-value', above which there is a net increase in heat energy demand with increasing glazing ratio. Further work towards creating either a software tool or design guidelines for the optimization of glazing ratios and window U-values would therefore be valuable. Put simply, heating and cooling energy demands can be calculated as a function of local climate, building design and surrounding morphological impacts (e.g. overshadowing). The minimization of heating and cooling energy demand through the optimization of window U-values and glazing ratio would be the objective of this research, in addition to considering possible over-heating in buildings with highly glazed facades.

**Ventilation and infiltration.** This study has highlighted the impact of changing wall insulation levels (U-values) on energy performance.

Next pages

left
London
Compact Urban Block
*Bing Maps*

right
Paris
Compact Urban Block
*Bing Maps*

However, as this study was primarily concerned with the effect of building form on energy consumption, the ventilation rate was necessarily set as a constant. It is intuitive that the better the wall insulation, the greater the relative importance of ventilation on energy performance. A trade-off analysis to maximise energy expenditure and minimise costs while varying both ventilation energy loss and wall insulation would be valuable here. Such a study might also wish to take account of the increase in wind speed, and therefore infiltration, that arises as buildings get taller. Furthermore, passive ventilation, through convection and an understanding of prevailing winds, can also have a significant impact on building energy consumption. Understanding possible trade-offs and synergies between passive ventilation and passive solar building design would be of value.

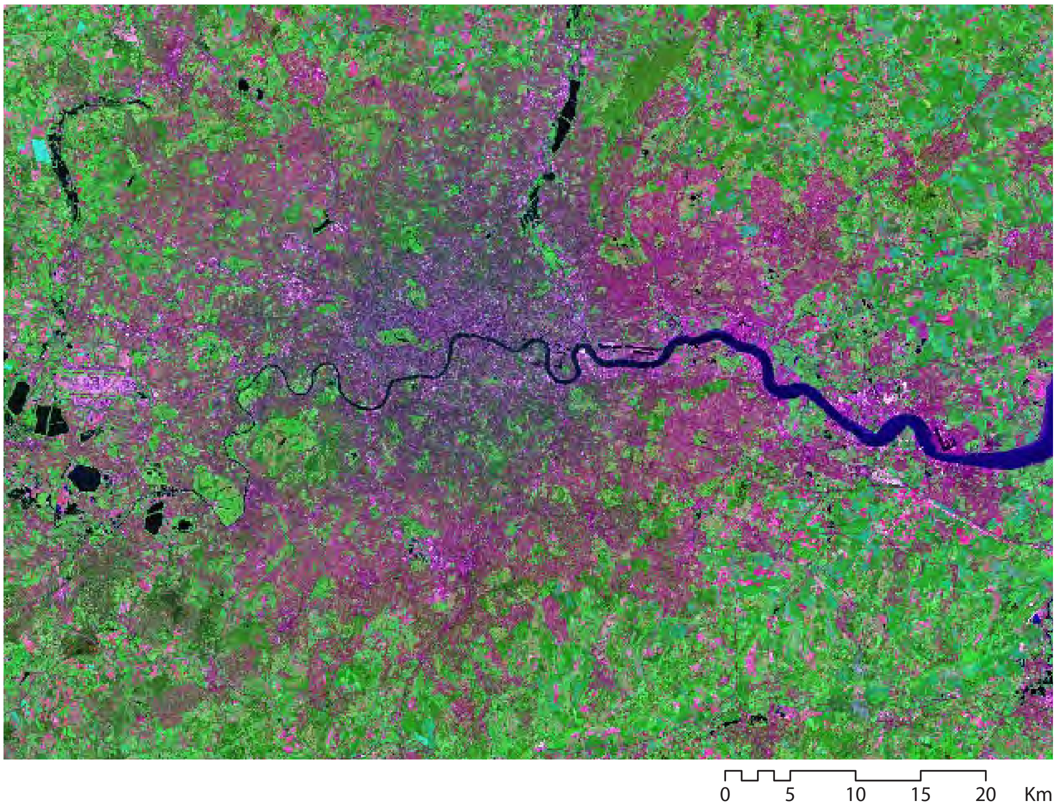
**Comparison with real heat energy demand data.** This work has focused on modelling heat energy demand based on a range of assumptions and resulting in theoretical energy performances rather than real energy demand. The results have been valuable primarily to allow for a relative comparison of the effect of solar gains on heat energy demand. Calibrating and testing these findings with real data would help both to refine the model and check the validity of the assumptions made. For example, a possible first test could include a comparison of the results with the actual gas and electricity consumption for the 500 by 500 metre samples in London, using the data published by the Department of Energy and Climate Change (DECC).

**Linking with individual building models.** This study has used a simplified energy demand model applied to large areas containing several buildings at the same time. Future work might look into linking this large-scale modelling with cases of detailed work performed at the individual building scale within the sample areas. This would help to corroborate and fine tune the large-scale modelling algorithm.

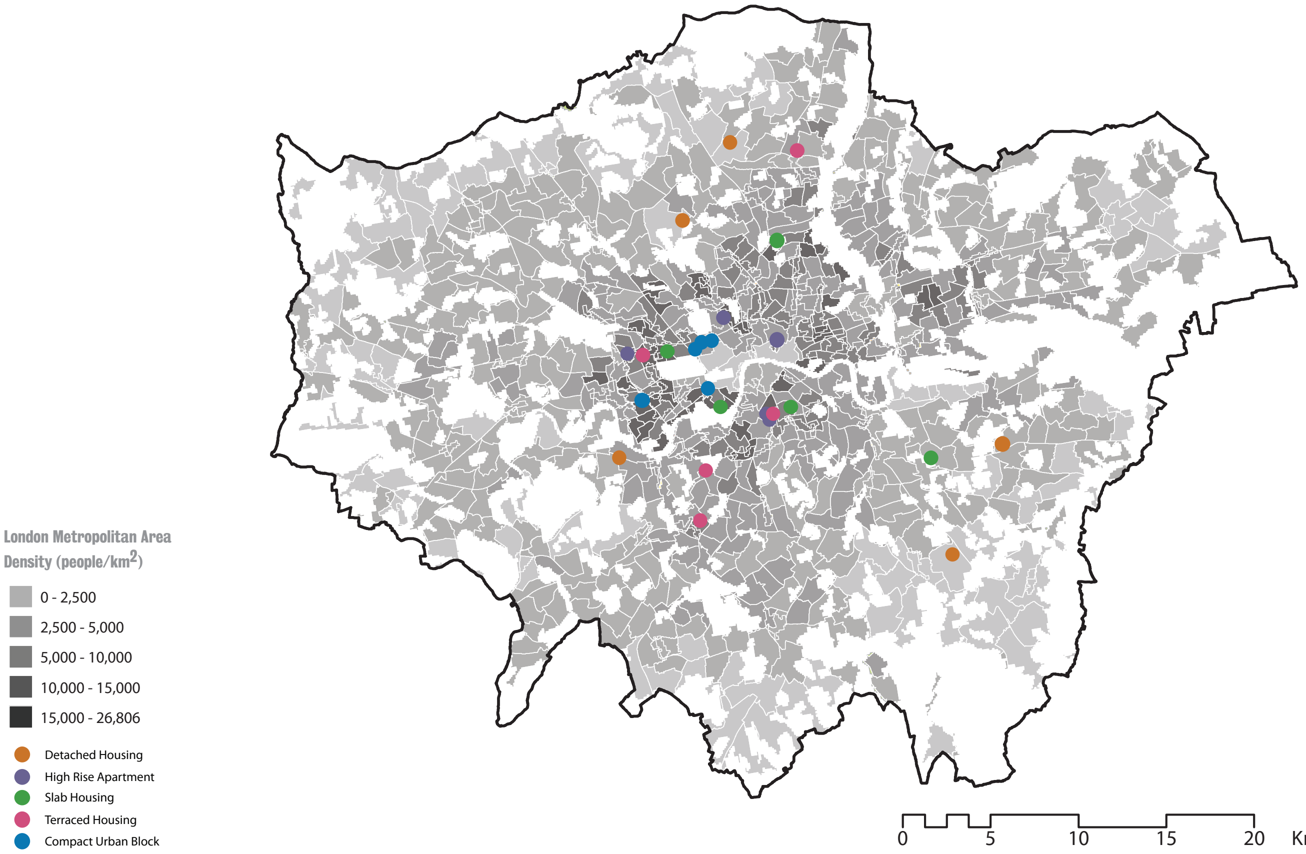
**Simple geometrical tests.** To investigate and understand the relationship between heat energy demand and the morphological parameters further, it would be useful to test simple geometrical changes. Keeping some physical parameters (for example surface-to-volume ratio) constant while changing others would allow a better understanding of what matters most in the shape of a building in a neighbourhood context.

**Synergies and trade-offs between different energy demands and local energy production.** The energy efficiency of different urban morphologies discussed in this report might change if energy demands other than space heating were considered. Besides cooling morphological effects related to, for example, lighting lifts in taller buildings and warm water (both expected to increase their share of the overall energy consumption) is particularly relevant. Similarly, relating morphological consideration to the potential for local energy production such as photovoltaic, solar-thermal, wind and geothermal, as well as for combined heat and power (CHP) could be considered. Finally, the embedded energy demand of different building types and insulation standards needs to be considered.

# A-1 LONDON MORPHOLOGIES




## A-1.1 DENSITY MAP AND LOCATION OF MORPHOLOGY SAMPLES




*Source: LSE Cities research*

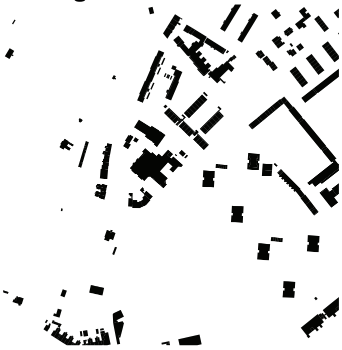
**Detached Housing**

**East Finchley DH01**

**Bickley DH02**

**High Rise Apartment**

**Kennington HRA01**



**Euston HRA02**

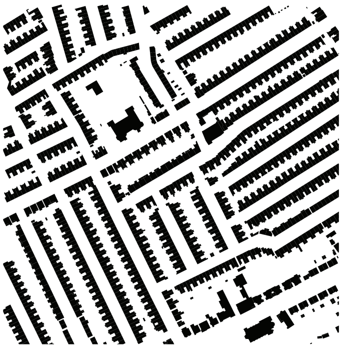
**Slab Housing**

**Pimlico SH01**

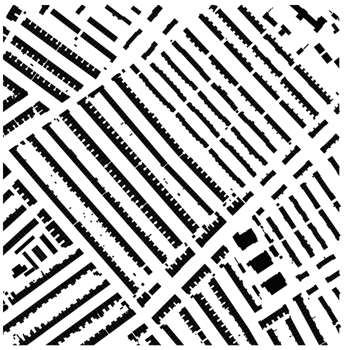
**Walworth SH02**

**Terraced Housing**

**Clapham South TH01**

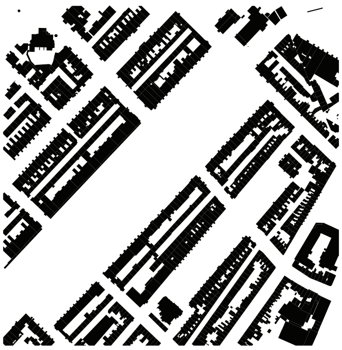


**Tooting TH02**

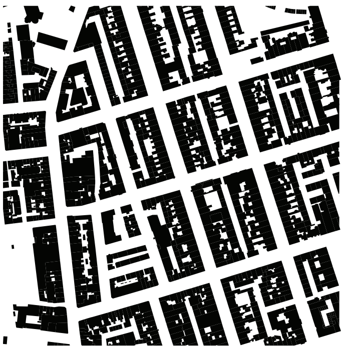


**Compact Urban Block**

**Victoria CUB01**



**Marylebone CUB02**

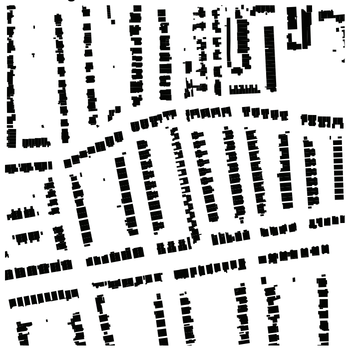


These two pages depict the five sample figure grounds for each of the five London typologies

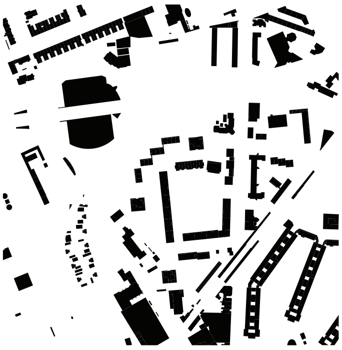
Falconwood DH03

Arnos Grove DH04

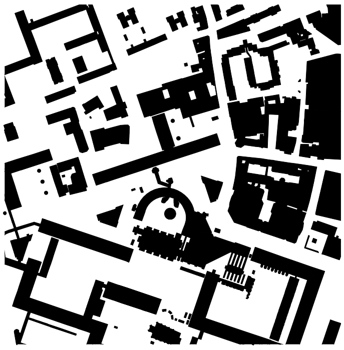
Putney DH05



Latimer Road HRA03

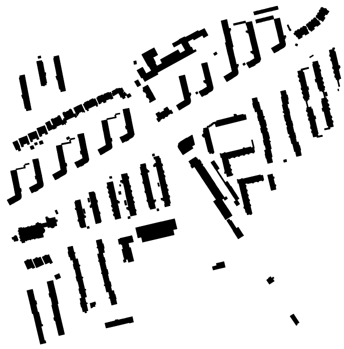


Barbican HRA04

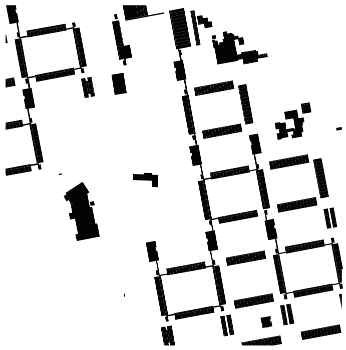


Camberwell HRA05

Manor House SH03

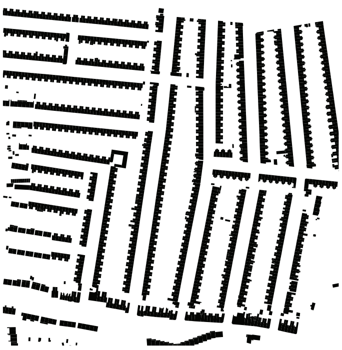


Kidbrooke SH04



Bayswater SH05

Edmonton TH03

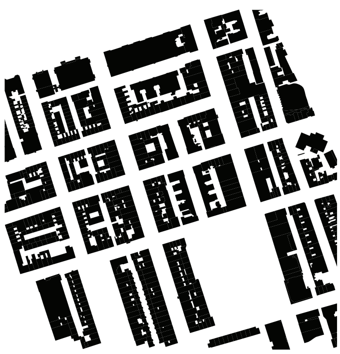


Kennington TH04

Notting Hill TH05

Paddington CUB03

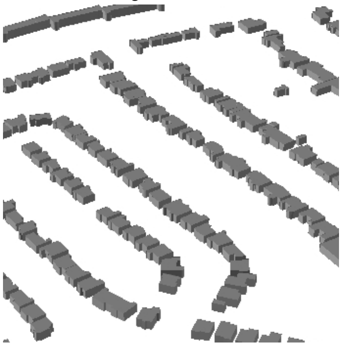
Baker Street CUB04



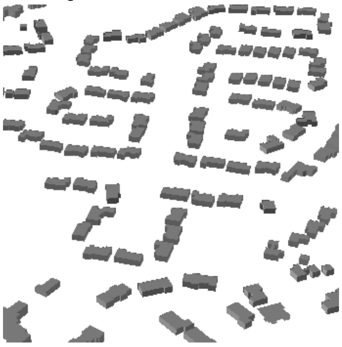
West Kensington CUB05

### Detached Housing

### East Finchley DH01

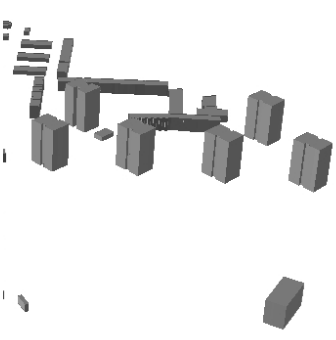


### Bickley DH02

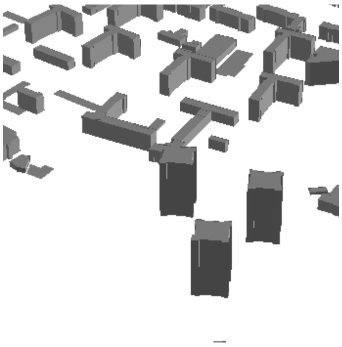


### High Rise Apartment

### Kennington HRA01

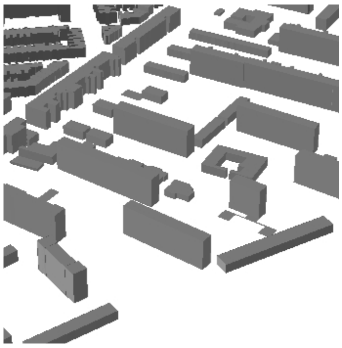


### Euston HRA02

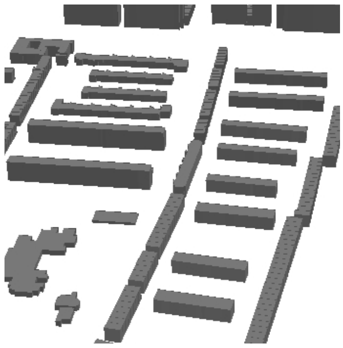


### Slab Housing

### Pimlico SH01

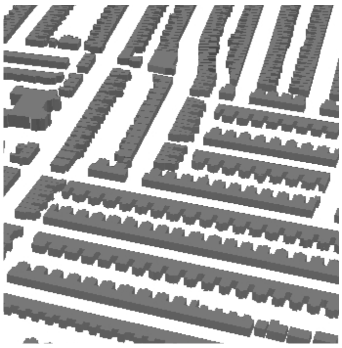


### Walworth SH02

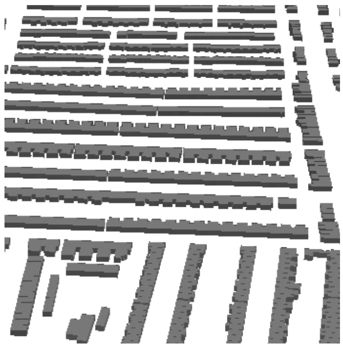


### Terraced Housing

### Clapham South TH01

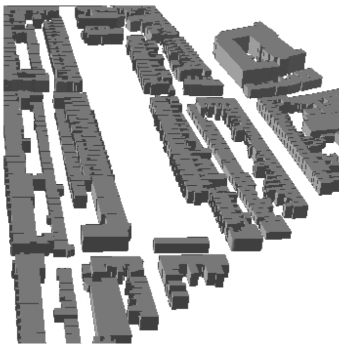


### Tooting TH02

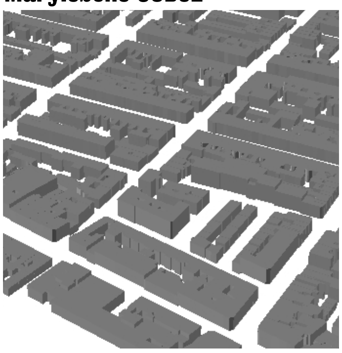


### Compact Urban Block

### Victoria CUB01

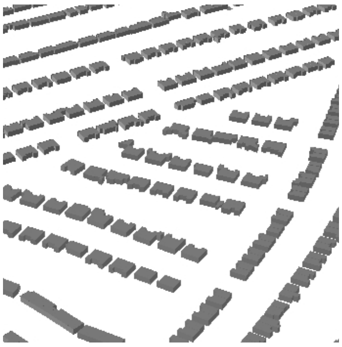


### Marylebone CUB02

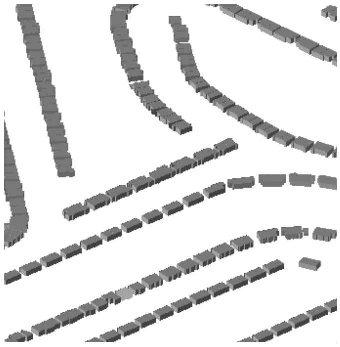


These two pages depict the five sample 3D models for each of the five London typologies

Falconwood DH03

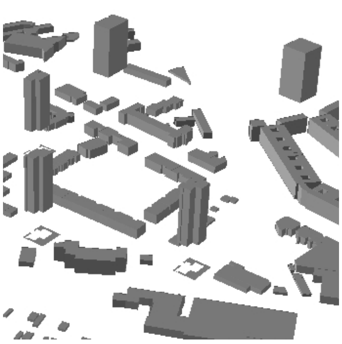


Arnos Grove DH04

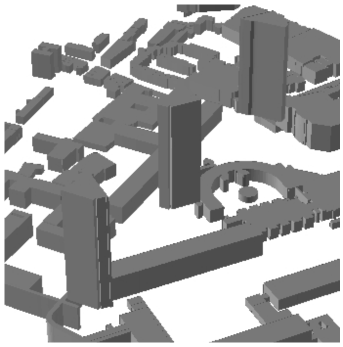


Putney DH05

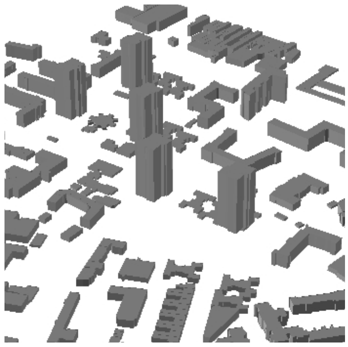
Latimer Road HRA03



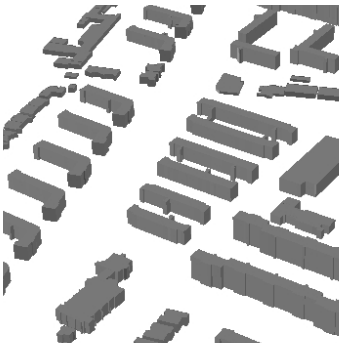
Barbican HRA04



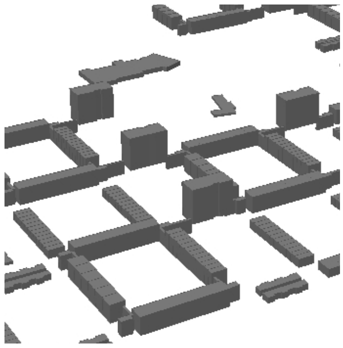
Camberwell HRA05



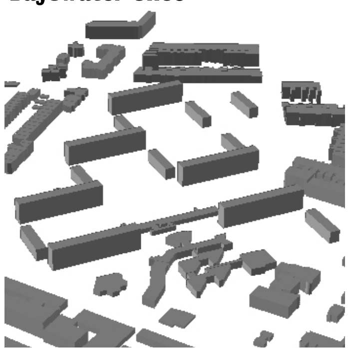
Manor House SH03



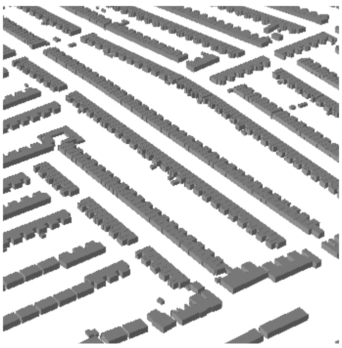
Kidbrooke SH04



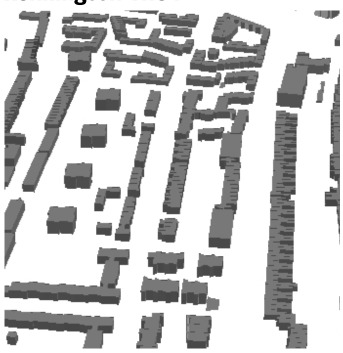
Bayswater SH05



Edmonton TH03

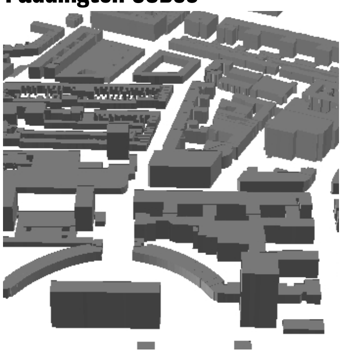


Kennington TH04

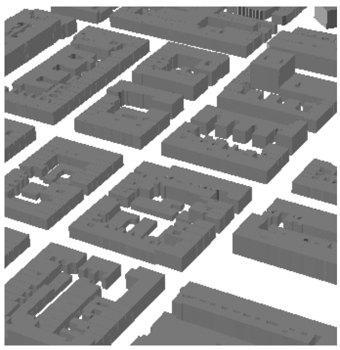


Notting Hill TH05

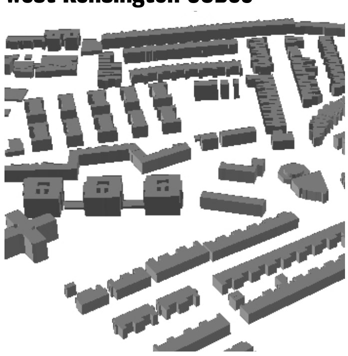
Paddington CUB03



Baker Street CUB04



West Kensington CUB05



## A-1.2 DETACHED HOUSING

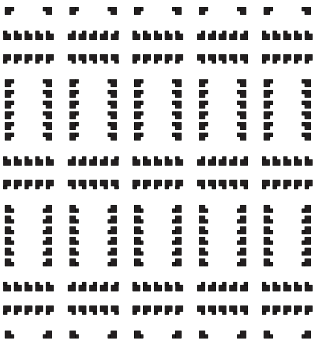
A visual and quantitative comparison of each London sample of Detached Housing. Data covering multiple factors and images over several scales is provided to enable a multi-layered comparison of samples.

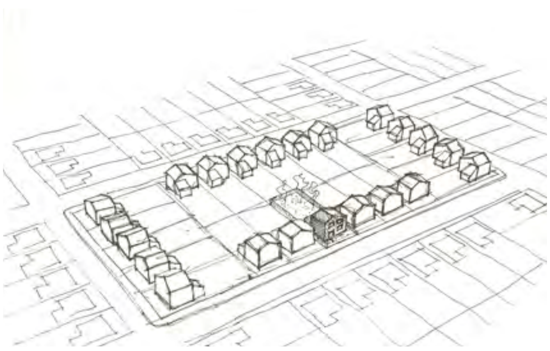
| | DH01 | DH02 | DH03 | DH04 | DH05 |
|---|---|---|---|---|---|
| **Built-up area (m²)** | 35,041 | 28,570 | 39,095 | 30,892 | 51,230 |
| **Land area (m²)** | 193,157 | 205,103 | 206,027 | 184,768 | 193,862 |
| **Coverage ratio** | 0.14 | 0.11 | 0.12 | 0.20 | 0.16 |
| **Floor area (m²)** | 108,327 | 62,638 | 78,087 | 63,280 | 152,316 |
| **Floor area ratio** | 0.43 | 0.25 | 0.25 | 0.61 | 0.31 |
| **% Built-up area** | 14.02 | 11.43 | 15.64 | 12.36 | 20.49 |
| **% Land area** | 63.25 | 70.61 | 66.77 | 61.55 | 57.05 |
| **% Road area** | 22.74 | 17.96 | 17.59 | 26.09 | 22.46 |


above
**Reference map**

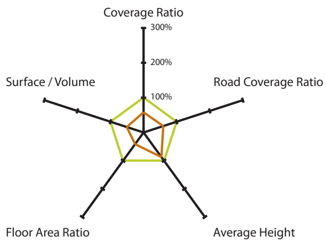
right
**Urban footprint of idealized Detached Housing**

below
**Sketch of idealized Detached Housing**

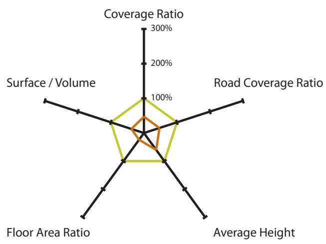




### East Finchley DH01

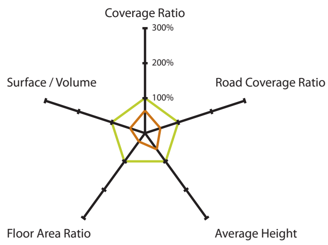


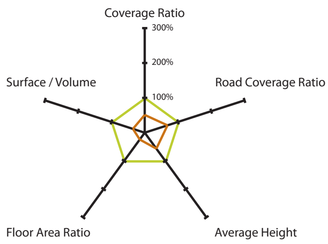

### Bickley DH02

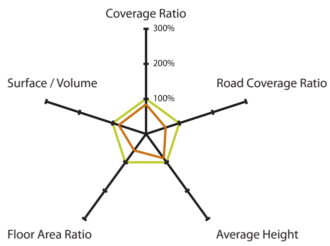



## Falconwood DH03 | Arnos Grove DH04 | Putney DH05

**Spider diagram**




**Street view**



**Bird's-eye-view**

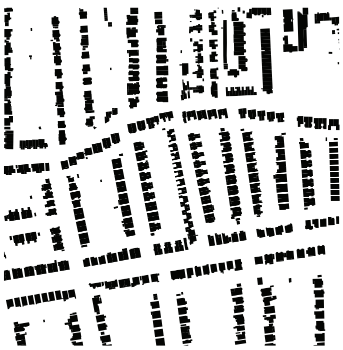


**Satellite view**



**Urban footprint**

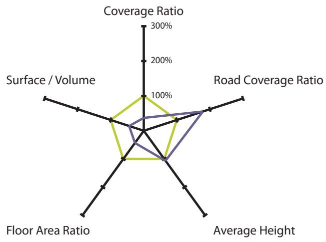




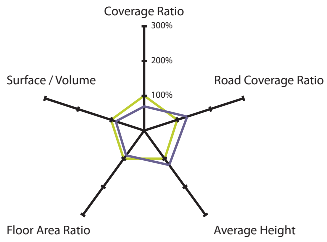
## A-1.3 HIGH RISE APARTMENT

A visual and quantitative comparison of each London sample of High Rise Apartments. Data covering multiple factors and images over several scales is provided to enable a multi-layered comparison of samples.

### Kennington HRA01




### Euston HRA02

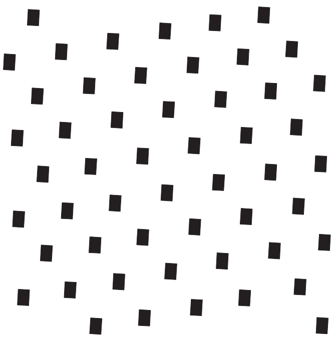


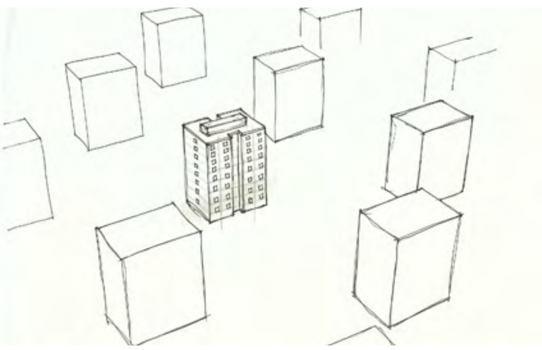

| | HRA01 | HRA02 | HRA03 | HRA04 | HRA05 |
|---|---|---|---|---|---|
| **Built-up area (m²)** | 22,360 | 42,157 | 41,900 | 96,456 | 63,616 |
| **Land area (m²)** | 79,481 | 125,891 | 168,584 | 185,572 | 167,719 |
| **Coverage ratio** | 0.09 | 0.17 | 0.17 | 0.39 | 0.25 |
| **Floor area (m²)** | 113,511 | 231,129 | 189,697 | 760,411 | 251,921 |
| **Floor area ratio** | 0.45 | 0.92 | 0.76 | 3.04 | 1.01 |
| **% Built-up area** | 8.94 | 16.86 | 16.76 | 38.58 | 25.45 |
| **% Land area** | 22.85 | 33.49 | 50.67 | 35.65 | 41.64 |
| **% Road area** | 68.21 | 49.64 | 32.57 | 25.77 | 32.91 |

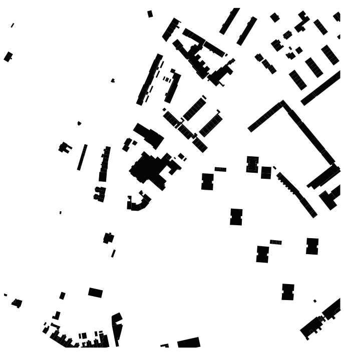

above
**Reference map**

right
**Urban footprint of idealized Tower Block Housing**

below
**Sketch of idealized Tower Block Housing**



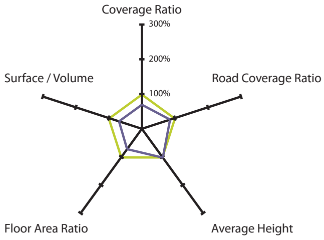




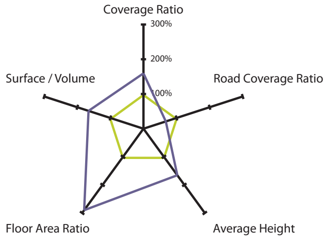
## Latimer Road HRA03 | Barbican HRA04 | Camberwell HRA05

**Spider diagram**

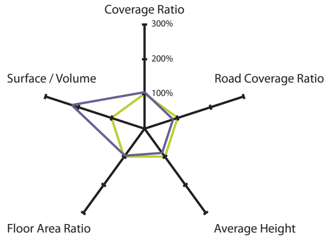
**Latimer Road HRA03**




**Barbican HRA04**




**Camberwell HRA05**




**Satellite view**



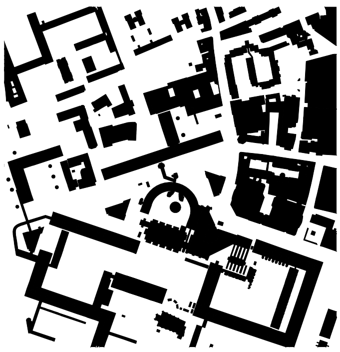
**Bird's-eye-view**



**Street view**



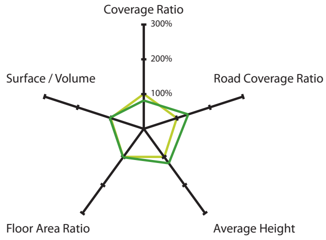
**Urban footprint**

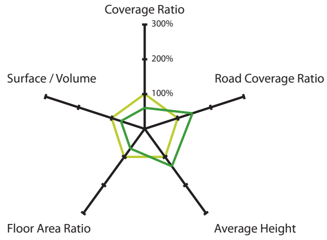

## A-1.4 SLAB HOUSING

A visual and quantitative comparison of each London sample of Slab Housing. Data covering multiple factors and images over several scales is provided to enable a multi-layered comparison of samples.

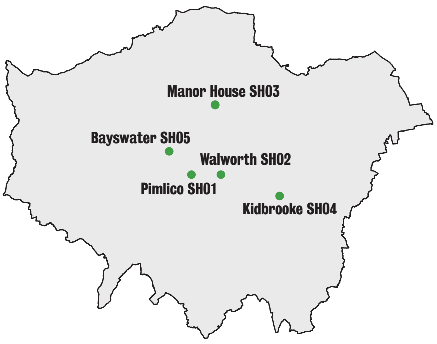
### Pimlico SH01




### Walworth SH02



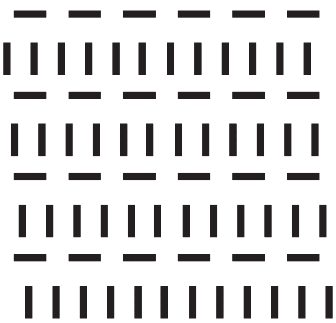

| | SH01 | SH02 | SH03 | SH04 | SH05 |
|---|---|---|---|---|---|
| **Built-up area ($m^2$)** | 49,362 | 36,522 | 30,787 | 33,961 | 84,841 |
| **Land area ($m^2$)** | 121,854 | 112,046 | 109,049 | 114,189 | 160,574 |
| **Coverage ratio** | 0.20 | 0.15 | 0.12 | 0.14 | 0.34 |
| **Floor area ($m^2$)** | 265,006 | 183,735 | 137,393 | 159,880 | 408,821 |
| **Floor area ratio** | 1.06 | 0.73 | 0.55 | 0.64 | 1.64 |
| **% Built-up area** | 19.74 | 14.61 | 12.31 | 13.58 | 33.94 |
| **% Land area** | 29.00 | 30.21 | 31.30 | 32.09 | 30.29 |
| **% Road area** | 51.26 | 55.18 | 56.38 | 54.32 | 35.77 |

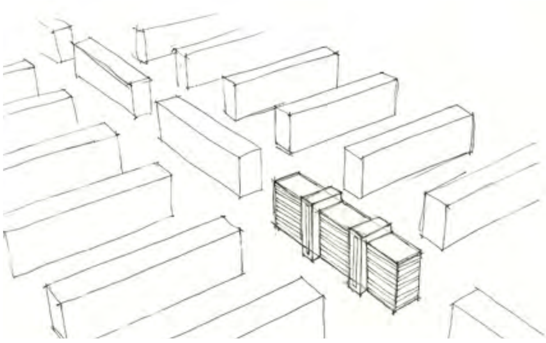



above
**Reference map**

right
**Urban footprint of idealized Slab Housing**

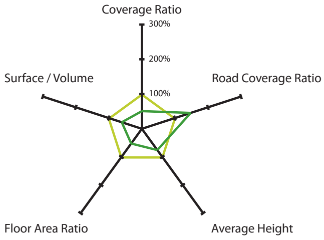
below
**Sketch of idealized Slab Housing**

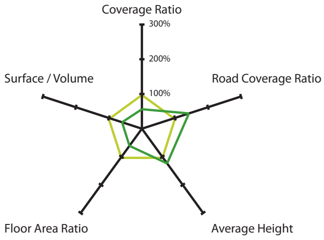


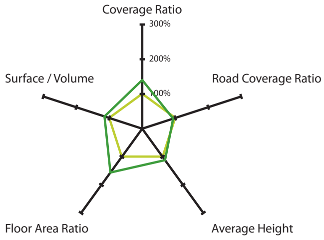


| | Manor House SH03 | Kidbrooke SH04 | Bayswater SH05 |
|---|---|---|---|

Spider diagram



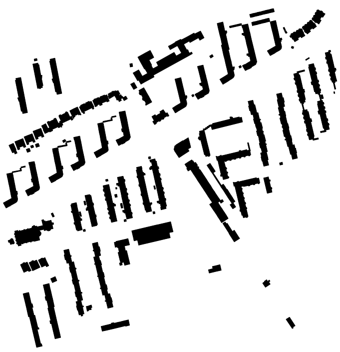



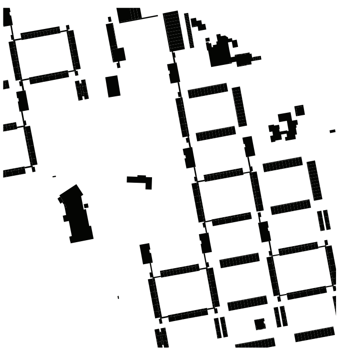

Street view

Bird's-eye-view

Satellite view

Urban footprint

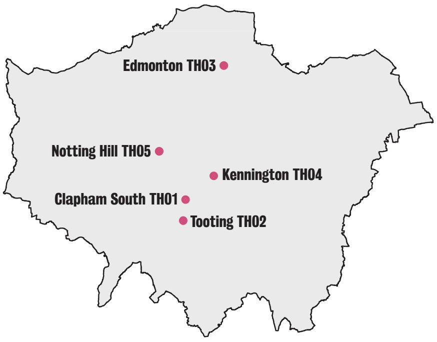




## A-1.5 TERRACED HOUSING

A visual and quantitative comparison of each London sample of Terraced Housing. Data covering multiple factors and images over several scales is provided to enable a multi-layered comparison of samples.

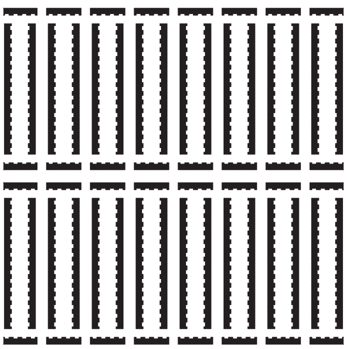
| | TH01 | TH02 | TH03 | TH04 | TH05 |
|---|---|---|---|---|---|
| **Built-up area ($m^2$)** | 74,606 | 73,640 | 59,024 | 55,259 | 56,406 |
| **Land area ($m^2$)** | 178,489 | 182,728 | 168,727 | 149,671 | 122,521 |
| **Coverage ratio** | 0.30 | 0.29 | 0.24 | 0.22 | 0.23 |
| **Floor area ($m^2$)** | 226,895 | 147,280 | 119,917 | 181,671 | 245,304 |
| **Floor area ratio** | 0.91 | 0.59 | 0.48 | 0.73 | 0.98 |
| **% Built-up area** | 29.84 | 29.46 | 23.61 | 22.10 | 22.56 |
| **% Land area** | 41.55 | 43.64 | 43.88 | 37.76 | 26.45 |
| **% Road area** | 28.60 | 26.91 | 32.51 | 40.13 | 50.99 |

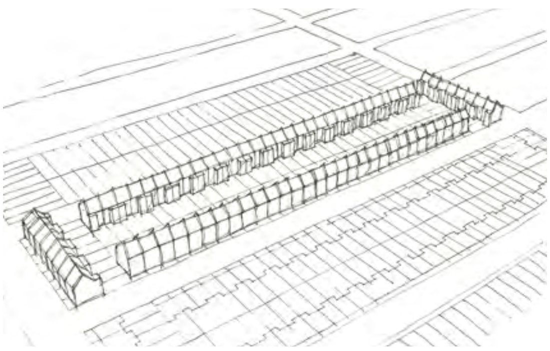



above
**Reference map**

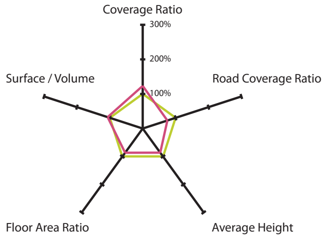
right
**Urban footprint of idealized Terraced Housing**

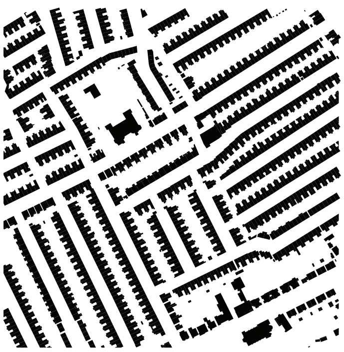
below
**Sketch of idealized Terraced Housing**



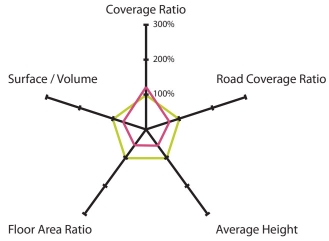


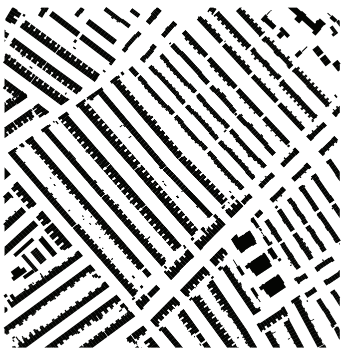
### Clapham South TH01



### Tooting TH02



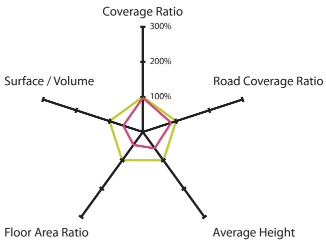



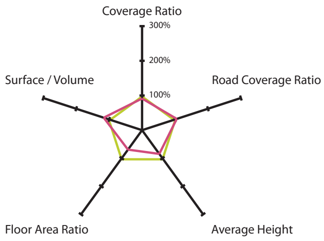
## Edmonton TH03

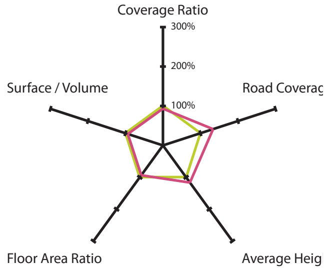
## Kennington TH04

## Notting Hill TH05

Spider diagram

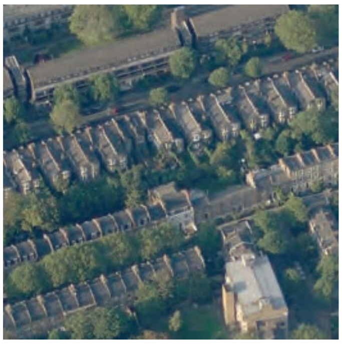


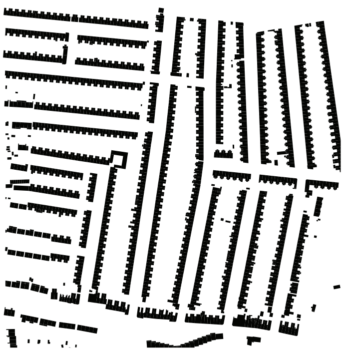

Street view

Bird's-eye-view



Satellite view

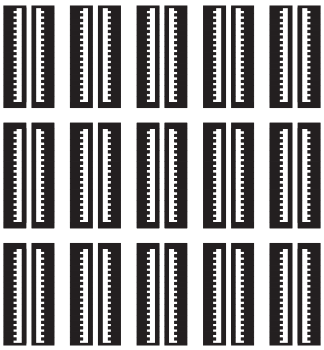
Urban footprint



## A-1.6 COMPACT URBAN BLOCK

A visual and quantitative comparison of each London sample of Compact Urban Blocks. Data covering multiple factors and images over several scales is provided to enable a multi-layered comparison of samples.

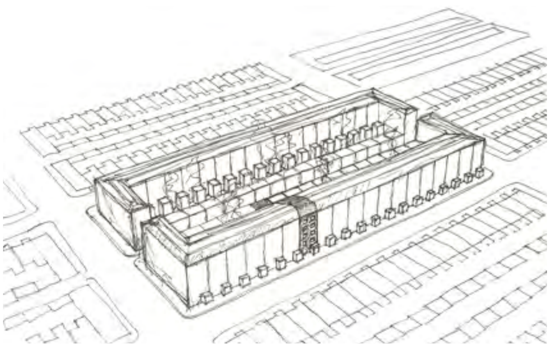
| | CUB01 | CUB02 | CUB03 | CUB04 | CUB05 |
|---|---|---|---|---|---|
| **Built-up area ($m^2$)** | 90,851 | 127,792 | 113,993 | 102,195 | 72,642 |
| **Land area ($m^2$)** | 128,019 | 162,714 | 155,423 | 131,654 | 158,586 |
| **Coverage ratio** | 0.36 | 0.51 | 0.46 | 0.41 | 0.29 |
| **Floor area ($m^2$)** | 423,157 | 586,839 | 623,373 | 498,148 | 336,303 |
| **Floor area ratio** | 1.69 | 2.35 | 2.49 | 1.99 | 1.35 |
| **% Built-up area** | 36.34 | 51.12 | 45.60 | 40.88 | 29.06 |
| **% Land area** | 14.87 | 13.97 | 16.57 | 11.78 | 34.38 |
| **% Road area** | 48.79 | 34.91 | 37.83 | 47.34 | 36.57 |

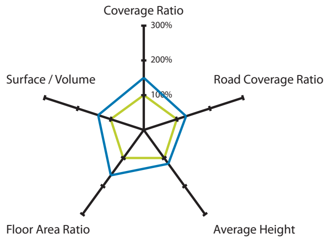
above
**Reference map**

right
**Urban footprint of idealized Continuous Urban Block**

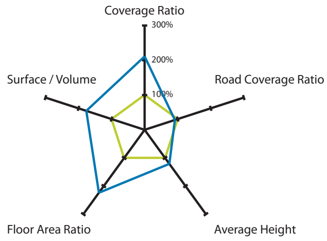
below
**Sketch of idealized Continuous Urban Block**

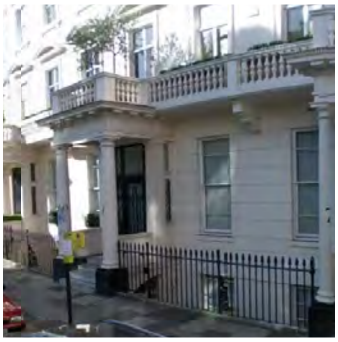


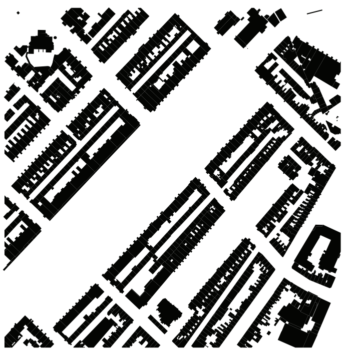
### Victoria CUB01




### Marylebone CUB02



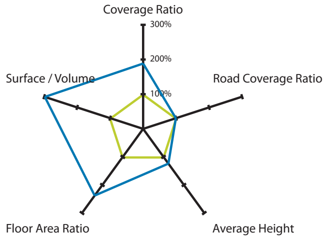





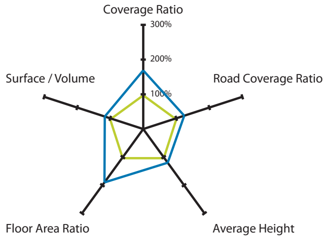
## Paddington CUB03 | Baker Street CUB04 | West Kensington CUB05

**Spider diagram**

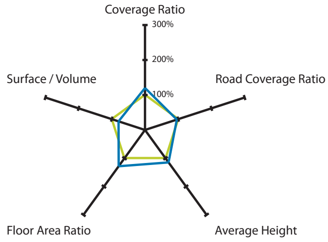
Paddington CUB03




Baker Street CUB04




West Kensington CUB05




**Street view**



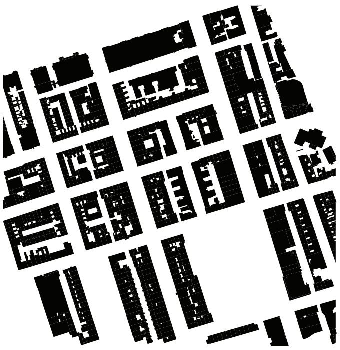
**Bird's-eye-view**



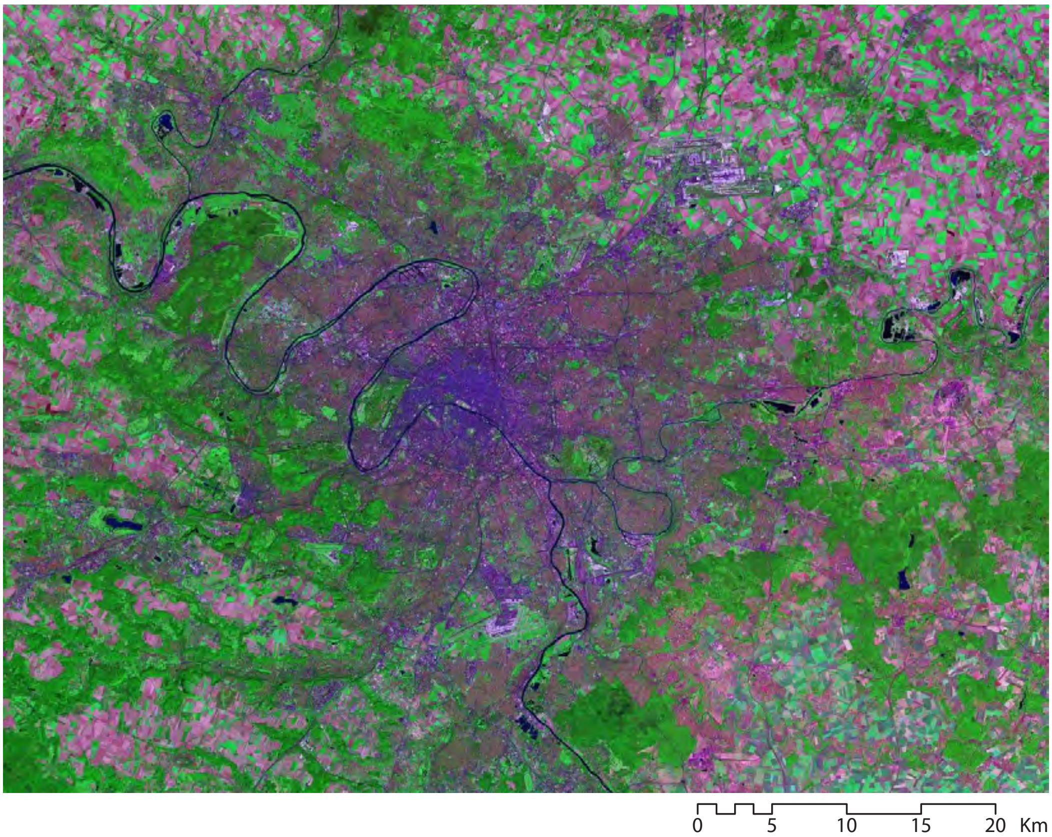
**Satellite view**



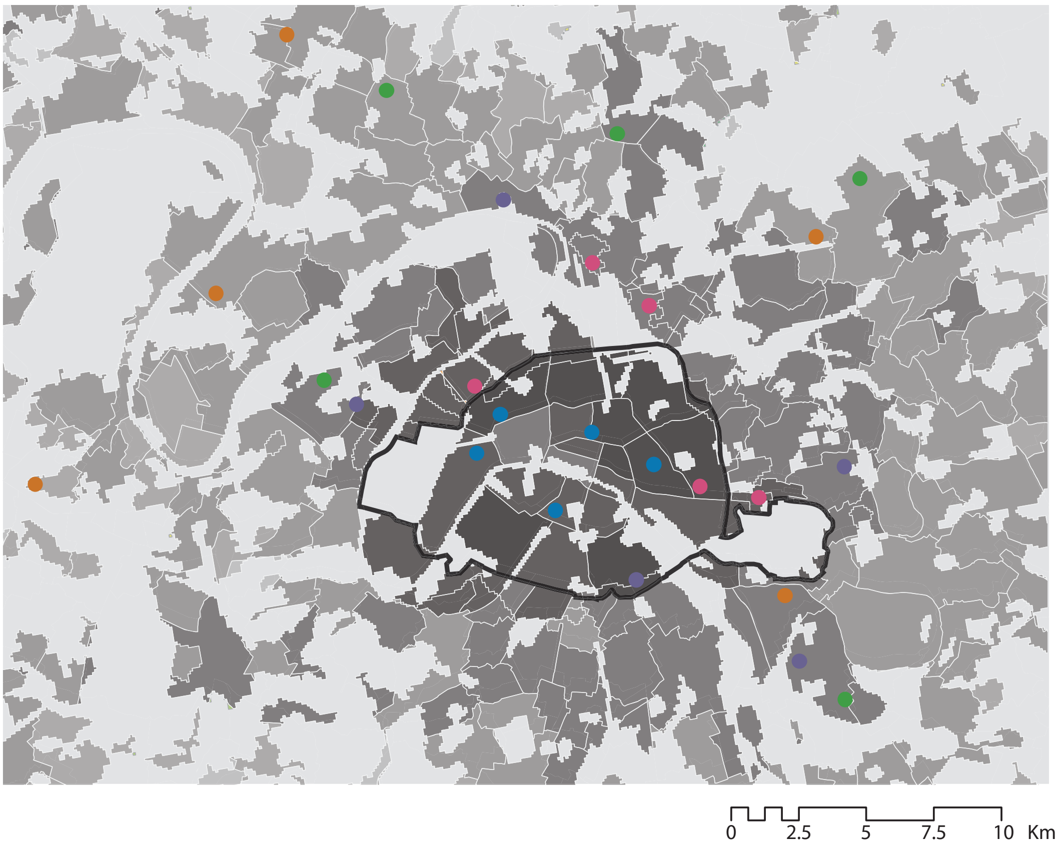
**Urban footprint**


# A-2 PARIS MORPHOLOGIES




## A-2.1 DENSITY MAP AND LOCATION OF MORPHOLOGY SAMPLES (PARIS CITY AND SURROUNDS)




**Paris City and Its Surrounds**
**Density (people/km$^2$)**

- 2,500 - 5,000
- 5,000 - 10,000
- 10,000 - 15,000
- 15,000 - 26,805
- 27,560 - 65,595

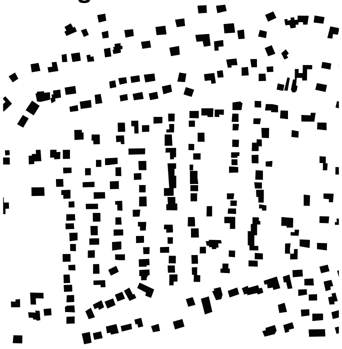
- Detached Housing
- High Rise Apartment
- Slab Housing
- Regular Urban Block
- Compact Urban Block

*Source: LSE Cities research*

**Detached Housing**

**Satrouville DH01**

**L'Etrang-la-ville DH02**



**High Rise Apartment**

**La Defense HRA01**

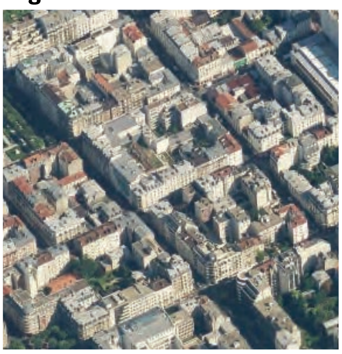
**Creteil Universite HRA02**

**Slab Housing**

**Nanterre Ville SH01**

**Gare de Gros Noyer St Prix SH02**

**Regular Urban Block**



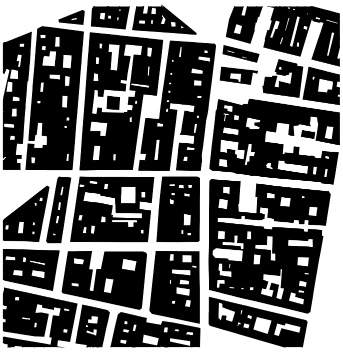
**Anatole France RUB01**

**Saint Denis Porte du Paris RUB02**

**Compact Urban Block**

**Saint Placide CUB01**

**Bonne Nouvelle CUB02**

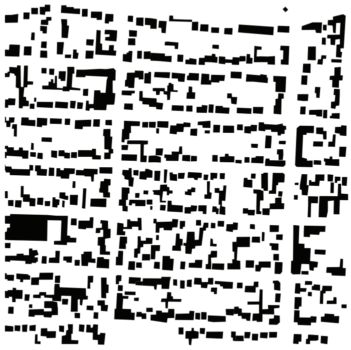


These two pages depict the five sample figure grounds for each of the five Paris typologies

Taverny DH03

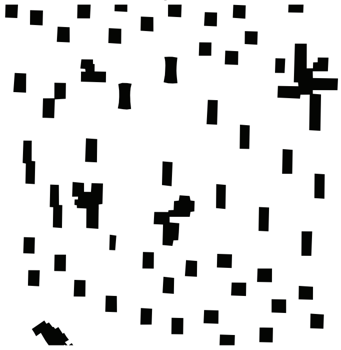
Le Blanc-Mesnil DH04

Maison-Alfort DH05



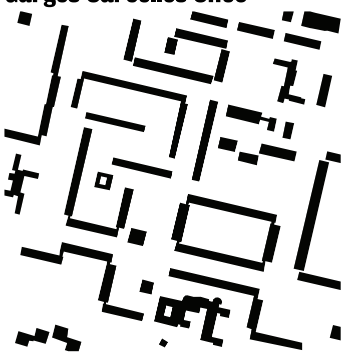
Epinay sur Seine HRA03

Val de Fontenay HRA04



Porte de Choisy HRA05

Garges Sarcelles SH03



Creteil Prefecture SH04

Villepinte SH05

Aubervilles RUB03

Buzenval RUB04

Vincennes RUB05

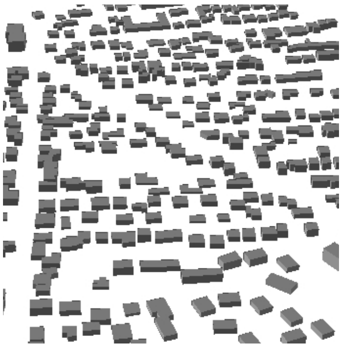
Courcelles CUB03

Saint Ambroise CUB04

Victor Hugo CUB05

### Detached Housing

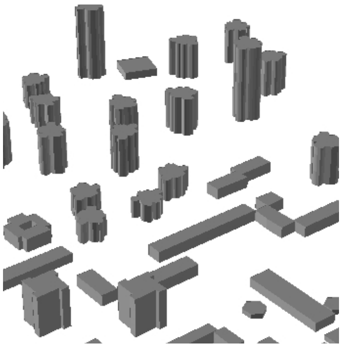
### Satrouville DH01



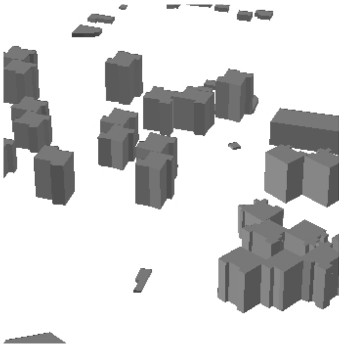
### L'Etrang-la-ville DH02

### High Rise Apartment

### La Defense HRA01

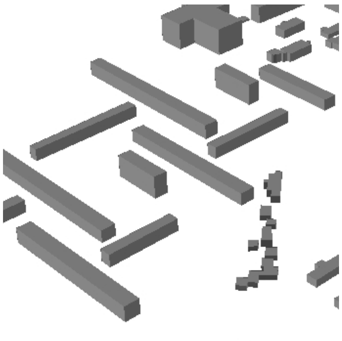


### Creteil Universite HRA02

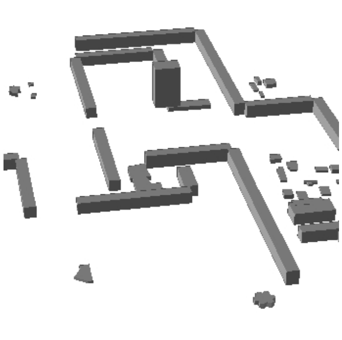


### Slab Housing

### Nanterre Ville SH01

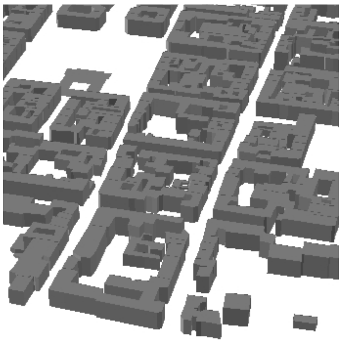


### Gare de Gros Noyer St Prix SH02

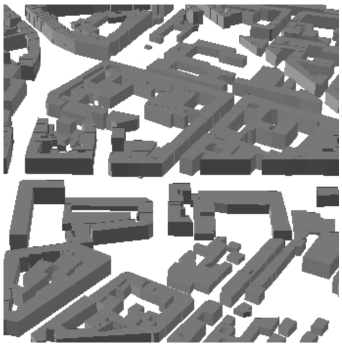


### Regular Urban Block

### Anatole France RUB01

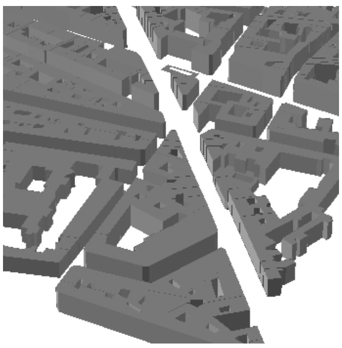


### Saint Denis Porte du Paris RUB02

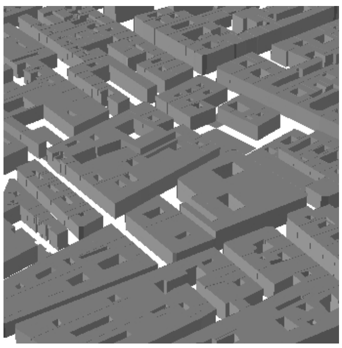


### Compact Urban Block

### Saint Placide CUB01

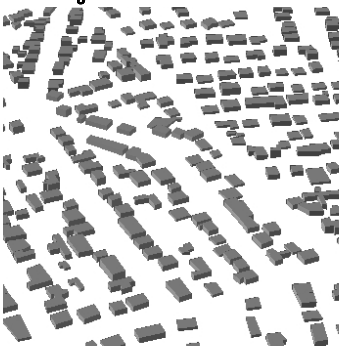


### Bonne Nouvelle CUB02

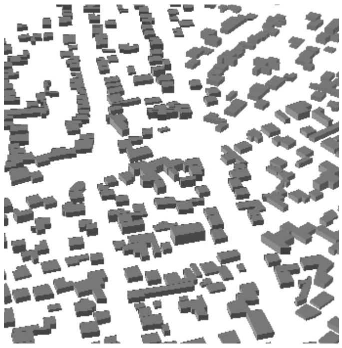


These two pages depict the five sample 3D models for each of the five Paris typologies

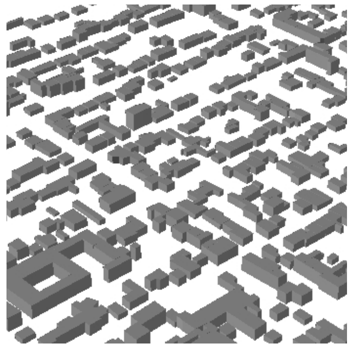
**Taverny DH03**



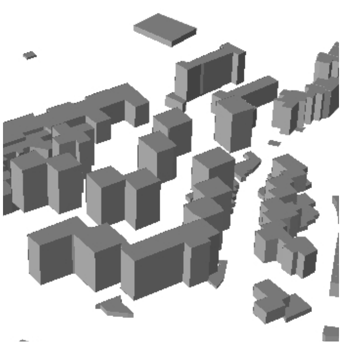
**Le Blanc-Mesnil DH04**



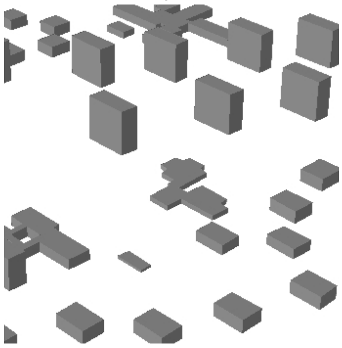
**Maison-Alfort DH05**



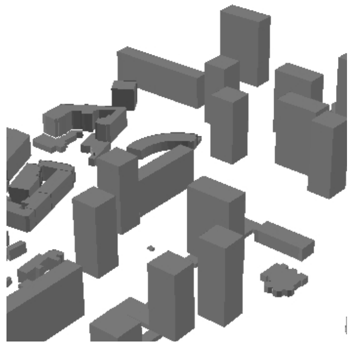
**Epinay sur Seine HRA03**



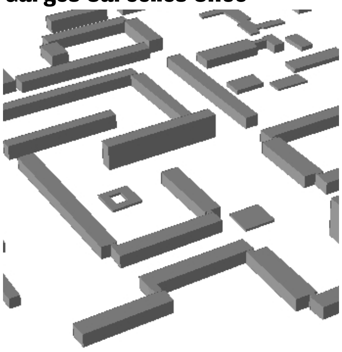
**Val de Fontenay HRA04**



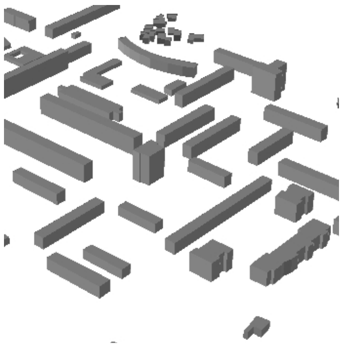
**Porte de Choisy HRA05**



**Garges Sarcelles SH03**

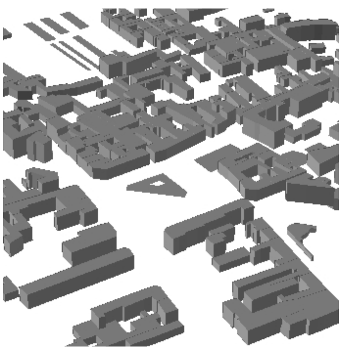


**Creteil Prefecture SH04**

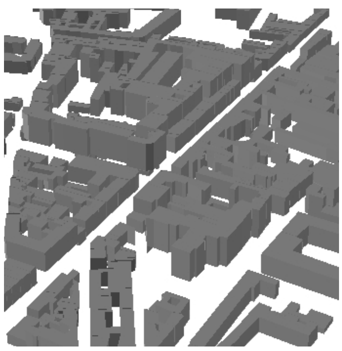


**Villepinte SH05**

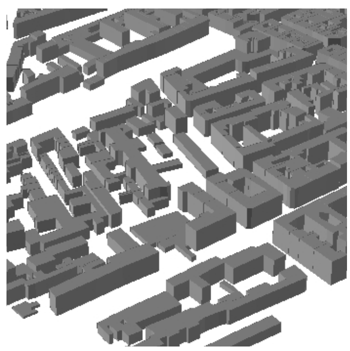
**Aubervilles RUB03**



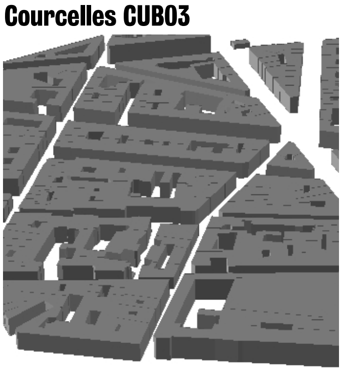
**Buzenval RUB04**



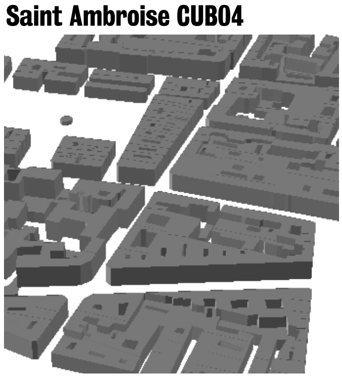
**Vincennes RUB05**



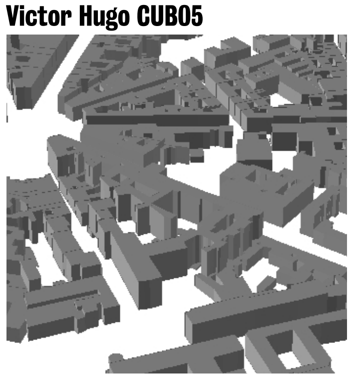
**Courcelles CUB03**



**Saint Ambroise CUB04**



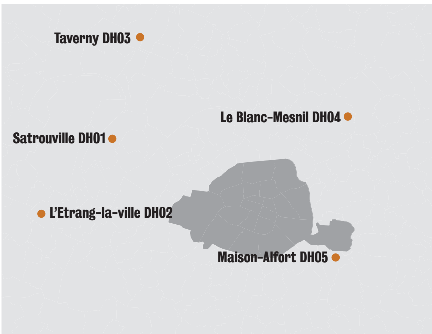
**Victor Hugo CUB05**



# A-2.2 DETACHED HOUSING

A visual and quantitative comparison of each Paris sample of Detached Housing. Data covering multiple factors and images over several scales is provided to enable a multi-layered comparison of samples.

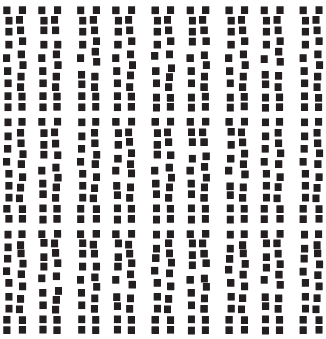
| | DH01 | DH02 | DH03 | DH04 | DH05 |
|---|---|---|---|---|---|
| **Built-up area (m²)** | 57,500 | 34,572 | 51,089 | 62,722 | 70,243 |
| **Land area (m²)** | 203,118 | 204,537 | 200,137 | 213,857 | 200,297 |
| **Coverage ratio** | 0.23 | 0.14 | 0.20 | 0.25 | 0.28 |
| **Floor area (m²)** | 129,748 | 65,402 | 94,433 | 130,651 | 217,696 |
| **Floor area ratio** | 0.52 | 0.26 | 0.38 | 0.52 | 0.87 |
| **% Built-up area** | 23.0 | 13.8 | 20.4 | 25.1 | 28.1 |
| **% Land area** | 58.2 | 68.0 | 59.6 | 60.5 | 52.0 |
| **% Road area** | 18.8 | 18.2 | 19.9 | 14.5 | 19.9 |

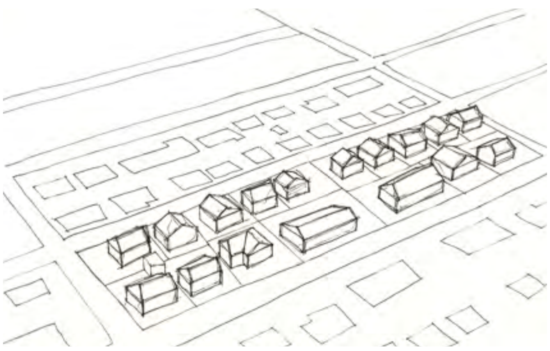



above
**Reference map**

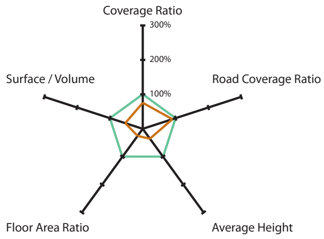
right
**Urban footprint of idealized Detached Housing**

below
**Sketch of idealized Detached Housing**

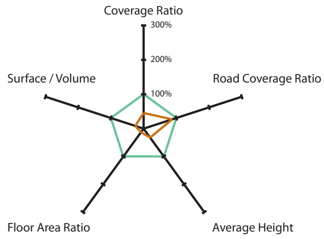


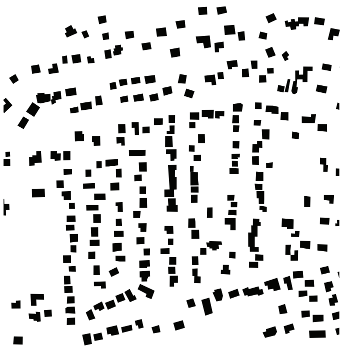


## Satrouville DH01



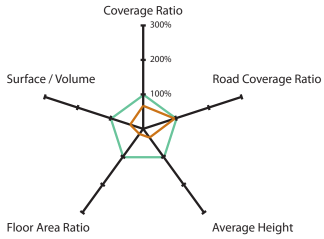

## L'Etrang-la-ville DH02

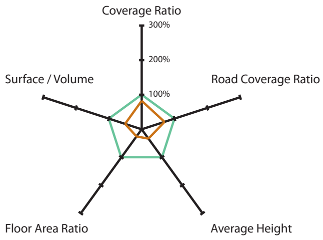


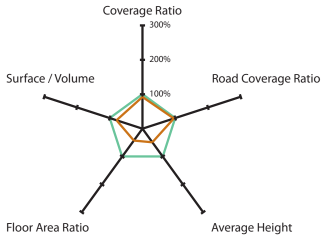



## Taverny DH03 | Le Blanc-Mesnil DH04 | Maison-Alfort DH05

**Spider diagram**



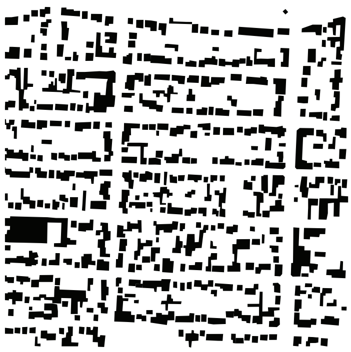




**Street view**

**Bird's-eye-view**

**Satellite view**

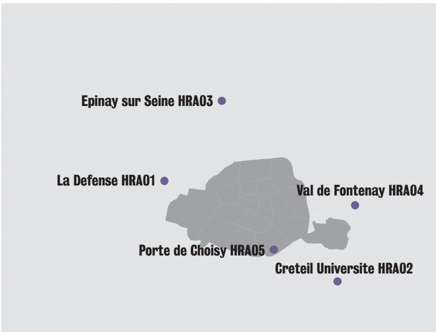
**Urban footprint**



## A-2.3 HIGH RISE APARTMENT

A visual and quantitative comparison of each Paris sample of High Rise Apartments. Data covering multiple factors and images over several scales is provided to enable a multi-layered comparison of samples.

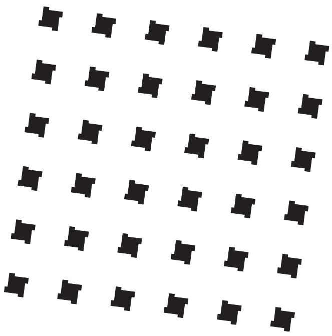
| | HRA01 | HRA02 | HRA03 | HRA04 | HRA05 |
|---|---|---|---|---|---|
| **Built-up area (m²)** | 35,735 | 32,253 | 45,235 | 33,114 | 48,974 |
| **Land area (m²)** | 248,011 | 163,796 | 233,653 | 159,588 | 167,932 |
| **Coverage ratio** | 0.14 | 0.13 | 0.18 | 0.13 | 0.20 |
| **Floor area (m²)** | 337,574 | 269,100 | 423,168 | 247,503 | 598,465 |
| **Floor area ratio** | 1.35 | 1.08 | 1.69 | 0.99 | 2.39 |
| **% Built-up area** | 14.3 | 12.9 | 18.1 | 13.2 | 19.6 |
| **% Land area** | 84.9 | 52.6 | 75.4 | 50.6 | 47.6 |
| **% Road area** | 0.8 | 34.5 | 6.5 | 36.2 | 32.8 |

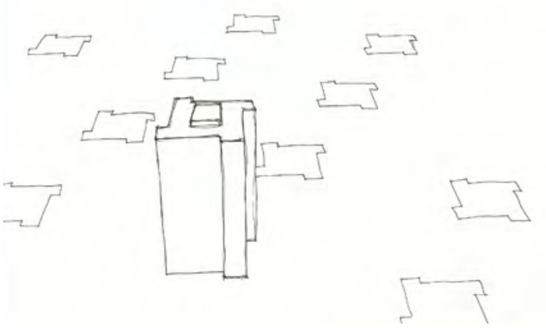



above
**Reference map**

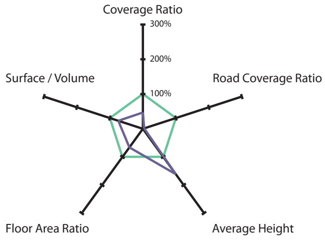
right
**Urban footprint of idealized Tower Block**

below
**Sketch of idealized Tower Block**

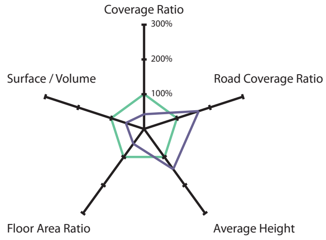




### La Defense HRA01

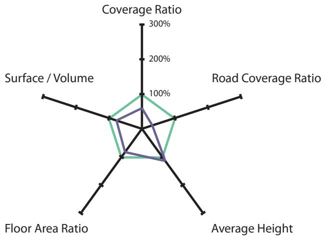


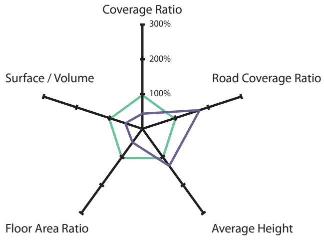

### Creteil Universite HRA02

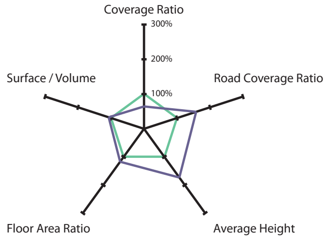



## Epinay sur Seine HRA03 | Val de Fontenay HRA04 | Porte de Choisy HRA05

Spider diagram



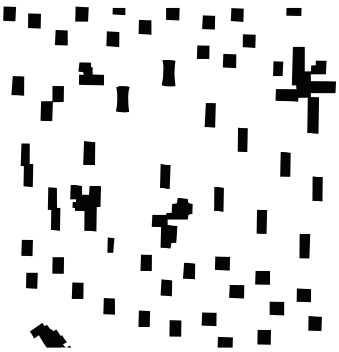




Street view

Bird's-eye-view

Satellite view

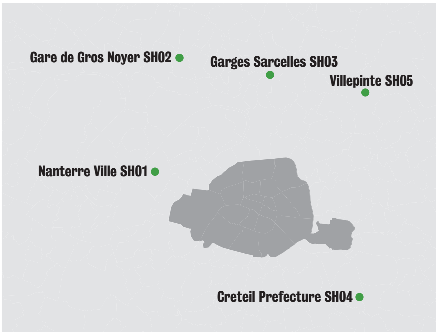
Urban footprint



## A-2.4 SLAB HOUSING

A visual and quantitative comparison of each Paris sample of Slab Housing. Data covering multiple factors and images over several scales is provided to enable a multi-layered comparison of samples.

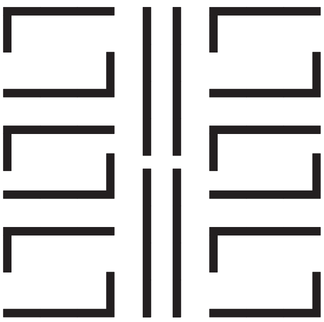
| | SH01 | SH02 | SH03 | SH04 | SH05 |
|---|---|---|---|---|---|
| **Built-up area (m²)** | 36,280 | 30,176 | 52,081 | 37,315 | 56,248 |
| **Land area (m²)** | 187,306 | 214,124 | 301,030 | 170,235 | 216,021 |
| **Coverage ratio** | 0.15 | 0.12 | 0.21 | 0.15 | 0.22 |
| **Floor area (m²)** | 203,455 | 143,130 | 279,787 | 220,054 | 341,985 |
| **Floor area ratio** | 0.81 | 0.57 | 1.12 | 0.88 | 1.37 |
| **% Built-up area** | 14.5 | 12.1 | 20.8 | 14.9 | 22.5 |
| **% Land area** | 60.4 | 73.6 | 99.6 | 53.2 | 63.9 |
| **% Road area** | 25.1 | 14.4 | -20.4 | 31.9 | 13.6 |

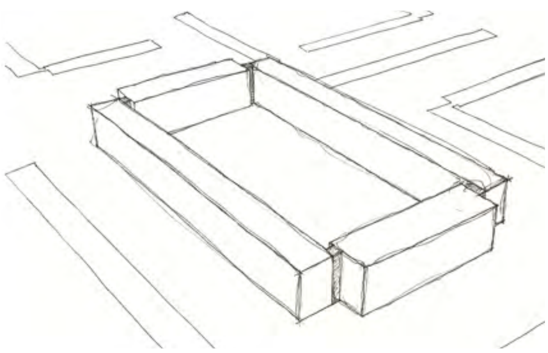



above
**Reference map**

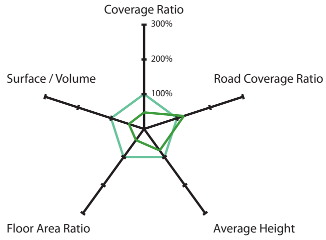
right
**Urban footprint of idealized Slab Housing**

below
**Sketch of idealized Slab Housing**

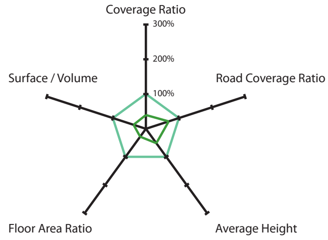


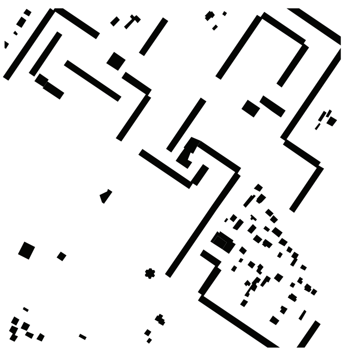


### Nanterre Ville SH01



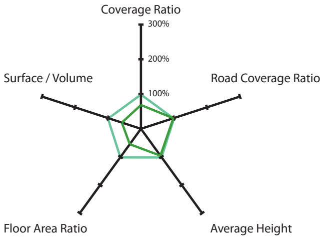

### Gare de Gros Noyer SH02

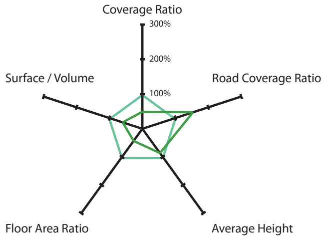


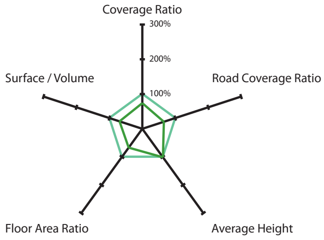



## Garges Sarcelles SH03 | Creteil Prefecture SH04 | Villepinte SH05

Spider diagram



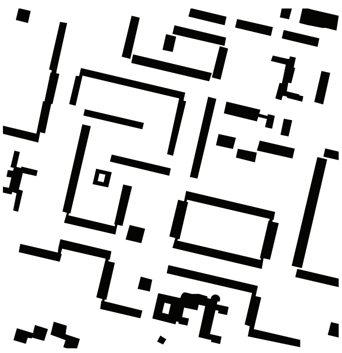



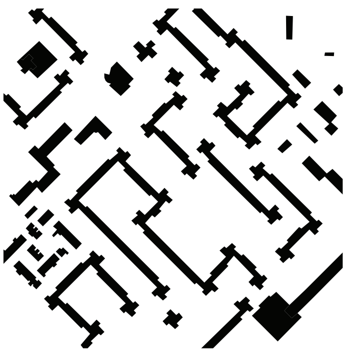

Street view

Bird's-eye-view

Satellite view

Urban footprint

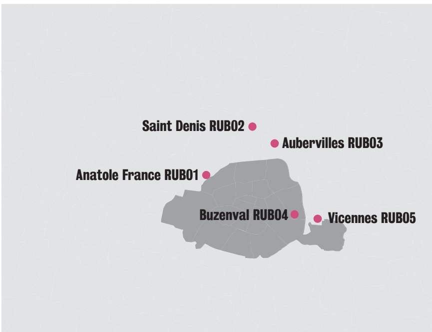




# A-2.5 REGULAR URBAN BLOCK

A visual and quantitative comparison of each Paris sample of Regular Urban Blocks. Data covering multiple factors and images over several scales is provided to enable a multi-layered comparison of samples.

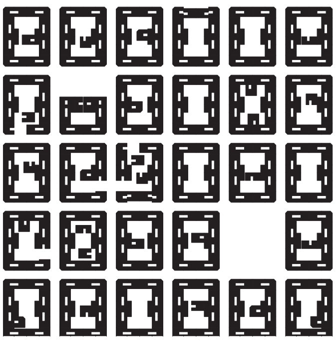
| | RUB01 | RUB02 | RUB03 | RUB04 | RUB05 |
|---|---|---|---|---|---|
| **Built-up area (m²)** | 111,936 | 88,925 | 83,075 | 120,296 | 118,402 |
| **Land area (m²)** | 180,806 | 205,378 | 206,609 | 205,507 | 201,431 |
| **Coverage ratio** | 0.45 | 0.36 | 0.33 | 0.48 | 0.47 |
| **Floor area (m²)** | 771,314 | 461,880 | 426,818 | 824,497 | 810,963 |
| **Floor area ratio** | 3.09 | 1.85 | 1.71 | 3.30 | 3.24 |
| **% Built-up area** | 44.8 | 35.6 | 33.2 | 48.1 | 47.4 |
| **% Land area** | 27.5 | 46.6 | 49.4 | 34.1 | 33.2 |
| **% Road area** | 27.7 | 17.8 | 17.4 | 17.8 | 19.4 |

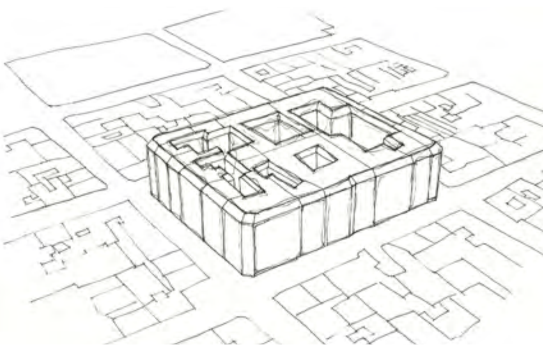



above
**Reference map**

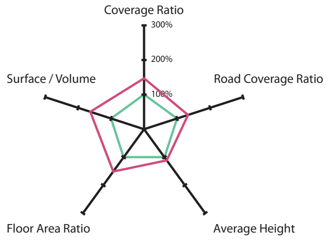
right
**Urban footprint of idealized Regular Urban Block**

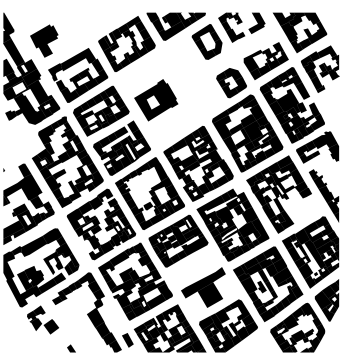
below
**Sketch of idealized Regular Urban Block**



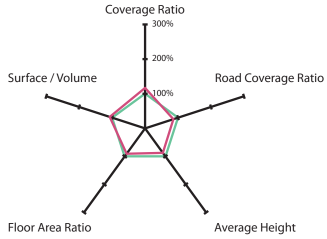


## Anatole France RUB01



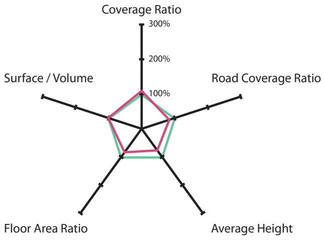
## Saint Denis RUB02



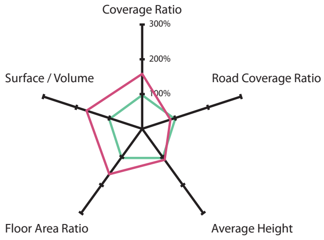

## Aubervilles RUB03 | Buzenval RUB04 | Vincennes RUB05

**Spider diagram**

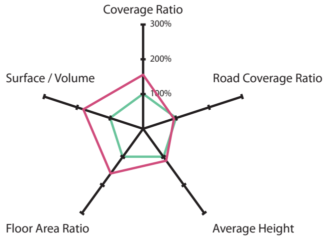
Aubervilles RUB03




Buzenval RUB04




Vincennes RUB05




**Street view**



**Bird's-eye-view**

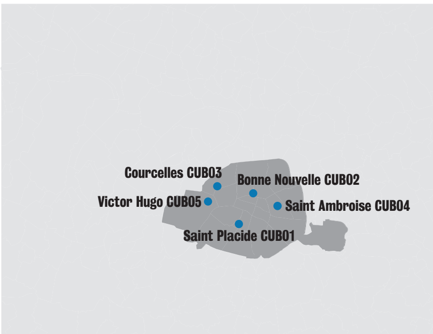
**Satellite view**

**Urban footprint**

## A-2.6 COMPACT URBAN BLOCK

A visual and quantitative comparison of each Paris sample of Compact Urban Blocks. Data covering multiple factors and images over several scales is provided to enable a multi-layered comparison of samples.

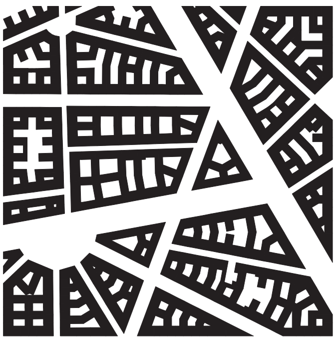
| | CUB01 | CUB02 | CUB03 | CUB04 | CUB05 |
|---|---|---|---|---|---|
| **Built-up area (m²)** | 129,937 | 163,909 | 142,191 | 135,244 | 126,283 |
| **Land area (m²)** | 190,013 | 220,724 | 174,351 | 180,594 | 205,198 |
| **Coverage ratio** | 0.52 | 0.66 | 0.57 | 0.54 | 0.51 |
| **Floor area (m²)** | 1,161,276 | 1,277,110 | 1,220,842 | 1,006,776 | 1,097,582 |
| **Floor area ratio** | 4.65 | 5.11 | 4.88 | 4.03 | 4.39 |
| **% Built-up area** | 52.0 | 65.6 | 56.9 | 54.1 | 50.5 |
| **% Land area** | 24.0 | 22.7 | 12.9 | 18.1 | 31.6 |
| **% Road area** | 24.0 | 11.7 | 30.3 | 27.8 | 17.9 |

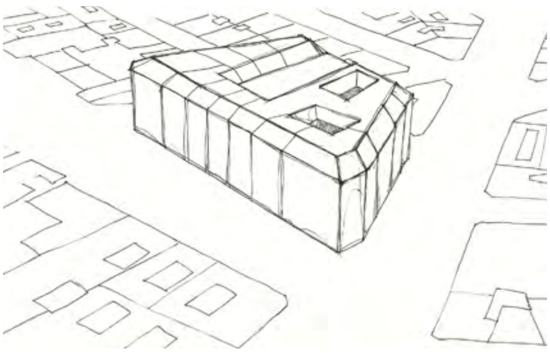



above
**Reference map**

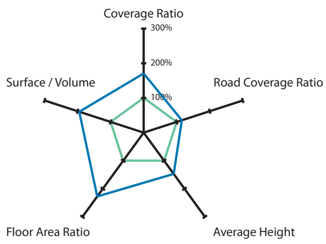
right
**Urban footprint of idealized Traditional Urban Block**

below
**Sketch of idealized Traditional Urban Block**

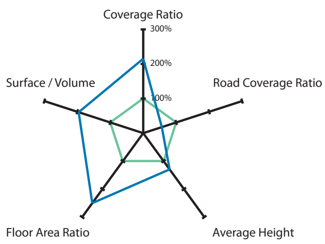




### Saint Placide CUB01




### Bonne Nouvelle CUB02

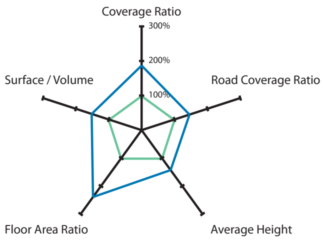


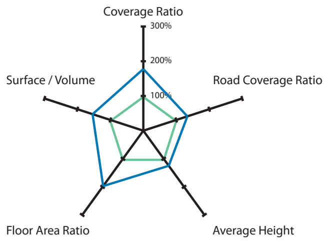

## Courcelles CUB03

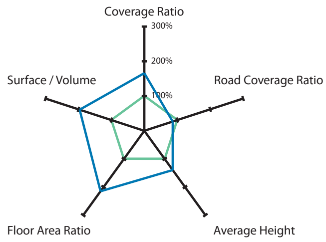
## Saint Ambroise CUB04

## Victor Hugo CUB05

Spider diagram



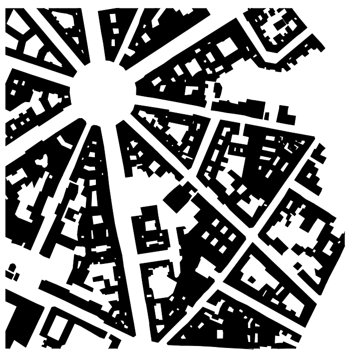




Street view

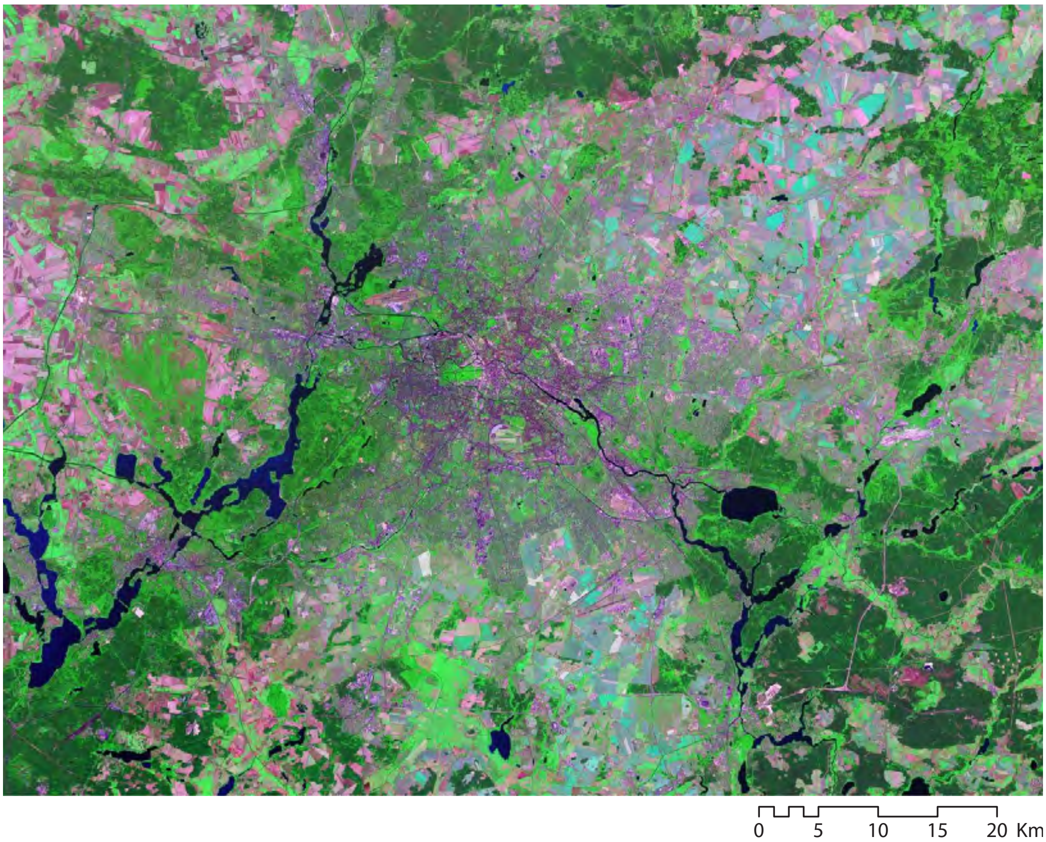
Bird's-eye-view

Satellite view

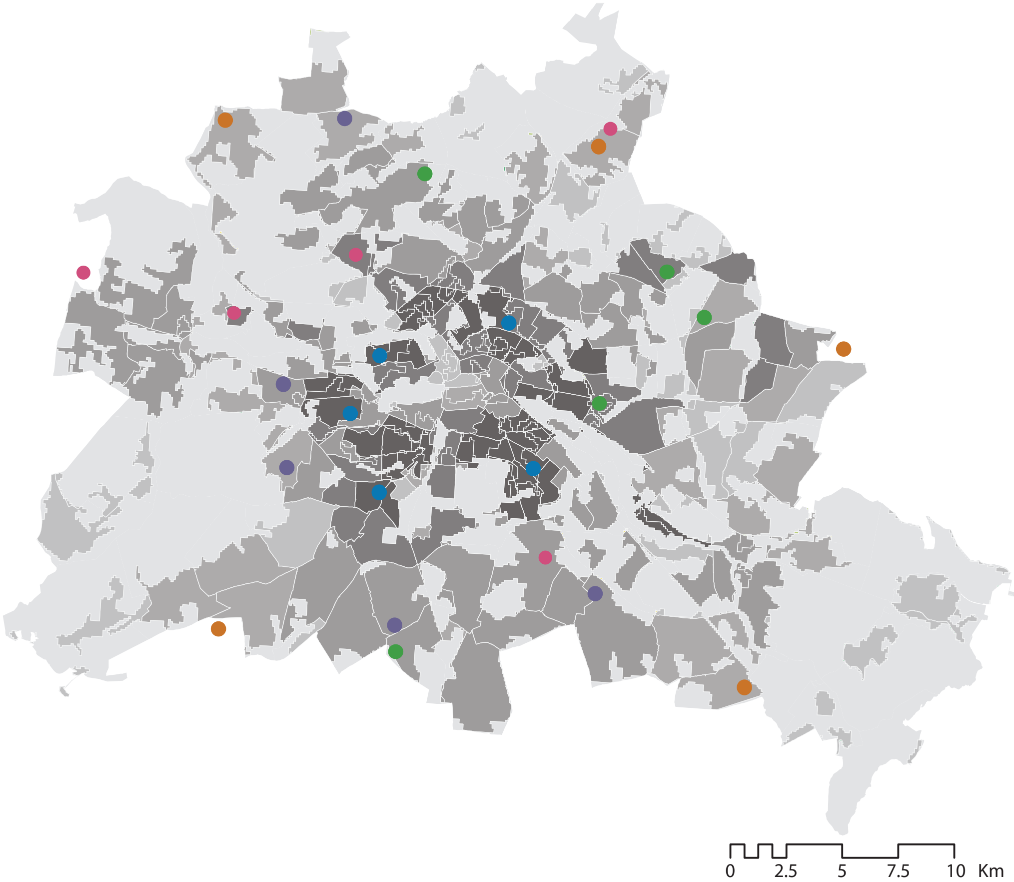
Urban footprint



# A-3 BERLIN MORPHOLOGIES




## A-3.1 DENSITY MAP AND LOCATION OF MORPHOLOGY SAMPLES




Berlin Metropolitan Area
Density (people/km$^2$)

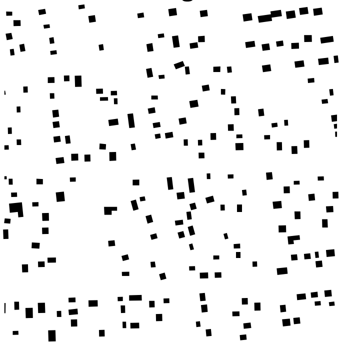
- 0 - 2500
- 2500 - 5000
- 5000 - 10,000
- 10,000 - 15,000
- 15,000 - 26,805

- Detached Housing
- Apartment Building
- Slab Housing
- Row Housing
- Compact Urban Block

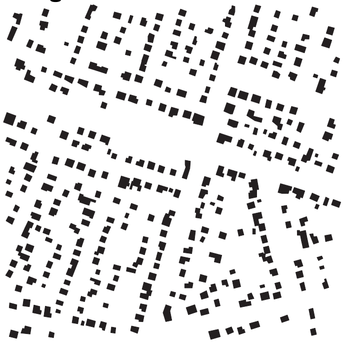
*Source: LSE Cities research*

### Detached Housing

### Hönower Siedlung DH01



### Heiligensee DH02



### Apartment Building

### Lankwitz AB01

### Neu-Westend AB02

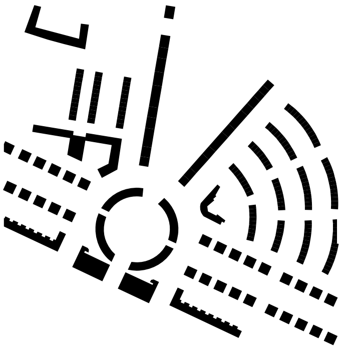
### Slab Housing

### Lichtenberg SH01

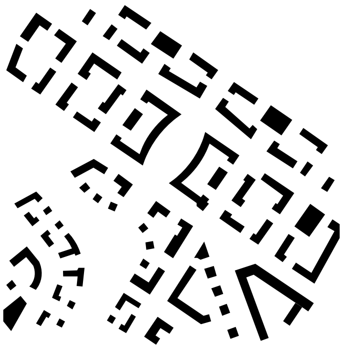
### Marienfelde SH02

### Row Housing

### Gartenstadt Falkenhöh RH01

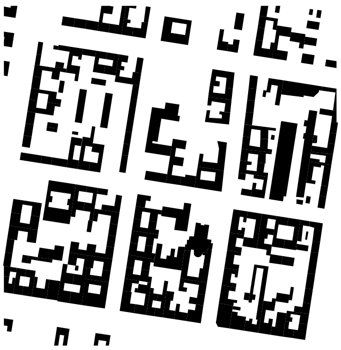


### Neu-Karow RH02

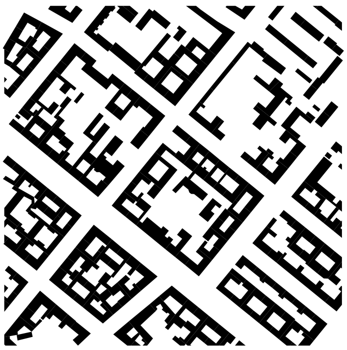


### Compact Urban Block

### Moabit CUB01

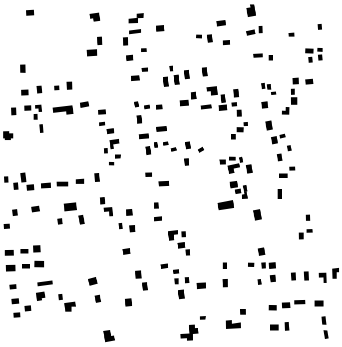


### Neukölln CUB02



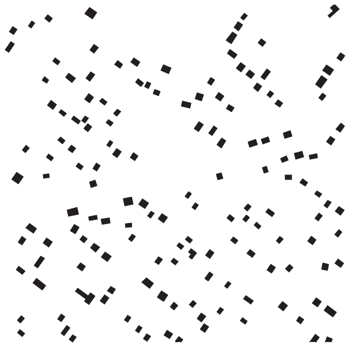
These two pages depict the five sample figure grounds for each of the five Berlin typologies

**Machnow DH03**

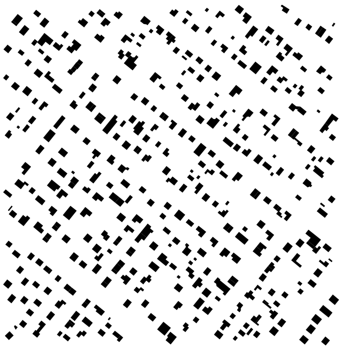


**Falkenhorst DH04**

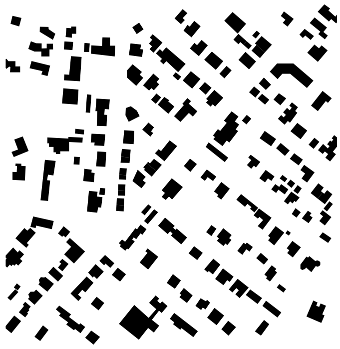
**Alt-Karow DH05**



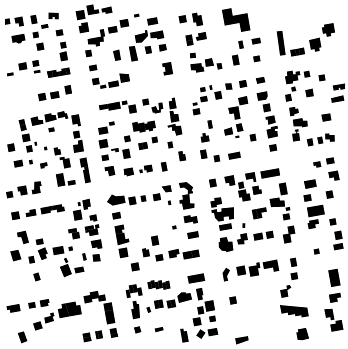
**Rudow AB03**



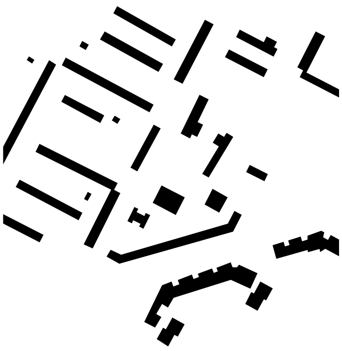
**Grünewald AB04**



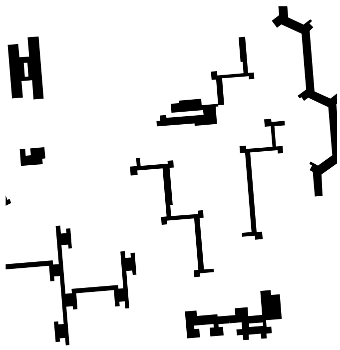
**Hermsdorf AB05**



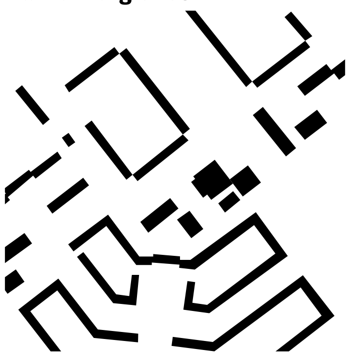
**Marzahn SH03**



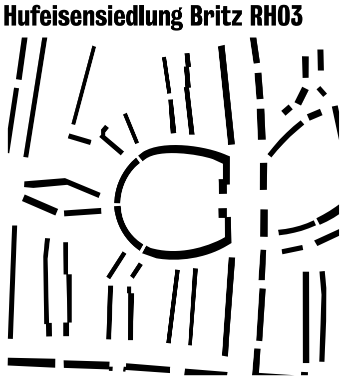
**Märkisches Viertel SH04**



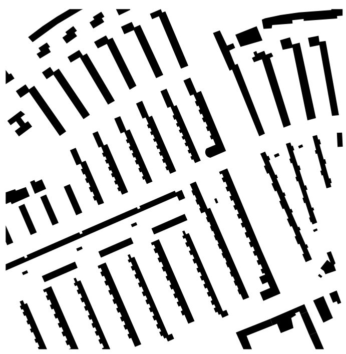
**Wartenberg SH05**



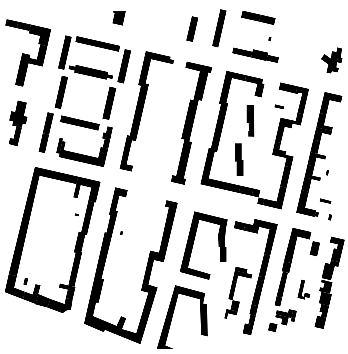
**Hufeisensiedlung Britz RH03**



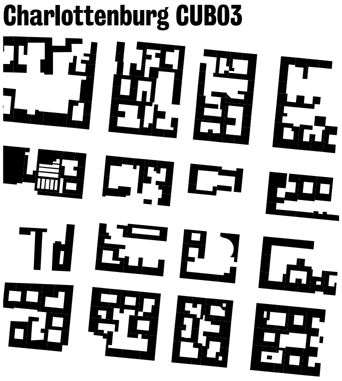
**Haselhorst RH04**



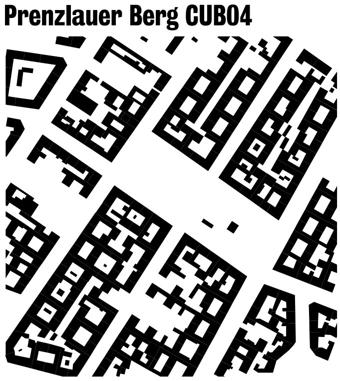
**Reinickendorf West RH05**



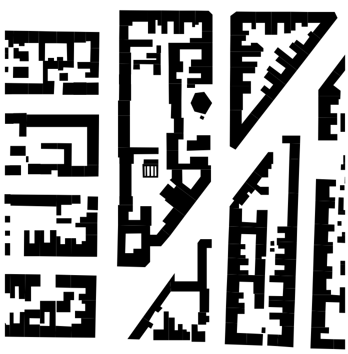
**Charlottenburg CUB03**



**Prenzlauer Berg CUB04**

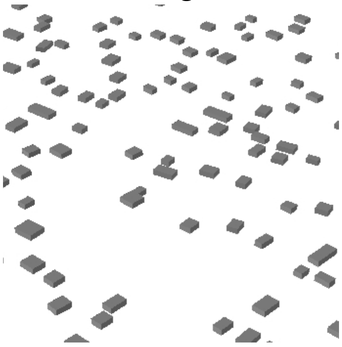


**Friedenau CUB05**

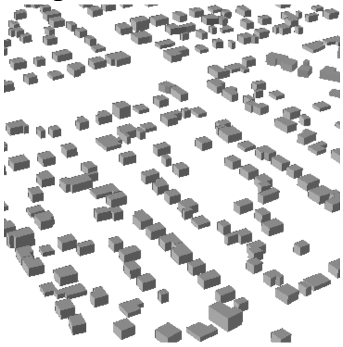


### Detached Housing

### Hönower Siedlung DH01

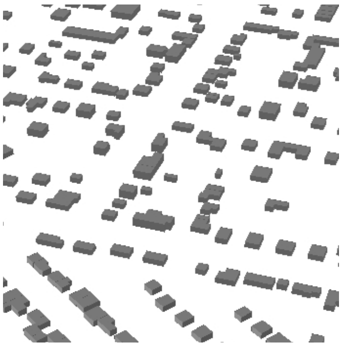


### Heiligensee DH02

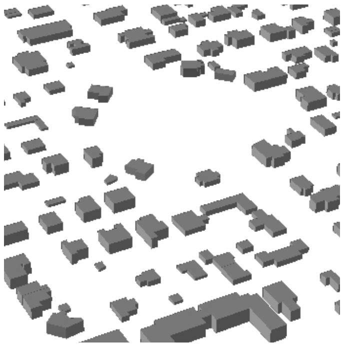


### Apartment Building

### Lankwitz AB01

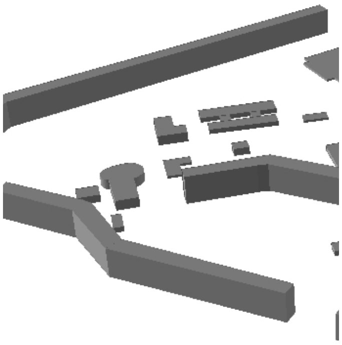


### Neu-Westend AB02

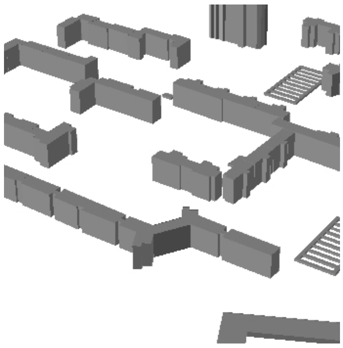


### Slab Housing

### Lichtenberg SH01

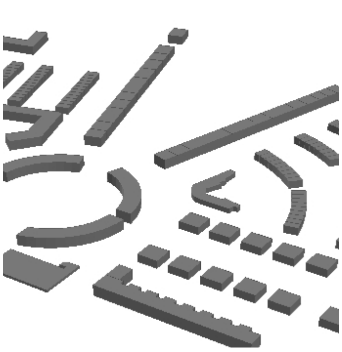


### Marienfelde SH02

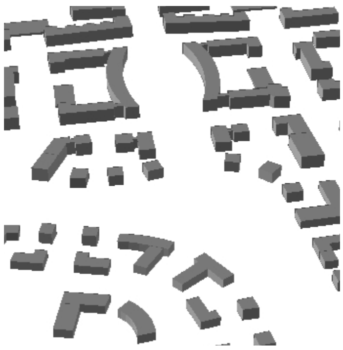


### Row Housing

### Gartenstadt Falkenhöh RH01

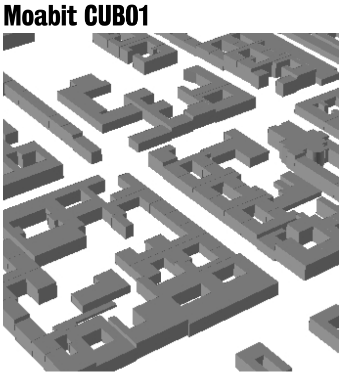


### Neu-Karow RH02

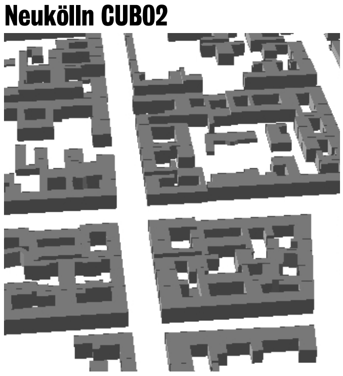


### Compact Urban Block

### Moabit CUB01

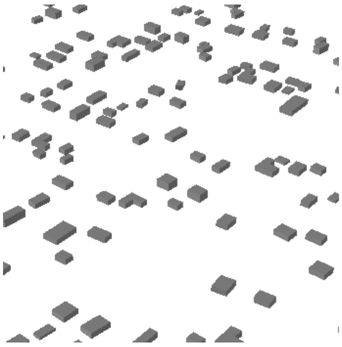


### Neukölln CUB02

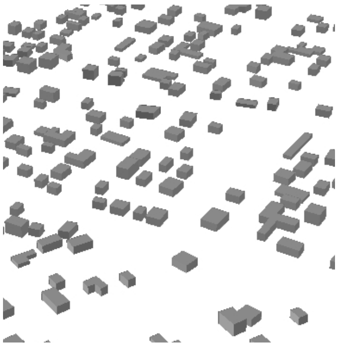


These two pages depict the five sample 3D models for each of the five Berlin typologies

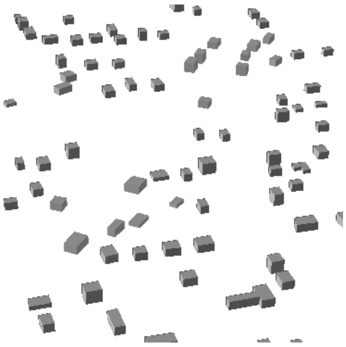
Machnow DH03



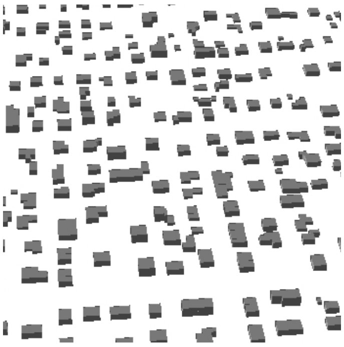
Falkenhorst DH04



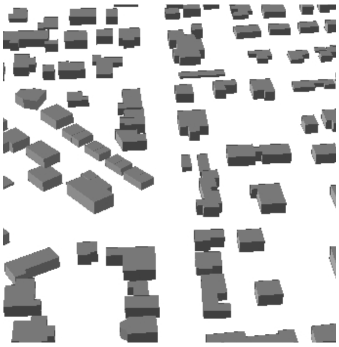
Alt-Karow DH05



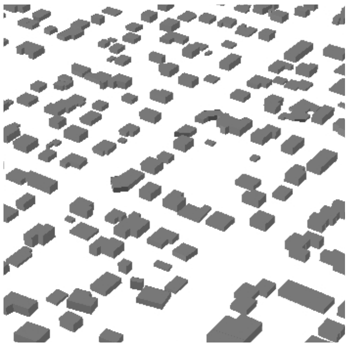
Rudow AB03



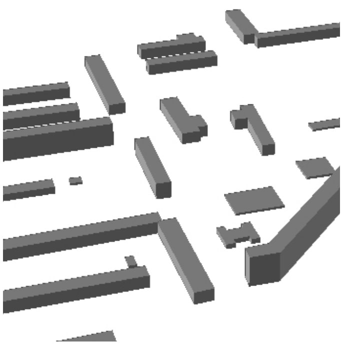
Grünewald AB04



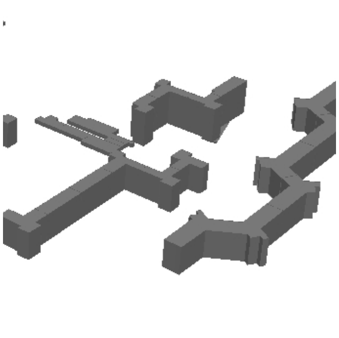
Hermsdorf AB05



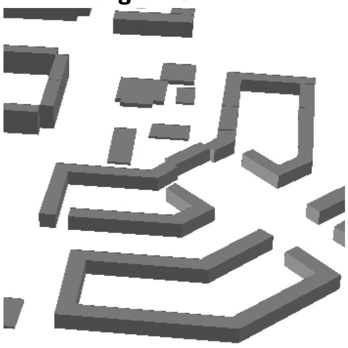
Marzahn SH03



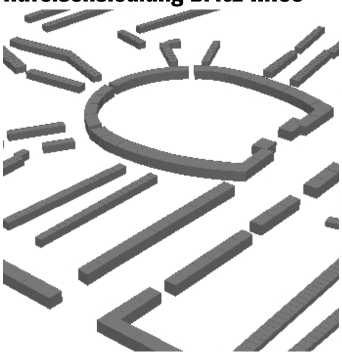
Märkisches Viertel SH04



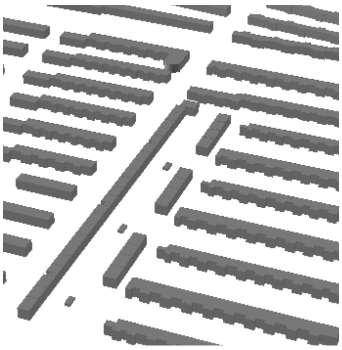
Wartenberg SH05



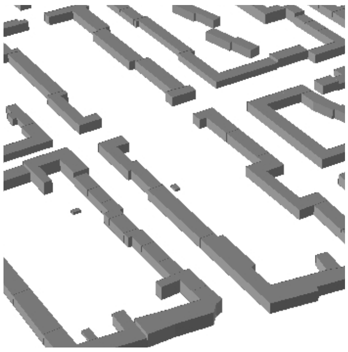
Hufeisensiedlung Britz RH03



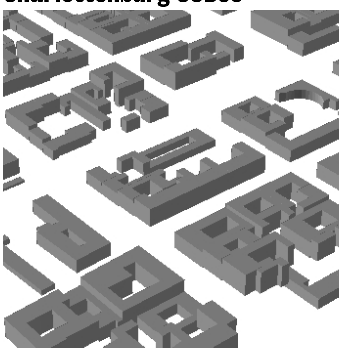
Haselhorst RH04



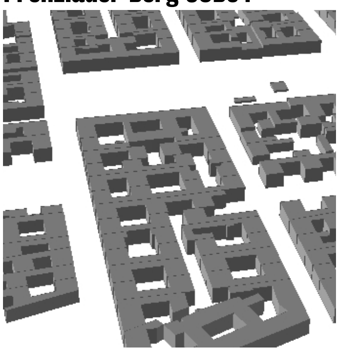
Reinickendorf West RH05



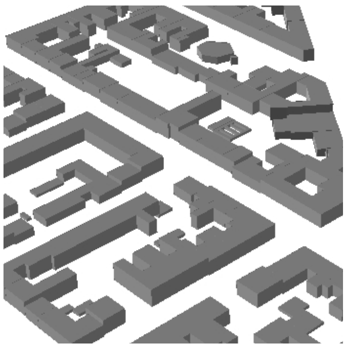
Charlottenburg CUB03



Prenzlauer Berg CUB04



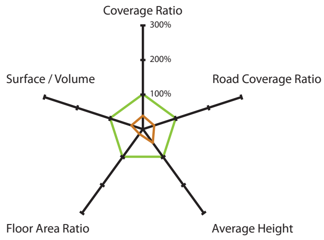
Friedenau CUB05



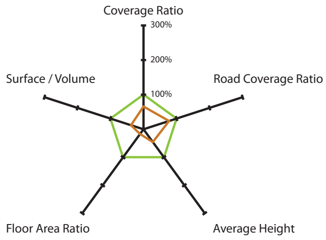
## A-3.2 DETACHED HOUSING

A visual and quantitative comparison of each Berlin sample of Detached Housing. Data covering multiple factors and images over several scales is provided to enable a multi-layered comparison of samples.

### Hönower Siedlung DH01




### Heiligensee DH02

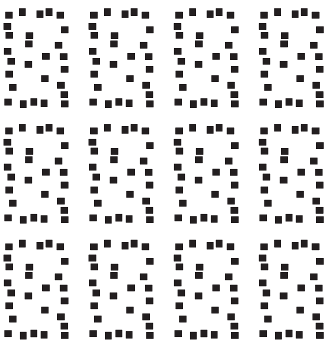


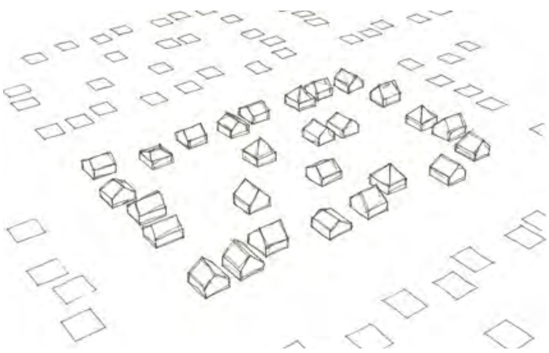

| | DH01 | DH02 | DH03 | DH04 | DH05 |
|---|---|---|---|---|---|
| **Built-up area (m²)** | 18,730 | 31,726 | 17,448 | 30,035 | 28,095 |
| **Land area (m²)** | 231,251 | 207,775 | 229,106 | 228,527 | 215,618 |
| **Coverage ratio** | 0.07 | 0.13 | 0.07 | 0.12 | 0.05 |
| **Floor area (m²)** | 37,367 | 36,887 | 36,505 | 31,743 | 30,528 |
| **Floor area ratio** | 0.15 | 0.24 | 0.15 | 0.23 | 0.11 |
| **% Built-up area** | 7.5 | 12.7 | 7.0 | 12.0 | 11.2 |
| **% Land area** | 85.0 | 70.4 | 84.7 | 79.4 | 75.0 |
| **% Road area** | 7.5 | 16.9 | 8.4 | 8.6 | 13.8 |

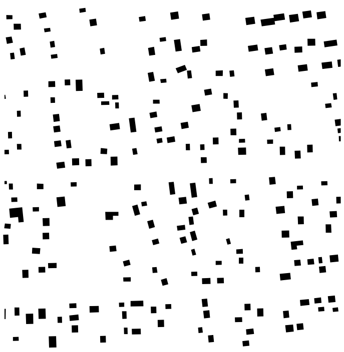

above
**Reference map**

right
**Urban footprint of idealized Detached Housing**

below
**Sketch of idealized Detached Housing**



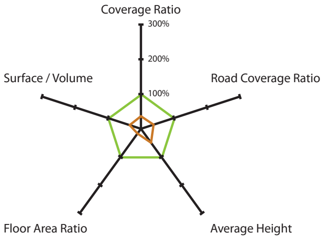




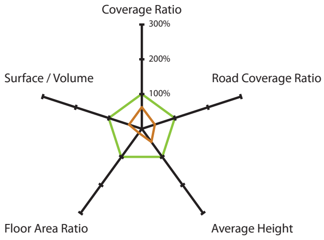
## Machnow DH03 | Falkenhorst DH04 | Alt-Karow DH05

**Spider diagram**

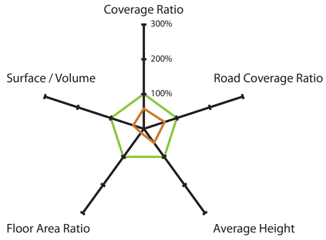
Machnow DH03




Falkenhorst DH04




Alt-Karow DH05




**Street view**



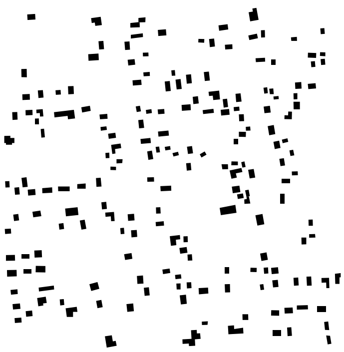
**Bird's-eye-view**

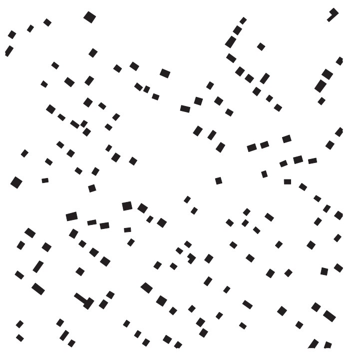


**Satellite view**



**Urban footprint**

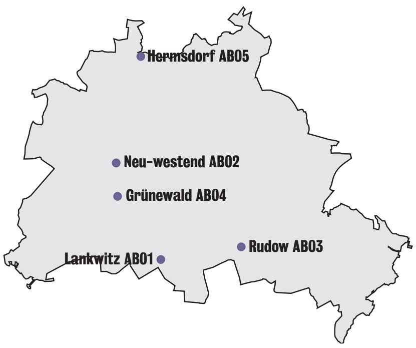




## A-3.3 APARTMENT BUILDING

A visual and quantitative comparison of each Berlin sample of Apartment Buildings. Data covering multiple factors and images over several scales is provided to enable a multi-layered comparison of samples.

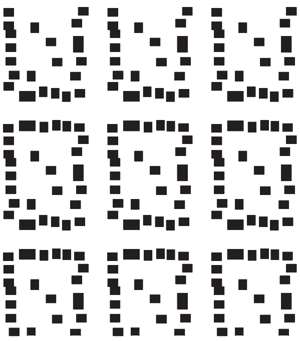
| | AB01 | AB02 | AB03 | AB04 | AB05 |
|---|---|---|---|---|---|
| **Built-up area (m²)** | 34,714 | 42,298 | 34,699 | 50,369 | 43,235 |
| **Land area (m²)** | 204,620 | 189,740 | 216,953 | 202,057 | 215,568 |
| **Coverage ratio** | 0.14 | 0.17 | 0.14 | 0.20 | 0.17 |
| **Floor area (m²)** | 75,142 | 135,431 | 66,670 | 182,797 | 103,648 |
| **Floor area ratio** | 0.30 | 0.54 | 0.27 | 0.73 | 0.41 |
| **% Built-up area** | 13.9 | 16.9 | 13.9 | 20.1 | 17.3 |
| **% Land area** | 68.0 | 59.0 | 72.9 | 60.7 | 68.9 |
| **% Road area** | 18.2 | 24.1 | 13.2 | 19.2 | 13.8 |

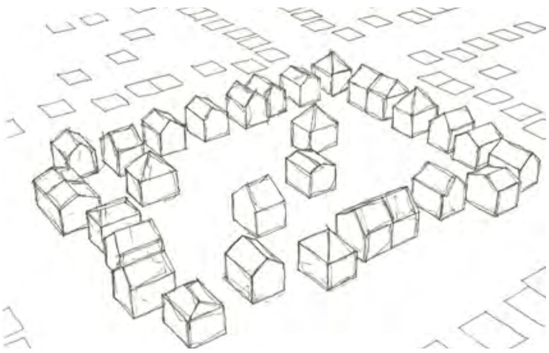



above
**Reference map**

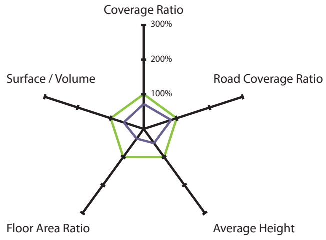
right
**Urban footprint of idealized Apartment Block**

below
**Sketch of idealized Apartment Block**

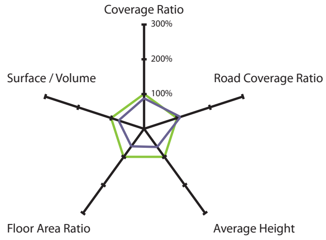




### Lankwitz AB01



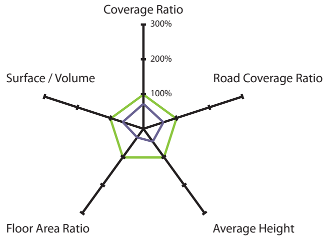

### Neu-Westend AB02



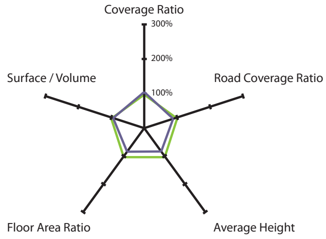

## Rudow AB03 | Grünewald AB04 | Hermsdorf AB05

### Spider diagram

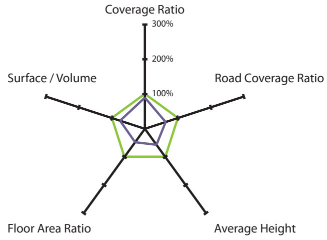
Rudow AB03




Grünewald AB04




Hermsdorf AB05

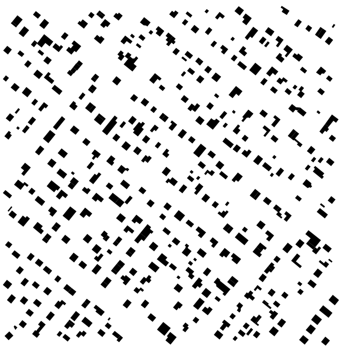


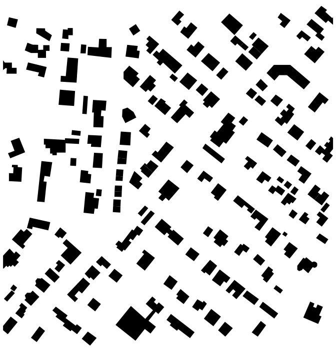

### Street view

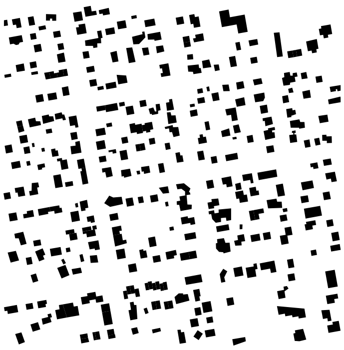
### Bird's-eye-view

### Satellite view

### Urban footprint







# A-3.4 SLAB HOUSING

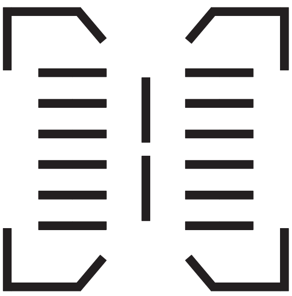
A visual and quantitative comparison of each Berlin sample of Slab Housing. Data covering multiple factors and images over several scales is provided to enable a multi-layered comparison of samples.

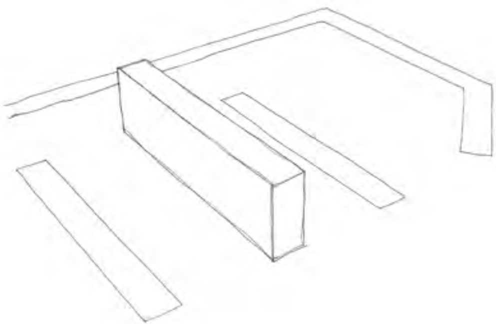
| | SH01 | SH02 | SH03 | SH04 | SH05 |
|---|---|---|---|---|---|
| **Built-up area (m²)** | 38,409 | 39,351 | 35,092 | 35,470 | 45,432 |
| **Land area (m²)** | 192,698 | 157,194 | 229,033 | 174,135 | 215,798 |
| **Coverage ratio** | 0.15 | 0.16 | 0.14 | 0.14 | 0.18 |
| **Floor area (m²)** | 286,994 | 326,018 | 240,825 | 330,200 | 280,660 |
| **Floor area ratio** | 1.15 | 1.30 | 0.96 | 1.32 | 1.12 |
| **% Built-up area** | 15.4 | 15.7 | 14.0 | 14.2 | 18.2 |
| **% Land area** | 61.7 | 47.1 | 77.6 | 55.5 | 68.1 |
| **% Road area** | 22.9 | 37.1 | 8.4 | 30.3 | 13.7 |


above
**Reference map**

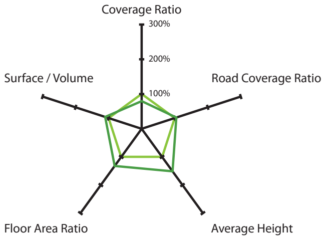
right
**Urban footprint of idealized Slab Housing**

below
**Sketch of idealized Slab Housing**

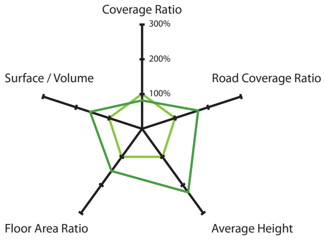




## Lichtenberg SH01




## Marienfelde SH02

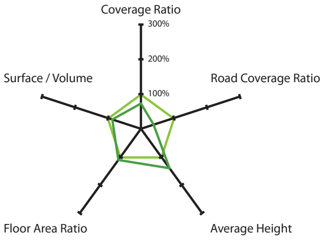


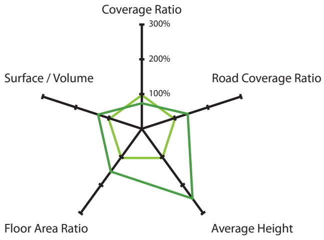

## Marzahn SH03

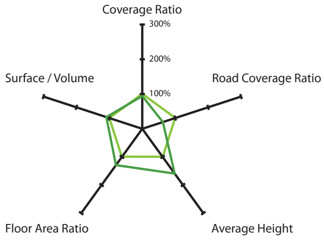
## Märkisches Viertel SH04

## Wartenberg SH05

**Spider diagram**



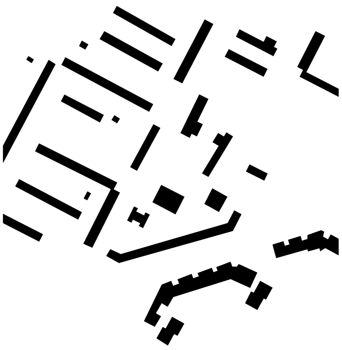



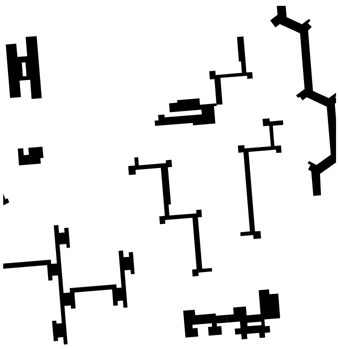

**Street view**

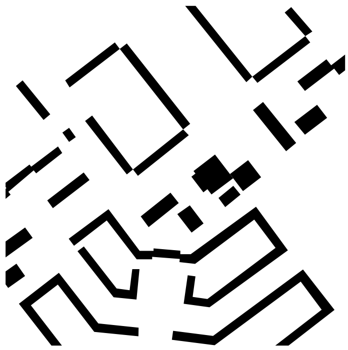
**Bird's-eye-view**

**Satellite view**

**Urban footprint**







## A-3.5 ROW HOUSING

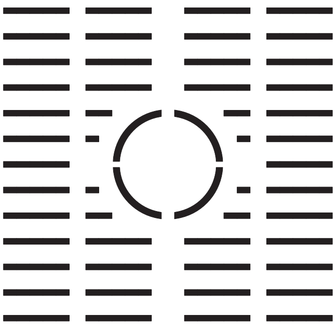
A visual and quantitative comparison of each Berlin sample of Row Housing. Data covering multiple factors and images over several scales is provided to enable a multi-layered comparison of samples.

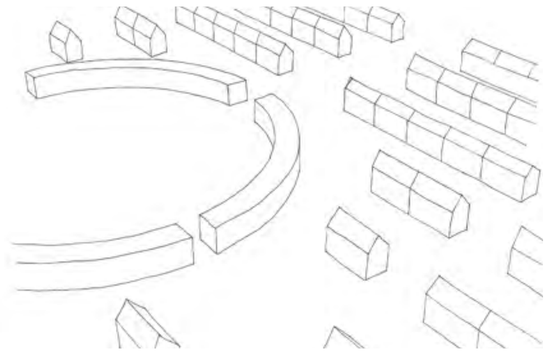
| | RH01 | RH02 | RH03 | RH04 | RH05 |
|---|---|---|---|---|---|
| **Built-up area ($m^2$)** | 38,040 | 41,687 | 37,486 | 53,922 | 53,671 |
| **Land area ($m^2$)** | 123,970 | 202,059 | 191,014 | 193,196 | 190,843 |
| **Coverage ratio** | 0.15 | 0.17 | 0.15 | 0.22 | 0.21 |
| **Floor area ($m^2$)** | 124,690 | 161,606 | 123,171 | 204,889 | 208,949 |
| **Floor area ratio** | 0.50 | 0.65 | 0.49 | 0.82 | 0.84 |
| **% Built-up area** | 15.2 | 16.7 | 15.0 | 21.6 | 21.5 |
| **% Land area** | 34.4 | 64.1 | 61.4 | 55.7 | 54.9 |
| **% Road area** | 50.4 | 19.2 | 23.6 | 22.7 | 23.7 |


above
**Reference map**

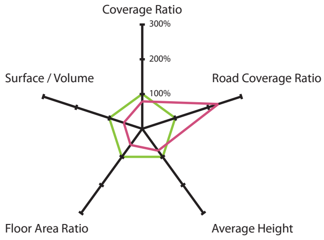
right
**Urban footprint of idealized Siedlung**

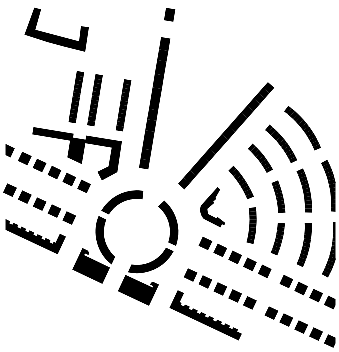
below
**Sketch of idealized Siedlung**



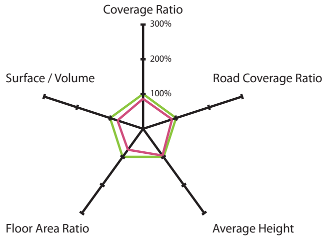


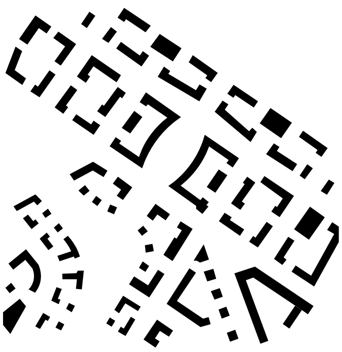
### Gartenstadt Falkenhöh RH01



### Neu-Karow RH02

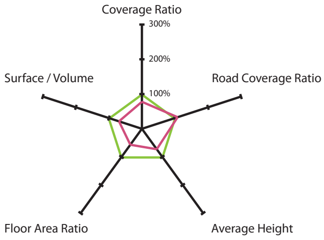


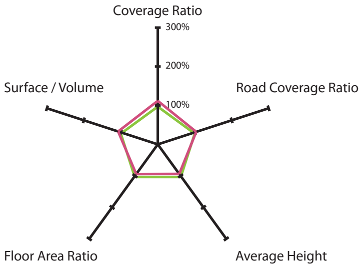
## Hufeisensiedlung Britz RH03 | Haselhorst RH04 | Reinickendorf West RH05

**Spider diagram**

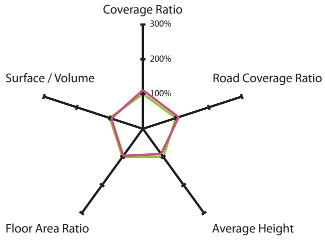
Hufeisensiedlung Britz RH03



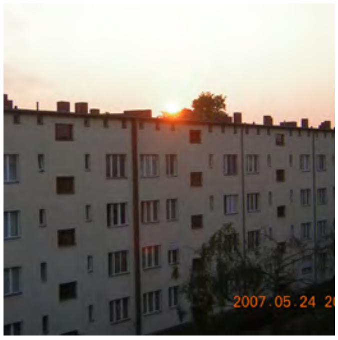

Haselhorst RH04




Reinickendorf West RH05



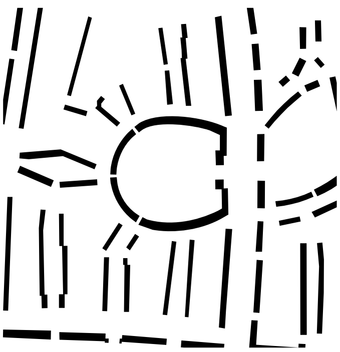

**Street view**

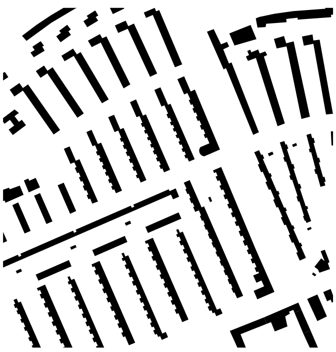


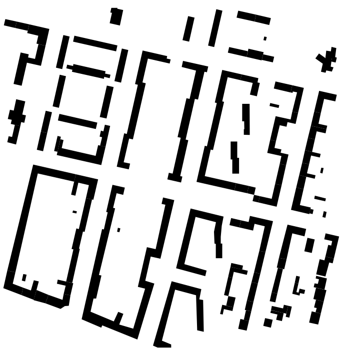

**Bird's-eye-view**

**Satellite view**

**Urban footprint**



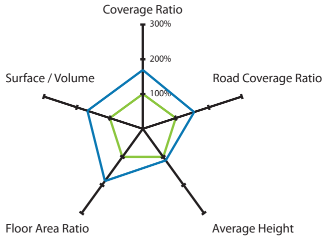




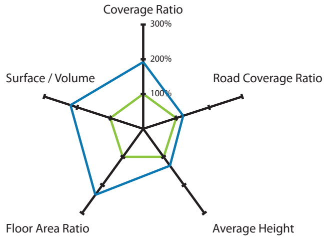
## A-3.6 COMPACT URBAN BLOCK

A visual and quantitative comparison of each Berlin sample of Compact Urban Blocks. Data covering multiple factors and images over several scales is provided to enable a multi-layered comparison of samples.

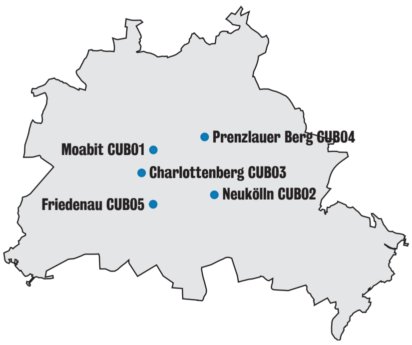
### Moabit CUB01

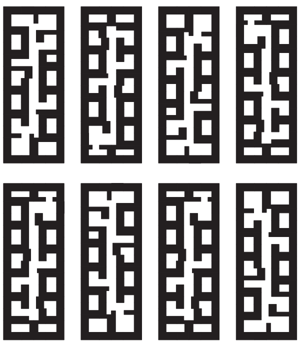



### Neukölln CUB02




| | CUB01 | CUB02 | CUB03 | CUB04 | CUB05 |
|---|---|---|---|---|---|
| **Built-up area (m²)** | 81,624 | 92,670 | 84,785 | 105,051 | 91,573 |
| **Land area (m²)** | 165,053 | 183,894 | 158,807 | 186,531 | 179,909 |
| **Coverage ratio** | 0.33 | 0.37 | 0.34 | 0.42 | 0.37 |
| **Floor area (m²)** | 403,715 | 510,324 | 473,146 | 593,547 | 422,468 |
| **Floor area ratio** | 1.61 | 2.04 | 1.89 | 2.37 | 1.69 |
| **% Built-up area** | 32.6 | 37.1 | 33.9 | 42.0 | 36.6 |
| **% Land area** | 33.4 | 36.5 | 29.6 | 32.6 | 35.3 |
| **% Road area** | 34.0 | 26.4 | 36.5 | 25.4 | 28.0 |

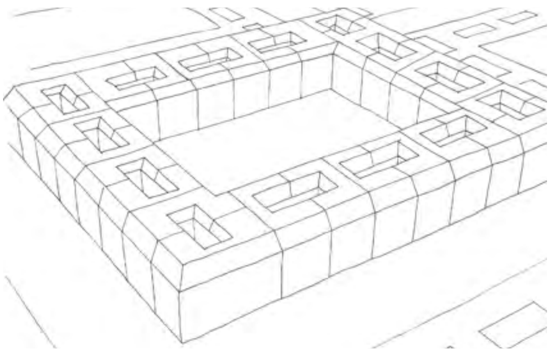


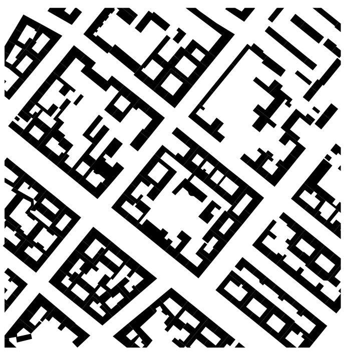



above
**Reference map**

right
**Urban footprint of idealized Regular Urban Block**

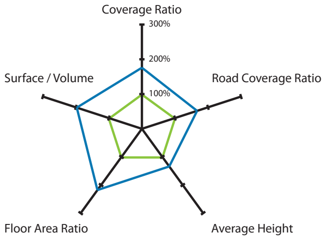
below
**Sketch of idealized Regular Urban Block**

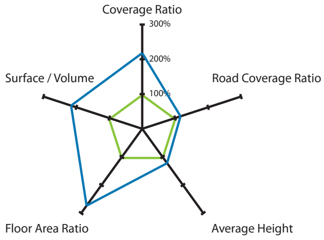


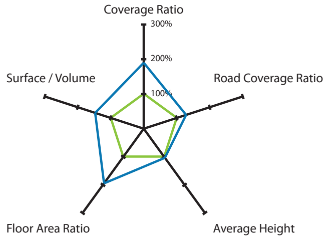


## Charlottenburg CUB03 | Prenzlauer Berg CUB04 | Friedenau CUB05

### Spider diagram



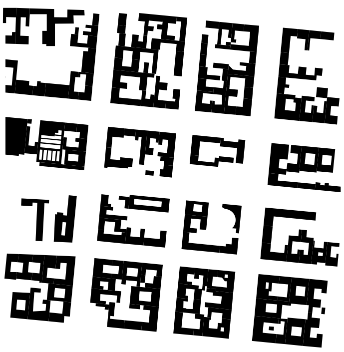



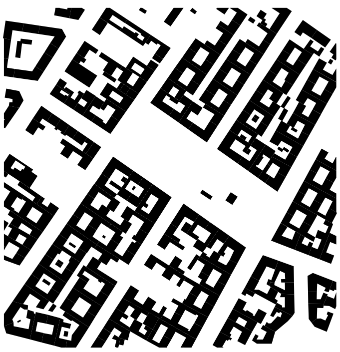

### Street view

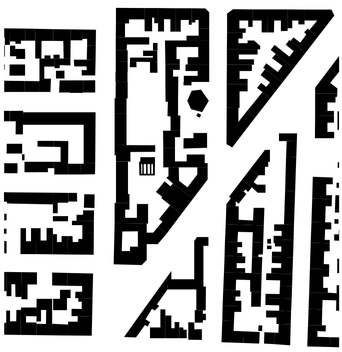
### Bird's-eye-view

### Satellite view

### Urban footprint

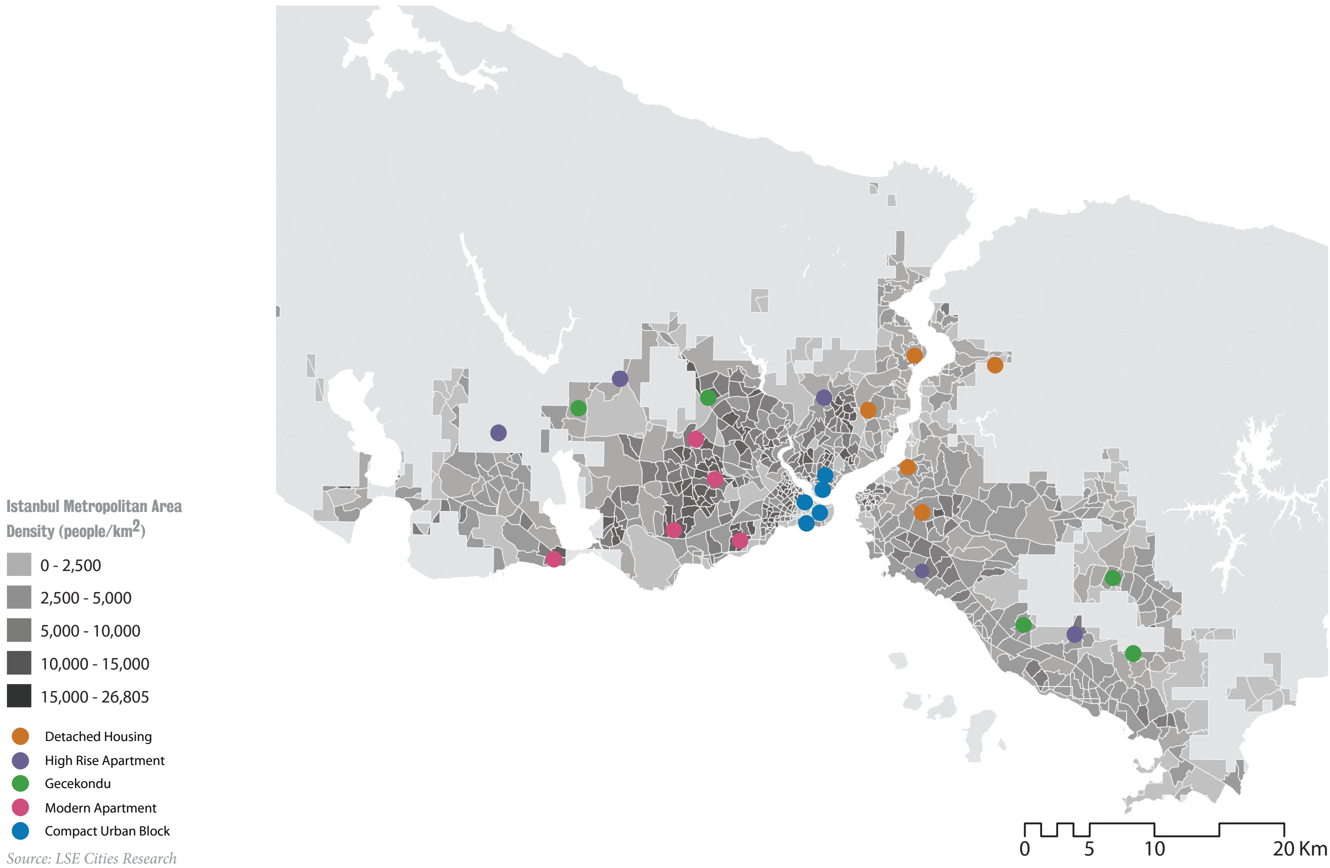






# A-4 ISTANBUL MORPHOLOGIES

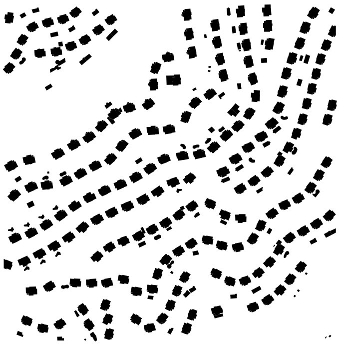

## A-4.1 DENSITY MAP AND LOCATION OF MORPHOLOGY SAMPLES




*Source: LSE Cities Research*

**Detached Housing**

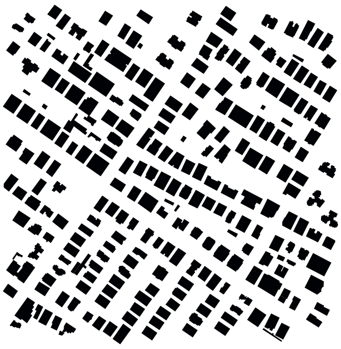
**Acarkent DH01**



**Küçük Çamlıca DH02**

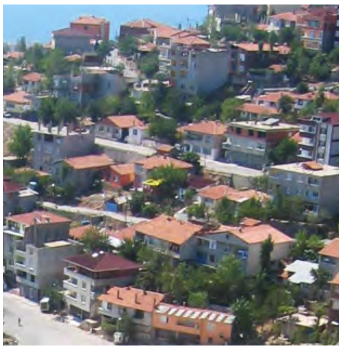
**High Rise Apartment**

**Erenköy HRA01**

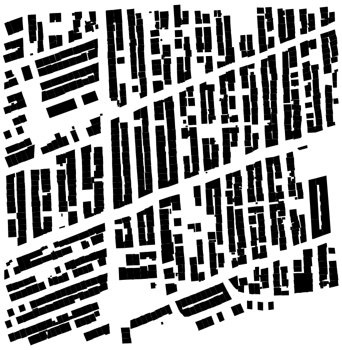


**Bahcesehir HRA02**

**Gecekondu**



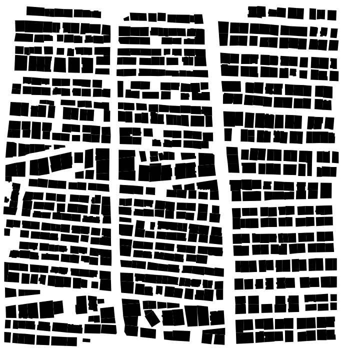
**50. Yıl G01**



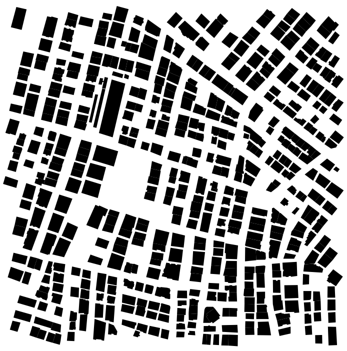
**Sultanbeyli G02**

**Modern Apartment**

**Zafer MA01**



**Denizköskler MA02**



**Compact Urban Block**

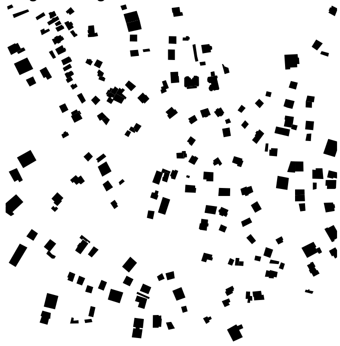
**Tophane CUB01**

**Tarlabası CUB02**

These two pages depict the five sample figure grounds for each of the five Istanbul typologies

Levent DH03

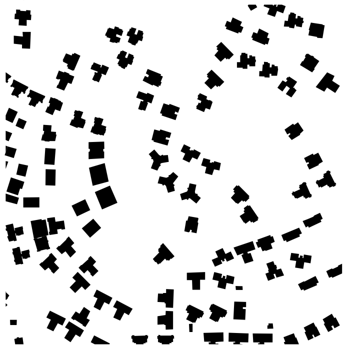
Beylerbeyi DH04



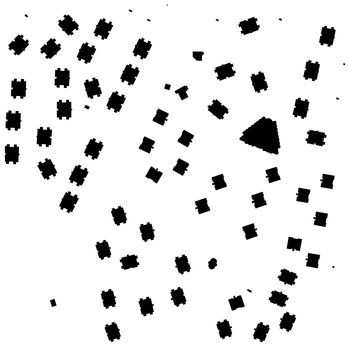
Yeniköy DH05

Kagıthane HRA03

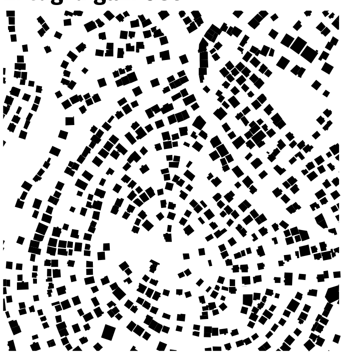
Ugur Mumcu HRA04



Basaksehir HRA05



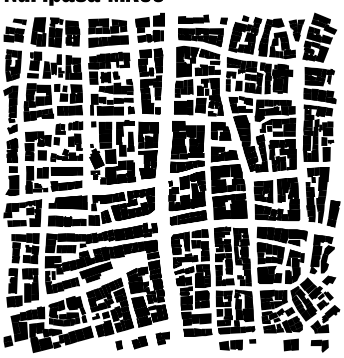
Ertugrulgazi G03



Altınsehir G04

Gülensu G05

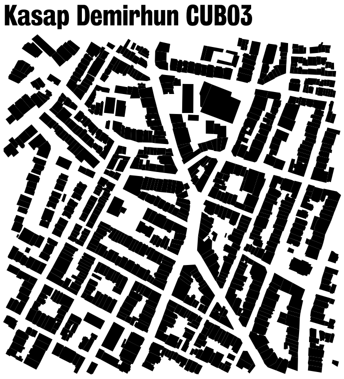
Nuripasa MA03



Oruçreis MA04

Nenehatun MA05

Kasap Demirhun CUB03

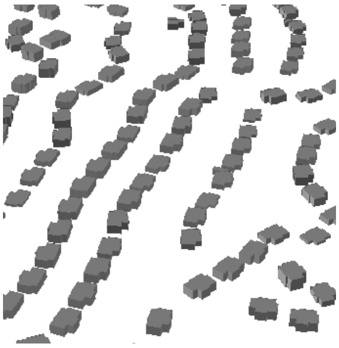


Kumkapı CUB04

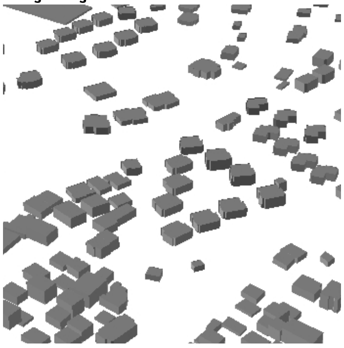
Süleymaniye CUB05

### Detached Housing

### Acarkent DH01

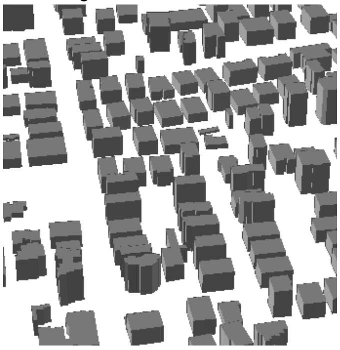


### Küçük Çamlıca DH02

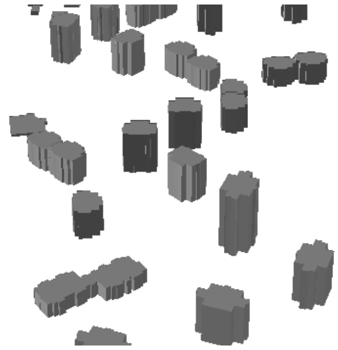


### High Rise Apartment

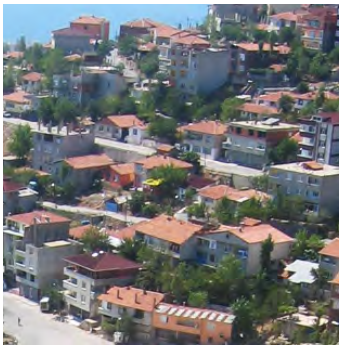
### Erenköy HRA01



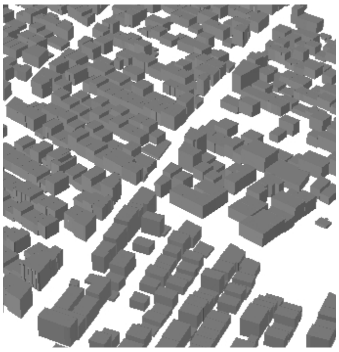
### Bahcesehir HRA02



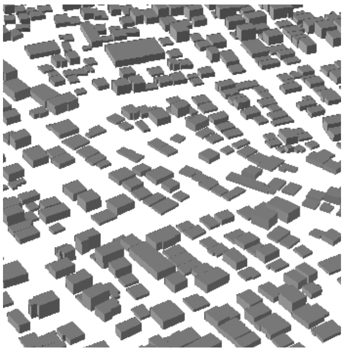
### Gecekondu



### 50. Yıl G01

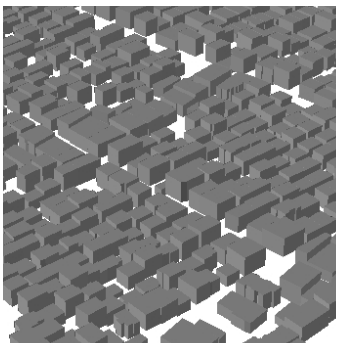


### Sultanbeyli G02

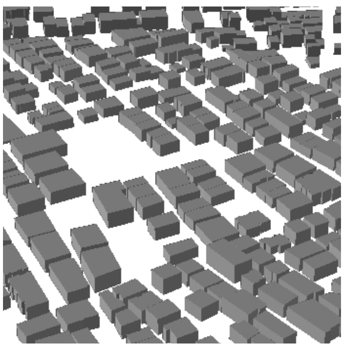


### Modern Apartment

### Zafer MA01

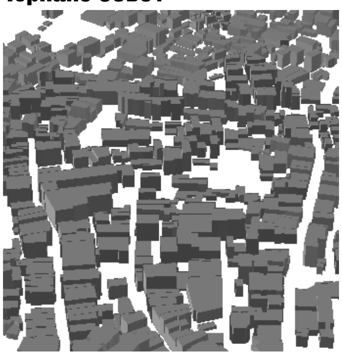


### Denizköskler MA02

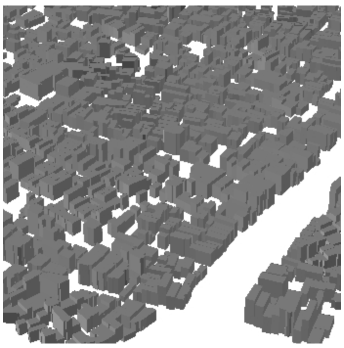


### Compact Urban Block

### Tophane CUB01

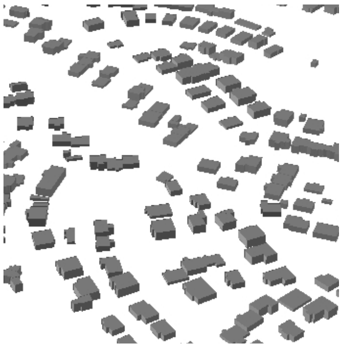


### Tarlabası CUB02

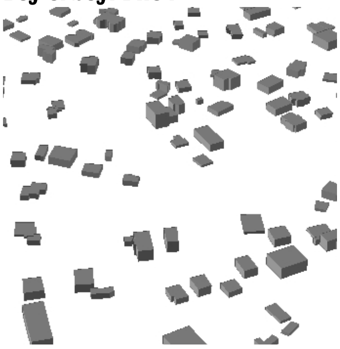


These two pages depict the five sample 3D models for each of the five Istanbul typologies

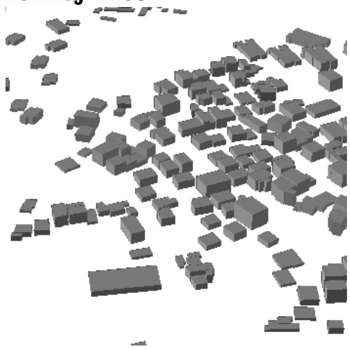
**Levent DH03**



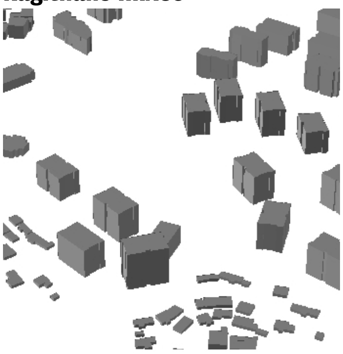
**Beylerbeyi DH04**



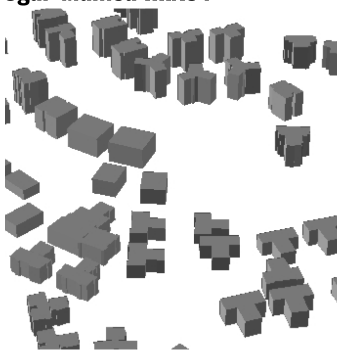
**Yeniköy DH05**



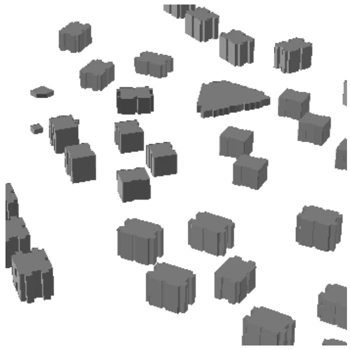
**Kagıthane HRA03**



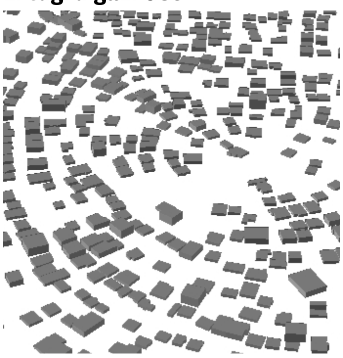
**Ugur Mumcu HRA04**



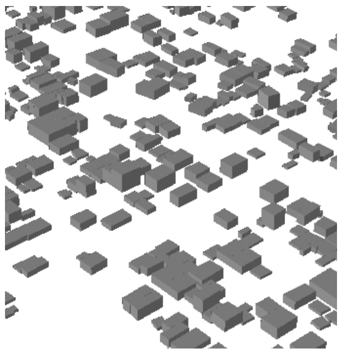
**Basaksehir HRA05**



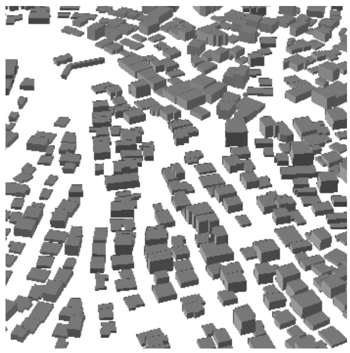
**Ertugrulgazi G03**



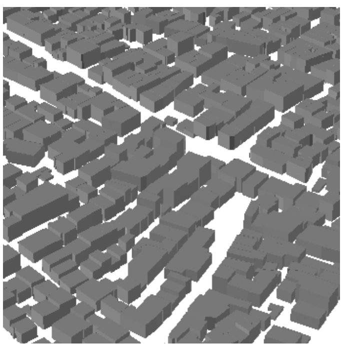
**Altınsehir G04**



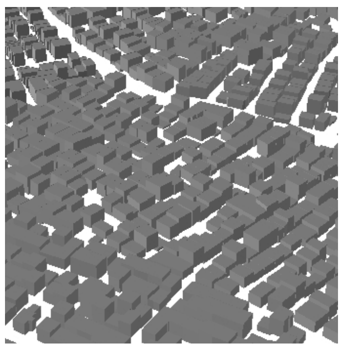
**Gülensu G05**



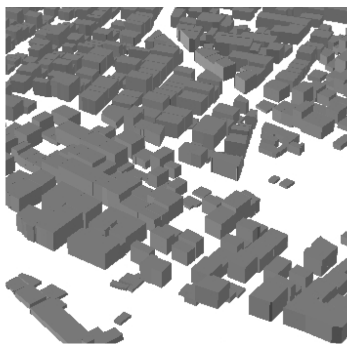
**Nuripasa MA03**



**Oruçreis MA04**

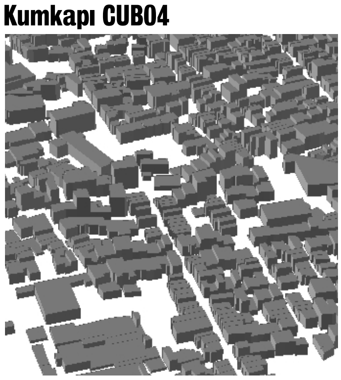


**Nenehatun MA05**

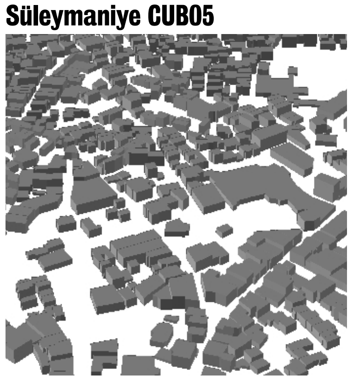


**Kasap Demirhun CUB03**

**Kumkapı CUB04**



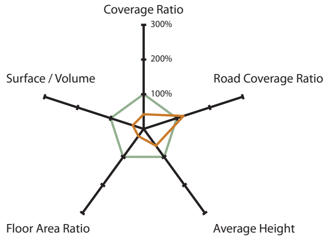
**Süleymaniye CUB05**



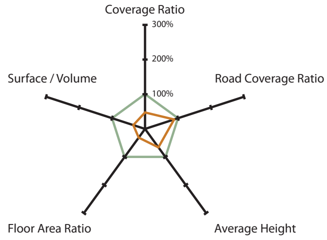
## A-4.2 DETACHED HOUSING

A visual and quantitative comparison of each Istanbul sample of Detached Housing. Data covering multiple factors and images over several scales is provided to enable a multi-layered comparison of samples.

### Acarkent DH01




### Küçük Çamlıca DH02

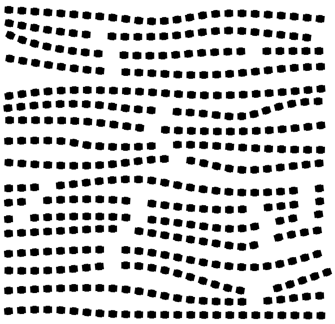


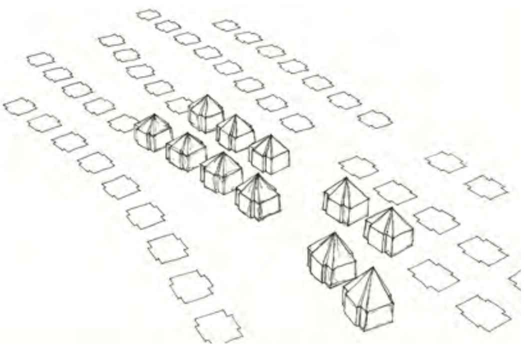

| | DH01 | DH02 | DH03 | DH04 | DH05 |
|---|---|---|---|---|---|
| **Built-up area (m²)** | 35,439 | 39,780 | 48,094 | 27,267 | 45,277 |
| **Land area (m²)** | 185,638 | 202,945 | 209,470 | 198,096 | 183,295 |
| **Coverage ratio** | 0.14 | 0.16 | 0.19 | 0.11 | 0.18 |
| **Floor area (m²)** | 89,804 | 108,001 | 108,368 | 70,903 | 125,364 |
| **Floor area ratio** | 0.36 | 0.43 | 0.43 | 0.28 | 0.50 |
| **% Built-up area** | 14.2 | 15.9 | 19.2 | 10.9 | 18.1 |
| **% Land area** | 60.1 | 65.3 | 64.6 | 68.3 | 55.2 |
| **% Road area** | 22.9 | 37.1 | 8.4 | 30.3 | 13.7 |

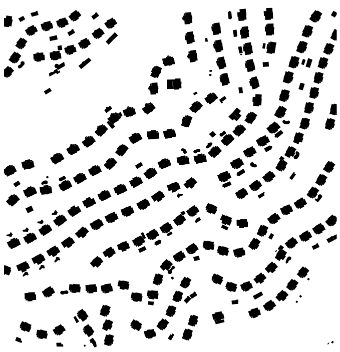

above
**Reference map**

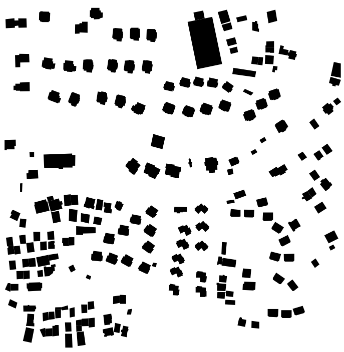
right
**Urban footprint of idealized Detached Housing**

below
**Sketch of idealized Detached Housing**





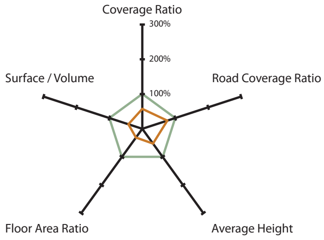




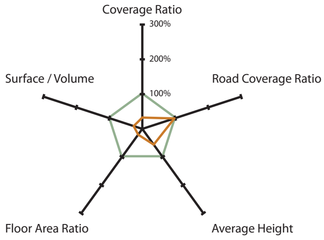
## Levent DH03 | Beylerbeyi DH04 | Yeniköy DH05

### Spider diagram

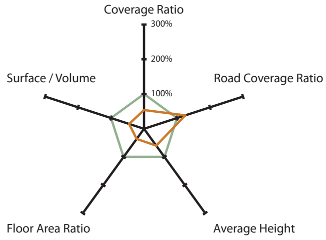
Levent DH03




Beylerbeyi DH04

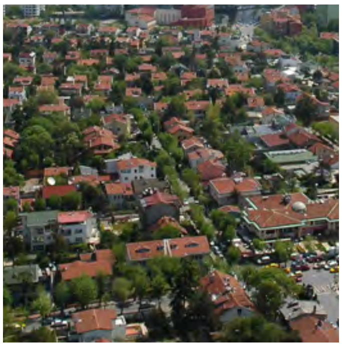



Yeniköy DH05



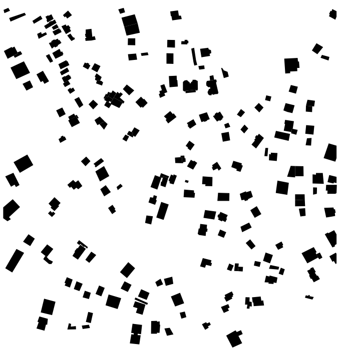

### Street view

### Bird's-eye-view



### Satellite view

### Urban footprint



## A-4.3 HIGH RISE APARTMENT

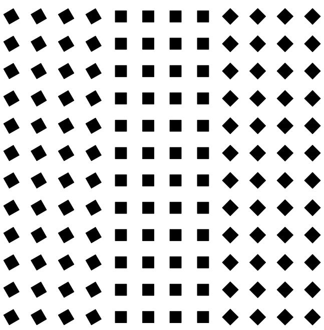
A visual and quantitative comparison of each Istanbul sample of High Rise Apartments. Data covering multiple factors and images over several scales is provided to enable a multi-layered comparison of samples.

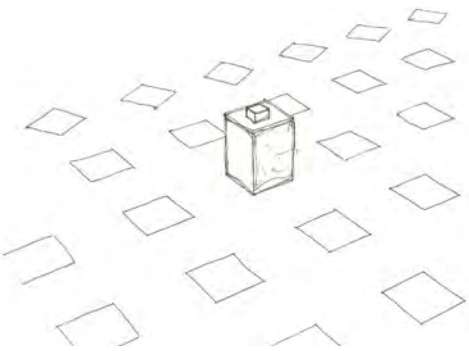
| | HRA01 | HRA02 | HRA03 | HRA04 | HRA05 |
|---|---|---|---|---|---|
| **Built-up area (m²)** | 80,291 | 21,490 | 39,613 | 42,273 | 27,490 |
| **Land area (m²)** | 235,136 | 175,668 | 164,554 | 197,791 | 162,274 |
| **Coverage ratio** | 0.32 | 0.09 | 0.16 | 0.17 | 0.11 |
| **Floor area (m²)** | 508,455 | 225,508 | 272,157 | 347,270 | 246,823 |
| **Floor area ratio** | 2.03 | 0.90 | 1.09 | 1.39 | 0.99 |
| **% Built-up area** | 32.1 | 8.6 | 15.8 | 16.9 | 11.0 |
| **% Land area** | 61.9 | 61.7 | 50.0 | 62.2 | 53.9 |
| **% Road area** | 22.9 | 37.1 | 8.4 | 30.3 | 13.7 |


above
**Reference map**

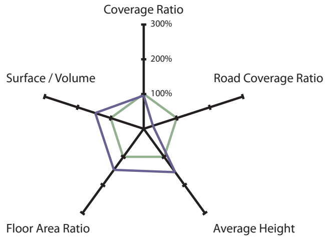
right
**Urban footprint of idealized High Rise Block Housing**

below
**Sketch of idealized High Rise Block Housing**

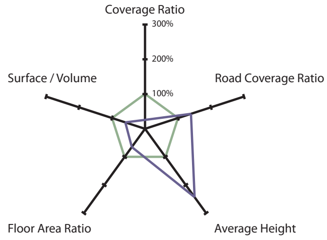


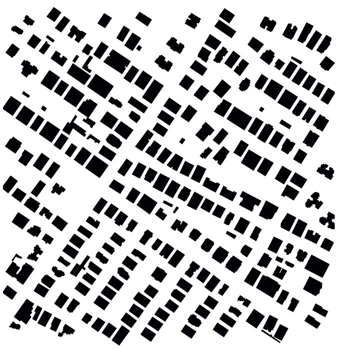


### Erenköy HRA01




### Bahcesehir HRA02

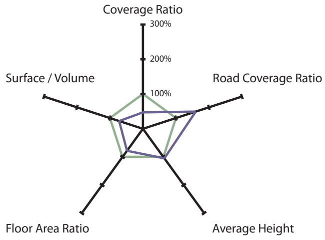


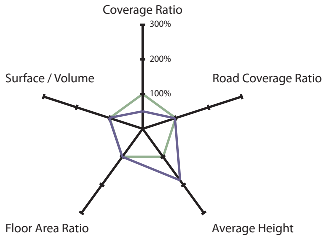
## Kagıthane HRA03 | Ugur Mumcu HRA04 | Basaksehir HRA05

**Spider diagram**

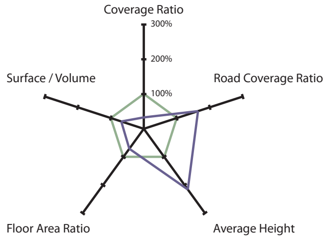
Kagıthane HRA03




Ugur Mumcu HRA04



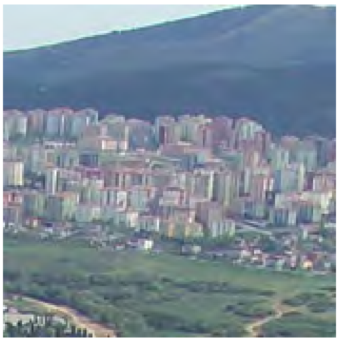

Basaksehir HRA05




**Street view**



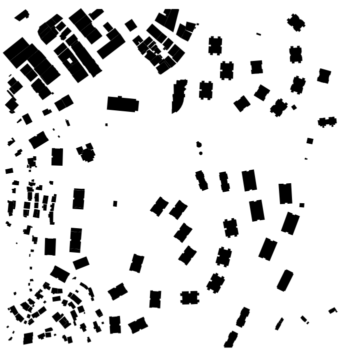
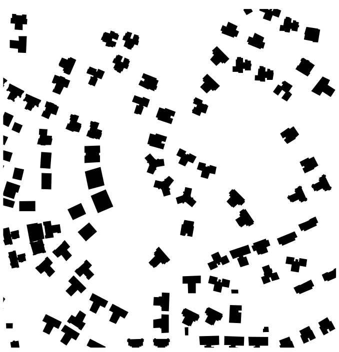
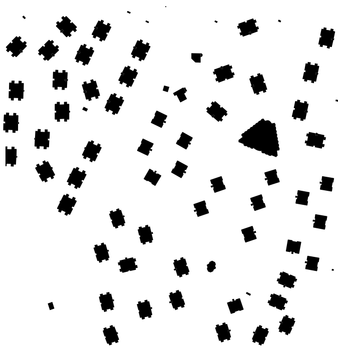
**Bird's-eye-view**


**Satellite view**



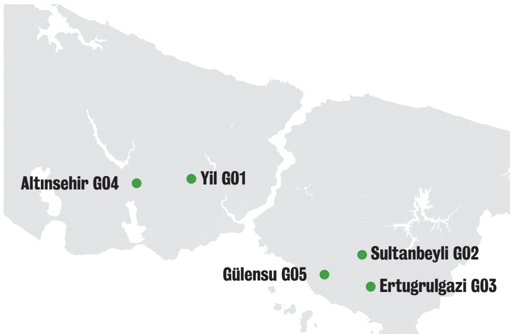
**Urban footprint**

## A-4.4 GECEKONDU

A visual and quantitative comparison of each Istanbul sample of Gecekondu. Data covering multiple factors and images over several scales is provided to enable a multi-layered comparison of samples.

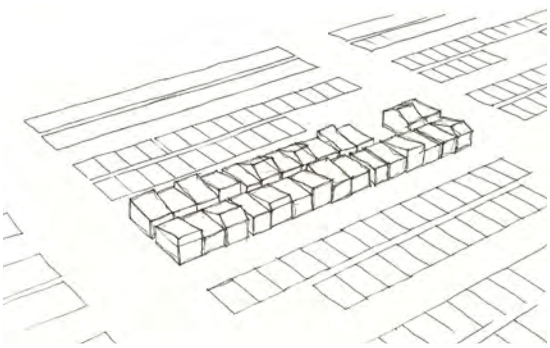
| | G01 | G02 | G03 | G04 | G05 |
|---|---|---|---|---|---|
| **Built-up area (m²)** | 110,288 | 87,491 | 64,091 | 64,825 | 95,655 |
| **Land area (m²)** | 171,538 | 212,008 | 201,411 | 208,600 | 211,800 |
| **Coverage ratio** | 0.44 | 0.35 | 0.26 | 0.26 | 0.38 |
| **Floor area (m²)** | 434,191 | 213,321 | 88,727 | 176,609 | 213,714 |
| **Floor area ratio** | 1.74 | 0.85 | 0.35 | 0.71 | 0.85 |
| **% Built-up area** | 44.1 | 35.0 | 25.6 | 25.9 | 38.3 |
| **% Land area** | 24.5 | 49.8 | 54.9 | 57.5 | 46.5 |
| **% Road area** | 22.9 | 37.1 | 8.4 | 30.3 | 13.7 |



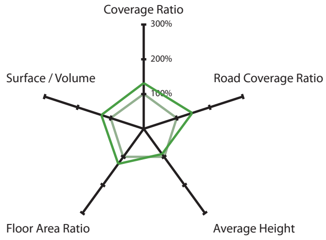

above
**Reference map**

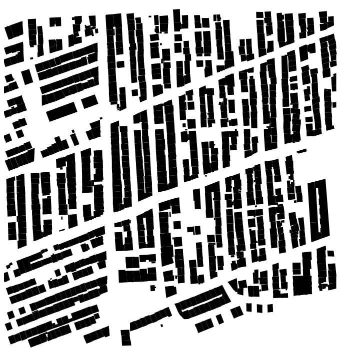
right
**Urban footprint of idealized Gecekondu Housing**

below
**Sketch of idealized Gecekondu Housing**

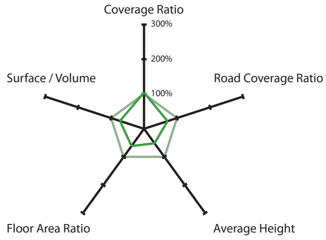


### Yıl G01



### Sultanbeyli G02

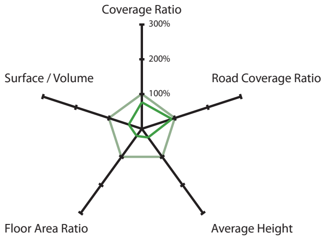


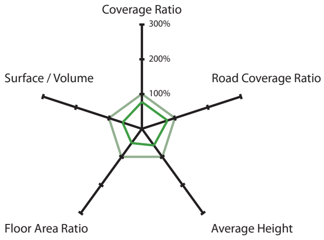

## Ertugrulgazi G03

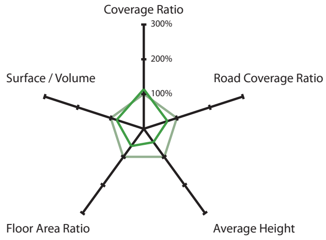
## Altınsehir G04

## Gülensu G05

Spider diagram

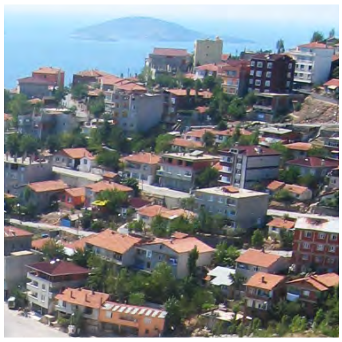


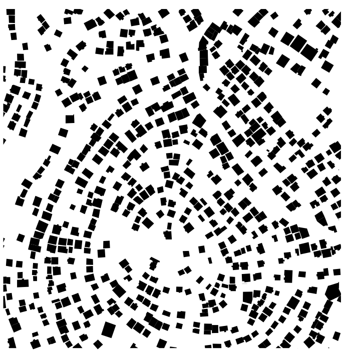

Street view

Bird's-eye-view



Satellite view

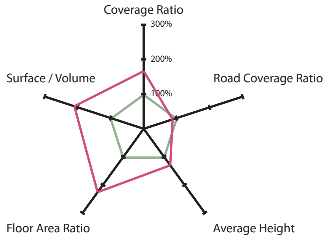
Urban footprint



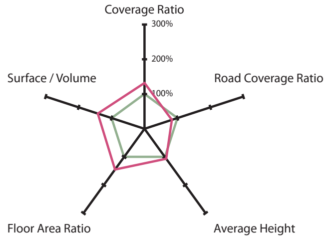
# A-4.5 MODERN APARTMENT

A visual and quantitative comparison of each Istanbul sample of Modern Apartments. Data covering multiple factors and images over several scales is provided to enable a multi-layered comparison of samples.

## Zafer MA01




## Denizköskler MA02

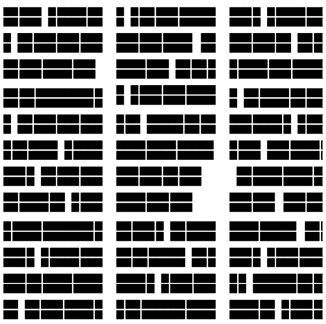


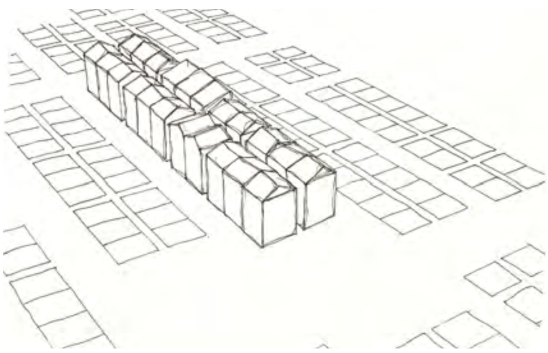

| | MA01 | MA02 | MA03 | MA04 | MA05 |
|---|---|---|---|---|---|
| **Built-up area (m²)** | 139,411 | 110,552 | 139,689 | 147,607 | 110,162 |
| **Land area (m²)** | 203,258 | 205,670 | 201,578 | 202,120 | 177,178 |
| **Coverage ratio** | 0.56 | 0.44 | 0.56 | 0.59 | 0.44 |
| **Floor area (m²)** | 786,775 | 503,965 | 684,194 | 622,971 | 511,386 |
| **Floor area ratio** | 3.15 | 2.02 | 2.74 | 2.49 | 2.05 |
| **% Built-up area** | 55.8 | 44.2 | 55.9 | 59.0 | 44.1 |
| **% Land area** | 25.5 | 38.0 | 24.8 | 21.8 | 26.8 |
| **% Road area** | 22.9 | 37.1 | 8.4 | 30.3 | 13.7 |

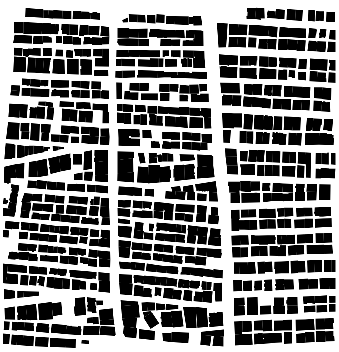

above
**Reference map**

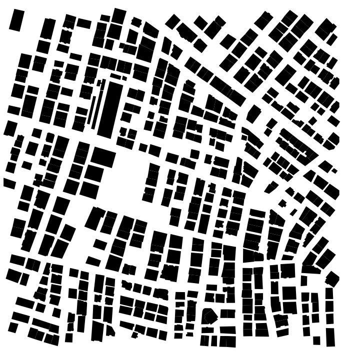
right
**Urban footprint of idealized Post-Gecekondu Housing**

below
**Sketch of idealized Post-Gecekondu Housing**





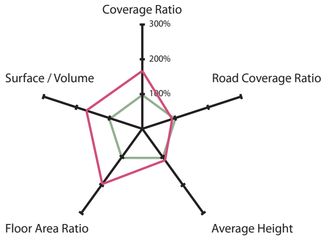




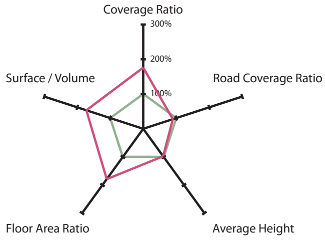
## Nuripasa MA03 | Oruçreis MA04 | Nenehatun MA05

**Spider diagram**

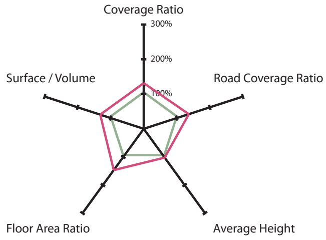
Nuripasa MA03




Oruçreis MA04




Nenehatun MA05




**Street view**



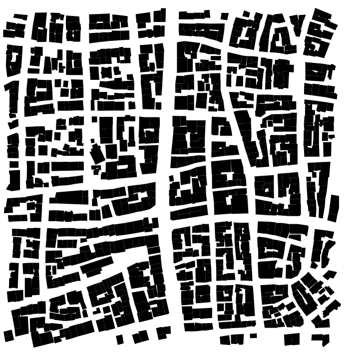
**Bird's-eye-view**



**Satellite view**



**Urban footprint**



# A-4.6 COMPACT URBAN BLOCK

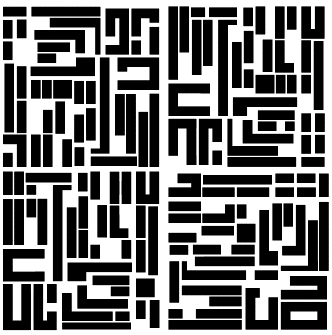
A visual and quantitative comparison of each Istanbul sample of Compact Urban Blocks. Data covering multiple factors and images over several scales is provided to enable a multi-layered comparison of samples.

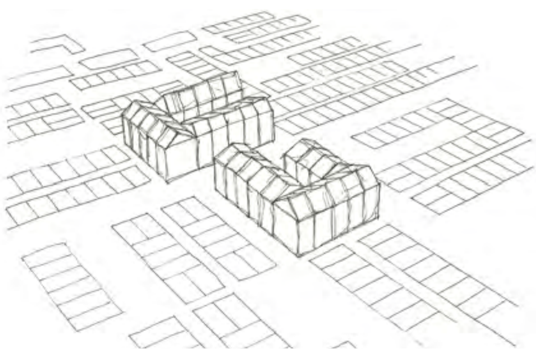
| | CUB01 | CUB02 | CUB03 | CUB04 | CUB05 |
|---|---|---|---|---|---|
| **Built-up area (m²)** | 117,094 | 133,511 | 83,782 | 139,576 | 92,846 |
| **Land area (m²)** | 208,934 | 190,477 | 168,951 | 209,721 | 171,898 |
| **Coverage ratio** | 0.47 | 0.53 | 0.34 | 0.56 | 0.37 |
| **Floor area (m²)** | 548,363 | 593,683 | 262,375 | 588,611 | 284,786 |
| **Floor area ratio** | 2.19 | 2.37 | 1.05 | 2.35 | 1.14 |
| **% Built-up area** | 46.8 | 53.4 | 33.5 | 55.8 | 37.1 |
| **% Land area** | 36.7 | 22.8 | 34.1 | 28.1 | 31.6 |
| **% Road area** | 22.9 | 37.1 | 8.4 | 30.3 | 13.7 |


above
**Reference map**

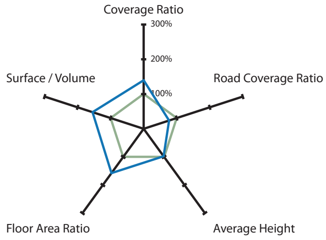
right
**Urban footprint of idealized Traditional Apartment**

below
**Sketch of idealized Traditional Apartment**

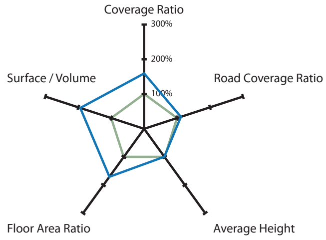


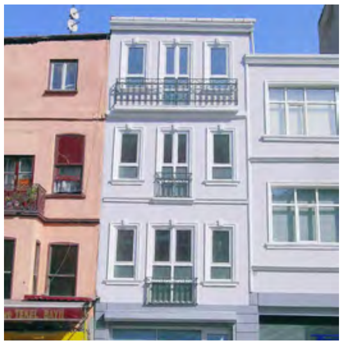


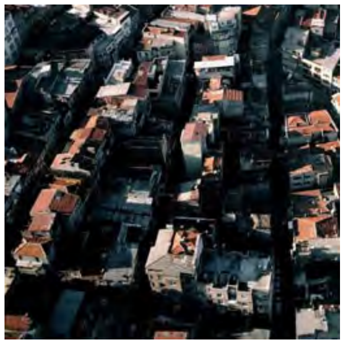
## Tophane CUB01




## Tarlabası CUB02



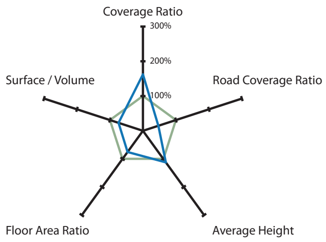





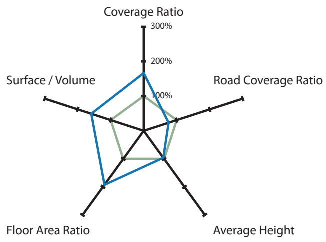
## Kasap Demirhun CUB03 | Kumkapı CUB04 | Süleymaniye CUB05

Spider diagram

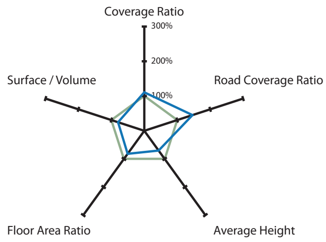
Kasap Demirhun CUB03




Kumkapı CUB04



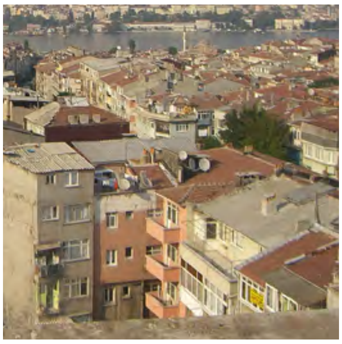

Süleymaniye CUB05

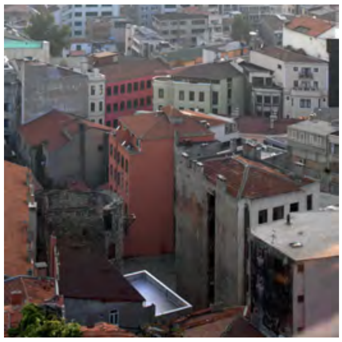



Street view



Bird's-eye-view





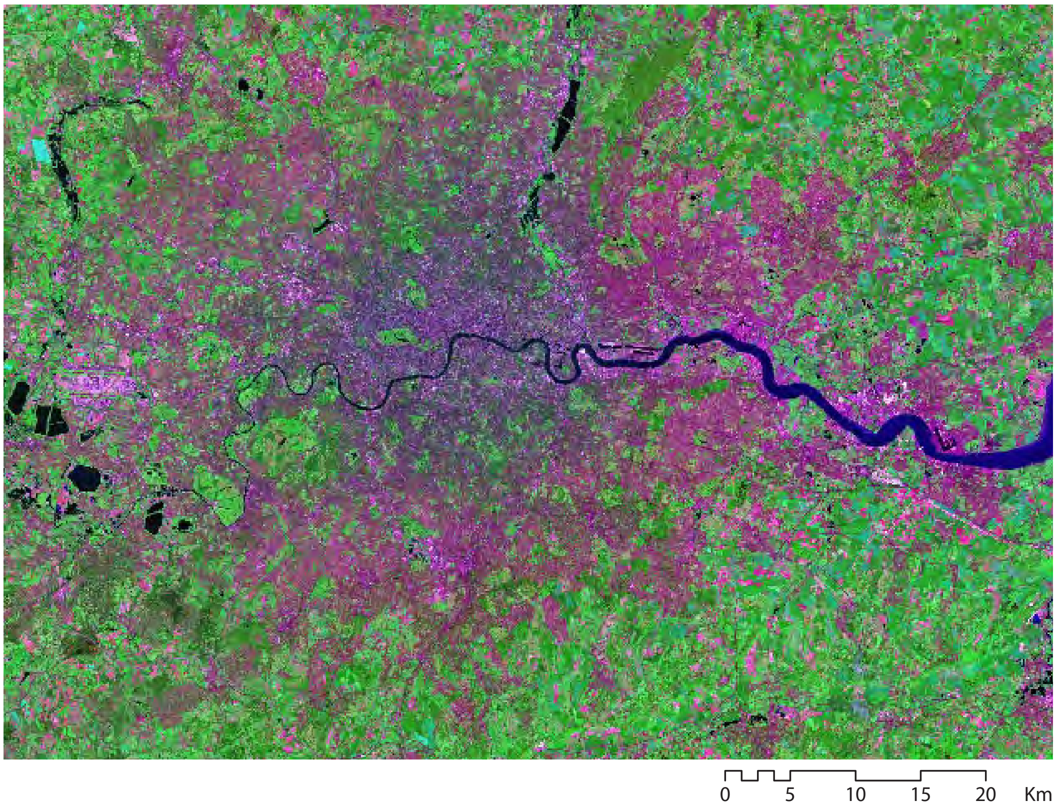
Satellite view



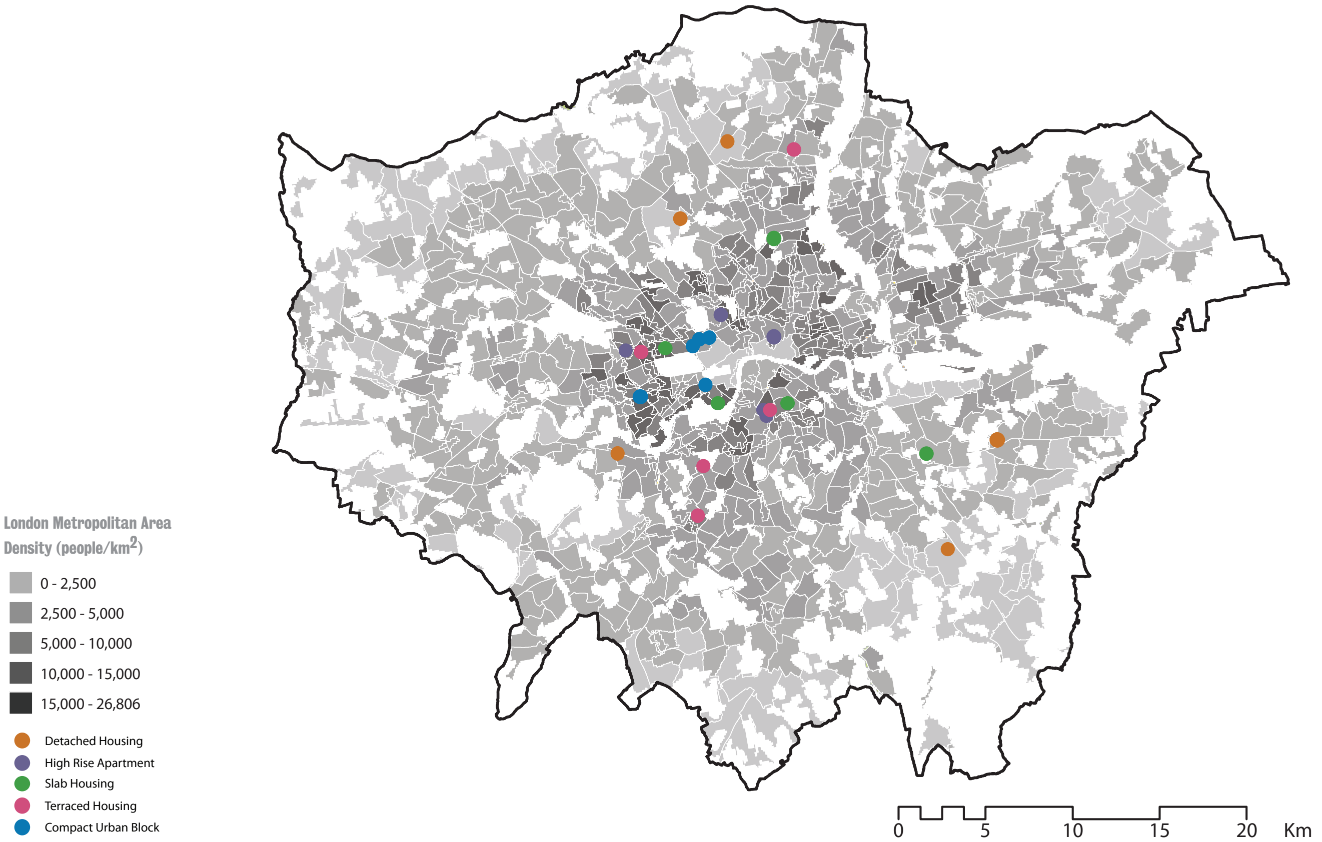
Urban footprint



# B-1 LONDON ENERGY PERFORMANCE



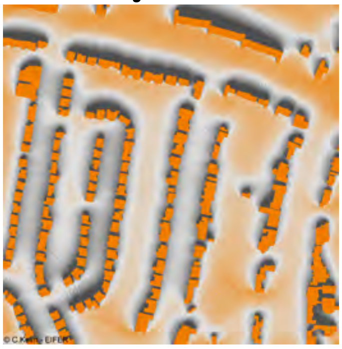

## B-1.1 DENSITY MAP AND LOCATION OF MORPHOLOGY SAMPLES



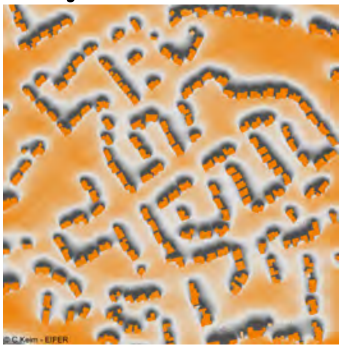

Source: *LSE Cities research*

## Detached Housing

## East Finchley DH01

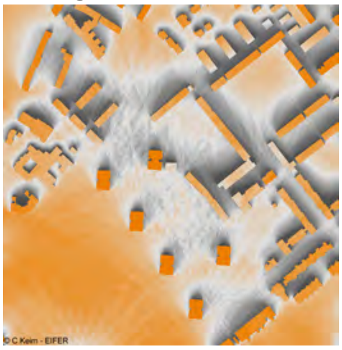


## Bickley DH02

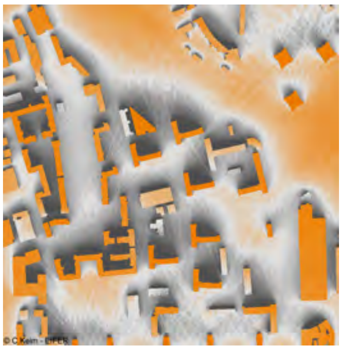


## High Rise Apartment

## Kennington HRA01

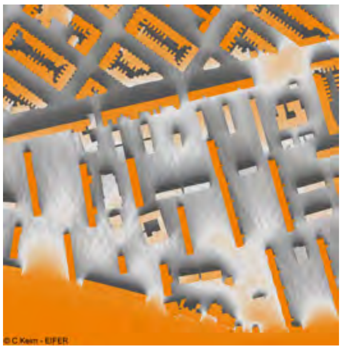


## Euston HRA02



## Slab Housing

## Pimlico SH01

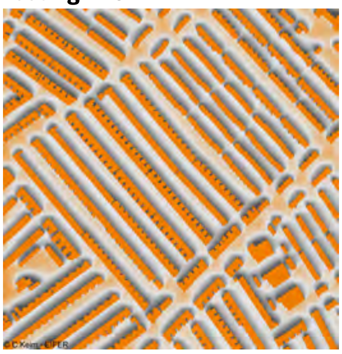


## Walworth SH02

## Terraced Housing

## Clapham South TH01

## Tooting TH02



## Compact Urban Block

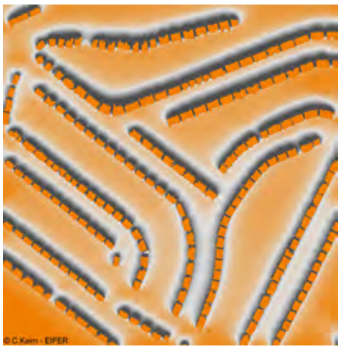
## Victoria CUB01

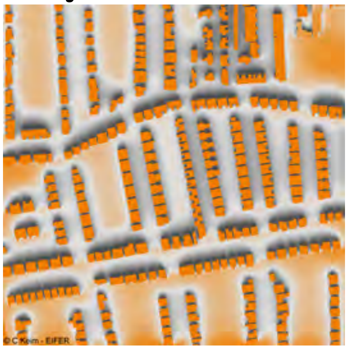
## Marylebone CUB02

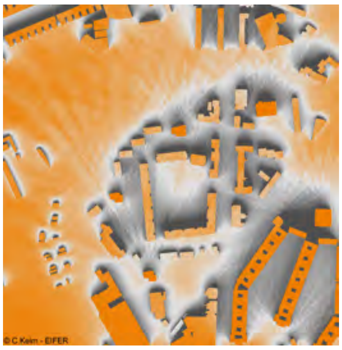
These two pages visually depict the duration of solar radiation for each London sample

### Falconwood DH03



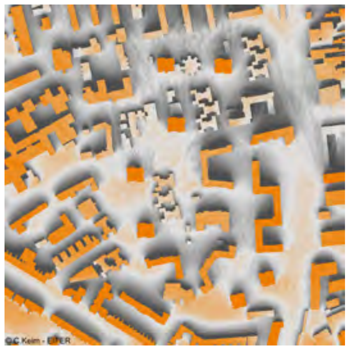
### Arnos Grove DH04


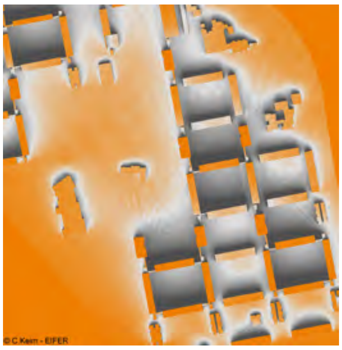

### Putney DH05


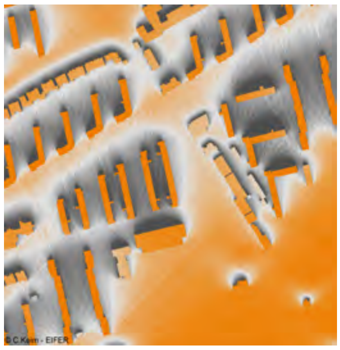

### Latimer Road TBC03



### Barbican TB04



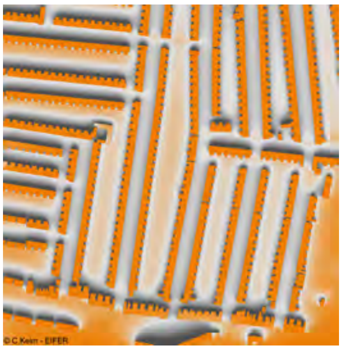
### Camberwell TB05



### Manor House SH03



### Kidbrooke SH04



### Bayswater SH05



### Edmonton TH03



### Kennington TH04

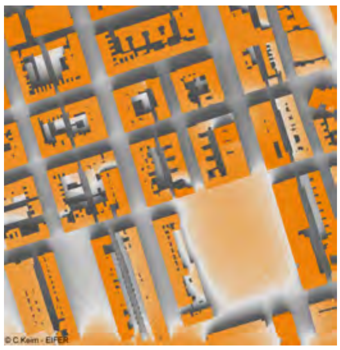


### Notting Hill TH05



### Paddington CUB03

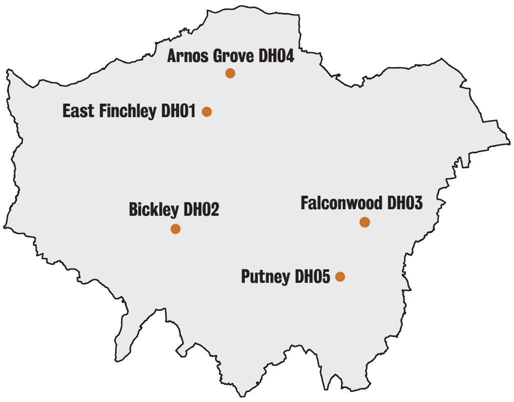


### Baker Street CUB04


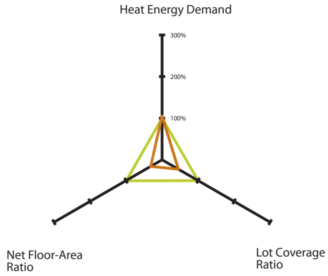

### West Kensington CUB05

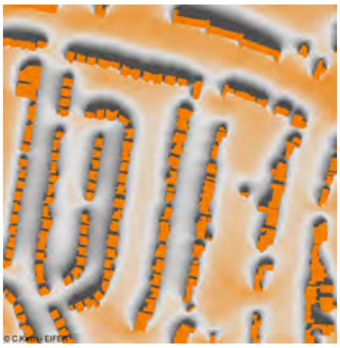

# B-1.2 DETACHED HOUSING

A visual display of the extent of solar radiation exposure and heat energy demand for each sample of Detached Housing in London.



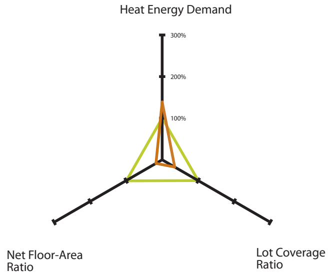

## East Finchley DH01

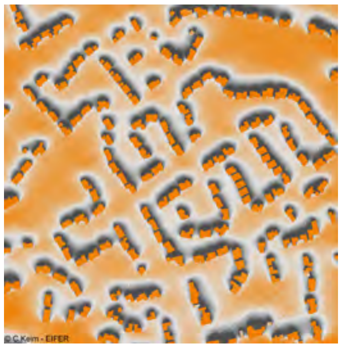





## Bickley DH02



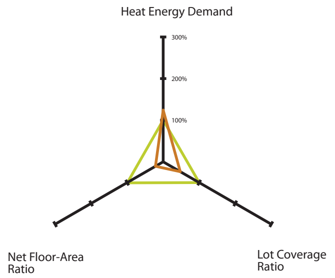


## Falconwood DH03 | Arnos Parke DH04 | Putney DH05

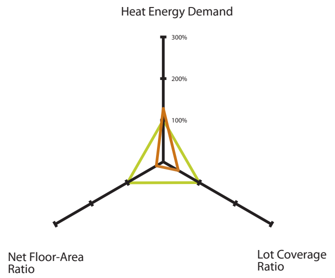
**Spider Diagram**

Relationship between the sample's heat energy demand and its physical characteristics

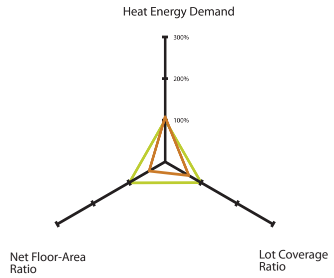
Falconwood DH03




Arnos Parke DH04



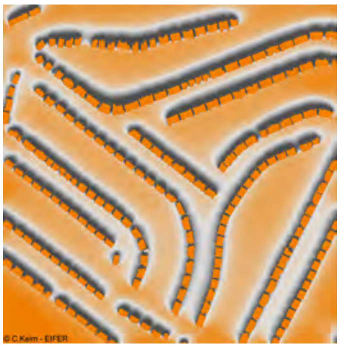

Putney DH05

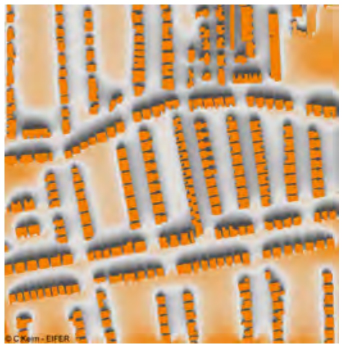



**Hours of direct solar radiation during periods where heating is required**

2134

0

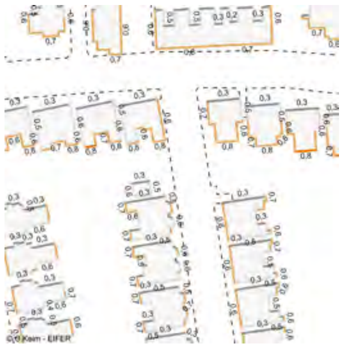




**Hours of direct solar radiation on building facades**

- 0,0 - 0,2
- 0,2 - 0,4
- 0,4 - 0,6
- 0,6 - 0,8
- 0,8 - 1,0

Hours of direct solar radiation coefficient [0-1]






**Primary heat energy demand [MWh/year]**

- < 25
- 26 - 50
- 51 - 100
- 101 - 150
- 151 - 200
- 201 - 250
- 251 - 350
- 351 - 500
- 501 - 750
- > 750



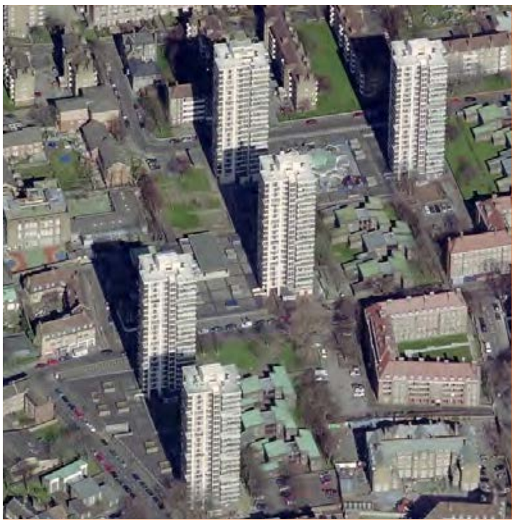

**Primary heat energy demand [kWh/m²/year]**

- < 50
- 51 - 75
- 76 - 100
- 101 - 125
- 126 - 150
- 151 - 175
- 176 - 200
- 201 - 225
- 226 - 250
- 251 - 275
- > 275

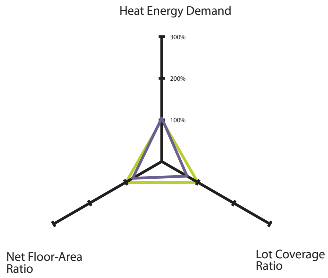


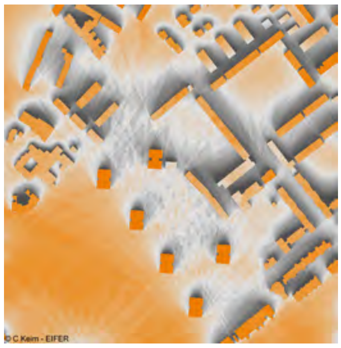
# B-1.3 HIGH RISE APARTMENT

A visual display of the extent of solar radiation exposure and heat energy demand for each sample of High Rise Apartments in London.

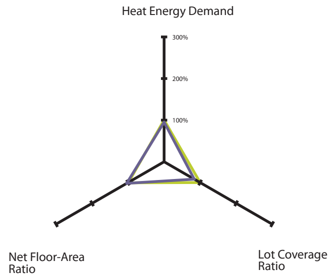
## Kennington HRA01

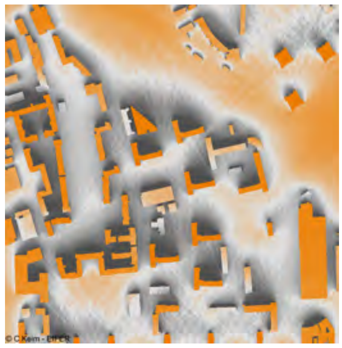


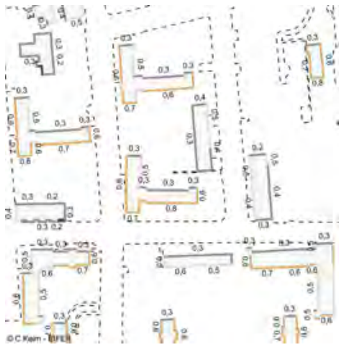





## Euston HRA02



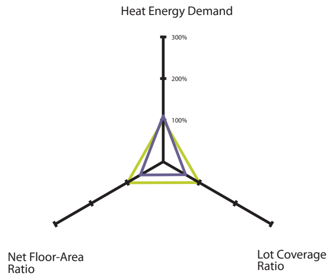


| | Latimer Road HRA03 | Baker Street HRA04 | St John's Wood HRA05 |
|---|---|---|---|

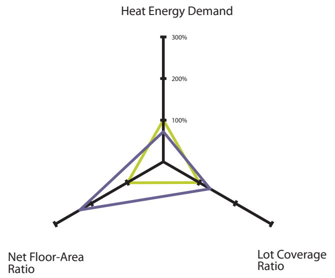
**Spider Diagram**

Relationship between the sample's heat energy demand and its physical characteristics

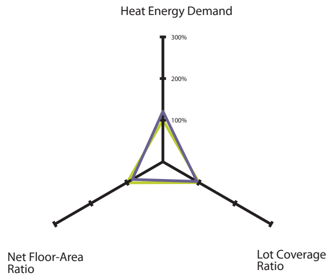
## Latimer Road HRA03




## Baker Street HRA04



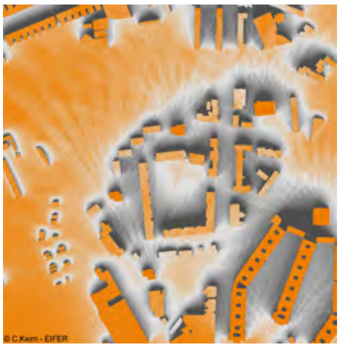

## St John's Wood HRA05

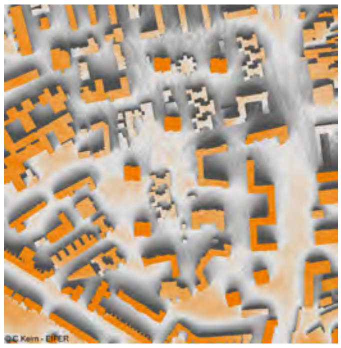



**Hours of direct solar radiation during periods where heating is required**

2134

0

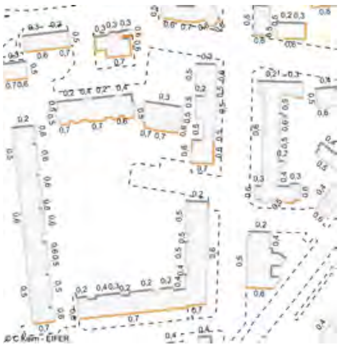




**Hours of direct solar radiation on building facades**

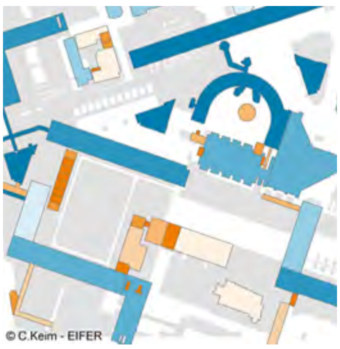
- 0,0 - 0,2
- 0,2 - 0,4
- 0,4 - 0,6
- 0,6 - 0,8
- 0,8 - 1,0

Hours of direct solar radiation coefficient [0-1]



**Primary heat energy demand [MWh/year]**

- < 25
- 26 - 50
- 51 - 100
- 101 - 150
- 151 - 200
- 201 - 250
- 251 - 350
- 351 - 500
- 501 - 750
- > 750

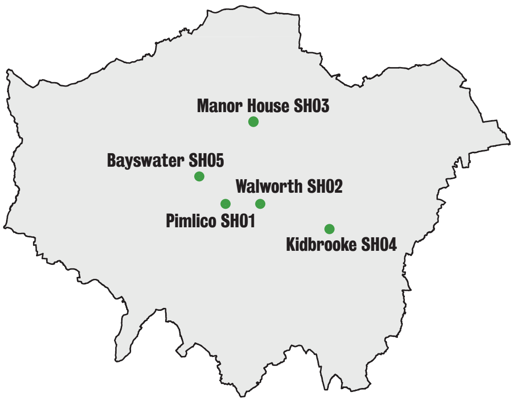



**Primary heat energy demand [kWh/m²/year]**

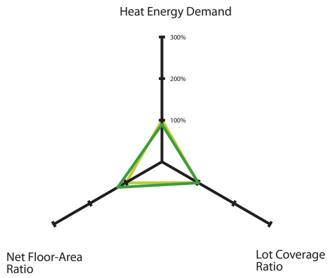
- < 50
- 51 - 75
- 76 - 100
- 101 - 125
- 126 - 150
- 151 - 175
- 176 - 200
- 201 - 225
- 226 - 250
- 251 - 275
- > 275

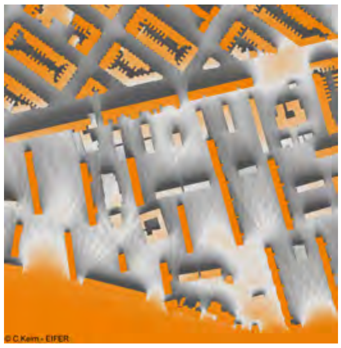
## B-1.4 SLAB HOUSING

A visual display of the extent of solar radiation exposure and heat energy demand for each sample of Slab Housing in London.




### Pimlico SH01

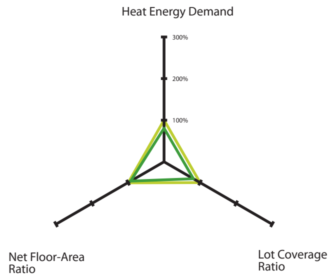


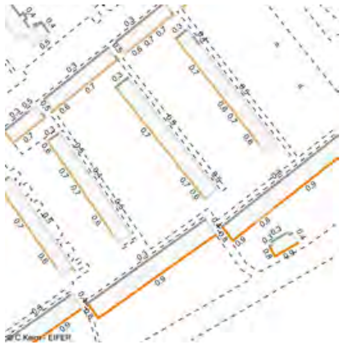




### Walworth SH02





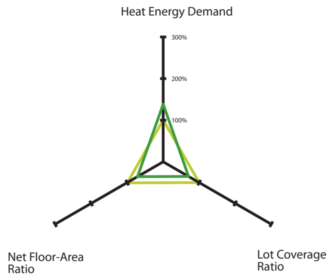


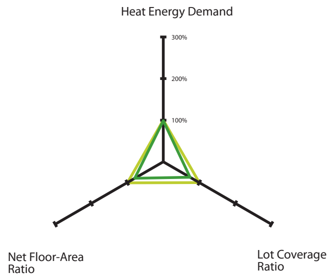


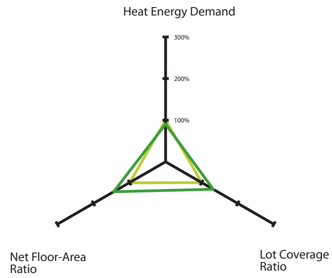
## Manor House SH03 | Kidbrooke SH04 | Bayswater SH05

**Spider Diagram**

Relationship between the sample's heat energy demand and its physical characteristics



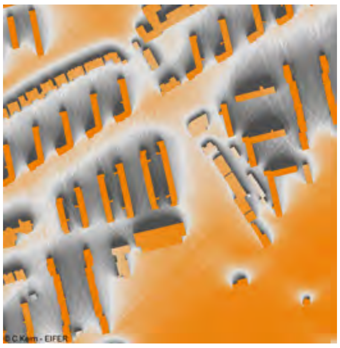
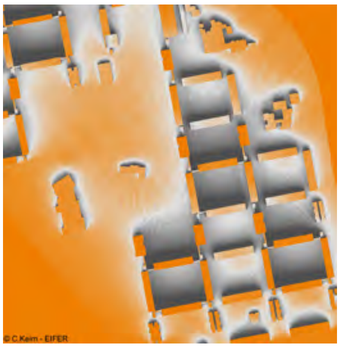
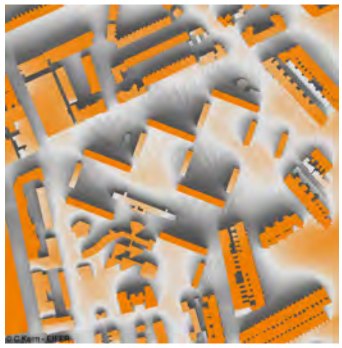




**Hours of direct solar radiation during periods where heating is required**

2134

0

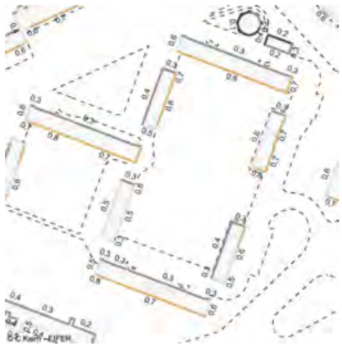




**Hours of direct solar radiation on building facades**

- 0,0 - 0,2
- 0,2 - 0,4
- 0,4 - 0,6
- 0,6 - 0,8
- 0,8 - 1,0

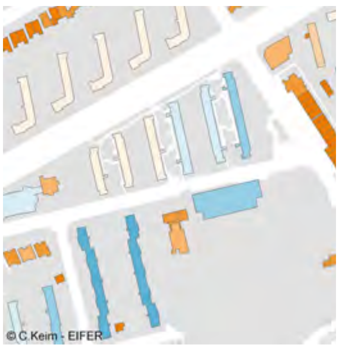
Hours of direct solar radiation coefficient [0-1]

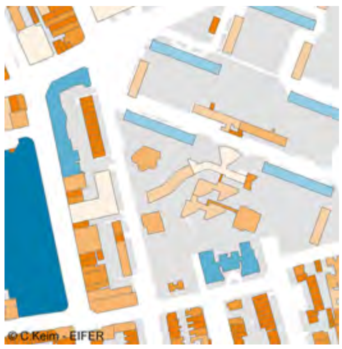




**Primary heat energy demand [MWh/year]**

- < 25
- 26 - 50
- 51 - 100
- 101 - 150
- 151 - 200
- 201 - 250
- 251 - 350
- 351 - 500
- 501 - 750
- > 750



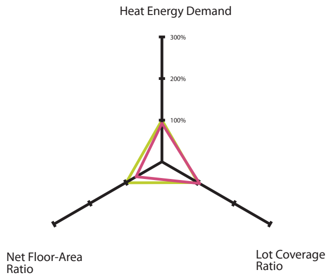

**Primary heat energy demand [kWh/m²/year]**

- < 50
- 51 - 75
- 76 - 100
- 101 - 125
- 126 - 150
- 151 - 175
- 176 - 200
- 201 - 225
- 226 - 250
- 251 - 275
- > 275

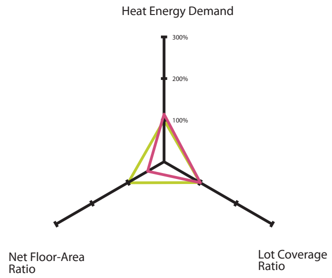

## B-1.5 TERRACED HOUSING

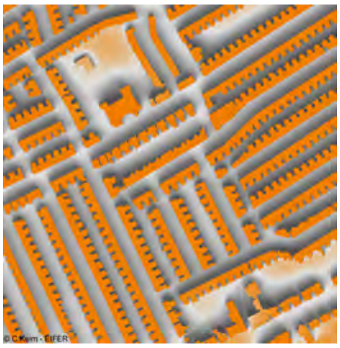
A visual display of the extent of solar radiation exposure and heat energy demand for each sample of Terraced Housing in London.

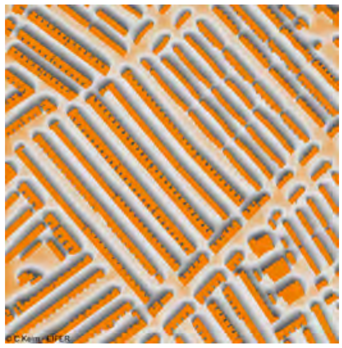
### Clapham South TH01

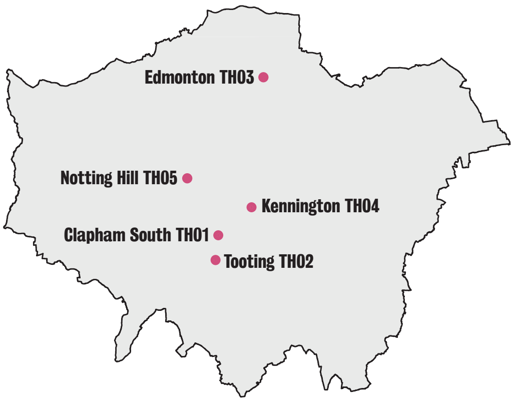


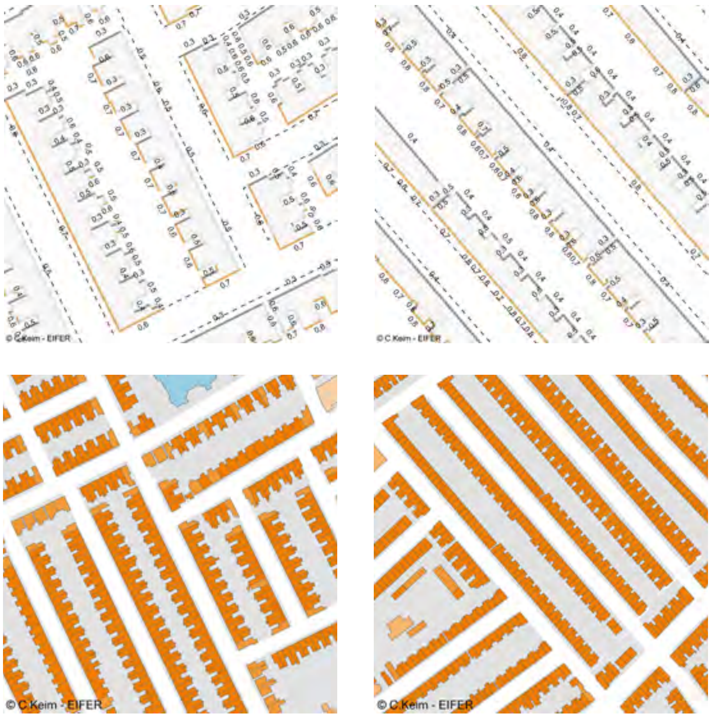

### Tooting TH02



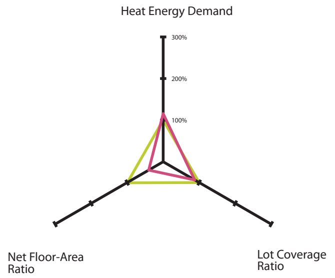



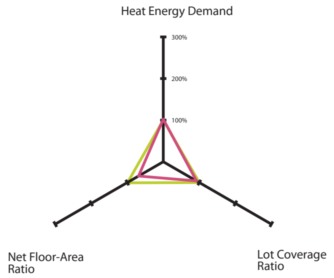

**Spider Diagram**

Relationship between the sample's heat energy demand and its physical characteristics

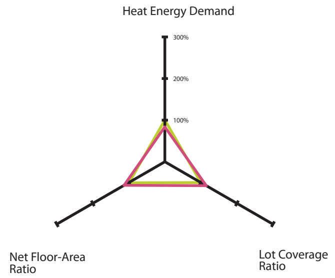
## Edmonton TH03




## Kennington TH04



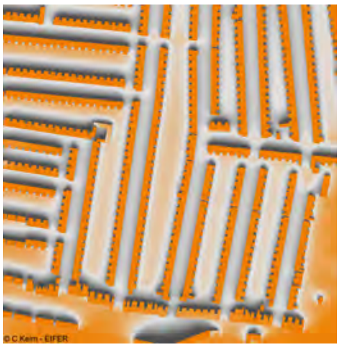

## Notting Hill TH05




**Hours of direct solar radiation during periods where heating is required**

2134

0

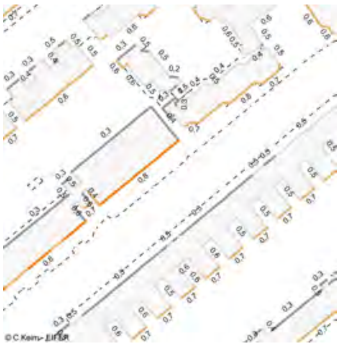





**Hours of direct solar radiation on building facades**

- 0,0 - 0,2
- 0,2 - 0,4
- 0,4 - 0,6
- 0,6 - 0,8
- 0,8 - 1,0

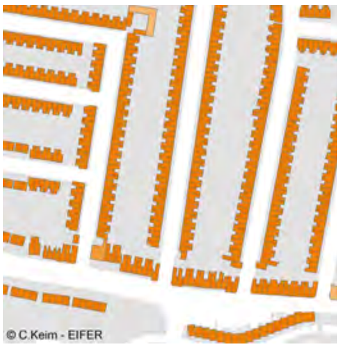
Hours of direct solar radiation coefficient [0-1]



**Primary heat energy demand [MWh/year]**

- < 25
- 26 - 50
- 51 - 100
- 101 - 150
- 151 - 200
- 201 - 250
- 251 - 350
- 351 - 500
- 501 - 750
- > 750






**Primary heat energy demand [kWh/m²/year]**

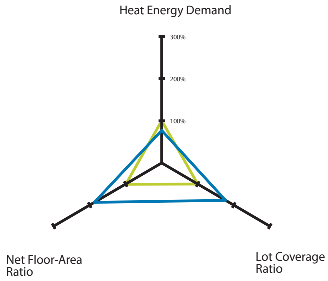
- < 50
- 51 - 75
- 76 - 100
- 101 - 125
- 126 - 150
- 151 - 175
- 176 - 200
- 201 - 225
- 226 - 250
- 251 - 275
- > 275



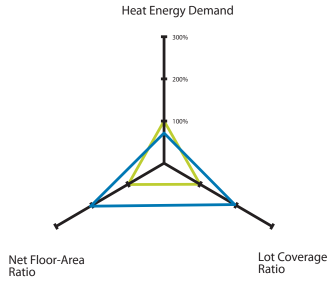
## B-1.6 COMPACT URBAN BLOCK

A visual display of the extent of solar radiation exposure and heat energy demand for each sample of Compact Urban Blocks in London.

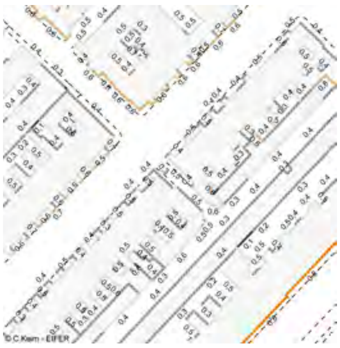
### Victoria CUB01

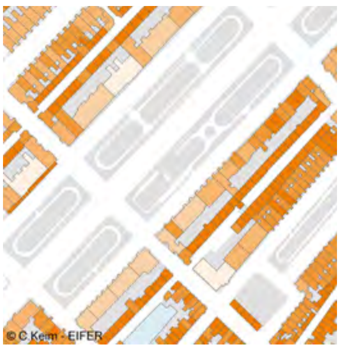



### Marylebone CUB02

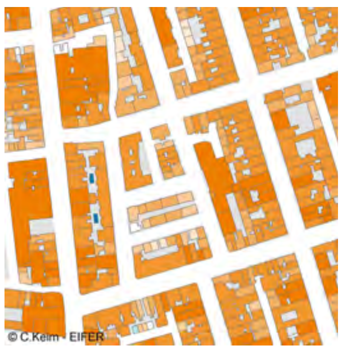








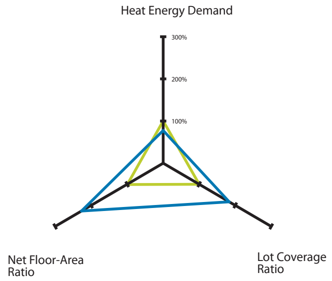


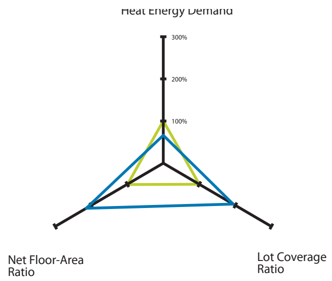
## Spider Diagram

Relationship between the sample's heat energy demand and its physical characteristics

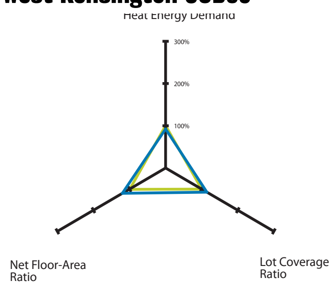
### Paddington CUB03




### Baker Street CUB04



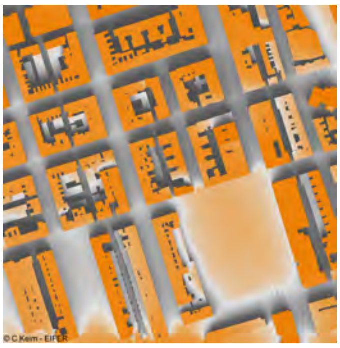

### West Kensington CUB05




## Hours of direct solar radiation during periods where heating is required

2134

0



## Hours of direct solar radiation on building facades

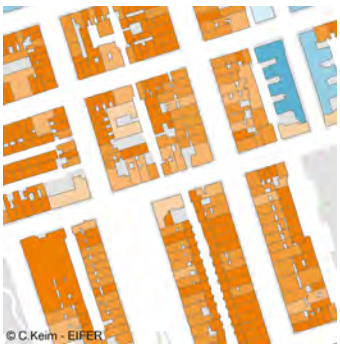
0,0 - 0,2
0,2 - 0,4
0,4 - 0,6
0,6 - 0,8
0,8 - 1,0

Hours of direct solar radiation coefficient [0-1]




## Primary heat energy demand [MWh/year]

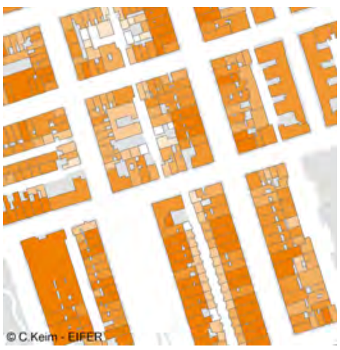
< 25
26 - 50
51 - 100
101 - 150
151 - 200
201 - 250
251 - 350
351 - 500
501 - 750
> 750



## Primary heat energy demand [kWh/m²/year]

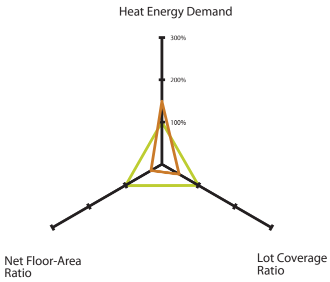
< 50
51 - 75
76 - 100
101 - 125
126 - 150
151 - 175
176 - 200
201 - 225
226 - 250
251 - 275
> 275

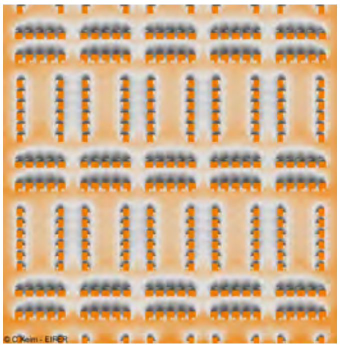



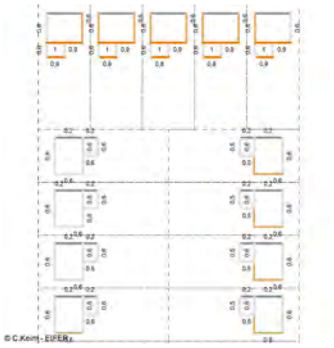

# B-1.7 LONDON IDEALISED SAMPLES

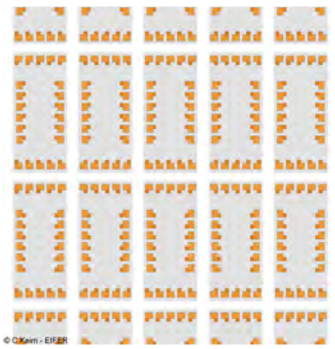
A visual display of the performance of the Idealised Samples for London tyopologies in terms of solar radiation exposure and heat energy demand.

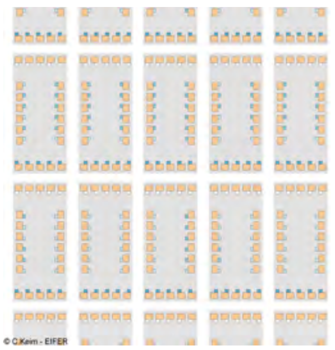
## Detached Housing



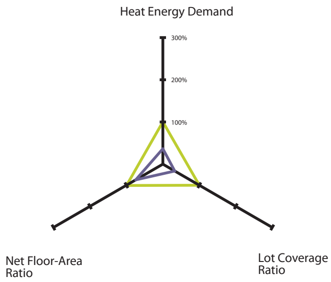



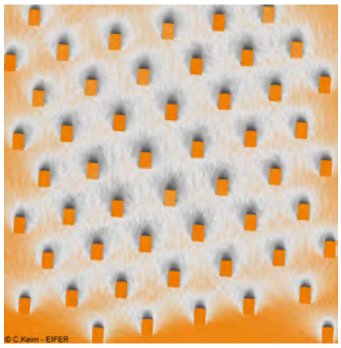



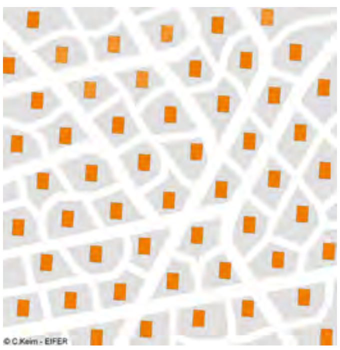




## High Rise Apartment





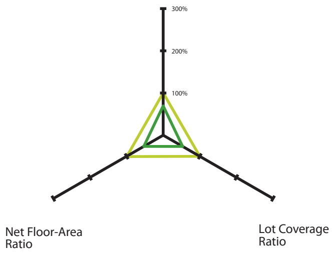



## Slab Housing | Terraced Housing | Compact Urban Block

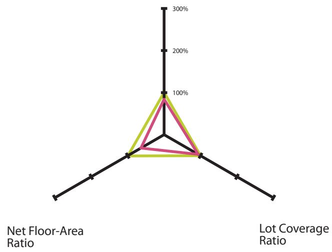
**Spider Diagram**

Relationship between the sample's heat energy demand and its physical characteristics

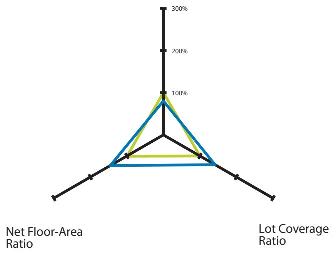
### Slab Housing



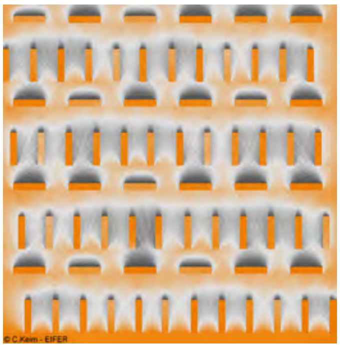

### Terraced Housing

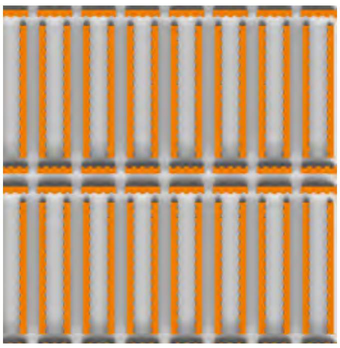


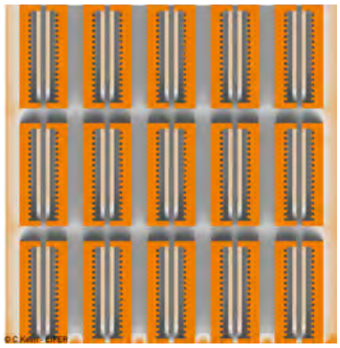

### Compact Urban Block




**Hours of direct solar radiation during periods where heating is required**

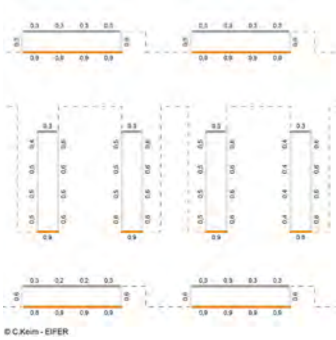



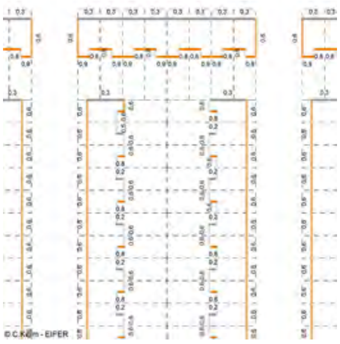


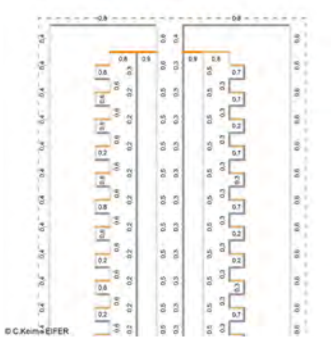

**Hours of direct solar radiation on building facades**

- 0,0 - 0,2
- 0,2 - 0,4
- 0,4 - 0,6
- 0,6 - 0,8
- 0,8 - 1,0

Hours of direct solar radiation coefficient [0-1]

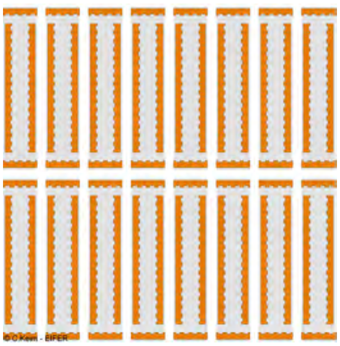


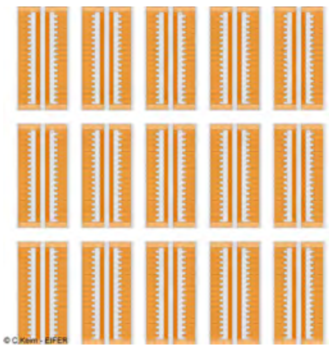




**Primary heat energy demand [MWh/year]**

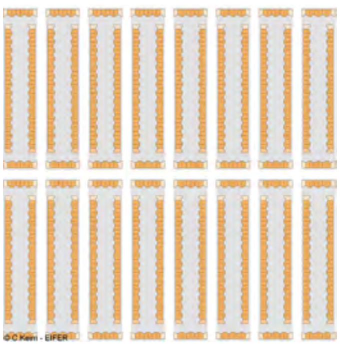
- < 25
- 26 - 50
- 51 - 100
- 101 - 150
- 151 - 200
- 201 - 250
- 251 - 350
- 351 - 500
- 501 - 750
- > 750

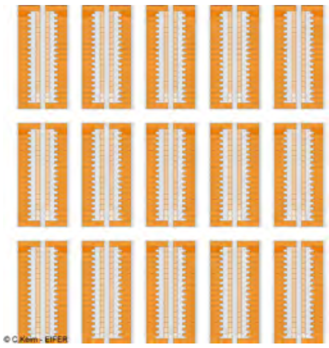



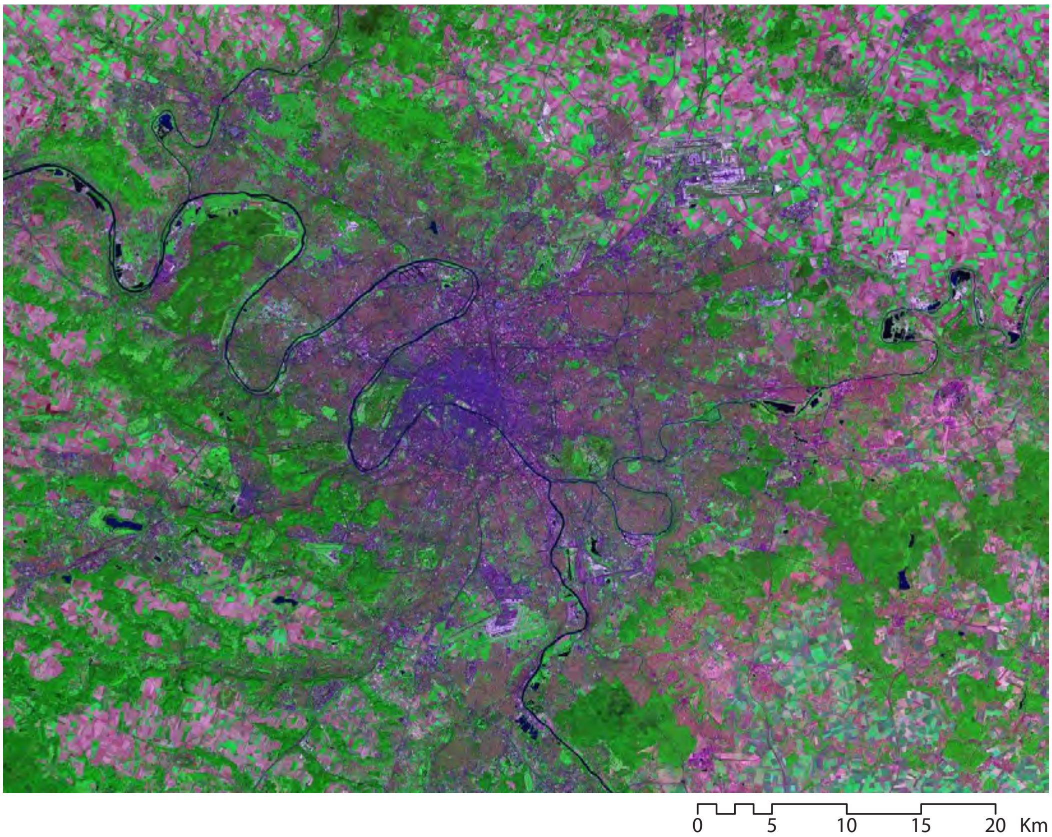

**Primary heat energy demand [kWh/m²/year]**

- < 50
- 51 - 75
- 76 - 100
- 101 - 125
- 126 - 150
- 151 - 175
- 176 - 200
- 201 - 225
- 226 - 250
- 251 - 275
- > 275

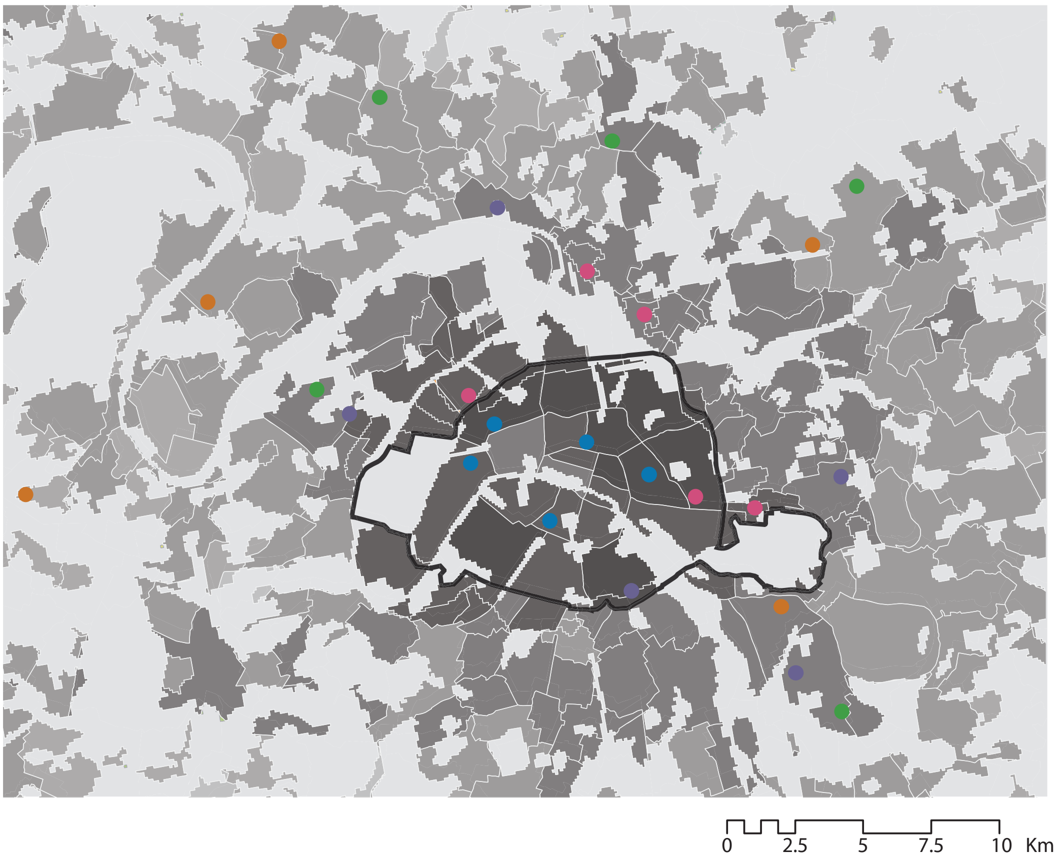



# B-2 PARIS ENERGY PERFORMANCE




## B-2.1 DENSITY MAP AND LOCATION OF MORPHOLOGY SAMPLES (PARIS CITY AND SURROUNDS)




**Paris City and Its Surrounds**
**Density (people/km$^2$)**

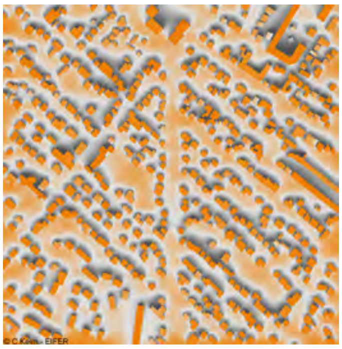
- 2,500 - 5,000
- 5,000 - 10,000
- 10,000 - 15,000
- 15,000 - 26,805
- 27,560 - 65,595

- Detached Housing
- High Rise Apartment
- Slab Housing
- Regular Urban Block
- Compact Urban Block

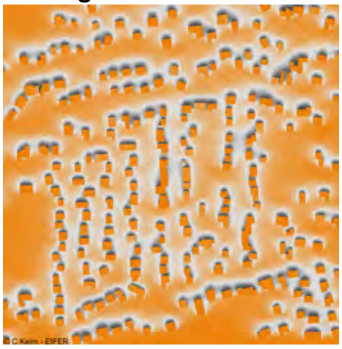
*Source: LSE Cities research*

### Detached Housing

### Satrouville DH01

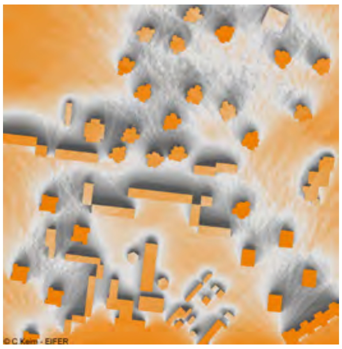


### L'Etrang-la-ville DH02



### High Rise Apartment

### La Defense HRA01



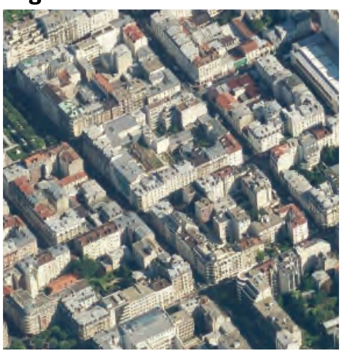
### Creteil Universite HRA02

### Slab Housing

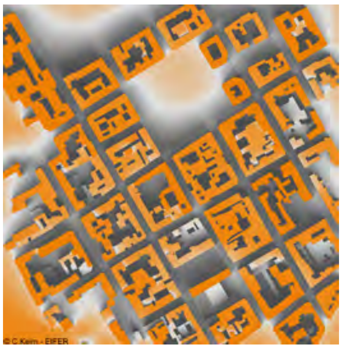
### Nanterre Ville SH01

### Gare de Gros Noyer St Prix SH02

### Regular Urban Block



### Anatole France RUB01



### Saint Denis Porte du Paris RUB02

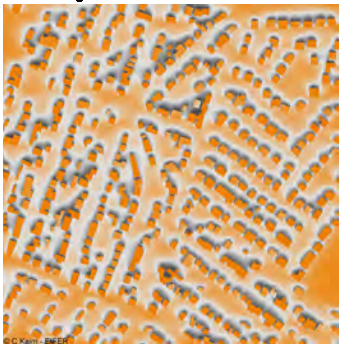
### Compact Urban Block

### Saint Placide CUB01

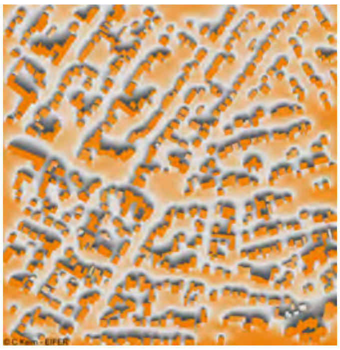
### Bonne Nouvelle CUB02

These two pages visually depict the duration of solar radiation for each Paris sample

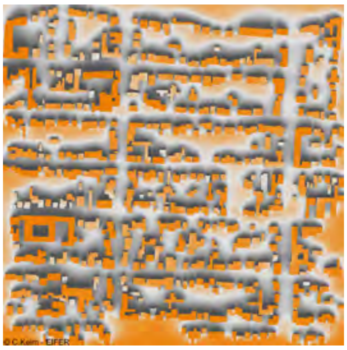
**Taverny DH03**



**Le Blanc-Mesnil DH04**



**Maison-Alfort DH05**

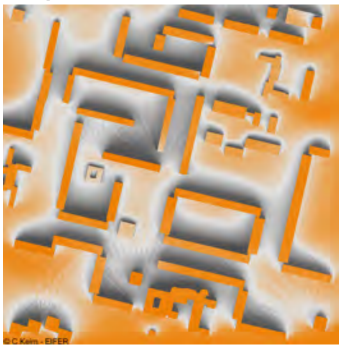


**Epinay sur Seine HRA03**

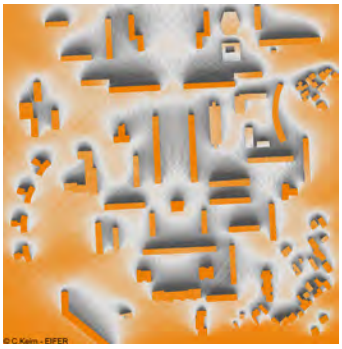
**Val de Fontenay HRA04**

**Porte de Choisy HRA05**

**Garges Sarcelles SH03**



**Creteil Prefecture SH04**



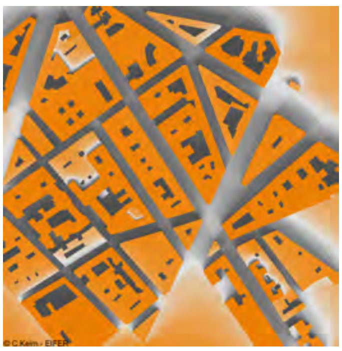
**Villepinte SH05**

**Aubervilles RUB03**

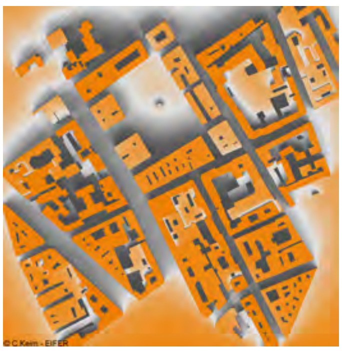
**Buzenval RUB04**

**Vincennes RUB05**

**Courcelles CUB03**



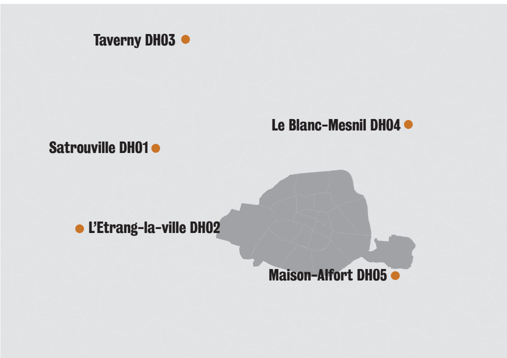
**Saint Ambroise CUB04**



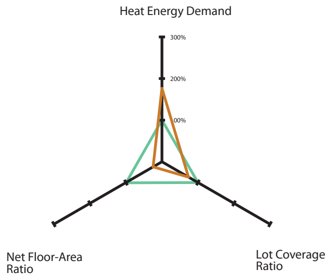
**Victor Hugo CUB05**

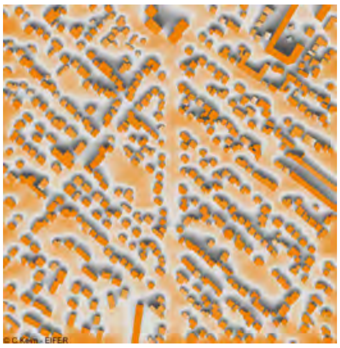
# B-2.2 DETACHED HOUSING

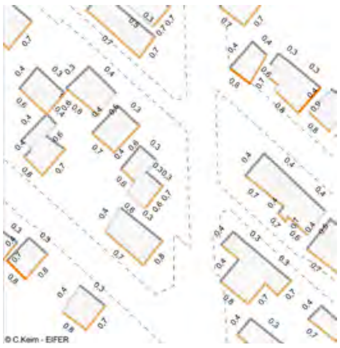
A visual display of the extent of solar radiation exposure and heat energy demand for each sample of Detached Housing in Paris.




## Satrouville DH01

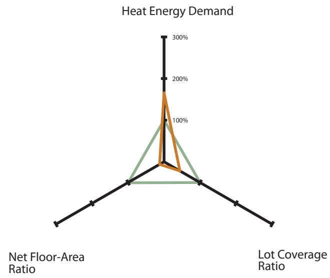


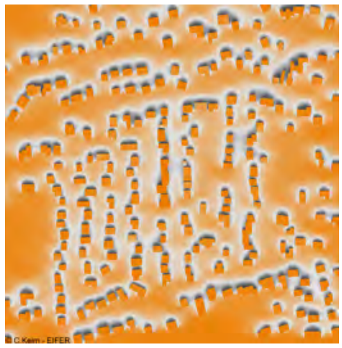



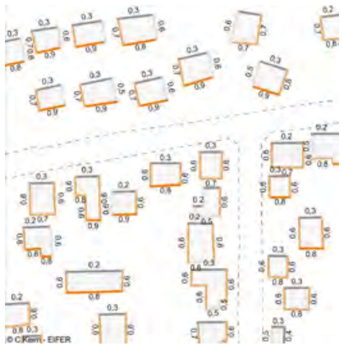





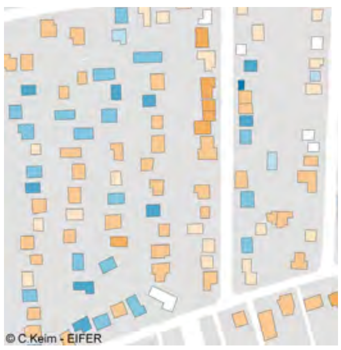

## L'Etrang-la-ville DH02



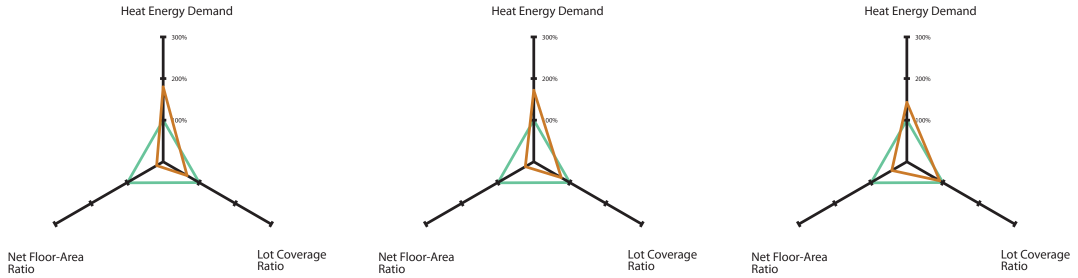




## Taverny DH03 | Le Blanc-Mesnil DH04 | Maison-Alfort DH05

**Spider Diagram**

Relationship between the sample's heat energy demand and its physical characteristics




**Hours of direct solar radiation during periods where heating is required**

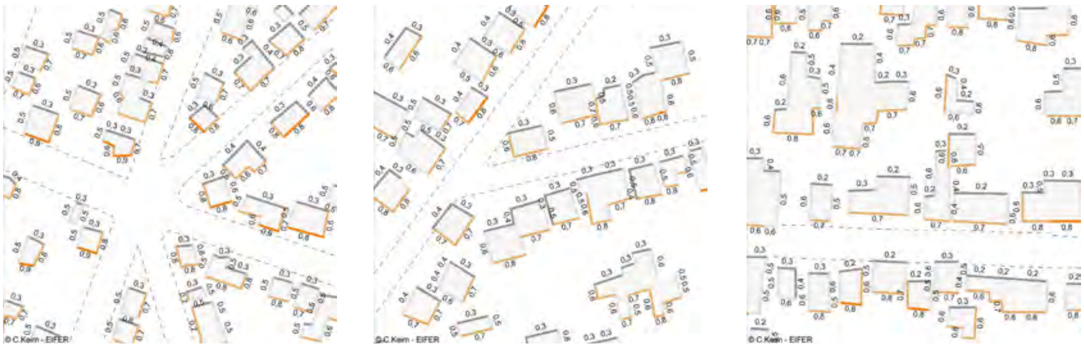
2134

0


**Hours of direct solar radiation on building facades**

- 0,0 - 0,2
- 0,2 - 0,4
- 0,4 - 0,6
- 0,6 - 0,8
- 0,8 - 1,0

Hours of direct solar radiation coefficient [0-1]




**Primary heat energy demand [MWh/year]**

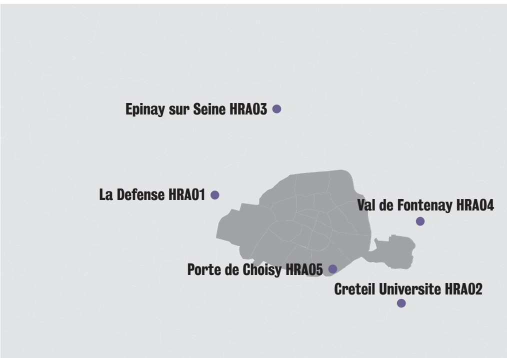
- < 25
- 26 - 50
- 51 - 100
- 101 - 150
- 151 - 200
- 201 - 250
- 251 - 350
- 351 - 500
- 501 - 750
- > 750


**Primary heat energy demand [kWh/m²/year]**

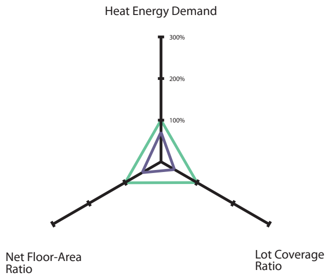
- < 50
- 51 - 75
- 76 - 100
- 101 - 125
- 126 - 150
- 151 - 175
- 176 - 200
- 201 - 225
- 226 - 250
- 251 - 275
- > 275

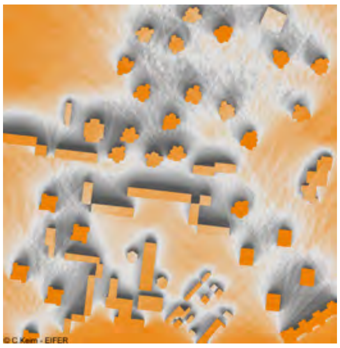
## B-2.3 HIGH RISE APARTMENT

A visual display of the extent of solar radiation exposure and heat energy demand for each sample of High Rise Apartments in Paris.




### La Defense HRA01

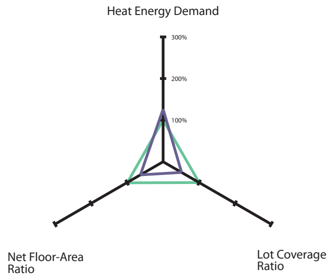






### Creteil Universite HRA02



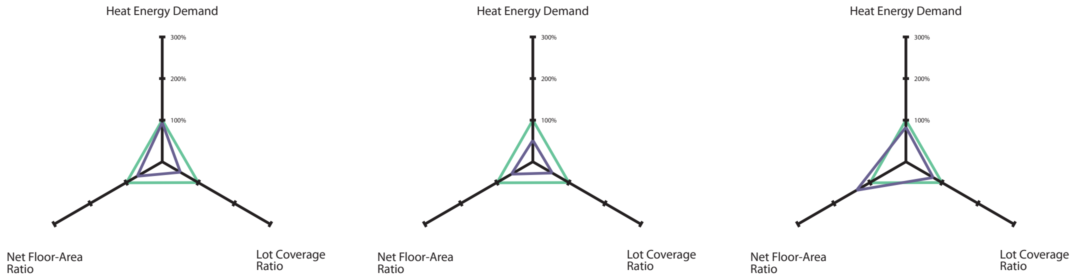




## Epinay sur Seine HRA03 | Val de Fontenay HRA04 | Porte de Choisy HRA05

**Spider Diagram**

Relationship between the sample's heat energy demand and its physical characteristics




**Hours of direct solar radiation during periods where heating is required**

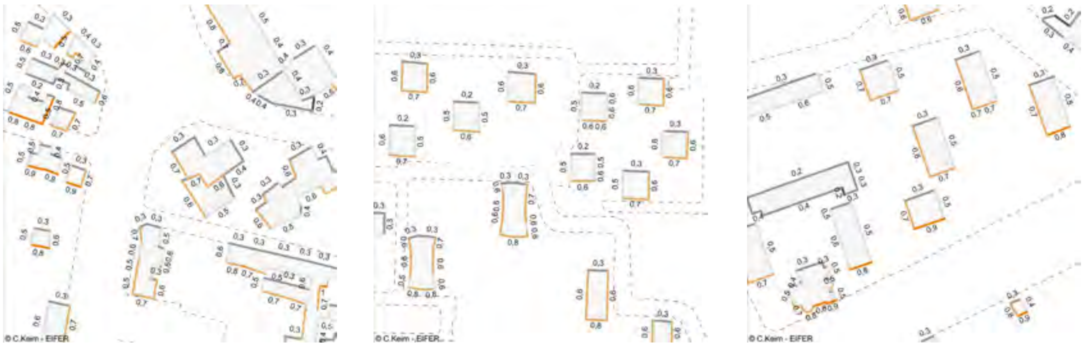
2134

0


**Hours of direct solar radiation on building facades**

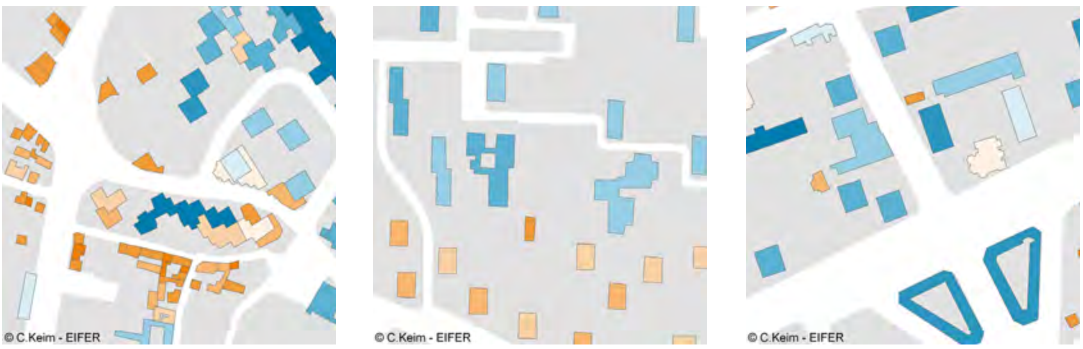
- 0,0 - 0,2
- 0,2 - 0,4
- 0,4 - 0,6
- 0,6 - 0,8
- 0,8 - 1,0

Hours of direct solar radiation coefficient [0-1]



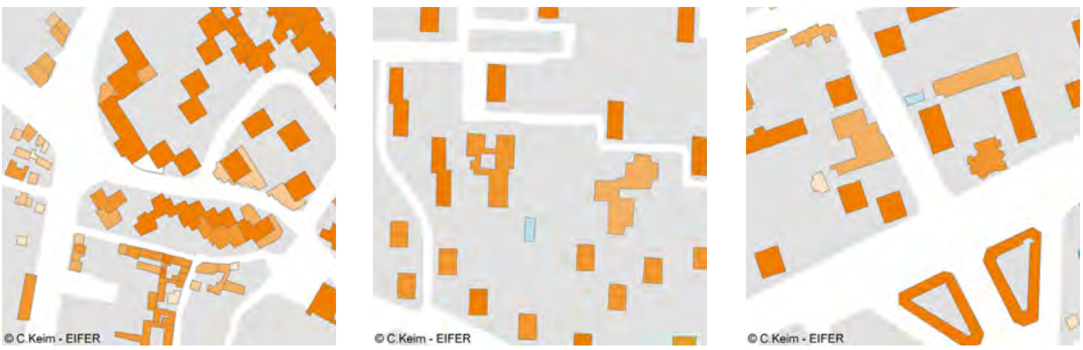

**Primary heat energy demand [MWh/year]**

- < 25
- 26 - 50
- 51 - 100
- 101 - 150
- 151 - 200
- 201 - 250
- 251 - 350
- 351 - 500
- 501 - 750
- > 750




**Primary heat energy demand [kWh/m²/year]**

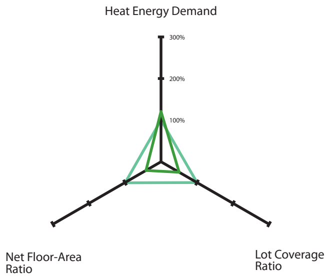
- < 50
- 51 - 75
- 76 - 100
- 101 - 125
- 126 - 150
- 151 - 175
- 176 - 200
- 201 - 225
- 226 - 250
- 251 - 275
- > 275



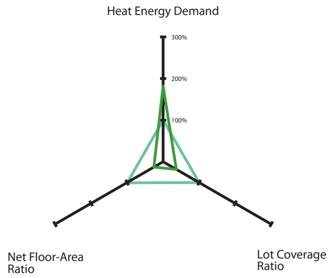
## B-2.4 SLAB HOUSING

A visual display of the extent of solar radiation exposure and heat energy demand for each sample of Slab Housing in Paris.

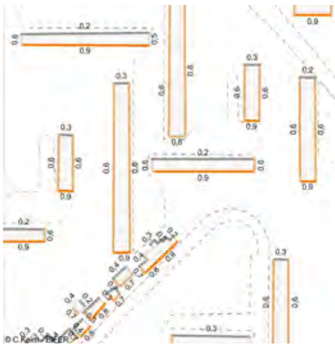
### Nanterre Ville SH01



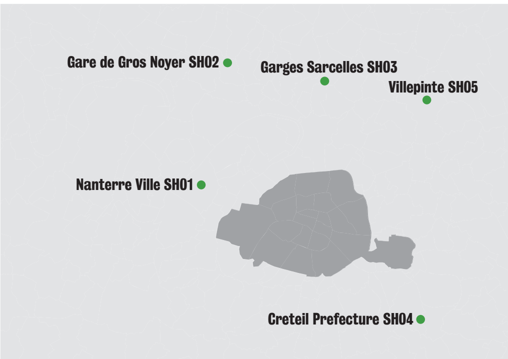

### Gare de Gros Noyer St Prix SH02

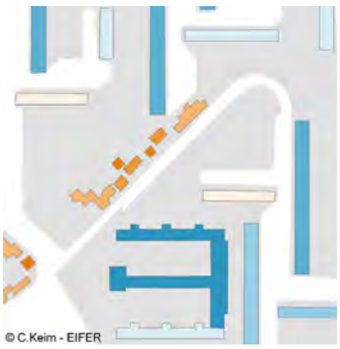








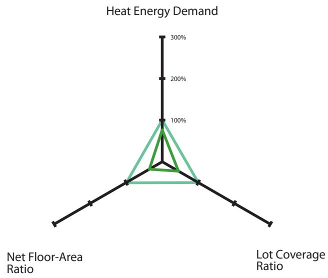





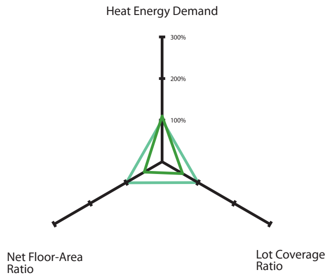

**Spider Diagram**

Relationship between the sample's heat energy demand and its physical characteristics

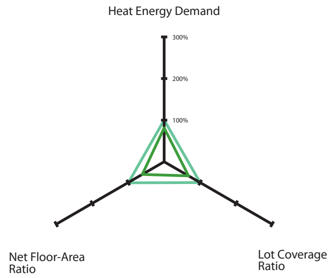
## Garges Sarcelles SH03




## Creteil Prefecture SH04



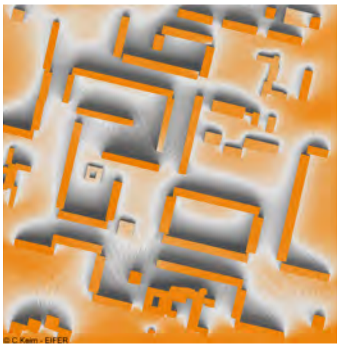

## Villepinte SH05

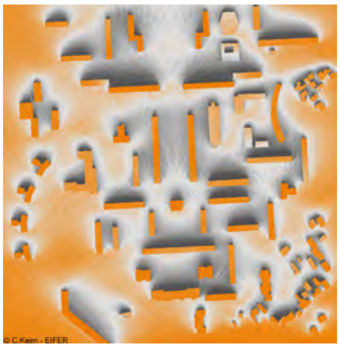



**Hours of direct solar radiation during periods where heating is required**

2134

0



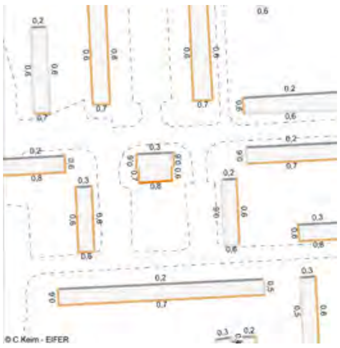





**Hours of direct solar radiation on building facades**

- 0,0 - 0,2
- 0,2 - 0,4
- 0,4 - 0,6
- 0,6 - 0,8
- 0,8 - 1,0

Hours of direct solar radiation coefficient [0-1]

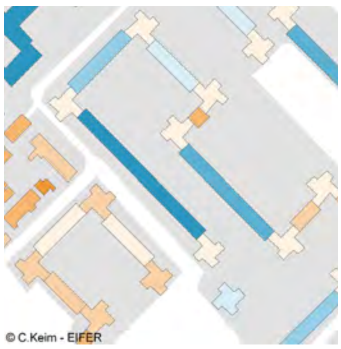





**Primary heat energy demand [MWh/year]**

- < 25
- 26 - 50
- 51 - 100
- 101 - 150
- 151 - 200
- 201 - 250
- 251 - 350
- 351 - 500
- 501 - 750
- > 750

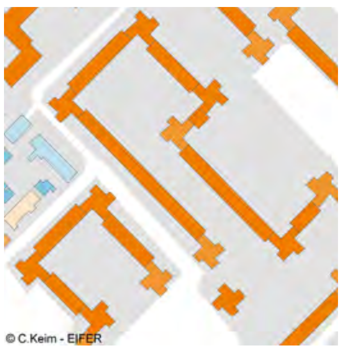





**Primary heat energy demand [kWh/m²/year]**

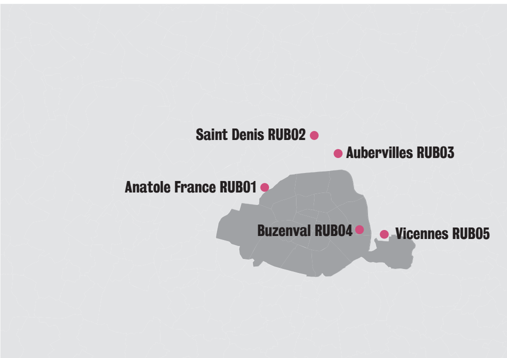
- < 50
- 51 - 75
- 76 - 100
- 101 - 125
- 126 - 150
- 151 - 175
- 176 - 200
- 201 - 225
- 226 - 250
- 251 - 275
- > 275

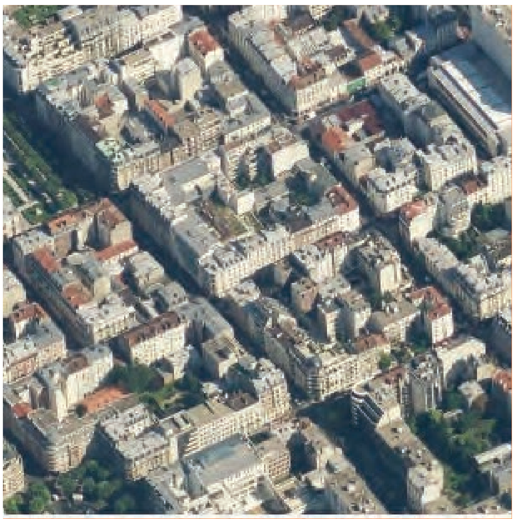




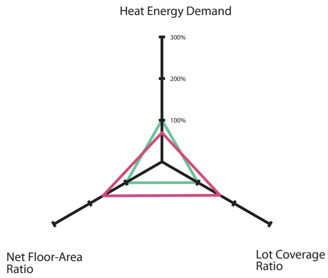
# B-2.5 REGULAR URBAN BLOCK

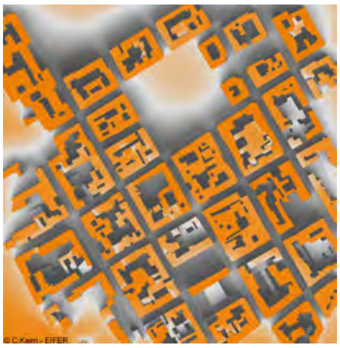
A visual display of the extent of solar radiation exposure and heat energy demand for each sample of Regular Urban Blocks in Paris.

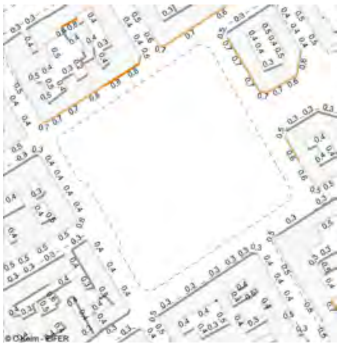


## Anatole France RUB01

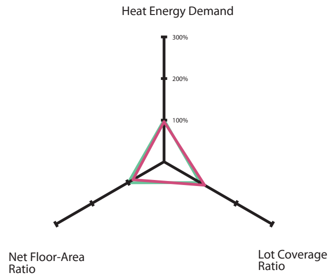


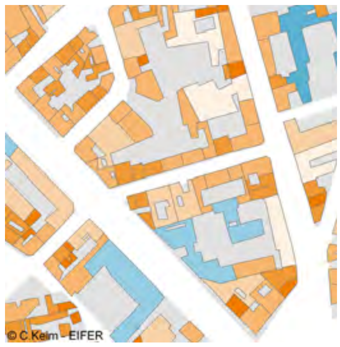



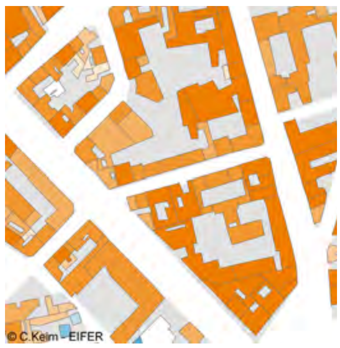



## Saint Denis Porte du Paris RUB02





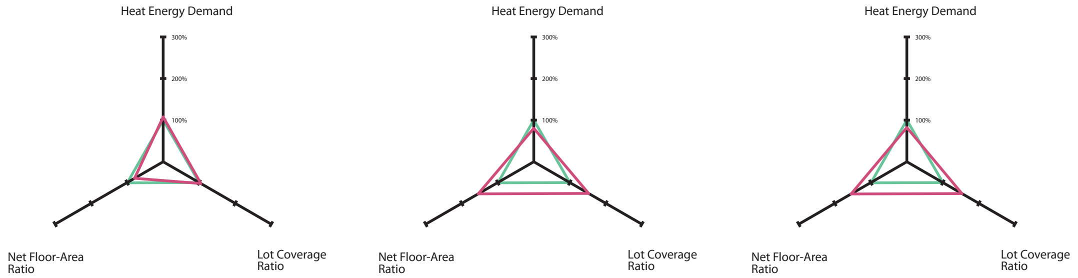



## Aubervilles RUB03 | Buzenval RUB04 | Vincennes RUB05

**Spider Diagram**

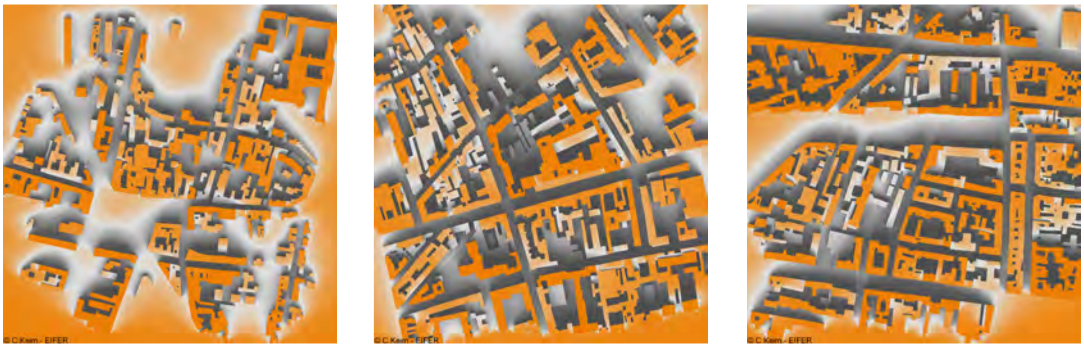
Relationship between the sample's heat energy demand and its physical characteristics




**Hours of direct solar radiation during periods where heating is required**

2134

0



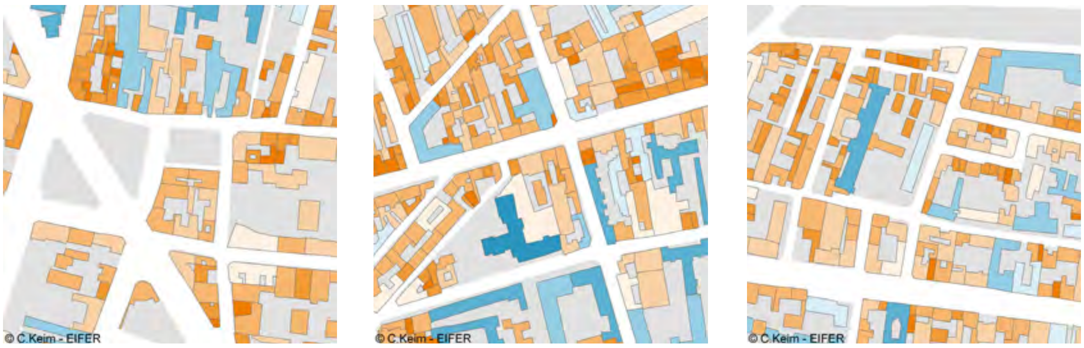

**Hours of direct solar radiation on building facades**

- 0,0 - 0,2
- 0,2 - 0,4
- 0,4 - 0,6
- 0,6 - 0,8
- 0,8 - 1,0

Hours of direct solar radiation coefficient [0-1]

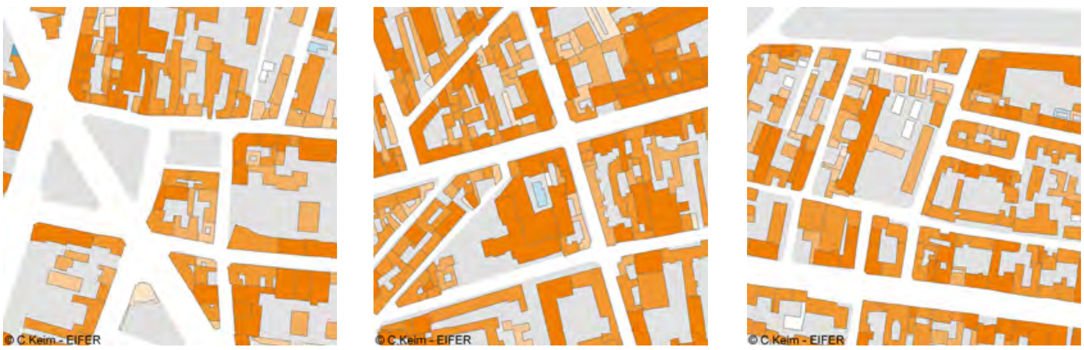

**Primary heat energy demand [MWh/year]**

- < 25
- 26 - 50
- 51 - 100
- 101 - 150
- 151 - 200
- 201 - 250
- 251 - 350
- 351 - 500
- 501 - 750
- > 750




**Primary heat energy demand [kWh/m²/year]**

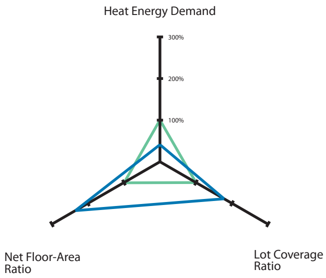
- < 50
- 51 - 75
- 76 - 100
- 101 - 125
- 126 - 150
- 151 - 175
- 176 - 200
- 201 - 225
- 226 - 250
- 251 - 275
- > 275



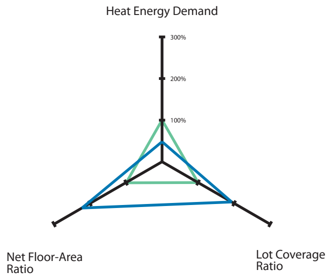
## B-2.6 COMPACT URBAN BLOCK

A visual display of the extent of solar radiation exposure and heat energy demand for each sample of Compact Urban Blocks in Paris.

### Saint Placide CUB01



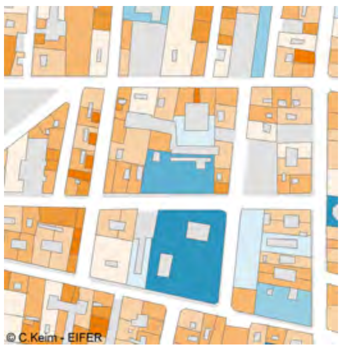

### Bonne Nouvelle CUB02









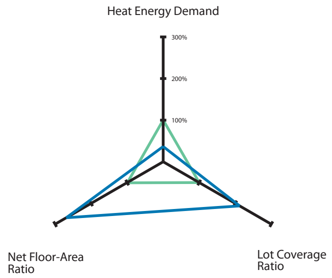


## Courcelles CUB03 | Saint Ambroise CUB04 | Victor Hugo CUB05

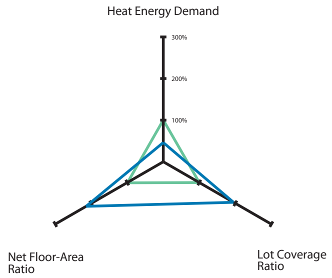
**Spider Diagram**

Relationship between the sample's heat energy demand and its physical characteristics

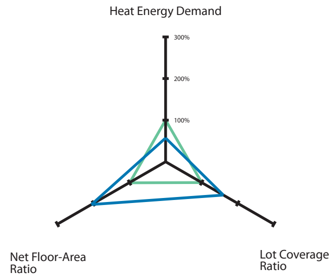
Courcelles CUB03




Saint Ambroise CUB04



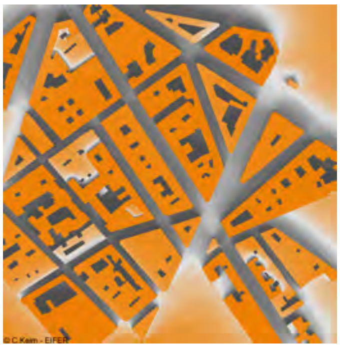

Victor Hugo CUB05

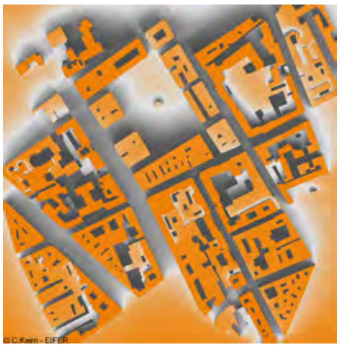



**Hours of direct solar radiation during periods where heating is required**

2134

0



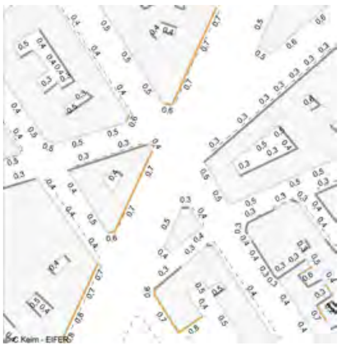





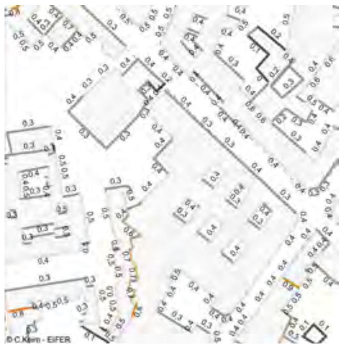
**Hours of direct solar radiation on building facades**

- 0,0 - 0,2
- 0,2 - 0,4
- 0,4 - 0,6
- 0,6 - 0,8
- 0,8 - 1,0

Hours of direct solar radiation coefficient [0-1]








**Primary heat energy demand [MWh/year]**

- < 25
- 26 - 50
- 51 - 100
- 101 - 150
- 151 - 200
- 201 - 250
- 251 - 350
- 351 - 500
- 501 - 750
- > 750




**Primary heat energy demand [kWh/m²/year]**

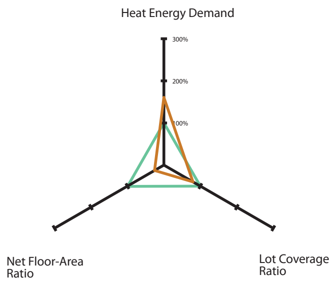
- < 50
- 51 - 75
- 76 - 100
- 101 - 125
- 126 - 150
- 151 - 175
- 176 - 200
- 201 - 225
- 226 - 250
- 251 - 275
- > 275



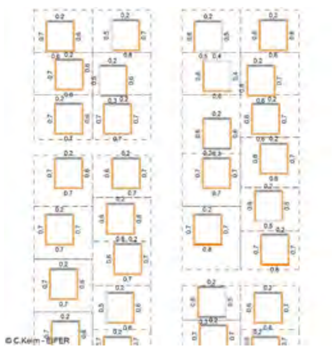
## B-2.7 PARIS IDEAL SAMPLES

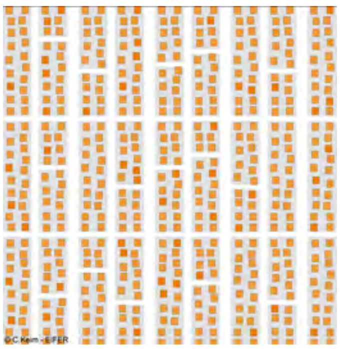
A visual display of the performance of the Idealised Samples for Paris tyopologies in terms of solar radiation exposure and heat energy demand.

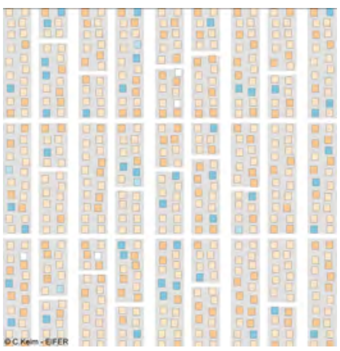
### Detached housing



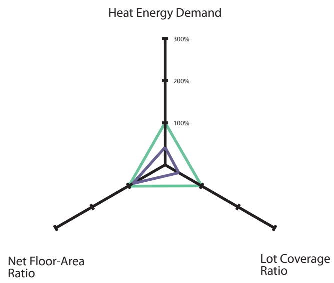


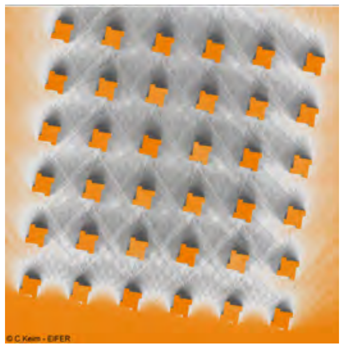


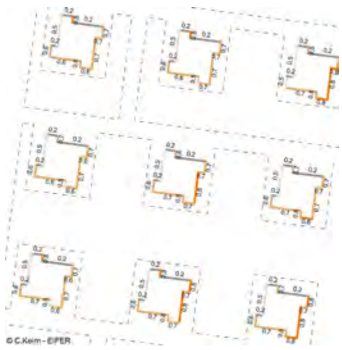



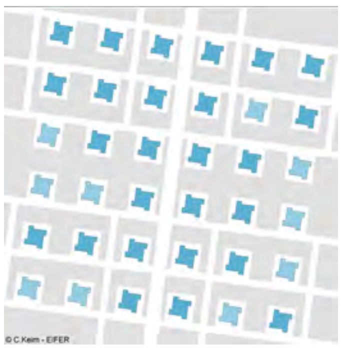



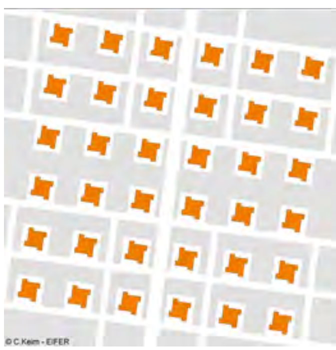

### High Rise Apartment



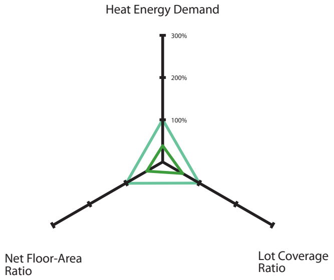



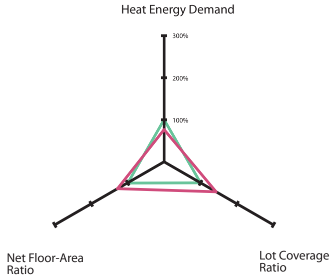
**Spider Diagram**

Relationship between the sample's heat energy demand and its physical characteristics

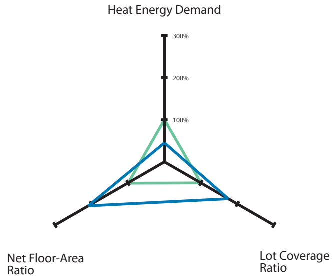
## Slab housing




## Regular urban block



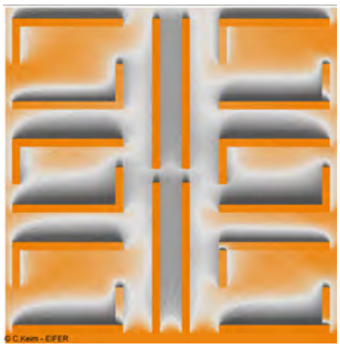

## Compact Urban Block

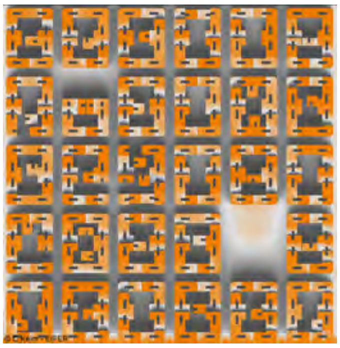


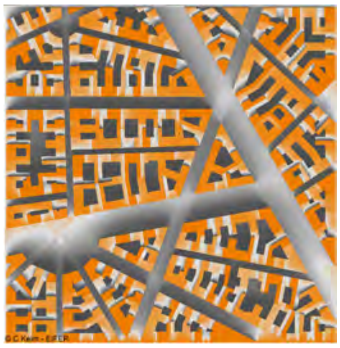

**Hours of direct solar radiation during periods where heating is required**

2134

0



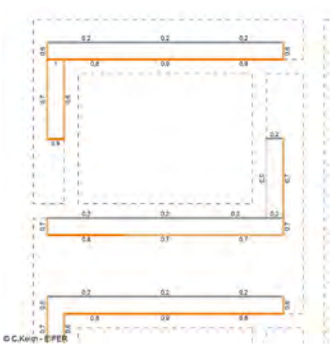



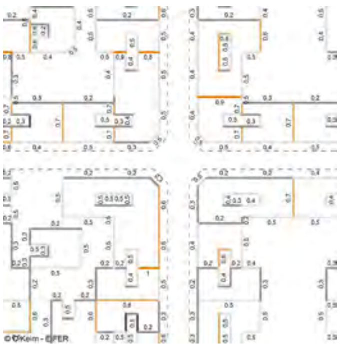


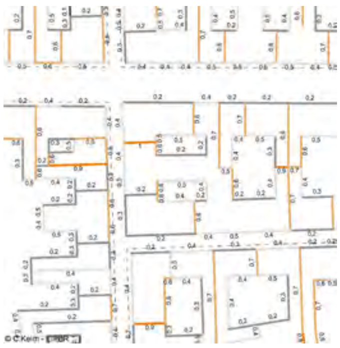

**Hours of direct solar radiation on building facades**

- 0,0 - 0,2
- 0,2 - 0,4
- 0,4 - 0,6
- 0,6 - 0,8
- 0,8 - 1,0

Hours of direct solar radiation coefficient [0-1]

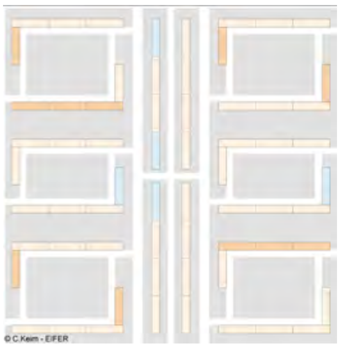


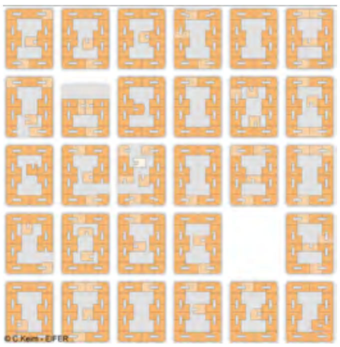



**Primary heat energy demand [MWh/year]**

- < 25
- 26 - 50
- 51 - 100
- 101 - 150
- 151 - 200
- 201 - 250
- 251 - 350
- 351 - 500
- 501 - 750
- > 750

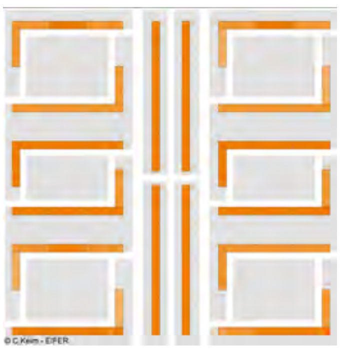




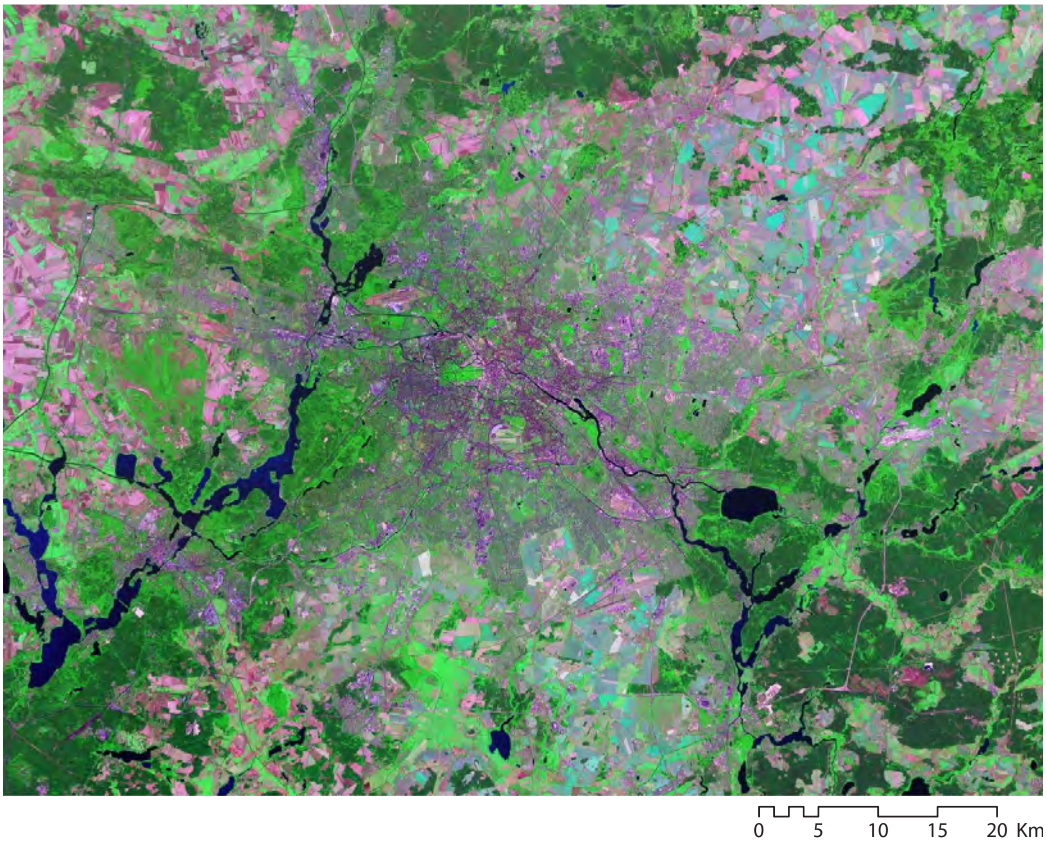
**Primary heat energy demand [kWh/m²/year]**

- < 50
- 51 - 75
- 76 - 100
- 101 - 125
- 126 - 150
- 151 - 175
- 176 - 200
- 201 - 225
- 226 - 250
- 251 - 275
- > 275

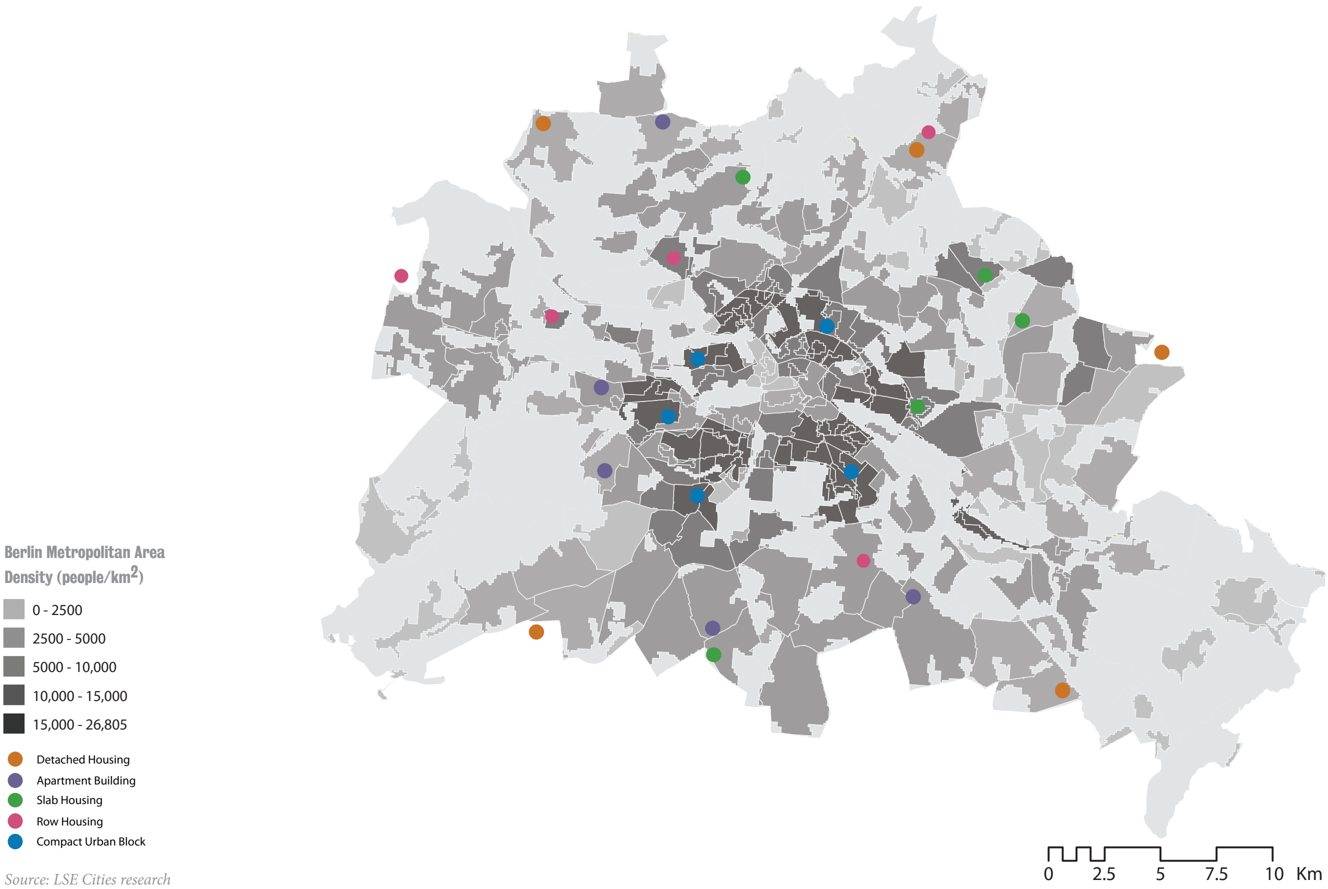




# B-3 BERLIN ENERGY PERFORMANCE



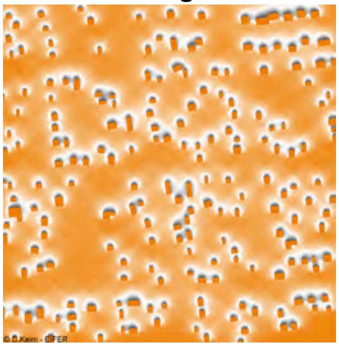

## B-3.1 DENSITY MAP AND LOCATION OF MORPHOLOGY SAMPLES



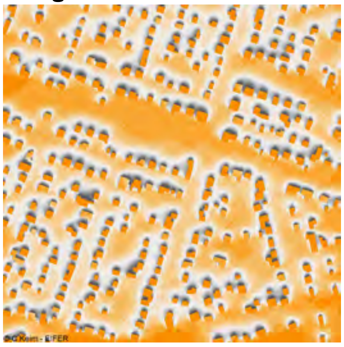

*Source: LSE Cities research*

### Detached Housing

### Hönower Siedlung DH01



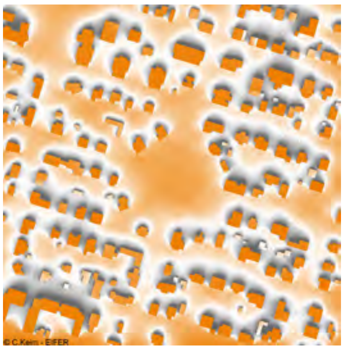

### Heiligensee DH02




### Apartment Building

### Lankwitz AB01


### Neu-westend AB02




### Slab Housing

### Lichtenberg Süd SH01


### Marienfelde SH02


### Row Housing

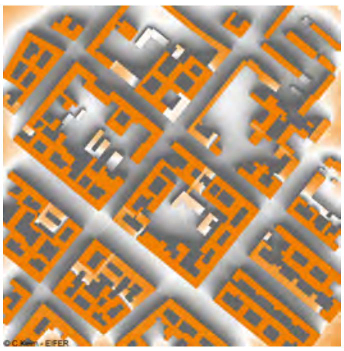
### Gartenstadt Falkenhöh RH01


### Neu-Karow RH02

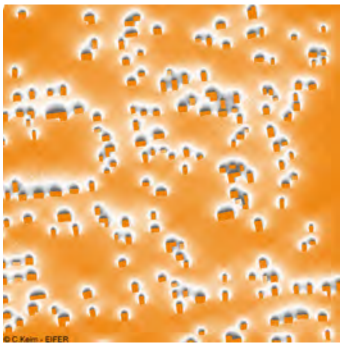

### Compact Urban Block

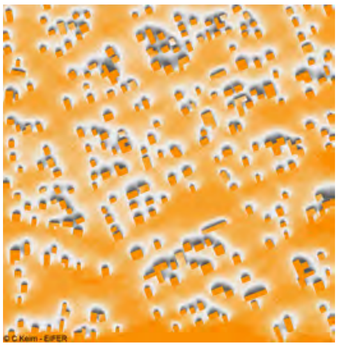
### Moabit CUB01

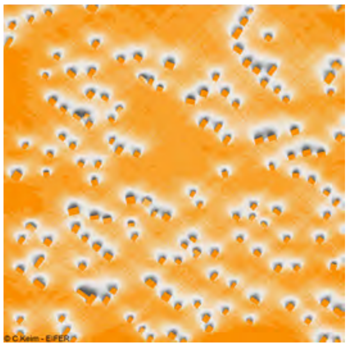

### Neukölln CUB02

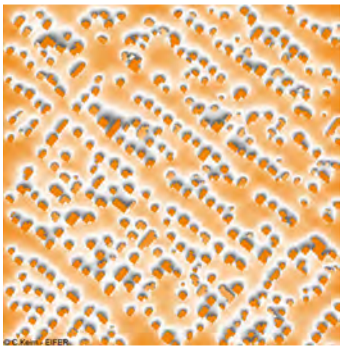


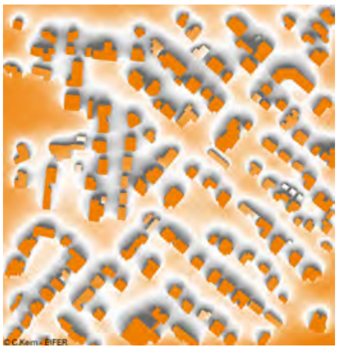

These two pages visually depict the duration of solar radiation for each Berlin sample

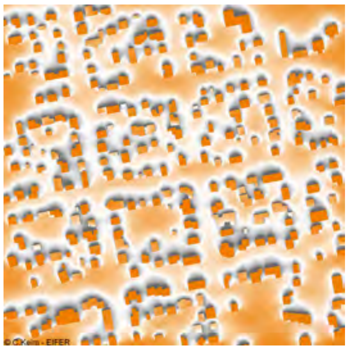
### Machnow DH03



### Falkenhorst DH04



### Alt-Karow DH05



### Rudow AB03



### Grünewald AB04



### Hermsdorf AB05



### Marzahn SH03



### Märkisches Viertel SH04



### Wartenberg SH05



### Hufeisensiedlung Britz RH03

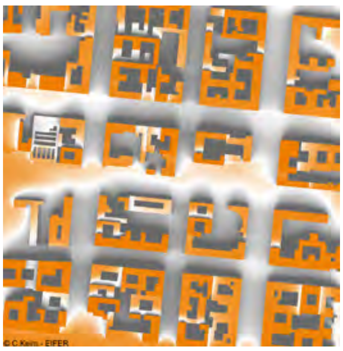


### Haselhorst RH04



### Reinickendorf West RH05



### Charlottenburg CUB03



### Prenzlauer Berg CUB04

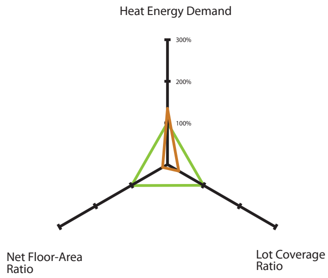


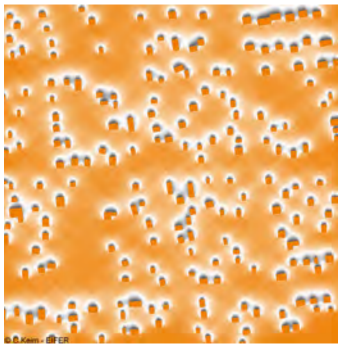
### Friedenau CUB05


## B-3.2 DETACHED HOUSING

A visual display of the extent of solar radiation exposure and heat energy demand for each sample of Detached Housing in Berlin.


### Hönower Siedlung DH01

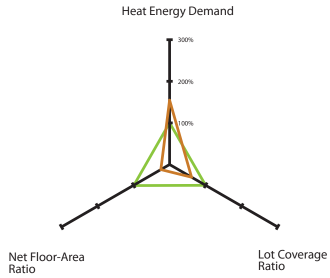


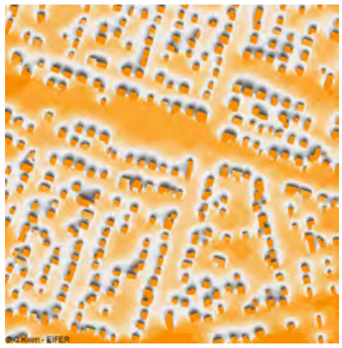



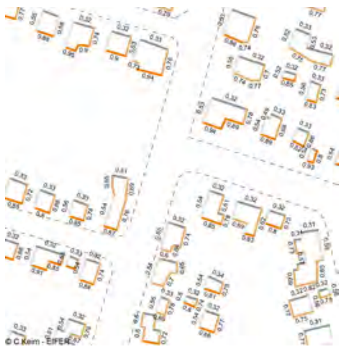




### Heiligensee DH02



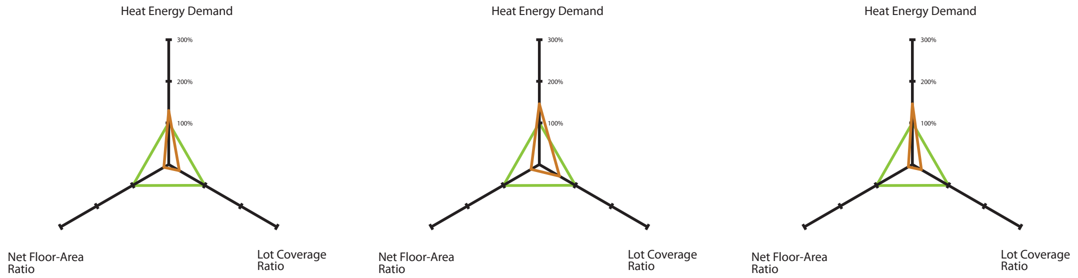





## Kleinmachnow DH03 | Falkenhorst DH04 | Alt-Karow DH05

**Spider Diagram**

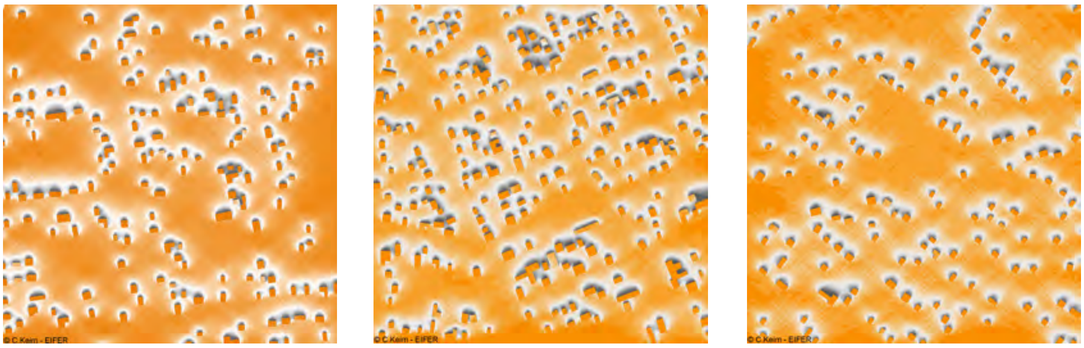
Relationship between the sample's heat energy demand and its physical characteristics




**Hours of direct solar radiation during periods where heating is required**

2134

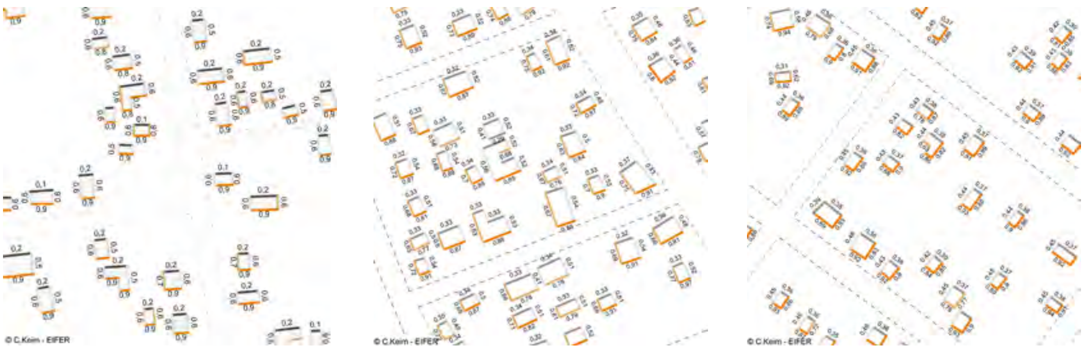
0




**Hours of direct solar radiation on building facades**

- 0,0 - 0,2
- 0,2 - 0,4
- 0,4 - 0,6
- 0,6 - 0,8
- 0,8 - 1,0

Hours of direct solar radiation coefficient [0-1]




**Primary heat energy demand [MWh/year]**

- < 25
- 26 - 50
- 51 - 100
- 101 - 150
- 151 - 200
- 201 - 250
- 251 - 350
- 351 - 500
- 501 - 750
- > 750

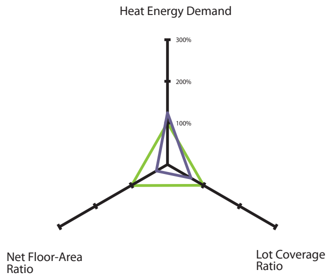

**Primary heat energy demand [kWh/m²/year]**

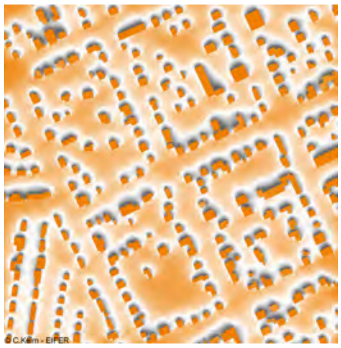
- < 50
- 51 - 75
- 76 - 100
- 101 - 125
- 126 - 150
- 151 - 175
- 176 - 200
- 201 - 225
- 226 - 250
- 251 - 275
- > 275

# B-3.3 APARTMENT BUILDING

A visual display of the extent of solar radiation exposure and heat energy demand for each sample of Apartment Buildings in Berlin.

## Marienfelde AB01

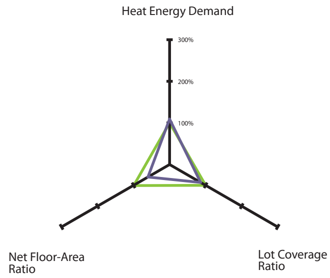


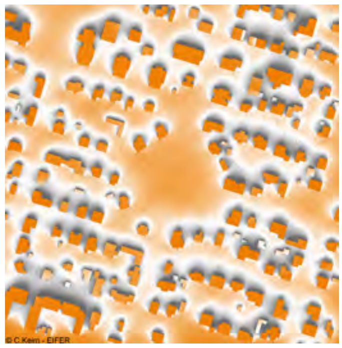



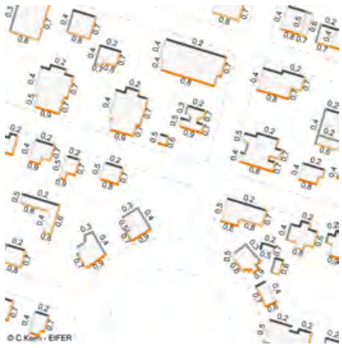




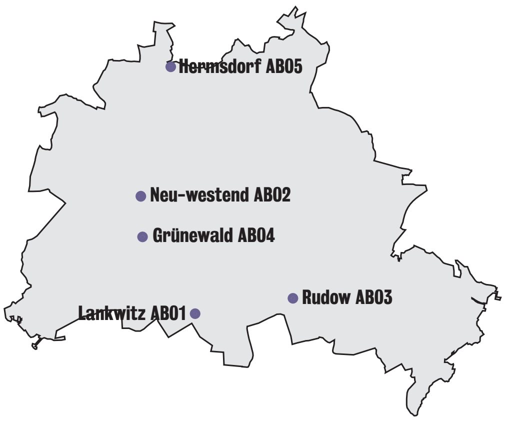
## Ruhlleben AB02





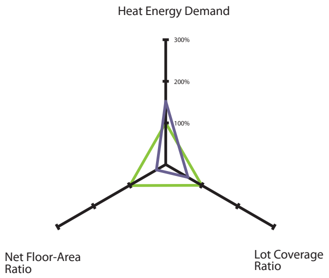




## Rudow AB03 | Grünewald AB04 | Hermsdorf AB05

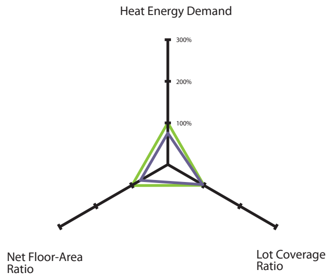
**Spider Diagram**

Relationship between the sample's heat energy demand and its physical characteristics

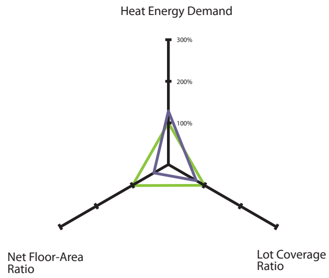
### Rudow AB03




### Grünewald AB04



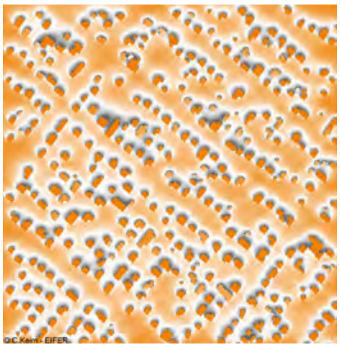
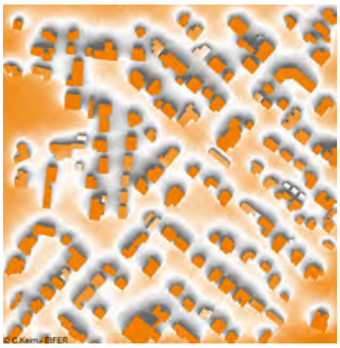
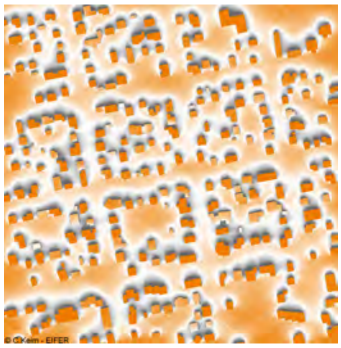

### Hermsdorf AB05




**Hours of direct solar radiation during periods where heating is required**

2134

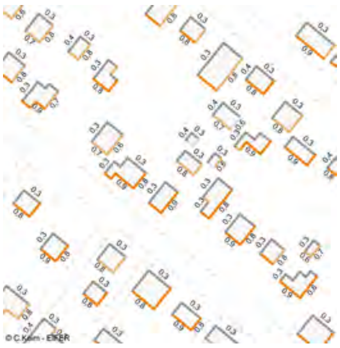
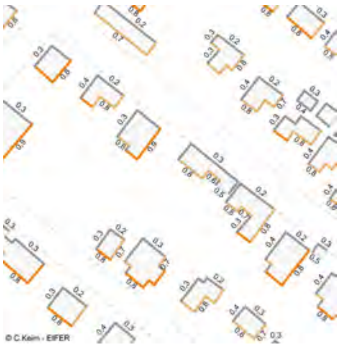
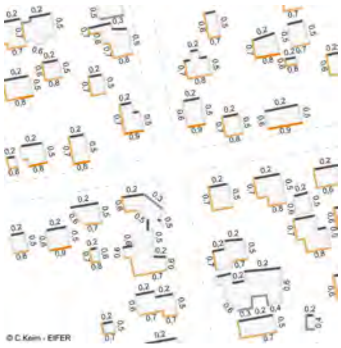
0

**Hours of direct solar radiation on building facades**

- 0,0 - 0,2
- 0,2 - 0,4
- 0,4 - 0,6
- 0,6 - 0,8
- 0,8 - 1,0

Hours of direct solar radiation coefficient [0-1]

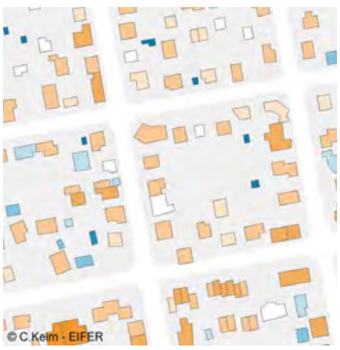




**Primary heat energy demand [MWh/year]**

- < 25
- 26 - 50
- 51 - 100
- 101 - 150
- 151 - 200
- 201 - 250
- 251 - 350
- 351 - 500
- 501 - 750
- > 750

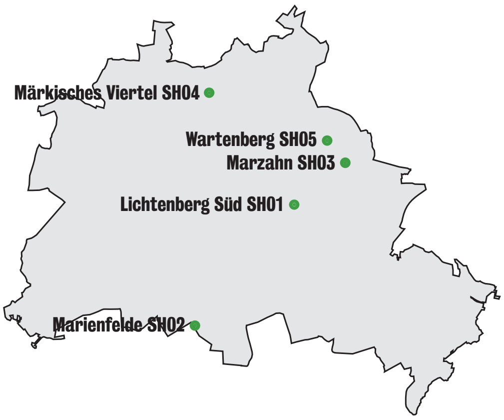

**Primary heat energy demand [kWh/m²/year]**

- < 50
- 51 - 75
- 76 - 100
- 101 - 125
- 126 - 150
- 151 - 175
- 176 - 200
- 201 - 225
- 226 - 250
- 251 - 275
- > 275

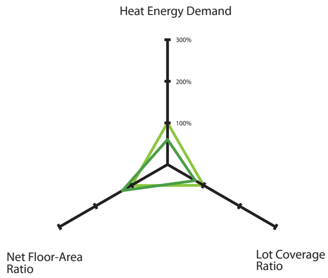


## B-3.4 SLAB HOUSING

A visual display of the extent of solar radiation exposure and heat energy demand for each sample of Slab Housing in Berlin.



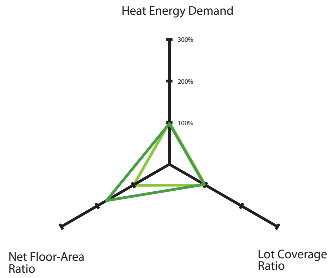

### Lichtenberg SH01








### Marienfelle SH02



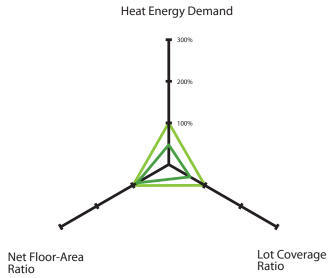


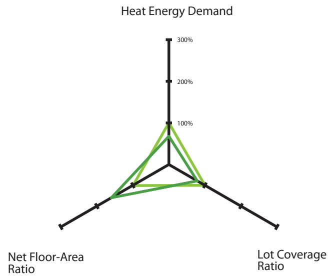


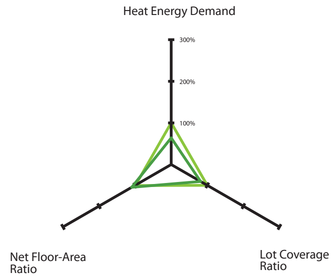
## Marzahn SH03 | Rosenthal SH04 | Wartenberg SH05

### Spider Diagram

Relationship between the sample's heat energy demand and its physical characteristics




### Hours of direct solar radiation during periods where heating is required

2134

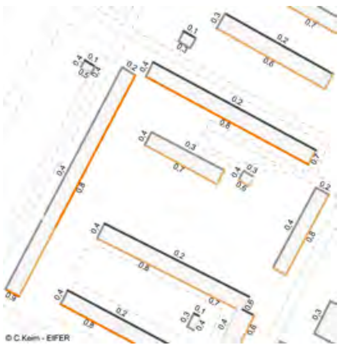
0




### Hours of direct solar radiation on building facades

- 0,0 - 0,2
- 0,2 - 0,4
- 0,4 - 0,6
- 0,6 - 0,8
- 0,8 - 1,0

Hours of direct solar radiation coefficient [0-1]






### Primary heat energy demand [MWh/year]

- < 25
- 26 - 50
- 51 - 100
- 101 - 150
- 151 - 200
- 201 - 250
- 251 - 350
- 351 - 500
- 501 - 750
- > 750




### Primary heat energy demand [kWh/m²/year]

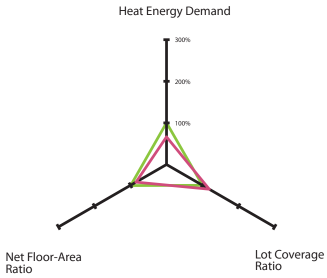
- < 50
- 51 - 75
- 76 - 100
- 101 - 125
- 126 - 150
- 151 - 175
- 176 - 200
- 201 - 225
- 226 - 250
- 251 - 275
- > 275



## B-3.5 ROW HOUSING

A visual display of the extent of solar radiation exposure and heat energy demand for each sample of Row Housing in Berlin.

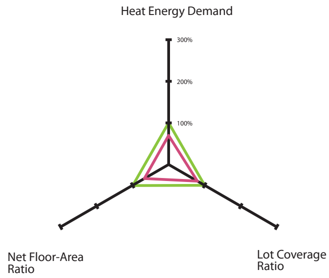

### Falkenhagen RH01








### Buch RH02



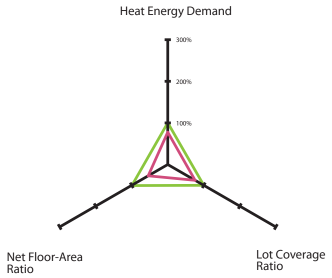




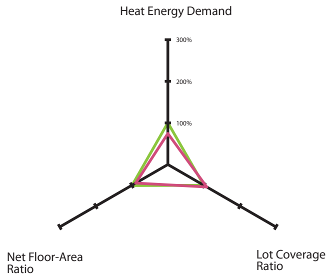
**Spider Diagram**

Relationship between the sample's heat energy demand and its physical characteristics

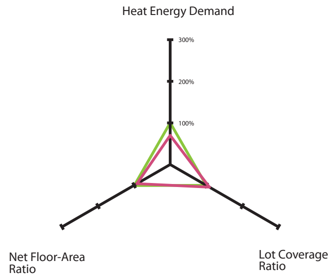
## Britz RH03




## Haselhorst RH04



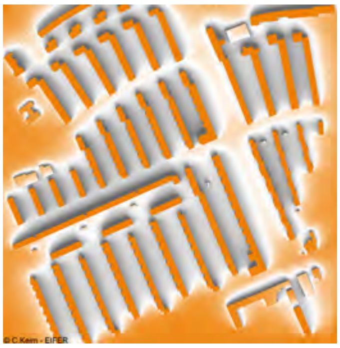

## Tegel RH05




**Hours of direct solar radiation during periods where heating is required**

2134

0



**Hours of direct solar radiation on building facades**

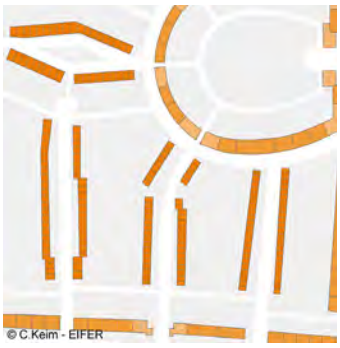
- 0,0 - 0,2
- 0,2 - 0,4
- 0,4 - 0,6
- 0,6 - 0,8
- 0,8 - 1,0

Hours of direct solar radiation coefficient [0-1]




**Primary heat energy demand [MWh/year]**

- < 25
- 26 - 50
- 51 - 100
- 101 - 150
- 151 - 200
- 201 - 250
- 251 - 350
- 351 - 500
- 501 - 750
- > 750





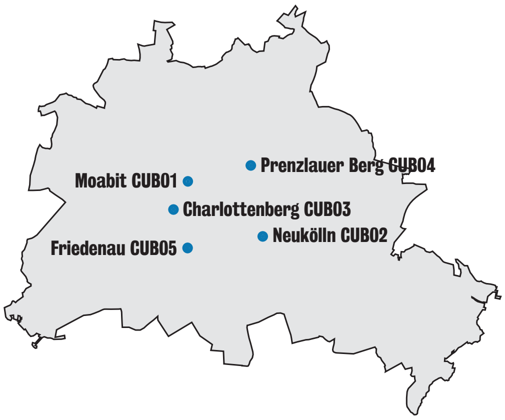

**Primary heat energy demand [kWh/m²/year]**

- < 50
- 51 - 75
- 76 - 100
- 101 - 125
- 126 - 150
- 151 - 175
- 176 - 200
- 201 - 225
- 226 - 250
- 251 - 275
- > 275

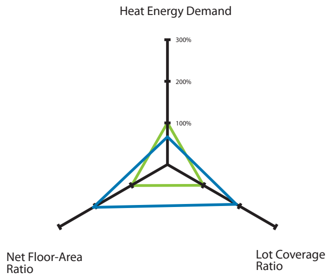


## B-3.6 COMPACT URBAN BLOCK

A visual display of the extent of solar radiation exposure and heat energy demand for each sample of Compact Urban Blocks in Berlin.

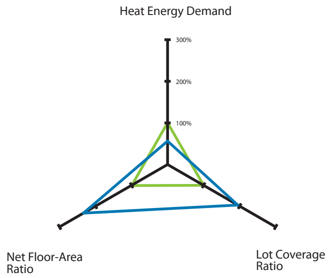


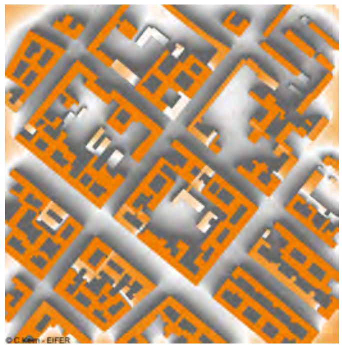

### Tiergarten CUB01

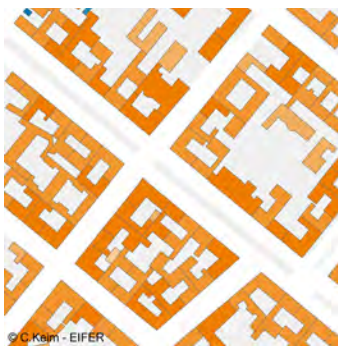





### Neukölln CUB02



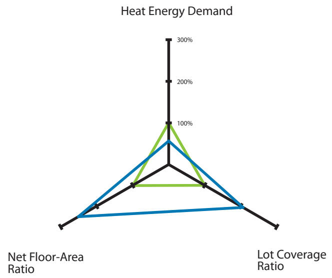



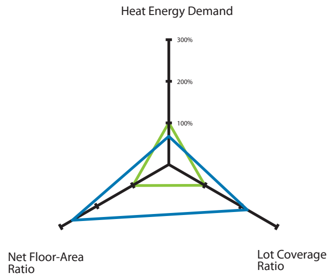



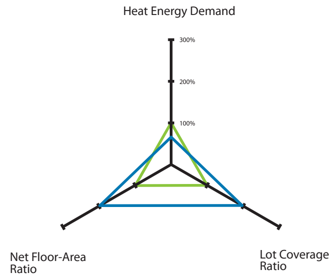
## Charlottenburg CUB03 | Prenzlauerberg CUB04 | Friedenau CUB05

**Spider Diagram**

Relationship between the sample's heat energy demand and its physical characteristics




**Hours of direct solar radiation during periods where heating is required**

2134

0


**Hours of direct solar radiation on building facades**

- 0,0 - 0,2
- 0,2 - 0,4
- 0,4 - 0,6
- 0,6 - 0,8
- 0,8 - 1,0

Hours of direct solar radiation coefficient [0-1]


**Primary heat energy demand [MWh/year]**

- < 25
- 26 - 50
- 51 - 100
- 101 - 150
- 151 - 200
- 201 - 250
- 251 - 350
- 351 - 500
- 501 - 750
- > 750

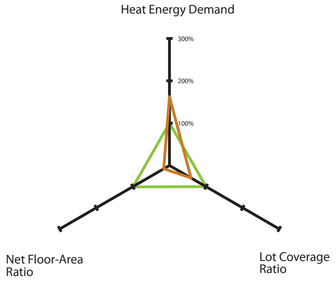

**Primary heat energy demand [kWh/m²/year]**

- < 50
- 51 - 75
- 76 - 100
- 101 - 125
- 126 - 150
- 151 - 175
- 176 - 200
- 201 - 225
- 226 - 250
- 251 - 275
- > 275

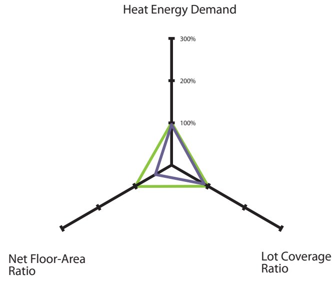
## B-3.7 BERLIN IDEAL SAMPLES

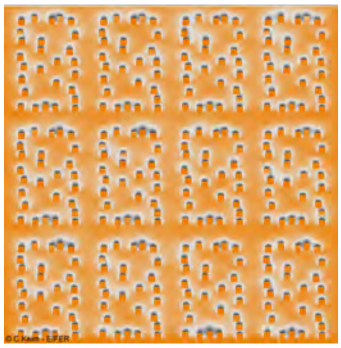
A visual display of the performance of the Idealised Samples for Berlin tyopologies in terms of solar radiation exposure and heat energy demand.

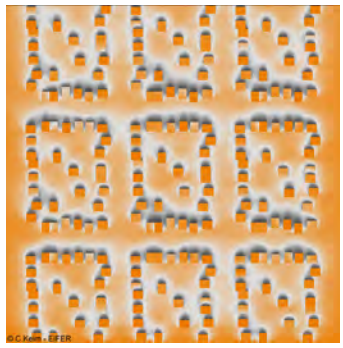
### Detached Housing

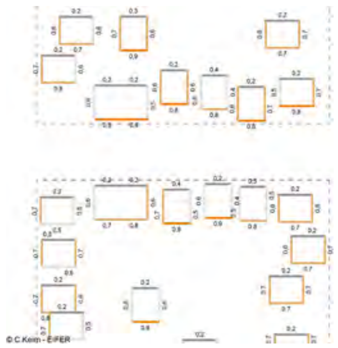


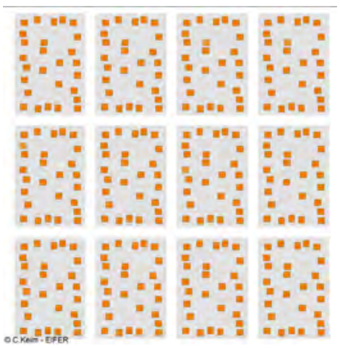

### Apartment Building

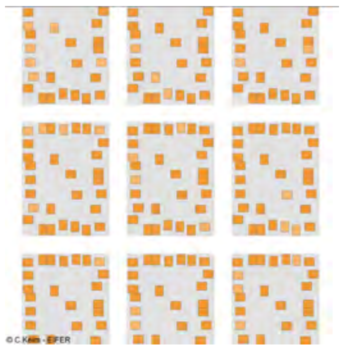


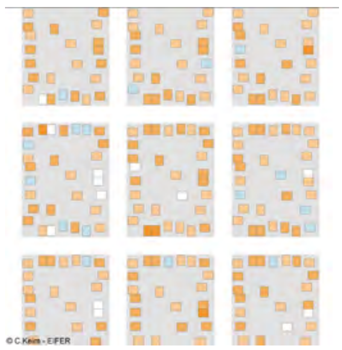











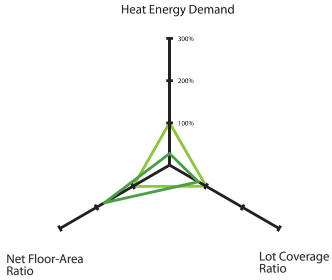


| | Slab Housing | Row Housing | Compact Urban Block |
|---|---|---|---|

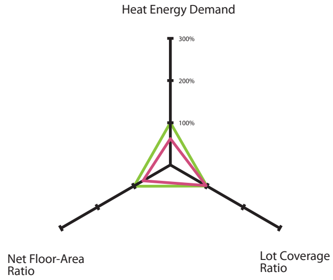
**Spider Diagram**

Relationship between the sample's heat energy demand and its physical characteristics

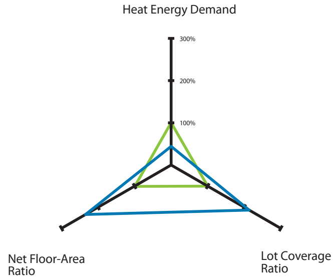
## Slab Housing




## Row Housing



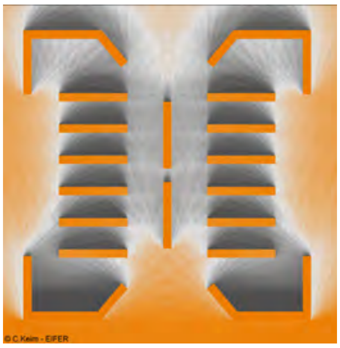

## Compact Urban Block

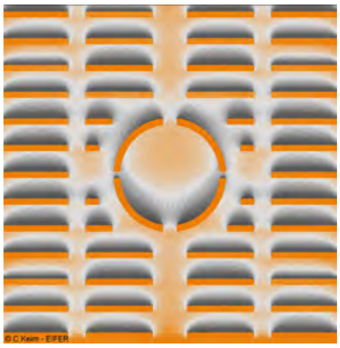


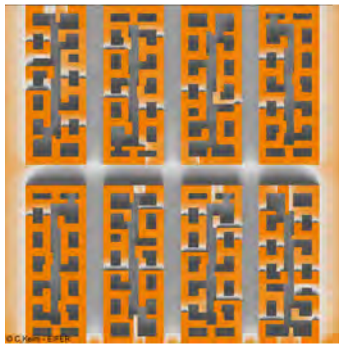

**Hours of direct solar radiation during periods where heating is required**

2134

0



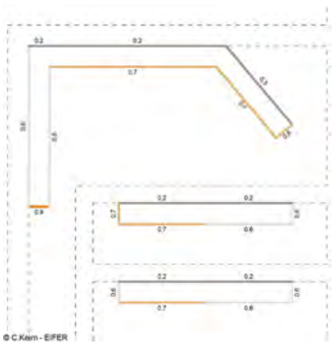


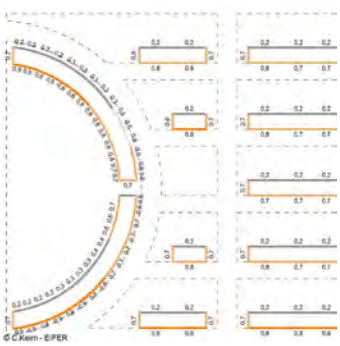


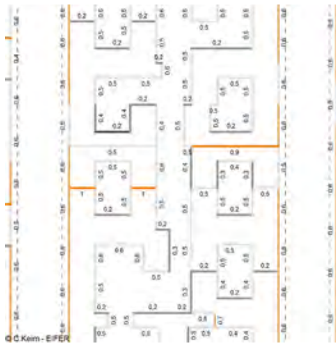
**Hours of direct solar radiation on building facades**

- 0,0 - 0,2
- 0,2 - 0,4
- 0,4 - 0,6
- 0,6 - 0,8
- 0,8 - 1,0

Hours of direct solar radiation coefficient [0-1]

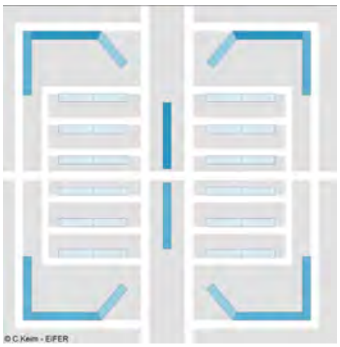


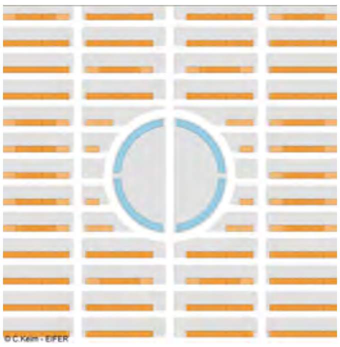




**Primary heat energy demand [MWh/year]**

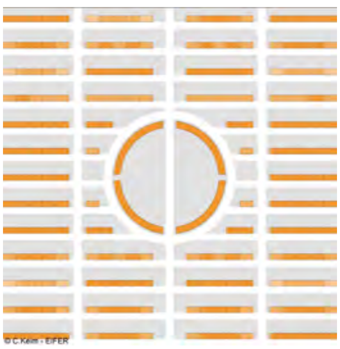
- < 25
- 26 - 50
- 51 - 100
- 101 - 150
- 151 - 200
- 201 - 250
- 251 - 350
- 351 - 500
- 501 - 750
- > 750

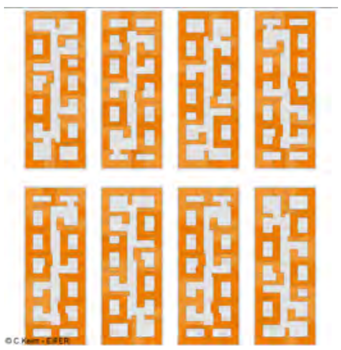




**Primary heat energy demand [kWh/m²/year]**

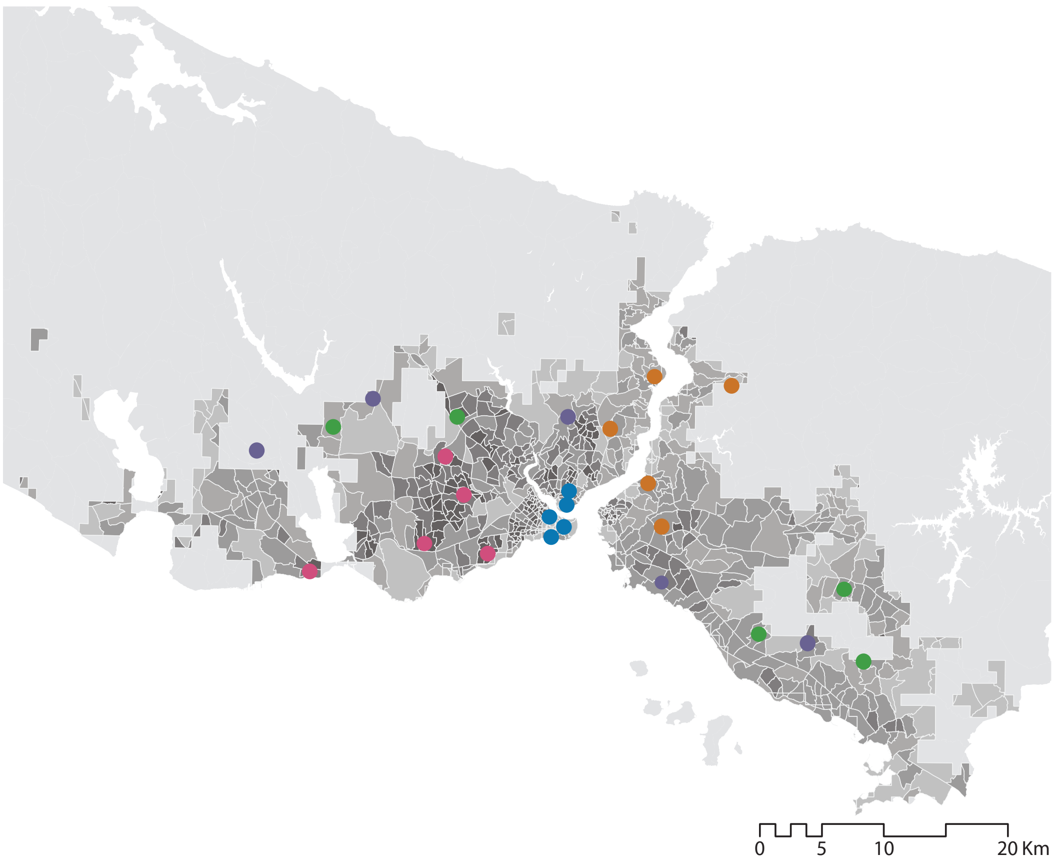
- < 50
- 51 - 75
- 76 - 100
- 101 - 125
- 126 - 150
- 151 - 175
- 176 - 200
- 201 - 225
- 226 - 250
- 251 - 275
- > 275





# B-4 ISTANBUL ENERGY PERFORMANCES


## B-4.1 DENSITY MAP AND LOCATION OF MORPHOLOGY SAMPLES




**Istanbul Metropolitan Area Density (people/km$^2$)**

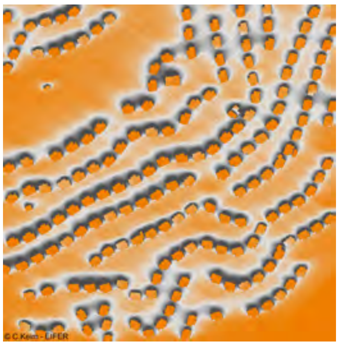
- 0 - 2,500
- 2,500 - 5,000
- 5,000 - 10,000
- 10,000 - 15,000
- 15,000 - 26,805

- Detached Housing
- High Rise Apartment
- Gecekondu
- Modern Apartment
- Compact Urban Block

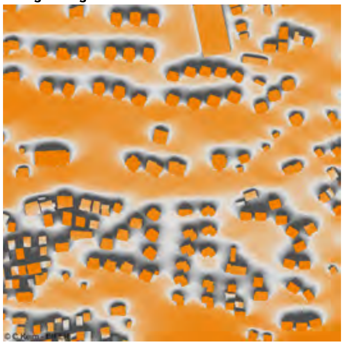
*Source: LSE Cities Research*

### Detached Housing

### Acarkent DH01

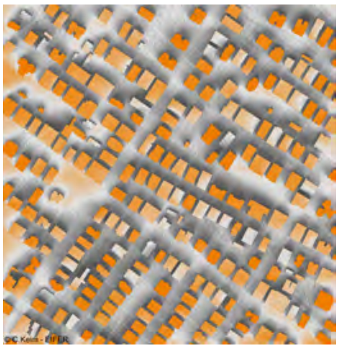


### Küçük Çamlıca DH02

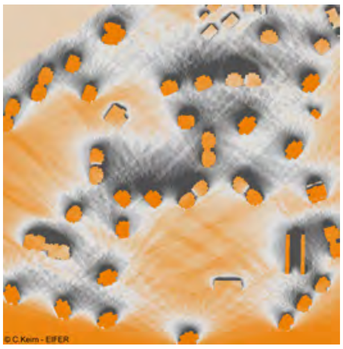


### High Rise Apartment

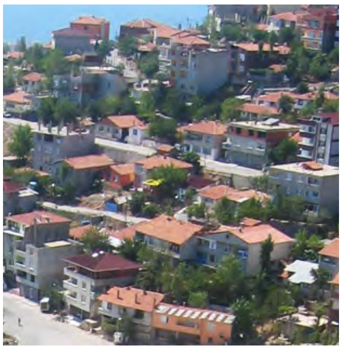
### Erenköy HRA01



### Bahcesehir HRA02

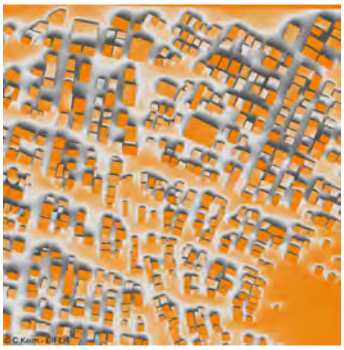


### Gecekondu



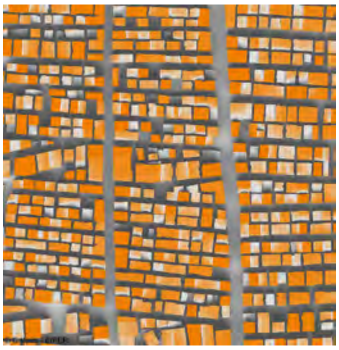
### 50. Yıl G01

### Sultanbeyli G02

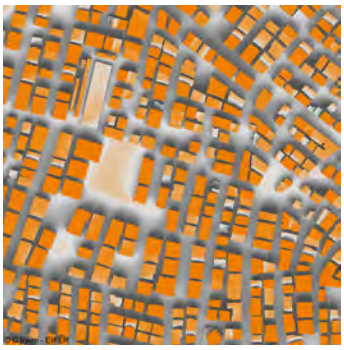


### Modern Apartment

### Zafer MA01



### Denizköskler MA02



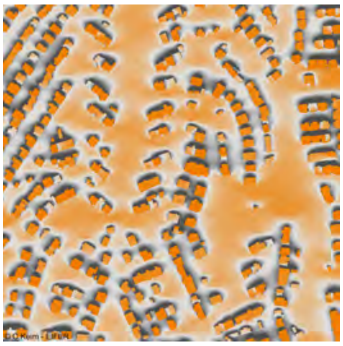
### Compact Apartment

### Tophane CUB01

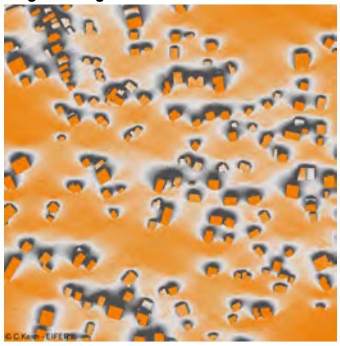
### Tarlabası CUB02

These two pages visually depict the duration of solar radiation for each Istanbul sample

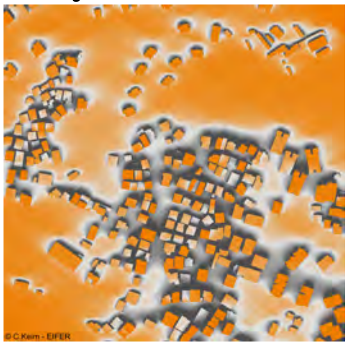
**Levent DH03**



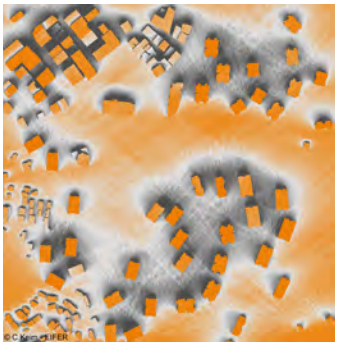
**Beylerbeyi DH04**



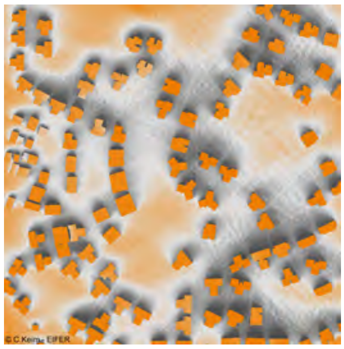
**Yeniköy DH05**



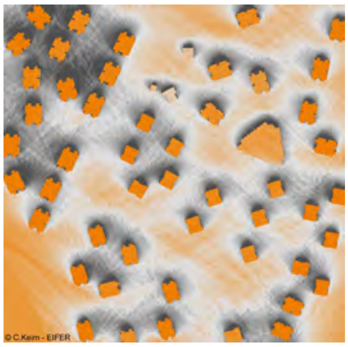
**Kagıthane HRA03**



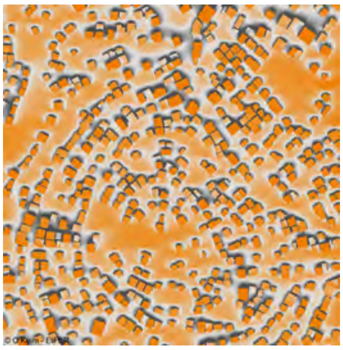
**Ugur Mumcu HRA04**



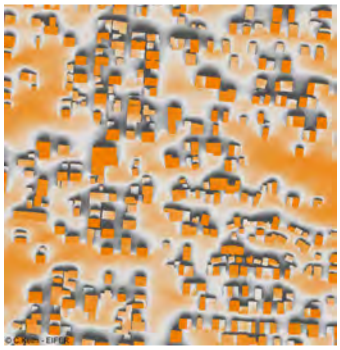
**Basaksehir HRA05**



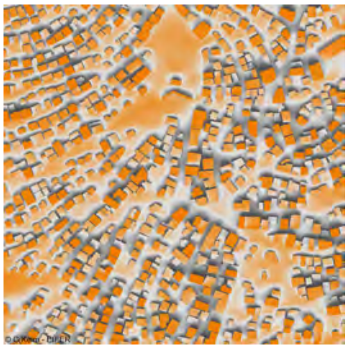
**Ertugrulgazi G03**



**Altınsehir G04**



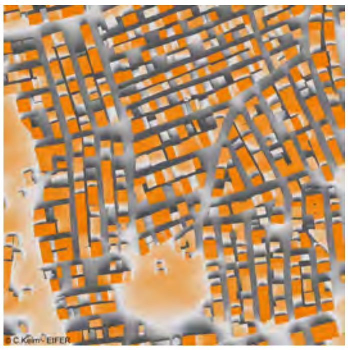
**Gülensu G05**



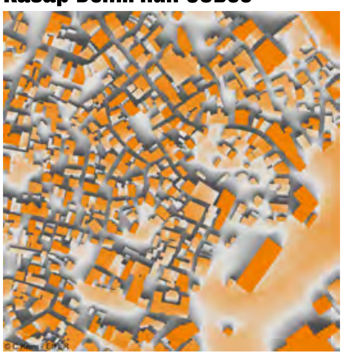
**Nuripasa MA03**

**Oruçreis MA04**

**Nenehatun MA05**



**Kasap Demirhun CUB03**



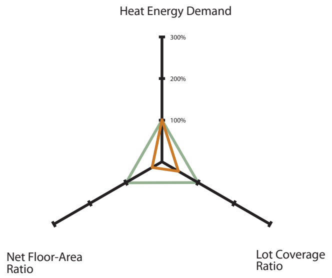
**Kumkapı CUB04**

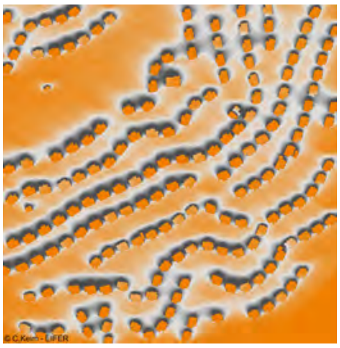
**Süleymaniye CUB05**

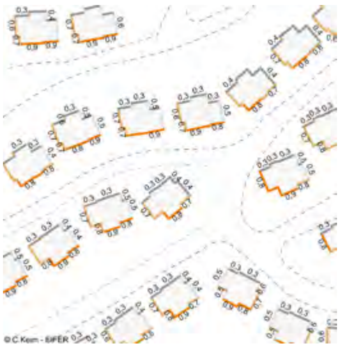
# B-4.2 DETACHED HOUSING

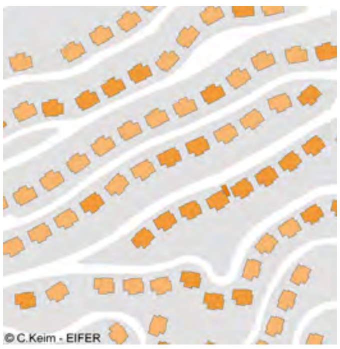
A visual display of the extent of solar radiation exposure and heat energy demand for each sample of Detached Housing in Istanbul.


## Acarkent DH01



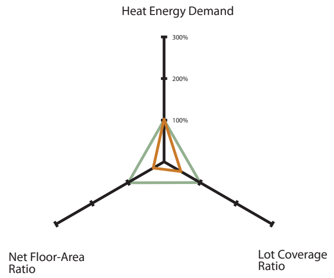



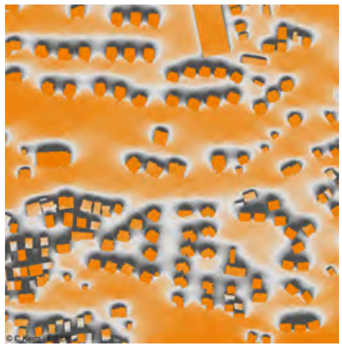





## Küçük Çamlıca DH02



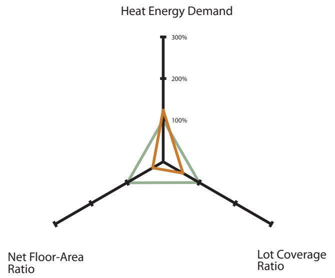



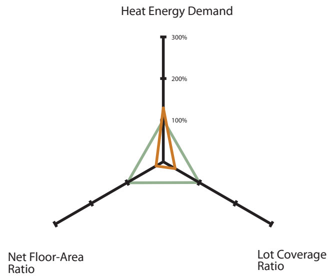


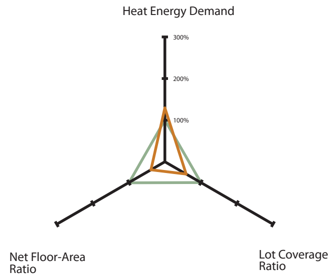
## Levent DH03 | Beylerbeyi DH04 | Yeniköy DH05

**Spider Diagram**

Relationship between the sample's heat energy demand and its interior and physical characteristics



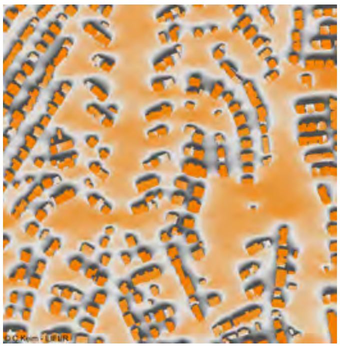



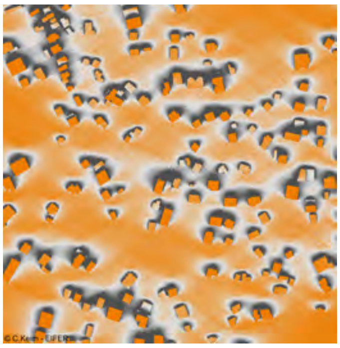



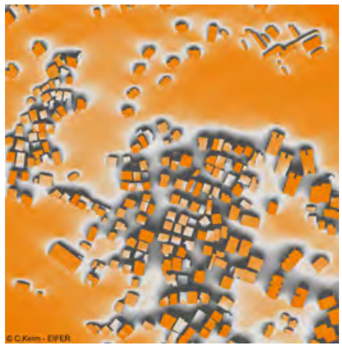

**Hours of direct solar radiation during periods where heating is required**

2134

0



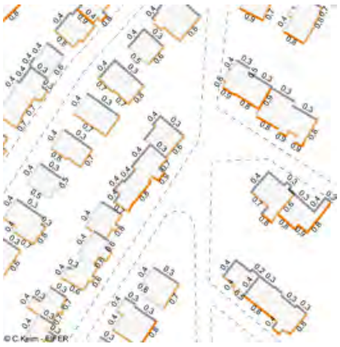



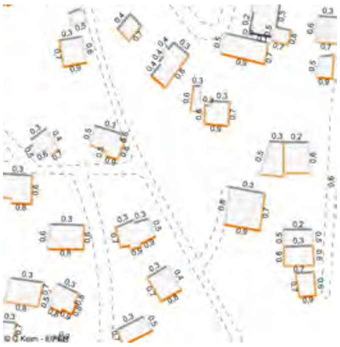




**Hours of direct solar radiation on building facades**

- 0,0 - 0,2
- 0,2 - 0,4
- 0,4 - 0,6
- 0,6 - 0,8
- 0,8 - 1,0

Hours of direct solar radiation coefficient [0-1]





**Primary heat energy demand [MWh/year]**

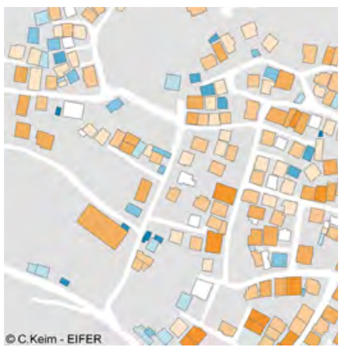
- < 25
- 26 - 50
- 51 - 100
- 101 - 150
- 151 - 200
- 201 - 250
- 251 - 350
- 351 - 500
- 501 - 750
- > 750




**Primary heat energy demand [kWh/m²/year]**

- < 50
- 51 - 75
- 76 - 100
- 101 - 125
- 126 - 150
- 151 - 175
- 176 - 200
- 201 - 225
- 226 - 250
- 251 - 275
- > 275

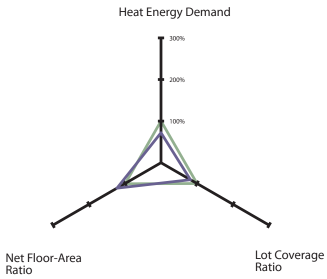


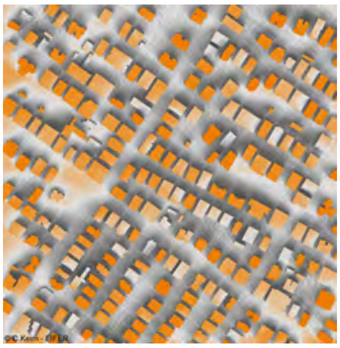


# B-4.3 HIGH RISE APARTMENT

A visual display of the extent of solar radiation exposure and heat energy demand for each sample of High Rise Apartments in Istanbul.


## Erenköy HRA01

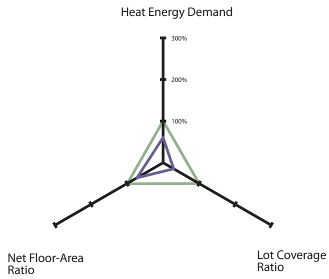


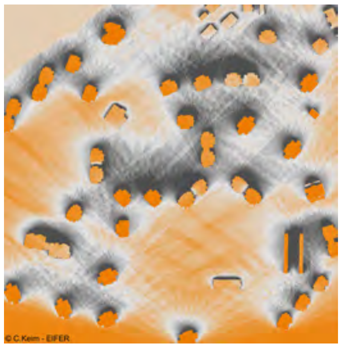







## Bahcesehir HRA02



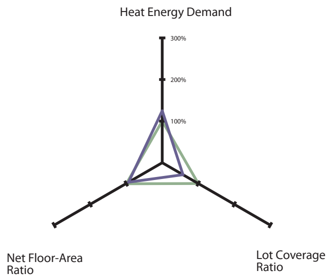





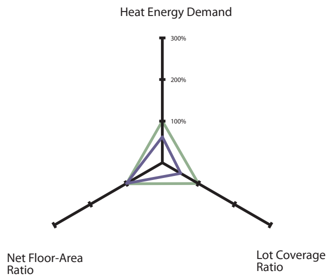

**Spider Diagram**

Relationship between the sample's heat energy demand and its exterior and physical characteristics

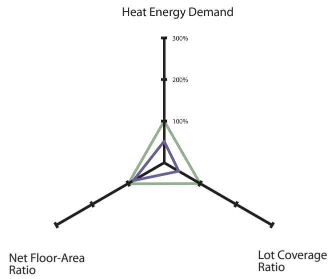
## Kagıthane HRA03




## Ugur Mumcu HRA04



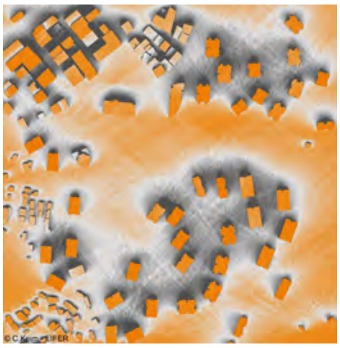

## Basaksehir HRA05

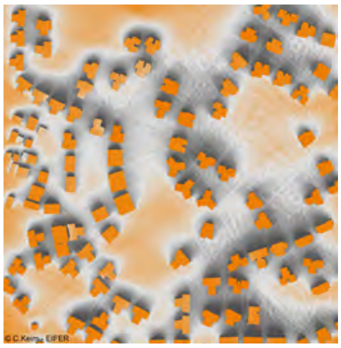


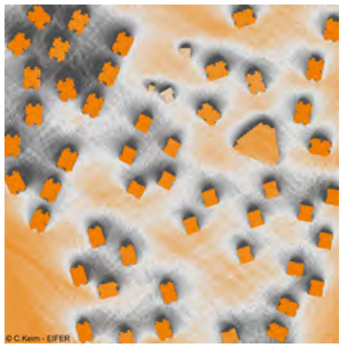

**Hours of direct solar radiation during periods where heating is required**

2134

0



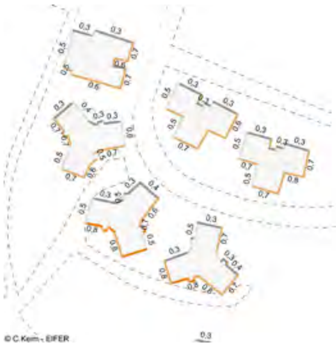




**Hours of direct solar radiation on building facades**

- 0,0 - 0,2
- 0,2 - 0,4
- 0,4 - 0,6
- 0,6 - 0,8
- 0,8 - 1,0

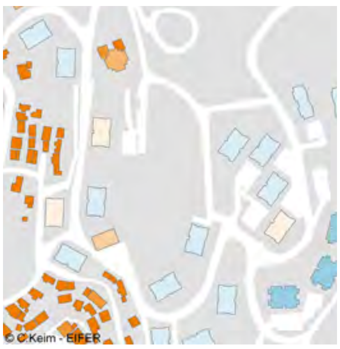
Hours of direct solar radiation coefficient [0-1]



**Primary heat energy demand [MWh/year]**

- < 25
- 26 - 50
- 51 - 100
- 101 - 150
- 151 - 200
- 201 - 250
- 251 - 350
- 351 - 500
- 501 - 750
- > 750





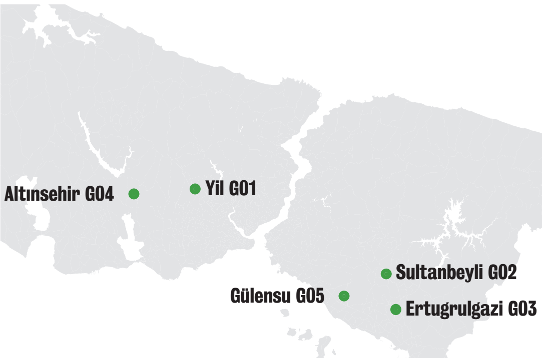

**Primary heat energy demand [kWh/m²/year]**

- < 50
- 51 - 75
- 76 - 100
- 101 - 125
- 126 - 150
- 151 - 175
- 176 - 200
- 201 - 225
- 226 - 250
- 251 - 275
- > 275

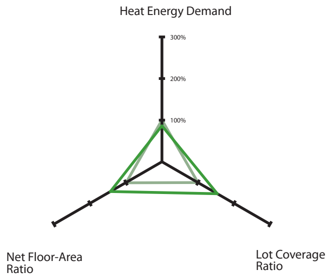


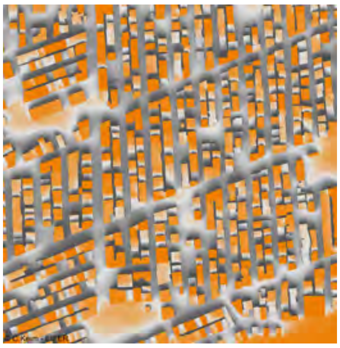
## B-4.4 GECEKONDU

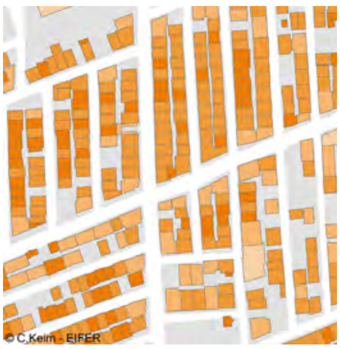
A visual display of the extent of solar radiation exposure and heat energy demand for each sample of Gecekondu in Istanbul.




### 50. Yıl G01

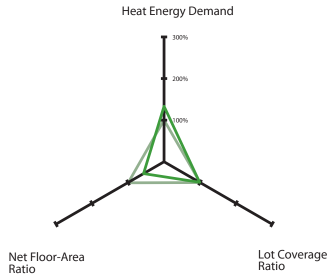


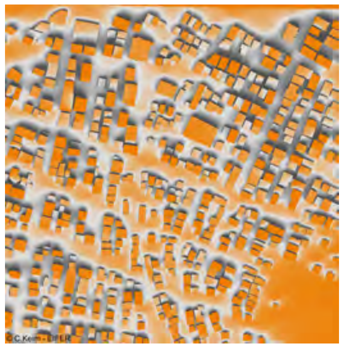



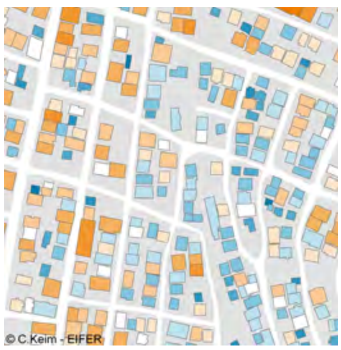




### Sultanbeyli G02



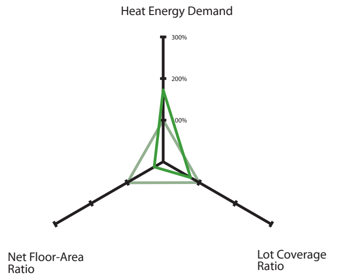



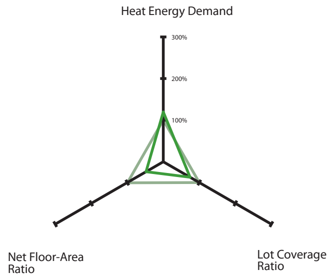



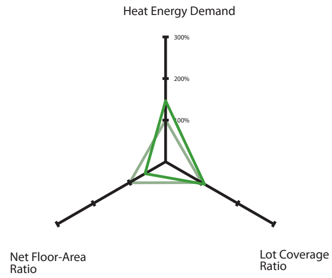
## Ertugrulgazi G03 | Altınsehir G04 | Gülensu G05

**Spider Diagram**

Relationship between the sample's heat energy demand and its exterior and physical characteristics



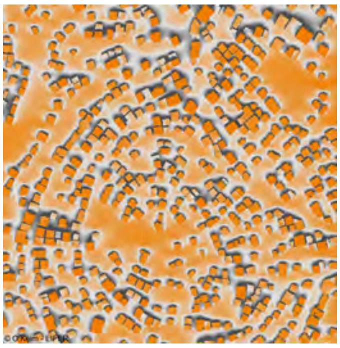



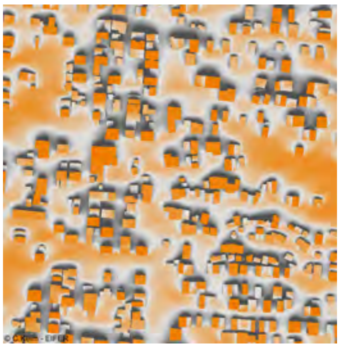



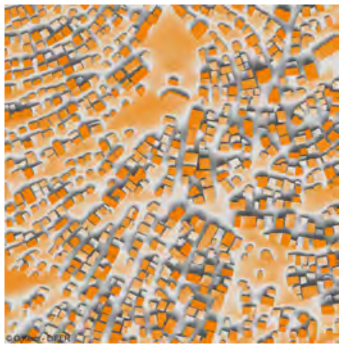

**Hours of direct solar radiation during periods where heating is required**

2134

0



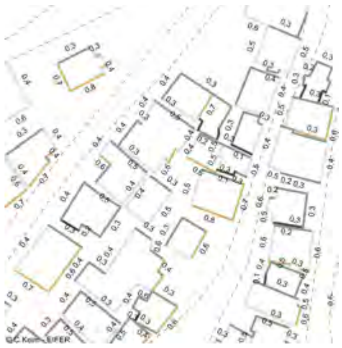




**Hours of direct solar radiation on building facades**

- 0,0 - 0,2
- 0,2 - 0,4
- 0,4 - 0,6
- 0,6 - 0,8
- 0,8 - 1,0

Hours of direct solar radiation coefficient [0-1]





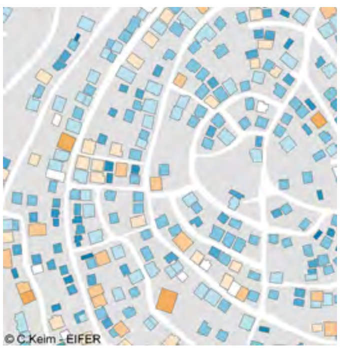

**Primary heat energy demand [MWh/year]**

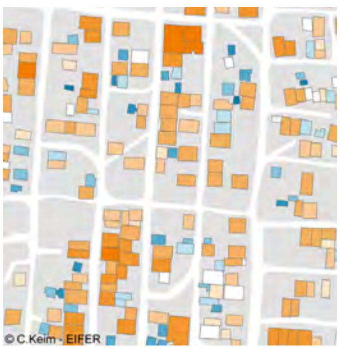
- < 25
- 26 - 50
- 51 - 100
- 101 - 150
- 151 - 200
- 201 - 250
- 251 - 350
- 351 - 500
- 501 - 750
- > 750

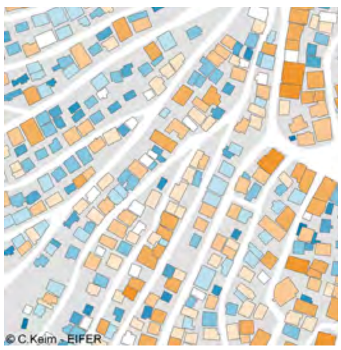



**Primary heat energy demand [kWh/m²/year]**

- < 50
- 51 - 75
- 76 - 100
- 101 - 125
- 126 - 150
- 151 - 175
- 176 - 200
- 201 - 225
- 226 - 250
- 251 - 275
- > 275



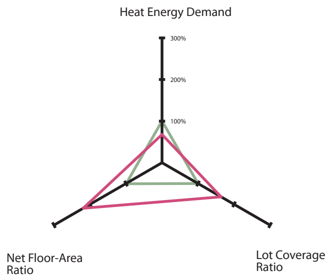



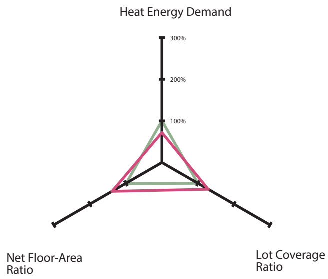
# B-4.5 MODERN APARTMENT

A visual display of the extent of solar radiation exposure and heat energy demand for each sample of Modern Apartments in Istanbul.


## Zafer MA01




## Denizköskler MA02



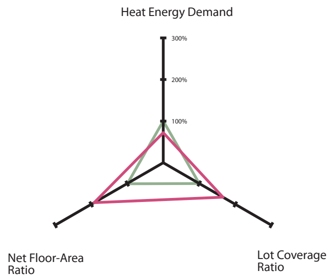

## Nuripasa MA03

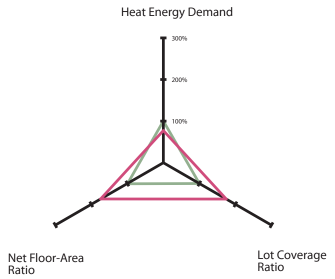
## Oruçreis MA04

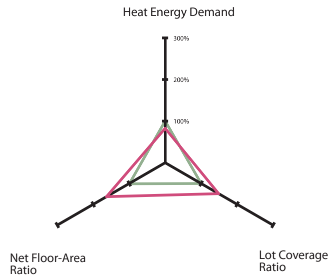
## Nenehatun MA05

**Spider Diagram**

Relationship between the sample's heat energy demand and its interior and exterior physical characteristics variables



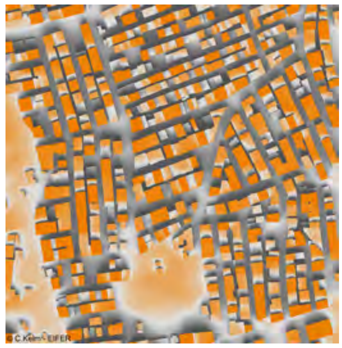




**Hours of direct solar radiation during periods where heating is required**

2134

0



**Hours of direct solar radiation on building facades**

- 0,0 - 0,2
- 0,2 - 0,4
- 0,4 - 0,6
- 0,6 - 0,8
- 0,8 - 1,0

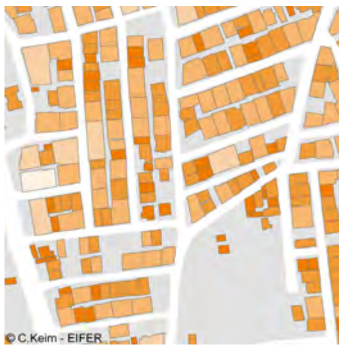
Hours of direct solar radiation coefficient [0-1]



**Primary heat energy demand [MWh/year]**

- < 25
- 26 - 50
- 51 - 100
- 101 - 150
- 151 - 200
- 201 - 250
- 251 - 350
- 351 - 500
- 501 - 750
- > 750






**Primary heat energy demand [kWh/m²/year]**

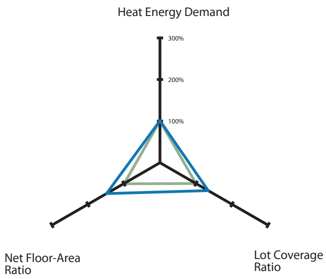
- < 50
- 51 - 75
- 76 - 100
- 101 - 125
- 126 - 150
- 151 - 175
- 176 - 200
- 201 - 225
- 226 - 250
- 251 - 275
- > 275

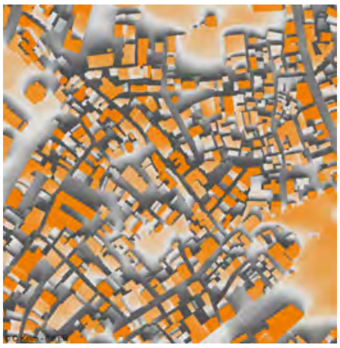


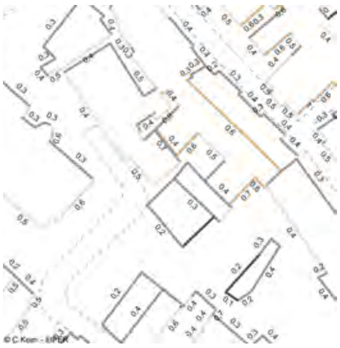
# B-4.6 COMPACT URBAN BLOCK

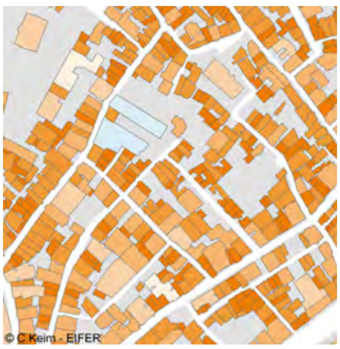
A visual display of the extent of solar radiation exposure and heat energy demand for each sample of Compact Urban Blocks in Istanbul.

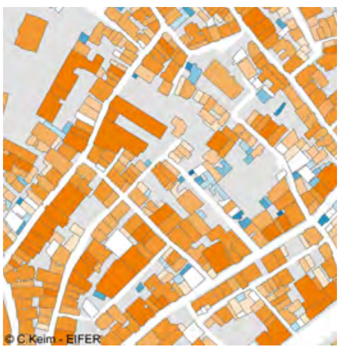

## Tophane CUB01



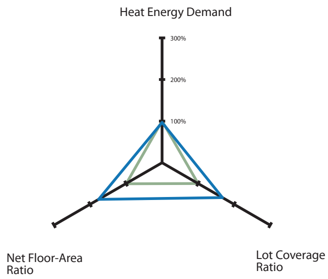



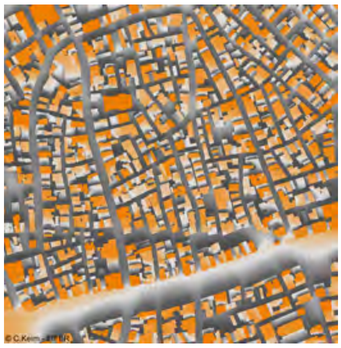


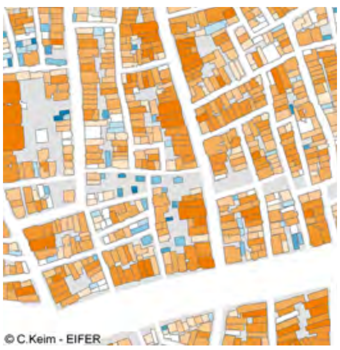



## Tarlabası CUB02



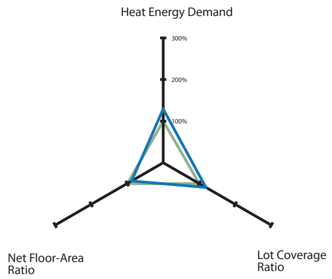



## Kasap Demirhun CUB03 | Kumkapı CUB04 | Süleymaniye CUB05

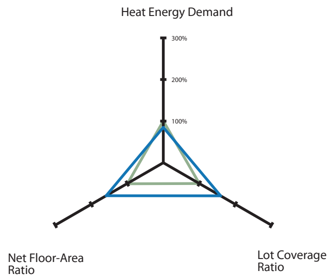
**Spider Diagram**

Relationship between the sample's heat energy demand and its physical characteristics

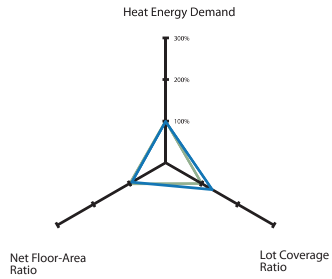
### Kasap Demirhun CUB03




### Kumkapı CUB04



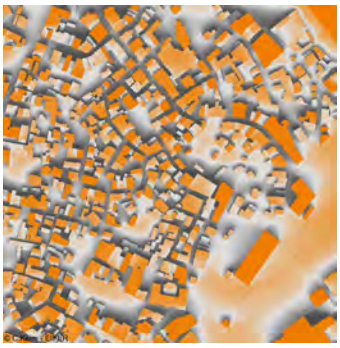

### Süleymaniye CUB05

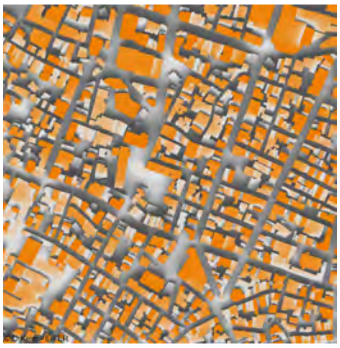


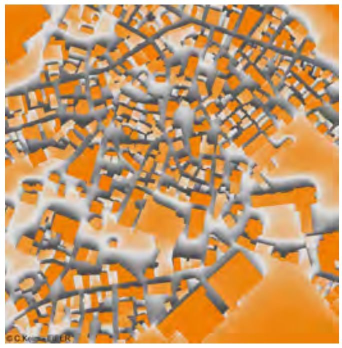

**Hours of direct solar radiation during periods where heating is required**

2134

0




**Hours of direct solar radiation on building facades**

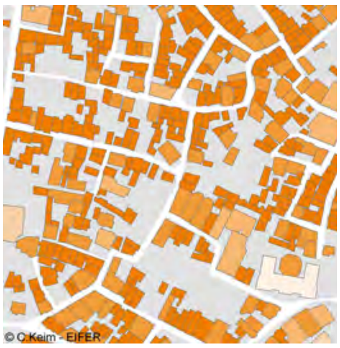
- 0,0 - 0,2
- 0,2 - 0,4
- 0,4 - 0,6
- 0,6 - 0,8
- 0,8 - 1,0

Hours of direct solar radiation coefficient [0-1]




**Primary heat energy demand [MWh/year]**

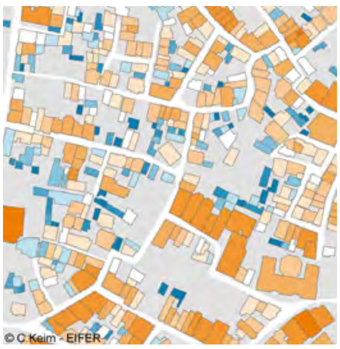
- < 25
- 26 - 50
- 51 - 100
- 101 - 150
- 151 - 200
- 201 - 250
- 251 - 350
- 351 - 500
- 501 - 750
- > 750

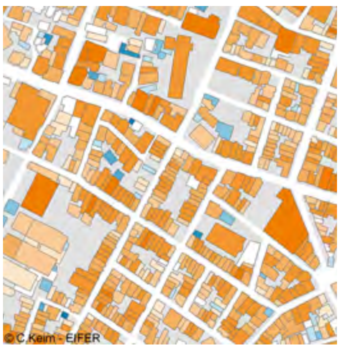


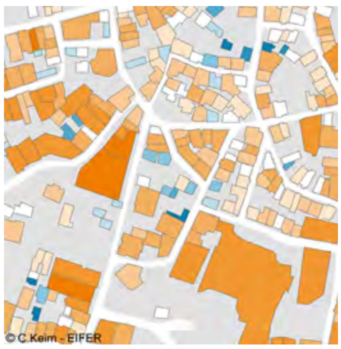



**Primary heat energy demand [kWh/m²/year]**

- < 50
- 51 - 75
- 76 - 100
- 101 - 125
- 126 - 150
- 151 - 175
- 176 - 200
- 201 - 225
- 226 - 250
- 251 - 275
- > 275



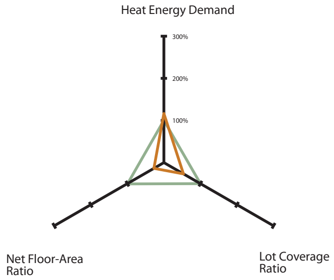



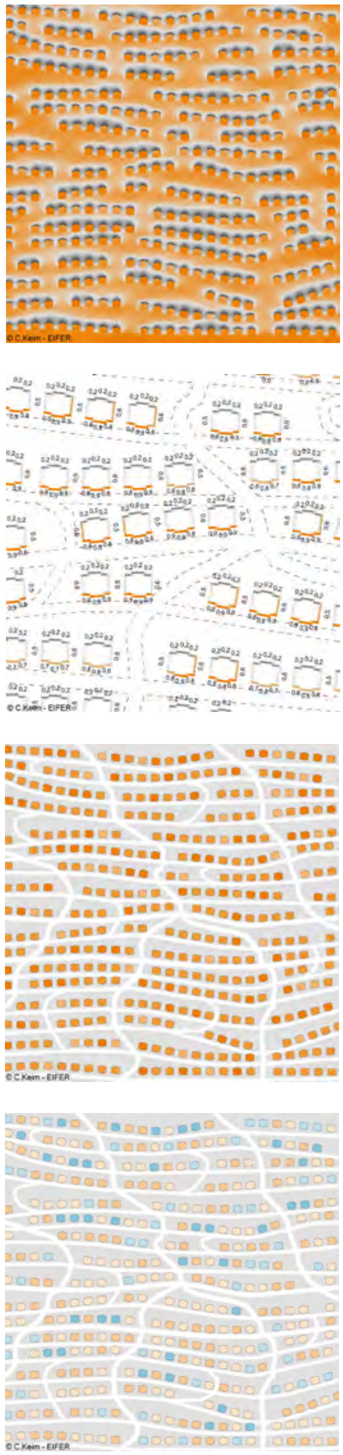



## B-4.7 ISTANBUL IDEALISED SAMPLES

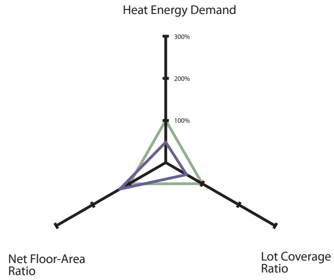
A visual display of the performance of the Idealised Samples for Istanbul tyopologies in terms of solar radiation exposure and heat energy demand.

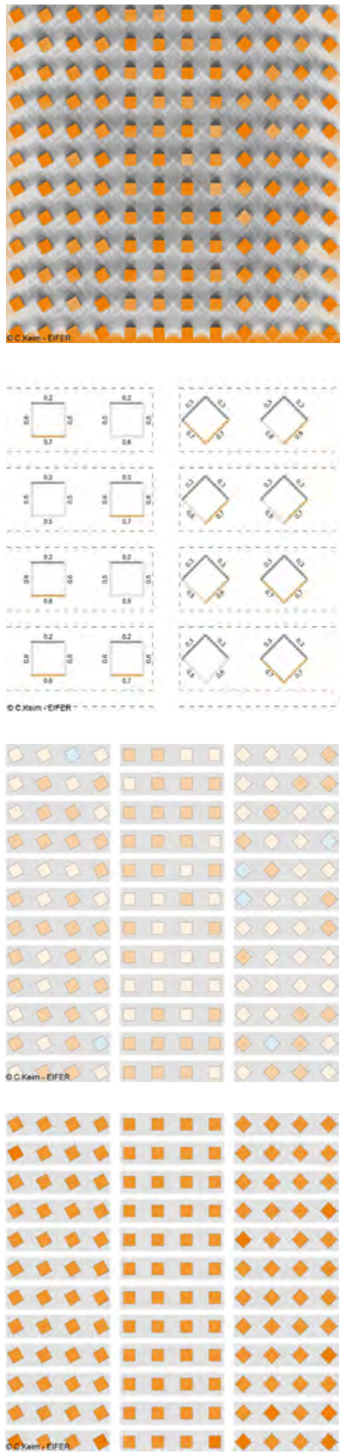
### Detached housing




### High Rise Apartment

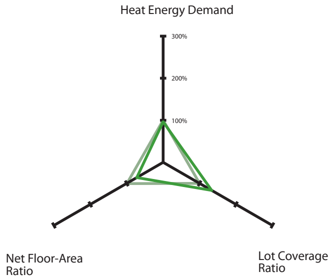


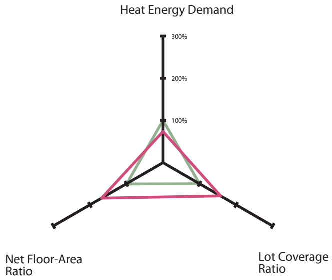
**Spider Diagram**

Relationship between the sample's heat energy demand and its interior and exterior physical characteristics variables

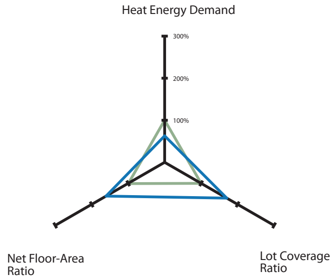
## Gecekondu




## Modern Apartment



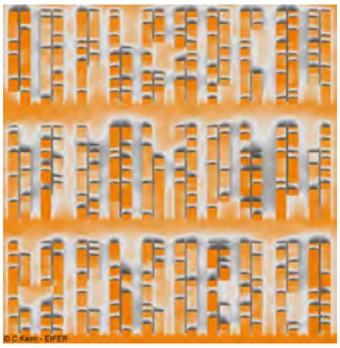

## Compact Urban Block

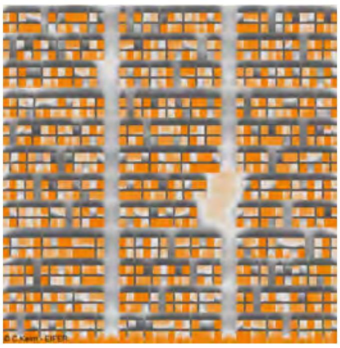


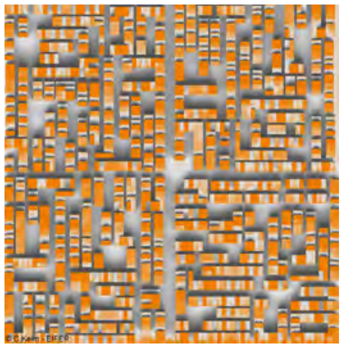

**Hours of direct solar radiation during periods where heating is required**

2134

0



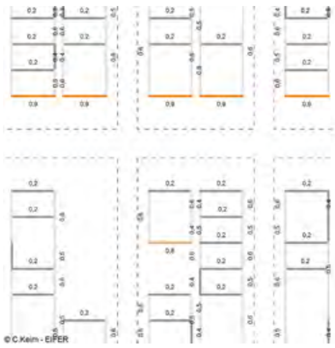



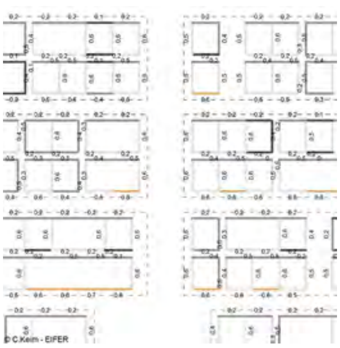



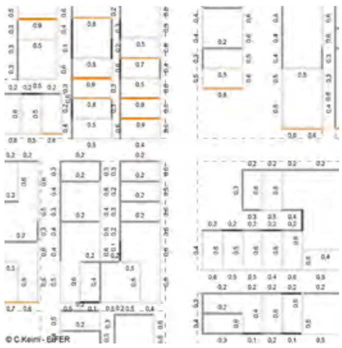

**Hours of direct solar radiation on building facades**

- 0,0 - 0,2
- 0,2 - 0,4
- 0,4 - 0,6
- 0,6 - 0,8
- 0,8 - 1,0

Hours of direct solar radiation coefficient [0-1]

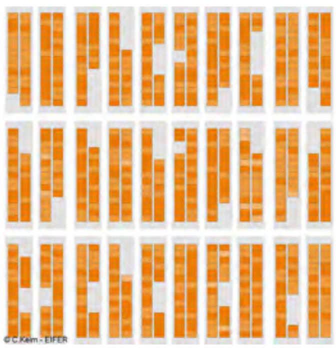


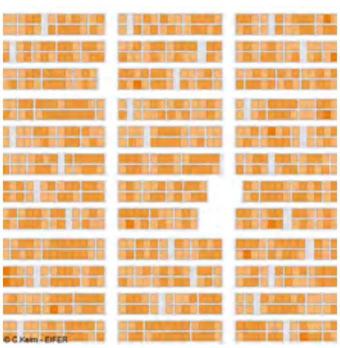



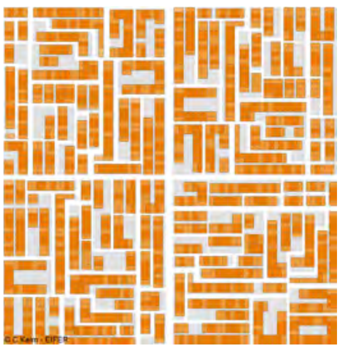




**Primary heat energy demand [MWh/year]**

- < 25
- 26 - 50
- 51 - 100
- 101 - 150
- 151 - 200
- 201 - 250
- 251 - 350
- 351 - 500
- 501 - 750
- > 750

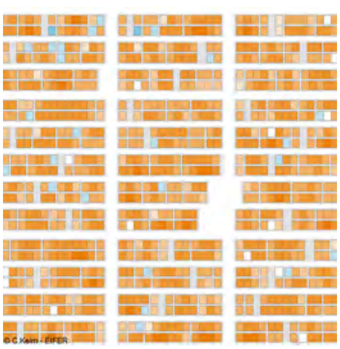


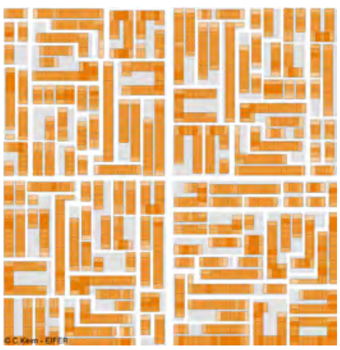




**Primary heat energy demand [kWh/m²/year]**

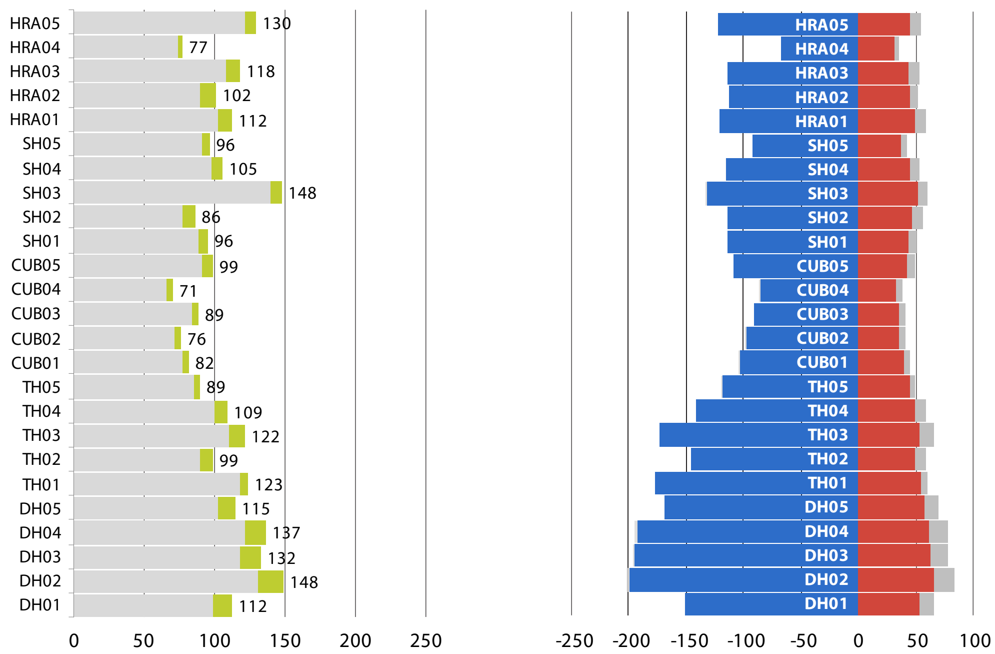
- < 50
- 51 - 75
- 76 - 100
- 101 - 125
- 126 - 150
- 151 - 175
- 176 - 200
- 201 - 225
- 226 - 250
- 251 - 275
- > 275

# C TABLES AND GRAPHICS

## C.1 HEAT ENERGY DEMAND AND TYPOLOGY OVERVIEW




### London typologies

Left:

**Average kWh/m² year for each typology;**

Colour - reference scenario

Grey - local climatic conditions

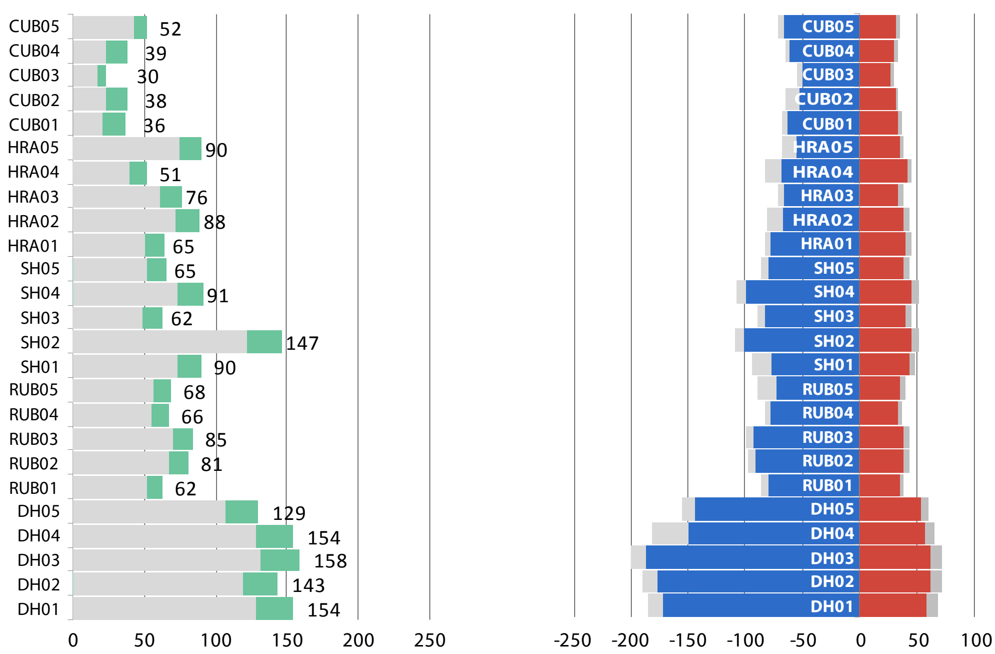
Right:

**Average heat energy losses and gains**

Blue - average heat energy losses [kWh/m2 year]

Orange - average heat energy gains [kWh/m2 year]

*Source: LSE Cities and EIFER research*




### Paris typologies

Left:

**Average kWh/m² year for each typology;**

Colour - reference scenario

Grey - local climatic conditions

Right:

**Average heat energy losses and gains**

Blue - average heat energy losses [kWh/m2 year]

Orange - average heat energy gains [kWh/m2 year]

*Source: LSE Cities and EIFER research*

## Berlin typologies

Left:

**Average kWh/m² year for each typology;**

Colour - reference scenario

Grey - local climatic conditions

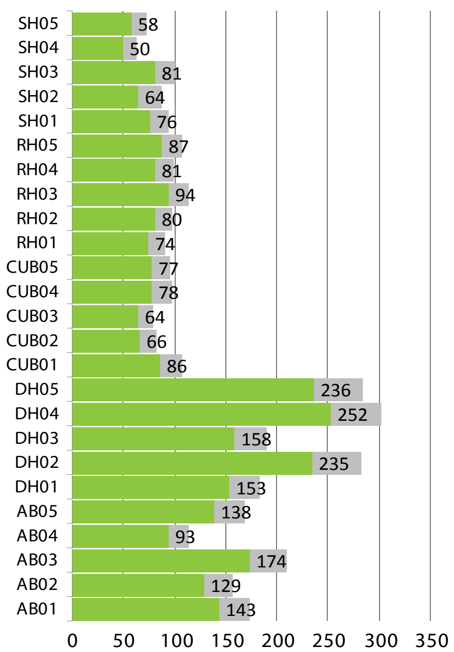
Right:

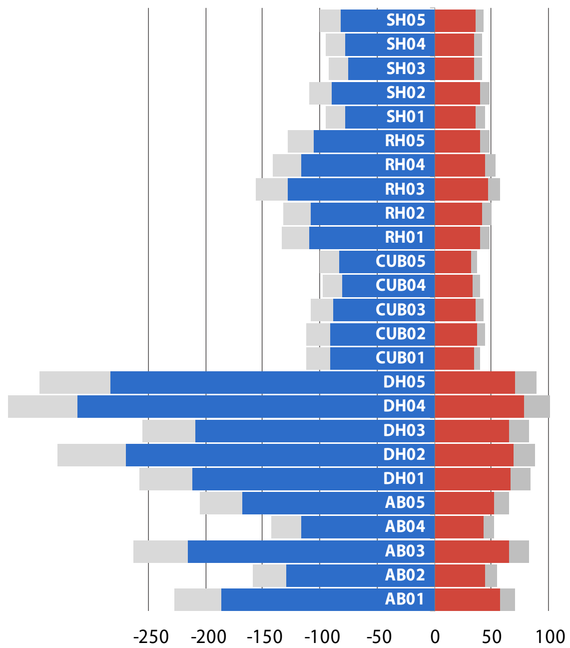
**Average heat energy losses and gains**

Blue - average heat energy losses [kWh/m2 year]

Orange - average heat energy gains [kWh/m2 year]

*Source: LSE Cities and EIFER research*




## Istanbul typologies

Left:

**Average kWh/m² year for each typology;**

Colour - reference scenario

Grey - local climatic conditions

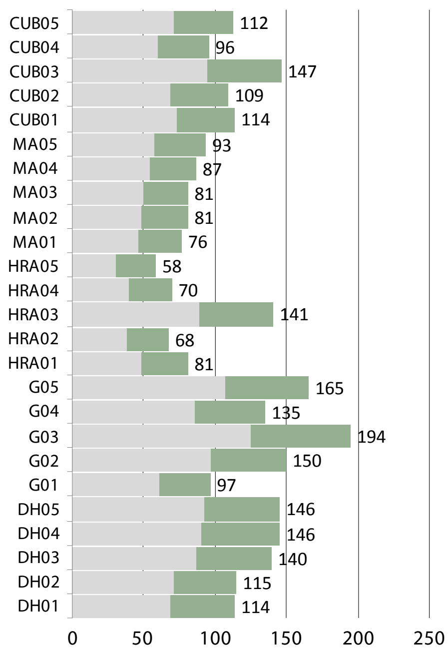
Right:

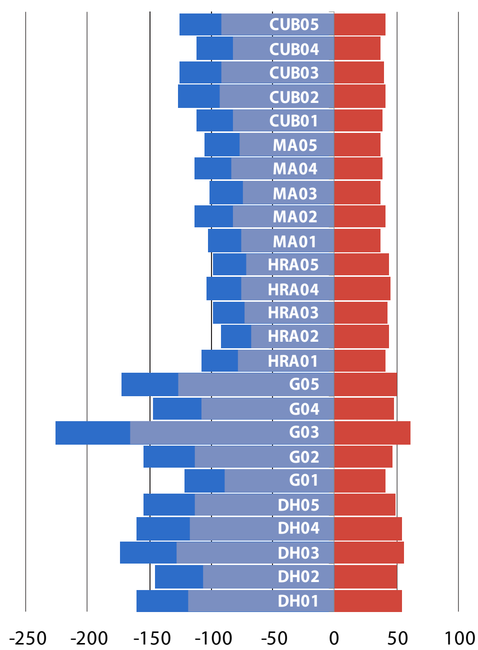
**Average heat energy losses and gains**

Blue - average heat energy losses [kWh/m2 year]

Orange - average heat energy gains [kWh/m2 year]

*Source: LSE Cities and EIFER research*



# C.2 GLAZING RATIO AND WINDOW INSULATION

**London DH**

| U-value \ Glazing ratio | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
|---|---|---|---|---|---|---|---|---|
| 2.0 | 194 | 182 | 169 | 155 | 140 | 125 | 109 | 92 |
| 2.2 | 196 | 186 | 176 | 165 | 152 | 140 | 126 | 112 |
| 2.4 | 198 | 191 | 183 | 174 | 164 | 154 | 144 | 132 |
| 2.6 | 200 | 195 | 190 | 183 | 176 | 169 | 161 | 152 |
| 2.8 | 203 | 200 | 197 | 193 | 188 | 183 | 178 | 172 |
| 3.0 | 205 | 205 | 204 | 202 | 200 | 198 | 195 | 192 |
| 3.2 | 207 | 209 | 210 | 211 | 212 | 212 | 212 | 211 |
| 3.4 | 209 | 214 | 217 | 221 | 224 | 226 | 228 | 231 |
| 3.6 | 212 | 218 | 224 | 230 | 235 | 240 | 245 | 250 |

**London HRA**

| U-value \ Glazing ratio | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
|---|---|---|---|---|---|---|---|---|
| 2.0 | 72 | 66 | 58 | 50 | 42 | 34 | 25 | 15 |
| 2.2 | 73 | 68 | 61 | 55 | 48 | 40 | 33 | 25 |
| 2.4 | 74 | 69 | 64 | 59 | 53 | 47 | 40 | 34 |
| 2.6 | 75 | 71 | 67 | 63 | 58 | 53 | 48 | 43 |
| 2.8 | 76 | 73 | 70 | 67 | 63 | 59 | 55 | 51 |
| 3.0 | 77 | 75 | 73 | 71 | 68 | 66 | 63 | 60 |
| 3.2 | 78 | 77 | 76 | 75 | 73 | 72 | 70 | 68 |
| 3.4 | 79 | 79 | 79 | 79 | 79 | 78 | 77 | 77 |
| 3.6 | 80 | 81 | 82 | 83 | 84 | 84 | 85 | 85 |

**London SH**

| U-value \ Glazing ratio | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
|---|---|---|---|---|---|---|---|---|
| 2.0 | 107 | 99 | 90 | 81 | 71 | 60 | 50 | 38 |
| 2.2 | 108 | 101 | 94 | 85 | 77 | 68 | 59 | 49 |
| 2.4 | 109 | 103 | 97 | 90 | 83 | 75 | 68 | 59 |
| 2.6 | 111 | 106 | 101 | 95 | 89 | 83 | 76 | 70 |
| 2.8 | 112 | 108 | 104 | 100 | 95 | 90 | 85 | 80 |
| 3.0 | 113 | 110 | 108 | 105 | 101 | 98 | 94 | 90 |
| 3.2 | 114 | 113 | 111 | 109 | 107 | 105 | 103 | 100 |
| 3.4 | 115 | 115 | 115 | 114 | 113 | 112 | 111 | 110 |
| 3.6 | 116 | 117 | 118 | 119 | 119 | 119 | 120 | 120 |

**London TER**

| U-value \ Glazing ratio | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
|---|---|---|---|---|---|---|---|---|
| 2.0 | 126 | 116 | 105 | 94 | 82 | 69 | 56 | 42 |
| 2.2 | 127 | 118 | 109 | 99 | 89 | 78 | 67 | 55 |
| 2.4 | 128 | 121 | 113 | 105 | 96 | 87 | 77 | 67 |
| 2.6 | 130 | 124 | 117 | 110 | 103 | 95 | 87 | 79 |
| 2.8 | 131 | 126 | 121 | 116 | 110 | 104 | 97 | 90 |
| 3.0 | 132 | 129 | 125 | 121 | 117 | 112 | 107 | 102 |
| 3.2 | 134 | 132 | 129 | 127 | 124 | 120 | 117 | 113 |
| 3.4 | 135 | 134 | 133 | 132 | 131 | 129 | 127 | 125 |
| 3.6 | 136 | 137 | 137 | 138 | 137 | 137 | 137 | 136 |

**London CUB**

| U-value \ Glazing ratio | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
|---|---|---|---|---|---|---|---|---|
| 2.0 | 114 | 109 | 104 | 98 | 92 | 86 | 80 | 73 |
| 2.2 | 116 | 112 | 108 | 103 | 99 | 94 | 89 | 84 |
| 2.4 | 117 | 114 | 112 | 109 | 105 | 102 | 98 | 95 |
| 2.6 | 118 | 117 | 115 | 114 | 112 | 110 | 107 | 105 |
| 2.8 | 119 | 119 | 119 | 119 | 118 | 117 | 116 | 115 |
| 3.0 | 121 | 122 | 123 | 124 | 124 | 125 | 125 | 126 |
| 3.2 | 122 | 124 | 126 | 129 | 131 | 133 | 134 | 136 |
| 3.4 | 123 | 127 | 130 | 134 | 137 | 140 | 143 | 146 |
| 3.6 | 124 | 129 | 134 | 139 | 143 | 148 | 152 | 156 |

**Effect of changing window insulation (u-value) and glazing ratio on heat energy demand**

*Source: LSE Cities and EIFER Research*

Lower HED
Medium HED
Higher HED

**Paris DH**

| U-value \ Glazing ratio | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
|---|---|---|---|---|---|---|---|---|
| 2.0 | 180 | 168 | 155 | 142 | 128 | 113 | 98 | 82 |
| 2.2 | 181 | 171 | 161 | 149 | 138 | 125 | 112 | 98 |
| 2.4 | 183 | 175 | 166 | 157 | 147 | 137 | 126 | 114 |
| 2.6 | 185 | 179 | 172 | 165 | 157 | 148 | 139 | 130 |
| 2.8 | 187 | 182 | 177 | 172 | 166 | 160 | 153 | 146 |
| 3.0 | 189 | 186 | 183 | 179 | 176 | 171 | 167 | 162 |
| 3.2 | 190 | 190 | 189 | 187 | 185 | 183 | 180 | 177 |
| 3.4 | 192 | 193 | 194 | 194 | 194 | 194 | 194 | 193 |
| 3.6 | 194 | 197 | 200 | 202 | 204 | 205 | 207 | 208 |

**Paris HRA**

| U-value \ Glazing ratio | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
|---|---|---|---|---|---|---|---|---|
| 2.0 | 63 | 56 | 48 | 40 | 32 | 23 | 13 | 4 |
| 2.2 | 64 | 58 | 51 | 44 | 37 | 29 | 21 | 13 |
| 2.4 | 65 | 60 | 54 | 48 | 42 | 35 | 28 | 21 |
| 2.6 | 66 | 61 | 57 | 52 | 47 | 41 | 36 | 30 |
| 2.8 | 67 | 63 | 60 | 56 | 52 | 47 | 43 | 38 |
| 3.0 | 68 | 65 | 63 | 60 | 57 | 53 | 50 | 47 |
| 3.2 | 68 | 67 | 65 | 64 | 62 | 59 | 57 | 55 |
| 3.4 | 69 | 69 | 68 | 67 | 66 | 65 | 64 | 63 |
| 3.6 | 70 | 71 | 71 | 71 | 71 | 71 | 71 | 71 |

**Paris SH**

| U-value \ Glazing ratio | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
|---|---|---|---|---|---|---|---|---|
| 2.0 | 82 | 76 | 69 | 62 | 55 | 47 | 40 | 31 |
| 2.2 | 83 | 78 | 72 | 66 | 60 | 53 | 46 | 39 |
| 2.4 | 84 | 79 | 74 | 69 | 64 | 58 | 53 | 47 |
| 2.6 | 85 | 81 | 77 | 73 | 69 | 64 | 59 | 54 |
| 2.8 | 85 | 83 | 80 | 76 | 73 | 69 | 66 | 62 |
| 3.0 | 86 | 84 | 82 | 80 | 77 | 75 | 72 | 69 |
| 3.2 | 87 | 86 | 85 | 83 | 82 | 80 | 78 | 76 |
| 3.4 | 88 | 88 | 87 | 87 | 86 | 85 | 84 | 84 |
| 3.6 | 89 | 89 | 90 | 90 | 91 | 91 | 91 | 91 |

**Paris RUB**

| U-value \ Glazing ratio | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
|---|---|---|---|---|---|---|---|---|
| 2.0 | 93 | 88 | 83 | 78 | 72 | 66 | 60 | 53 |
| 2.2 | 94 | 90 | 87 | 82 | 78 | 73 | 68 | 63 |
| 2.4 | 95 | 93 | 90 | 87 | 84 | 80 | 77 | 73 |
| 2.6 | 96 | 95 | 93 | 91 | 89 | 87 | 85 | 83 |
| 2.8 | 98 | 97 | 97 | 96 | 95 | 94 | 93 | 92 |
| 3.0 | 99 | 99 | 100 | 101 | 101 | 101 | 101 | 101 |
| 3.2 | 100 | 102 | 103 | 105 | 107 | 108 | 110 | 111 |
| 3.4 | 101 | 104 | 107 | 110 | 112 | 115 | 118 | 120 |
| 3.6 | 102 | 106 | 110 | 114 | 118 | 122 | 126 | 129 |

**Paris CUB**

| U-value \ Glazing ratio | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
|---|---|---|---|---|---|---|---|---|
| 2.0 | 61 | 58 | 55 | 52 | 48 | 45 | 41 | 37 |
| 2.2 | 62 | 60 | 57 | 55 | 52 | 49 | 46 | 43 |
| 2.4 | 63 | 61 | 59 | 57 | 55 | 53 | 51 | 49 |
| 2.6 | 63 | 62 | 61 | 60 | 59 | 58 | 56 | 55 |
| 2.8 | 64 | 64 | 63 | 63 | 62 | 62 | 61 | 60 |
| 3.0 | 65 | 65 | 65 | 66 | 66 | 66 | 66 | 66 |
| 3.2 | 65 | 67 | 67 | 68 | 69 | 70 | 71 | 72 |
| 3.4 | 66 | 68 | 70 | 71 | 73 | 74 | 76 | 77 |
| 3.6 | 67 | 69 | 72 | 74 | 76 | 78 | 81 | 83 |

**Berlin DH**

| U-value \ Glazing ratio | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
|---|---|---|---|---|---|---|---|---|
| 2.0 | 245 | 230 | 214 | 198 | 180 | 162 | 143 | 123 |
| 2.2 | 247 | 234 | 220 | 206 | 191 | 175 | 158 | 141 |
| 2.4 | 249 | 238 | 226 | 214 | 201 | 188 | 173 | 158 |
| 2.6 | 251 | 242 | 232 | 222 | 211 | 200 | 188 | 176 |
| 2.8 | 253 | 246 | 238 | 230 | 222 | 213 | 203 | 193 |
| 3.0 | 254 | 250 | 244 | 239 | 232 | 225 | 218 | 210 |
| 3.2 | 256 | 254 | 250 | 247 | 242 | 238 | 232 | 227 |
| 3.4 | 258 | 258 | 257 | 255 | 253 | 250 | 247 | 244 |
| 3.6 | 260 | 262 | 263 | 263 | 263 | 262 | 261 | 260 |

**Berlin AB**

| U-value \ Glazing ratio | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
|---|---|---|---|---|---|---|---|---|
| 2.0 | 154 | 145 | 135 | 125 | 115 | 104 | 92 | 81 |
| 2.2 | 155 | 147 | 139 | 131 | 122 | 112 | 103 | 92 |
| 2.4 | 156 | 150 | 143 | 136 | 129 | 121 | 113 | 104 |
| 2.6 | 158 | 153 | 147 | 142 | 136 | 129 | 123 | 116 |
| 2.8 | 159 | 155 | 151 | 147 | 143 | 138 | 133 | 127 |
| 3.0 | 160 | 158 | 156 | 153 | 150 | 146 | 143 | 139 |
| 3.2 | 162 | 161 | 160 | 158 | 156 | 154 | 152 | 150 |
| 3.4 | 163 | 163 | 164 | 164 | 163 | 163 | 162 | 161 |
| 3.6 | 164 | 166 | 168 | 169 | 170 | 171 | 172 | 173 |

**Berlin SH**

| U-value \ Glazing ratio | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
|---|---|---|---|---|---|---|---|---|
| 2.0 | 67 | 62 | 56 | 51 | 45 | 38 | 32 | 25 |
| 2.2 | 68 | 64 | 59 | 54 | 49 | 44 | 39 | 33 |
| 2.4 | 69 | 66 | 62 | 58 | 54 | 50 | 45 | 41 |
| 2.6 | 70 | 67 | 65 | 62 | 59 | 55 | 52 | 49 |
| 2.8 | 71 | 69 | 67 | 65 | 63 | 61 | 59 | 56 |
| 3.0 | 72 | 71 | 70 | 69 | 68 | 67 | 65 | 64 |
| 3.2 | 72 | 73 | 73 | 73 | 72 | 72 | 72 | 71 |
| 3.4 | 73 | 74 | 75 | 76 | 77 | 78 | 78 | 79 |
| 3.6 | 74 | 76 | 78 | 80 | 82 | 83 | 85 | 86 |

**Berlin RH**

| U-value \ Glazing ratio | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
|---|---|---|---|---|---|---|---|---|
| 2.0 | 115 | 107 | 100 | 91 | 83 | 74 | 64 | 55 |
| 2.2 | 116 | 110 | 103 | 96 | 89 | 81 | 73 | 65 |
| 2.4 | 117 | 112 | 107 | 101 | 95 | 89 | 82 | 75 |
| 2.6 | 118 | 114 | 110 | 106 | 101 | 96 | 91 | 85 |
| 2.8 | 119 | 117 | 114 | 111 | 107 | 103 | 99 | 95 |
| 3.0 | 121 | 119 | 117 | 115 | 113 | 111 | 108 | 105 |
| 3.2 | 122 | 121 | 121 | 120 | 119 | 118 | 117 | 115 |
| 3.4 | 123 | 124 | 124 | 125 | 125 | 125 | 125 | 125 |
| 3.6 | 124 | 126 | 128 | 130 | 131 | 132 | 134 | 135 |

**Berlin CUB**

| U-value \ Glazing ratio | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
|---|---|---|---|---|---|---|---|---|
| 2.0 | 81 | 77 | 72 | 67 | 62 | 57 | 52 | 46 |
| 2.2 | 82 | 78 | 75 | 71 | 67 | 62 | 58 | 53 |
| 2.4 | 83 | 80 | 77 | 74 | 71 | 68 | 64 | 60 |
| 2.6 | 84 | 82 | 80 | 77 | 75 | 73 | 70 | 68 |
| 2.8 | 84 | 83 | 82 | 81 | 79 | 78 | 76 | 75 |
| 3.0 | 85 | 85 | 85 | 84 | 84 | 83 | 82 | 82 |
| 3.2 | 86 | 87 | 87 | 88 | 88 | 88 | 88 | 88 |
| 3.4 | 87 | 88 | 90 | 91 | 92 | 93 | 94 | 95 |
| 3.6 | 88 | 90 | 92 | 94 | 96 | 98 | 100 | 102 |

**Istanbul DH**

| U-value \ Glazing ratio | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
|---|---|---|---|---|---|---|---|---|
| 2.0 | 185 | 173 | 161 | 148 | 134 | 120 | 105 | 90 |
| 2.2 | 186 | 177 | 166 | 155 | 144 | 132 | 119 | 106 |
| 2.4 | 188 | 180 | 172 | 163 | 153 | 143 | 133 | 122 |
| 2.6 | 190 | 184 | 177 | 170 | 162 | 154 | 146 | 137 |
| 2.8 | 192 | 187 | 183 | 177 | 172 | 166 | 159 | 152 |
| 3.0 | 193 | 191 | 188 | 185 | 181 | 177 | 172 | 168 |
| 3.2 | 195 | 195 | 193 | 192 | 190 | 188 | 185 | 183 |
| 3.4 | 197 | 198 | 199 | 199 | 199 | 199 | 199 | 198 |
| 3.6 | 199 | 202 | 204 | 206 | 208 | 210 | 211 | 213 |

**Istanbul HRA**

| U-value \ Glazing ratio | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
|---|---|---|---|---|---|---|---|---|
| 2.0 | 81 | 75 | 68 | 60 | 53 | 44 | 36 | 27 |
| 2.2 | 83 | 77 | 71 | 65 | 59 | 52 | 45 | 37 |
| 2.4 | 84 | 79 | 75 | 70 | 64 | 59 | 53 | 47 |
| 2.6 | 85 | 81 | 78 | 74 | 70 | 66 | 62 | 57 |
| 2.8 | 86 | 84 | 81 | 79 | 76 | 73 | 70 | 67 |
| 3.0 | 87 | 86 | 85 | 83 | 82 | 80 | 78 | 76 |
| 3.2 | 88 | 88 | 88 | 88 | 87 | 87 | 86 | 85 |
| 3.4 | 89 | 90 | 91 | 92 | 93 | 94 | 94 | 95 |
| 3.6 | 90 | 93 | 95 | 97 | 99 | 101 | 102 | 104 |

**Istanbul G**

| U-value \ Glazing ratio | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
|---|---|---|---|---|---|---|---|---|
| 2.0 | 147 | 143 | 139 | 135 | 130 | 126 | 121 | 116 |
| 2.2 | 148 | 145 | 142 | 138 | 135 | 131 | 128 | 124 |
| 2.4 | 149 | 147 | 144 | 142 | 139 | 137 | 134 | 131 |
| 2.6 | 150 | 148 | 147 | 145 | 144 | 142 | 140 | 138 |
| 2.8 | 150 | 150 | 150 | 149 | 148 | 147 | 146 | 145 |
| 3.0 | 151 | 152 | 152 | 152 | 153 | 153 | 153 | 153 |
| 3.2 | 152 | 153 | 155 | 156 | 157 | 158 | 159 | 160 |
| 3.4 | 153 | 155 | 157 | 159 | 161 | 163 | 165 | 167 |
| 3.6 | 154 | 157 | 160 | 163 | 166 | 169 | 171 | 174 |

**Istanbul MA**

| U-value \ Glazing ratio | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
|---|---|---|---|---|---|---|---|---|
| 2.0 | 111 | 107 | 103 | 99 | 94 | 90 | 85 | 80 |
| 2.2 | 112 | 109 | 107 | 103 | 100 | 97 | 93 | 89 |
| 2.4 | 113 | 112 | 110 | 108 | 106 | 104 | 102 | 99 |
| 2.6 | 114 | 114 | 113 | 113 | 112 | 111 | 110 | 109 |
| 2.8 | 115 | 116 | 117 | 117 | 118 | 118 | 118 | 118 |
| 3.0 | 117 | 119 | 120 | 122 | 124 | 125 | 126 | 128 |
| 3.2 | 118 | 121 | 124 | 127 | 129 | 132 | 135 | 137 |
| 3.4 | 119 | 123 | 127 | 131 | 135 | 139 | 143 | 147 |
| 3.6 | 120 | 125 | 131 | 136 | 141 | 146 | 151 | 156 |

**Istanbul CUB**

| U-value \ Glazing ratio | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
|---|---|---|---|---|---|---|---|---|
| 2.0 | 98 | 94 | 90 | 86 | 82 | 77 | 72 | 67 |
| 2.2 | 99 | 96 | 93 | 90 | 87 | 83 | 79 | 76 |
| 2.4 | 100 | 98 | 96 | 94 | 91 | 89 | 86 | 84 |
| 2.6 | 101 | 100 | 99 | 98 | 96 | 95 | 93 | 92 |
| 2.8 | 102 | 102 | 102 | 101 | 101 | 101 | 100 | 99 |
| 3.0 | 103 | 104 | 104 | 105 | 106 | 106 | 107 | 107 |
| 3.2 | 104 | 105 | 107 | 109 | 111 | 112 | 114 | 115 |
| 3.4 | 104 | 107 | 110 | 113 | 115 | 118 | 120 | 123 |
| 3.6 | 105 | 109 | 113 | 117 | 120 | 124 | 127 | 131 |

# GLOSSARY

**Building category**

A broader classification of building types.

**Building configuration**

The arrangement of height, volume, footprint shape and size of individual buildings and their relationship to each other.

**Building density**

See FAR.

**Building type or typology**

Describes the form and function of individual buildings.

**Building height**

The 'height' of a building is measured in 'number of storeys'.

**DEM**

Digital elevation model. A digital figure ground drawing overlaid with topographical data resulting in a simple 3-D building model.

**FAR**

Floor area ratio. The ratio of the total internal floor area of buildings to the land upon which they sit for a given sample area.

**GIS**

Geographic information system. A generic name given to the set of software tools which deal specifically with geographical data.

**GPS**

Global positioning system. A cloud of earth-orbiting satellites which are constantly transmitting positional data to earth. This can be interpreted by GPS receivers to calculate very accurate location data.

**Heat energy demand**

Heat energy demand measured in $kWhm^2$ per year.

**LT method**

Lighting and thermal method. An analogue method created by Baker and Steemers (2000) to enable the simple estimation of a building's lighting, heating and cooling energy demand based on form.

**Surface coverage**

The ratio of the land covered by buildings to the total surface of a given area.

**Surface-to-volume ratio**

The ratio of the envelope (external facades and roof) of a building to the entire volume of that building.

**Urban morphology**

The spatial structure and form of a metropolitan area, city, town or neighbourhood and its constituent parts.

**Open space ratio**

The ratio of the unbuilt area to the gross floor area of any given space.

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