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IMPACT OF URBAN MORPHOLOGY ON BUILDING ENERGY NEEDS: A REVIEW ON KNOWLEDGE GAINED FROM MODELING AND MONITORING ACTIVITIES

Pol, Olivier August ; Robinson, Darren

- **Presented at:** CISBAT 2011, Lausanne, September 14-16
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Urban morphology is one of the main parameters influencing directly and indirectly buildings' energy needs. Despite an increasing number of urban energy and environmental modelling tools addressing these issues, the complexity of physical relationships at this level often constrain urban energy modelers to simplify the problems by considering only parts of the phenomena, thus leading to diverging findings and recommendations related to the relevance of urban morphology. A systematic review of published research works in the field of urban energy and environmental modelling is performed. This involves characterising the research approach, evaluating the physical effects taken into consideration in the models applied, the types of models applied, identifying whether the effect of urban morphology is isolated from other effects, whether the urban scene considered is real or theoretical and parametrised and recognising the performance indicators used for assessment. Last but not least, the type of result and the robustness of the ensuing recommendations in terms of sustainable urban design are critically evaluated according to clearly defined assessment criteria. The main findings related to the impact of urban morphology on energy needs in the built environment are summarised and put in relation to the physical effects taken into consideration, showing that there is no common basis allowing for a generalisation of the knowledge available. Beyond an attempt to cluster the different approaches, the authors conclude that there is a clear need to further develop more comprehensive tools, but also to propose a minimal set of requirements for computational modelling activities in the urban energy field.

Reference

Laboratoires

LESO-PB - Solar Energy and Building Physics Laboratory

Documents

Documents principaux

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Impact of Urban Morphology on Building Energy Needs: A Review on Knowledge Gained from Modeling and Monitoring Activities

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Abstract

Urban morphology is one of the main parameters influencing directly and indirectly buildings' energy needs. Despite an increasing number of urban energy and environmental modelling tools addressing these issues, the complexity of physical relationships at this level often constrain urban energy modelers to simplify the problems by considering only parts of the phenomena, thus leading to diverging findings and recommendations related to the relevance of urban morphology.

A systematic review of published research works in the field of urban energy and environmental modelling is performed. This involves characterising the research approach, evaluating the physical effects taken into consideration in the models applied, the types of models applied, identifying whether the effect of urban morphology is isolated from other effects, whether the urban scene considered is real or theoretical and parametrised and recognising the performance indicators used for assessment. Last but not least, the type of result and the robustness of the ensuing recommendations in terms of sustainable urban design are critically evaluated according to clearly defined assessment criteria.

The main findings related to the impact of urban morphology on energy needs in the built environment are summarised and put in relation to the physical effects taken into consideration, showing that there is no common basis allowing for a generalisation of the knowledge available. Beyond an attempt to cluster the different approaches, the authors conclude that there is a clear need to further develop more comprehensive tools, but also to propose a minimal set of requirements for computational modelling activities in the urban energy field.

Introduction

Following the overall ambition to improve the quality of planning guidelines for sustainable urban development, the implications of urban morphology on the overall urban energy balance are worth being considered first. Having started from a functional description of the area of study, urban planners and designers soon translate these requirements in terms of morphological typologies included later in urban masterplans. Then, whereas other factors (e.g. share of glazing area, building performance) can still be amended in later project phases, morphological characteristics usually can not be completely redefined once the masterplans have been accepted by the responsible local authorities.

Urban morphology directly and indirectly impacts the overall urban energy balance. In the building sector, the direct impact is mainly related to radiation exchanges between building outside surfaces and their surroundings as well as heat transmission and convection losses through the building envelope, all three effects being influenced by geometrical built form properties. In the mobility sector, urban morphology influences mobility patterns mainly because of its implications on the preferred routes and transportation modes. In addition to this, a clear indirect impact is related to the dependency of building energy needs on urban climate, which again depends on urban morphology. Focusing on heat island effect in the Altanta region, the influence of urban morphology on urban climate was for instance assessed by [21]. The other effect, consisting in understanding the implications of urban climate on building energy consumption, was analysed already by [18] based on measurements performed in Athens. The demonstrated existence of both direct and indirect implications is sufficient to justify the necessity to further investigate the impact of urban morphology on the urban energy balance.

All these phenomena are increasingly being addressed by the research community, with a number of urban energy and environmental modelling tools that have recently emerged. To reduce the scope of the present study, the implications on mobility sector are not considered here. But even at the level of the built environment, the high complexity of physical relationships implies that the models developed only can handle parts of the effects, so it is clear that the related studies might lead to diverging results and interpretations. Starting from the pioneering work of Martin and March [9], this paper therefore presents the results of a review of the contributions of past studies on the impact of urban morphology on buildings' energy needs, by applying a clear set of assessment criteria. The outcome is a critical analysis of the results gained from these works and aims at paving the way for future related modelling and monitoring activities at urban scale.

METHOD

The literature review is limited to scientific publications dealing with direct and indirect implications of urban morphology on energy needs. It does not have the ambition of providing an exhaustive list of all that has been written on these topics. It refers to most cited and practically accessible articles and to contributions fulfilling a minimal set of scientific quality criteria in the eyes of the authors.

Name of criterion	Approach / value of criterion	Relevance
Scientific approach chosen	1) Computational modelling 2) Experimental procedure 3) Literature review	Whether the publication is based on theoretical and computational activities, experimental work or literature review indicates the degree of innovation of the findings presented.
Physical effects taken into consideration in the models applied (scope of physical phenomena modelled)	1) Urban climate 2) Radiation exchange between building and surroundings 3) Building energy demand calculation (for heating, cooling and lighting) based on building and urban physics	The physical effects taken into consideration indicate how far the chosen model is from reality and therefore what are the limits of applicability of ensuing recommendations.
Types of models applied	1) Meteorological model including CFD computations 2) Ray-tracing model for daylight analysis 3) Building thermal model	The types of models applied indicate how physical effects have been considered and therefore the degree of accuracy and precision of the results.
Type of urban scene considered	1) Real case study 2) Simplified geometrical form	Whether the urban scene considered is real or theoretical and parametrised indicates the degree of abstraction of the work and the scope of applicability of results. Simplified geometrical forms (archetypes) can be easily parameterised but can loose any relation to reality.
Climate zone considered	Name of location or climate zone	The specification of the climate zone considered indicates the field of applicability of results.
Urban morphology parameters	1) *individual building parameters*: wall surface area, ratio envelope area to floor area, facade convolution index, building orientation, ratio of passive to non-passive floor area 2) *parameters characterising the direct environment of a building*: obstruction angle, urban horizon angle, sky view factor, H/W ratio, surrounding building density 3) *parameters characterising a neighbourhood*: site coverage, directionality, clustering typology, directional spacing angle difference, directional space ratio	The way how urban morphology is parametrised indicates the type of urban morphology variations which are tested in the study. The parameters can be divided into 3 categories, depending on whether they describe building form only (1), the direct morphological surrounding of a given building (2) or the morphological patterns of an entire neighbourhood (3).
Main performance indicators used in performance assessment	1) *indicators of solar radiation distribution*: solar exposure, percentage of daily direct solar radiation distribution on urban surfaces (roofs, facades, ground), irradiance on facades 2) *indicators of daylight availability in internal spaces*: indicators of daylight factor, daylight autonomy, UDI (useful daylight illuminance) 3) *indicators of building energy performance*: fabric heat losses, cooling and heating energy demand, lighting electricity consumption, total energy use, change in space heating, increase in space heating, change in primary energy use	The performance indicators used show the basis on which different urban morphologies are assessed or which are the target criteria for urban morphology optimisation. The indicators can be divided into 3 categories, depending on whether they quantify the solar radiation distribution (1), the daylight availability in internal spaces (2) or the building energy performance (3).
Knowledge gained	Qualitative or quantitative description of impact of urban morphology on building energy needs	
Robustness of the ensuing recommendations	5 assessment criteria presented in Table 2	See Table 2.

Table 1: Assessment criteria used

Assessment criteria

The analysis of a high number of diverse publications (both in scope, method applied, degree of innovation, quality) is performed by applying the set of criteria presented in Table 1 and by categorising the publications (author, date, publication medium). It has been noticed that computational modelling is not the only scientific approach chosen; even when this is the case the models used do not always take into consideration all physical effects or are of different nature. Then, there are different possibilities for considering urban scenes which can be immersed in different climate zones. Last and because it might not be necessary for their works, the authors do not always isolate urban morphology parameters from other parameters. The robustness of the ensuing recommendations is assessed using the criteria reported in Table 2.

Criteria for the robustness of recommendations	Relevance
The study is performed without any initial non-verified postulate.	Taking non-verified postulates for granted is questionable in any research work.
The effects of single parameters were isolated (other parameters were normalised).	Isolating the effects of given parameters implies normalising other parameters to neutralise their influence.
Plausibility check: trends and results obtained are plausible.	Plausibility checks are necessary to be convinced of the results' validity.
A validation procedure has been applied or is under way (e.g. monitoring).	Validating the results obtained is necessary for robustness of recommendations.
The limits of applicability are clearly presented.	Presenting the limits of applicability is an indicator of awareness one's own limitations.

Table 2: Criteria used to assess the robustness of recommendations

RESULTS

30 publications written between 1972 and 2011 have been considered. This includes 5 books (some of them gathering more than one publication related to the topic of interest), 14 journal articles and 8 conference papers.

Scientific approach chosen

Given the difficulty to isolate the impact of selected morphological parameters in situ and monitor their impact on energy use in real case studies, nearly all publications assessed are based on computational modelling activities. Only few works rely on measurements performed at urban scale: mainly [18] and more recently [23] use monitored data to characterise the local urban climate ([23] uses an empirical climate prediction model based on Singapore data) in which buildings are immersed, but in both works building energy needs are practically calculated. [21] uses high resolution IR-thermography to characterise indirectly the heat island intensity, but this approach is not frequently followed. Comparing and referring to other published works is the main approach of 6 of the assessed publications, which do no rely on any new computational modelling activity.

Physical effects taken into consideration in the models applied and types of models applied

Despite the known implications of urban climate on energy needs and the available possibilities to model urban climate conditions based for instance on the work of [11], only 4 of the assessed publications consider a climate model (empirical or urban boundary-layer model) in the computations. It is clear that studies of solar radiation availability on outside building surfaces do not require an urban climate model. However, 6 publications draw conclusions on thermal building energy needs without considering or mentioning the possible implications of urban morphology on the local climate and its impact on energy needs.

The radiation models used are either based on a ray tracing or radiosity algorithm in which anisoptropic sky radiance distributions, diffuse sky occlusions and reflections from occluding surfaces may each be handled (6 publications), or relatively simplified models are used in which a limited number of these phenomena are represented.

Thermal building models, ranging from the highly simplified heat loss calculation over the building envelope used by [9] to commercial or self-developed transient building energy performance simulation tools, are applied in 14 publications. In 3 of these publications, implications on cooling energy needs are ignored. In 10 of these publications, electricity needs for artificial lighting are not considered.

Type of urban scene considered

Two approaches are used to consider urban scenes. Some authors (7 publications) use models of real urban neighbourhoods, having the major advantage to be representative of real urban design morphologies. However in these cases, there are usually limited possibilities to generalise the findings gained on the case study cities, unless there is a high number of cases characterised according to given parameters. [7]

. considers 25 different urban block types in four categories: discontinuous collective housing, continuous collective housing, dense individual housing and dispersed individual housing.

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Publication reference	**Urban climate model**	**Radiation model for surrounding s**	**Building thermal model**	**Cooling needs calculated**	**Energy use for lighting calculated**	**Main findings: impact of urban morphology on buildings' energy needs (summary)**
[1]	TEB	Y	TRNSY S	Y	-	The effect of H/W ratio of an urban canyon is assessed and demonstrated to be not as significant as the effect of other parameters (thermal insulation, window ratio).
[4]	-	Y	-	-	-	The impact on buildings' energy needs is not assessed but it is demonstrated that solar energy available for utilisation may be increased by up to 20% if optimisation algorithms are applied on urban morphology.
[5]	-	Y (albedo)	Energy Plus	Y	Radianc e and Daysim	Increasing site coverage implies higher heating and lighting needs and lower cooling needs. The results of the performed sensitivity analyses are presented graphically.
[6]	-	Radianc e	-	-	-	The impact of site coverage on the solar irradiation on buildings is proven to be relatively low but the implications on energy needs are not commented. The effect of self-obstructions is proven to be relevant.
[7]	-	-	TAS	Y	-	The impact of urban morphology is not assessed because urban form parameters are not isolated from other parameters (thermal building envelope quality).
[8]	-	-	Static calculati on	-	-	Theorem 1: "A simple rectangular block of given volume loses the least amount of heat if the dimension of each edge is proportional to the mean thermal transmittance value of the faces defined by the other two edges."
[9]	-	-	Static calculati on	-	Y	Based on the parametric study it is proven that increasing density impacts energy use for lighting rather than heating energy use.
[12]	ENVI-MET	Y	-	-	-	The impact on buildings' energy needs is not assessed.
[14] & [15]	-	Y?	LT	-	LT	The passive to non-passive area ratio is proven to impact buildings' energy needs. A 10% difference is shown between the specific energy needs of different urban morphologies, when default values are attributed to all other variables.
[13]	-	-	-	-	From DEM	The surface to volume ratio is used as indicator of good thermal performance.
[16]	-	Y	-	-	-	The impact on buildings' energy needs is not assessed.
[17]	-	Y	SUNTO OL	Y	Y	The impact of H/W ratio on energy use for cooling, heating and lighting is calculated for different glazing ratios in a parametric study. Results are graphically presented.
[18]	Measure ments	-	TRNSY S	Y	-	The impact of urban morphology is not directly assessed, but the effect of urban climate on energy consumption in buildings (heating and cooling) is quantified.
[19]	-	-	N	-	-	The impact on buildings' energy needs is not assessed.
[20]	-	-	LT (partly)	Y	LT	"Relatively high housing densities can be achieved before a negative impact on the energy demand becomes significant" (based on a limit obstruction angle of 30%).
[22]	-	Y (albedo)	Energy Plus	Y	Radianc e and Daysim	Heating and cooling energy demand can be reduced by 10% to 20% by optimising urban morphology.
[23]	Empiric model	-	TAS	Y	-	In the range considered, height and density are not as relevant as green plot ratio. Cooling energy demand can be reduced in a range between 5 and 10% if green areas are addressed effectively.

Table 3: Assessment results of the publications reporting the results of computational modelling activities at neighbourhood scale

The other publications (i.e. the majority) use simplified urban morphological archetypes which can more easily be parameterised, both for performing sensitivity analyses and urban morphology optimisation, but which have the risk to lose any connection to realistic urban design proposals. Often inspired by [9], the most frequently assessed archetypes are pavilions (8), including shape variations for high-rise buildings ("I", "L", "F" and "+" shape in [6]), courtyard configurations (4), row houses and slabs (3) and urban street canyons (1). The more frequent typologies are therefore pavilions and courtyard typologies.

There is one case of real building geometry immersed in different urban contexts [23] and one case of a newly developed building form typology ("residential solar block" in [12]).

Climate zone considered

Authors have different ways to refer to climate conditions. Only few authors characterise the climate by mentioning a climate zone (locations at 48° latitude for [12], an arid climate for [13]), suggesting their results may be valid for similar latitudes in the considered zones.

Urban morphology parameters

Table 1 shows the high variety of parameters used to characterise urban morphology, illustrating the various possibilities for its parameterisation. The height to width ratio between buildings is the most frequently used parameter, followed by site coverage, plot ratio and sky view factor (and related equivalent parameters); often using ill-adapted radiation models. Few authors quantify the overall neighbourhoods' energy performance in dependency on more abstract neighbourhoods' morphological parameters.

Main performance indicators used in performance assessment

As for urban morphology parameters, Table 1 shows the high variety of performance assessment indicators used in the assessed publications, being a proof of the different authors' positions in relation to what defines an energy efficient urban morphology. The use of indicators of solar irradiation on building envelope indicates that the maximisation of solar radiation on building envelope is considered as a target function. However, even if followed in 7 of the assessed publications, this approach can only be considered as a computational exercise and can not be translated in any morphological recommendation. If thermal building energy needs are calculated by applying a thermal building model, specific energy performance ratings (specific heating energy and cooling energy needs, if applicable) or variations of these indicators are used to characterise energy performance. Indicators for electricity use for lighting are considered only in four of the assessed publications.

Knowledge gained

Generally speaking, all publications assessed confirm the impact on urban morphology on building energy needs but its intensity is rated differently, mainly depending on the physical effects taken into consideration. Few authors really conclude on percentage variations or quantify building energy performance rating in dependency of urban morphology. The last column of Table 3 is an attempt to summarise the main findings presented in the publications assessed.

Robustness of the ensuing recommendations

The robustness of the recommendations from some of the papers cited here are somewhat questionable. [12] for example proposes a "holistic approach to energy efficient building forms", without considering the seasonal differences when it comes to analysing the contribution of solar radiation and without calculating buildings' energy performance; whilst [13] uses the surface area to volume ratio as performance indicator.

The effect of urban morphology parameters is isolated in many cases, but the normalisation is rarely performed on the same way. Sometimes plot ratio and volume to facade ratio are normalised, sometimes the built volume and passive to non-passive ratio; in other works U-values as well as the share of glazing area are maintained whereas morphological parameters are varied. In 5 publications the effects of urban morphology are not isolated, which makes it impossible to deduce recommendations from this point of view.

In nearly all cases, the plausibility of trends and results obtained is commented by the authors, but only the theorems of [9] are mathematically demonstrated, mainly because they are based on very simplified problems which do not require any computational modelling to be solved. Other publications never rely on energy use monitoring to validate the findings presented, with exception of the work of [5] which mentions a satisfying comparison with energy use monitoring data from the case study.

The limits of applicability are nearly always clearly presented, with the exception of 3 cases where the recommendations provided seems to go beyond the field of application at the eyes of the authors (extrapolation is not justified).

. CONCLUSIONS

The literature reviewed here seems to confirm the implications of urban morphology on energy needs. However, given that different physical effects are considered, different parameters are varied and different indicators are used for assessment, it is difficult to generalise and compare the authors' findings; there is a need for consistence regarding the phenomena examined and the manner in which the ensuing results are expressed. The next step in this work is to propose one such framework.

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Types of models applied	1) Meteorological model including CFD computations 2) Ray-tracing model for daylight analysis 3) Building thermal model	The types of models applied indicate how physical effects have been considered and therefore the degree of accuracy and precision of the results.
Type of urban scene considered	1) Real case study 2) Simplified geometrical form	Whether the urban scene considered is real or theoretical and parametrised indicates the degree of abstraction of the work and the scope of applicability of results. Simplified geometrical forms (archetypes) can be easily parameterised but can loose any relation to reality.
Climate zone considered	Name of location or climate zone	The specification of the climate zone considered indicates the field of applicability of results.
Urban morphology parameters	1) *individual building parameters*: wall surface area, ratio envelope area to floor area, facade convolution index, building orientation, ratio of passive to non-passive floor area 2) *parameters characterising the direct environment of a building*: obstruction angle, urban horizon angle, sky view factor, H/W ratio, surrounding building density 3) *parameters characterising a neighbourhood*: site coverage, directionality, clustering typology, directional spacing angle difference, directional space ratio	The way how urban morphology is parametrised indicates the type of urban morphology variations which are tested in the study. The parameters can be divided into 3 categories, depending on whether they describe building form only (1), the direct morphological surrounding of a given building (2) or the morphological patterns of an entire neighbourhood (3).
Main performance indicators used in performance assessment	1) *indicators of solar radiation distribution*: solar exposure, percentage of daily direct solar radiation distribution on urban surfaces (roofs, facades, ground), irradiance on facades 2) *indicators of daylight availability in internal spaces*: indicators of daylight factor, daylight autonomy, UDI (useful daylight illuminance) 3) *indicators of building energy performance*: fabric heat losses, cooling and heating energy demand, lighting electricity consumption, total energy use, change in space heating, increase in space heating, change in primary energy use	The performance indicators used show the basis on which different urban morphologies are assessed or which are the target criteria for urban morphology optimisation. The indicators can be divided into 3 categories, depending on whether they quantify the solar radiation distribution (1), the daylight availability in internal spaces (2) or the building energy performance (3).
Knowledge gained	Qualitative or quantitative description of impact of urban morphology on building energy needs	
Robustness of the ensuing recommendations	5 assessment criteria presented in Table 2	See Table 2.

Table 1: Assessment criteria used

Assessment criteria

The analysis of a high number of diverse publications (both in scope, method applied, degree of innovation, quality) is performed by applying the set of criteria presented in Table 1 and by categorising the publications (author, date, publication medium). It has been noticed that computational modelling is not the only scientific approach chosen; even when this is the case the models used do not always take into consideration all physical effects or are of different nature. Then, there are different possibilities for considering urban scenes which can be immersed in different climate zones. Last and because it might not be necessary for their works, the authors do not always isolate urban morphology parameters from other parameters. The robustness of the ensuing recommendations is assessed using the criteria reported in Table 2.

Criteria for the robustness of recommendations	Relevance
The study is performed without any initial non-verified postulate.	Taking non-verified postulates for granted is questionable in any research work.
The effects of single parameters were isolated (other parameters were normalised).	Isolating the effects of given parameters implies normalising other parameters to neutralise their influence.
Plausibility check: trends and results obtained are plausible.	Plausibility checks are necessary to be convinced of the results' validity.
A validation procedure has been applied or is under way (e.g. monitoring).	Validating the results obtained is necessary for robustness of recommendations.
The limits of applicability are clearly presented.	Presenting the limits of applicability is an indicator of awareness one's own limitations.

Table 2: Criteria used to assess the robustness of recommendations

RESULTS

30 publications written between 1972 and 2011 have been considered. This includes 5 books (some of them gathering more than one publication related to the topic of interest), 14 journal articles and 8 conference papers.

Scientific approach chosen

Given the difficulty to isolate the impact of selected morphological parameters in situ and monitor their impact on energy use in real case studies, nearly all publications assessed are based on computational modelling activities. Only few works rely on measurements performed at urban scale: mainly [18] and more recently [23] use monitored data to characterise the local urban climate ([23] uses an empirical climate prediction model based on Singapore data) in which buildings are immersed, but in both works building energy needs are practically calculated. [21] uses high resolution IR-thermography to characterise indirectly the heat island intensity, but this approach is not frequently followed. Comparing and referring to other published works is the main approach of 6 of the assessed publications, which do no rely on any new computational modelling activity.

Physical effects taken into consideration in the models applied and types of models applied

Despite the known implications of urban climate on energy needs and the available possibilities to model urban climate conditions based for instance on the work of [11], only 4 of the assessed publications consider a climate model (empirical or urban boundary-layer model) in the computations. It is clear that studies of solar radiation availability on outside building surfaces do not require an urban climate model. However, 6 publications draw conclusions on thermal building energy needs without considering or mentioning the possible implications of urban morphology on the local climate and its impact on energy needs.

The radiation models used are either based on a ray tracing or radiosity algorithm in which anisoptropic sky radiance distributions, diffuse sky occlusions and reflections from occluding surfaces may each be handled (6 publications), or relatively simplified models are used in which a limited number of these phenomena are represented.

Thermal building models, ranging from the highly simplified heat loss calculation over the building envelope used by [9] to commercial or self-developed transient building energy performance simulation tools, are applied in 14 publications. In 3 of these publications, implications on cooling energy needs are ignored. In 10 of these publications, electricity needs for artificial lighting are not considered.

Type of urban scene considered

Two approaches are used to consider urban scenes. Some authors (7 publications) use models of real urban neighbourhoods, having the major advantage to be representative of real urban design morphologies. However in these cases, there are usually limited possibilities to generalise the findings gained on the case study cities, unless there is a high number of cases characterised according to given parameters. [7]

considers 25 different urban block types in four categories: discontinuous collective housing, continuous collective housing, dense individual housing and dispersed individual housing.

Publication reference	Urban climate model	Radiation model for surroundings	Building thermal model	Cooling needs calculated	Energy use for lighting calculated	**Main findings: impact of urban morphology on buildings' energy needs (summary)**
[1]	TEB	Y	TRNSYS	Y	-	The effect of H/W ratio of an urban canyon is assessed and demonstrated to be not as significant as the effect of other parameters (thermal insulation, window ratio).
[4]	-	Y	-	-	-	The impact on buildings' energy needs is not assessed but it is demonstrated that solar energy available for utilisation may be increased by up to 20% if optimisation algorithms are applied on urban morphology.
[5]	-	Y (albedo)	Energy Plus	Y	Radiance and Daysim	Increasing site coverage implies higher heating and lighting needs and lower cooling needs. The results of the performed sensitivity analyses are presented graphically.
[6]	-	Radiance	-	-	-	The impact of site coverage on the solar irradiation on buildings is proven to be relatively low but the implications on energy needs are not commented. The effect of self-obstructions is proven to be relevant.
[7]	-	-	TAS	Y	-	The impact of urban morphology is not assessed because urban form parameters are not isolated from other parameters (thermal building envelope quality).
[8]	-	-	Static calculation	-	-	Theorem 1: "A simple rectangular block of given volume loses the least amount of heat if the dimension of each edge is proportional to the mean thermal transmittance value of the faces defined by the other two edges."
[9]	-	-	Static calculation	-	Y	Based on the parametric study it is proven that increasing density impacts energy use for lighting rather than heating energy use.
[12]	ENVI-MET	Y	-	-	-	The impact on buildings' energy needs is not assessed.
[14] & [15]	-	Y?	LT	-	LT	The passive to non-passive area ratio is proven to impact buildings' energy needs. A 10% difference is shown between the specific energy needs of different urban morphologies, when default values are attributed to all other variables.
[13]	-	-	-	-	From DEM	The surface to volume ratio is used as indicator of good thermal performance.
[16]	-	Y	-	-	-	The impact on buildings' energy needs is not assessed.
[17]	-	Y	SUNTOOL	Y	Y	The impact of H/W ratio on energy use for cooling, heating and lighting is calculated for different glazing ratios in a parametric study. Results are graphically presented.
[18]	Measurements	-	TRNSYS	Y	-	The impact of urban morphology is not directly assessed, but the effect of urban climate on energy consumption in buildings (heating and cooling) is quantified.
[19]	-	-	N	-	-	The impact on buildings' energy needs is not assessed.
[20]	-	-	LT (partly)	Y	LT	"Relatively high housing densities can be achieved before a negative impact on the energy demand becomes significant" (based on a limit obstruction angle of 30%).
[22]	-	Y (albedo)	Energy Plus	Y	Radiance and Daysim	Heating and cooling energy demand can be reduced by 10% to 20% by optimising urban morphology.
[23]	Empiric model	-	TAS	Y	-	In the range considered, height and density are not as relevant as green plot ratio. Cooling energy demand can be reduced in a range between 5 and 10% if green areas are addressed effectively.

Table 3: Assessment results of the publications reporting the results of computational modelling activities at neighbourhood scale

The other publications (i.e. the majority) use simplified urban morphological archetypes which can more easily be parameterised, both for performing sensitivity analyses and urban morphology optimisation, but which have the risk to lose any connection to realistic urban design proposals. Often inspired by [9], the most frequently assessed archetypes are pavilions (8), including shape variations for high-rise buildings ("I", "L", "F" and "+" shape in [6]), courtyard configurations (4), row houses and slabs (3) and urban street canyons (1). The more frequent typologies are therefore pavilions and courtyard typologies.

There is one case of real building geometry immersed in different urban contexts [23] and one case of a newly developed building form typology ("residential solar block" in [12]).

Climate zone considered

Authors have different ways to refer to climate conditions. Only few authors characterise the climate by mentioning a climate zone (locations at 48° latitude for [12], an arid climate for [13]), suggesting their results may be valid for similar latitudes in the considered zones.

Urban morphology parameters

Table 1 shows the high variety of parameters used to characterise urban morphology, illustrating the various possibilities for its parameterisation. The height to width ratio between buildings is the most frequently used parameter, followed by site coverage, plot ratio and sky view factor (and related equivalent parameters); often using ill-adapted radiation models. Few authors quantify the overall neighbourhoods' energy performance in dependency on more abstract neighbourhoods' morphological parameters.

Main performance indicators used in performance assessment

As for urban morphology parameters, Table 1 shows the high variety of performance assessment indicators used in the assessed publications, being a proof of the different authors' positions in relation to what defines an energy efficient urban morphology. The use of indicators of solar irradiation on building envelope indicates that the maximisation of solar radiation on building envelope is considered as a target function. However, even if followed in 7 of the assessed publications, this approach can only be considered as a computational exercise and can not be translated in any morphological recommendation. If thermal building energy needs are calculated by applying a thermal building model, specific energy performance ratings (specific heating energy and cooling energy needs, if applicable) or variations of these indicators are used to characterise energy performance. Indicators for electricity use for lighting are considered only in four of the assessed publications.

Knowledge gained

Generally speaking, all publications assessed confirm the impact on urban morphology on building energy needs but its intensity is rated differently, mainly depending on the physical effects taken into consideration. Few authors really conclude on percentage variations or quantify building energy performance rating in dependency of urban morphology. The last column of Table 3 is an attempt to summarise the main findings presented in the publications assessed.

Robustness of the ensuing recommendations

The robustness of the recommendations from some of the papers cited here are somewhat questionable. [12] for example proposes a "holistic approach to energy efficient building forms", without considering the seasonal differences when it comes to analysing the contribution of solar radiation and without calculating buildings' energy performance; whilst [13] uses the surface area to volume ratio as performance indicator.

The effect of urban morphology parameters is isolated in many cases, but the normalisation is rarely performed on the same way. Sometimes plot ratio and volume to facade ratio are normalised, sometimes the built volume and passive to non-passive ratio; in other works U-values as well as the share of glazing area are maintained whereas morphological parameters are varied. In 5 publications the effects of urban morphology are not isolated, which makes it impossible to deduce recommendations from this point of view.

In nearly all cases, the plausibility of trends and results obtained is commented by the authors, but only the theorems of [9] are mathematically demonstrated, mainly because they are based on very simplified problems which do not require any computational modelling to be solved. Other publications never rely on energy use monitoring to validate the findings presented, with exception of the work of [5] which mentions a satisfying comparison with energy use monitoring data from the case study.

The limits of applicability are nearly always clearly presented, with the exception of 3 cases where the recommendations provided seems to go beyond the field of application at the eyes of the authors (extrapolation is not justified).

CONCLUSIONS

The literature reviewed here seems to confirm the implications of urban morphology on energy needs. However, given that different physical effects are considered, different parameters are varied and different indicators are used for assessment, it is difficult to generalise and compare the authors' findings; there is a need for consistence regarding the phenomena examined and the manner in which the ensuing results are expressed. The next step in this work is to propose one such framework.

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