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ZERO-ENERGY-BUILDINGS IN DIFFERENT CLIMATES: DESIGN STRATEGIES, SIMULATION AND PROGNOSIS METHOD FOR ENERGY DEMAND

Udo Dietrich, Franz Kiehl, Liana Stoica
HafenCity Universität Hamburg, Germany
REAP Research Group

ABSTRACT

The European Directive 2010/31 claims that by 2020 only (nearly-)Zero-Energy-Buildings may be built. To reach this goal, it is pertinent for buildings to be energetically optimised first. The remaining energy demand must then be covered by on-site renewable energies (PV, geothermal etc.).

With the area of use (energy demand) and the size of the building envelope / estate (renewable energy supply) in competition with each other, the maximum number of building storeys will be most likely limited.

For 15 different climatic locations worldwide, the energy demand of optimised office rooms was simulated and compared with the possible renewable energy production on site.

For every location, a good correlation was found between the simulated energy demand and data like heating and cooling degree hours. Correspondent linear equations are given here. As another result, the maximum number of possible storeys for Zero-Energy-Buildings was derived as to be between 3 and 10 depending on the location.

INTRODUCTION

In the European Union, the building sector is responsible for 40% of the primary energy demand. Thus, a notable reduction could be achieved by the energetically optimising of the building stock, especially in the context of zero-energy standard being pursued. According to the Energy Performance of Buildings Directive (EPBD) 2010/31/EU new and retrofitted nearly-Zero-Energy-Buildings should be reached by 2020, thus setting minimum requirements for both the envelope and the technical systems" (EPBD, 2010).

In a Zero-Energy-Building (ZEB) 100% of the purchased primary energy is to come from renewable energy sources. As claimed by the directive, these renewable energies must be gained on site, e.g. on the building's facades / roof and/or in the estate's ground. Weaker ZEB definitions allow compensating measures to balance energies: transfer of renewable energies produced off site or co-generation etc.

Up to now, two different concepts of energetically optimised buildings exist. A passive method where the building's energy demand is minimised by passive measures ("Passive House") and an active approach where solar panels and similar active measures are used to cover the energy demand ("Solar House"). Both principles on their own are not sufficient to reach a ZEB; a well-designed synthesis of both is necessary. The sequence of priorities is:

1. Reduce the building's primary energy demand to its minimum
2. Cover the remaining primary energy demand with renewable energy gained on site
3. Use compensating measures to bring the balance to zero, if this is not completely possible (for some locations in the world it will be, for others not)

The first two points create new competition between the façade's transparent areas (for optimal daylight supply and minimal power demand for artificial light) and opaque areas (for solar panels to gain renewable energy). Furthermore, the whole building shape will become an important passive measure to optimise energy demand and production. The architect can apply these optimised shapes at an early design stage.

Because of the access of solar radiation to the façades and roofs size, distance and placement of buildings in an urban situation will become a central aspect. Therefore, an integrated energy concept starts with urban planning and not just on the building level.

Different locations have diverse needs and preconditions, leading to different design rules and architectural solutions for zero-energy urban quarters and buildings in different climates. A design approach such as this is climate responsive and will be based on a new culture of climate-responsive architecture.

METHODOLOGY

The M.Sc. Degree Programme "Resource Efficiency in Architecture and Planning" (REAP, 2012) at the HafenCity University Hamburg emphasises the use of holistic design for sustainable urban development projects, while taking including scientific approaches to water, materials and energy concepts into consideration. Based on this interdisciplinary approach, students investigate on resources, technology, architecture, urban planning, legal instruments and socio-economics. In this context, the course "Climate-responsive Architecture and Urban Planning" encourages the students to apply knowledge of building physics to real buildings around the world using a specific teaching method. With the task of adapting buildings to local climates and optimising indoor comfort, students are required to investigate their own case study and apply passive and active measures as far as possible. The overall aim of the course is to find out if and how far it is possible to realise ZEBs in all parts of the world.

Each group of two or three students chose one of the locations provided to them and worked with it as "their" location for the whole semester. In three short semester presentations, the results were presented in visual form to the other student groups with different locations. The main target of these presentations was to compare the results of the other groups/locations with the own ones and to discuss the differences.

To simplify the task and to be comparable between all the groups / locations it was predetermined to deal with a standard office room for 12 users (area of usage 168 m²). It was assumed that this room could be one of a series of rooms, situated in the middle of an office building so that the building continues horizontally and vertically.

As a starting point "before optimisation", an "international style" standard room was defined.

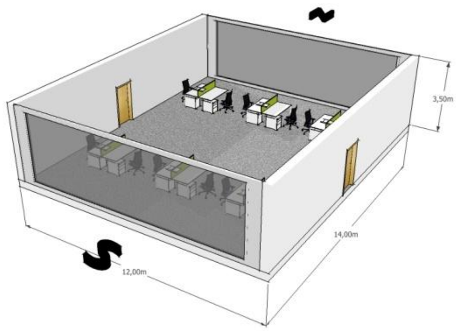

Figure 01: International style office room

This room has fully glazed and sealed facades, an internal shading system, air conditioning and artificial light, which are all operating during the whole time of use.

The international style office room's energy demand was simulated in advance for all the locations, data of the energy demand for heating, cooling, artificial light and ventilation were supplied to students.

The subjects of the first short presentation included:

1. Local conditions: Energy supply, water availability (for evaporative cooling), materials, standards and laws
2. Calculation of facades / roof areas and/or estate area required to cover the international style office room's energy demand with renewable energies
3. Estimation of the maximum number of storeys and the minimum distance of buildings to reach a ZEB with international style rooms
4. Comment, if these results are satisfying
5. First proposals on how to improve the room

The subjects of the second short presentation included:

1. Climate analysis and derivation of design rules and strategies
2. Study of examples for vernacular and best practice architecture
3. Second proposals on how to improve the

The subjects covered in the third short presentation were:

1. Calculation of facades / roof areas and/or the estate area required to cover the optimised office room's energy demand with renewable energies
2. Estimation of the maximum number of storeys and the minimum distance of buildings to reach a ZEB with optimised rooms
3. Comment, if these results are satisfying
4. Determination of first rules for regulations in climate-responsive urban planning
5. Comments if compensating measures are necessary or not (If yes, inclusion of detailed proposals what and where this could be)

In the last short presentation, in order for students to show the climate-adaptive buildings final design and urban situation it was necessary for them to have information about the energy demand of this optimised room as a starting point. One possibility for them was to simulate the proposed optimised room during the course. Although this is possible, our experience shows that these simulations are so complex that they consume most of students' time and distracts from the main target of the course.

For this reason, we developed another method avoiding these simulations. The products of the first cycle of our course were a row of optimised rooms for different locations. We simulated these rooms, compared the energy demand with other typical data for the same location like heating or cooling degree hours and found a very good correlation between them.

Based on these correlations, we could then offer student groups an estimated energy demand for optimised rooms in their location. The results are accurate enough for the main target of the course and help avoid the execution of further simulations.

CHOICE OF CLIMATES AND LOCATIONS

Annual and monthly average temperatures as well as the amount of precipitation and its distribution pattern are important parameters to indicate climate.

Published in 1884 and later modified, the most widely used climate classification system in the world was created by W. P. Köppen and R. Geiger (Köppen, Geiger 2011). It consists of three classification types, which refer to the main climate zones (A, B, C, D, E), the precipitation (type) and the temperature (subtype). Some examples for the chosen locations include:

- Af, Tropical rainforest climate
- Am, Tropical monsoon climate
- Aw, Tropical savannah climate
- BWh, Hot desert climates
- Csa / Csb, Dry-summer subtropical climates or Mediterranean climates
- Cfb, Maritime temperate climates or oceanic climates
- Cwb, Temperate climate with dry winters
- Cfc, Maritime subarctic climates or sub polar oceanic climates
- Dfa, Dwa, Hot summer continental climate
- Dfb, Dwb, Warm summer continental climate

In order to find out the influences of the climate on architectural design, representative climates from the poles to the equator were regarded. Cities from all continents and with different cultural backgrounds were factored in. The final choice of cities comprises the following locations:

- Reykjavik, Iceland, Europe, 64N, Cfc
- Oslo, Norway, Europe, 59N, Dfb
- Hamburg, Germany, Europe, 53N, Cfb
- Chicago, USA, America, 41N, Dfa
- Beijing, China, Asia, 39N, Dwa
- Cairo, Egypt, Africa, 30N, BWh
- Delhi, India, Asia, 28N, BSh
- Mexico City, Mexico, America, 19N, Cwb
- S. Domingo, Dom. Rep, America, 18N, Am
- Addis Ababa, Ethiopia, Africa, 9N, Cwb
- Singapore, Asia, 1N, Af
- Dar es Salaam, Tanzania, Africa, 6S, Aw
- Jakarta, Indonesia, Pacific, 6S, Aw
- Sydney, Australia, Pacific, 33S, Cfb
- Santiago de Chile, Chile, America, 33S, Csb

The local climate data for these locations was generated with Meteonorm 6.1 (Meteonorm 2010).

ANALYSIS OF CLIMATES

The climates were analysed with Climate Consultant 5.2 (Climate Consultant 2012). Single parameters correspond to passive and active measures of climate responsive architecture:

- Solar radiation for the PV-harvest.
- Sun position for the placement of PV modules and the design of shading systems like overhangs and wing walls
- Sky cover range for estimating the minimal part of windows for good daylight supply. As a rule of thumb, the sky type is defined as “cloudy” if the sky cover range exceeds 70% during more than 6 month and a minimum of 50% of the façade area should be reserved for windows. In the other case the sky type is “clear” and windows should account for at least 35% of the façade. These estimations are in accordance with vernacular architecture and best-practice examples
- Monthly values of air temperature to estimate if and in which seasons heating and cooling are required. For monthly temperatures below 10°C / above 23°C heating / cooling demand was assumed
- Daily changes in temperature and especially night-time temperature for establishing if night ventilation could help to limit temperatures during the day. A heavy construction should be integrated in the design
- Ground temperature to estimate the potential of geothermal systems
- Relative humidity for estimating the potential of evaporative cooling
- Wind velocity and direction for estimating the potential for natural ventilation and for establishing rules for the placement of ventilation openings

ASSUMPTIONS AND LIMITATIONS

International style standard office room

Everywhere in the world, there are “international style” office buildings that have fully glazed and sealed facades and pay absolutely no attention to local climates and needs. To ensure comfort inside, a lot of energy is needed for heating, cooling, lighting and ventilation.

The simulated standard room has the dimensions (width x height x depth) 12 x 3.5 x 14 m (See Figure 1). Thus, it has two external facades and two internal boundary walls.

14 m building depth is a very common assumption as it follows the principle for providing a good daylight supply onto the desks. In some other locations, if an optimised room is to be achieved, other dominating principles may require a different building depth. For example, it was found out from vernacular architecture that a building depth of only 8 to 10 m for natural cross ventilation in hot and humid locations works well; a depth of 14 m would be a remarkable reduction.

The other simulation parameters for the international style standard office room are as follows:

- facade orientation to south/north
- fully glazed facades, double pane window
- internal shading system, Fc = 0.75
- all internal constructions are light (skeleton)
- time of use 11 hours from 7 am to 6 pm
- artificial light during time of use
- mechanical ventilation during time of use, air change 2 h^{-1} (summer) and 1 h^{-1} to consider heat recovery (winter)
- 12 employees with their equipment (internal gains)
- Cooling temperature set to 26°C

Systems for the production of renewable energies on site

The Energy concept that should be applied in all case studies is based on a combination of geothermal heating and cooling and solar energy (PV modules) for the generation of electricity.

The geothermal system consists of borehole heat exchangers in the ground coupled with an electrically driven heat pump. The boreholes are assumed with a depth of 100 meters using the ground as a heat source in winter and as a heat sink in summer. Each borehole needs to be placed a specific distance away from the next one, 10 % of their length was utilized here leading to the rule of thumb that one meter of borehole needs 1 m² of estate. One meter of borehole is able to deliver 600 Wh of thermal energy per day (Zimmermann, 1999).

For the heat pump, a coefficient of performance (COP) of 2.5 was assumed for cooling and 3.5 for heating. These values represent an average, because a separate investigation revealed that the influence of the ground temperature (which is near to the yearly mean value of the air temperature) does not have a strong influence on the COP. Thus, the accuracy of these values is acceptable for all locations.

Geothermal systems are being used more and more around the world, especially in combination with optimised buildings. They seem to have a big future.

For power a primary energy factor of 3 was used for all the calculations.

Limitations in the use of active systems on site

The power demand of the heat pump, artificial light and mechanical ventilation has to be covered by PV modules, which can be installed on either the building's roof or facades.

Based on the position of the sun a placement directly on a horizontal flat roof only works well in locations near the equator. For other locations, the modules need a slope. Modules can be elevated on the roof, but then inter-row spacing is needed to prevent solar panels from shading one another. As a result, only a part of the roof area can be effectively covered with PVs. A pitched roof can provide an optimal area for solar reception, one that is bigger than the building's footprint. However, especially in some locations, buildings with pitched roofs are remarkably higher than buildings with flat roofs – to avoid one building from shading the next; the distance between them has to be expanded. Additionally pitched roofs influence the building's architectural design, meaning their suitability has to be discussed.

With reductions in the solar harvest, PV modules can be placed on the facades, too. Here the same problem of shadowing and expanded building distances also exists.

The thermal energy demand for heating and cooling has to be covered with the previously described geothermal system. Its size is determined by the maximum daily heating or cooling energy resp. For example, a daily cooling demand of 300 Wh/m² d (10 hours with 30 W/m²) needs 300 / 600 = 0.5 m borehole in the ground and with this 0.5 m² of estate.

In general, the area of use producing demand of thermal energy and power competes with the size of the estate (for the geothermal system) and the size of the roof and the facades (for PV modules). In case of non-optimised, "international style" buildings the required estate and PV area might be so dominant that urban zero-energy quarters are only possible with buildings with a low number of storeys and/or buildings with distances far from a normal street width.

If it is not possible to meet the target use only on-site renewable energies in an urban scenario, meaning compensating measures must also be utilised.

For the most relevant climates, this will be investigated in detail in this document's "Case study results" chapter.

ADAPTIVE, HYBRID OR AIR-CONDITIONED?

An adaptive building is understood as a building where the users can adapt their surrounding according to their preferences: Operable windows, personal switches for artificial light, mechanical ventilation, thermostats etc. If users are allowed to adapt themselves to (higher) indoor temperatures during hot periods by changing their clothes (no or weakened dress code!) then investigations show that users feel well in remarkably higher temperatures than in non-adaptive surroundings (air-conditioned buildings).

Adaptive comfort models such as (EN 15251, 2007) differ between naturally ventilated (adaptive) and air-conditioned (non-adaptive) buildings. For both building classes EN 15251 defines three different comfort classes:

1. Highest standard, for special use like in hospitals
2. Good standard, for all new buildings

3. Low standard, acceptable for refurbished buildings

The relevant comfort belt may be exceeded during a limited part (3 or 5%) of the hours of use. For an office room which is occupied 11 hours a day (7 am to 6 pm) and 5 days a week, 3 % means 85 allowed hours of exceeding per year.

In air-conditioned buildings, the user expects a constant temperature (mostly 26°C) independent of the outdoor situation. In adaptive buildings, the expected temperature varies slightly with the mean value of outdoor temperature.

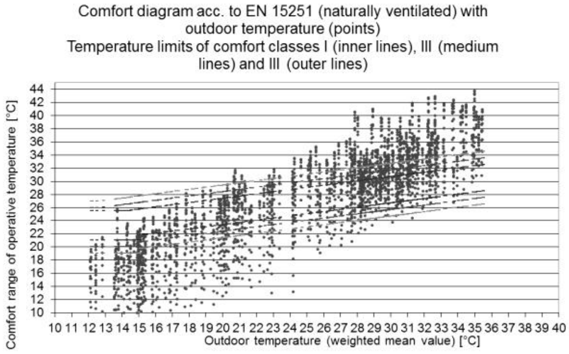

Figure 02: Comfort diagram according to the scheme of EN 15251, assessment of outdoor temperature Delhi.

Figure 2 illustrates this situation. The comfort belts for the three comfort classes are marked in the graph. The indoor temperatures are normally displayed as points in this EN 15251 scheme to assess indoor climate. In this diagram however, the points represent outdoor temperatures.

Obviously, in an adaptive building with "only" natural ventilation (very high air change) the indoor temperature must be equal to outdoor temperature. Given the fact that for real air changes indoor temperatures remain a few degrees below outdoor temperatures for heavy construction – or are almost equal to outdoor temperatures for light construction, an adaptive comfort model such as EN 15251 provides a good tool for pre-assessing, if there is a chance that comfort can be reached during hot periods with passive measures (natural ventilation).

Figure 2 shows a lot of points both below and above the upper comfort limit – the number of points exceeding the comfort level is much more than 3%. To conclude however, that comfort can't be reached in an adaptive building but only in an air-conditioned one would be premature. If we change the x-axis of the EN 15251 scheme into the real-time axis, we attain a different picture (See Figure 3).

Now it can be seen, that the upper line of the comfort belt is not exceeded during a number of month, thus; an adaptive building is possible here. An adaptive building is only not possible only during the hottest months and air conditioning should be used. In summary, we recommend a hybrid building with 5 month of adaptive operation (saves a lot of energy for the mechanical ventilation and cooling system) and 7 month with air conditioning.

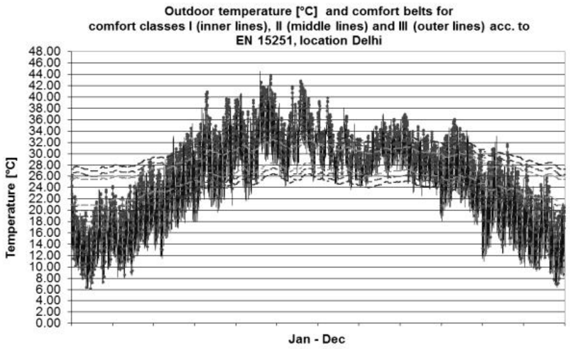

Figure 03: Diagram with comfort belts according to EN 15251 and outdoor temperature, Delhi.

Furthermore, it is usually the case that in hotter countries people are more accustom to higher temperatures. Their expected comfort temperature was found to be as up to 4 degrees higher than the proposals made in EN 15251 (Keonil, Sahachaisaeree, 2011). This fact can be introduced in the assessment of outdoor climate with EN 15251 but should be discussed in detail with local people.

Comfort class 2 can be reached the whole year round in the following locations, which were examined: Reykjavik, Oslo, Hamburg, Mexico-City, Addis Ababa and Sydney – here adaptive building concepts are possible without any restriction.

If the upper line of the comfort belt is shifted upwards, comfort class 2 can be reached in Singapore, Santiago de Chile (1 degree), Beijing, Santo Domingo, Dar es Salaam (2 degrees), Cairo and Jakarta (3 degrees). If users accept this upward shift, adaptive buildings are possible. If not, hybrid or air-conditioned solutions have to be developed.

Comfort class 2 will never be reached in Delhi, meaning a fully adaptive building is not possible, a hybrid one like described would be the best option.

CASE STUDY RESULTS

"International style" standard office room

Figure 4 shows the primary energy demand for all 15 locations. With high solar transmission occurring through the facades, cooling demand is a dominant factor. The highest demand occurs in the hottest locations (Delhi, Cairo, and Jakarta). Even in locations with moderate temperatures during summer such as Oslo and Hamburg cooling demand exists.

In general, the level of primary energy demand is very high - a clear sign of the potential to optimise "international style" office buildings.

In order to cover the power demand for heat pump, artificial light and mechanical ventilation with PV modules (installed on the building's envelope) a limited number of storeys is only possible. In the worst case (less than) one (Oslo, Reykjavik) up to 3 storeys (Mexico-City, Addis Ababa).

Due to high demand of thermal energy for heating and especially for cooling a large estate is required to implement the geothermal system. To supply a five-storey building the required distances between buildings starts at 30 m (Mexico-City, Addis Ababa, Santiago de Chile) and continues all the way up to more than 100 m (Delhi, Oslo).

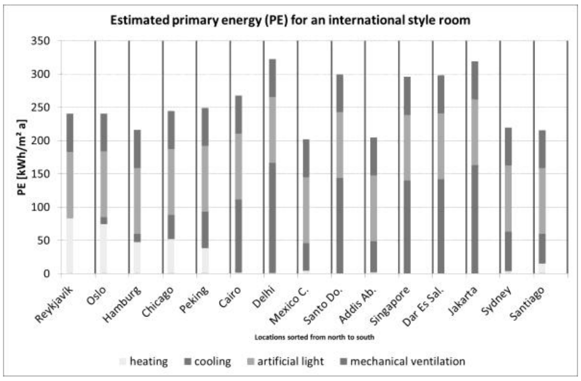

Figure 04: Primary energy demand of "international style" standard office room for 15 locations

In general, the attempt to develop a zero-energy urban situation using "international style" buildings delivers unsatisfying results. The energy demand is too high. It is necessary to reduce this demand firstly to reach a satisfying situation.

Finally it should be noted that the primary energy demand for existing "international style" buildings may be much higher (up to a factor of two or three more) than calculated here. To compare it with the optimised room, we assumed the same geothermal system with high efficiency. Most of the real buildings have different systems with higher primary energy demand (e.g., a standard absorption chiller has a COP of about 1.5, meaning that the primary energy is nearly doubled for cooling).

Optimised standard office room

Before starting with the optimisation of the room it is necessary to decide if users are allowed to behave adaptive not (e.g. dress code, company philosophy, number of users per operable window/thermostat etc.).

If so, an adaptive building can be proposed and designed. If necessary because of very hot periods, switching to an air-conditioned building can be considered, resulting in a hybrid building.

If not, an air-conditioned building has to be designed. It would be a wise idea to work together with building users to investigate both options and to come to a mutual decision.

The cases examined in the following are for air-conditioned buildings. This is not meant to reduce the relevance of adaptive building solutions but only to demonstrate the potential for energetically optimising buildings. With adaptive solutions it can be seen that the energy demand would be remarkably further reduced!

In every case, it is assumed that no artificial light is used as soon as enough daylight is available.

Figure 5 shows the primary energy of an (air-conditioned) optimised room in comparison with the "international style" office room.

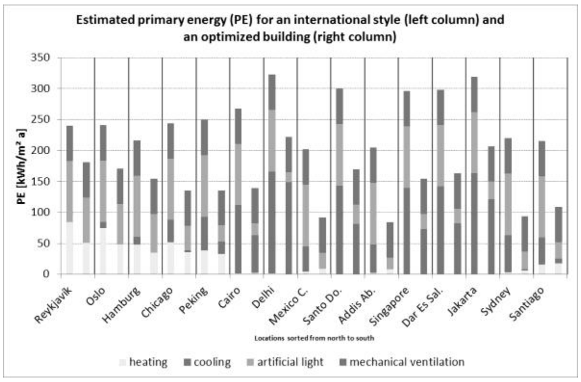

Figure 05: Primary energy demand of optimised and "international style" standard office room for 15 locations

The reduction potential is remarkable for all locations but differs for each one. For locations with cold winters, the optimised room has opaque facades with high thermal insulation, leading to a small reduction of heating demand. The power demand for artificial light has the greatest reduction in locations with a clear sky and receiving 12 hours of daylight year-round (e.g. near the equator, see Cairo, Delhi, Addis Ababa).

Cooling demand can arise from high solar transmission through facades and/or a high outdoor temperature. To counteract solar transmission buildings can be optimised with adequately sized window areas and efficient shading systems. Important here however is that very high (or even very low) temperatures are not blocked out. Thus, the highest heating demand occurs in locations with the lowest temperatures and the smallest opportunity to have solar gains during winter (Reykjavik, Oslo). The highest cooling demand occurs in locations with the highest temperatures (Delhi, Jakarta).

The highest reduction in energy demand is found n locations where the cooling demand for an "international style" room arises from solar transmission (Santo Domingo, Singapore, Dar es Salaam, Sydney). Inversely a high cooling demand remains for locations with high temperatures (Delhi, Jakarta) - here the potential for optimisation is limited.

To cover the power demand with PV modules installed on building's envelope we see once again that only a limited number of storeys is possible. In the worst case again only (less than) one storey (Oslo, Reykjavik), 4 storeys and more (Cairo, Singapore, Sydney, Santiago de Chile, Dar es Salaam) and up to 9 storeys (Mexico-City, Addis Ababa). Thus, with the reduced primary energy demand for the optimised office room, typical urban dimensions can be reached for some locations!

The optimisation of heating and cooling demand leads to a remarkable reduction of the geothermal system and thus to a smaller required estate size. To supply a five-storey building with thermal energy the resulting distances between buildings are now within acceptable urban range (street width of about 15 m, Mexico-City, El Salvador, Sydney, Santiago de Chile, Addis Ababa) or not far from it (Santo Domingo, Singapore, Cape Town) but reach up again to 100 m in the most extreme case (Delhi).

In general, the attempt to develop a zero-energy urban situation with optimised buildings leads to very satisfying results in some locations. For other locations, a big part of the primary energy can be covered on site; only in extreme locations does it remain very difficult to reach the target. In this case, compensating measures are necessary.

General conclusions from case study results

The size of the geothermal system is determined by the peak values of heating and cooling demand, i.e. the strength of heat and cold waves but not the yearly demand. The biggest geothermal system is required in Delhi (hot and dry) for cooling and in Chicago(!) for heating. Locations with high but not extreme temperatures (the hot and humid ones: Santo Domingo, San Salvador, Singapore, Jakarta) have a high yearly cooling demand but they need a relatively small geothermal system to cover it. Moreover, vice versa, locations with shorter but extreme heat waves have a smaller yearly cooling demand but they need a huge system to cover it.

The global solar radiation is the main source to cover the energy demand. We find the best offer in the hot and dry locations (Cairo, Delhi). Here, there highest supply meets the highest demand! It seems that both can be brought into balance but only with buildings with a limited number of 3 to 5 storeys.

Locations near the Earth’s poles (Reykjavik, Oslo) have a very low solar supply, especially during the heating period. As a result, they also have a high demand of artificial light (darkness during time of use). Also because of the low position of the sun in the sky, the use of PV to cover the demand seems not to be a valid solution. Consequently, other possibilities for the supply of renewable power or compensating measures should be regarded (Fortunately, both Reykjavik and Oslo are locations where power is almost 100% renewable).

We found that the best situation exists in locations with moderate temperatures (near to the sea or with a high elevation) and high level of solar radiation (Mexico-City, Sydney, Santiago de Chile). Here zero-energy urban solutions are possible! Figure 6 shows an urban arrangement for Santiago de Chile with six storey buildings with pitched roofs (5 plus one in the roof) and a distance of 21 m.

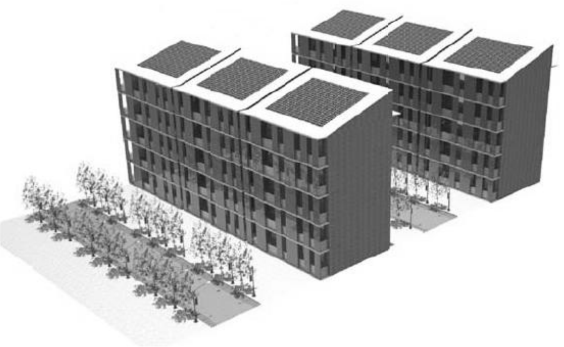

Figure 06: Example for an urban arrangement of ZEBs, location Santiago de Chile (Arboledas, Jaen, 2011)

Zero-energy buildings as well as urban arrangements are possible for many locations but not for all. This holds true for European countries where the Directive must be fulfilled. Compensating measures, however, are then necessary.

CORRELATIONS BETWEEN ARCHITECTURAL AND CLIMATIC PARAMETERS (PROGNOSIS METHOD)

The architectural parameters heating and cooling demand in optimised buildings are assumed to be determined essentially by the outdoor temperature. Therefore, a correlation between them and climatic parameters such as heating and cooling degree hours is likely.

$$HDHy = \Sigma (20 - Te) \quad \text{if } Te < 16°C \tag{1}$$

$$CDHy = \Sigma (Te - 26) \quad \text{if } Te > 26°C \tag{2}$$

sum only over hours of use

$$GRHy = \Sigma (1) \quad \text{if } Igl,hor > 200 W/m^2 \tag{3}$$

sum only over hours of use

Equations (1) to (3) give the definitions of the used climatic parameters heating and cooling degree hours and the global radiation hours. For cooling and artificial light, it is assumed that both are running only during the time of use. As a result, the sums in Equations (2) and (3) considers only the time of use. For artificial light it is assumed that it could be switched off if the global horizontal radiation reaches 200 W/m².

The parameters HDHd [Kh/d] and CDHd [Kh/d] resp. are the daily maximum values of heating and cooling degree hours. They are representative for the temperature peaks in the climate; a correlation with the size of the geothermal system could be expected.

The energy demand and the size of the geothermal system were simulated for the optimised (but air-conditioned!) office room. Between these architectural parameters and the five climatic parameters, a good correlation was found by using these regression equations: Y = A * X + B.

Table 1
Variables of regression equations between architectural and climatic parameters

Y	A	X	B
Yearly cooling energy demand [kWh/m² a]	0.0108	CDHy	-3.4542
Yearly heating energy demand [kWh/m² a]	0.0005	HDHy	-3.9752
Maximum daily cooling energy demand [Wh/m² d]	7.3567	CDHd	-84.788
Maximum daily heating energy demand [Wh/m² d]	0.7691	HDHd	-62.944
Power demand artificial light [kWh/m² a]	0.0106	GRHy	-0.6389

The fit (R^2 value) of these regressions lies between 74 % and 99 %; Figure 7 shows a typical example.

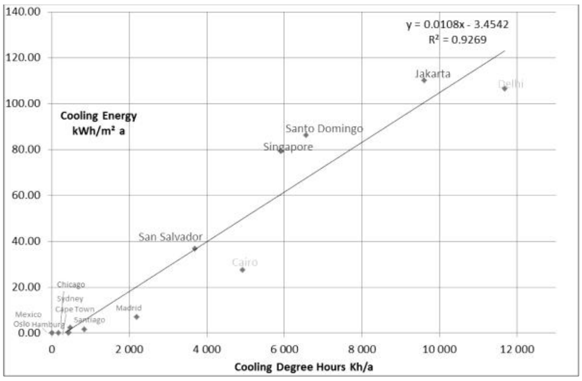

Figure 07: Correlation between yearly cooling energy demand and cooling degree hours CDHy and regression line.

In Figure 7 it is interesting to note that all the hot and humid locations are above the regression line (cooling demand is higher than forecasted) and all the hot and dry ones are below (smaller cooling demand). The reason for this may be that in hot and dry climates the combination of heavy construction and night ventilation with cool night air helps to reduce cooling demand. In hot and humid locations, this is very limited, leading to higher cooling demand. Thus, a detailed look into the correlations between these two climate types should help to determine more accurate regression equations.

In general, based on the regression equations given in Table 1, the energy demand for an optimised (but air-conditioned) building for any location in the world can be forecasted based on its climatic parameters alone.

CONCLUSION AND OUTLOOK

The equations in Table 1 provide a simple method for predicting how far energy demand can be reduced when optimising the building according to local climates.

The proposed correlations seem to be a good approach. Of course, with only 15 locations, the database is weak and requires expansion. The rooms were also only theoretically optimised in student projects, meaning there is no practical evidence. Here further detailed investigations should help achieve a prognosis method that is more accurate. On the other hand, the correlations are surprisingly good and plausible. Results are in accordance with real ZEBs or zero-energy urban solutions.

This tool is helpful for architects who can't conduct detailed simulations in early design stages. In end, the purpose of this paper is to show possible strategies to design climate-responsive architecture and offer a simple prognosis method as well as guidelines to measure the size of building services.

NOMENCLATURE

HDHy = yearly heating degree hours [Kh/a]
CDHy = yearly cooling degree hours [Kh/a]
GRHy = yearly global radiation hours [h/a]
Igl,hor = global horizontal radiation [W/m²]
Te = hourly outdoor temperature [°C]

REFERENCES

Arboledas, M.C., Jaen, R.M. 2011, MA course "Climate responsive Architecture and urban Plannung", 3rd short presentation, HafenCity University Hamburg

Climate Consultant 2012, http://www.energy-design-tools.aud.ucla.edu/, accessed December 2012

EN 15251 2007, Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics

EPBD 2010. Energy Performance of Buildings Directive, http://www.epbd-ca.eu/, accessed June 2012

REAP 2012, https://www.hcu-hamburg.de/master/reap-resource-efficiency/, accessed June 2012

Keonil, Sahachaisaeree, 2011, Energy-efficient management modelling towards interior thermal comfort: A case of composite dwellings features manipulation in Bangkok, PLEA 2011, p. 211

Köppen, Geiger 2011, Vetmeduni Vienna, http://koeppen-geiger.vu-wien.ac.at/, accessed September 2011

Meteonorm 2010, Meteotest, Meteonorm Handbook part II: Theory, Version.6.120, April 2010

Zimmermann, M. 1999, Handbuch der passiven Kühlung, Rationelle Energienutzung in Gebäuden