SOLUTIONS FOR BUILDINGS AND SETTLE-MENTS

Traditional urban fabric in Yazd, Iran [Wehage, P.]

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Energy and Space – Housing Design in Urban Context in the MENA Region

Introduction

Energy and sun as impact for spatial design in the MENA region

This article presents a design-based research process for sustainable neighbourhoods in the MENA (Middle East/North Africa) Region that focuses on the case study of Hashtgerd New Town in Iran.

Due to the fact that as much as 70% of the MENA region is classified as arid and semi-arid [Pahl-Weber et al., 2013] and the Islamic society represents a region-wide, socio-cultural context; the geographic and socio-cultural site-specifics of the location represent a background for further dissemination of the project results through transfer and adaptation to other locations in the region.

The intense solar radiation in the region and expected synergetic benefits from a holistic approach for urban and building design establishes the potential for locally-adapted, resource-efficient, and climate-sensitive spatial design for the emerging megacity regions in the Middle East.

Background

A significant proportion of energy consumption worldwide is related to the built environment. The use of renewable energy resources and the efficient application of energy through technological progress and innovative design offer a high impact on global energy demand.

Iran is a fast-growing and developing society. In the past three decades alone, the population has doubled from about thirty-five million to seventy million inhabitants [Habibi et al., 2005]. This demographic development has been accompanied by a massive rural-urban migration. The Iranian New Towns Programme, set up in the nineteen-seventies, aimed to govern the urbanisation process by the foundation of new settlements in order to relieve existing metropolitan areas. About 40% of the national energy consumption is related to the building sector in Iran [Nasrollahi, 2011]. The most common energy sources in Iran are generated from fossil fuels.

Due to the high rate of housing construction in the New Towns Programme, the implementation of resource-sensitive strategies on such a large-scale can have a high impact on energy demand and consumption of resources in the region.

The area of the pilot case study is situated in Hashtgerd New Town approximately sixty-five kilometres northwest of Tehran. The programme, created out of an existing framework, provides a housing district with around 2,000 dwellings that includes social infrastruc-

Fig. 1 The integrated planning and design process and district plan of pilot area Shahre Javan Community [Pahl-Weber, E.]

ture for roughly 8,000 inhabitants. The urban design process led to a specific urban layout [Pahl-Weber et al., 2012] including systems for water treatment, energy supply, mobility, as well as the design for resource-efficient open spaces and built-up areas.

Scope of the study

This study focuses on the strategies and measures relating to spatial design for enhancing resource-efficiency in the pilot case study of the area, Shahre Javan Community. With regard to urbanism and architecture, the task from this context can be formulated as: the development of efficient urban structures using passive energy and the reduction of consumption of natural resources through the synergy of integrated processes [Figure 1 ↗]. The installation of sustainable approaches on an urban scale allows for intervention at an early phase in the project. Through the involvement of all relevant disciplines and actors in an integrated design approach from the beginning, further aspects on a smaller scale can be prepared and interests and conflicts from individual demands and requirements can be balanced into an optimal solution.

Design solutions for sustainable neighbourhoods

Architecture and urban design, as integrating disciplines in the building and planning sectors, collects the technological, functional, and programmatic brief and requirements from all involved actors, and transforms them in a context-specific design solution to create spatial and functional units on building, neighbourhood, and city-scale.

According to the fifteenth century Italian theorist, Leon Battista Alberti, architectural quality is defined by the fact, that: “Nothing should be subtracted, nothing could be added” [Neumeyer, 2002]. This definition shows the broad approach of architectural and urban design, integrating all components and elements to a complex unit, and gives illuminates the complex process of finding design solutions. Supposing that in a final design nothing could be subtracted and nothing could be added, then the solution could only apply to a specific task in a specific context. Therefore, the choice of strategies, measures, and elements for a design solution is bound to the specifics of the brief and the context. In this sense the tools and strategies for sustainable architecture and urban design, have to be developed out of the specific context. This leads to the definition of sustainable architecture as "contextualized architecture" as coined by McDonough and Braungart [McDonough et al., 2012].

Potential of architecture

Architecture contains aspects of volumetric design, as well as structural, technological, and management aspects. This claim illustrates the close relationship between engineering and planning disciplines and the need for integrative solutions. Volumetric design allows for the optimisation of measures for enhancing the impact of passive energy and avoiding thermal loss. The optimisation of structural systems is a key factor for a contextually-adapted, economic design. Technological optimisation represents strategies for reducing energy consumption through the application and the use of innovative materials and systems. In other words: the grade of resource-efficiency is dependent on measures of static design, as well as on the operation of systems and qualified procedural management.

The framework of architecture

Besides an architectural approach, synergetic effects on an urban scale allow for further enhancement. Passive design measures, such as shading or the exposure of buildings to wind and sun, are in need of consideration in the urban context. The successful application of innovative energy systems, such as de-centralised energy-supply, is dependent on the urban layout. Through integrative planning with a continuity of scale from urban unit to the single building, the control and the assessment of synergetic potentials is guaranteed. Every measure and intervention applied in the urban context formulates the framework for detailed application on a building scale.

In the case of contextualised design, the specific framework should be defined using a sustainable approach. Ecologic, economic, and socio-cultural aspects are in need of consideration. The aim of energy and resource-efficient design in the MENA region ought to be adapted to the local and regional conditions. Climate and site, as geographical context, formulate a physical framework whilst economic and socio-cultural aspects are linked to the society. The influence of these aspects leads to specific design forms and strategies. 'Soft' aspects, from social acceptance to economic feasibility, as well as 'hard', physical or topographical aspects have to be balanced in this framework in order to create a sustainable design.

The energy relevant elements of spatial design

The energy and resource-efficient value of architecture and urban design can be viewed on a multi-level approach.

In order for the better identification of active and passive design measures, the following design levels of influence are seen to be most relevant:

- The urban form, defined as three-dimensional arrangement of buildings and open spaces
- The building envelope, defined as the closure of the building volume in its surroundings
- The building plan with access, infrastructure, and support structure seen as a fixed approach for the interior organisation of the building volume

The urban form influences the morphological design in architecture. Any strategies for passive energy have to be integrated into the given urban context. Passive solar impact for buildings is greatly influenced by urban determinants regarding orientation and urban density. The spatial demand for all technical and infrastructural needs has to be considered and arranged in the urban form. The gradation of building density and the design of open spaces influence the quality and quantity of natural resource cycles.

The façade, the roof and ground slap, as thermal envelope of the building, define the boundary of the tempered interior to the exposed exterior. The structure and appearance of the façade is related to the construction and functional aspects, as well as to socio-cultural and site aspects. Through openings in the façade, the flow of light and air guarantees the functioning of the building. The design of surfaces and apertures affects the passive solar impact as well as the thermal loss. The energy quality is related to surface design and technical execution.

The organisation of the floor plan balances the requirements of the users with the site context of the building volume. Spatial, functional, and technical demands have to be integrated into a well-designed floor layout. The functionality of the energy supply has to be considered through the suitable integration of spatial demand in the design of the floor plan. The potential for passive energy impact through orientation and the avoidance of energy loss through compactness ought to be considered in the spatial arrangement of the floor plan.

The design process

This case study, *Energy-Efficient-Homes*, represents an urban and architectural design for sustainable housing in the pilot area, Shahre Javan Community in Hashtgerd New Town. As a specific design scheme presented in plans and drawings, it shows the spatial arrangement of an urban neighbourhood with a mixture of terraced and multi-storey housing units. The design is based in a typological catalogue developed in the context of the urban design concept for the pilot area integrating the parameters of a compact urban form. In acknowledgement of the site specifics, the modular spatial concept of the typology is transformed into an innovative, courtyard housing settlement, which respects the socio-cultural demand for high levels of privacy and uses the advantages of climate-adapted morphology.

Methodology

The development of the housing typology followed a holistic research method using a design process. Design approaches with general aspects (e.g., typology, use, and function) were contextualised (e.g., to urban and climate context) and vice versa. The design process as 'interactive development' produced solutions in various scales with different detailing. Results from every work phase had an impact on the definition of tasks for the following phase. As with most design processes, the development of the housing typology was characterised by the, more or less simultaneous, balancing of creativity and analysis [Figure 2 ↗].

Fig. 2 The research by design process of pilot area, Shahre Javan Community [Pahl-Weber, E.]

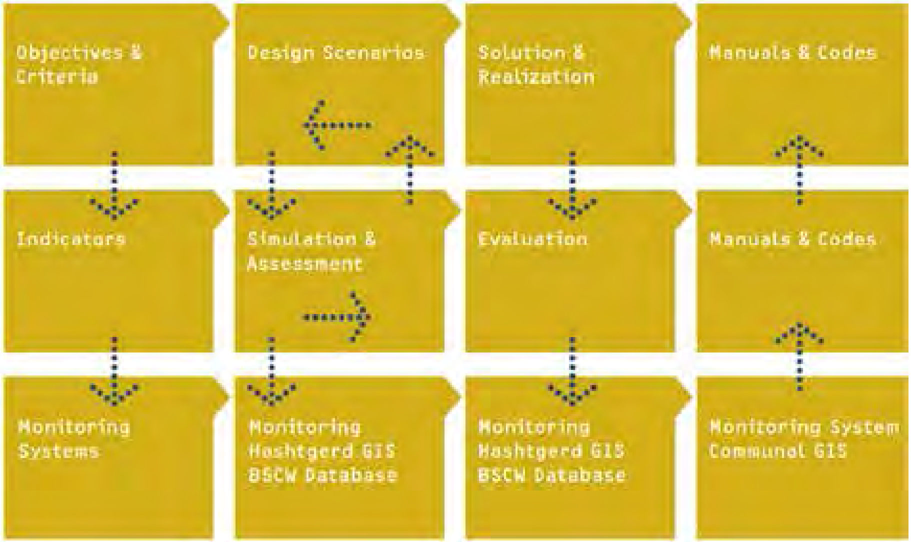
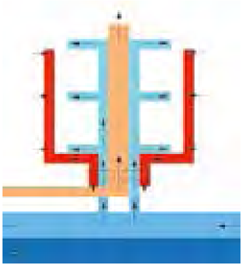


Fig. 3 (left): Basic principle-passive solar impact [Wehage, P.]
Fig. 4 (right): Upgrade-heat recovery [Wolpert, A.]



Layers for energy savings in architecture

Research has defined the potential of energy savings in the building sector with a low-cost approach by up to 25% of the total savings potential [McIntosh, A., 2013]. This approach includes all measures based on architectural design, such as volumetric organisation and quality of execution. The remaining potential of about 75% are connected with the application of innovative and supplementary systems based on energy systems and design with extra costs, which need to be integrated into the design solution. Using this definition, a multi-layer approach was developed for the design of a sustainable housing scheme in the MENA region.

The identification of the urban, architectural, and technical components and elements for sustainable building design lead to the definition of a basic principle and to possible improvements [Figure 3-4 ↗]. This categorisation helps to define different standards for application as well as a scientific basis for a planning process of sustainable housing in the region.

The so-called 'Basic Principle' is the design strategy born out of a spatial approach without any additional technical demands. The strategy contains all planning and design measures to reduce energy demand out of spatial configuration, such as building orientation and compactness, adaption to the site and the cultural context. The Basic Principle can be seen as a low-cost approach and defines a basic standard for the Middle-East region.

The 'Upgrade' level contains all measures for raising the standard of the Basic Principle. Supplementary technologies are integrated into the spatial approach. It starts with simple mechanical elements for light and energy guidance, such as solar-shutters, and continues with the use of soil temperature through earth tubes – and its combination with a heat exchanger concept – and leads to the application of higher technological materials, such as photovoltaic fabrics, to generate supplementary energy. The measures are characterised by a planning dimension as well as by technological and economical dimensions. The choice of implementing upgrading measures is dependant on the economic and technological context.

The close relationship between technical supply and spatial arrangement asks for integration of the strategies and the measures in the design process from the beginning. The specific design of the building is the result of this process.

Design Approaches out of the Basic Principle

The Basic Principle represents architectural design measures based on planning disciplines for volumetric design. Following the constraints from the urban design, the design of the building volume influences the demand on energy based on general physical principles. Concerning the building volume and arrangement, two core principles can be identified [Wehage et al., 2013b]:

Maximisation of passive energy impact through south-orientated facades with a high proportion of openings – the exposure of building forms to the climate [Brunner et al., 2009]. This measure allows for a high level of solar incidence as passive energy impact. The floor plan should be organised according to this. Primary living zones should be situated on the south facades in order to reduce the high heating demand. This floor plan arrangement results in rather linear building forms, which need to be considered in the urban configuration. On one hand, the density of buildings is limited to the required distances for solar gain and building height, on the other hand, the linear orientation ought to be tested with the urban form.

In most areas of the MENA region, the high solar impact can create a surplus of heat through solar radiation, particularly in summer. This fact must be considered in the planning of building forms and south-orientated façades. With regard to the façade design, shading devices ought to be provided to prevent over-heating in summer.

Minimisation of energy loss through the optimised building volume – the protection of building volumes from the climate [Brunner et al., 2009]. The volume to surface ratio influences the compactness of building volumes. The thermal envelope (roofs, façades and ground slaps) as surface to the exterior is the most important element for the control of energy benefits and loss through heating or cooling. Because of the high demand for quality in the construction and detailing, the surface is a cost-intensive building component. By the optimisation of surface area through compactness, building costs can be reduced and a constant interior climate can be achieved for a deep volume. The floor plan organisation ought to consider the high ratio of interior spaces with low levels of natural lightning. One measure is to install an access and service zone in the inner areas of the volume (e.g., staircases and bathrooms) or, in deep volumes, to create courtyards or niches for supplying inner zones with sufficient light and ventilation. The supplementary surfaces, created by niches or courtyards however, decrease the compactness. In hot and dry climates, as in

Fig. 5 (left): Private courtyard in case study [Wehage, P./ Wolpert, A.]
Fig. 6 (right): Urban unit of case study [Wehage, P.]

most areas of the MENA region, this measure could help to reduce outside temperature of façades through shading.

Both these strategies help to increase resource-efficiency in architectural design without any further need for technical or infrastructure investments. A mix of the strategies should be considered even though possible contradictions might occur (e.g., high ratio of façade surface for passive solar impact versus the optimisation of volume to surface ratio).

Design measures from the Basic Principle

In the context of the pilot area, the consequent north-south orientation of the building in urban form was combined with the compact, closed coverage to the eastern and western sides as a kind of contemporary courtyard house typology [Wehage et al., 2013a] [Figure 5–6 ↗]. The dense urban configuration with reduced street and path widths in urban areas produces shaded open spaces that avoid summer heat islands. Courtyards were incorporated into the volume of the two to three-storey buildings in order to create private and shaded open spaces with a good micro-climate. Supplementary south façades, orientated to the courtyards, increased the potential for passive sun impact during winter months by maintaining relatively compact building volumes with a surface to volume ratio of approximately 0,4–0,6, depending on the specific design and site position. Through this measure, the cost-intensive façade surface was reduced up to 30% compared to existing building typologies in Hashtgerd New Town. Regional experts estimated the building construction costs of the case study, including the high quality standard of the thermal envelope, to about 250-300 $€_{2011}$ per square metre, which represents average costs for Tehran region [Gholizadeh, 2011]. Compared to the Iranian energy code standards (Code 19), the chosen ETICS (Exterior Insulation Composite System) construction reduces the U-value for exterior walls by up to 53% [Nytsch-Geusen et al., 2012]. In simulations the dense urban configuration and the self-shading of the building volumes showed a reduction of energy demand for cooling by up to 6% [Nytsch-Geusen et al., 2012] compared to un-shaded volumes. This value increases if the insulation quality of the building surfaces is lower than in the design presented.

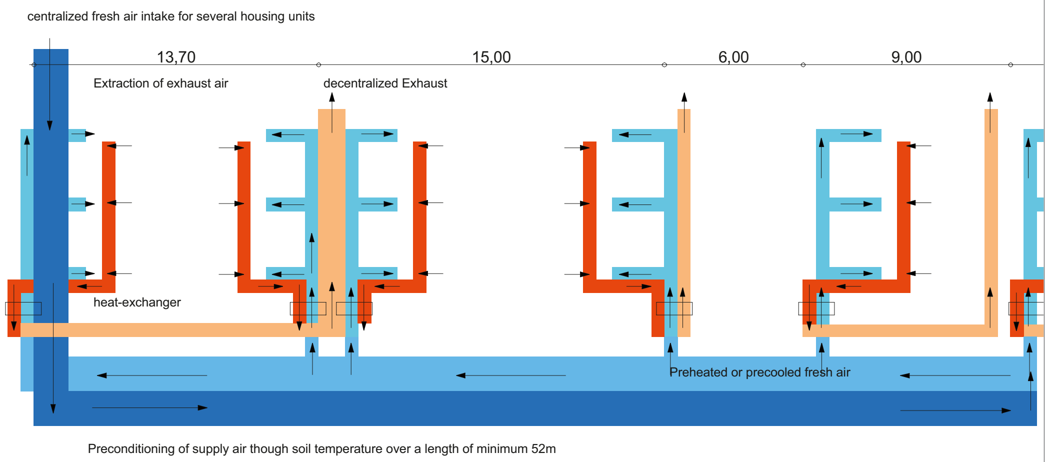
Design approaches out of Upgrade

The upgrading level represents measures based on the integration of efficient technologies in architectural design. Through the application of advanced technologies, efficiency can be enhanced on district and building level. These measures need to be considered and integrated in the energy supply system of the building and the neighbourhood. The combination of district and building scaled measures creates benefits for the community and the single customer. The suitable measures can be identified in two categories: the integration in the interior arrangement of the building design and the integration of additional design layers [Wehage et al., 2013b].

A strategy for reducing energy demand is characterised by the integration of technologies through the provision and the arrangement of built elements or spaces in the building design. An example of this is the heat recovery system. Advanced architectural design needs to consider air ventilation. Air exchange, with the help of thermal principles, is a regionally-rooted system in vernacular architecture. This is visible in the traditional courtyard houses and wind towers in hot, arid regions. Furthermore, with advanced technologies, great benefits in the reduction of energy demands are possible. A suitable system, with little technological effort, is the heat exchanger. In combination with a pre-tempered air supply, e.g., through an earth tube collector on a defined urban scale and the distribution in buildings through an air-channel, the heat exchanger recovers the heated air for the pre-tempering of fresh air from outside. The pre-tempering helps to reduce the energy demand from the cooling and heating supply.

The second strategy is the integration of technologies as additive design layers. Shading devices help to regulate solar impact within the building. Especially in hot regions, shading through curtains or the covering of open areas benefits the microclimate. As an element from vernacular architecture, the covering of courtyards through mechanical or textile elements reduces direct solar impact and creates a tempered semi-open space. In advanced technologies, these elements can be combined with the effect of light guidance (e.g., for naturally-shaded spaces in winter) or energy benefits through high-tech fibres (e.g., photovoltaic fabric). Because of the advanced technological and quality standard, such elements and systems need to be considered with regard to the economic and technological standard in the region and for the specific project.

Fig. 7 Schematic section – pre-tempering of outside air and its distribution in buildings [Wolpert, A.]



Earth Tube Register and Heat Exchange

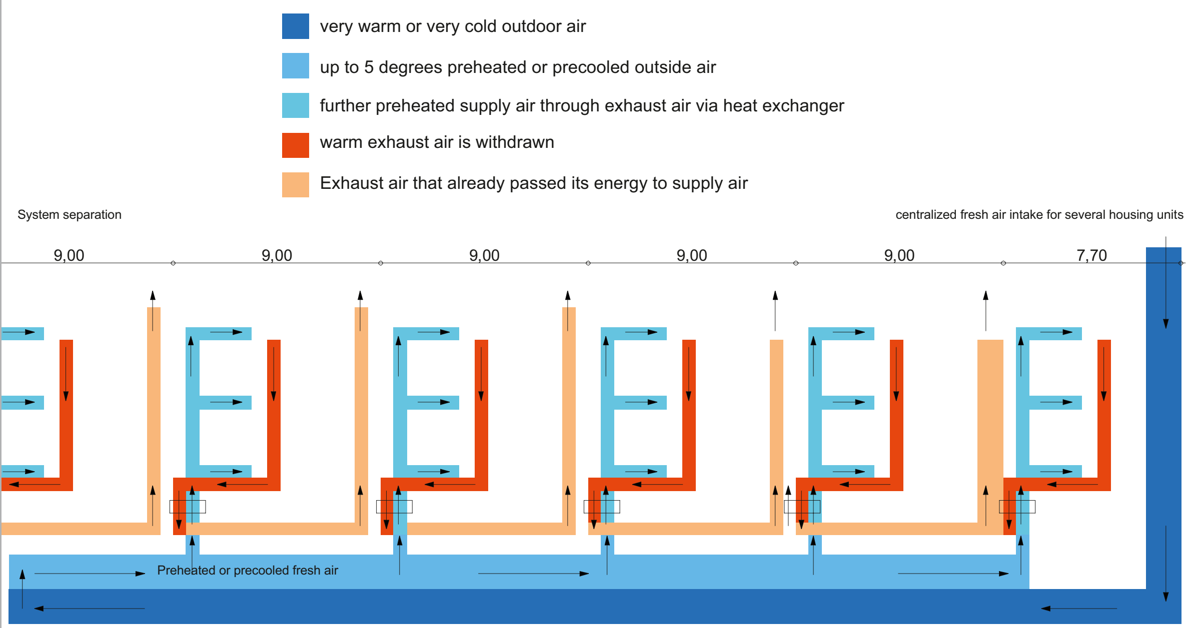
A strategy of combined urban and building-scaled measures was implemented in the design of the case study [Wehage et al., 2013b].

Currently, the Iranian Cooling System works with evaporation chillers during summer months. For an apartment of 120 m^2 with a room height of 2.8 metres one requires an air-exchange rate of 25 l/h to retain temperatures within the comfort zone. This system demands the use of 2.920 kWh and 63.5 m^3 water per cooling season [Nytsch-Geusen et al., 2012].

Considering the high air exchange rate and the fact that the exhaust air still is far cooler than the supply/outside air, it is obvious that the temperature difference between exhaust air and supply air should be used to precondition the supply air. Preconditioning with exhaust air is possible in both summer and winter. In summer, warm/hot incoming air is cooled down with cooler, exhaust air and in winter when exhaust air is far warmer than supply air, it can be used to preheat outside air to reduce additional heating requirements.

This preconditioning of supply air can be achieved by installing a heat exchanger. A heat exchanger functions on the precept that energy strives to be in balance, meaning that heat energy automatically moves to cooler materials. A heat exchanger simply transfers heat (energy) from one material to another. The use of a heat exchanger allows the recovery of otherwise ‘lost’ energy from the exhaust air. The described heat exchange on building/apartment scale can be adopted on an urban scale. Here, the earth temperature at an approximate depth of 1,5 – 4 metres is used to precondition the supply/outside air.

A central supply air intake for several housing units can be installed. The fresh air is blown through earth tubes that run in loops and allow the air to be either warmed up or cooled down by geothermal energy through direct contact with the earth. Blowing the air over the length



Preconditioning of supply air though soil temperature over a length of 44 / 53 m

Fig. 8 Earth tube register in an urban unit (Wolpert, A.)

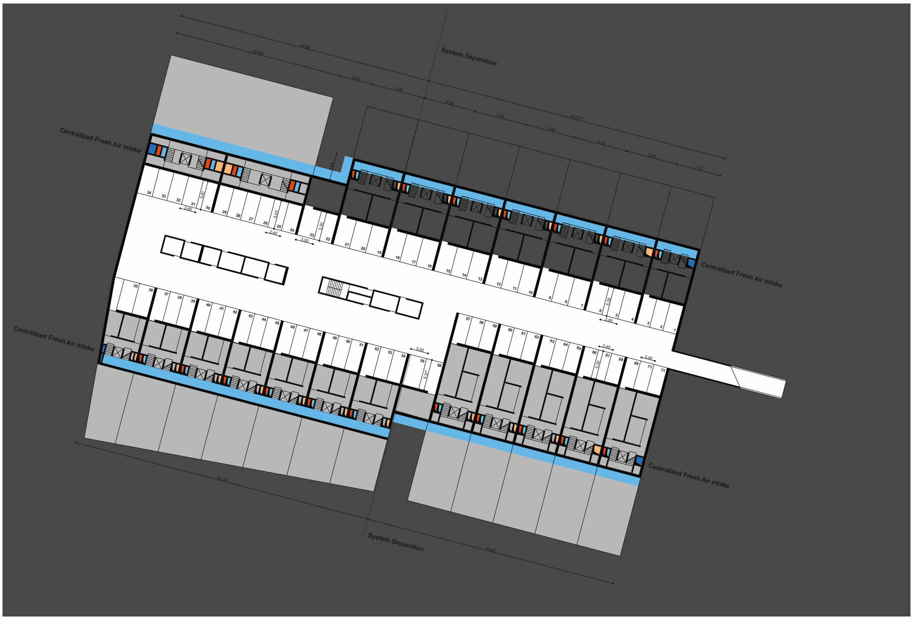
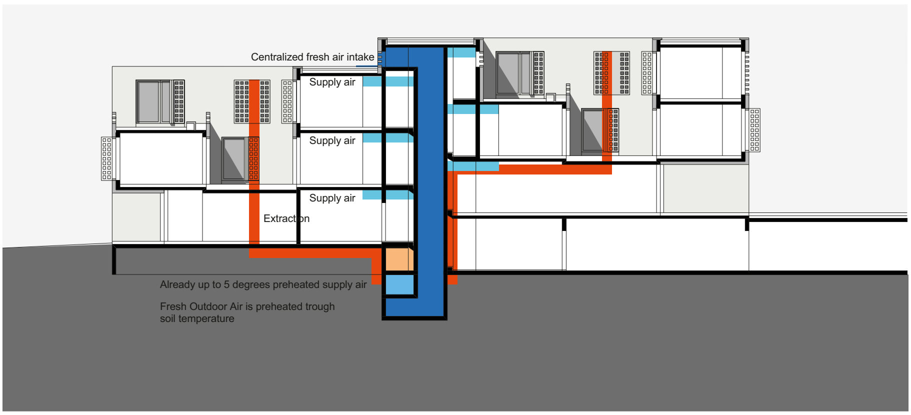


Fig. 9 Heat exchange in building [Wolpert, A.]



very warm or very cold outdoor air

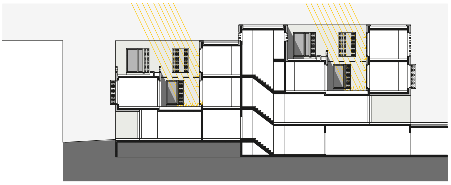
upt to 5 degrees preheated or precooled outside air

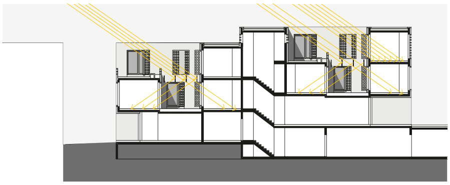
further preheated supply air through exhaust air via heat exchanger

warm exhaust air is withdrawn

Exhaust air that already passed its energy to supply air

Fig. 10 (left): Light shelves (Louvre) – summer position [Wolpert, A.]
Fig. 11 (right): Light shelves (Louvre) – winter position [Wolpert, A.]





of fifty metres and at a depth of two metres, the supply air can be warmed up or cooled down by at as much as five degrees Celsius. This is a rather low estimation for the Hashtgerd region with its climatic conditions, as simulations could not be carried out within the scope of this project. However, the assumption is based on detailed studies for different regions and climatic data which show that the air-temperature can be lowered or raised by as much as ten or eleven degrees Celsius depending on the specific climate conditions [Blümel et al., 2001].

Combining several housing units allows a more economic installation of earth tubes [Figure 7 ↗]. For an urban unit, this could mean a division into four quarters [Figure 8 ↗]. While the supply air intake is centralised, the exhaust air could be decentralised and function with a heat exchange system as described above [Figure 9 ↗].

Light diverting devices

Because of the intense solar radiation, a high potential of sunlight incidence for energy provision was identified as a suitable upgrade in the context of the pilot area [Wehage et al., 2013a].

In the design of the case study, light diverting devices affect the guidance of sunlight as a possible Upgrade [Figure 10–11 ↗]. It can be used as a protection against too much light exposure or to increase daylight incidence, for example in rooms with deep plans. In both cases, light diversion reduces energy consumption. On one hand, it reduces the cooling energy demand as it prevents overheating in summer and, on the other hand, the reduction of artificial lighting reduces energy consumption. The provision of daylight depends on various factors e.g., the degree of sun exposure, the angle of incidence, the overall plan layout, number/dimension of transparent openings, glazing type/factor of light transmission, and the position of openings.

Light-diverting devices are available for internal and external use. External devices are more efficient. Daylight is transmitted into the room via external devices e.g., reflectors or prism plates, generally used for sunshading, but sometimes also used to divert light.

The installation of mechanical light shelves in a vertical position above the courtyards enhances solar impact during the heating season in winter. Approximately 50% of the sunlight can be diverted into the north facing rooms of the courtyard. Thus, the rooms opening onto the courtyard, from north and south, are illuminated and preheated by the sun. The horizontal, summer position of the light shelves reduces the direct sunlight incidence in the courtyard and the south-facing rooms.

As an alternative to large-scale rotatable shelves across the courtyard, a sunscreen made of photovoltaic fabric can cover the courtyard in summer. The shading prevents the inner courtyard and adjacent rooms from overheating and produces energy simultaneously. During the evening, this energy can be used to partially illuminate the same spaces. During winter months, the fabric is pushed aside allowing the sun to heat and illuminate the inner courtyard and the adjacent rooms.

Fig. 12 The integrated approach: scales – dimensions – process [Pahl-Weber, E.]

	Spatial Dimension	Technical Dimension	Socio-Economic Dimension
Region	-- Regional Setting -- Topography	-- Waste -- Mobility	-- Economics -- Demography
City	-- Climate -- Urban Form	-- Water -- Energy	-- Employment -- Market
Neighborhood	-- Buildings -- Green Space	-- Information and Communications Technology	-- Education ...
Stakeholders & civil society			
Process Design			

Conclusion

The contextualisation of architectural design is a key factor for the success of an integrated approach for sustainable architecture and urban design. General approaches of energy-related aspects of spatial design are in need of adaptation to specific site conditions, resources, and socio-cultural contexts. The continuity of scale from region, to neighbourhood, to individual buildings is a crucial factor for generating synergies and benefits out of integrated processes [Figure 12 ↗], such as the use of pre-tempered air through earth tube registers, heat exchanger technologies, or the use of reconditioned waste water for the irrigation of open spaces.

Concerning architectural design in an urban context of the case study, all the measures described above – including the insulated thermal envelope and the energy supply system, – led to energy demand reductions in total of around 73% compared to the existing energy code of Iran [Nytsch-Geusen et al., 2012].

The design shows an adapted solution for housing developments in the Tehran region. The identification of natural resources for passive energy use in the region – such as the use of solar radiation, and the provision of different levels of economic and technological standards – formulate a general approach for a contextualised and adapted low-energy housing design typology in the MENA region.

The basic principle of the design, based on an architectural design which uses natural resources, defines a low-cost standard achieved through integrated planning and can be adapted to most MENA countries as a first step towards low-energy housing. The supplementary integration of advanced technologies can be adapted to specific economic contexts, for example, in the wealthy gulf region.

The development of the housing typology from the vernacular archetype of the courtyard house represents a suitable contemporary building form for the MENA region. The climate-related advantages, in combination with the culturally-rooted demand for privacy of such housing; offer a high level of adaptation potential for the whole region.

Fig. 13 The site of the case study pilot area in Hashtgerd New Town/Iran, looking north [Wehage, P.]

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