Proceedings of the 8th Conf. Int. Forum Urban., E00^6, doi:10.3390/ifou-E006.

True Smart and Green City?
8th Conference of the
International Forum on Urbanism

Conference Proceedings Paper

Energy Toolbox and Potential for Zero-Emission-Buildings in European and Asian Cities

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Abstract: A zero or plus energy house in many cases, is a continuation of the Passive House. For this purpose, space, and resources have to be provided and the building structure needs to be adjusted. These adjustments have to be accounted for early in the architectural design of the building. The aim of this study was to develop a concept for an Energy Toolbox (ETB), which should support architects in the design phase of the planning. As the ETB aims to be a widely-accessible easy-to-use tool to design Zero Emission Buildings (ZEB), that also allows for continuing inclusion of new technologies. The building structure design is introduced in the first part of the ETB, and accounts for basic elements in building physics. This part determines energy demand for heating, cooling, electrical demand for light and facilities, and how to meet the Passive House criteria. Also, the climate parameters for solar-radiation, heating and cooling degree days, base temperature and other relevant temperatures for the building calculation have been set, as they are relevant for the calculation of heat transfer coefficients, heat gains and ventilation losses. The second part of the Energy Toolbox determines technologies that could be used to cover the thermal and electric energy demand of buildings. These include heat pump systems with different heating and cooling sources, solar technologies as well as adiabatic cooling. In addition, technologies and methods that contribute to a reduced energy demand are presented, such as greened facades, adaptable dynamic lighting and shading devices. Accordingly the proposed systems facilitate to balance energy consumption and renewable energy production of buildings to a degree that they correspond with the concept of net zero-energy-building or even net plus-energy-buildings.

Keywords: Zero Emission Buildings, Net Zero Buildings, Plus Energy buildings, Passive House, renewable energy, Energy Toolbox, simulation tool, covering the energy demand

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1. Introduction

Humans spend up to 90% of their time in buildings, while building systems contribute up to 40% to mankind's energy demand [1]. Approximately 80% of the human population is expected to live in cities by 2050 [2]. This translates into a requirement for new perspectives and solutions to preserve our limited resources in a sustainable way. Zero Emission Buildings (ZEB), represent a feasible solution to reduce urban resource consumption. Such buildings exert positive environmental impacts by producing energy, water and other resources instead of harmful emissions [1]. The international research project ZEBISTIS (Integrating Sustainable Technologies and Infrastructure Systems), aimed to enforce and improve the design of ZEBs. One specific target of this project was the development of tools and methods to combine the three ZEB subzones: Biomass, water and energy to support interdisciplinary users when planning ZEB at an early stage in the planning process. Simple and free tools are rare and so called toolboxes could help to spread the idea of ZEB [1].

This paper presents a guideline on how to develop an Energy Toolbox (ETB), based on Microsoft Excel by using well known technologies for high efficient buildings and systems to design the energetic behavior of a ZEB. Therefore important climatic parameters as well as important physical background and calculation methods are introduced. Different building layouts are necessary to prevent high energy demands for heating and cooling in different climatic requirements. With the framework of the Passive House standard and the concept of Net Zero- or Plus- Energy Buildings a starting basis for the energetically behavior of ZEB is set [3].

The primary goal of the ETB is to give a first impression on the requirements for the building design as well as needed area for technologies onsite. These include efficient and renewable technologies to generate heat, cold and electrical energy as well as technologies to lower the buildings service energy demand to reduce the heat-/cooling loads inside buildings and in the urban space.

2. Methods

To design a ZEB building, the ETB can be used to determine input parameters such as building utilization, number of residents, building structure, shape and position. The ETB is divided into two parts, the *"building design"* and the "*covering the energy demand*" part. The output of the building design is the annual primary energy demand. This is composed of the heat demand for domestic hot water (DHW) and heating, plus the electrical demand for lights, facilities and additional system components. With the output (energy demand) of the building design part, the connection to the second part of the ETB is done. Here several technologies can be utilized to achieve the energy demand on the basis of a Net Zero Building. The choice of technology depends on the location and the local climate. By selecting different technologies in the second part of the toolbox the overall output of the ETB can be evaluated (for example area for photovoltaic or a solar thermic system). Overall, the energy demand and technical background for building physics of this ETB adhere to the Passive House Standard.

2.1 First part of the ETB – building design

The guideline for the first part of the ETB follows the Swiss SIA 380/1 norm and is based on the international norm EN ISO 13790. This norm gives a detailed guideline on how to implement the calculations for the heating and cooling demand of a building. The calculation method is referring on the energy balance on the exterior building envelope and relate to heat fluxes in a building in order to balance the heat demand with heat gains and heat losses. Most important energy fluxes within the building envelope are illustrated in Figure 1 and explained in Table 1.

Figure 1. Energy (heat) flux diagram according to SIA 380/1 [4] .

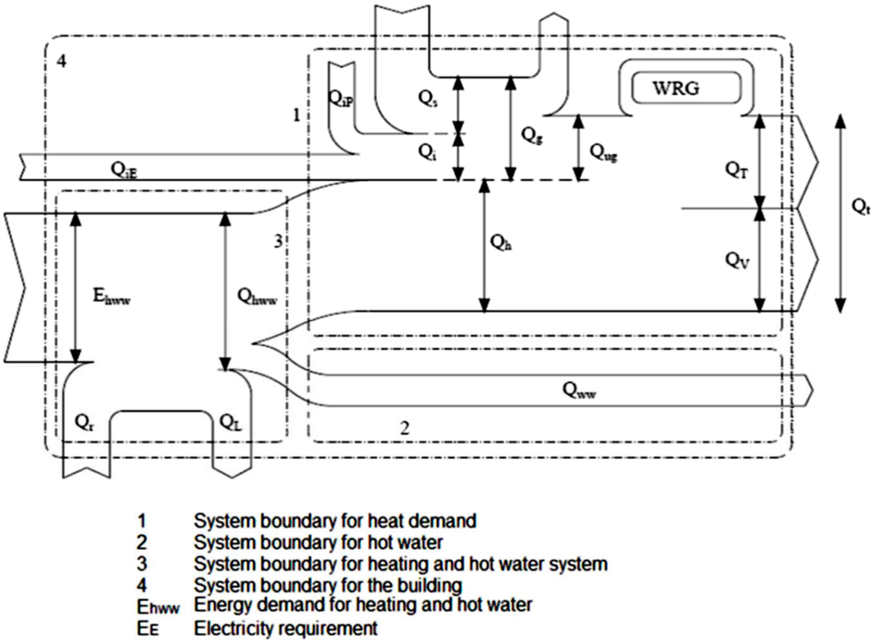


Table 1. Description for the most important energy (heat) fluxes in the energetic behavior of a building.

Q_t	Total heat loss with: Transmitted heat loss (Q_T), ventilation heat loss (Q_V), and the heat demand for DHW (Q_{WW})
Q_{ug}	Usable heat gains from: Solar (Q_s), internal-(Q_i), human (Q_{ip}) and heat gains from electrical equipment (Q_{iE})
Q_h/Q_w	Heating demand for heating, and hot domestic water (DHW)
Q_L	Heat loss due to storage and distribution of (DHW)
Q_r	Heat from the environment
E_{hww}	Energy required to cover the remaining heat demand
WRG	Heat recovery (HRC) of exhaust air

For the calculation of the heat/cooling demand according to EN ISO 13790, heat losses due to transmission, ventilation and heat gains are considered. An overview on the most important operators and formulas is listed in Table 2.

The transmission conductance value for the entire building envelope consists of the sum of all individual transmission values for the different building components. This procedure is important to include in the calculations in order to respect building components, for example adjoining ground which have a better conductivity value compared to such adjoining ambient air. In addition heat losses due to heat bridges are considered in EN ISO 13790 with building component related conductivity values (Formula 4).

Table 2. Important equations used to calculate the thermal behavior of buildings according to EN ISO.

$$Q_h = \sum [Q_T + Q_v + \eta_g (Q_i + Q_s)] \tag{1}$$

Q_h: Heat demand; Q_T: Transmission losses in [kWh/month] or [kWh/a]; Q_v: Ventilation heat losses; ηg: Performance ratio for the heat gains (depending on the building structure); Q_i: Internal heat gains; Q_s: Solar heat gains

$$Q_{cn} = (1-\eta_g) * Q_{gcn} \qquad \text{if } Q_{\text{gains per month}} > Q_{\text{losses per month,}} \quad \text{if not } Q_{cn} = 0 \tag{2}$$

Q_{cn}: Cooling demand per Month [kWh]; Q_{gcn}: Total heat gains per month; η_g: Performance ratio for heat gains (depending on the building structure. Simplified according to EN ISO 13790: Heavy = 1; lightweight: 0.90)

$$Q_T = 0,024 * L_T * HGT \tag{3}$$

Q_T: Transmission losses in [kWh/M] or [kWh/a] ; L_T: Transmission-conductance value; HGT (HDD): Heizgradtage in German/heating degree days in English

$$L_T = Le + Lu + Lg + L\psi + L\chi \tag{4}$$

Conductance values for the building components in [W/K]: Le: Building components adjoining ambient air; Lu: Building components adjoining unheated rooms; Lg: Buildaing components adjoining ground; $L\psi$: Additional value for linear heat bridges; $L\chi$: Additional value for punctual heat bridges

$$Q_{sS} = G_{sS} * Aws * 0,9 * g\perp * F_F * F_{ss}/AE \tag{5}$$

Q_{sS}: Solar heat gains (here example in direction south) [MJ/m²]; G_{sS}: Global sun radiation [MJ/m²]; Aws: Window area south [m²]; $g\perp$: total energy transmittance value; F_{ss}: shading factor south; F_F: Reduction value – window frame (0.6-0.9); AE: Energy reference area [m²]; the factor 0,9 is defined by the SIA 380/1

$$Qi = 0.024 * q_i * BGF_h * HT \tag{6}$$

Q_i: Internal heat gains in [kWh/M] or [kWh/a]; q_i: heat flow density; BGF_h: heated gross area; HT: Heiztage (heat days)

$$Q_v = 0,024 * L_v * HGT \tag{7}$$

Q_v: Ventilation heat losses [kWh/M] or [kWh/a]; HGT (HDD): Heizgradtage(German) heating degree days (English); L_v: Ventilation conductivity value

$$Q_{DHW} = c_w * m_{DHW} * \Delta T \quad \text{in [kJ]} \tag{8}$$

*Q_{DHW}: Heating energy for DHW; c_w: Specific heat capacity of water (~4,2 KJ/kg*K);m: mass_{DHW} (water); ΔT: Temperature difference (K)*

The influence of different climatic situations is a crucial point in the calculations. High heat gains (solar/internal heat gains) lead to a reduction of the heat demand during winter time or overheating of buildings in hot climate zones. A Passive House for example, can be in some cases heated without a heating system just by the solar- and internal heat gains [5]. In dependence on the climatic conditions, the building shape and the distribution of the window area needs to be adjusted. Therefore climatic influences (heating and cooling degree days (HDD/CDD), heat days (HT)) are mainly considered in the transmission heat losses (Formula 3), the solar/internal heat gains (Formula 5 and 6) and the ventilation losses (Formula 7). These formulas are also a starting basis for the application on Microsoft Excel. Further detailed information on the background of formulas and values to calculate the energy demand of a building are described in EN ISO 13790.

2.1. Climatic influencing factors for calculating the energy demand

The climatic conditions at the building site play an important role in understanding the adaptation of technologies and design on a building (Table 3).

Table 3. Climatic parameters for calculating the energy demand of a building in the ETB.

Heat days (HT)	The mean ambient temperature is below the heating limit and the heating system is required to maintain room temperature. Heat days are measured as days per annum. The heating limit is set to be below 10°C for Passive Houses (dependent on cultural behavior). It can drop below 0°C when intensive sun radiation is present [7].
Heating-/cooling degree days (HDD) / (CDD)	"HDD", are a measure of how much (in degrees), and for how long (in days), outside air temperature was lower than a specific "base temperature" (or "balance point")" [8]. Cooling degree days (CDD) are corresponding to the definition of HDD (temperature beyond a specific base temperature) [8].
Base temperature t_{ht}/t_{ct}	Base Temperature (°C) is lowest temperature before heating is required and similar to the HT. It depends on thermal properties of the building, heating schedule and external influences such as solar gains [8]. Most standards, set base temperatures between 15.5°C and 17°C for heating. In contrast, the base temperature for a passive house can be set to 10°C [9]. For CDD it is usually set on 24-26°C [10].
Norm ambient temperature θ_{ne}	Is the lowest temperature (°C) during a cold spell, happening 10 times in 20 years over a length of at least two consecutive days. The heating system power must be adjusted to this temperature [8].

2.2 Second part of the ETB – covering the energy demand

A pre-selection of required technologies is made by the definition of the location, and thus the climatic circumstances. The user can also decide what kind of technologies should be included in their building design. In general it needs to differ between technologies which are able to cover the energy demand (solar technologies, geothermal etc.) and technologies that reduce the energy demand such as heat exchangers (HRC), dynamic adaptive shading and lightening (Table 4). These technologies are later on put together in several systems such as heat pumps (HP) with different heat sources (air, geothermal, waste water) or a solar thermic system, optional with seasonal storage (Swiss Jenni system). The heat and cooling demand which is covered by HP or adiabatic cooling and their alternatives can be calculated, for example with factors or ratios given by the annual performance factor ($APF_{heating}$), energy efficiency ratio ($EER_{cooling}$), seasonal efficiency ratio ($SEER_{cooling}$). The result of this are the required kilowatt hours for the HP (electrical input energy) or cubic meters of water for the adiabatic cooling. Results referring to the electrical consumption are the input for the simulation of the required space for a photovoltaic plant (PV). Those simulations can be done (for example) with the program PV*SOL under the specification of orientation (west, east, south, SW, SE) and angle (optimal angle at the location and in the façade). Solar thermal and heat pump systems can be calculated with T*SOL or the Swiss program Polysun. To evaluate the performance of such systems it is important to take the whole system into account as the definition of the APF and the covering ratios of the solar thermic (ST) system are depending on each other. The performance numbers given by HP manufacturers are often not representing the performance of the heat pump system in reality, especially, when compared on an international level [6].Therefore performance values from experts were used for a realistic as possible adoption. The coefficient of performance (COP) does not reflect the performance HP systems in a proper way. According to this a better definition is given with the APF for applying HP systems in the ETB.

Table 4. Inputs and outputs for technologies applied in the second part of the ETB.

Inputs	**Technologies**	**(Inputs → Outputs)**	**Outputs ETB**
Electricity	Dynamic electric lighting control	(Electricity → Heat & Light)	Reduction on the electrical (el.) demand for lightening
Solar Radiation	Photovoltaic	(Solar radiation → Electricity)	PV area (m²) on site
	Solar thermal collector	(Solar radiation → Heat)	ST area (m²) on site
	Dynamic adaptive shading control	(Solar radiation → Heat & Light)	Reduction on the el. demand for cooling
Heat	Heat pump	(Heat/Electricity → Heat)	KWh → m² PV (ST) area
	Thermal Storage	(Heat → Heat)	M³ storage capacity on site
	Evaporative adiabatic Cooling	(Heat → Heat)	M³ (rain) – water
	Heat recovery from greywater	(Heat → Heat)	Reduction of the energy demand on DHW

3. Results

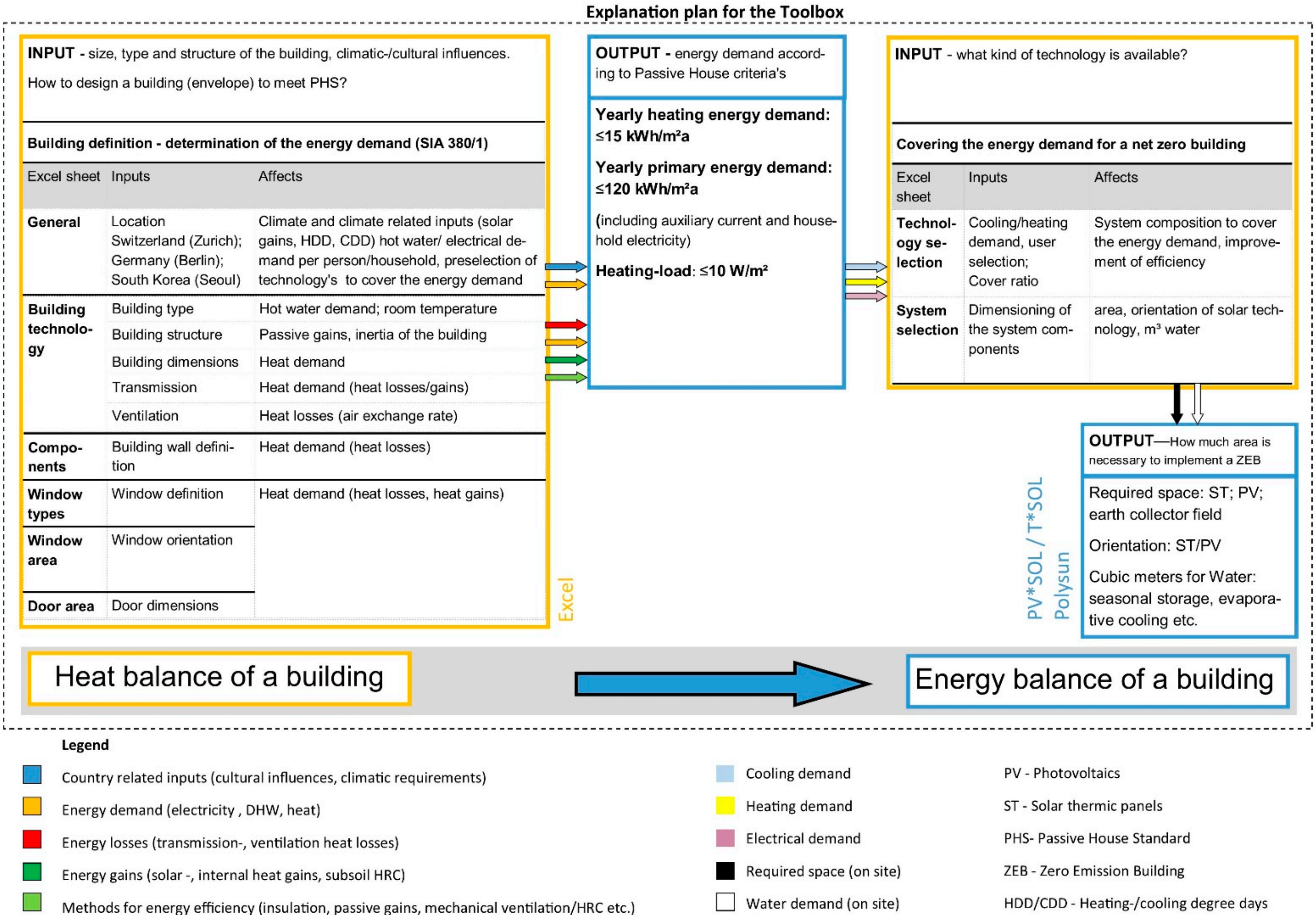
Figure 3 shows how the *building design part* and *covering the energy demand part* of the ETB could be methodically implemented in Microsoft Excel.

3.1 Implementation in the ETB – building design

The ETB can be used for new and renovated buildings. Basically the building structure needs to be adapted on the climatic requirements. In cold climates, this would lead to enhanced- insulation and proportion of passive heat gains (heat storage in building components) for to the heat balance. On the other side in warm climates the passive heat gains for example through windows, must be reduced. In climate zones with both extremes a particularly detailed building planning is necessary, which considers both aspects: Protection against high heat losses (winter) and overheating (summer). In the ETB this can be done by changing the building shape (for example shading and distribution of window area), the composition of building components (thermal insulation of the exterior walls) and the building technology such as a ventilation with heat recovery (HRC). The output of this first part is the energy demand of the building and must be adjusted in the ETB until the energy demand meets at least Passive House criteria.

gives an example on how climate data could be implemented in the ETB based on Microsoft Excel. Researches on ZEB were done in the listed cities during the ZEBISTIS project and represents important metropolises in three different climate zones (Table 5).

Figure 2. Schema of the energy toolbox - with the building site as system border. Heat balance of a building = part one; energy balance of a building = part two.



Explanation plan for the Toolbox

INPUT - size, type and structure of the building, climatic-/cultural influences.
How to design a building (envelope) to meet PHS?

Building definition - determination of the energy demand (SIA 380/1)

Excel sheet	Inputs	Affects
General	Location Switzerland (Zurich); Germany (Berlin); South Korea (Seoul)	Climate and climate related inputs (solar gains, HDD, CDD) hot water/ electrical demand per person/household, preselection of technology's to cover the energy demand
Building technology	Building type	Hot water demand; room temperature
	Building structure	Passive gains, inertia of the building
	Building dimensions	Heat demand
	Transmission	Heat demand (heat losses/gains)
	Ventilation	Heat losses (air exchange rate)
Components	Building wall definition	Heat demand (heat losses)
Window types	Window definition	Heat demand (heat losses, heat gains)
Window area	Window orientation	
Door area	Door dimensions	

OUTPUT - energy demand according to Passive House criteria's

Yearly heating energy demand: ≤15 kWh/m^{2}a

Yearly primary energy demand: ≤120 kWh/m^{2}a

(including auxiliary current and household electricity)

Heating-load: **≤10 W/m^2**

INPUT - what kind of technology is available?

Covering the energy demand for a net zero building

Excel sheet	Inputs	Affects
Technology selection	Cooling/heating demand, user selection; Cover ratio	System composition to cover the energy demand, improvement of efficiency
System selection	Dimensioning of the system components	area, orientation of solar technology, m^3 water

OUTPUT—How much area is necessary to implement a ZEB

Required space: ST; PV; earth collector field

Orientation: ST/PV

Cubic meters for Water: seasonal storage, evaporative cooling etc.

Legend

🟦 Country related inputs (cultural influences, climatic requirements)
🟧 Energy demand (electricity , DHW, heat)
🟥 Energy losses (transmission-, ventilation heat losses)
🟩 Energy gains (solar -, internal heat gains, subsoil HRC)
🟩 Methods for energy efficiency (insulation, passive gains, mechanical ventilation/HRC etc.)
🟦 Cooling demand
🟨 Heating demand
🟪 Electrical demand
⬛ Required space (on site)
⬜ Water demand (on site)

PV - Photovoltaics
ST - Solar thermic panels
PHS- Passive House Standard
ZEB - Zero Emission Building
HDD/CDD - Heating-/cooling degree days

Table 5. Climatic circumstances and their impact of the technology selection and building design.

Zurich and Berlin	The temperate, Sub-oceanic climate lead to an enhanced heating demand in the winter season from January till April and October till December. On the other hand extreme temperatures during summer time where a cooling system is required are rare.
Istanbul	Subtropical climatic characteristics with wet winters and Mediterranean dry summers. Buildings situated in this climate zone should be considered with an intelligent cooling as well as heating concept. Here the heating period is from December till March and peak temperatures in July and August.
Seoul	Subtropical/humid continental climate. In summertime warm temperatures and constantly moist during the winter season cold due to Siberian winds from northwest. These quite contrary climatic conditions do not only have to take heating and cooling technologies into the planning, also problems with humidity should be considered. Solar yields for PV plants are also affected by the rainy season during summertime [10].

Table 6. Example for climate data for the studied cities (* I: solar radiation incident on the facade).

City	**CDD**	**HDD**	θ_{ne}	HT	*I_{South}	*$I_{Eeast/West}$	*I_{North}	$I_{horizontal}$
	Kd/a		°C	d	kWh/m²a			
Zurich (CH)	22	1655	-8	$HT_{20/12}$ 212	807	680	388	1127
Berlin (D)	26	1615	-14	$HT_{20/12}$ 212	826	650	360	1041
Seoul (KOR)	881	2432	-18	$HT_{20/15}$ 181	864	694	439	1185
Istanbul (TUR)	101	588	- 1	$HT_{20/12}$ 121	965	838	436	1367

Electrical demand

To reduce the electrical energy demand it is crucial to use highly efficient devices and intelligent lighting. Table 7 shows some basic methods, which can contribute to significant electrical energy savings in a household [11]. The electrical consumption of devices and equipment is not directly dependent on the number of residents. The type of building, such as apartment or a single-family house, plays an important role. Most applications have a "base consumption". In order to this the electrical consumption per person for a household with one or two residents is higher compared to a household with four persons [11]. For the ETB and the design of a ZEB an (very) efficient household is presumed. An assumption of the electrical demand based on a typical Swiss household is shown in Table 8.

Table 7. Methods to reduce the electrical consumption of a household [11].

Washing machines	Cold washing and connection to the DHW supply.
Tumble dryer with integrated heat pump	Reduction of up to 50 % compared to condenser tumble dryers.
Avoiding standby mode	Up to 20% reduction is possible.
PC/Laptops with SSD and OLED – Monitors	Reduction up to 50% compared to conventional systems.
Building services	Usage of high efficient circulation pumps.
Lighting	By using LED (light emitting diodes) up to 90% of the electrical energy compared to conventional light bulbs can be saved. Maximization of daylight usage.

Table 8. Example for the electrical demand of a typical Swiss household with adaption on an efficient household due to efficient devices [11]

	kWh/a
Electrical consumption for lights and facilities of conventional household in Switzerland with two persons (2,350 kWh/a)	2,350/2 = 1,175 (per person)
Correction factors for efficient households in Switzerland	
Lights more than 80% are efficient (for example light emitting diodes-LED)	-275
No tumble dryer	-119
Washing machine / Dishwasher connected to DHW cycle	-122
Electrical consumption per person and year in a very efficient household	**659**

Domestic hot water consumption

The domestic hot water (DHW) consumption has a significant impact on the energy demand of a Passive House. While in old buildings it is around 10 % of the total energy consumption, the energy demand for DHW in Passive Houses increases up to 45 % [12]. Moreover, the water consumption can be reduced by about one third when using water-saving appliances [10]. In Switzerland for example a DHW consumption of 35 l/d is set by the norm SIA 385/1. This needs to be adjusted on cultural behavior when transferred on other countries.

3.2 Selection of heating technologies for covering the energy demand

Heat pump systems in connection with different heat sources (geo-, sewage- and solar thermal) are common technologies for heating modern buildings. High efficient heat pump systems reach an APF up to 6 (optimum heat source-, low fore flow temperatures and good insulation of the building presumed) according to an interview with technical assistances from the German HP manufacturer Stiebel Eltron (2014). That means that only 1/6th of the necessary heating energy is needed in form of electrical energy for the HP. This electrical energy can be provided by a PV plant in order to fulfill the concept of a Net Zero Building. Besides conventional and well known methods to use heat sources for HP, the usage of waste water is another option (Table 9). Significant energy is lost through unused heat in wastewater, especially in bigger cities [6]. This heat can be extracted and used as a heat source for the HP with a sewage heat exchanger, without endangering the processes in a sewage plant. Using waste water could be a good alternative to earth probes especially if they are restricted by governmental laws [6].

Table 9. Annual performance factors (APF) of heat pump systems applicable for the ETB.

HP System	**Performance**	**Remarks**
Conventional Air to water HP	APF: 2	Usually not suitable to reach Passive House standard, due to a disadvantageous COP with decreasing outdoor temperature [10].
Water/Brine to water HP with geothermal source	B0W35: APF 3.5 B5W35: APF 4.5	High source temperatures results in a better APF (low fore flow temperature presumed). APF numbers are based on simulations with T*SOL and Polysun.
Compact devices Heating	APF: 3	Air to water HP with better efficiency due to preheated outside air (Heat exchanger). They can also provide: hot water and ventilation with a HRC efficiency up to 90% [22].
Sewage usage	APF: 4 – 5.5	Better APF are expected in Asia than in Europe by reason of warmer waste water (source for HP) [6].

Solar thermic systems

To achieve high energy yields form the collector area, the whole system needs to be considered, also in simulations for the ETB. It is important to balance storage tank for hot water and the collector area to each other (Table 10). Collectors with a steeper angle of attack reduces the risk of overheating the system in summertime and produces sufficient energy in wintertime due to the lower altitude of the sun. Therefore collectors integrated into the facade of a building should be an effective solution [21].

Table 10. Layout parameters for a solar thermic (ST) system for high energy yields.

Typical cover ratios for ST systems	Solar thermal plants are usually used to preheat, with typical cover ratios of 60% for DHW or 30% for the heating system (yearly energy usage).
High performance ratios up to 100% (seasonal storage), using	
Collector type	Vacuum tube- or flat collectors with high performance grade
Size storage tank	175 to 200 l and maximum 1000 l per m² collector area [21].
Insulation storage tank	20-30 cm [21].

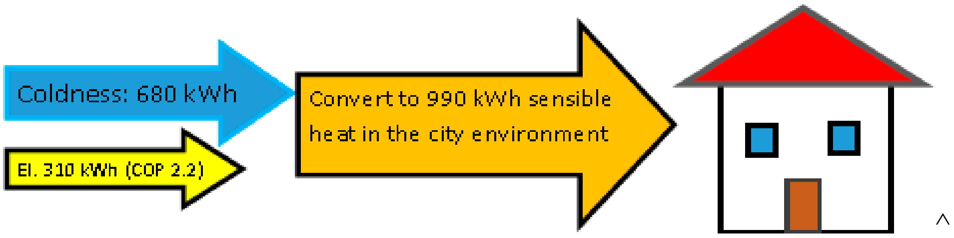
3.3 Selection of cooling technologies for covering the energy demand

The necessity of implementing cooling system is very important in modern building design due to the increased use of glass facades and better insulating materials. The European energy efficiency goal for heating is to save 40% of energy until 2020. On the flipside, it is estimated that the cooling energy demand for buildings will rise more than 200% during the same time [13].

Evaporative adiabatic cooling

"We need evaporation in order to cool down the climate" [13]. Water evaporates on plants and later condensates and forms clouds. Every day, vegetation coverage of the size of Berlin (Germany), is lost and results in overheating which is especially present in cities. The ideal solution to discharge heat from the cities is water evaporation [14]. Adiabatic cooling is a special technology where the synergy of evaporating and cooling is harnessed in a near-natural process. By using rainwater for the phase change, adiabatic cooling is restoring or supporting the natural water cycle. This cools down the climate in urban areas, increases local rainfall and could help to decrease or even prevent the so called *Urban Heat Island Effect* [13]. Green roofs for example evaporate two third of the net radiation, while conventional urban roofs without vegetation convert most of the global radiation into heat. By guiding the heat through evaporation and condensation into clouds the energy "disappears" in the natural water circle [13].
Conventional electrical compressor cooling systems (refrigerator) contribute to the overheating problem in cities. A shift of energy takes place when energy is transformed from electrical to heat (Figure 3).
Adiabatic cooling is a technology that could prevent this problem [13].

Figure 3. Problem of increase the urban heat island effect by using electrical cooling systems.



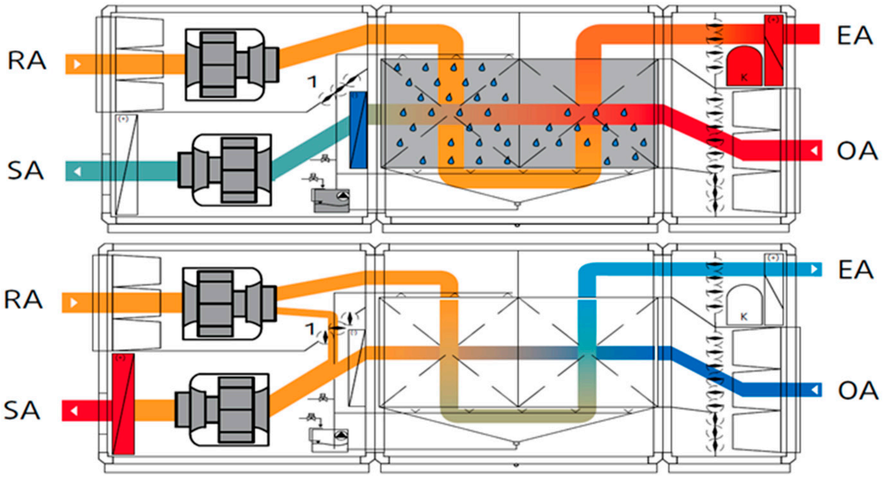
The basic element of the adiabatic cooling process is a ventilation system with heat recovery. The exchanger can be used to regain heat in winter and to cool during summer. All major components of adiabatic cooling are thus already present in modern building technology. The only additional component needed is a humidifier for exhaust air prior to the heat exchanger [14]. How adiabatic cooling could be implemented in the ETB is listed in Table 11.

Table 11. Overview on important specifications and benefits of adiabatic cooling.

Field of application	At outside temperatures up to 30°C, the supply air can be cooled to 20°C to 22°C Energy savings up to 70% at ambient temperature of 38°C can be achieved compared to conventional systems [14]..
Performance	The evaporation of one cubic meter water produces 680 kWh of cold energy [14]
Benefits compared to "solar cooling"	Adiabatic cooling is up to eight times cheaper in its installation-, operation- and maintenance costs [13].

A technical solution from the German manufacturer *Menerga* uses an integrated adiabatic evaporative cooling system with an ERR up to 7.3 [15]. An additional compressor refrigerator system increases the cooling capacity of the overall system at high temperatures and allows the dehumidification of outside air. An included exchanger is used for precooling the outdoor air and can be also used for heat recovery in wintertime (Figure 4) [15].

Figure 4. Scheme of the adiabatic cooling process (top) and heat exchanger (bottom) in a Menerga system; RA = return air; SA = supply air; OA = outside air; EA = exhaust air; source: [15].



Green roofing

Green roofs convert 58% of the radiation balance in the evaporation of water in the summer months. Conventional roofs without vegetation convert up to 95% into heat [16]. This effect causes a reduction of the summer-related energy demand in a typical building by 60%. Also it contributes to the insulation in winter time with an additional insolation up to 10% (with the assumption that 22% of the heat losses occur via the roofs). As well the synergy for photovoltaic plans and green roofs is given as the cooling effect of the green roof is also contributing to a higher efficiency ratio of the photovoltaic panels [14].

Green facades

Climbing plants can serve as a natural sun blinds. In front of glass facades, they prevent the entry of solar radiation in summer and thus overheating of buildings. In winter, when shortwave radiation is desired to enter the internal of the building, most plants have lost their leaves. In addition green facades serves the evaporative cooling and leads to cool down the building. Evaporation takes place outside the building envelope, but there are advantages in building climate as well compared to a conventional sun blinds. Especially with wrong user behavior when opening the window at high ambient temperatures or thermal bridges just to name some examples. Green facades can lead to a cooling energy reduction of about 70% compared to buildings without sun blinds [16].

Cooling with HP systems

Table 12 lists heat pump systems that can be used for heating in wintertime and for cooling in summertime.

Table 12. Cooling technologies in connection with heat pump systems

Passive cooling with an earth probe	A significant advantage of this free cooling method is that the soil can be regenerated during summertime. This means that the lowering of the temperature during winter due to the heat extraction can be compensated. Simulations showed that the passive cooling with geothermal probe and underfloor heating the temperature inside the building can be reduced by 2 to 4°C or 70 % of the heat probes heating power (approximately 50 W/m / 100 kWh/(m*a) for heating) [17].
Active cooling with HP	This can be done by a reversible heat pump system with changing the flow direction of the cooling refrigerant. There are products, which combine heating (also DHW), cooling and ventilation (HRC up to 90 %.) in one unit. These compact devices are air to water HP, which use the outside air as source but with better efficiency due to the HRC. For the cooling in summer water is circulating through the cooling (heating) manifold system (floor heating -/cooling or wall surface heating / cooling etc.) and thereby removes the room heat with an EER of 3 [22].
Cooling with wastewater	Wastewater usually reaches a temperature in summer of about 25-28 °C. With this source temperatures an ESEER ($APF_{cooling}$) of about 3.5 to 3.8 can be achieved for cooling. Conventional split systems reach values of about 1.5 to 2.5 (EER) due to higher outside air temperature in hot countries [6].

Selection of technologies for increasing efficiency

An overview on technologies which can be used to lower the energy demand of a building is listed in Table 13.

Table 13. Selection of technologies for increasing efficiency

Adaptive shading (controlled sun blinds)	7 % reduction on energy demand for cooling [18]
Dynamic adaptive lightening	28 % reduction on the electrical demand for lightening [18]
Heat recovery from waste water (in the building)	Heat demand reduction of DHW of 1/3 [19]
Component activation	3 m^3 in the building components = 1 m^3 reduction of the (seasonal) storage tank for hot water (ST) [20]

4 Conclusions

This paper clarifies the required physical background and represents a guideline for the further development of the ETB. Future investigations will ensure the reliability of input parameters for the applied technologies under different climatic and cultural conditions. The climate, which plays a central role in the building design, is considered in the proposed ETB under the criteria of Swiss building standards (SIA 380/1). An important task will be to translate national specifications for climatic data and building components to an international level, with considering cultural behavior. Especially the definition for HGT, HDD and the heating limit are critical values that vary internationally.

To further expand the application of the ETB, other important themes of a ZEB should be considered in greater detail in order to respect all energy fluxes. An aquaponic system or a sewage plant (onsite) for example could have a significant impact on the energy demand. Additionally, the implementation of the environmental impact for embodied energy (building components) and used technologies should be considered. Heat pumps in Switzerland should reach at least an APF of three to be classified as efficient technology, respecting the composition of the Swiss electricity supply. Below this value, precious electrical energy creates heat and is lost. This would be in contrast to any efficiency recommendations. Also the financial background, for example the payback period could be later on added to the ETB.

In conclusion, planning an energetic layout for buildings is highly complex. While difficulties due to a huge number of influencing factors can arise, the energy layout process provides creative potential to implement new technologies and building shapes. The ETB that could be developed with the guideline presented in this thesis has the potential to serve as a platform for global sharing and testing of technologies and ideas.

5. Acknowledgments

I would like to express my gratitude to my supervisors for their help and support: Prof. Dr. Ing. Thorsten Schuetze and Prof. Dr. Ranka Junge and all partners of the ZEBISTIS project for their contribution to my thesis and the opportunity to be part of the ZEBISTIS Symposium in Wädenswil (2014) and the project in general. Christoph Koller for his supervision and technical assistance with the project. Valentin Software for supporting the project with simulation tools (http://www.valentin-software.com/).

Special thanks to the persons who have supported me personally: Franziska Brück, Jens Vent-Schmidt for being a good friend and supporter, Erich T-G for taking the time to discuss questions on climate.

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