

Covering the energy demand of domestic buildings in Korea with Renewable Energy

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ABSTRACT: In the framework of the described research is investigated how the energy demand of Passive-House buildings in Korea can be covered with renewable energy. The starting basis for the investigation is the reduction of the energy demand in domestic buildings in Korea by the adoption of the Passive-House principle to typical Korean residential buildings. This is done by the analysis and evaluation of specific climate conditions, architecture, building practice as well as specific comfort criteria. The energetically optimization of the buildings is based on the modification of common building designs. According to the research findings residential passive buildings can be realized in Korea with a relatively low additional constructive and monetary effort compared to the common building practice. For the calculation of the energy demand of the buildings for cooling, heating, hot water and electricity consumption two programs were used, the passive house development package PHPP 20007 and Primetor Korea. The remaining required energy demand for heating and hot water production can be covered completely by renewable energies. Solar-thermal collectors installed on the roof or in facades can provide the required thermal energy. In combination with heat pumps the required hot water storage volume as well as the surface area of solar-thermal collectors can be reduced. The required energy demand for electricity can be covered by photovoltaic systems. Therefore the required energy demand of Passive Houses in Korea can completely be covered by renewable energy.

Keywords: renewable energy, photovoltaic, solar-thermal, passive-house, heat pump

1. INTRODUCTION

In the framework of the described research it is investigated how the energy demand of domestic buildings in the Republic of Korea can be covered with renewable energy. The starting basis is the significant reduction of the primary energy demand for the service of residential buildings in Korea. The aim of the research is to limit the primary energy

consumption of buildings (including heating, cooling, warm water production and electricity consumption for building service and household appliances) to 120 kWh/m². Therefore it is investigated how the Passive-House principle can be adapted to typical Korean residential buildings. This is done by the analysis and evaluation of specific climate conditions, architecture, building practice as well as specific comfort criteria. The effort for the construction and service of Passive-Houses in Korea is investigated on the basis of a comparison of Passive-House designs with common buildings (e.g. heating and cooling energy demand, heat and cool load as well as required components). The feasibility of the construction of Lowest-Energy buildings is investigated instancing Korea because the basic conditions, like climate, urban structure, building typology and construction technologies, are comparable with other fast growing economies in East Asia (e.g. in China and Vietnam). The climate in Korea is quite harsh and between continental (in the winter) and sub-tropical (in the summer). Due to the high solar radiation in Korea, particularly during the winter, thermal and photovoltaic solar energy systems are chosen for the generation of the required amount of energy for the supply of Lowest-Energy Buildings.

For the calculation of the heating and cooling load as well as for the energy demand of the buildings for cooling, heating, hot water and electricity consumption, two programs were used; the practically proven Passive-House Development Package (PHPP 20007) and Primentor Korea, which is a worksheet that is newly developed for the Korean situation and especially for the early design process.

2. APARTMENT BUILDINGS IN KOREA

In the Republic of Korea most residential buildings are massive constructions made of cast-in-place concrete according to the present building practice. This is true for the structural as well as the room building elements, which are connected frictional. The buildings are constructed on site and no prefabricated concrete components are used. The insulation (expanded polystyrene) with a required minimum thickness of 10 cm is fixed to the inner surface of the outside walls and ceilings and is covered with gypsum boards. Indoors insulation reduces the thermal storage capacity of the indoor, which is important for keeping a stable indoor temperature and implies thermal bridges.



Illustration 1: Example for a typical urban redevelopment area in Seoul, before demolition of point houses (left) and after construction of high-rise apartment buildings (right). [1]

The building types in Korean cities can be differentiated in two building types, “apartment buildings” and “point houses” which can be also assigned to specific urban settings (illustration 1). Apartment buildings are the most widespread domestic housing

type in Korea. More than 80 percent of the Korean population lives in apartment buildings, with a rising tendency. The buildings have generally a compact rectangular building shape and 5 to 45 storeys. According to the building code the opposite located buildings must have a minimum distance to each other that is similar to the height of the higher building.

The comfort temperature in Korean apartments is approx. 24°C. According to the Korean culture, the users accept only apartments equipped with a floor-heating system. The application of cooling systems are applied in the design of lowermost-energy buildings in Korea to guarantee a comfortable indoor climate with a temperature of maximum 25°C throughout the year.

3. REDUCING THE ENERGY DEMAND OF DOMESTIC BUILDINGS IN KOREA

The design of Passive-Houses for the Republic of Korea is based on the analysis of experiences with the construction of Lowest-Energy buildings in different climate zones and the specific basic conditions in Korea. Two different building designs, which can be assigned to the typical residential building types, are the starting basis for the design of Passive-Houses in Korea. The energetically optimization of the buildings is based on the modification of common building designs and standard constructions. Locally available materials, components and building technologies are used as far as possible, to allow a relatively easy and economically realization of Lowest-Energy houses in Korea, based on the results of the described research. For the energetically optimization of both investigated building types, materials and components with the same physical properties were used. Therefore the influence of the different surrounding conditions (specific urban setting, specific building design, surface to volume ratio and orientation) on the specific energy demand of the investigated buildings can be evaluated in the framework of the described research. The spatial structures of the apartment as well as of the point house are out of cast-in-place concrete.

All tempered indoors are insulated outside of the load bearing structure, mainly to reduce heat bridges but also to guarantee a high thermal storage capacity inside the buildings. Extruded polystyrene with a total thickness of 20 cm is used as insulation material. The outside walls of the buildings are insulated with a thermal insulation composite system. The U-values vary between 0.145 and 0.147 W/m²K for wall and roof constructions and 0.128 to 0.131 W/m²K for base constructions. Commercially available box windows, consisting of two layers of insulation glass, each with u-values of 2.6 W/m²K, are used for the design of the transparent parts of the building skin. The U-value of the whole component is 1.3 kWh/m²K.

For the calculation of the primary energy demand of the heating systems as well as for the hot water production the energy sources district heating and gas were used. The primary energy factor in Korea for both is 1.1. For the calculation of the primary energy demand for cooling the electricity demand of standard air conditioning systems were accounted. Additionally the electricity demand for the efficient ventilation systems with heat recovery of 79 percent and an

air exchange rate of 0.3/h was taken into account for the calculation of the heating as well as for the cooling energy demand. The primary energy factor for electricity is 3.

3.1 Specific properties of the apartment buildings

The staircases, which are connecting cellar, ground floor, the upper storeys and the roof are part of the tempered building volume. Therefore the walls between staircase, cellar and roof as well as the bottom and the roof of the staircase are also insulated. Heat bridges are not avoided completely, but appropriated detailing can reduce them significantly.

The analysis of the energy demand of the apartment buildings includes the effect of different building orientations (either north or south orientation of living rooms with big window portions in the facades). In case of south orientation the heating energy demand is generally lower but the cooling energy demand is higher than in case of north orientation, due to higher solar gains. The partly shading of the investigated buildings by apartment buildings, which are located opposite, as well as the eastern and western sides, is included in the calculations. The investigated urban situation confirms with the typical urban setting according to the requirements of the Korean urban planning codes.

4. ENERGY DEMAND OF LOWEST-ENERGY BUILDINGS

Different scenarios with different indoor temperatures were chosen for the calculation of the energetically properties of the investigated building types. The results allow an interpretation and comparison of the buildings, regarding the specific urban settings, the indoor comfort temperatures in Korean flats (24°C) and the indoor temperatures for the calculation of the energy characteristics of Passive-Houses in Europe (20°C).

For the apartment buildings, for two locations, Seoul and Cheju Island, a north and a south orientated version with indoor temperature of 20°C, 22°C and 24°C were chosen. For the point houses, only for the location Seoul and only one version with indoor temperature of 20°C, 22°C and 24°C were chosen.

The results of the comparing calculations with Primentor Korea and PHPP 2007 are displayed in the tables in illustrations 5 and 6. The results of the two programs for the specific buildings are alike but not identical. In average the results of Primentor are higher for the heating energy demand and lower for the cooling and primary energy demand. This is caused by different calculation methods.

The requirements of European passive houses concerning the maximum primary energy demand (120 kWh/m²a), the maximum heating load (10 W/m²) and the climate dependent heating energy demand (15 kWh/m²a) at an average indoor temperature of 20°C can be met by the above described measures for the apartment buildings but not for the point houses, because the apartment buildings are basically more energy efficient than the investigated point houses. For the calculation of realistic heating energy demand values in the Republic of Korea, an

average indoor temperature of 24°C has to be taken into account, while the calculation with an average indoor temperature of 20°C allows the international comparison of Passive-Houses.

building type	room temperatures, building location & building orientation	PHPP 2007		Primentor		PHPP 2007		Primentor		cooling, hot water and electricity demand are calculated for all room temperatures	PHPP 2007		Primentor						
		PE (PE incl. cooling)				HD		HDD			kWh/m²a								
20° C																			
Apartmenthouse																			
Cheju	north (south orientation)	99,0	136,8	87,4	111,7	3,0	1,9	47,7	52,6	cooling, hot water and electricity demand are calculated for all room temperatures	cooling		Primentor						
	south (north orientation)	105,0	137,4	95,5	115,3	6,0	9,1	47,7	52,6		14,0 8,1								
Apartmenthouse																			
Seoul	north (south orientation)	109,0	144,1	99,3	113,1	10,0	12,5	72,1	74,8		13,0 4,6								
	south (north orientation)	113,0	145,4	107,0	119,0	14,0	19,2	72,1	74,8		12,0 4,0								
Pointhouse																			
Seoul	north	139,0	166,0	122,0	137,3	40,0	40,7	72,1	74,8		10,0 5,1								
	south	103,0	135,4	91,0	105,1	22,0	24,9	72,1	74,8		12,0 4,7								
22° C																			
Apartmenthouse																			
Cheju	north (south orientation)	102,0	139,8	90,0	114,3	5,0	4,5	56,7	65,9		cooling, hot water and electricity demand are calculated for all room temperatures	hot water		Primentor					
	south (north orientation)	108,0	140,4	100,0	119,8	10,0	13,3	56,7	65,9			30,9 30,9							
Apartmenthouse																			
Seoul	north (south orientation)	112,0	147,1	104,0	117,8	14,0	16,6	81,9	87,1			30,9 30,9							
	south (north orientation)	117,0	149,4	111,0	123,0	19,0	23,6	81,9	87,1			30,9 30,9							
Pointhouse																			
Seoul	north	148,0	175,0	132,0	147,3	48,0	49,5	81,9	87,1			27,8 27,8							
	south	109,0	141,4	98,0	112,1	29,0	30,8	81,9	87,1			23,0 23,0							
24° C																			
Apartmenthouse																			
Cheju	north (south orientation)	105,0	142,8	94,0	118,3	8,0	7,7	65,7	79,1			cooling, hot water and electricity demand are calculated for all room temperatures			electricity		Primentor		
	south (north orientation)	113,0	145,4	106,0	125,8	14,0	18,2	65,7	79,1						23,3 17,2				
Apartmenthouse																			
Seoul	north (south orientation)	116,0	151,1	109,0	122,8	18,0	20,9	91,7	101,7						23,3 17,2				
	south (north orientation)	122,0	154,4	117,0	129,0	24,0	28,4	91,7	101,7						23,3 17,2				
Pointhouse																			
Seoul	north	159,0	186,0	143,0	158,3	56,0	59,2	91,7	101,7						23,9 15,5				
	south	116,0	148,4	105,0	119,1	34,0	37,4	91,7	101,7						19,8 12,9				

legend:

PE:	primary energy value (kWh/m ² a)
PE incl. cooling:	primary energy value (kWh/m ² a) incl. electricity demand for cooling
HD:	heating demand (kWh/m ² a)
HDD:	heating degree days (kKh)
Cooling:	energy demand for limiting internal temperature to maximum 25°C
hot water:	energy demand for production of 60 l per person and day
electricity:	consumption in private households (household appliances and lighting)

Illustration 2: Energy demand of the investigated building types and locations for different indoor temperatures. The results are based on calculations with the Passive-House Development Package (PHPP 2007) and Primentor Korea (Primentor)

water production and heating) and enhanced insulation of the building skin (e.g. by better insulation and glazing).

5. COVERING THE ENERGY WITH RENEWABLE ENERGIES

In the previous chapter the primary energy demand of the investigated buildings was calculated for heating and warm water production with gas or district heating, which have a primary energy factor of 1.1; for cooling with air-conditioning facilities based on electricity it is calculated with a primary energy factor of 3. Alternatively the use of renewable energies for the coverage of the required energy demand is investigated. For the subsequently described concept the building type “apartment house south (north orientation)” is used, located in Seoul. Due to the location and bad orientation for passive solar energy use (the big windows are orientated to the north), the heating load and the heating demand of this building type are

Taking into account the higher indoor comfort temperature of 24°C and the energy demand for cooling, the primary energy value of 120 kWh/m²a is only under-run by the apartment building with south orientation, located on Cheju Island. This is only true for the calculation results of Primentor.

According to the results of PHPP all buildings have a primary energy demand of more than 120 kWh/m²a. This is caused mainly by the higher cooling energy demand according to the PHPP results.

The primary energy demand can be reduced, e.g. by avoidance of cooling demand by acceptance of a maximum comfort temperature of 27°C, the use of renewable energies (e.g. solar thermal for hot

higher, compared with buildings that have a south orientation and are located in warmer climates. For the description of the building construction and the energy values please refer to the previous chapters. Due to the bad orientation and the comparable high energy demand, the results of the described analysis can be easily transferred to buildings with a more appropriate orientation for passive solar energy use and locations in a warmer climate. In case of a similar building construction but lower heating energy demand, the technical effort and the related investment costs are accordingly lower.

The investigated concept is based on the installation of thermal solar collectors, which are installed on the roof of the apartment building with south orientation and a slope of 30 degrees. The available roof surface area of 300 m² is covered with flat bed solar collectors. This area is similar to approx. 10 m² per apartment. The collectors are feeding two hot water storage tanks. One tank with a capacity of 6.3 m³ is used permanently as buffer-storage for the warm water supply. The second tank with a capacity of 8 m³ is used as a buffer tank for the heating system during the heating period. With the described system 90% of the heating and warm water demand of the building could be covered by solar thermal energy. *(If flat bed collectors would be elevated on a flat roof (which offers more surface area for the installation than the sloped roof) or if vacuum tube collectors with a higher efficiency would be used, the required thermal energy demand could be even covered by 100% by solar thermal energy.* The concept includes also the installation of an air to water heat pump, which allows the application of comparable small buffer tanks for the storage of warm water and contributes to investment cost savings for the solar heating system. The heat pump can generate the remaining 10% of the required heating demand. It can also be used for the additional heating of the warm water storage in times of need (particularly during the winter in periods with low solar radiation). Additionally such a heat pump facilitates the reversal of the heating system to a cooling system for the summer period. The buffer tank, which is used for the heating system during the winter, is used for the cooling system in summer. In this case the water inside the tank is cooled down by the heat pump to a minimum temperature of 18° C. The floor heating systems, which are installed in the apartments, can be used during the summer for cooling purpose. The occurrence of condensate on the cooled floor during the hot and humid summer months might be avoided through the service of a ventilation facility with heat recovery equipped with air to air heat exchangers which facilitate the transfer of humidity from the outdoor air to the indoor air by special capillary heat exchangers. Additionally it can be avoided by the electronically control of the floor cooling system, based on indoors and outdoors data about temperature and relative humidity, collected by sensors and transferred to an electronic control unit.

The application of the described concept contributes significantly to savings in the primary energy demand compared with standard applications for heating and cooling. The primary energy demand of the investigated conventional Passive-House, for a permanent indoor temperature between 24° and 25° C all over the year (calculated with Primetor Korea) is:

- 117 kWh per m² and year without consideration of the cooling demand
- 129 kWh per m² and year with consideration of the cooling demand

The portions of the primary energy demand, differentiated according specific uses are:

- 52 kWh per m² and year for household electricity (including ventilation facility)
- 34 kWh per m² and year for warm water
- 31 kWh per m² and year for heating
- 12 kWh per m² and year for cooling

The total primary energy demand for heating, warm water and cooling is 77 kWh per m² and year. It can be reduced by 66 kWh, to 11 kWh per m² and year by the application of the described system, based on the installation of solar-thermal facilities and air to water heat pump for heating and warm water production. In consideration of the electricity demand of private households of 52 kWh per m² and year, the total primary energy demand of the alternative concept is 63 kWh per m² and year, which is similar to primary energy savings and the related CO₂ emissions of 51 % (or approx. 1/2), compared with the conventional Passive-House.

The useful energy balance for the alternative heating system consists for the whole building of solar earnings, of 230,000 kWh per year, and a heat demand of 254,000 kWh per year. The remaining 24,000 kWh per year are covered by a heat pump with a COP of 4. The electricity demand for the heat pump is 6,000 kWh per year while it is 4,000 kWh per year for the service of control and pumps of the solar thermal facility.

The investment costs without the installation of the described facilities are approx. 140,000 Euro for the solar facility, (including all required components) and 20,000 Euro for the heat pump. The total costs are accordingly 160,000 Euro. This is similar to investment costs of 5,333 Euro per apartment or 43 Euro per m² living space. In consideration of the cost for a Passive-House certified ventilation facility with heat recovery, of approx. 80,000 Euro (2,667 Euro per apartment), the total additional costs are 8,000 Euro per apartment, which is similar to 65 Euro per m² living space. [2]

The remaining electric energy demand can be covered with building integrated photovoltaic (PV). The required space demand and an optimal orientation of the PV generators is available on the sloped roof. However, there is not enough space to install the required amount of PV and solar thermal collectors. For the reduction of the required space demand for solar thermal collectors (by approx. 30%), vacuum tube collectors should be installed in front of the south façade of the apartments. The required area of approx. 7 m² per flat can easily be provided on the front façade in front of the floor structures or railings.

The electric energy demand for the ventilation facilities of 13,000 kWh per year can be covered with a photovoltaic generator of approx. 13 kW_{peak}. The required area for a PV generator consisting out of poly-crystalline silicone is approx. 130 m². The electricity demand for the service of the solar thermal facility of 10,000 kWh per year can be covered with a PV generator of approx. 10 kW_{peak}, with a space demand of approx. 100 m². The total required energy demand of 23,000 kWh per year requires a PV generator with 23 kW_{peak} and an area of approx. 230 m² (7.7 m² per apartment). The total investment costs are approx. 100,000 Euro (3,300 Euro per apartment) in case of a grid-connected facility.

For the coverage of the remaining electricity demand of private households (of approx. 60,000 kWh per year) the installation of an additional PV capacity of 60 kW_{peak} and an area of approx. 600 m² (20 m² per apartment) would be required. The total investment cost would be 260,870 Euro (8,700 Euro per apartment).

6. CONCLUSION:

The described modifications of typical contemporary constructions for residential buildings in Korea can reduce the energy demand for domestic housing significantly. The energy demand

of the modified apartment buildings is in the range of European passive buildings. According to the research findings residential passive buildings can be realized in Korea with a relatively low additional constructive and monetary effort compared to the common building practice. The remaining energy demand for heating and cooling can be comparable easy covered with solar energy. Also the coverage of the total energy demand with solar thermal and photovoltaic systems is feasible. However, the space demand for the required solar system is exceeding the available space on the roof. To provide the required area for the installation of these facilities in the building skin, strategies for the building integration of PV generators and solar thermal collectors on roofs as well as facades of buildings have to be developed and applied.

7. REFERENCES:

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