Shape Factor as an Indicator of Heating Energy Demand

Gebäudeformbeiwert als Indikator für den Heizenergiebedarf

La forme du bâtiment: un indicateur du besoin de chauffage

Fattore di forma dell'edifico quale indicatore per il consumo dell'energia di riscaldamento

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Allen's rule: A race of warm-blooded species in a cold climate typically has shorter protruding body parts (nose, ears, tail, and legs) relative to body size than another race of the same species in a warm climate.
Joel Asaph Allen, American zoologist and ornithologist 1877
Source*:* A Dictionary of Zoology, 1999, Michael Allaby

"Je kleiner dieses Verhältnis ist, desto kompakter (energiesparender) ist das Haus."
web-site *energiesparhaus.at/fachbergriffe/azuv.htm* about A/V ratio

1. Introduction

Compactness of a building is in many occasions expressed using an indicator called *shape factor*. When comparing architectural concepts or optional design solutions, shape factor can be used for evaluating whether or not the shape of the volume supports energy-efficiency. In planning process, it can be used as an early indication of the heating energy demand of the building.

Since 2002 German Building Code for the energy performance of the buildings, *EnergieEinsparverordnung (EnEV)*, has set the requirement for the total primary energy demand of the buildings in relation to the shape factor. In Finland the total energy approach and national primary energy factors will be introduced in the new building code 2012. There is already increasing number of building projects, such as Passive Houses, which are targeted to meet very low heating energy demand specified with a fixed value. Whenever the total energy approach is applied, it is important for an architect to understand the influence of the shape on the energy-efficiency.

The experiences gained in the planning processes have proved that the early decisions have the greatest impact on the energy-efficiency of a building. A simple indicator such as shape factor could be used to evaluate the very first ideas and concepts, already before any energy calculation tools can be applied.

2. Objectives

The study of the compactness is one part of doctoral thesis project, which aims at providing more knowledge and deeper understanding about the impact of architectural solutions on the heating energy demand of a building in the Northern climate. Although the means for reducing the heating energy demand by design are similar all over the northern hemisphere, the importance of the properties of the building envelope seems to be somewhat different in Finland and in the Central European climate.

The research question is, if shape factor can provide a reliable indication of the heating energy demand. Two known ways of defining a shape factor are compared. The correlation between shape factor and the heating energy demand is studied through energy simulations.

Another aim is to introduce the concept of shape factor in the discussion in the context of energy-efficient building in Finland, and suggest a proper terminology to be used considering the influence of the shape on the heating energy demand.

As no existing definition of shape factor is in use in Finland at the moment, this is a good moment to compare the definitions in use in Sweden and Germany, evaluating how reliable and useful they are as an indicator of the heating energy demand.

3. Architecture and Energy-efficiency

3.1. Architectural Design and Heating Energy Demand

The heating energy demand of a building is a result of both technical and architectural choices made during the planning process. The design solutions affecting the heating energy demand are:

- location, orientation and micro-climate
- shape of the building
- window and door surface area, orientation
- utilization of internal heat gain, especially passive solar
- thermal mass
- thermal insulation of the building envelope, doors and windows
- air-tightness of the building envelope
- heat recovery of the ventilation system

The first three of these derive from the architectural design.

The most important decisions, which have an effect on the energy performance of the building, are carried out in the sketch phase[1]. The energy calculation can usually start only after the sketch is ready.

There are also other indicators for the compactness of the building volume. Some of these methods take into consideration the different heat losses through the floor, walls and roof. This approach takes the method one step closer to the real heating energy demand calculation, but also makes it more complicated and slow to calculate. In the sketch phase, a quick response and simple means of evaluation are needed for comparison of the optional ideas and architectural concepts.

4. Climate Dependancy

The studies by Kurnitski and Jokisalo have shown that the thermal inertia has less significant effect on the energy consumption of a residential building in the Finnish climate than in the Central European Climate.[2] Furthermore, the possibilities of utilizing passive solar energy are limited in the well-insulated buildings in the North, because during the relatively short heating season there is not much solar gains available. It seems that the various means of design for reducing heating energy demand have different weight in the Northern Climate than in the moderate Central European climate. Thus, through a deeper understanding of climatic differences, energy-efficiency may even emphasize the aspect of locality in architectural design.

Measuring the compactness of the building volume should by no means replace or diminish the importance of other aspects of good architectural design, but especially in larger projects a numeric indication of the compactness can be a valuable means for guiding the design solutions in the direction where the target level of energy-efficiency can be met in the end of the process. For this reason, there is a need to express the quantitative properties of the building envelope with a reliable indicator.

[1] Lappalainen, Markku (ed.): Energiakäsikirja. Suomen Arkkitehtiliitto. Rakennuskirja, Helsinki, 1983. p. 12; pp. 64–65.

[2] Jokisalo, Juha; Kurnitski, Jarek: Effect of the thermal inertia and other building and HVAC factors energy performance and thermal comfort in Finnish apartment buildings. Report B79. Helsinki University of Technology. Department of Mechanical Engineering. Laboratory of Heating, Ventilating and Air Conditioning. B. Espoo 2005. pp.53–54.

5. Shape Factor definitions

5.1. Shape Factor A/V

The shape factor is most often calculated as the ratio between the outside surface area of the thermal insulation in the building envelope (A) and the heated volume (V). In German-speaking countries this indicator is called *Form Faktor* or *A/V-Verhältnis*. Shape factor A/V has an important function in German EnEV 2009, which sets the requirements for the total primary energy demand of the buildings by the shape factor.

Shape factor is also used as a guideline in the educational material for passive house architects. The shape factor for a typical single-family house is 0.8 - 1.0 m²/m³. According to some sources, the recommended shape factor for a passive house[3] is ≤ 0.8 m²/m³; according to another[4] source 0.5 m²/m³. Shape factor A/V is dependant on the size of the building. A shape factor of 0.2 m²/m³ can be achieved only in large and very compact buildings. In published passive house projects, A/V ratio is often announced among the key figures of the project.

5.2. Shape Factor A/A

Swedish passive house experts have used the shape factor (*formfaktor)* A_{om}/A_{temp}, which is calculated as a ratio between the inside surface area of the building envelope (A_{om}) and the heated floor area (A_{temp}). The consults of the Swedish passive house center (*Passivhuscentrum*), have successfully used A_{om}/A_{temp}-value as an indicator of the compactness of the building shape in the workshops for architecture students.

The sketches of *Stadsskogen* pre-school in Alingsås, close to Gothenburg, Sweden, were already drawn, when the decision was done to make the project a passive house. In the end of the process the building failed to meet the passive house criteria. According to Swedish researchers, one of the main reasons for this was the unfavourable shape factor of the house[5]. The architectural concept of the house was based on one-storey-high volumes with a relatively complex shape both in plan and section, with good functionality but relatively high heat losses. When the energy target was set, after the sketch phase, it was too late to implement radical changes of the architectural concept.

[3] http://energiesparhaus.at/fachbegriffe/azuv.htm.
[4] http://www.passivhaus-platform.de/Gebaeudeform.103.0.html.
[5] Bülow-Hübe, Helen: Analys av förutsättningar och begränsningar vid utformning av skolor, förskolor och äldreboenden som passivhus i Sverige. In Conference Proceedings. Passivhus Norden 2008. The 1st Nordic Conference on Passive Houses. Trondheim 2008, pp. 270–280.

6. Simulation

The correlation between shape factor and the heating energy demand of a single-family house was studied by dynamic energy simulation software *IDA Indoor energy and climate 4.0*. The heating energy demand of buildings with net floor area of 150 m² and varying shape factors were calculated using a simplified building information model in IFC format. The simulations were carried out using the climate data of Helsinki (Finland), Gothenburg (Sweden) and Frankfurt am Main (Germany).

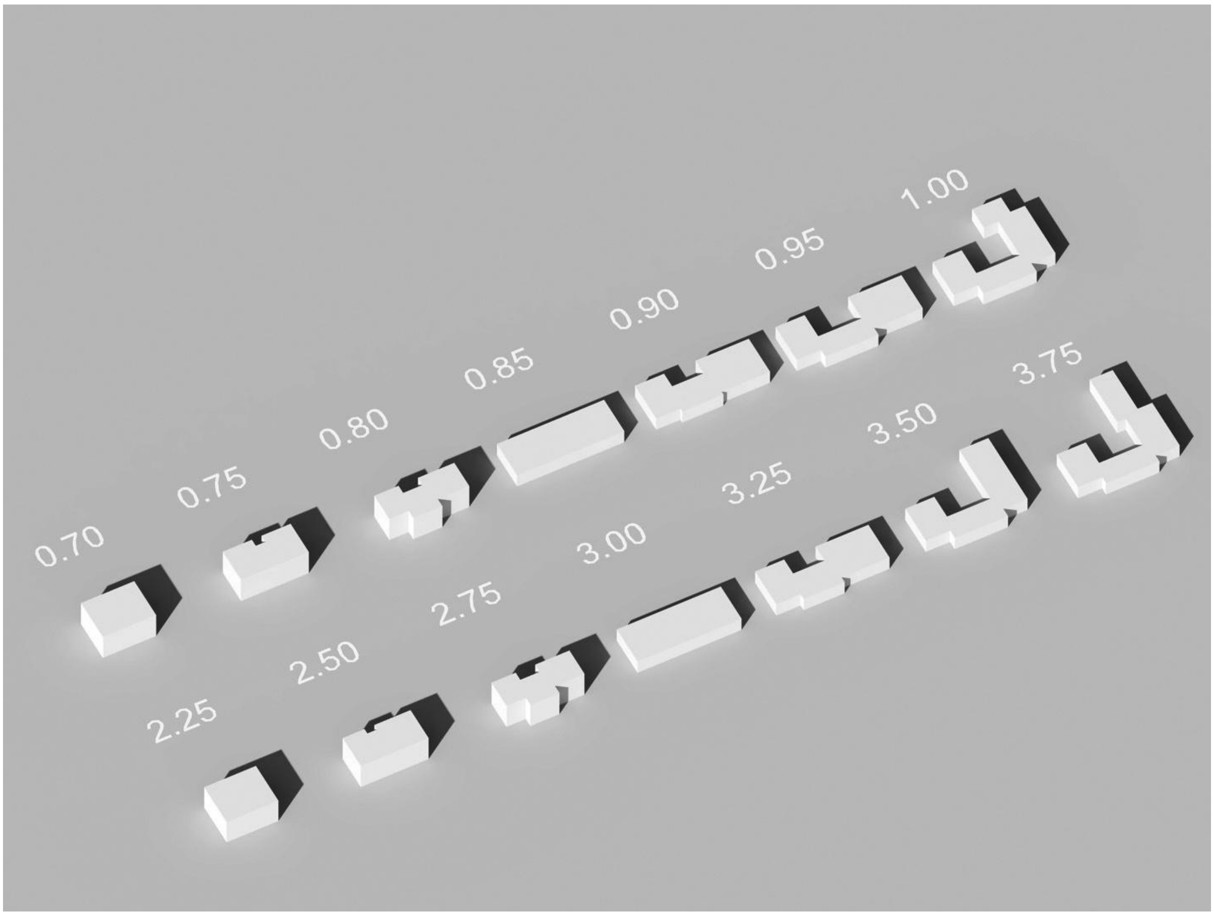

Image 1: Simulation cases with the net floor area of 150 m². In upper row the A/V ratio grows from 0.70 to 1.00. In lower row the A/A ratio grows from 2.25 to 3.75. A/V is calculated using the outside dimensions of the insulation layer. A/A is calculated using the interior dimensions of the building envelope.

Windows and doors were not built in the IFC-model to avoid inaccuracies caused by the variation in passive solar gains. The U-values were set according to the solutions of the first Finnish passive house pilot buildings with timber frame:

Exterior wall	0.10 W/m²K
Roof	0.08 W/m²K
$\text{Floor}_{\text{slab-on-the-ground}}$	0.09 W/m²K

Table 1: A/V ratio shows good correlation with the simulated heating energy demand, when the room height remains the same (2.7 m except the 2nd floor of the fist case, resulting to the shape factor of 0.70 m²/m³). The two storey high cases (0.70, 0.75 and 0.80 m²/m³) have extra 5 m² floor surface area for the staircase opening in the intermediate floor.

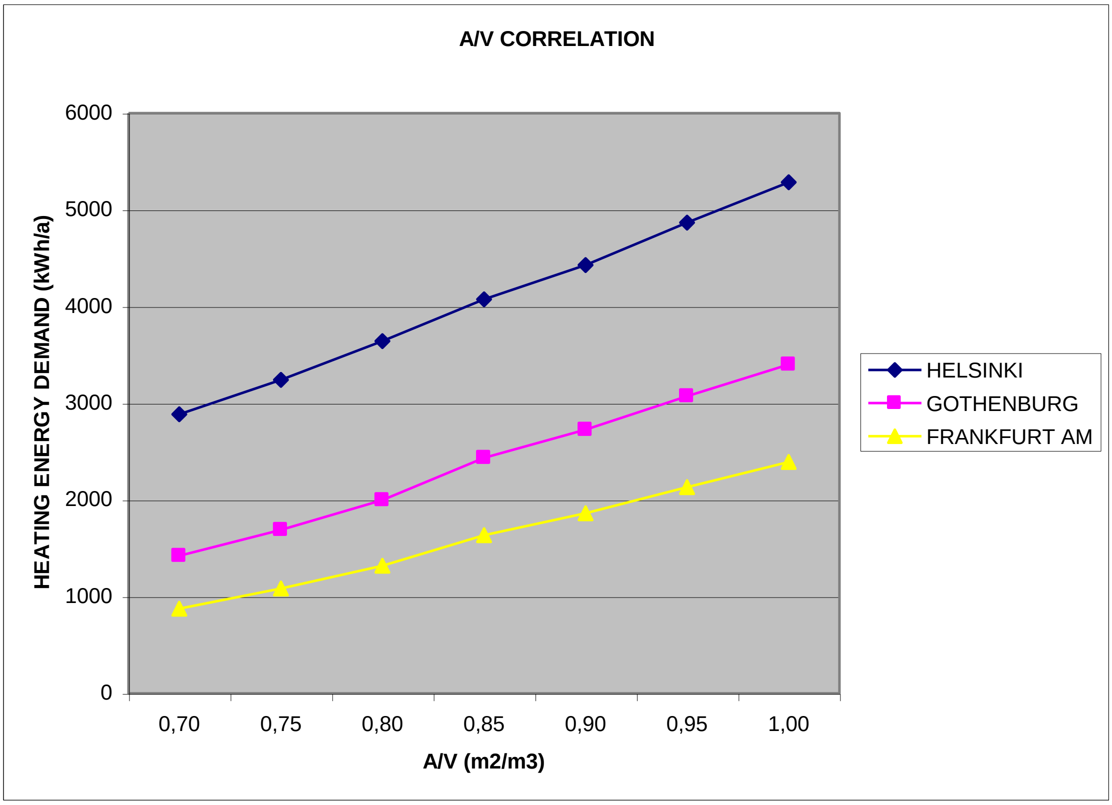

Table 2: A/A ratio shows good correlation with the simulated heating energy demand, but there is a clear shift in the results between the two-storey and one-storey cases. The two storey high cases (2.25, 2.50 and 2.75) have extra 5 m² floor surface area for the staircase opening in the intermediate floor.

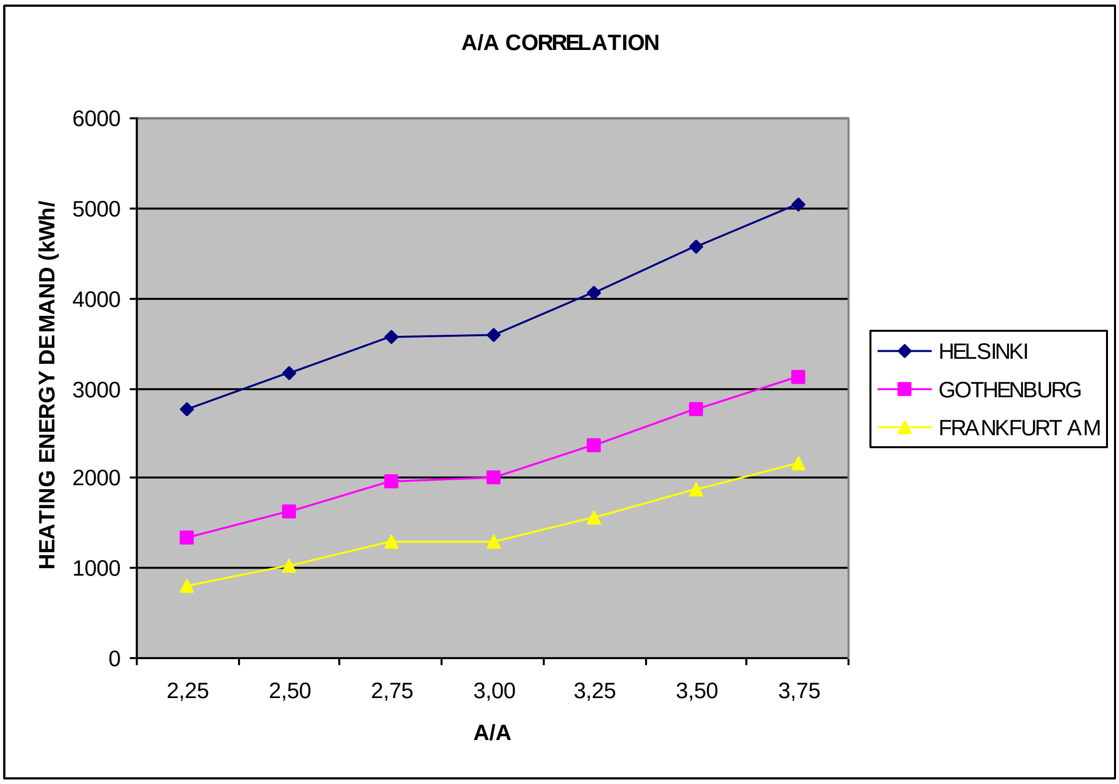

Table 3: When the height of the space increases, the heated volume and the heating energy demand grow. A/V ratio falsely indicates, that the architectural shape would get more compact when the height is increased. A/A ratio shows relatively good correlation with the simulated heating energy demand.

NET FLOOR AREA	INTERNAL HEIGHT	A / V	A / A	HEATING ENERGY DEMAND	INCREASE IN A / A (%)	INCREASE IN HEATING EN. (%)
150	2,4	0,89	2,90	3382	0	0
150	2,5	0,88	2,94	3464	1,30	2,42
150	2,6	0,86	2,98	3547	2,59	4,88
150	2,7	0,85	3,02	3629	3,89	7,30
150	2,8	0,84	3,05	3712	5,19	9,76
150	2,9	0,83	3,09	3794	6,48	12,18
150	3,0	0,81	3,13	3877	7,78	14,64
150	3,1	0,80	3,17	3960	9,07	17,09
150	3,2	0,79	3,20	4043	10,37	19,54
150	3,3	0,78	3,24	4126	11,67	22,00
151	3,4	0,77	3,28	4209	12,96	24,45

7. Discussion

The first simulation results confirm that shape factor A/V is not always a reliable indication of the heating energy demand, since increasing the height of the interior space increases the heating energy demand but decreases the A/V ratio. Thus it should not be used as a guideline for architectural design of energy efficient buildings. A/V ratio seems to be a proper indicator for the efficiency of the pure geometrical shape, but not architectural shape, where the efficiency of the solution is dependant on the functional floor area. Shape factor A/A describes the heat loss surface area in relation to the floor surface area, and in this sense it gives a better indication of the efficiency of the architectural solution than A/V. Based on the first simulation results, the A/A value seems to have a better correlation with the heating energy demand, but remarkable inaccuracy is caused by the solutions such as window surface area and thermal insulation properties of the building envelope. However, for evaluating if the shape of a building supports the low heating energy demand, A/A value can be used.

In terminology, the difference between the two ways of calculating the shape factor could be described as follows: the A/V ratio reflects the efficiency of the 3-dimensional volume; the A/A reflects the efficiency of the architectural volume, where the floor area (rather than volume) gives a better quantitative indication of the result.

Making the shape of the building less compact increases the heating energy demand more in the Helsinki climate than in the climates in Gothenburg or Frankfurt. If calculated in percentages, a poor shape factor means higher increase in the heating energy demand in the Central European climate than in Finland.

The Swedish way of defining the shape factor has certain benefits when used as an indicator of compactness and heating energy demand. It expresses the surface area of the building envelope in relation to floor area instead of heated volume. Since architectural design is commissioned in square meters and the targets for heating energy demand are set per square meter instead of cubic meters, the shape factor A_{om}/A_{temp} is more logical method for the rough evaluations of the sketch phase design. Using the inner surface area of the thermal insulation in the building envelope instead of the outside surface area might make the indicator even more useful. In the sketch phase the dimensions of insulation layer are not known yet; in practise they are defined later in the planning process based on the energy calculations. The shape factor could also be independent of the dimensions of the thermal insulation layer, if it is used as a mere indicator of the compactness of the building shape.

Further studies are needed to verify if the indication of the first simulation results is correct.

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[3] EnEV 2002

[4] EnEV 2009

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