Heated atrium in multi-story buildings: A design for better energy efficiency and social interactions

Itai Danielski, The Department of Ecotechnology and Sustainable Building Engineering, Mid Sweden University, SE-831 25 Östersund, Sweden, itai.danielski@miun.se

Gireesh Nair, The Department of Ecotechnology and Sustainable Building Engineering, Mid Sweden University, SE-831 25 Östersund, Sweden, gireesh.nair@miun.se

Morgan Fröling, The Department of Ecotechnology and Sustainable Building Engineering, Mid Sweden University, SE-831 25 Östersund, Sweden, morgan.froling@miun.se

Abstract

The shape factor of a building expresses the ratio between the building's thermal envelope area and its volume, or alternatively to its useful floor area. Buildings with lower shape factors will have lower heat losses through the thermal envelope and lower specific final energy demand. The shape factor of building could be reduced by a compact building shape design, and by increasing the volume of the building. However, the requirement for indoor natural light put a limit on the size of the building and therefore may limit the value of the shape factor. One possible solution to address this aspect is designing building with a heated atrium.

An atrium is a large enclosed space within a building, and may have a glazed roof. In a multi-story apartment building an atrium has the potential to increase the social interaction between the residents and, with the right design, at the same time reduce the heating demand of the building due to lower building shape factor. However, the use of atrium in residential buildings in Nordic countries has not yet gained popularity.

In this paper the impact of the heated atrium building with cylindrical shape design on the specific final energy is investigated by comparing such building design to conventional design buildings with similar floor area. The *Nydalahuset* project, in city Umeå in the north of Sweden, which is a multi-story residential building with a heated atrium, is used as a case study to investigate the affect of the atrium on the social interaction among the building occupants.

The results show that heated atrium building with cylindrical shape design is a better energy efficient design than the conventional buildings. Such buildings in cold climate could help to reduce the heat losses through the thermal envelope and facilitate to achieve the passive house criteria. Moreover, the *Nydalahuset* project suggests that the atrium design could improve the social interaction of occupants in residential buildings.

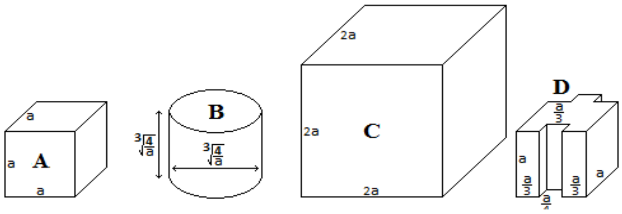
Keywords: Heated atrium, shape factor, social interaction, Nydalahuset, multi-story building, final energy demand.

1. Introduction

There are three main heat loss sources in residential buildings: through the ventilation system, through the sewage system and through the thermal envelope of the building. Among the three, the thermal envelope is responsible for large part of the total heat losses in most of the building stock in Nordic countries. According to the International Passive House Association (iPHA), heat demand of buildings could be reduced by 80% if the buildings are constructed according to the passive house standards [iPHA 2010]. iPHA provides five criteria for achieving a passive house standard: (i) exceptional high level of thermal insulation; (ii) well-insulated window frames with triple low-e glazing; (iii) thermal-bridge-free construction; (iv) airtight building envelope; and (v) comfort ventilation with highly efficient heat recovery [iPHA 2010]. Apart from these, the heat losses through the thermal envelope of the building could be reduced by having a lower shape factor [Danielski 2012], and a lower shape factor may be achieved by heated atrium building design. In addition to the possible energy savings a heated atrium in the building provides a common place for its occupant to meet throughout the year regardless of outdoor weather conditions. The social interaction may facilitate in creation of social capital and also may encourage energy efficiency behavior among the residents.

1.1. The shape factor

The shape factor is the ratio between the size of the thermal envelope and the volume of the building and its value is depended on three factors: the shape of the building, the size of the building and the smoothness of its facades as illustrated in Figure 1. Buildings with lower value of shape factor will have relatively smaller thermal envelope area. Smaller size of thermal envelope may reduce both conduction heat losses and infiltration flow rate. Similarly, reducing the amount of corners and edges in building façade could result in significant energy use reduction.



	A	B	C	D
Volume	a^3	a^3	$8a^3$	a^3
Thermal envelope	$6a^2$	**5.5**a^2	$24a^2$	$7a^2$
Shape factor	6/a	**5.5**/a	3/a	7/a

Figure 1 The value of the shape factor depends on the shape of the building for a given volume as illustrated by building A and B. Both buildings have similar volume but different thermal envelope areas, which results in different shape factors. The shape factor is also influenced by size of the building, as illustrated by buildings A and C. Larger building with similar shape will have lower shape factor. Irregular façades with trenches and bulges, e.g. heated balconies that extend beyond the façade will also increase the shape factor as illustrated by building D.

1.2. Heated atrium as energy efficient design

Residential buildings have requirement for natural light, as stated for example by the Swedish building regulations “Rooms in buildings, where people are present other than occasionally shall be designed and oriented to ensure adequate access to direct daylight” [Boverket 2011]. The penetration of natural light into the buildings is limited which thus limits the possible depth of the dwellings. To reach low values of shape factor, the size of the building should increase in all direction.

At the same time the natural light availability requirement also needs to be met. This dichotomy could be addresses by the heated atrium building design.

An atrium can be defined as a covered courtyard within the walls of the building. A courtyard within buildings is an old concept that can be found in the architecture of Romans, Chinese and Islamic civilizations. Historically, such courtyards were used for many purposes including cooking, sleeping, working, playing and gardening. The people also used such courtyards for social gatherings. However, the courtyard in the buildings from those period were not fully enclosed [Saxon 1986]. The climatic conditions determine the relevance of fully enclosed atrium, especially for social gathering purpose. For example, the buildings in tropical regions may not require a fully enclosed atrium, while regions with long winter period may require a fully enclosed atrium.

Buildings with roofed atriums were constructed during the 19th century. These buildings were mainly hotels or offices [Saxon 1986]. Such buildings were few in numbers till late 1960s, partly due to the advancement of mechanical heating and artificial lighting [Sharples and Lash 2007]. However, the construction of Hyatt Regency hotel, Atlanta in 1967 gave a new momentum for such buildings. The atrium at Hyatt with the wall climber elevator was a commercial success and lead to renewed interest in such buildings [Saxon 1986].

In modern context, the atrium design offers potential benefits to four functions of the buildings: cultural, economic, shelter and accommodation. From a residential buildings' perspective the shelter function may be most important as it provides a gathering space during all weather conditions [Saxon 1986].

1.3. Social aspects related to heated atrium building design

Social interactions provide an opportunity for residents in a locality to know each other better. This in turn would build the trust amongst the residents and creates a social network [Pretty and Ward 2001]. The social net working is an important aspect for the development of social capital [Portes 1998]. It is argued that the social capital contributes to several socio-economic benefits such as lower crime rate, better health and increased gross domestic product [Williams 2005]

The structure of the community and its social norms can have an important role in shaping the individuals' energy use decisions [Biggart 2007]. Several research indicates that community based activities could result in household energy efficient behaviors [Heiskanen et al. 2010; Hoffman and High-Pippert 2010]. The social interaction is the key for community based activities [Hori et al., 2013]. The availability of an appropriate common place or room may lead to face-to-face social interaction and thereby creating a community pride and ownership.

In multi-story apartment buildings, factors such as proximity of the apartments, its orientation towards other apartments, position and quality of common place, surveillance within the community affect the social interactions among dwellers [Cooper Marcus 1986; McCammant 1994; Abu-Gazzeh 1999]. The location of the common place is important for social interaction and if the place is centrally located and accessible then more dwellers will use it [Williams 2005]. Furthermore, the ability of the residents to see and hear others using the common place will encourage the social interaction [Williams 2005].

A common social gathering place in neighborhoods that consisted mainly of multi-story apartment blocks could be either inside or outside the buildings. An indoor common place could be of more utility in cold climatic regions as it provides a space for social interactions irrespective to the external weather conditions. However, the heated common room in multi-story apartment buildings are usually not designed in a way that the space could become an integral part of the homeowners' day-to day activities. There are a few exceptions to this and we use one such building as a case study.

1.4 Objective

The aim of this study is to analyze how heated atrium design would contribute to lower final energy demand in residential buildings. We also discuss on how heated atrium building design could contribute to the social interaction among the residents of the building.

2. Method

This study compare between two existing multi-story residential building, henceforth reference buildings, and a hypothetical building with a heated atrium design. The advantage of heated atrium building design is the ability to increase the size of the building for a specific building height.

The two reference buildings are identical in size with five floors and a rectangular plan design (Figure 2). The heated atrium building is a hypothetical building chosen to have five floors but with cylindrical shape design. The heated atrium building has similar apartment floor area, similar ratio of window to floor area and similar height as the two reference buildings jointly. One of the major differences between the two building designs is their shape factor. Because of its larger size and the smooth cylindrical shape design, the heated atrium building has 50% lower shape factor.

2.1. Reference buildings

The reference comprises of two identical multi-story buildings that were constructed during 2002. Each building has five floors with 2.7 m in height and a total of 1710 m^2 floor area divided among 16 apartments and common areas. Each building has 258 m^2 of glazed area, which is 15% of the total floor area. One of the two buildings is presented in Figure 2.

Figure 2 Illustration of the case study building.

2.2. Heated atrium building design.

The heated atrium building design was chosen to have cylindrical shape design (Figure 3) in order to explore the potential of energy efficiency to its extreme by shape and design. This design can provide lower shape factor than cuboid buildings (Figure 1) plus smoother façade that result with less linear cold bridges from corners and edges, where two walls meet.

Cylindrical shape design for residential buildings is not as common as a cuboid building design, but can still be found in different parts of the world, such as the cylindrical Candle house at Granary Wharf, Leeds, UK [Leeds Architecture Awards 2011].

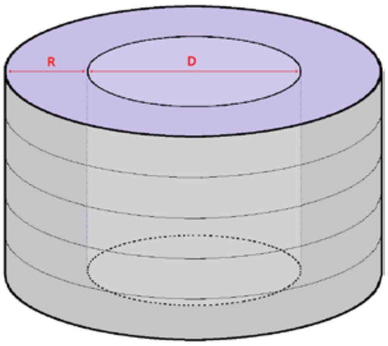


Figure 3 Cylindrical shape design with an atrium at its centre.

The heated atrium building's dimensions: 'R' and 'D' in Figure 3, were chosen to be 7 m and 21.6 m providing the same apartment area as the two reference building. Furthermore, the above dimension would provide the heated atrium with 366 m^2, similar to the atrium area in the *Nydalahuset* project (section 2.5). The total floor area of the building is 3420 m^2 which is divided among 32 apartments and common areas. The building has 516 m^2 of glazed area, which is 15% of the total floor area, and is higher than the minimum 10% suggested by the Swedish building codes [Boverket 2012]. Part of the atrium roof is assumed to be transparent to solar radiation. The transparent roof area should have good thermal properties and be optimized for sufficient daylight and low overheating in the atrium space. The design of the transparent roof is out of the scope of this paper. We assume that it is possible to provide sufficient daylight in the heated atrium[1].

2.3. Basis for energy calculations

The differences in specific final energy, land use and material use are analyzed and compared between the reference buildings and heated atrium building. The specific final energy demand of the building was calculated with the VIP-Energy simulation program. Four different scenarios of thermal properties were used, as listed in Table 1. The VIP-Energy simulation software [Strusoft 2013] is a commercial dynamic energy balance simulation program that calculates the energy performance of buildings hour by hour. VIP-Energy has been validated by IEABESTEST, ASHRAE-BESTEST and CEN-15265. Monitored data for wind, solar radiation and humidity obtained from the Climate Diagnostics Center at the Earth System Research Laboratory (NOAA) for the city of Göteborg in Sweden.

Table 1. Insulation thickness and U-values used in each of the four thermal envelope scenarios.

Scenarios	External wall		Roof		Ground floor		Window
	Insulation thickness	U-value W/(m^2 K)	Insulation thickness	U-value W/(m^2 K)	Insulation thickness	U-value W/(m^2 K)	U-value W/(m^2 K)
1	480	0.09	500	0.09	400	0.087	0.7
2	360	0.118	400	0.112	300	0.115	0.9
3	300	0.14	300	0.147	240	0.142	1.1
4	240	0.173	250	0.175	200	0.169	1.3

2.4. Assumptions

The buildings are assumed to be connected to the local district heating for space and domestic water heating. The buildings are assumed to have balanced ventilation with 75% heat recovery and specific fan power (SFP) of 1.85 kW/(m^3/sec). Values that are depended on occupants' activities and behavior are assumed as per the *FEBY12* report [FEBI 2012] listed in Table 2.

Table 2. Other parameters considered for the energy calculations [FEBY 2012].

Activity	Value
Indoor temperature in the apartments/common areas	21 ºC / 18 ºC
Solar shading factor	50 %
Heat from persons	1 W/(m2 year)
Domestic water heating*	25 W/(m2 year)
Household electricity**	30 W/(m2 year)
Infiltration by door and window openings	4 W/(m2 year)

* was considered as waste heat with no contribution to space heating.
**The demand for household electricity is not constant and assumed to vary throughout the year as described in *FEBY12*.

The apartment interior of cylindrical buildings will be different compared to traditional houses. Such houses, especially, multi-story apartment buildings are rare. Accordingly, the design we discussed is conceptual and with the assumption that such design could meet all the building regulations.

[1] The daylight aspect in the heated atrium does not seems to be a concern in the *Nydalahuset* project.

2.5. A case study on social aspects of heated atrium: *Nydalahuset building*

The *Nydalahuset* project at Umeå (Figure 4) is probably the only multi-story apartment building in North Sweden with a heated atrium. The building is located in Tomtebo, which is approximately five kilometers away from Umeå city centre.

Figure 4 *Nydalahuset* project at Umeå.

Figure 5 The heated atrium with private balconies.

The *Nydalahuset* project was constructed during 2005-2006. This five story building, managed by a co-operative housing association, has 32 apartments with 2-4 rooms and also has a heated courtyard (Figure 5). The total floor area of the apartments and the heated courtyard is 2891m^2 and 400 m^2, respectively. The building has windows on both its external and internal façades and an atrium with a glazed roof. The apartments have a private balcony at the exterior façade and a semi-private balcony facing towards the atrium (Figure 5). The design building heating demand is 61 KWh/m^2 with an average indoor temperature 20^{o}C and 13^{o}C in the apartment and atrium, respectively.

To understand the social benefits of the case study building we conducted an interview with the main architect of the *Nydalahuset* project. The interviewee has several decades of experience on sustainability issues. The interview, conducted on 14th February 2013, was based on a semi-structured questionnaire and lasted for approximately one hour. The questionnaire consisted questions about the reasons for constructing such a building, homeowners' general perception towards the concept, specific lessons learned from the project, and how more similar buildings could be constructed across Sweden. The interview was recorded. This paper provides the opinion of one architect who also designed the building with heated atrium.

3. Results and discussion

3.1. Buildings' specific heat demand

Figure 6 illustrates and compares the specific final energy demand, excluding energy for household electricity, between the reference buildings and the heated atrium building design. The comparison is shown for four scenarios of different thermal envelope properties. Under all the four scenarios the heated atrium design has lower specific final energy demand. The difference in specific final energy demand, between the reference and the heated atrium design, reduces as the thermal envelope properties of the buildings are improved. This is illustrated in Figure 7.

As per the Swedish passive house criteria the specific final heat demand of the building should not exceed 50 kWh/(m^2 year) [FEBY 2012]. The reference buildings with the best thermal envelope scenario will require 53 KWh/(m^2 year) (Figure 6). To meet the passive house criteria those buildings may install solar water heating to replace part of the district heating energy or need to further improve their building envelope.

On the other hand, the heated atrium building design is likely to achieve the passive house criteria even with the worst building envelope scenario (Figure 6). These values correspond to insulation thickness of about 200mm-250mm, which is current normal building practice in Sweden.

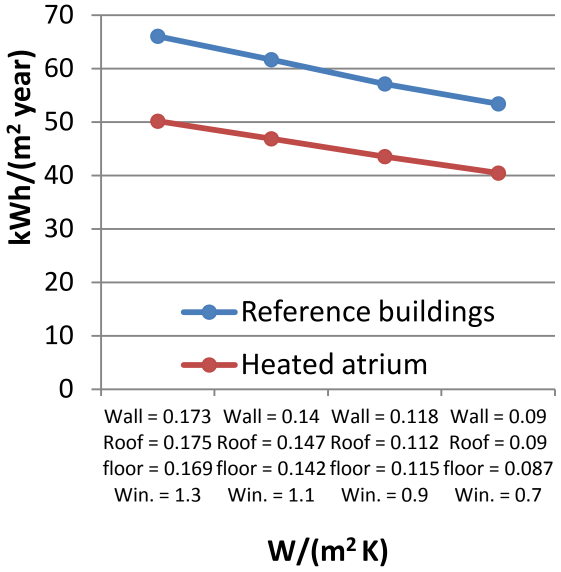


Figure 6 The specific final energy demand, excluding household electricity, for the reference buildings and the heated atrium building design under different scenarios of thermal envelope properties.

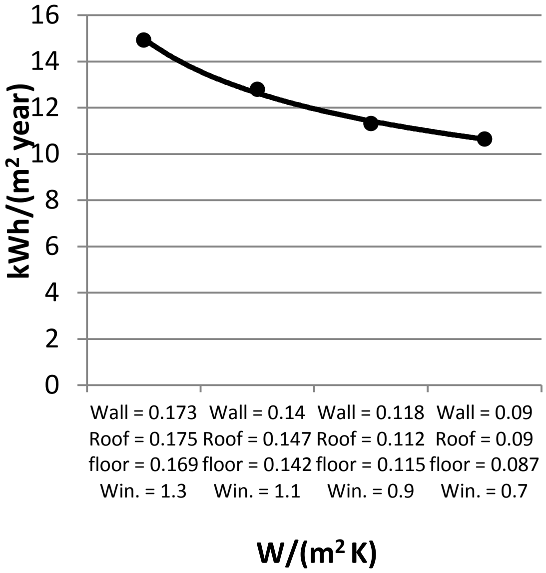


Figure 7 The difference in specific final energy demand between the reference buildings and the heated atrium building design under different scenarios of thermal envelope properties.

The heated atrium building design may use larger ground area due to the atrium. In this study 14% more ground area than the combined area of the two reference buildings. However, the total land used by the two reference buildings is larger because of the need for the green area in between them, as illustrated in Figure 8. In this specific case the construction of buildings with heated atrium will result with lower land use for the same apartment floor area and building height.

The total envelope area of the analyzed heated atrium design building is 15% lower in comparison to the total envelope area of the two reference buildings. The heated atrium design building has also an interior façade, which include walls and windows. The temperature difference between the apartment areas and the heated atrium are less compared to that outside the building. Hence less energy efficient envelope material may be used for the inner façades of the building. Accordingly, compared to the reference buildings the heated atrium building design may have lower embodied energy. However, the difference in total building embodied energy between the two building designs needs further analysis.

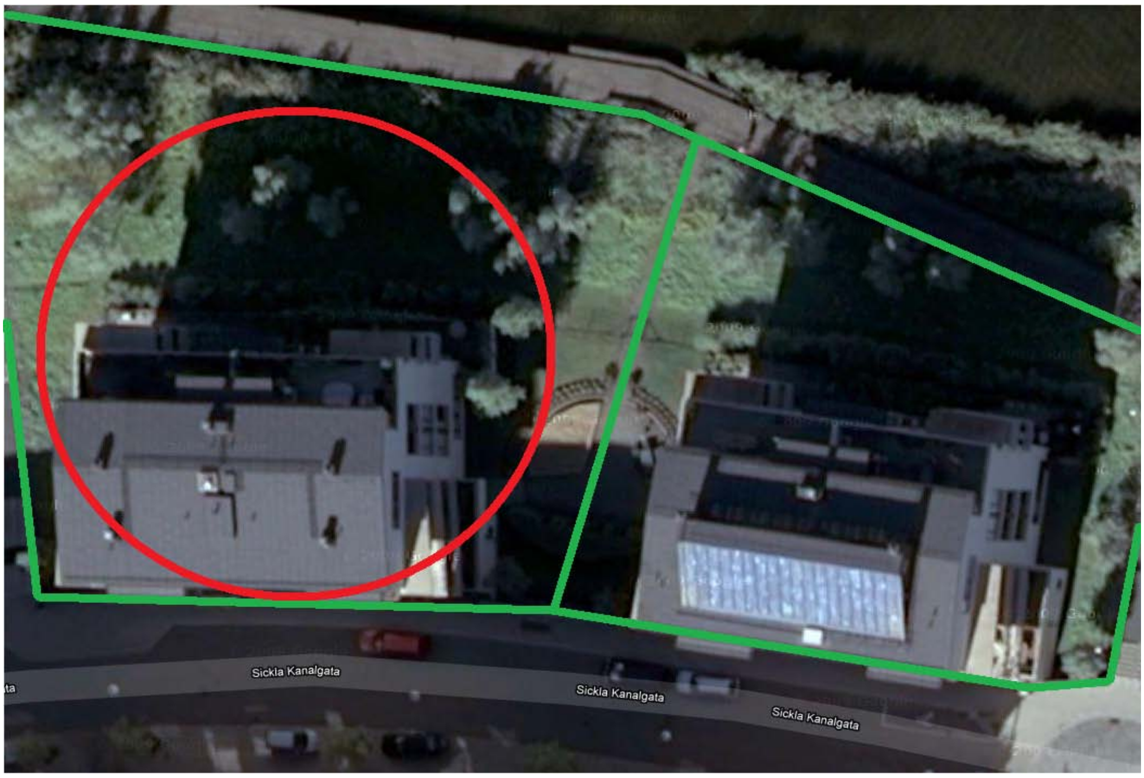


Figure 8 A comparison between the land use of the two similar reference buildings (green boundary) and the land that would have been used by the heated atrium building design (red circle).

3.2. Perceptions of the building architect

The following sections are based on the interview we had with Anders Nyquist: the architect of *Nydalahuset* project.

The building was constructed on a commercial model and the design was driven mainly by a social vision. According to Anders the conventional multi-story buildings doesn't encourage social interaction among the neighbors. Also, such building structure is isolating people and is psychologically stressful.

> "They [conventional apartment buildings] are flats….with an entrance and an elevator and people go straight to their apartments…..it is a way to store people in the night"

> "In such apartments we might meet somebody in the entrance or in the elevator… but my experience suggest that when people feel somebody is going in the same entrance/elevator we might walk faster to avoid them"

> "You live close to other people but usually it will be only after several years that you will know about them"

The possibility of social interaction in a building with a heated atrium might be higher. For example, many homeowners' the *Nydalahuset* might keep their front door open.

> " it means that I am at home and if you require something….come along"

The residents, especially during Friday evening will have food together at the heated atrium. Also, they occasionally organize concerts in that place. Accordingly, the heated atrium provides an opportunity for social gathering and interaction among the neighbors. The community belongingness of the residents was reported to be higher. The residents are willing to exchange support. For example, the younger residents when they go out for shopping may ask their elder neighbors for shopping help, while the elders offer babysitting their younger neighbors' child.

The people who first bought the apartments in *Nydalahuset* building were motivated by the heated atrium concept. The original owners of the apartments belong to middle-class people and from different age cohorts. The homeowners' were satisfied with the social concept but were reported to be unsatisfied about a few quality aspects with the buildings. Also, there may be a communication gap with the way the apartments was marketed as having a heated courtyard that could provide Mediterranean climate. The builder incurred additional expenditure to address the homeowners' concerns.

According to Anders the adoption rate of high energy efficient building with heated atrium is very slow. The different stakeholders are not sufficiently interested in such buildings. Such buildings will cost more compared to a conventional buildings but the operational cost will be significantly less. As per Anders the potential buyers' main interest is the initial investment and building location, while builders want to construct buildings at the cheapest cost that comply with the existing building regulations. The important step to facilitate the rate of adoption of such buildings is to construct more demonstration projects that could convince its attractiveness to the stakeholders.

4. Conclusions

This study shows that the building's design can play an important role in reducing the energy demand in residential buildings. To reduce the heat losses from the building envelope the shape factor of the building should be minimized to the extent possible. This could be done by the choice of the building shape, by reducing the amount of linear thermal bridges and by increasing the size of the building.

A way to increase the size of multi-story residential building is by cylindrical shape buildings with a heated atrium at its center. This specific design will "relocate" part of the external façade to an indoor environment and will reduce the shape factor of the building. In comparison to the apartment areas the atrium has lower specific final energy demand. Accordingly, its contribution to the final energy demand of the building is not significant. Therefore the volume of such buildings is not as important as its shape factor for achieving the low final energy demand.

Additional advantage of heated atrium building design is the possibility to create a sense of community belongingness among its occupants. By providing a common space for social interactions, it may also facilitate energy efficiency improvements initiatives among residents. However, heated atrium designs for multi-story buildings are rare in Sweden. More demonstration projects are needed to better understand the energy and social benefits of such buildings. Similarly, it is pertinent to collect the opinions of the actual users of such residential buildings.

Acknowledgement

The financial support from the European Union Regional Development Fund is gratefully acknowledged.

5. References

[Abu-Gazzeh 1999] Abu-Gazzeh, T., Housing layout, social interaction and the place of contact in Abu-nuseir, Jordan, Journal of Environmental Psychology 19, 41-73 (1999)

[Biggart 2007] Biggart, N.W., Economic sociology and the social problem in energy inefficiency. American Behavioral Scientist 50, 1070-1087 (2007)

[Boverket 2011] The National Board of Housing, Building and Planning (Boverket), Building Regulations, BBR 19, web accessed at http://www.boverket.se/ on 2013.

[Cooper Marcus 1986] Cooper Marcus, C.a.S., W., Housing as if people mattered. Site design for medium density family housing. Berkley, CA, University of California (1986)

[Danielski 2012] Danielski, I., Large variations in specific final energy use in Swedish apartment buildings: Causes and solutions. Energy and Buildings, 49(0): p. 276-285 (2012)

[FEBI 2012] Sveriges Centrum för Nollenergihus (Swedish center for zero energy houses), Kravspecifikation för nollenergihus, passivhus och minienergihus Bostäder (The specification for zero energy, passive and minienergihus buildings), 2012, web accessed at http://www.nollhus.se/ on 2013, (in Swedish).

[Heiskanen et al. 2010] Heiskanen, E., Johnson, M., Robinson, S., Vadovics, E., Saastamoinen, M., Low-carbon communities as a context for individual behavioural change. Energy Policy 38, 7586–7595, (2010)

[Hoffman and High-Pippert 2010] Hoffman, S.M., High-Pippert, A., From private lives to collective action: recruitment and participation incentives for a community energy program. Energy Policy 38, 7567–7574 (2010).

[Hori et al., 2013] Hori, S., Kondo, K., Nogata, D., Ben, H., The determinants of household energy-saving behavior: Survey and comparison in five major Asian cities. Energy Policy 52, 354-362 (2013)

[iPHA 2010] iPHA International Passive house association, Active for more comfort: The passive house, web eccessed at http://www.passivehouse-international.org/ on April 2013 (2010)

[Leeds Architecture Awards 2011] The Leeds Architecture Awards, web accessed at http://www.leedsarchitectureawards.co.uk/award-winners on 2013 (2011).

[McCammant 1994] McCammant, K., Durret, C., Cohousing: A contemporary approach to housing ourselves. CA, Ten Speed Press (1994)

[Pretty and Ward 2001] Pretty, J., Ward, H: Social Capital and the Environment. World Development 29, 209- 227 (2001).

[Portes 1998] Portes, A., Social capital: Its origins and applications in modern sociology. Annual Review of Sociology 24, 1-24 (1998)

[Sharples and Lash 2007] Sharples, S., Lash, D., Daylight in Atrium Buildings: A Critical Review. Architectural Science Review 50, 301-312 (2007)

[Saxon 1986] Saxon, R., Atrium Buildings: Development and design. The Architectural Press, London (1986)

[Strusoft 2013] Strusoft, VIP-Energy simulation program, web accessed at http://www.strusoft.com on 2013.

[Williams 2005] Williams, J., Designing neighbourhoods for social interaction: The case of cohousing. Journal of Urban Design 10, 195-227 (2005)