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# Heated atrium in multi-storey apartment buildings, a design with potential to enhance energy efficiency and to facilitate social interactions

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ABSTRACT

The design concept of conditioned atria gains increasing popularity in commercial and service buildings all over the world, but is still not a common building design in the residential sector. This study investigates the potential of such design in residential buildings in Nordic climates as means to enhance both energy efficiency as well as social interaction among residents. Energy modelling was used to compare energy efficiency among designs of residential buildings with and without atrium and to identify important design parameters. Social interaction was analysed, based on a survey evaluating the perception of residents living in an existing multi-storey apartment building designed with a heated atrium in the north of Sweden.

The results show that heated atrium in Nordic climates have a potential to reduce the total final energy demand while at the same time increase the conditioned space of the building. To positively impact energy efficiency, the atrium should fulfil three requirements: (i) it should be designed to reduce the shape factor for the whole building; (ii) it should have the minimum glazed area that comply with the building requirements concerning natural light and visual comfort; and (iii) adjustable solar shading should be installed in the atrium's façades to avoid unwanted overheating. The survey results indicate that the additional space created by the atrium has a potential to facilitate and promote social interaction among residents and to increases a sense of neighbourliness and belongingness, which are often discussed as important parameters in relation to social sustainability.



## 1. Introduction

Sustainable development can be expressed as stable societies where people are able to satisfy their basic needs and live good lives, within the limits of planetary boundaries [1]. The built environment holds a major challenge for sustainable development as it impacts both environment and society. In Nordic countries it is responsible for one-third of the final energy demand [2] and plays an important role regarding social issues like interactions of people and sense of community [3]. While there are both environmental and social aspects to consider, regarding technical solutions to move society in the direction of sustainable development, focus is most often solely on one of these aspects, and their interlinkage is rarely explored. In this paper both energy and social aspects are studied regarding residential buildings designed with heated atrium in Nordic climates.

An atrium or open courtyard is an old design concept that can be found in warmer climates in the architecture of ancient civilisations such as the Romans, Greeks, Chinese and Arab cultures [4]. Courtyards from those periods were generally not fully enclosed [5] and where important for social life through interaction during variety of social activities like working and gardening within a sheltered environment. Social interactions provide opportunities for social ties which in turn are beneficial for the psychological well-being of individuals [6]; it facilitates a community feeling and sense of pride and attachment among people living in a specific area [7]. A sense of community provides individuals with a sense of the "right to

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belong" [8], of security, emotional safety [9] and improved subjective wellbeing [10]. The courtyard also had positive effects on the indoor thermal and visual comfort within the adjacent buildings to the courtyard. It provided daylight, passive solar gains [11] and was part of the natural ventilation system as it acted as an air channel to enhance convective airflow through and around the adjacent buildings [12].

In Nordic climates, an open courtyard design within buildings may not entail large benefits as a place for social interaction within the building due to shorter daylight hours and poorer outdoor thermal comfort during the cold season. A design with an enclosed and heated courtyard within a residential building (henceforth called "heated atrium") may be utilized to a greater extent throughout the year.

### 1.1. Atrium buildings – design aspects

Studies concerning unconditioned atria in residential buildings [13–15] have indicated that the type of atrium, geometry and size, are important for the overall energy efficiency of buildings. The relation between geometry, building size and energy performance can be addressed by the shape factor of a building. The shape factor is a measure of the compactness of buildings. Buildings with lower shape factors have smaller thermal envelope area in proportion to their volume and therefore lower heat losses during the heating season [16–18]. The shape factor of a building can be reduced by a building design that combine both compact form and large volume [18]. Larger building volume can be achieved by increasing the height and the length of a building. However, the maximum possible width of residential buildings is limited due to requirements of natural light and visual comfort. According to the Swedish building regulations [19]: "*Rooms in buildings, where people are present other than occasionally shall be designed and oriented to ensure adequate access to direct daylight*". Baker and Steemers [11] defined spaces that benefit from daylight solar gains (and natural ventilation) as the "passive zone". They approximated the maximum width of the passive zone to twice the floor height, or about 5.5 m in a typical residential building. Beyond that depth, artificial light is needed also during daytime [11]. The feasibility of atrium design with respect to daylight is described in extensive reviews on daylight in atrium buildings by Sharples and Lash [20] and by Samant [21]. Cooling demand can be another concern in an atrium due to extensive solar radiation through the glazed area. Excess heat could be reduced by shading devices, or removed by higher ventilation flow or by active cooling [22–24].

### 1.2. Atrium buildings – energy aspects

Early buildings with enclosed atria were constructed during the 19th century following advances in iron and glazing manufacturing technology [20]. During the 20th century the atrium design became less popular, probably due to advances in heating ventilation and air conditioning systems and the use of artificial lighting, which could provide similar advantages as atria at the cost of energy use [20]. The construction of Hyatt Regency hotel, in Atlanta in 1967 gave a new momentum for enclosed atrium building design. The atrium at Hyatt, with its wall climbing elevator was a commercial success and lead to renewed interest in such buildings [5]. Atria in commercial and service buildings have become common all over the world, and are expected to continue to be developed in various degrees and applied in modern architecture, in particular, to large-scale buildings [25].

Atrium design in service buildings, like shopping centres, office and school buildings, has been analysed in several studies concerning daylight-linked lighting controls [26,27], thermal comfort [28,29], passive cooling [30], shopping and socializing [31], and spatial integration [32]. Aldawoud and Clark [14] compared the energy performance of an office building with unheated centralized atrium to the same building having an open courtyard in the Netherlands. They concluded that high rise buildings with enclosed atria have better energy performance in comparison to low rise buildings. Aldawoud [33] also analysed a commercial office building with centralized atrium design with different length to width ratios and different height. He concluded that: a square-shaped atrium is more energy efficient, low rise atrium buildings are more efficient in temperate and cold climates, and high rise atrium buildings are more efficient in hot dry climates. Harris [29] compared the energy performance of two school buildings designed with atria; one atrium was heated while the other had floating temperature. He concluded that the atrium increases heating demand but also result in comfortable conditions for a greater proportion of the winter time. However, the two buildings and their atria had different geometries and design. Laouadi et al. [34] studied the thermal and energy performance of centralized, semi enclosed and linear atria in cold climates. Their analysis include different alternatives like glazing types, glazing area and skylight shape. They showed that the glazing type and glazing area have large impacts on both heating and cooling demand in the atrium, but no details were provided about the adjacent building or the effect of the atrium on the heating and cooling demand in the adjacent buildings. In addition there was no comparison to non-atrium buildings and it is not clear if an atrium increases the total energy efficiency of a building in comparison to building without atrium design.

Only a few studies have investigated the energy performance of residential buildings designed with atria. Taleghani et al. [35] analysed the effects of open courtyard and enclosed atrium spaces on energy performance and indoor thermal comfort of terrace buildings in the Netherlands. They showed that a glazed roof atrium reduces the heating demand during the heating season, but increases the number of discomfort hours in summer in comparison to open courtyard.

Wall [13] investigated a terraced building with unheated atrium design, a multi-storey apartment building with unheated atrium design, and street with glazed roof, all located in Sweden. The investigated parameters were the atrium indoor temperature and the energy demand in the adjacent buildings enclosing the atrium. She concluded that an unheated atrium with adjacent buildings on its three sides was the best at collecting and retaining solar heat gains, but it would not achieve thermal comfort conditions during the heating season. It would have only minor effect on the energy demand in the adjacent atrium buildings if used as a climate buffer zone or to preheat the supply air to the adjacent buildings.

According to Wall [13], if atria will be heated to thermal comfort conditions in Nordic climates, the overall final energy demand of the building will increase, i.e. both for the atrium and adjacent buildings. Wall calculated 65 kWh/(m$^2$ year) net increase heating demand for an atrium with adjacent building on three sides. However, both Taleghani et al. [35] and Wall [13] analysed atria that were designed to have floating temperature, i.e. the atria were not intended to be heated to thermal comfort conditions during the cold season.

### 1.3. The aim

This study investigates the integration of heated atrium design in multi-storey apartment buildings in Nordic climates to enhance both environmental and social sustainability. Enclosed and heated atrium design in multi-storey apartment buildings is not common in the Nordic regions and indoor common areas in multi-story