POTENTIAL FOR ENERGY SAVING IN TRANSITIONAL SPACES IN COMMERCIAL BUILDINGS

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ABSTRACT

As it is known, the energy consumption of buildings is directly linked to their energy demand. Therefore, the most direct strategy to reduce the energy consumption of a building is to minimise its energy demand. This can be done in two ways. On the one hand, the energy demand can be reduced by minimising the size of some energy consuming spaces in the building. It can also be reduced by minimising the requirements of their comfort conditions. This second strategy is especially effective in transitional spaces, where the comfort requirements have wider limits than in normally occupied zones so energy savings are possible by allowing for a modest relaxation of the comfort standards. This paper reports on an analytical study into the energy-saving potential associated with modifications in thermal comfort limits in transitional spaces in commercial buildings. Such transitional spaces may not require the same high level and close control as more fully indoor or fully occupied areas, and thus a wider variation in conditions and interpretation of thermal comfort may be permitted. They also take up a significant fraction of the total volume of these kinds of buildings and give rise to significant energy use to provide comfort by means of heating or cooling systems. Initial trial calculations have been conducted using standardised commercial building layouts in order to determine the potential for energy savings. Commercial buildings have been chosen not only due to the extensive presence of this kind of building in almost all cities, but also because of the considerable percentage of transitional spaces that these buildings have in a standard floor plan. The relationship between these transitional spaces and the indoor areas will also be considered in this study. Estimates are made of the energy-saving potential based on different commercial buildings located in the climate of the Barcelona area in Spain.

INTRODUCTION

Transitional spaces

There are spaces in architecture that cannot be classified as either indoor or outdoor and whose existence cannot be explained in terms of any precise or specific use [1]. We can find this kind of space between the indoor environment and the outdoor environment, without defined limits between inside and outside. They are the transitional spaces and they have existed across different cultures throughout the history of architecture. Moreover, although transitional spaces may not have any specific use, they are required to fulfil a function of transition between the outdoors and the internal constructed environment, so this is why they are such adaptable and comfortable spaces, as well as why they are found in such a diverse array of places.

This paper deals with transitional spaces from an environmental point of view, due to the opportunity that such spaces provide for possibly modifying the comfort requirements.

Strategies to lower energy consumption

The energy consumption of buildings is directly related first to the efficiency of artificial energy systems and secondly to the energy demand of the buildings themselves. Due to the fact that the rise in the energy efficiency or performance of air conditioning and heating systems has its limits, and therefore there is little margin for reducing consumption, the challenge lies in reducing the energy demand without changing the users' perception of comfort.

From the standpoint of architectural design, this drop in the building's energy demand can be made both by minimising the size of some of the spaces inside the building that consume energy (which would have clear repercussions on the formal resolution of buildings and the consequent use and behaviour of the users), and by lowering the requirements in certain areas of the building, which would be more or less feasible depending on the kind of space in which we are acting. In this sense, the second strategy is particularly effective in transitional spaces, where we can allow greater variation in the thermal conditions and where the environmental needs have much broader limits than in the remaining spaces, leading to potentially quantifiable energy savings. Furthermore, in many cases transitional spaces bring added value to the architectural design regarding the users' perception of thermal comfort, as they dynamically adapt to environmental conditions halfway between indoor and outdoor and thus are not as static as the unvarying interior conditions.

Lowering the demand in transitional spaces

As a direct consequence, according to the typology of the building being studied, this reduction in consumption can be more or less important. This study concentrates on all the transitional spaces in public buildings. Despite the fact that they might also show private transitional elements (such as galleries, balconies, etc.), most of their functional demands require them to have large communal transitional spaces (such as entry lobbies, hallways, etc.).

Within these public buildings, we can find a series of examples (such as schools, museums, markets, airports and commercial buildings) that are based on the routes the users take through the building. That is, they all share the common feature of possessing large transitional spaces. In these cases, the hallway is one of the transitional elements between outdoors and indoors, and it is also the element that joins the different service-providing units (such as classrooms, works of art, market stalls, shops or products for sale, etc.).

By analysing the thermal needs of these transitional spaces, we reach the conclusion that they largely depend on the thermal needs of the different units to which the spaces lead, as well as on the relationships existing with these units. Furthermore, the thermal needs of transitional spaces also depend on the degree to which they are exposed to the outdoor environment (closely or loosely related) as well as on their own function, that is, how long the users are in them and these users' expectations, adaptation time, etc.

Therefore, this study focuses specifically on commercial buildings since a priori they seem to be clear examples of transitional spaces with a vast potential for energy savings, associated first with the wide margin of their levels and environmental control limits and secondly with the high percentage of the total volume they occupy in the standard floor of this kind of buildings. What is more, there are extensive examples of this building model throughout history as well as in the majority of cities in the world today: from the Mediterranean Greek and Roman agorae and stoas to the bazaars and souks of the warm Islamic climates, and even the porticoed galleries found in rainy climates and today's shopping malls.

METHOD

Existing environmental conditions

This study is based on real examples and was calculated for the city of Barcelona, which is located at a latitude of 41º 20’ N and in a mild, humid Mediterranean climate which is hot in the summer (Csa), according to the Köpen-Geiger climate classification from the University of Melbourne. Regarding the temperatures, the winters are mild with average temperatures of 9º C to 11º C, while the summers are hot, with average temperatures ranging between 23º C and 24º C and a moderate thermal amplitude and average yearly rainfall of around 600 mm.

Study models

Based on an analysis of the contemporary casuistic of shopping centres in the city, we generated three basic calculation models. The first is the traditional shop model, usually on a local scale and relatively small in size, rectangular-shaped and attached to other shops on the side facades and with a relatively permeable facade facing the street outdoors through which customers enter (model A). On the other extreme is the mall-type building, which usually has a large interior volume and is shaped compactly and hermetically as a building. This model usually has a percentage of opaque facade and slightly lower percentage of glass-encased facade. Furthermore, the circulation to reach the goods for sale takes place inside the building, so in this case the goods for sale and the transitional space have the same environmental conditions (model C). Between model A and model C are commercial buildings which, like bazaars or ancient porticoed galleries, contain a series of independent shops connected to a transitional space with its own environmental conditions, halfway between the indoor conditions of the shops and the outdoor conditions. Therefore, these are rectangular-shaped shops attached to each other on their side facades with a highly permeable main facade leading towards a transitional space with environmental conditions between indoors and outdoors and an opaque rear facade facing outdoors (model B).

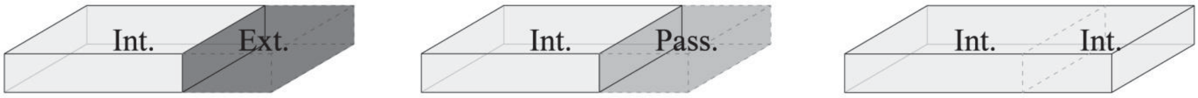

Figure 1: From right to left, model A, model B and model C of shops used in the simulation.

The top exponent of this kind of commercial building (model B) in Barcelona is Illa Diagonal, a building dating from 1993 designed by Rafael Moneo and Manuel de Solà-Morales. This building was taken as the reference for obtaining the initial values of volumes, surfaces, compactness, etc. Likewise, the shops near the city’s commercial arteries, such as Sants Street, and the shops in Barcelona’s Ensanche district were taken as references for model A. The El Corte Inglés department store in Francesc Macià Square was taken as a reference for model C.

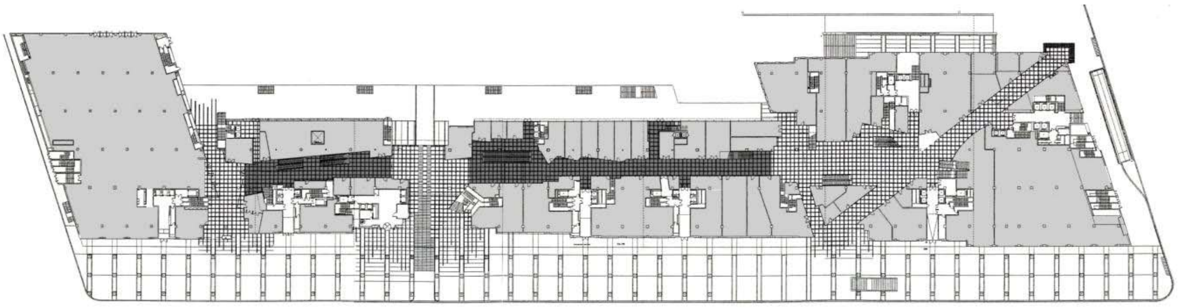

Figure 2: Ground floor of the Illa Diagona. Heated/air conditioned shops (gray), semi-h./a.c. transitional spaces (dark squares) and not h./a.c. transitional areas (light squares).

Calculations and simulation

A simulation was planned of the three basic models using the Archisun v3.0 software [2] developed by the Architecture and Energy research group at the U.P.C. This programme calculates the energy behaviour of buildings in a natural scheme and provides climatic and consumption results for 15 days in the four seasons. A variety of general parameters are taken into consideration in the calculations, including the building's location and its climatic data, those related to the definition of its immediate environment, as well as parameters related to the building's shape (such as the orientation, compactness and porosity), the volume, internal contributions and how it is used. Other more specific parameters are also taken into account, related to the interior design of the model and the definition of its skin (with variables on its placement, attachment to other buildings, the average coefficients of its skin thermal transmission, the hermeticity of its practicable surfaces, reflectances and transparencies, weights, protective and obstructive factors, and many others).

Therefore, a simulation was performed based on the three. In all three models, we assumed average outdoor temperatures of 26.6º C in the summer and 8.1º C in the winter.

Regarding model A, the standard volume was taken, and it was assumed that both the floor and ceiling and three of the four facades are attached to areas with the same environmental conditions (24º C in summer and 21º C in winter). To the contrary, the main facade, which is in contact with outdoor conditions, has a higher thermal transmission coefficient (U), since it is made of glass, and is also more permeable to the air.

Regarding model B, the same standard volume was taken, and it was assumed that the floor, ceiling and two of the four facades are attached to spaces with the same environmental conditions described above. Likewise, the rear facade has a low thermal transmission coefficient (of a standard opaque closure) in relation to the outdoor conditions. In contrast, the main facade has a greater thermal transmission coefficient since it is made of glass, plus it is more permeable to the air. However, the main facade does not exchange with an atmosphere in outdoor conditions; rather it exchanges with the naturally controlled atmosphere of the transitional space.

Since the Archisun software only allows one outdoor atmosphere to be presented, we introduced a coefficient "α" which relates the outdoor temperature conditions with the temperature conditions of the transitional area, such that in model B the exchanges of the rear facade are calculated by relating the indoor atmosphere with the outdoor atmosphere, and the exchanges of the main facade are calculated by relating the indoor atmosphere with the atmosphere in the transitional area (outdoor atmosphere times coefficient "α").

This coefficient "α" is obtained as follows:

- Assuming that the artificially heated or air conditioned shops will exchange energy primarily with the transitional space (due to the fact that the ground, ceiling and two facades in model B are attached to spaces with the same conditions and that the rear facade has a very small thermal transmission coefficient in relation to the large coefficient of the main facade and its extreme permeability to the passage of air).

- Assuming as well that the transitional space exchanges energy primarily with the outdoor atmosphere (due to its permeability to the air and the presence of large glass-encased spaces).

We conclude that the heat flow lost from the commercial spaces to the transitional space should be equal to the heat flow lost from the transitional space to the outdoor environment (bearing in mind in both cases the transmission, ventilation and internal contribution).

Thus, if the heat flow is equal to 0:

$$\sum Q = 0$$

Therefore:

$$Qin. \rightarrow trans. = Qtrans. \rightarrow out.$$

$$\boxed{Qtrans.in. + Qvent.in. + Qcont.in. = Qtrans.out. + Qvent.out. + Qcont.out.}$$

In which:

$$Qtrans. = \sum Si Ui \cdot \Delta T$$

$$Qvent. = Vi \cdot \delta \cdot Ce$$

$$Qcont. = in.contribution$$

With this, we obtain a function with three unknowns: the indoor temperature, the temperature of the transitional space and the outdoor temperature:

$$Tpas. = \frac{(k \cdot Tin.) + (k' \cdot Tex.) + k''}{k''''}$$

Assuming the outdoor and indoor conditions described above for the summer and winter, the result is:

$$\alpha = \frac{\Delta Tin.}{\Delta Tex.} = \frac{Tin. - Tpas.}{Tin. - Tex.}$$

Thus, we obtain the values: summer α = 0.4; and winter α = 0.26, in order to simulate with Archisun.

Regarding model C, the standard volume was once again taken, but adding the proportional part of the transitional area which is integrated into the inside of the shop and in the same environmental conditions. We also assumed that the floor is attached to a space with the same environmental conditions. To the contrary, we assumed the same kind of attachment for the ceiling, but with the percentage of roof proportional to the total volume of the building (since in this case there are neither homes nor offices above it). The four side facades were assumed to be open to spaces in the same environmental conditions, but also with the corresponding percentage of glass-encased or opaque facade corresponding to the volume of the model in relation to the total volume of the building.

RESULTS

The results of the simulations are as follows:

SUMMER	**Model A**	**Model B**	**Model C**
Outdoor temp. (ºC)	26.6	26.6	26.6
Transitional area temp. (ºC)	-	24.8	-
Natural indoor temp. (ºC)	27.1	27.1	27.6
Cooling energy consumption (kWh/m^3·year)	0.59	0.60	0.85

Table 1: List of outdoor temperature, temperature of the transitional area and natural indoor temperature as well as energy consumption for air conditioning in the summer scenario.

WINTER	**Model A**	**Model B**	**Model C**
Outdoor temp. (ºC)	8.1	8.1	8.1
Transitional area temp. (ºC)	-	17.6	-
Natural indoor temp. (ºC)	13.7	14.7	13.4
Heating energy consumption (kWh/m^3·year)	3.99	2.76	4.36

Table 2: List of outdoor temperature, temperature of the transitional area and natural indoor temperature as well as energy consumption for heating in the winter scenario.

DISCUSSION

Based on the simulations, we can see that the natural temperature results and therefore consumption are not significantly different. However, we can conclude that there are two variables that are particularly influential when calculating the results and which therefore must also be particularly influential when designing commercial spaces. First, we found that the parameter of the renewals per hour that the space experiences is particularly influential, that is, whether it is a very hermetically sealed place or, on the opposite extreme, highly ventilated (and therefore with high accessibility, but also with a higher energy exchange with the contiguous space). Secondly, we also noted that the parameter of internal contributions from the shop is also particularly influential, that is, the amount of heat dissipated inside it due to the activity of people, lighting points, computers, etc. Thus, we can see how the influence of the energy exchange due to the thermal transmission of the walls is not a priority parameter in the commercial spaces, and therefore when designing them a sound study of the ventilation and internal contributions from the commercial space will be much more decisive than the thermal insulation itself.

CONCLUSION

Finally, we should note that bearing in mind that the results of consumption are much more balanced than what might have been forecasted at first, model B does show an advantage regarding comfort, since it manages to achieve a more gradual thermal adaptation of the shop users with a higher adaptation time since they go from an outdoor to a fully heated and/or air conditioned indoor atmosphere through an intermediate atmosphere in environmental conditions that are halfway between indoors and outdoors.

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