Optimisation of Heating Energy Demand and Thermal Comfort of a Courtyard-Atrium Dwelling

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ABSTRACT: In the light of energy reduction, transitional spaces are recognised as ways to receive natural light and fresh air. This paper analyses the effects of courtyard and atrium as two types of transitional spaces on heating demand and thermal comfort of a Dutch low-rise dwelling, at current and future climate in 2050. The inclusion of a courtyard within a reference Dutch terraced dwelling showed an increase in annual heating energy demand and a decrease in the number of discomfort hours. In contrast, covering the courtyard and making an atrium led to reduction in the heating demand but more discomfort hours. Results showed that using a courtyard in May through October and covering that (as an atrium) for the rest of the year is the most efficient situation in the Netherlands.
Keywords: heating demand, indoor thermal comfort, courtyard, atrium, climate change

INTRODUCTION

There is a growing concern about energy use and its implications for the environment. Transitional spaces have been used for thousands of years [1-3] and have emerged in different types (courtyards, atria, balconies, corridors, etc.) for varied purposes. Nowadays, several studies seek solutions to cope with climate change. This paper investigates courtyard and atrium, as possible passive strategies for buildings in the temperate climate of the Netherlands. More precisely, the courtyard and the atrium as transitional spaces will be analysed to see whether they can provide energy efficient and more comfortable environment for dwellings in the Netherlands in the light of climate change by 2050. In other words, the main aim of the study presented is whether the use of transitional spaces in low-rise dwellings can be a solution for temperate climates if these become subject to climate change.

CLIMATE CHANGE IN THE NETHERLANDS

Climate change has eight identified effects: warming oceans, shrinking ice sheets, sea level rise, global temperature rise, declining arctic sea ice, glacial retreat, extreme weather events and ocean acidification [4]. It is difficult to estimate to what extent these effects of climate change will occur, and in which timeframe. Therefore the IPCC works with different variants, sets of probabilities, each leading to different outcomes for the temperature increase and sea level rise. The Royal Dutch Meteorological Institute (KNMI) has translated the IPCC variants to four main scenarios in 2050, divided as in a matrix of two times two: a moderate and warm scenario (+1°C, +2°C temperature increase respectively) versus unchanged or changed air circulation patterns. Figure 1 presents these four scenarios in the Netherlands.

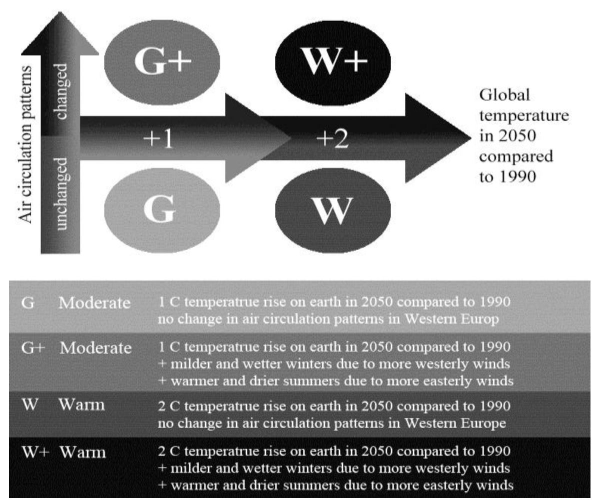

Figure 1: Four climate scenarios for the Netherlands in 2050 [5].

Recent investigations in the Netherlands show a greater probability towards W (Warm) and W+ (Warm+) rather than G (Moderate) and G+ (Moderate+), implying higher temperatures throughout the year as well as dryer summers and wetter winters. For dwellings, this is more important because the indoor thermal comfort needs to be adjusted to higher outdoor temperatures due to climate change. Preferably, this needs to be done without mechanical interventions, because correction by means of air conditioning units would increase the fossil fuel consumption, thereby more provoking climate change and heating up urban areas locally due to waste heat from the air conditioning devices. Another consequence of the most probable

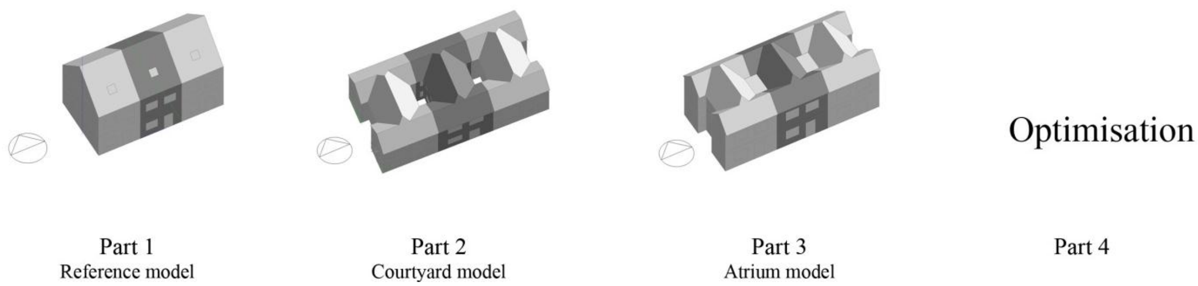

Figure 2: The research parts.

scenarios is an increase of precipitation in winter and heavier showers in summer, which in a common Dutch situation would be discharged as quickly as possible, but this now already creates flood problems, so local retention will become necessary.

METHODOLOGY

This paper is based on simulations in four parts. Part one introduces the reference model for this study. This reference model is a typical Dutch mid-terraced dwelling, which does not have any form of transitional space. In the second part, a courtyard model is made by introducing a small courtyard in the reference dwelling of part one. In part three, the courtyard of the dwelling from part two is covered with a glazed roof, creating an atrium. In the last part, the courtyard dwelling from part 2 has a glazed roof in winter (from October through April) and no roof in summer (from May through September). For the simulations of this paper, the DesignBuilder Software v.3 is used. This simulation software is a user-friendly interface for EnergyPlus. The simulation is based on hourly weather data and among others takes into account solar heat gains through windows, heat conduction and convection between different zones and the energy applied or extracted by mechanical systems [6].

For the calculations of summer thermal comfort, this study uses ASHRAE 55-2010 [7]. Thermal comfort boundaries are limitations that help to estimate to what extent a building should be heated or cooled. In other word, when the indoor temperature of a building falls below or raises above comfort boundaries heating or cooling is needed. Regarding the weather data for the simulations, the climate of De Bilt (52°N, 4°E) in the Netherlands is used as a temperate climate (Based on the classification of Köppen-Geiger). The prevailing wind is South-West and the mean annual dry bulb temperature is 10.5°C. The summer thermal comfort standard is applicable for the free running mode. This mode typically occurs from 1st of May until 30th of September in the Netherlands.

RESULTS

PART ONE: THE REFERENCE MODEL

Based on this model in DesignBuilder, the representative climate of the Netherlands (NEN5060) [8] and the severest climate scenario (W+) were simulated. These simulations help to understand how climate change affects the dwelling's indoor environment and energy use. Figure 3 depicts the indoor operative temperatures. As illustrated, the indoor operative temperatures are more or less identical in winter for each situation. The reason is that in wintertime, this temperature is not so much influenced by the outdoor conditions but by the heating system of the dwelling. However, during the free running time (May- September), the indoor operative temperatures differ. In this period, the models are not conditioned and their indoor environment mainly depends on outdoor conditions. The highest indoor operative temperature increase, equal to 2.5°C, can be found in the W+ scenario in the months June, July and August. For that climate scenario, the monthly average outdoor dry bulb temperature increase approximately equals 3.0°C in the respective months.

Correspondingly, the heating energy demands of the models based on the two sets of weather data are monitored in Table 1 and 2. Considering air temperature raise due to the climate change, it is logical that less energy is needed for heating in winter in the future scenario. Thus, the heating energy demand of the reference dwelling based on the representative weather data of current climate is 26 kWh/m^2/a and for the future climate scenario (W+) is 19 kWh/m^2/a (27% less). Because of the increase of indoor operative temperature during free running time, the number of thermally comfortable hours changes. Calculations using the adaptive thermal comfort model from ASHRAE 55-2010 show that by the increase of outdoor drybulb temperature, the number of hours that the indoor temperature exceeds the 80% satisfaction range increases from 46 hours (from the current climate) to 331 hours (for W+), which equals respectively 4% and 31% of the total number of hours.

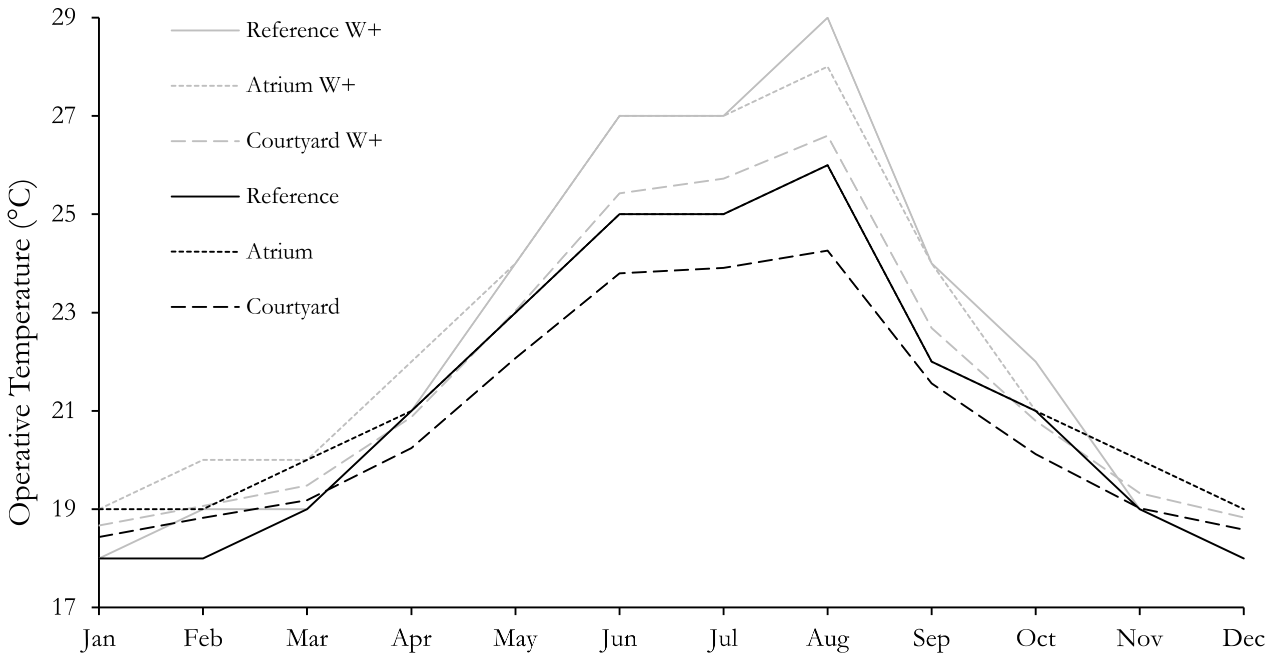

Figure 3: Operative temperatures of the models based on NEN5060 and W+ climate scenario.

PART TWO: THE COURTYARD EFFECT(S)

At this step, the effect(s) of having a courtyard as a transitional space within the reference dwelling is studied. For this reason, a courtyard dwelling based on the reference model is simulated (with the same specifications). The simulated monthly heating energy demands of the models in the current climate and climate scenario W+ are depicted in Table 1 and 2. The courtyard dwelling has a higher heating demand than the reference model (45 and 26 kWh/m^2/a respectively). Although an open transitional space like this courtyard increases solar gains, it makes the building prone to more transmission, ventilation and infiltration heat losses. With the increase of outdoor temperature (due to climate change), the heating energy demand is consequently decreased. The average reduction during a year for the model is 1.1 kWh/m^2 for the reference model and 1.7kWh/m^2 for the courtyard. Since the courtyard model has a higher surface to volume ratio than the reference model, the differences in heating energy demand also show how surface to volume ratio relates outdoor environment to the heating demand of a building.

From the summer thermal comfort point of view, the indoor operative temperatures of the model needs to be analysed and compared together. In Figure 3, the indoor operative temperatures of the reference and the courtyard dwelling are illustrated in the context of the two sets of climate. Comparing the reference model and the courtyard model during free running mode, the indoor operative temperature of the reference model is 1°C and 3°C higher than of the courtyard model in the current climate and W+ scenario. These differences between the reference model and the courtyard model are due to the transmission losses through the surfaces. Apparently, since the courtyard model has a higher surface to volume ratio, it is easily prone to heat loss and ventilation. Based on the calculated comfort temperatures for this period of 5 months, 15% of the occupied hours are not comfortable. As shown in the last part, the reference model has the largest number of discomfort hours (31% of occupied hours) in the future scenario.

PART THREE: THE ATRIUM EFFECT(S)

In this part, the open roof of the courtyard model simulated in part two is covered with a glass roof (U-value of 2.2 W/m^{2}K). In the last part, the simulated dwelling with a courtyard showed an increase in heating demand in comparison to the reference dwelling. In this step, the courtyard is covered to analyse whether this strategy increases the energy efficiency of the dwelling in wintertime. Referring to Table 1, the heating demand of the courtyard dwelling is compared with the atrium model in the current and future climates of the Netherlands. During the cold months, the differences are clearly noticeable. In this regard, the average winter monthly difference (November- April) for the courtyard and the atrium dwelling is 2.3 kWh/m^2. This difference

Table 1: Monthly heating energy demand and discomfort hours (based on the current climate scenario) At=atrium; Cy**= courtyard. *At=Atrium, **Cy=Courtyard.*

	Reference model		Courtyard		Atrium		Priority	Optimised model	
	Heating kWh/m^2	Discomfort hour	Heating kWh/m^2	Discomfort hour	Heating kWh/m^2	Discomfort hour		Heating kWh/m^2	Discomfort hour
Jan	8	-	12	-	9	-	At*	9	-
Feb	5	-	7	-	5	-	At	5	-
Mar	3	-	5	-	3	-	At	3	-
Apr	1	0	1	0	0	0	At	0	0
May	0	2	0	0	0	16	Cy**	0	0
Jun	0	56	0	31	0	66	Cy	0	31
Jul	0	36	0	22	0	48	Cy	0	22
Aug	0	31	0	5	0	38	Cy	0	5
Sep	0	0	0	0	0	0	Cy/At	0	0
Oct	1	0	1	0	1	0	Cy/At	1	0
Nov	4	-	6	-	4	-	At	4	-
Dec	6	-	10	-	7	-	At	7	-
Sum	28	125	43	58	30	168	-	30	58

indicates that in a temperate climate covering the transitional space can save the heating energy demand up to 11 kWh/m^2 for a whole year for the courtyard dwelling. Considering the models in the severest climate scenario (W+), the heating energy demands have been reduced (as visible in Table 2). As an illustration, the average reduction during a year for the models from the current climate to the future climate scenario W+ is 1.2 kWh/m^2 for the atrium dwelling.

Also overheating risk needs to be checked for the atrium (because a glassed roof environment is easily prone to increase the number of summer discomfort hours). Figure 3 clearly shows how the indoor operative temperature increases during summer in the atrium model compared to the courtyard dwelling for the current climate and W+ climate scenario. As the average monthly operative temperatures of the models are shown, converting the courtyard model to an atrium increases indoor operative temperature. Generally, it shows covering a courtyard and converting it to an atrium, makes the indoor environment warmer. Furthermore, the mentioned models in the context of W+ climate scenario are considered. With this intention, the atrium model is 1.2°C warmer than the courtyard model. Consequently, the atrium model has higher number of discomfort hours. As an illustration, the increased percentage of discomfort hours for the atrium model is 18% higher than the courtyard model (for the climate scenario W+).

PART FOUR: OPTIMISATION

As discussed in the last part, adding an atrium to a dwelling decreases its annual energy use but increases the number of discomfort hours in summer. Contrary, adding a courtyard to a dwelling increases its annual energy use but decreases the number of discomfort hours in summer.

At this stage, it is tried to combine the two types of buildings simulated in last parts optimise them for both thermal comfort and heating energy demand. Therefore, in this step the two types of transitional spaces are considered for different periods in a year. It is assumed to have an atrium in wintertime (October - April) and an open courtyard in summer (May - September). For this analysis, the same parameters used in the last parts – thermal comfort and heating energy demand- are the main indices for the optimisation. Therefore, in the beginning of this part, the period of five typical summer months for the open transitional space will be tested, and if the results show an increase in efficiency and thermal comfort, the duration of the period will be widened or shortened.

For the first step of the optimisation, the monthly heating energy demands and the number of discomfort hours are monitored in Table 1 and 2. Thus in one hand, from the heating energy demand point of view, the atrium model is 13 kWh/m^2 (in the context of the current climate) and 7 kWh/m^2 (in W+ climate scenario) in a year more efficient than the courtyard dwelling. On the other hand, having a look at the indoor operative temperature (in summer) as illustrated in Figure 3, Table 1 and 2, the number of discomfort hours in the courtyard dwelling is less than in the atrium dwelling. Therefore, the combination of the two modes of transitional spaces (open or closed) for a dwelling could be based on the advantages and disadvantages of monthly performance of the modes.

Table 2: Monthly heating energy demand and discomfort hours (based on the W+ climate scenario).

	Reference model		Courtyard		Atrium		Priority	Optimised model	
	Heating kWh/m^2	Discomfort hour	Heating kWh/m^2	Discomfort hour	Heating kWh/m^2	Discomfort hour		Heating kWh/m^2	Discomfort hour
Jan	6	-	9	-	7	-	At	7	-
Feb	3	-	5	-	4	-	At	4	-
Mar	2	-	3	-	2	-	At	2	-
Apr	0	0	0	0	0	0	Cy/At	0	0
May	0	28	0	8	0	34	Cy	0	8
Jun	0	96	0	63	0	106	Cy	0	63
Jul	0	73	0	52	0	84	Cy	0	52
Aug	0	134	0	43	0	125	Cy	0	43
Sep	0	0	0	0	0	2	Cy/At	0	0
Oct	0	0	0	0	0	0	Cy/At	0	0
Nov	2	-	4	-	3	-	At	3	-
Dec	5	-	8	-	6	-	At	6	-
Sum	18	331	29	166	22	351	-	22	166

In Table 1 and 2, the “Priority” columns show which one of the models- courtyard or atrium- has the best performance concerning energy use and/or summer thermal comfort. According to the results, the courtyard model has a higher heating energy demand while lower number of discomfort hours in comparison with the atrium dwelling. Thus, an optimised model could be made based on the benefits of the two types of models; the atrium should be used for winter (reducing heat losses through the transitional space), while the advantages of the courtyard should be used for summer (allowing fresh air and decreasing overheating). Based on the simulations, it would be more efficient if the transitional space within the reference model is open for about 4 to 6 months (May until August, September or October) and be glazed for the rest of the year. For this optimised model and in the context of the current climate, the heating energy demand is 30 $kWh/m^2/a$ and 5% for discomfort hours. Regarding the future climate scenario (W+), the heating energy demand will be 22 $kWh/m^2/a$ and 15% for discomfort hours.

CONCLUSIONS

This paper considered the effect of using a transitional space in a Dutch mid-terraced dwelling (based on AgenstchapNL; Netherlands Ministry of Economic Affairs). The main aim was to increase the energy efficiency and summer thermal comfort. In this regard, the dwelling was simulated in the context of current climate and the future climate scenario in 2050. In one hand, the results of adding a courtyard within the dwelling showed that it reduces the indoor operative temperature in summer, and consequently the number of discomfort hours, but increases the annual heating demand of the dwelling. On the other hand, covering the courtyard and converting it to an atrium led to a lower heating energy consumption of the dwelling but also led to more thermal discomfort in summer. During the optimisation part, different months were considered for both thermal comfort and heating energy demand between courtyard and atrium situation. Monitoring the different performances of the two models showed that the optimal period of having a courtyard is between the months of May through October. In the period from November until April, the courtyard should be covered with glass. It is worthy to mention that this optimisation was based on monthly performance of the models. Further research can consider hourly performance of buildings to make a balance between courtyard and atrium model during day and night time. An open courtyard could allow sun and fresh air during warm hours and keep the transitional space covered (with an atrium) during cool hours.

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