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Energy use impact of and thermal comfort in different urban block types in the Netherlands

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ABSTRACT

This paper discusses the energy and comfort impact of three types of urban block configuration in the Netherlands. The annual heating and lighting energy demand, and summer thermal comfort hours are compared. In total, 102 thermal zones forming single, linear and courtyard building combinations are simulated within the Netherlands' temperate climate. The results demonstrate the importance of the surface-to-volume ratio in achieving both annual energy efficiency and summer thermal comfort. Considering different types with 1-, 2- and 3-storey heights, the courtyard model has the lowest energy demand for heating and the highest number of summer thermal comfort hours.

1. Introduction

The idea of using the environmentally best building shape was addressed in the 1960s by architects [1] and urban planners [2]. In the beginning, urban designers and planners considered the most favourable land use, whereas architects studied the forces of nature that shape our buildings. Ever since, with increasing environmental concerns and diminishing fossil fuels, more intense attention has been directed to the effect of urban morphology [3–9] and building form [10–12] on energy consumption within the built environment. In this regard, urban designers generally concentrated on the outdoor environment and architects and building physicists on the indoor environment.

On this account, architects' and urban designers' responsibilities overlap at the scale of the urban block, potentially causing design conflicts. For instance Olgyay [1], as a building physicist, states "*all shapes elongated on the north–south axis work both in winter and summer with less efficiency than the square one. The optimum lies in every case (climate) in a form elongated somewhere along the east–west direction*". However, many studies from urban designers as Yezioro [13] show: "*rectangular urban squares elongated along the north–south direction are the best solution (for solar gains)*". Therefore, this paper tries to investigate the effect of different urban block layouts (urban designers' decision) on indoor environment (building physicists' objective).

There is a body of literature dealing with urban block layout effects on the indoor environment. Regarding different layouts, Steemer et al. [7] proposed six archetypal generic urban forms for London (51°N) (Fig. 1) and compared incident solar radiation, built potential and day-lighting criteria. They concluded that the courtyard performs best among these six archetypes. Ratti et al. [14] conducted similar analyses for the hot climate city of Marrakech (31°N). Okeil [15] generated a built form named the residential solar block (RSB), which later was compared with a slab and a pavilion court [16]. The RSB was found to lead to an energy efficient neighbourhood layout for a hot and humid climate at a latitude of 25°N. Furthermore, Thapar and Yannas [17] showed the importance of ventilation in urban squares for the hot and humid climate of Dubai. They also indicated the role of vegetation in providing a comfortable microclimate. Yang, Li [18] studied four parameters in Beijing's climate that influence the urban block thermal environment: block height, thermal mass, material conductivity and surface albedo. They found the geometry (height) of the square is the most important, and the surface albedo the least one. Moreover, Taleghani et al. [19] indicated that a single-family house with no open space is more energy efficient than a courtyard, an atrium and a building with a sunspace in Rotterdam (52°N). The explanation related to the surface-to-volume ratio of dwellings. This paper continues this work on an urban building scale. In addition, since solar radiation plays an important role in heat gains, each urban block form in all of these studies is optimised for a specific latitude.

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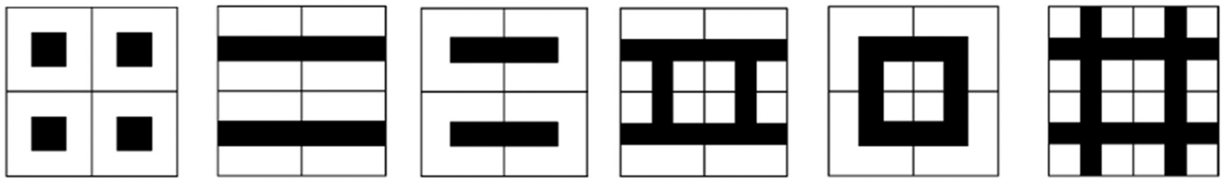

Fig. 1. Generic urban forms. From left to right: pavilions, slabs, terraces, terrace-courts, pavilion-courts and courts [14].

In this paper, the categories of Steemers et al. [7] shown in Fig. 1 is simplified to three urban layouts. These urban layouts shape almost all urban layouts; single shape like villa and free standing buildings, linear shape like all urban canyons and streets, and finally courtyard form which is visible in all urban blocks and plazas.

The heating and lighting energy demand and thermal comfort of dwellings in these urban forms were studied for the climate of Rotterdam in the Netherlands. One hundred and two simulations were run to estimate the heating and lighting energy demand of zones within the three different urban forms, in one, two and three storey configurations. Afterwards, calculations with different algorithms were done to estimate the thermal comfort in each. Finally, the results were interpreted based on the following indices: surface-to-volume ratio (the level of zone exposure to its outdoor environment), solar gains (the effect of the sun), heat loss through external air (the effect of wind), and daylight factor (the potential of zones to benefit from natural lighting).

2. Method and models

For this building simulation research the DesignBuilder software was used, which is based on the state-of-the-art building performance simulation engine, EnergyPlus. The simulation principle used by DesignBuilder is one of the most comprehensive methods with dynamic parameters and it includes comprehensive accounting of energy inputs and energy losses. The simulation is based on EnergyPlus hourly weather data of the Netherlands, taking into account solar heat gains through windows, heat conduction and convection between different zones and the energy applied or extracted by mechanical systems [20,21], among other things. Moreover, DesignBuilder is validated through the BESTest (Building Energy Simulation TEST) technique, developed under auspices of the International Energy Agency. For this study, the following was implemented in DesignBuilder:

Construction In the simulations, the wall, roof and glazing types were parameterised with the data in Table 1.

HVAC The heating system considered for models is based on radiator (same as actual Dutch low-rise dwellings). It is assumed that radiators turn on with the heating set point of 21 °C (and the heating set-back is 12 °C). Generally, radiators are based on electricity and hot water. For the simulations, radiators work with hot water supplied by a gas boiler. Moreover, the radiant fraction assumed is 0.65. Radiant fraction determines what fraction of the power input to the radiator is actually transferred to the space as radiant heat.

Regarding the ventilation, it is assumed to use natural ventilation by opened windows (15%) when the indoor air temperature has risen to above 22 °C. The models are not equipped with a cooling system since the predominant parts of Dutch dwellings are in free running mode during summer. Furthermore, there is an operation schedule for the zones. The operation schedule specifies the times when full setback and set points should be met. In this regard, the zones are assumed to be occupied between 16:00 and 23:00.

Glazing type and lighting Most of Dutch dwellings have large glazing to achieve maximum daylight. This is mostly because of the high latitude (52°N) and consequently low sun angle during the winter time (15° at 12:00 on 21st of Dec). The amount of 30% window to wall ratio is a very close average used for modelling in the Netherlands. The external window type for the models is a double glazed (Dbl LoE) with an air gap in between layers (U-value = 2.55 W/(m^{2}K)). Fig. 2 shows the input data used for the

Table 1
the wall and roof properties used in the simulations and calculations.

Section	U-value W/(m^{2}K)	R_c-value (m^{2}K)/W
Wall: - Brickwork Outer Leaf (100 mm) - Air Gap (40 mm) - EPS Expanded Polystyrene (100 mm) - Concrete Block (100 mm) - Gypsum Plastering (10 mm)	0.31	3.0
Roof: - Bituminous roof finish (2 mm) - Fibreboard (13 mm) - XPS Extruded Polystyrene (80 mm) - Cast Concrete (100 mm) - Gypsum Plastering (15 mm)	0.33	2.9
Glazing: - Generic PYR B Clear (6 mm) - Air (6 mm) - Generic Clear (6 mm)	2.55	0.39

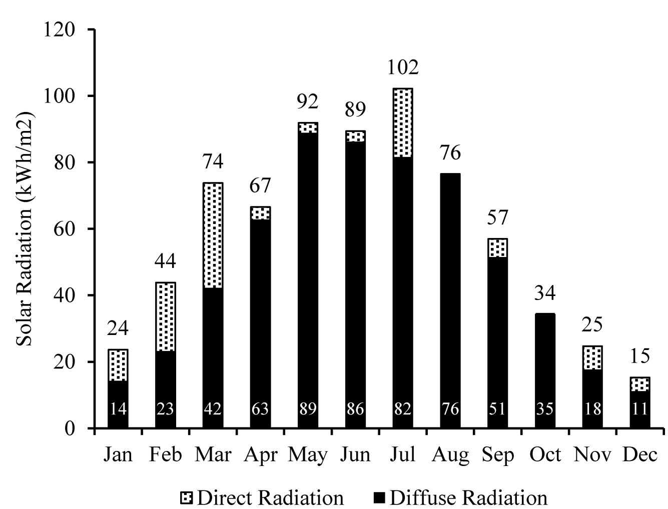

Fig. 2. Monthly average global radiation levels in Rotterdam, split into diffuse radiation and direct radiation.