Low energy and level of requirements
The example of flexibility in space planning

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ABSTRACT: Through the example of space flexibility, this paper explores the connection between choices made by real estate developers and the feasibility of low energy buildings. It shows that high requirement levels lead to architectural and technical consequences that make low energy architecture more difficult or more expensive. This study concludes on a vision of the buildings' design process, where architecture is seen as the creation of a potential for low energy achievements. The balance of forces between investment capacities and requirements levels turns this potential into low, medium or high energy buildings.
Keywords: flexibility, space planning, design process, low energy

INTRODUCTION

Most of researches in the PLEA context handle with two fields: the shape and form of architecture (through parameters as orientation, insulation, opening ratios, natural lightning …) and the performance of techniques (energy efficiency, renewable energies, new materials...). Another field more recently considered is the “human parameter”. In the building's physics' literature, we identify two ways this parameter is considered. The first way focuses on the occupant itself, through studies about the thermal, visual or acoustic comfort and its perception. The most obvious examples of this approach are the works of P.O. Fanger and the traditional PMV comfort index [1]. The second way to consider the human parameter is to investigate how the building's occupants interact with the built environment. Illustrations of this consideration are for example the adaptive comfort criteria concepts [2] or the proposal of intelligent controllers handling with the occupant’s preferences or actions [3].

The starting point of this paper is the idea that, in the case of real estate development of commercial buildings, there is another scarcely considered linking between the occupant and the energy efficiency of the building: the relation between the occupant’s level of requirements at the design step and the feasibility of low energy design. We refer to the expression “level of requirement” as “the expression of comfort desires”. Typical examples of comfort desires are a minimal or maximal temperature, or a tolerated noise level. But we want to refer here to a broader definition of comfort that includes space planning comfort next to the physical comfort. The space planning comfort can be compared to the user-friendliness concept in computer science, and includes for example the space planning flexibility, or the easiness and cost efficiency of the maintenance of HVAC techniques and surface materials. For all those comfort parameters, the future occupant of the building express to the architect or design team desires and needs. Those may be seen as requirements levels. This paper intends to show that there is a connection between those requirement levels and the ability to build low energy buildings.

METHODOLOGY

To show this, we focus on the example of space planning flexibility requirements. We define space planning flexibility as the ability to partition an office level into multiple and various smaller spaces. In the case of commercial buildings, the future occupant is often unknown when the building is designed. So his voice in the early design stages is carried on by real estate developers. They usually promote a concept of “full flexibility”, as they look for the lowest limitations for the unknown future occupant of the building.

In a first part, we expose the consequences of this lack of limitation on the façade design, the natural and artificial lighting and the HVAC techniques, for a theoretical office space. In a second part, we develop an alternative concept of “aware flexibility” and once again show the architectural and HVAC consequences. Both are then compared from the energy and investments point of views. This exercise is conducted and discussed for a typical 1,2m architectural mesh. This study is to be seen as a starting point for further and more systematic researches. It intends to draw attention on the issue and identify relationships between factors.

FULL FLEXIBILITY STUDY

From a technical point of view, full flexibility means that every axis of the structural/architectural grid could become a dividing wall. The choice of the occupant on whether an axis should or should not be a dividing wall must not have consequences on the thermal and visual comfort level of the spaces newly created. Thus, an irregular configuration of work spaces must be allowed and comfortable. The criteria we choose to test the achievement of full flexibility is the ability to place a 2 modules wide office (2*1,2m) everywhere in the plan without reducing comfort in some other parts of the office space. Also, changes in the offices configuration must be allowed on a regular time base without expensive charges for HVAC or artificial lighting adaptations. This means that the techniques to install when the building is under construction have to be designed in a way allowing a freedom of change as large as the one authorized in the space partitioning.

Facade design

It is obvious that with a façade glazed on its whole length, every thinkable office configuration will lead to comfortable working spaces regarding to visual and lighting comfort, as long as glare problems are solved. But is it still the case with facades only partly opened? Fig.1 shows an example of an irregular space division with 2, 3 and 4 modules wide offices next to an open space office. Various façade rhythms are tested. The first attempt corresponds to a fully glazed design, the others correspond to façade designs based on regular arrays of windows. In one case small windows are placed for every two axis, and in the other case wider windows are placed for every three axis. It shows that for the tested office space configuration, facades based on an array of windows lead locally to less comfortable working spaces and technical issues. So we can say that to create a fully flexible office which offers every occupant a working space in front of a window, a full length glazing configuration is needed.

Natural lighting

Since the previous paragraph leads to the conclusion that a full flexibility requirement asks for a continued window frame all the façade long, there is no further connection to look for. To maximize natural lighting, measures to be taken are about the offices depth and the glazing properties, not about partitioning.

Artificial lighting

About artificial lighting, two strategies are possible. The first is to ensure an ambient lighting of 200-300 lux, combined with local desk lamps to reach 500lux on the task. 500 lux is the

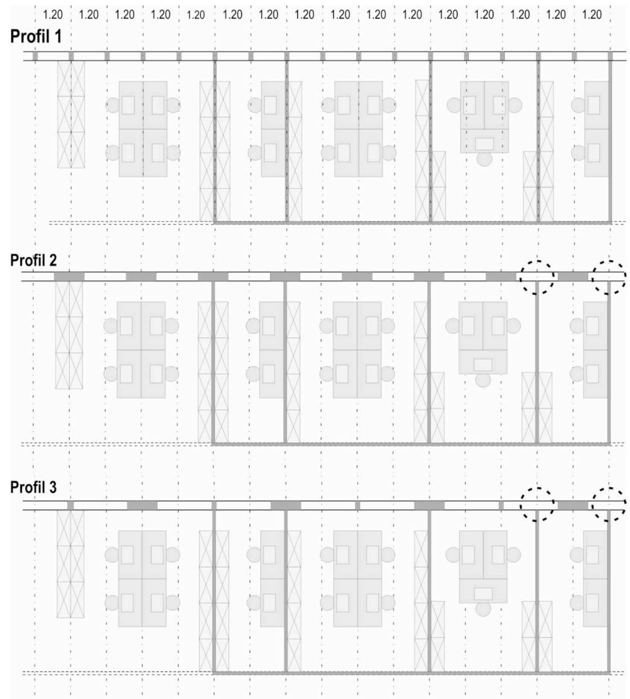

Figure 1: Confrontation of an irregular space division (full flexibility test) with 3 facade designs: fully glazed, window's array based (1for every 2 axis) and window's array based (1 every 3 axis). For designs based on window's array, local discomfort occurs (dotted circles).

lighting level requested on a working plane following the European norm EN12464-1:2002 [4]. But from our experience, this solution is frequently rejected by real estate developers. They see the need for local desk lamps as the proof of a lack in the comfort fulfillment by the building itself. The second strategy is to ensure lighting levels using ambient lighting devices only.

With a full flexibility concept, the working plane which needs 500 lux can be placed almost everywhere. In consequence, this lighting level must be reached on every place where a working plane could possibly be. To achieve this uniform 500 lux level, lighting devices on every 1.2m module are needed. Any reduction, such as the equipment of only 1 module for every 2, is inadequate when confronted to a partitioning in small office units, on one hand because it has to be compensated with a local oversizing, and on the other hand because uniformity requirements of EN12464 are not fulfilled anymore. Also, an expensive relighting is needed when changing the partition of the building. In consequence, we find the minimal lighting power to be installed in a full flexibility scenario to be 13.12W/m², based on a DIALUX simulation, using amongst the most efficient devices available today (Fig.2). This minimal lighting power is already quite good, compared to usual standards of 15W/m² [5]. Fig.2 shows that with this power, the respect of EN12464 is quite well achieved in the small office used as full flexibility tester. But the same lighting devices configuration leads to overlighting in wider offices.

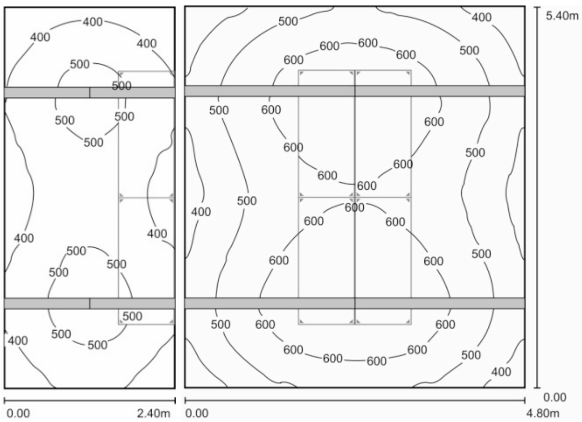

Figure 2: Dialux simulation of the artificial lighting in a full flexibility concept. Lighting devices simulated are Philips TBS340 LC 1xTL-D36W/840 CON C6. Resultant power is 13.12 W/m².

Heating, cooling and ventilation

About HVAC devices, we need:

a/ one heating/cooling device for every 2 axis. It is useless to provide devices on every axis because we can assume that a minimal office unit will be 2 modules wide (2.4m). But to be sure that enough power is supplied in the case of a 3 modules wide office centered on the heating/cooling device, every device has to be oversized by a factor 1.5, in order to keep a equivalent specific power, expressed in W/m²;

b/ one fresh air supply device for every 2 axis (either a mechanical ventilation supply or a natural supply through a grid in the facade). Once again, an oversizing factor is needed in order to ensure a sufficient ventilation rate in the case of a 3 modules office with only 1 supply device.

AWARE FLEXIBILITY STUDY

The concept of « aware flexibility » can be defined by opposition to the full flexibility concept. In this concept, some renouncement in space design freedom is accepted. A full freedom is no longer allowed, but it is nevertheless necessary to keep enough flexibility to create efficient working spaces. At this stage of the study, we do not propose to strictly quantify flexibility. We rather focus on a discrete approach with 2 examples of alternative space planning design. Such a systematic quantification is however an important and necessary future work.

We discuss here what can be seen as two levels of aware flexibility (Fig.3): a first level allowing to create 2 modules wide offices or multiples of 2 modules wide offices, with dividing walls being allowed on only 1 axis for every 2, and a second level allowing only 4 modules wide offices or multiples of 4 modules wide offices, with dividing walls being allowed on only 1 axis for every 4. Those levels are only examples of the concept. A 3 modules wide base would also be an interesting solution. The key point is not the wide base (2, 3 or 4 modules). It is the obligation to design every partition on integer multiples of the chosen base. The first level studied here is quite close to a full flexibility concept, but already allows energy savings, as shown later. The second level is more efficient from an energy point of view, but induces more constraints in space planning.

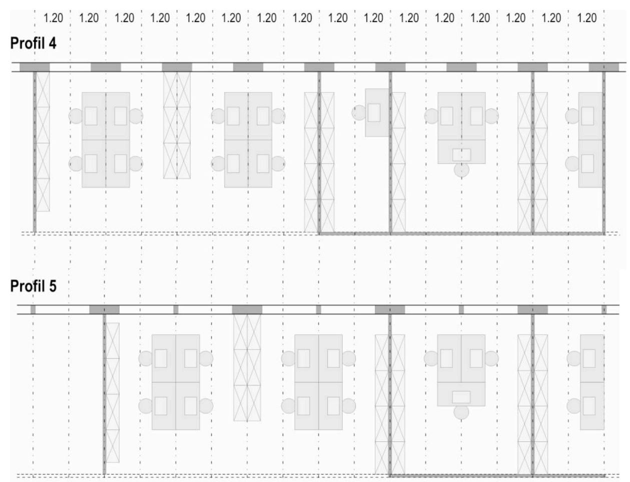

Figure 3: Examples of the aware flexibility concept: first level, on a 2 modules base (above) and second level, on a 4 modules base (under).

Questions may rise about losses of occupation density or the impossibility to create some useful office configurations. About density losses, table 1 shows the floor area available per worker, for all the configurations shown in figure 1 for full flexibility or in figure 3 for aware flexibility. It can be seen that the occupation densities for the proposed configurations are equivalent. About the impossibility to create some useful office configurations, in the case of aware flexibility - level one, only the 3 modules office configuration cannot be created. Occupations allowed by this size of office are 2 or 3 worker offices and direction offices including a small meeting area. The first can be adapted to 2 or 4 modules offices, and the last to 4 modules offices. Some losses of surfaces may occur in this last case. In the case of aware flexibility - level two, small units cannot be created. Therefore this configuration should be used carefully, for example in only parts of buildings, in combinations with more flexible configurations used locally.

Table 1: occupation densities for various offices configurations shown in Fig.1 and Fig.3

Case	Maximal # of occupants	Maximal density (m²/occup)	Flexibility level
2 modules offices (12.96 m²)	2	6.48	Full flexibility Aware flex. level 1
3 modules offices (19.44 m²)	3	6.48	Full flexibility
4 modules offices (25.92 m²)	4	6.48	Full flexibility Aware flex. level 1 Aware flex. level 2
Open space	4 (for 4 modules)	6.48	Full flexibility Aware flex. level 1 Aware flex. level 2

Facade design

With aware flexibility, it is no more useful to create a fully glazed or continued window along the whole façade, as shown in Fig.3. It is now possible to avoid uncomfortable situations (windows in front of walls or lack of views to the outside for office occupants) while designing a regular window pattern. That was impossible with full flexibility.

Natural lighting

It is well known that it is not necessary to have a fully glazed facade to obtain a high level of natural lighting. Especially, a glazing area placed next to the floor level is useless for lighting but leads to undesired energy loads (overheating in summer and poor insulation level in winter, compared with an insulated opaque wall), and should then be avoided. Fig.4 shows that the windows framed façade suggested in Fig.3 leads to acceptable results in terms of daylighting, according to LEED 2.1 standard of daylight factor=2 on 75% of spaces occupied for critical visual tasks [6]. The presented simulation is done with only 40% of the façade being glazed and usual reflection coefficients for walls and ceiling.

Artificial lighting

Results of an exercise of artificial lighting design are shown in figures 5 and 6. Lighting powers are smaller than in the case of the full flexibility concept.

Heating, cooling and ventilation

As many HVAC devices are needed with the first level of the aware flexibility concept as for a full flexibility concept. But it is no more useful to oversize them. The 3 module offices wide case that leads to this need is not possible anymore. With the second level of aware flexibility concept (the one allowing 4 modules wide

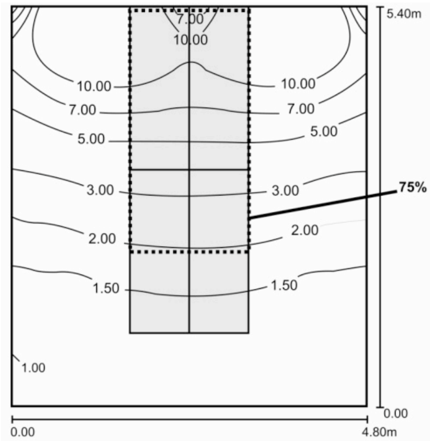

Figure 4: daylight factor levels for the "aware flexibility – level one" concept shown in Fig.3 and a 40% glazed facade. The dotted line identifies the 75% of spaces occupied for critical visual tasks.

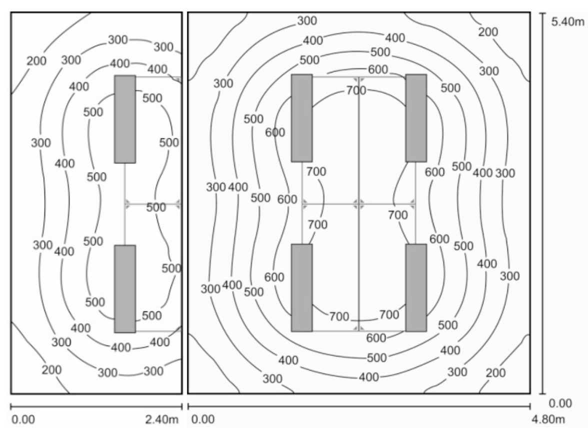

Figure 5: Dialux simulation of the artificial lighting in an aware flexibility concept – level one. Lighting devices simulated are Zumtobel L-FIELDS A A 2/28W. Resultant power is 9.46 W/m².

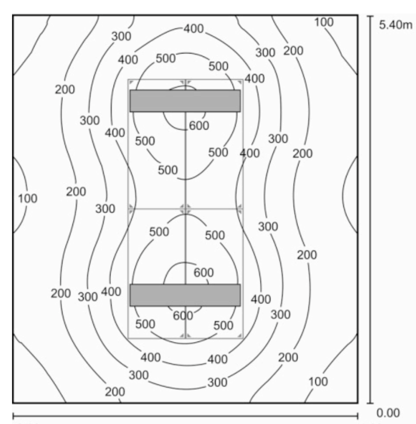

Figure 6: Dialux simulation of the artificial lighting in an aware flexibility concept – level two. Lighting devices simulated are Zumtobel L-FIELDS A A 2/35W T16. Resultat power is 5.83 W/m².

offices only), half of devices may be spared, while only one every four modules is necessary. But the total power is equivalent with the first level.

FINDINGS

Energy impact

From previous sections, we see that the full flexibility requirement leads to either continued windows all the façade long, or a fully glazed facade, while an aware flexibility concept is compatible with a windows' frame facade. To evaluate the impact of this parameter on the energy consumptions, we refer to the *alter*-CLIM software [**7**]. This software is an interface for a dynamic simulation's results' database, based on Trnsys 16 simulations. The energy consumption of the office in various cases is shown in figure 7. It shows an average difference of 20% in energy consumption due to the reduction of the glazed part of the façade (for the North-West European oceanic climate).

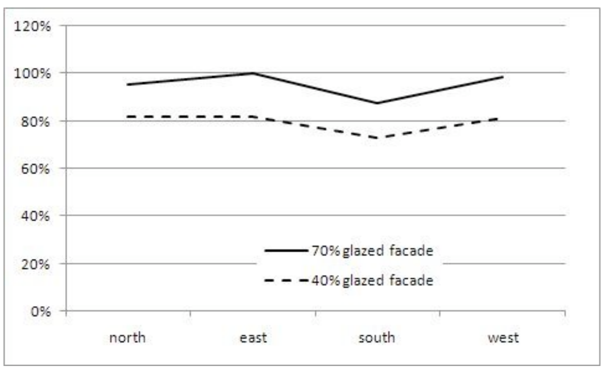

Figure 7: Relative primary energy consumption of a single office (summing heating, cooling and humidity control) as a function of orientation and façade design.

Energy impact of the reduced lighting power can be deduced from Dialux simulations (Fig.2, Fig.5, Fig.6): 28% for the aware flexibility level one and 56% for the aware flexibility level two. Those values do not consider savings due to the artificial lighting control (dimming), easiest to implement in the aware flexibility concept (less lighting devices to be equipped).

Cost impact

Three aspects have to be considered: the lighting devices' cost, the façade cost, and the HVAC costs. It is difficult to introduce cost aspects in such a study because they may vary quite fast from one building to another. But it nevertheless can be said that:

a/ The artificial lighting designs presented for aware flexibility concepts are assumed to be less expensive than the one presented for the full flexibility concept. They need less lighting devices, although those have to be more efficient in order to achieve the uniformity requirement of the EN12464-1 norm. It is also easiest and then less expensive in that case to implement a dimming technology linked to natural lighting, because fewer sensors and ballasts are needed.

b/ About HVAC devices, it is shown that a full flexibility requirement leads to an oversizing by a factor 1.5. The full flexibility thus leads to extra costs.

c/ Finally, glazed parts of a facade are usually more expensive than the unglazed ones (for example insulated panels in curtain walls). Since the full flexibility doesn't allow reducing the glazing surface but induces a continuous window all the façade long or a fully glazed façade, it can be said that the full flexibility once again leads to extra investments costs. This may be discussed if the glazing reduction leads to a change in construction methods (heavy walls and traditional frames for example), since local construction ways and the size of the building have to be considered.

Conclusion

We have shown that the expression of a full flexibility requirement may leads to decisions such as a highly glazed facade and technical consequences such as a minimal lighting power of 13.12 W/m² and oversized HVAC devices. Those decisions and consequences are not induced if an aware flexibility is preferred. It is also argued that, compared with "full flexibility", the concept of "aware flexibility" can be used to reach higher energy performances with smallest or equivalent investments. In both cases, specific investments can be done to minimize energy consumptions, but with the aware flexibility, those can already be reduced without extra costs. Finally, it is shown that both concepts are able to offer comfortable working spaces, with various kinds of offices, and equivalent occupation density. Only in the case of aware flexibility – level two, small 1 or 2 peoples' offices cannot be created.

Various aspects such as impacts of the flexibility on robustness and possible refurbishment of the building (and thus on intrinsic energy) are not considered here, since the paper focuses on operating costs. Those aspects may argue for a larger flexibility. But authors believe that the aware flexibility concept is a robust enough design starting point to allow exceptions, variations and interpretations by architects in order to offer interesting solutions for those non-studied aspects. An experimentation phase on real projects is needed to demonstrate this belief.

DISCUSSION

Potential architecture

Based on the example of flexibility choices in space planning, we conclude on a new vision of the building design process in the field of real estate development, resumed in Fig.8. We see the architectural work as the creation of a potential for low energy buildings. When designing the shape of the building, the architect may take into account well known tools leading to low energy or passive buildings such as orientation, natural lighting, or natural ventilation considerations. But those are not sufficient to create a low energy building, because the architect or engineer is not the one who fixes the requirements for the building, occupies the building or makes financial decisions.

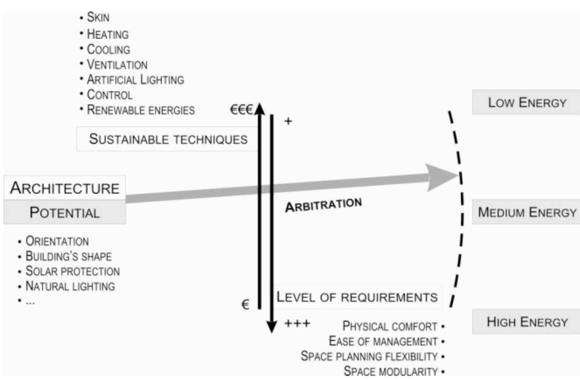

Figure 8: "Potential architecture concept"

Opposite forces

So, the design team also has to look at the combination of opposite forces which turn the potential they create in low energy, medium energy or high energy buildings. Those opposite forces are the level of requirements of the developer or occupant and the technical and financial availability of sustainable techniques. By techniques we mean both HVAC techniques, renewable energy techniques and the design of the building's skin (glazing ratio, insulation level …). To reach low energy, there is to choose between high requirements (to be compensated by expensive techniques, such as renewable, to reach low energy), and reducing the requirements' level (allowing to implement less expensive techniques to reach the same low energy level).

Back on the example of flexibility: a developer who wants to build a low energy building with a full flexibility requirements has to compensate energy consumptions induced by a highly glazed façade and larger artificial lighting power, for example with sophisticated and expensive double skin facade techniques and renewable. Those may be too expensive for the developer who will then reduce is energy expectations. On the opposite, if the developer reduces his flexibility requirements, the architect is able to reduce glazed surfaces and save energy and investment costs. Low energy expectations may then be kept.

Shared responsibility

Through this vision of the design process, the responsibility of every decision maker is underlined, including the real estate developer and the occupant. This vision also emphasizes the concept of "shared responsibility" which is part of a sustainable development as defined by the Rio declaration [8]. The proposed vision of the design process may be successfully included in the thinking about "integrated design methods" [9]. Those try to include all decision makers in one design team. That is obviously an opportunity to question those decision makers and to show them the impact of their choices.

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