INFLUENCE OF BUILDING FORM OF HOSPITAL ON ITS ENERGY PERFORMANCE

Vladyslav Shchuchenko, M.Sc., PhD fellow
Telemark University College, Norconsult, Norway
Bernt Lie*, *PhD, Prof.
Telemark University College, Norway
Trond Thorgeir Harsem*, *M.Sc, Associate Prof.
Norconsult, Oslo and Akershus University College, Norway

Abstract

In this study thermal performance of hospital buildings with various geometries is examined.

The aim of the work is to study the impact of the hospital building geometry on the total energy consumption. Three types of buildings are investigated – an arcade with glazed roof, a pavilion and a tower on a base (or in some literature called "matchbox on a muffin"). These hospital geometries (with some degree of deviation) are most commonly used in healthcare.

The hospital geometries were simulated in several steps: beginning from existing (base case) hospital and further applying energy measures to achieve low energy hospital (with better insulated building body and demand controlled ventilation and lighting). The latter type is in its emerging phase and will be more and more in focus as authorities implement stricter building codes and as the demand on energy effective buildings rises continuously.

The area of the modeled hospital is about 96 500 m^2. The model represents an "average" large university hospital in Norway. Occupancy, schedule, internal gains, ventilation rates and fabric data are kept constant for each of the simulated cases. Influence of the hospital geometry in moderate and polar climate were also investigated.

Building envelope data and technical systems data have been varied during the simulation in order to see how big influence has geometry on existing and low energy hospitals.

Building models are simulated using Simien building energy and indoor climate software [1].

The results of this study show that, in general, geometry of the hospital building has very little influence on its energy use.

Keywords: Building form, hospital, energy

Introduction:

While building sector is responsible for about 40 % of energy use [2], hospitals represent ca. 6 % of the total energy consumption in the public building sector [3]. Hospitals are one of the most energy intensive building categories. A hospital uses 2.5 times more energy than a similar sized office building [4].

Breakdown of the energy flows in hospital is shown in Figure 1. The "Other" category in this Figure represents electricity consumption by medical and office equipment.

All hospitals are unique in shape and size and also in services they provide. This study focuses on large university hospitals, such as e.g. Rikshospitalet (The National Hospital) in Oslo.

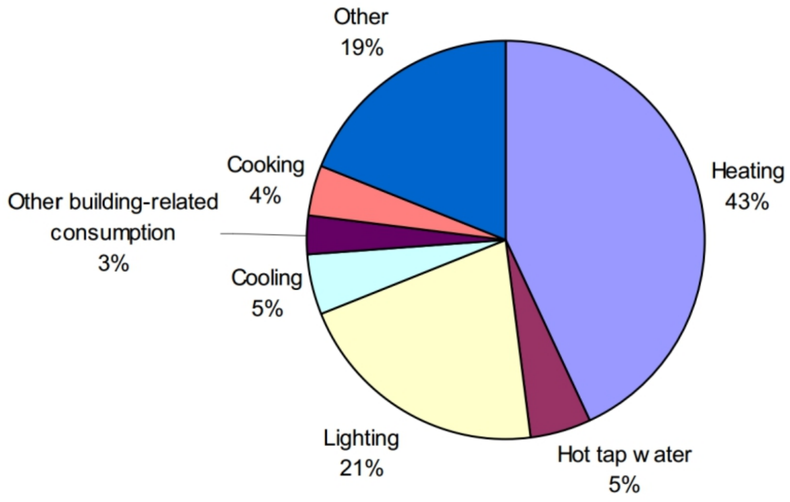


Figure 1. Breakdown of the energy flows in a hospital building [5]

Form of a hospital building:

The building geometry of hospital has experienced some changes in accordance to flexibility issues and research findings, which shows how daylight is important for recovery of patients.

During the fifties and sixties hospitals were represented by buildings with massive ward blocks [6]. A typical example of that era is a "tower on a base"[6] type of hospital building.

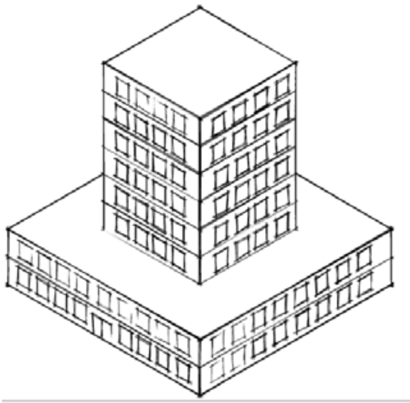
Later in the eighties and nineties, when flexibility became an issue, more neutrally designed buildings appeared [7]. More flexibility and more internally-oriented design with focus on daylight access were programmed in these hospitals. Glazed streets and atriums are distinctive elements in these hospitals. A "glass-covered arcade" type is an example of this type of hospital.

A "Pavilion" type of hospital is suitable, when it comes to fitting the hospital to an urban environment with a lack of available area while keeping daylight access on a quite high level.

A "tower on a base" type

Figure 2 shows a "tower on a base" hospital. In this type, the lowest 2 (3) floors represent diagnostic and treatment functions as well as public areas such as cafeteria, reception etc. The tower (usually about 10 floors high) represents nursing units. This building is very compact compared to other types of hospital buildings, having smaller surface area exposed to the environment. It is also critical to any rebuilding with a possibility to vertical expansion, which is not always allowed because of regulations and an extra weight on the existing structure. However, adaptation and expansion is also possible on the lowest floors.

[6] Also called "tower on a podium" or " matchbox on a muffin"




a) *b)*

Figure 2. A tower on a base type. Simplified model (a) and real building (b)

Glass-covered arcade type

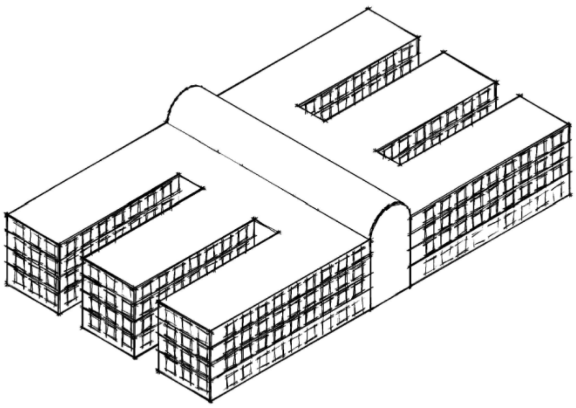
Figure 3 shows a glass-covered arcade hospital. The glass-covered arcade hospital emerged as a new model in the early eighties and has been employed in several hospital buildings in Norway. Some of the biggest hospitals in Norway namely Rikshospitalet, Østfold hospital (under construction) and AHUS are of this type.

This concept has horizontal building organization as a main feature. Building parts are connected with each other by a glass-covered street. The street combines functions of the main traffic area and also houses some public functions, such as pharmacy, shops, cafeteria and reception. The street provides daylight to the attached areas and also serves as a place which creates social interaction.

Pavilion type

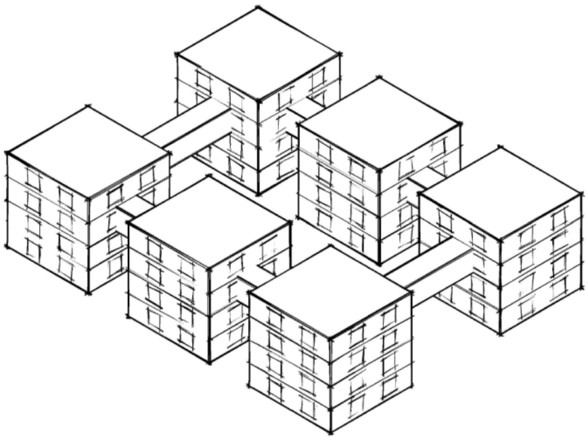
Figure 4 shows a "Pavilion" type of hospital. Several standalone buildings are connected by above- or underground corridors in order to assure proper logistics between the buildings. This type of hospital is quite flexible, when it comes to expansion, if there is enough area available on site. However, it is also possible to build on the top of building elements.

An example of this type of hospital is St. Olav's Hospital in Trondheim, Norway shown in Figure 4 (b).




a) *b)*

Figure 3. Glass-covered arcade type. Simplified model (a) and real building (b)



a)

b)

Figure 4. Pavilion type. Simplified model (a) and real building (b)

Modeling development approach:

In order to investigate the energy performance of the above mentioned hospital building types, three models were created using Simien energy simulation software [1]. All three models were simulated in several stages. In the first stage, characteristics of existing hospital have been applied to see the current situation. In the next simulation rounds energy saving measures have been applied gradually. As shown in Table 1, four simulation rounds were performed for each of the building type.

Table 1 Simulation cases

Case	**Case description**
a	Existing hospitals, with more than 16/7[7] operating hours in most of the functional zones
b	energy measures applied to air handling units, in this case reduced SFP[8] factor from 2 to 1.2 kW/(m^3/s) and better ventilation heat recovery units with 80 % efficiency instead of 70 %
c	energy measures applied to the building body, i.e. better insulated building body (lower heat transfer coefficients, cold bridges and infiltration rate)
D	energy measures which take into account occupants behavior, i.e. lighting and ventilation demand control. It includes automatic on-off light control and dimming, as well as demand control ventilation (when it is rational and dependent on a functional unit).

Functional zones

The models were divided into a number of zones representing functional units. Each functional unit could be expressed as one or several zones dependent on building geometry. A functional unit can be defined as a group of rooms and related traffic areas interrelated by shared activity or processes. See Table 3 for the full list of the functional units used in the models.

Base case and low energy hospital

Input data for the building body as well as SFP, infiltration rate and heat recovery efficiency is shown in Table 2.

Input data for internal loads and ventilation rates in the base case hospital are shown in Table 3. Operating schedules for this type of hospital were taken from the Norwegian standard NS 3031 [8], where hospital operates 16/7. However some functional units in Table 3 have other operating hours. For example, acute care and

[7] hours a day / days a week

[8] SFP=Specific Fan Power

nursing units assumed to be in operation 24/7, while administration and research units – just 12 hours a day, which is closer to the real situation.

Table 2 Input data for the base case and the low energy hospital

Parameter	Base case hospital	Low energy hospital
Heat recovery efficiency	70 %	80 %
Specific fan power (SFP)	2 kW/(m^3/s)	1.2 kW/(m^3/s)
Infiltration rate[9]	1.5 h^{-1}	0.6 h^{-1}
Cold bridges	0.06 W/m^2K	0.04 W/m^2K
U-value external walls	0.21 W/m^2K	0.13 W/m^2K
U-value roof	0.2 W/m^2K	0.11 W/m^2K
U-value floor	0.11 W/m^2K	0.1 W/m^2K
U-value windows	1.17 W/m^2K	1.0 W/m^2K

Ventilation, lighting and equipment schedules have the same pattern here. Hot water energy loads for simplicity's sake were assumed to be constant throughout the day.

When it comes to the low energy hospital model, the demand controlled ventilation and lighting were assumed to be used as the major energy saving measures. In order to take into account variable needs in ventilation and lighting, reduction coefficients were used. The coefficients were based on registered activities in two Norwegian hospitals [9] and on a best guess made in cooperation with hospital HVAC consultants. The first two columns in Table 4 show reduction percentage, while the last two show average ventilation rates and lighting loads during the operating hours. Equipment and hot water energy loads are kept the same as in the base case hospital model.

Table 3 The base case air volumes, internal loads and schedules

	Functional unit	**Operating schedule,** h	**Ventilation,** m^3/hm^2	**Lighting,** W/m^2	**Equipment**, W/m^2	**Hot water**, W/m^2
1	Acute care	24	20(0)	15(0)	20	5.1
2	Out-patient clinic	16	16(5)	15(5)	20(5)	5.1
3	Nursing	24	8(0)	8(0)	12	3.4
4	Surgery	16	50(7)	15(5)	25(0)	5.1
5	Diagnostic imaging	16	16(3)	15(5)	25(5)	3.4
6	Laboratories	16	25(7)	15(5)	20(5)	3.4
7	Pharmacy	16	25(7)	15(5)	20(5)	1.6
8	Sterilization	16	25(7)	8(5)	20(5)	7
9	Medical services	16	16(3)	10(0)	15	5.1
10	Other services[10]	16	16(3)	8(2)	15	5.1
11	Administration	12	16(3)	8(2)	11(2)	1.6
12	Hotel	16	12(3)	8(3)	10(2)	5.1
13	Research/Teaching	12	13(3)	8(2)	11(3)	1.6
14	Personnel service	16	16(3)	8(2)	12	5.1
15	Patient service	16	16(3)	8(2)	15	5.1
16	Technical areas	16	10(3)	8(2)	10	3.4

[9] Shows amount of air changes under 50 Pa pressure difference over the building envelope.

[10] Under "Other services" it is meant reception/admission, kitchen, cleaning, print center, facilities management and other services not directly related to patients treatment.

Table 4 Reduction of lighting and ventilation loads when demand control systems are installed

	Functional unit	**Ventilation reduction, %**	**Lighting reduction,%**	**Ventilation,** m^3/hm^2	**Lighting,** W/m^2
1	Acute care	30	30	14	5.6
2	Out-patient clinic	70	70	4.8(3)	4.5(2)
3	Nursing	65	80	2.8	1.6
4	Surgery	70	70	18(7)	4.5(2)
5	Diagnostic imaging	70	80	4.8(3)	3(2)
6	Laboratories	65	65	7(5)	5.25(2)
7	Pharmacy	65	65	8.75(5)	5.25(2)
8	Sterilization	40	65	12.5(5)	2.8(2)
9	Medical services	65	65	5.6(3)	3.5
10	Other services	50	50	8(3)	5(2)
11	Administration	75	75	4(3)	2(2)
12	Hotel	65	80	4.2(3)	1.6(1)
13	Research/Teaching	75	75	3.2(3)	2(2)
14	Personnel service	85	85	2.4(3)	1.2(1)
15	Patient service	0	20	16(3)	6.4(2)
16	Technical areas	20	20	8(3)	6.4(2)

More details about the models and zones arrangements are shown in Appendices.

Results:

The results shown in Figure 5 indicate a little impact of the hospital geometry on its energy performance. All the way from the base case to the low energy hospital alternative the difference between the maximum and the minimum values is about 3-4%. Due to the more compact form the "tower on a base" type of hospital shows the lowest energy consumption compared to the other forms in all four cases (a-d). Another thing, which may contribute to a leading position of this type of hospital, is that light intensity was chosen to be constant in each of the simulation rounds for all of the three types. However in the "tower on a base" type it is expected that energy used for lighting is a bit higher compared to the other types due to relatively large area with only artificial lighting (in the core of the building). Drawback of this type of hospital is that healing effects and psychological conditions of patients and their relatives may suffer due to lack of the daylight.

Under extreme polar conditions hospital geometry plays a little more important role than in Oslo climate. However, as shown in Figure 6, the differences between the building geometries are rather small to influence the bigger picture.

The climate place was Kirkenes (69^0 N) - a small town close to the Norwegian-Russian border, with the year average temperature -0.6 ^{0}C.

What is remarkable, when comparing Figure 5 and Figure 6, is that the low energy hospital (case d) has almost the same energy consumption in Oslo and Kirkenes climate in spite of the higher year average temperature in Oslo (6.2 ^{0}C). At the same time the existing hospital alternative (case a) uses about 20 % more energy in Kirkenes than in Oslo.

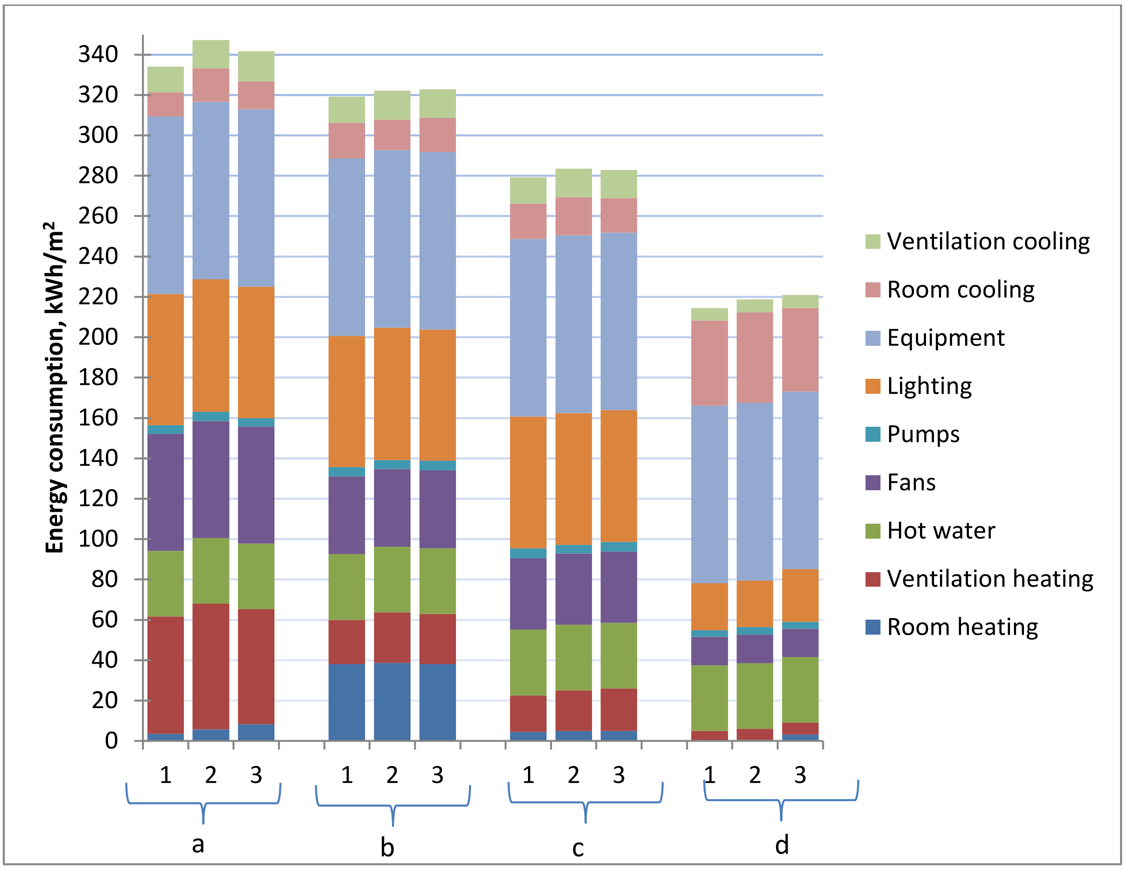


Figure 5 Energy performance of three hospital forms (Oslo climate): 1 - tower on a base, 2 - pavilion, 3 - glass-covered arcade. a-d cases are described in Table 1.

Orientations of the buildings were not taken into consideration. Neither was integration of functional units with simultaneous heating and cooling demand done. An example of a functional unit with almost continuous cooling demand throughout a year could be diagnostic imaging department with heat releasing equipment such as MRT and CT[11]. So it is suggested to investigate this integration in future work.

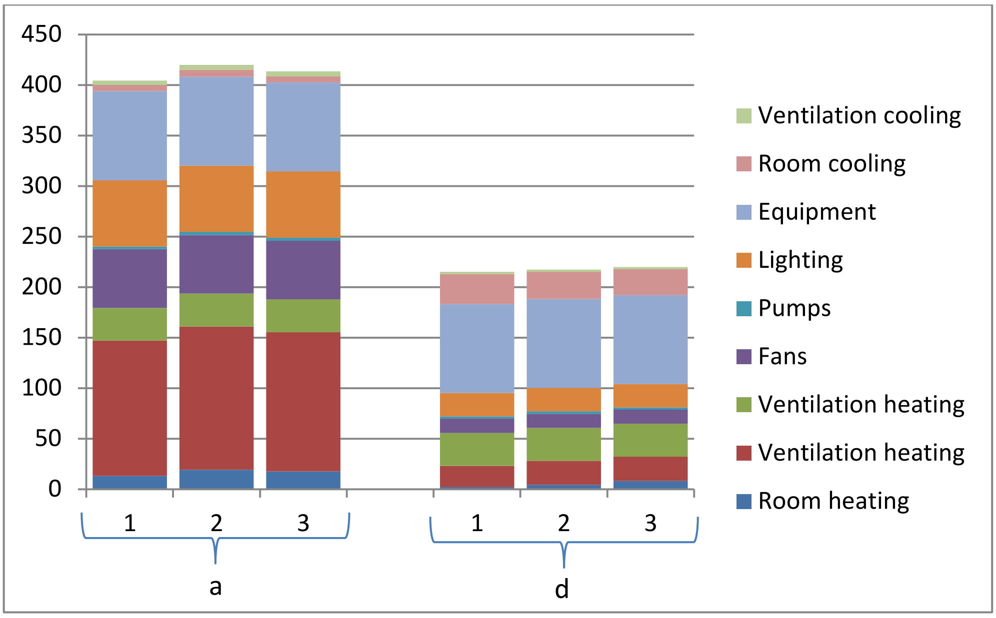


Figure 6 Energy performance of the three hospital buildings in polar climate in Kirkenes (Norway). 1 - tower on a base, 2 - pavilion, 3 - glass-covered arcade

[11] Magnet Resonance and Computer Tomography

Conclusion:

As the results show, the difference between different forms of hospital building is marginal. That is why "glass-covered arcade" looks more attractive when access to the daylight is taken into account. Proven daylight's effect on faster recovery of patients [10] and its positive influence on patient's psychological conditions become a critical point in choosing hospital geometry.

Pavilion-type hospital performs the worth which is explained by its larger area exposed to the environment and, hence, higher heat losses.

Hospital model with atrium or glass-covered street has quite high infiltration rate and big air volume needed to be warmed up, but as the results show it does not affect total energy consumption very much.

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Appendices:

Appendix A. List of the functional units and their areas and shares

	Functional units	**Area, m²**	**Share of total area, %**
1	Acute care	3060	3,2
2	Out-patient clinic	6970	7,2
3	Nursing	17935	18,5
4	Surgery	5270	5,4
5	Diagnostic imaging	3400	3,5
6	Laboratory	7140	7,4
7	Pharmacy	2040	2,1
8	Sterilization	1700	1,8
9	Medical services	3774	3,9
10	Administration	14110	14,6
11	Hotel	2380	2,5
12	Research/Teaching	2380	2,5
13	Personnel services	5984	6,2
14	Patient service	1326	1,4
15	Technical services	14481	15,0
16	Other services	4894	5,1
	Total	**96 844**	100

Appendix B. "Tower on a base" hospital

Floor	**Functional units**	**Area,m²**
ground	Technical areas	14 481
1	Acute care, Pharmacy, Sterilization, Patient service, Out-patient clinic, Research/Teaching	17 476
2	Surgery, Administration	17 476
3	Diagnostic imaging, Medical services	7174
4	Laboratories	7140
5	Personnel services, Administration	7888
6	Nursing	7000
7	Nursing	7000
8	Nursing	6315
9	Other services	4894

Appendix C. "Pavilion" hospital

Building / Floor	**Building 1**	**Building 2**	**Building 3**	**Building 4**	**Building 5**	**Building 6**
Ground	Technical areas 2413 m²	Technical areas 2413 m²	Technical areas 2413 m²	Technical areas 2413 m²	Technical areas 2413 m²	Technical areas 2413 m²
1	Acute care 3060 m²	Sterilization, Pharmacy 3740 m²	Medical Services 3774 m²	Administration, Research/Teachin 4490 m²	Laboratory 3570 m²	Administr. 3000 m²
2	Surgery 3000 m²	Out-patient 3500 m²	Nursing 3000 m²	Nursing, 3000 m²	Laboratory 3570 m²	Administr. 3000 m²
3	Hotel 2380m²	Personnel service 3000 m²	Nursing 3000 m²	Nursing, 3000 m²	Out-patient 3500 m²	Administr. 3000 m²
4	Surgery 2270 m²	Personnel service 3000 m²	Nursing 3000 m²	Nursing, 3000 m²	Diagnostic imaging 3400 m²	Administr. 3000 m²
5	Patient service 1326 m²		Other services 1894 m²	Other services 3000 m²		

Appendix D. "Glass-covered arcade" hospital

Building / Floor	**Building 1**	**Building 2**	**Building 3**	**Building 4**	**Building 5**	**Building 6**	**Glazed street**
Ground	Technical areas 3095 m^2	Technical areas 3095 m^2	Technical areas 3095 m^2	Technical areas 3095 m^2			Technical areas 2100 m^2
1	Acute care 3060 m^2	Sterilization, Pharmacy 3740 m^2	Medical Service 3774 m^2	Laboratory 3570 m^2	Research/ Teaching 2380 m^2	Administr. 3527 m^2	Other services (such as reception, cafeteria etc ., which are reasonable to place in glazed street) 2100 m^2
2	Surgery 3000 m^2	Out-patient care 3500 m^2	Other services 2794 m^2	Laboratory 3570 m^2	Nursing 3000 m^2	Administr. 3527 m^2	
3	Hotel 2380 m^2	Personnel service 3000 m^2	Nursing 3000 m^2	Out-patient 3500 m^2	Nursing 3000 m^2	Administr. 3527 m^2	
4	Surgery 2270 m^2	Personnel service 3000 m^2	Nursing 3000 m^2	Diagnostic imaging 3400 m^2	Nursing 3000 m^2	Administr. 3527 m^2	
5		Patient service 1326 m^2	Nursing 3000 m^2				