Building optimization combined with solar heating and cooling in Nepal

Michael Strobel[1,2], Uli Jakob[1,2], Manuel Ostheimer[1,3], Daniel Neyer[1,3]

[1] Universtität Innsbruck, Unit of energy efficient building, Innsbruck (Austria)

[2] Dr. Jakob energy research GmbH & Co. KG, Weinstadt (Germany)

[3] Neyer Brainworks GmbH, Bludenz (Austria)

Abstract

To meet future heating and cooling needs in buildings, energy efficiency is required at both the technical level of a system and at the building energy efficiency level, followed by the integration of renewable energy. The BEEN project (Building Energy Efficiency in Nepal) aims to establish energy-efficient construction in Nepal, taking into account the country's climatic and topological characteristics. As Nepal's building stock expands rapidly due to economic and population growth, the country has one of the highest urbanization rates in the world. Therefore, the project is active in various areas, such as developing passive design guidelines, manuals and training programs for experts and policy makers, as well as providing technical support to several building case studies. The presented study links improving the energy efficiency of buildings with their coverage by solar heating and cooling systems. Two buildings are used as case studies, one is an office building in a warm climate in Rupandehi district and the other is a hotel building in a cold climate at high altitude in Mustang district. It turns out that a combination of different measures can reduce the total cooling demand by 75% and the sensible heating demand by 98% and increase interior comfort.

Keywords: Building optimization, solar heating, solar cooling, energy efficiency, Passive House

1. Introduction

July 2023 was by far the hottest month ever recorded, with a global average 1.5 °C above the long-term average for July between 1850 and 1900 (Copernicus 2023). This increases the global demand for space cooling and the need for cool and comfortable indoor air conditions. Energy consumption related to building operation already 30 % (International Energy Agency 2023) of the worldwide energy consumption. 20% of global electricity consumption is dedicated to the operation of air conditioners and fans (Dean et al. 2018) Driving factor for the future space cooling demand is the increase of more extreme and longer lasting heat waves alongside the global warming, the growing world population which runs with a growing rate urbanization and the economic development especially of developing countries in Asia and Africa, such as Indonesia and Nigeria. Developing countries are often located in the Sunbelt region between the 20th and 40th latitude on the Northern and Southern hemisphere, where the climate already causes space cooling demand. The economic development causes an increase in individual buying power causing higher number in sales of cooling equipment. The rapid urbanization worldwide connected to dense urban construction also causes the increased and intense occurrence of Urban Heat Islands (UHI), again causing heat stress to counteract via mechanical cooling. All these reasons already caused a tripling in energy consumption for space cooling from 1990 to 2020 (Dean et al. 2018). A projection for the increasing demand for space cooling demand in Nepal is presented in a paper related to the IEA SHC Task 65 (Bonomolo et al. 2023). This projections is based on the methodology of the Cooling Demand Market Index (CDMI) developed in 2023 by Strobel et al. (Strobel et al. 2023). In addition, the building stock worldwide is rising as well. Even though the development of global warming leads in general to an increase of cooling demand and a decrease in heating demand, the space heating sector must be decarbonized in order to meet the goals to minimise the climate change.

A promising way to face these difficulties is the optimization of the building quality to reduce the cooling and heating demand as well as the load in the first place. This optimization includes the correct combination of single measures

10.18086/swc.2023.04.13 Available at http://proceedings.ises.org

for a building in relation to its climate and its use. In the second place, the final energy demand must be supplied in a most efficient and preferably renewable way. A minimization of the non-renewable primary energy consumption and greenhouse gas (GHG) emissions is the target of the technical systems.

The EU funded project Building Energy Efficiency in Nepal (BEEN) takes both of these topics into account, with a greater focus on the building optimization (BEEN 2023). Its target is to establish national guidelines and best communicate practices in Nepal to reduce the GHG emissions for space heating and cooling and to increase the thermal comfort of buildings. Stakeholder groups involve architects, engineers, construction companies, suppliers as well as local municipalities. Nepal has a variety of different climates, from tropical climate with dry season in the border region to India to alpine climates in the Himalayas. This inhomogeneity in climates is a challenge to establish basic guidelines. Thus, individual building studies are required to demonstrate and analyse options to optimize buildings with different backgrounds.

To disseminate and promote the integration of efficient solar solutions for heating and cooling is the fundament of International Energy Agency (IEA) Solar Heating and Cooling (SHC) Task 65.

2. Materials and Methods

2.1. Building energy demand

The focus of this study is the analyses of building energy performance via the Passive House Planning Package (PHPP), developed by the Austrian base Passive House Institute. Two different already existing buildings in two different climate zones with different use are studied and simulated. The building in the warmer climate located in Butwal, Rupandehi district in Nepal, is home the local regional municipality administration with office-use. The other building is a hotel located in Muktinath, Mustang district, sits in a cold climate at 3,760 m elevation. The two buildings are 3D modelled using SketchUp to picture the correct dimensions of the building and the shading effect of the environment, such as neighbouring buildings. Both buildings are optimized in the simulation software to identify measures and their impact on the energy performance.

2.2. Solar system design

The study includes the energy supply analysis via solar energy. The study is based on a monthly approach and solutions for the individual needs. The solar system design partly originates from PHPP solar heating tool. This tool is able to take different solar thermal collectors into consideration. However, this tool is primarily used to receive initial data of monthly solar heat per area, given in kWh/m². Instead, an individual methodology was set up to design the system.

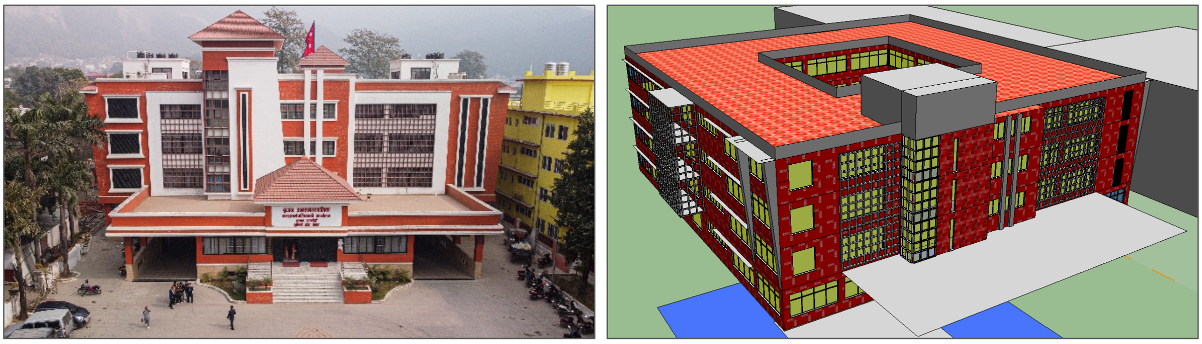
3. Calculation

This chapter provides description of the building models and the simulation boundary conditions of both the building constructions as well as information on the simulation itself.

3.1. Building models

The 3D models are created using SketchUp software with the designPH plug-in. Using this approach, the design and the information of size and number of individual surfaces to picture each building is generated.

The office building in Butwal is characterized by a square ground plot with an also square courtyard. It is surrounded by close standing neighbouring building in the south and trees and area of different use in the north. In the East and West is open space. To consider the shading effect, the neighbouring building is represented as shading surfaces in the model. The characteristics of the façade are also represented in the model to considering the shading effect of overhangs and balconies.



(a) (b)

Figure 1: Comparison of existing building in Butwal (a) and the 3D model (b) representation using SketchUp 2017. Source: (a) (CP Khanal 2023).

The hotel in Muktinath is characterized by its short façade to the street, its relatively narrow ground plan and its stepped roof. The construction based on stone masonry in between RCC pillars is also represented in the model. The open staircase and public place leading to the upper hotel rooms leads to an increase of surface exposed to the ambient. A further characteristic is its closed courtyard with glazed roof. This generates an open space of three levels. On the 3rd floor, there is a closed terrace facing the street with a RCI roof. Figure 2 shows and outside view and an inside view of the existing building and the 3D model in SketchUp.

(a) (b) (c)

Figure 2: External view of the Hotel (a), internal view of the closed courtyard (b) and the 3D model (c) representation using SketchUp 2017.

3.2. Building simulation fundamentals

The building physical characteristics of the buildings are taken from the construction plans and the users. Both buildings are designed in RCC skeleton construction. In Butwal, the wall slabs are filled with bricks and the entire surface is covered with cladding. The wall slabs in Muktinath are different from those in Butwal. Due to the remote location of the site, locally available natural stone masonry is used in the construction on site. In both cases, there is no insulation in the building envelope. A detailed overview of the used construction types and materials can be found in the Appendix.

4. Results

4.1. Building energy demand

The energy demand differs between the two buildings due to their climates and the results are presented are presented for each case separately. The results for base case and the result of combined individual measures are presented for each case.

In the Butwal base case, representing the current state of the building, the sensible cooling energy demand accounts for 190.4 kWh/m²a while the latent cooling energy demand account for 54.6 kWh/m²a. Figure 3 shows the comparison of heat gains which equals in total the sensible cooling energy demand. Additionally, energy is required for dehumidification, pictured in the latent cooling energy demand. This energy is required in the wet season from June to September, whereas sensible cooling energy demand peaks from April to June. The vast majority of heat gains is based on the direct solar heat gains through the windows, followed by internal heat gains. The maximum sensible cooling load in the base case accounts for 61.4 W/m².

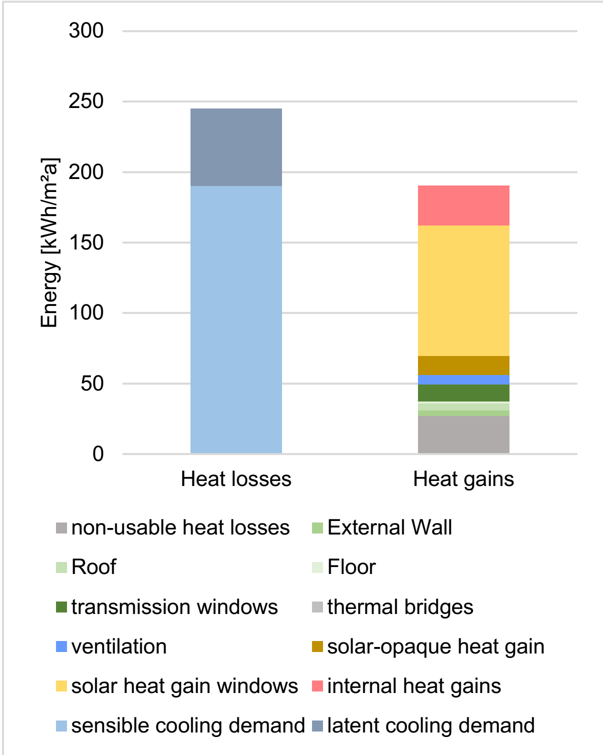


Figure 3: Cooling energy heat balance, comparing sensible cooling energy demand to heat gains.

In total, 28 single measures were implemented individually and assessed based on their impact on the total cooling energy demand. The list includes insulation on wall and roof, window glazing quality, window frame quality, flexible and fixed shading devices, absorption characteristics of the envelope, reduced infiltration and consideration of a ventilation system with heat recovery. The reduction in total cooling energy demand ranges from very little with changes of less than 1% for change in absorption quality in the envelope, over 8-10% due to insulation or window frame improvement to up to about 25% with changes quality of window glazing and reduced direct solar heat gains. Most applied measures cause a reduction of about 7% in total cooling reduction. The measures also differ in addressing only sensible cooling energy demand or both. The reduction in cooling load lies in the same range and shows linear relation to the reduction in cooling energy demand.

The study on combined measures includes 7 steps of single measures. The first step to version A includes a reduction of cooling set-point temperature form 26 °C to 25 °C due to the requirement of PH certification requirements. An improvement in window glazing using an argon filled triple glazing in version B (g-value = 0.35, U_g-value = 0.34 W/m²K) and window frame quality in version C (U_f = 0.64 W/m²K). These two passive measures combined cause a reduction in sensible cooling demand by nearly 100.0 kWh/m²a to version A. In Version D, the external flexible shading elements with a g-value of 0.1 are integrated. This again causes a reduction in sensible cooling demand due to reduced solar energy gains. Version E furthermore considers a 15 cm insulation on both roof and wall. Version E features a reduced sensible cooling demand of 63.7 kWh/m²a and a latent cooling demand of unchanged 54.6 kWh/m²a. Version F includes a reduced infiltration with an improvement of n_{50} from 7 1/h to 0.6 1/h and the final version G regards a central ventilation system with heat recovery of 80%. The combined measures lead to reduction of 66% in total cooling energy demand to a value of 46.2 kWh/m²a for sensible and 10.2 kWh/m²a for latent, achieving the compliance with the passive house requirements which are set at 81 kWh/m²a in total. The maximum cooling load was reduced from 61.6 W/m² to 9.6 W/m².

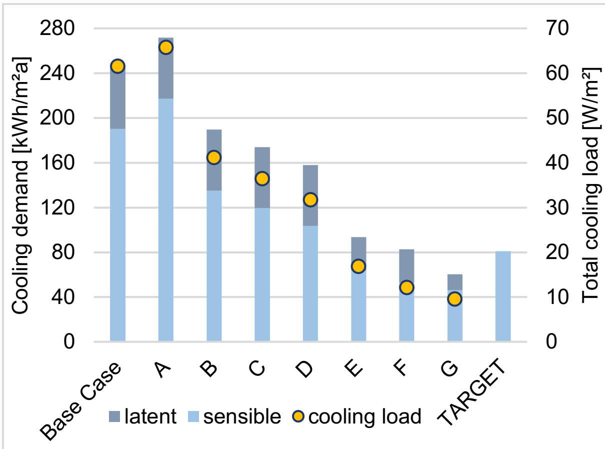


Figure 4: Step-wise reduction of cooling energy demand and load through cumulative integration of optimization measures.

The hotel building in Muktinath, Mustang, is characterized by an envelope of low-insulating properties and an inconsistent thermal separation between in- and outdoors. This results in a poor energy performance of the building and extraordinary high heating demand of 509.6 kWh/m²a. Losses through the building envelope, such as external walls or roofs, make up 84% of the total losses. The external walls alone are responsible for 50% of losses. Heating is required all year, with peaks especially in December and January. The solar gains are quite constant through the year. The building is affected by shading effects from mountains in the East and South and intensely affected by the directly neighbouring building, also located in the East. The greatest losses per area is present in the windows, followed by roof and external walls.

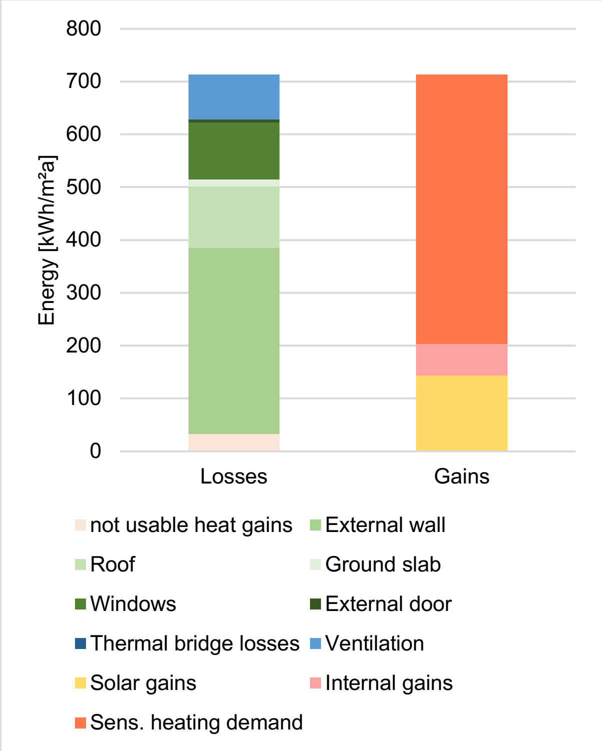


Figure 5: Heating energy balance comparing heat gains and losses of the hotel building in Muktinath, Mustang

An investigation of in total 30 measures revealed that insulation and improvement of window components reduce the heating demand between 8% and 10%. Most impact is identified in insulating the external wall, reducing the cooling demand from 54% (for 5cm insulation) up to 60% (for 20cm insulation). The least impact with a reduction of less than 4% was identified in the single insulation of the CGI roof and the change in window frame quality only. An integration of a central ventilation system with heat recovery between 75% and 90% efficiency brought a heating demand reduction of 4% to 5%.

The hotel is in Mustang offers a wide range in ways to optimize the building. First to mention is the external wall and the CGI roof. A step-wise optimization study is carried out on the hotel building. Figure 6 shows the results of this study presenting the specific annual heating demand and the heating load per version. The base case shows the results as it is. Version A includes an optimization of the insulating the RCC roof, whereas B includes furthermore insulating the CGI roof. In both cases, a 20 cm insulation with λ = 0.03 W/mK. In version C, the demand and load drop significantly when 20 cm insulation is also applied to the total external wall

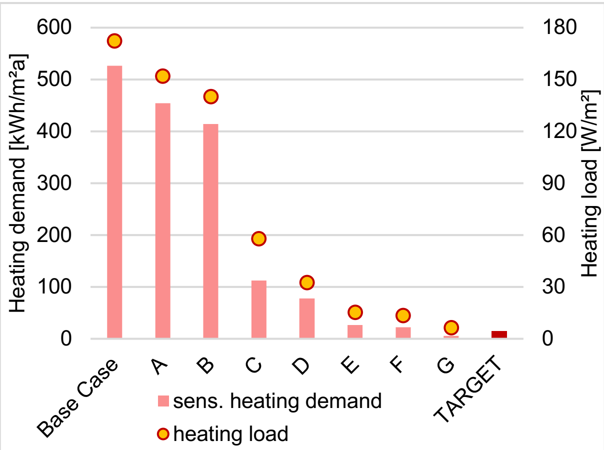


Figure 6: Step-wise reduction of annual heating demand and heating load due to building optimization measures.

4.2. Solar system design

The systems are separately designed for each case. For both cases, the sensible energy demand for both improved cases have been considered. For the basic calculation of solar and collector efficiency, the solar thermal system tool in the PHPP was used. In both cases, installation is considered on the buildings' roofs. Evacuated tube collectors (ETC) are used for solar thermal heat generation.

The office building in Butwal is characterized by highest cooling demand in summer times, from April to September. Figure 7 shows the monthly sum of solar radiation per m² for different slopes of surface facing the equator. A slope of 30° results in highest annual solar radiation of the five presented slopes, accounting for 1,673 kWh/m²a. A low slope results in highest solar radiation in summer times. The shading effect of surrounding mountains in Mustang region affect the solar radiation in winter times, minimizing the difference of solar radiation for different slopes. Considering the peak demand for cooling in summer times, a low slope of 10° is identified as most promising for the application of solar cooling in Butwal.

The hotel building in Muktinath was heat demand for heating purpose as well as for domestic hot water. Thus, the energy demands peaks in winter time and is lowest in summer time. However, the minimum is 19% below monthly average and maximum is 41% above it. This represents a relatively low variation between the monthly heat demands.

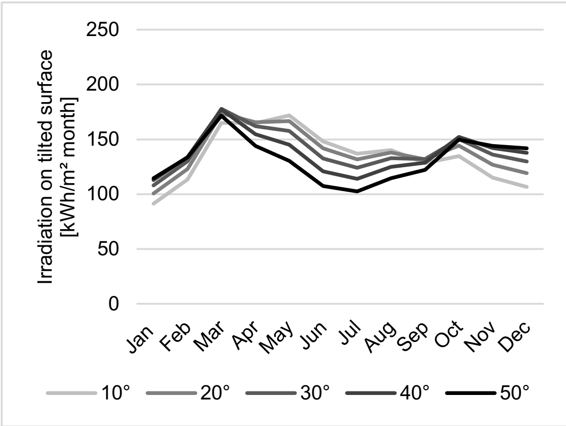


Figure 7: Monthly solar radiation per m² for different slopes of surface for Butwal location.

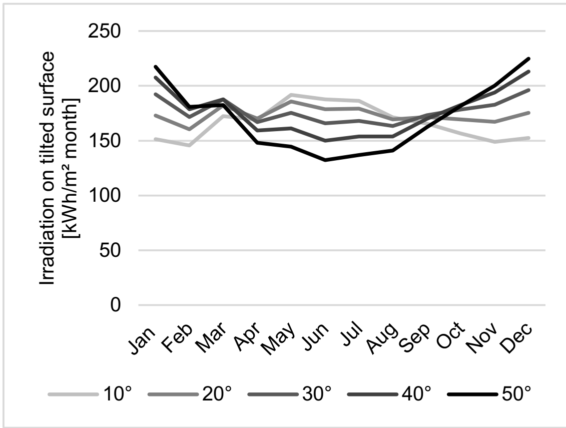


Figure 8: Monthly solar radiation per m² for different slopes of surface for Muktinath location.

A first quick analysis was made using the PHPP solar calculator for DHW. Figure 8 shows the monthly solar radiation per m² in kWh according to the slope of surface, facing the equator. The higher the slope, the is the higher is the solar radiation in from October to March. Thus, a set-up of collectors facing south with a slope of 50° result in most promising the heat demand schedule of the hotel building.

The systems differ in their form of final energy to provide to the user. This study considers following characteristics, as given in Table 1.

Table 1: Boundary conditions for solar thermal heating and cooling systems

Case	Boundary description	Value
Butwal	Shading influence (no shading = 100%)	85%
Muktinath	Shading influence (no shading = 100%)	70%
Both	Solar thermal system efficiency (no losses = 100%)	85%
Both	Heat/ cold dissipation system efficiency (no losses = 100%)	90%
Butwal	Collector outlet temperature	90 °C
Muktinath	Collector outlet temperature	50 °C
Butwal	COP of absorption chiller (constant)	0.65

The system set ups do take into consideration, that the collectors have a shading effect on each other, energy losses already occur on the solar thermal collector side and additionally on the heat respectively cold dissipation side. The effect of shading is different for the cases, as the collectors in Muktinath are more upstanding (50° slope) compared to the ones in Butwal (10° slope). Thus, the collectors in Muktinath suffer from more shading. Furthermore, the collector outlet temperature is different between the two case studies. While at Muktinath, the ETCs must provide heat at 50 °C for DHW and heating purpose, the collectors at Butwal must reach higher temperature. Reason is that an absorption chiller is considered to operate in the warm climate in Butwal to supply cooling to the user. Therefore, heat at 90 °C must be provided to the absorption chiller. It's coefficient of performance (COP) is defined as constantly 0.65. This COP is based on nominal value for absorption chillers (Kohlenbach et al. 2013). The ETC efficiency is varying between the months, taking the thermal losses of the collector to the ambient into account. For Butwal, the efficiency ranges from 10.6% in January to 31.5% in May and June. For Muktinath, the efficiency is higher due to a lower collector outlet temperature. It ranges from 37.5% in January to 44.1% in July.

The collector field is situated at each case on the roof of the building. The total roof area of the Butwal office building accounts for 1,378 m² and the one for the Muktinath hotel building for 207 m². Considering a distance to the roof top of 1 m, around 1,000 m² in Butwal and 110 m² across three roof areas in Muktinath are left. These areas are considered for solar thermal installation.

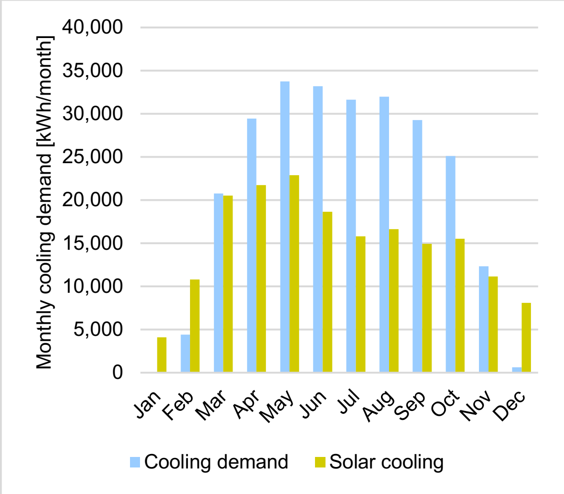


Figure 9: Comparison of monthly sensible cooling demand of the building and monthly generated solar cooling

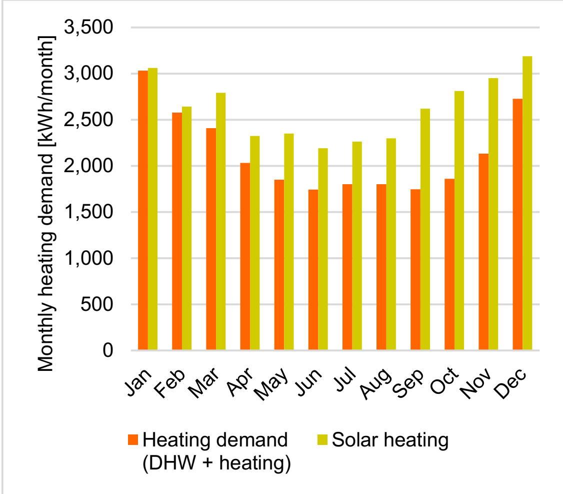


Figure 10: Comparison of monthly heating demand (DHW + space heating) of the hotel in Muktinath and the monthly generated solar heating.

Figure 9 shows the monthly demand in sensible cooling the cooling energy generated through solar cooling system. From November to March the cooling demand by ne fully covered by the solar cooling system. In the months from May to October the demand cannot be fully covered by the solar thermal cooling system only. This requires an additional cooling system to cover the peak loads. However, the annual demand can be covered by 64.5% (not including monthly surplus cooling energy).

The total heating demand of the Muktinath hotel is presented in Figure 10 and compared to the solar heating energy. A solar collector plant of 70 m² is enough to cover the heat demand of the total building throughout the complete year.

5. Conclusion

This study presents the analysis of both building optimization and solar heating and cooling technologies for two differently used buildings in a warm, respectively cold climate. It is demonstrated that through a combination of different measures, that the total cooling demand can be reduced by 75% and the sensible heating demand by 98% and indoor comfort can be increased.

Furthermore, a solar heating/ cooling system located on a building's roof can be provide a majority or even full demand for space cooling, respectively space heating and DHW energy need. A solar cooling with a collector field on the building's roof can cover 70% of the cooling demand in Butwal. The heat demand of the hotel in cold climate can be fully covered with a solar heating system with collectors on the roof. Solar solutions are beneficial at every climate, the system design however must match the demand.

6. Acknowledgement

This research received funding under Building Energy Efficiency in Nepal (BEEN) project by European Commission under the SWITCH-Asia-promoting sustainable consumption and production program, contract number ACA/2021/428-648.

7 Literature

BEEN (2023): Project Homepage. Available at https://been.minergynepal.com/, accessed 31.08.2023.

Bonomolo, M.; Jakob, U.; Neyer, D.; Strobel, M.; Vasta, S. (2023): Integration of Solar Cooling Systems in Buildings in Sunbelt Region: An Overview. In: Buildings, 13 (9), p. 2169. https://doi.org/10.3390/buildings13092169.

Copernicus (2023): Monthly Climate Bulletin. July 2023, the warmest month in Earth's recent history. Available at https://climate.copernicus.eu/july-2023-warmest-month-earths-recent-history, accessed 31.08.2023.

CP Khanal (2023): Pciture: Butwal Sub-Metropolitan city office. Available at https://maps.app.goo.gl/76QkyBnVXBBNceF39, accessed 05.09.2023.

Dean, B.; Dulac, J.; Morgan, T.; Remme, U. (2018): The Future of Cooling. Opportunities for energy-efficient air conditioning. International Energy Agency. Available at www.iea.org.

International Energy Agency (2023): Buildings. Available at https://www.iea.org/energy-system/buildings, accessed 31.08.2023.

Kohlenbach, P.; Besana, F.; Jakob, U.; Luca, M. de; Moser, H.; Podesser, E.; Reinholdt; Lars; Henning, H.-M.; Koller, T.; Eichhorn, A. (2013): Heat driven cooling technologies: closed cycles. In: : Solar cooling handbook. A guide to solar assisted cooling and dehumidification processes. Wien: Ambra V. ISBN: 978-3-99043-438-3, pp. 87–116.

Strobel, M.; Jakob, U.; Streicher, W.; Neyer, D. (2023): Spatial Distribution of Future Demand for Space Cooling Applications and Potential of Solar Thermal Cooling Systems. In: Sustainability, 15 (12), p. 9486. https://doi.org/10.3390/su15129486.

8 Appendix

Table 2: List of abbreviations

Abbreviation	Description
PH	Passive House
PHI	Passive House Institute
PHPP	Passive House Planning Package
RCC	Reinforced Cement Concrete
CGI	Corrugated Galvanized Iron
ETC	Evacuated Tube Collector
DHW	Domestic Hot Water

Table 3: Description of construction types for the office-use building in Butwal, warm climate.

Number	Type	Description (inside to outside)	U-value [W/m²K]
B01	Ext. wall	10 mm brick cladding 13 mm cement plaster 230 mm brick wall 13 mm cement plaster 10 mm wall putty 10 mm brick cladding	1.95
B03	Ext. window glazing	Single glazed window (g-value = 0.83)	5.72
B04	Ext. window frame	50 mm wooden frame	5.0
B05	Ext. roof	150 mm RCC 13 mm screed mortar 10 mm ceramic tiles	3.10

Table 4: Description of construction types for the hotel building in Muktinath, cold climate.

Number	Type	Description (inside to outside)	U-value [W/m²K]
M01	Ext. wall (I)	200 mm stoned masonry 22 mm plaster	3.86
M02	Ext. wall (II)	300 mm RCC	2.78
M03	Ext. window glazing	Single glazed window (g-value = 0.83)	5.72
	Ext. window frame	50 mm wooden frame	5.0
M04	Ext. roof (I)	CGI plate	20.1
M05	Ext. roof (II)	150 mm RCC	1.58

Table 5: Description of simulation boundaries applied to both buildings.

Boundary description	Value
Heating set-point temperature	20 °C
Cooling set-point temperature base case	26 °C
Cooling set-point temperature PH requirements	25 °C
Fresh air requirement	30 m³/hPerson