Potential for Building Integrated Photovoltaics Study for Sweden

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Report 1. Area of Building Envelopes

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Photo on the preceding side: PV on the facade of the office building of Göteborgs Energi

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Preface

This work of investigating the potential of building integrated photovoltaics (BIPV) in Sweden deals with the theoretical maximum use of all possible areas of building envelopes as mounting structures for PV modules. Several limitations are made, like the distribution of the PV-electricity in the grid, need of storage etc., which means that no concerns are made on how this kind of system would look like and how it would fit in with other power production sources and demand. Another aspect is that the building stock is changing in a very low speed; which means that the majority of the buildings of the future are already built. The question of changing the envelope of the existing buildings, is a question of decision of investments for all owners and this makes a big change of the scene unrealistic. Anyhow there is an interest of finding the figure of the total potential of the direct use of the power of the sun and how this could be used in Sweden. The potential is also possible to compare with other countries and the information be used in other types of projects and research areas.

This report presents the first part of the work concerning building integrated PV-systems within the Swedish national co-operation programme “SOLEL 97-99 – Applied research programme concerning photovoltaic systems for the period 1997-99”. The aim of this work is to define the long term potential of building integrated PV-systems in Sweden. The work is divided in three parts and this report is an analyse of the existing building stock in Sweden, with geographical and building typical variations.

Next part will analyse the irradiation on different surfaces, using weather data from different parts of Sweden. The possibility of producing electricity will be quantified by using “yield indexes” for different surfaces. As the market potential may vary significantly between different building types, special buildings like offices and schools will be discussed separately.

The last part is a deeper analyse of selected areas with different building agglomerations, in order to test assumptions and estimations regarding the missing factors in the statistical material.

This work is also a part of the Swedish contribution to the IEA PV Power System Program “PV in the Built Environment” (Task VII). This Task started in 1997 will and continue for 5 years.

The work is mainly done by Elisabeth Kjellsson, Lund University, dept. of Building Physics. Ola Gröndalen, Sydkraft Konsult AB, Malmö, has been contributing in planning of the project and is also a part of the reference group together with Lennart Spante, Vattenfall Utveckling AB, Älvkarleby, Mats Andersson, Energibanken i Jättendal, Sture Holmström, Birka Teknik & Miljö AB, Stockholm and Kjell Jonasson, Göteborg Energi, Göteborg.

Summary

To sum all the areas of the envelope of all the existing buildings in Sweden; the building stock has been divided into six categories: single-and two-family dwellings, multifamily dwellings, non-residential premises, industry, agricultural buildings and vacancy buildings. For the categories there are different kind of statistical data available, mainly from Statistics Sweden (SCB). There are no statistics regarding areas on the buildings envelope as well as orientations and tilt of the roofs, so to be able to quantify these, the buildings stock is analysed and several assumptions have to be made.

As a first survey the use of the ground is known from statistics regarding real estates. Only 2,7% of the total ground area is used for building purposes, which is about 11.000 km^2. This also includes areas for transportation, communication as well as real estates for buildings. From the area for dwellings (5.600 km^2), a first estimation of the total roof area may be done, by proposing that the maximum built area is e.g. 5%. This means that the roof area of the dwellings would be in the order of 280 km^2.

Going deeper into the material another starting point is to use the statistics regarding the number of real estates, number of buildings and dwellings. There are also statistics produced for analysing the energy use in buildings, from which the heated area in different kind of buildings are known. This gives an estimation of range of the size for the different building categories, but as the number of floor as well as the unheated areas are missing, these figures have to be approximated. The total heated area for single-and two-family dwellings are 250 km^2 and for multi-family dwellings 166 km^2. For the whole building stock the total heated area is 757 km^2. With a proposed average of 2 floors the roof area would be 378 km^2 for all heated buildings. To this figure another figure regarding non-heated areas must be added. One start may be to say that the unheated area is in the same order of size as the heated area which makes the total roof area to 757 km^2.

By closer studies of the different building-types from the starting point of the heated area, the number of buildings from different time periods, the average area per building, tilt of the roof, average number of floor during each time period and adding the non-heated buildings; the gross roof areas and the gross facade areas are calculated and the result is shown in the table below. For the facade areas an average reduction of 25% has been done for the doors and windows. Other kind of reductions are shown in the first table.

A summary of the gross and net areas for the different building types are shown in the table II. The reduction for the area of the thermal solar collectors has not been included in the net area, as this solar collector area is specified just for the best roof area, orientated to the south and the optimum tilt of 15-45°.

The areas in the tables includes all orientations and a separation in different orientations and tilts will be made in the next part of this work, in order to link the areas to the irradiation.

Table I. Summary of reductions for different areas.

All areas in km^2	**Gross area**		**Obstacles**	**Solar collectors Roof***		**Shading**		**Building historical reductions**	
	Roof	**Facade**	**Roof**	**Alt 1**	**Alt 2**	**Roof**	**Facade**	**Roof**	**Facade**
One-and two family-dwellings	290	277	29	5	120	29	83	46	44
Multifamily-dwellings	45	83	9	3	75	7	33	4	7
Non-residential premises	44	44	9	-	70	9	22	8	8
Industry	94	80	19			9	24		
Agricultural buildings	127	62	6			13	19		
Vacancy houses	70	60	7			7	18		
Totally	**670**	**606**	**79**	**8**	**265**	**74**	**199**	**58**	**59**

**Calculated roof area for solar collectors are referring only to the best orientation (south-east to south-west) and the best tilt (15-45°).*

Alt 1: Estimated energy-production from solar collectors 400 kWh/m^2, year, covering 40-50% of the heat demand for the domestic hot water in dwellings, which means systems with only short term heat storages.

Alt 2: Energy-production from solar collectors as Alt 1 covering the whole yearly heating demand for heating and domestic hot water (losses excluded).

Table II. Gross and net areas of roofs and facades of different building types.

All areas in km^2	**Roof**			**Facade**		
	Gross areas	Sum of reductions*	Net areas	Gross areas	Sum of reductions*	Net areas
One-and two family-dwellings	290	104	186	277	127	150
Multifamily-dwellings	45	20	25	83	40	43
Non-residential premises	44	26	18	44	30	14
Industry	94	28	66	80	24	56
Agricultural buildings	127	19	108	62	19	43
Vacancy houses	70	14	56	60	18	42
Totally	**670**	**211**	**459**	**606**	**258**	**348**

**solar collectors not included*

1. Introduction and scope of the study

Potential of PV electricity in a country or in a system or building is not one single conception. Potential can be looked from several angles. Very often the maximum theoretical technical potential in a distant future is considered. A more fruitful approach appears to be a market oriented consideration, taking into account several aspects of the value of the complete PV system like the value of the electricity, the value and costs as building element etc. Some examples are given below:

- Theoretical technical potential at a certain time in the country (Sweden), in a city, in a district or at a building
- Area potential for PV systems integrated to the public grid now and in the future
- Market potential for PV systems integrated to the public grid including storage now and in the future
- Area potential for PV in buildings now and in the future
- Market potential for PV in buildings now and in the future
- Potential for PV in buildings from the investors view
- Potential for PV in buildings in competition with solar thermal collectors
- Potential in different niche markets
- Potential for production of fuel (hydrogen)

The cost is today an obstacle for a more common use of PV for general electricity production but PV has now started to compete and in regions with a lot of sun, a high use of electricity during daytime and a relatively expensive electricity, the PV systems are coming closer a commercial use in larger scale (California). In Sweden there is probably a long time before a large commercial use. With a large-scale future use, also costs for integration to the public grid will be added, like short-time and seasonal storage including losses and investments.

There are many ways of defining the potential of PV as described above. This study of the potential for PV in Sweden is mainly concentrating on the area potential of the buildings in Sweden and the possible maximum electricity produced from building integrated or rooftop PV applications. In this study the area potential related to buildings has been defined as the area of roofs, facades, solar shadings etc. The next part of the work will include the areas in different directions and with different slopes. These different areas will be grouped together with a "yield index", which expresses the level of irradiation on the areas.

The future potential of areas are linked to the future building stock. The rate of construction of new buildings are in Sweden at the moment very low and there is now predictions that this will increase to the high levels. Therefore no detailed study has been done regarding the potential in specific years in the future. This means that the majority of the existing building stock is already built during this time scale. Although, as most of these buildings have to be renovated, there are possibilities for building integration in a renovation situation. In other cases the PV modules may be mounted on the envelope.

In this study of the future potential of electricity from PV, all discussions about storage (short and long-term), regulations, distributions and grid connections are excluded. The technical potential of the production of PV modules, with the need for different PV-cell material is also excluded.

The study is mainly an area potential of the envelope of the existing building stock, with different kind of obstacles taken into account, and later an analyze of the solar irradiation on these areas will be included. As the market potential is of interest, the number of some types of the buildings are separated. Offices are interesting because of the high need of electricity during summer. Schools are interesting because of the pedagogical and informative value.

2. PV in buildings

Traditionally PV modules have been mounted on special support structures. However, there are several architectural, technical and financial reasons for using PV in buildings.

The building integrated PV (BIPV) modules give several advantages compared to other PV systems:

- Less losses - as the demand is close to the point of production
- Less costs – the envelope of the building can be used as a part of the supporting construction and/or replace building material for roofs or facades
- Architectural opportunities – a new way of expressing a building. Already now, but more in the future, there will be a variety in design, structure, color, semi-transparency etc. of the PV modules.
- New elements in the built environment – as rain or sun shading elements around the buildings
- No need for land – PV can be used in dense populated areas

One of the main reason for using PV in buildings is that there is no extra land area required and PV can therefore also be utilized in densely populated areas. It does not require any additional infrastructure installations and can provide electricity during summer peak times. As the user is close, it may reduce transmission and distribution losses and may cover all or a significant part of the electric energy use of the corresponding building. The requirement of the electric power (W) from the outside depends on the degree that solar power and the load coincide. As the PV modules may replace conventional building material and also serve as the building skin, there are investment benefits, especially when comparing with expensive facade material in e.g. office- buildings. It can also provide an improved aesthetic appearance in an innovative way. The maintenance, control and operation of the PV-system can be integrated with the other installations and systems in the building.

The main applications of using PV in buildings is on the roofs or the facades, but also in coverings of different purposes, like rain, sun and/or wind shelters, light-filtration or noise protection walls. It can either be used as an opaque building material or as a semi-transparent building element in daylighting applications. The PV-modules are also characterized visually in terms of modular geometry, dimension, color and mounting system (with exposed frame or without frame) (Sick & Erge 1996).

3. Using Energy from the Sun

Even if the energy from the sun gives the base for all life in the world, the direct conversion from the irradiation to useful heat or electricity are used to an almost negligible amount. During the past, several attempts have pushed the technology forward, but there have always been alternatives in cheaper and easier ways of producing heat and electricity. In countries like Greece and Israel, with higher solar irradiation compared to Sweden, the use of solar collectors for domestic hot water have become popular and solar energy is now covering a considerable part of the energy use. One of the main differences between the thermal solar collector systems in the south and the north latitudes, is the need of freeze protection in the northern countries, which increases the cost for the system. The solar irradiation is also lower in the north, but e.g. comparing only the summer period April – September, on a surface facing south with about 30° tilt, the solar irradiation is about 20% lower in the south of Sweden (around 900 kWh/m^2) compared to some places in Greece (around 1100 kWh/m^2).

Producing electricity directly from solar irradiation is possible in two different ways. The most used in energy terms are thermal electric technologies and there are three systems available: parabolic troughs, power towers and dish/engine systems. All systems concentrate the sunlight in different ways and heats the fluid/steam systems to temperatures between 400 to 750°C. The heat is used for generating electricity in either conventional turbine generators or in small engines, e.g. Stirling engines. The characteristic size of these systems are 10 – 300 MW for the parabolic trough and power towers and 5 – 25 kW for the dish/engine systems. Only in the Mojave Desert in California there are 354 MW installed electric generating capacity with parabolic troughs, which is the most proven solar thermal electric technology.

The other way of converting sunlight into direct current-electricity is by solar photovoltaic modules or "PV", which are solid-state semiconductor devices with no moving parts. Although based on the science that began with Alexandre Edmond Becquerel´s discovery of light-induced voltage in electrolytic cells over 150 years ago, significant development began after the invention of the silicon solar cell in 1954. PV´s first major application was to power satellites in the late 1950s, an application where simplicity and reliability were paramount and cost was nearly ignored. Enormous progress in PV performance and cost reduction, driven first by the space program needs, has been made over the last 40 years. 1997 the annual global production amounted to 122 MW_p and is believed to expand approximately 20% per year. In addition to the ongoing use in space, the present cost and performance also makes PV suitable for many grid-isolated applications in both developed and developing parts of the world, and the technology stands on the threshold of major energy-significant applications worldwide. The advantages are many like simplicity, versatility, reliability, low environmental impact and when the high cost is brought down to another order of magnitude, the use of PV will become an important source of power.

The presently largest PV application market segments in the world are:

1. Communications
2. Leisure houses (about 100.000 installations in Nordic leisure houses in the forests and mountains), boating and caravaning (mainly industrialized countries)

3. Solar home systems (major part in developing world)
4. Water pumping (developing world)

The installed whole world PV capacity was estimated to total roughly 350 MW_p in 1994 of which 70 MW_p (20% of the world) are installed in Europe. These figures have been calculated by eliminating the leisure, boating, caravan and indoor applications (EU 1996). In 1997 the total installed capacity in the world was estimated to 700 MW_p (Luther 1998).

In Europe the PV capacity of the installed grid connected systems was in 1994 about 25% of the total installed capacity. This market share is supposed to grow strongly as a result of an expected widespread building integration and rooftop applications (grid connected small scale PV applications). In the EC white paper "Energy for the future, renewable sources of energy" (November 1997) the projected share for the EU countries by 2010 is estimated at 3 GW_p for PV power production which would be 0,1% of the unions total electricity production.

4. PV-modules

There are several types of modules available at the moment and also more types will be available in the future. The most commonly used cell material is silicon and the average efficiency of PV-modules with monocrystalline cells is 13%. The polycrystalline silicon is easier to produce and therefore cheaper, although the efficiency is slightly lower, 12%. In order to low the cost of the PV-manufacturing, thin-film solar cells are being developed by means of using less material and faster manufacturing processes. The major work on thin films during the last 10 years has been focused on amorphous silicon. The long-term advantage of amorphous silicon as compared to crystalline silicon is the lower need for production energy leading to shorter energy pay-back time. The efficiency for the amorphous silicon modules are 5-8%. In laboratories, both silicon cells as well as other materials are tested, and significant increased efficiencies are measured. The PV-modules in the future will show an increasing efficiency, although the so far theoretical maximum for a PV-cell is about 30%. Thin film silicone is an interesting area of development because the good properties of silicone together with the thin film properties is promising from a cost and resource point of view. Other ways of increasing the efficiency of the PV systems may be to use reflectors to concentrate the sun or combine the PV modules with thermal systems and in the same time cooling PV modules by using the surplus heat.

5. PV-projects in Sweden

In Sweden several PV applications have been installed and tested, both stand alone systems and grid connected. Most of the projects are described below.

5.1 Grid-connected plants

One of the first grid connected PV system in Sweden was installed 1983 on the State Power Board Laboratory (Vattenfall) in Älvkarleby. The power was 1 kW_p but it was replaced about 10 years later with a new roof-integrated plant. The peak power is still 1 kW in the new plant.

In 1984 a grid connected plant was mounted on a multifamily building in Solna. This 2 kW_p plant is delivering 1 300 kWh per year to the grid.

During 1990 a 3,5 kW_p plant was taken in operation in Linköping. It was integrated on the roof of a single-family house.

In 1993 a grid connected PV system was mounted on the roof on a shopping center in Stockholm, “Ringen”. There are 90 PV modules, each with a peak power of 110 W (totally 9,9 kW_p for the system). 30 modules are mounted on a vertical wall facing south and the other 60 is placed on the roof with a 45° tilt. The modules were produced by Gällivare Photo Voltaic, Sweden. The area of one module is 0,65 x 1,3 m and the total area is 76 m^2.

In 1993 another grid connected system was installed at the flat roof of the Dalarna University in Borlänge. 72 modules from Gällivare Photovoltaic, with a total area of 35 m^2 and a peak power of 3,6 kW, was mounted on supports, with a possible variation of the tilt from 25 to 90°. The modules are installed in six sections, each with 12 modules.

The museum “Länsmuseet” in Härnösand has 80 PV modules mounted on a facade with a peak power of 4,4 kW_p. The total area is 34,3 m^2.

In Göteborg, a PV plant in St. Jörgens Park with 7 kW_p monocrystalline cells is mounted partly on the facade and partly as a PV-art-sculpture.

The so far largest plant in Sweden was mounted on an office building at IKEA in Älmhult during 1997. The peak power is totally 60 kW_p, separated in one plant with crystalline silicon modules on the roof (49,5 kW_p) and one plant with thin film with amorphous silicon on the south facade (11 kW_p). The produced electricity is used in the office building and is calculated to cover about 10% of the yearly demand. The plant will be evaluated during two years.

In October 1998 a new plant was taken in operation in Göteborg. This 7,3 kW_p plant, with thin film cells, is mounted on a facade of the office to “Göteborg Energi AB”, the utility company.

All these grid connected plants do not have any batteries but they have inverters, which converts the direct current from the PV-cells to alternate current going to the grid. The experiences of the PV-modules have been very good in all projects, but there has been several problems with the inverters.

5.2 Stand-alone projects

Stand-alone systems for buildings have been used in Sweden on e.g. islands east of Stockholm. The first project in a permanent living home was on Bullerö, where a PV system was installed in 1988. The modules were mounted on an existing watch tower and the power were during 1996 increased with additional PV modules, combined with a windgenerator. The peak power from the PV system is 1,45 kW_p. On another island, Huvudskär, a similar plant was taken in operation in 1991. This 1 kW_p plant with 16 modules was placed on the roof of an old building with 4 vacation flats.

Another stand-alone application is tested for illumination of bus shelters. In 1995 about 300 bus shelters in the area of Göteborg were installed. Problems with thefts and vandalism made it necessary to develop a new pole, where the 50 W modules are encapsulated in the lighting pole. This has been tested in the Stockholm area during 1997.

The use of PV modules in Sweden is today common in the sector leisure, boating and caravaning. In 1995 the estimation of the installed power was about 600 – 700 kW_p.

6. Earlier studies of PV potential in different countries

6.1 Comparisons of methods

Several studies of the PV-potential have been conducted in Europe and the US. There are mainly two methods of determining the area potential for PV; "the statistical attempt" and "the detailed study of selected area with extrapolations".

In the statistical attempt existing data like number, shape, vintage and localization of the building stock is used. This figures are further calculated with data for solar irradiation and the areas can be ranged in groups with different yield criteria. Depending on the data available and the quality, this way is a fast method to reach figures for more or less rough estimations. The accuracy of the result may not be to good, as several assumptions must be made of factors not included in any database.

The other starting point is to select one or several areas for detailed studies, where all surfaces are quantified and determined in order of orientation, tilt, shadows and obstacles. This gives a very precise result of that area and the uncertainties occurs when the result is extrapolated to large area.

To reach the most accurate result, both methods should be used, where the statistical attempt is used for the overall estimations and the detailed studies gives information about selected influencing factors. The detailed study can be made in several ways, using aerial photographs and different computer models. In the earlier studies referred below different methods have been used.

In the Swedish study (VBB 1983) the statistical attempt was used in combination with a detailed study of obstacles on roofs on both single and multifamily dwellings with different vintage and size. Aerial stereo-photographs were used and a reduction factor for obstacles like chimneys, ventilation channels, doors, shutters and roof-windows was determined to an average of 20% of the roof area for multifamily dwellings and 10% for single family dwellings. Non-residential premises and industries were suggested to use the figure for multifamily buildings, vacation houses to use the figure for single family houses and farm buildings was supposed to use 5% reduction factor.

The Swiss study (Gutschner 1995) also used both methods, with statistical data for numbers of buildings, insurance of buildings and building area. For the detailed studies the official “people and living register” (in Sweden corresponding to FoB) and the real estate register for different communities and aerial photographs were used. The goals for the detailed study were:

- To find missing data, to test estimations and hypotheses
- To make regional comparisons
- Starting point for extrapolations

The experiences of the detailed studies were that the representation of the result is strongly depending on how the choice of area or categories are made and which material that is possible to use. In this study there were problems to identify small differences in building height and there were exceptions like areas with special buildings that were not representative for rest of the area. As the orientation of the buildings have a strong influence of the possible solar irradiation, it is although of most importance to determine if e.g. the obstacles like chimneys etc. is on the north side of the tilted roof (which gives a small impact) or on the south side (which may reduce the area potential substantially).

The study in UK (Hill et al. 1992) started with detailed analysis of the solar irradiation on walls and roofs on buildings in eight city centre sites, each around 1 km^2 in area. The buildings were simulated by photogrammetric analysis of aerial stereophotographs. From these data, extrapolations have been made to estimate the solar irradiation incident on the UK building stock, assumed to be divided into three categories: commercial, industrial and domestic. As one of the assumptions behind the work was that the produced electricity should be used during standard office hours, the irradiation only between 8.30 and 17.30 was included.

6.2 Sweden

In Sweden a comprehensive study was reported in 1983 (VBB 1983). The building stock in the year 2000 was estimated from statistical data and the total envelope was calculated to 1000 km^2. Halve of this was the roof area and the other halve was the facades excluding windows. Concerning level of solar irradiation all areas were ranked according to tilt and direction and the percentage of the maximal yearly irradiation (using climate data for Stockholm 1971). With the limit of areas which reaches a level of irradiation of more than 75% of the maximal, only roofs oriented between west, south and east (and horizontal) remains, totally 288 km^2. After further reduction because of physical obstacles on the roofs, historical aspects, snow-shading and dirt, the suitable net area was estimated to 160 km^2. In this report, the assumption for electrical conversion was 20% and the yearly irradiation was calculated to 1000 kWh/m^2. This gives a total electricity production of 32 TWh/year. A simple correction for the more realistic average of 10% gives 16 TWh/year. An estimation in the report, of the possibility to use hydropower storage as seasonal storage gives the order of a electricity production of 5 TWh/year, that may be used without too big inconvenience. In this study no detailed analyze was made of the existing building stock and only the climate data of one year for Stockholm was used for the whole country.

6.3 Switzerland

Switzerland has conducted several potential studies. Reasons for a special interest of PV in Switzerland are the relative lack of indigenous fuels, the dense population and a limitation of land possible to use for energy purposes. An enhanced use of PV is therefore linked to the envelope of the buildings. The most comprehensive study has been carried out in 1995 and in this report the possible areas of PV on buildings are determined (Gutschner 1995). The buildings were categorized considering obstacles on the roofs and facades. With the use of a yield index of the possible solar irradiation, the potential area was decided, see table 1.

Table 1. Potential net building area and electricity production for different yield criteria in Switzerland (Gutschner 1995).

Yield criteria (% of maximum irradiation)	**>0,5**	**>0,6**	**>0,7**	**>0,8**	**>0,9**
Roof net area (km^2) (minimum and maximum)	180-256	175-248	153-217	126-179	46-65
Roof net area/inhabitant (m^2/person) (minimum)	26	25	22	18	7
Roof peak power production (GWp)	18-25			13-19	
Roof electricity production (TWh/year)	**15-21**			11-16	
Facade net area (km^2) (minimum and maximum)	57-91	36-55	-	-	-
Facade electricity production (TWh/year)	**3-5**				

6.4 Germany

For Germany several studies have been conducted, mainly regarding special cities or areas (Gutschner 1995):

Table 2. Potential net building area for PV presented in different studies for Germany (Gutschner 1995).

Author(s)	City/area (regarding year of the potential area)	Year of report	Net area (km^2)	Net area/ inhabitant (m^2/person)
Bischof	Aachen area (1991)	1993	2-4	14-25
Böhnisch et al.	Rottweil (2010)	1992	0,15	5,3
Kaltschmitt & Wiese	Stuttgart (1987)	1992	2	3,8
Kaltschmitt & Wiese	Konstanz (1987)	1992	0,3	4,5
Kaltschmitt & Wiese	Baden-Würtenberg (1987)	1992	74	7,8
Kaltschmitt & Wiese	Germany (1990)	1992	800	10
Leuchtner	München (1991)	1991	10	8
Luther & Nitsch	A model city in Germany (2025)	1990 - 92	4,7	9
Persch	Homburg/Saar (1987)	1991	0,7	22
Reismayr et al.	Berlin (1989)	1990	21	11
Sachse, Werner & Bach	Münster	1994	3,2	11,7

M. Kaltschmitt and A. Wiese conducted several studies of different cities. A report from 1992, *Solartechnische Flächenpotentiale*, includes comprehensive statistical data of roof tilts and orientation together with building types and size.

In a diploma work from 1993 (R. Bischof, *Möglicher Beitrag der Photovoltaic zur elektrischen Energieversorgung einer Stadt*) a method is developed for determination of built area, calculating roof area, considerations of restriction factors and thermal solar collectors and insulation levels depending on azimut and tilt (yield criteria). The study in Swizterland (Gutschner 1995) followed the same working method.

6.5 The Netherlands

In the Netherlands a computer program has been developed, which is possible to use for calculating the PV potential using of roofs and facades. This is reported in G. Bergsma (1995) *Het potentieel van PV op daken en gevels in Nederland*. The background is an existing database including the whole building stock with information about shape of the roofs, height and ground area of the buildings (Gutschner 1995).

6.6 United Kingdom

A study in UK reported 1992, *The potential generating capacity of PV-clad buildings in the UK* (Hill et al. 1992), used another method than the studies in e.g. Germany and Switzerland as described above. The areas are not described, only the potential electricity production.

For 1995, the extrapolation for UK was a potential of 208 TWh based on the assumption of the efficiency of the PV panels of 13%. For the year 2020 the efficiency was estimated to 20% and the potential to 364 TWh. The report also includes an economic analyse.

6.7 United States

In United States a study of the potential has been conducted in 1995 by A. D. Little, *Building-Integrated Photovoltaics: Analysis and U.S. Market Potential*. The study is mainly of the market potential and the area potential is given more by the order of size estimated by experts, rather than defined figures. A simulation model was used for the yield criteria. (Gutschner 1995).

6.8 International studies

An international study was made by M. Van Brummelen and E. A. Alsema, reported in 12th European Photovoltaic Solar Energy Conference, 11-15 April 1994, in Amsterdam, *Estimation of the PV-Potential in OECD-Countries*. The aim of this study was the technical and market potential using PV-systems. Geographical, economical and social conditions were regarded and statistical data was collected from all OECD countries. Extrapolations of population, market, size of households were made and the result of the potential should be regarded as the order of the size.

Another international study was made by the European Commission in the Altener programme with input from the European Photovoltaic Industry Association (EPIA). The report *Photovoltaics in 2010*, was published in 1996 and includes four parts (EU 1996):

1. *Current status and a strategy for European industrial and market development*
2. *A strategic plan for Europe*
3. *The world PV market to 2010*
4. *Micro and macroeconomics for sustainable policies on photovoltaics in Europe*

The report includes figures for all OECD countries regarding roof area (rooftop surface) and PV potential for the years 1990 and 2010. The figures for the area potential are identical as in the report above by Brummelen/Alsema. The estimation of rooftop surface is a way of evaluate and quantify the potential market demand for diffused small-scale grid-connected PV systems. The reason of not including facades is described as the facades would be of less interest because of technical, architectural and aesthetic problems with facade integration. Typical values for determine the net solar rooftop surface are utilization factors used for taking specific losses of available surface area into account:

Roofs of residential buildings	
Inclined roofs	20-25%, due to orientation and obstacles
Flat roofs	40-44%, due to row spacing and obstacles
Roofs of offices and service buildings	40-44%, due to row spacing and obstacles
Roofs of industrial buildings	40-44%, due to array distances and obstacles

The calculation do not take into consideration that a consistent part of the available solar rooftop surfaces will be used for competing thermal solar applications.

Typical efficiency values for crystalline silicon modules have been used in the calculations:

Year	Module efficiency	Cell efficiency
1990	12,5%	21,5%
2010	16,6%	25,5%

The system efficiency is assumed to be 70%.

Except for Japan with its high population density (and consequently low rooftop surface availability), all other OECD countries present a potential contribution of PV rooftop power of roughly 1000 kWh/ year and inhabitant, equaling more than 15% of the final electricity use. The figures for year 2010 are shown in Table 3. In order to extrapolate the results towards the year 2010, the key figure available rooftop surface per inhabitant assumes to present a basically constant behavior in time, defined by building standards, climate, economic conditions and cultural characteristics. Accordingly, extrapolation of available solar rooftop surfaces has been calculated in proportion to number of inhabitants.

The buildings in the calculations are divided into three groups: houses, offices & services and industrial buildings. The share of the potential solar rooftop surface is different between the countries. Sweden has compared to many other countries a relatively high potential energy production per person, considered the low irradiation. This is mainly an effect of the size of the dwelling area per person in combination with an average dwelling stock with only 1-1½ floors. When comparing Sweden and Spain, the irradiation in Spain is almost the double of the irradiation in Sweden, but as the potential area in Sweden is about the double per person compared to Spain, the potential energy production per person will be almost the same for both of the countries, 1200-1300 kWh/person and year.

Table 3. Potential net rooftop surface for PV in different countries (EU 1996)

Countries	Irradiation (kWh/m^2,year)	Area potential 1992 (km^2)	Area potential/ inhabitant 1992 (m^2/inhabitant)	Area potential 2010 (km^2)	Producible PV energy 2010 MWh/year	Producible PV energy 2010 kWh/year, inhabitant
Austria	1.200	78	9,9	80	11.122.629	1.376
Belgium	1.000	77	7,7	79	9.203.323	894
Denmark	1.000	51	9,8	53	6.126.082	1.139
Finland	900	64	12,8	69	7.175.555	1.338
France	1.200	569	9,9	622	86.665.891	1.381
Germany	1.000	988	12,3	968	112.464.956	1.424
Greece	1.500	81	7,9	91	15.898.363	1.370
Iceland	800	3	11,5	3	322.156	1.068
Ireland	1.000	25	7,1	29	3.408.049	830
Italy	1.300	542	9,4	529	79.847.648	1.416
Luxembourg	1.000	4	10,2	4	497.727	1.185
Netherlands	1.000	114	7,5	127	14.737.705	871
Norway	900	52	12,1	56	5.827.021	1.264
Portugal	1.700	76	7,8	78	15.311.039	1.531
Spain	1.600	256	6,5	253	46.961.150	1.217
Sweden	900	111	12,8	116	12.113.223	1.334
Switzerland	1.200	72	10,4	74	10.315.333	1.454
United Kingdom	1.000	467	8,1	484	56.196.799	938
Europe		**3.630**	**9,5**	**3.723**	**494.194.649**	**1.268**
USA – Alaska	1.000	8	17,7	10	1.175.005	2.057
USA - Rest	1.600	2.832	13,3	3.582	665.523.024	2.558
USA – South West	2.100	768	15,6	971	236.881.076	3.803
USA total		**3.608**	**14,1**	**4.563**	**903.579.106**	**2.797**
Canada	**1.200**	**355**	**13,0**	**413**	**57.587.360**	**1.806**
Australia	**2.000**	**214**	**12,2**	**265**	**61.456.001**	**2.840**
New Zealand	**1.400**	**44**	**12,9**		**8.206.059**	**2.104**
Turkey	**1.700**	**394**	**6,7**	**523**	**103.185.630**	**1.330**
Japan	**1.300**	**1.039**	**8,3**	**1.050**	**158.503.338**	**1.260**

7. Determination of available building surface area in Sweden

7.1 Context

Sweden is a country with a long tradition of using indigenous fuels. The hydro power is still producing almost 50% of the total production of electricity. In 1995 the total electricity production was 143,3 TWh and the hydro power produced 67,1 TWh. The nuclear power plants were almost producing the same (66,7 TWh) and the rest was produced by oil, coal, gas and biomass (9,5 TWh). The use of biomass is increasing, mainly for heating purposes and there is also a potential of more use of indigenous biomass, both in single dwellings, district heating and in combined heat and power plants.

The vision of the energy system of the future is a phasing out of the nuclear power plants, replaced with renewable energy sources, mainly biomass but also wind and solar energy. The direct use of solar energy is a most attractive technique, as there are no emissions, no waste products and no noise pollution at the point of the use. The fuel, the sun, may also be regarded as unlimited, as it is the base for the human living on this planet. To be able to increase the use of the sun for electricity production significantly, the PV-technique must be further developed in order to decrease the cost. As this technique still is a "new" technique, improvements are foreseen both technically and economically. There are many advantages with using PV on buildings and this technique is the potential future application for a use of solar-electricity in the northern countries.

In order to investigate the potential area of possible use of PV-modules, the existing building stock is analyzed and a theoretical possible potential is obtained. The land area in Sweden is not as restricted as in more populated countries, but there is a big difference within the country.

7.2 Population

The average population density in Sweden is low with an average of 22 inhabitants/km^2 compared to e.g. the average in the EU, which is 115 inhabitants/km^2. Germany has about 229 inhabitants/km^2 and the Netherlands 453 inhabitants/km^2. Although in Sweden about 80% of the inhabitants are living in 1/3 of the area in the south part. That means a wide range of the population density between the different counties, from 3 – 269 inhabitants/km^2.

As facts about the population is a well known statistical subject, some result of interest can be made as an estimation for geographical variations in the building stock. There are three big-city areas in Sweden; Stockholm, Göteborg and Malmö, and there are almost totally 2000 urban localities, where most of the population are living (7.7 million). About 260.000 people are living in rural agglomerations and the final 1.1 million people are living in other rural areas, se Table 4.

Table 4. Number and population in urban localities, rural agglomerations, and other rural area 1995, by county.

County	Land area (km^2)	Density of pop./km^2*	Localities		Rural agglomerations		Other rural areas	Total
			Number	Population	Number	Population	Population	Population
South region								
Malmöhus	4.938,3	166	134	740.045	176	17.191	59.786	817.022
Kristianstad	6.088,8	48	107	229.373	127	12.394	52.942	294.709
Blekinge	2.941,3	52	46	119.916	75	6.647	26.174	152.737
Kalmar	11.170,9	22	95	187.562	102	9.551	46.259	243.372
Kronobergs	8.457,9	21	54	135.851	50	4.782	39.744	180.377
Jönköpings	9.943,5	31	86	258.391	55	5.279	49.016	312.686
Gotlands	3.140,1	18	18	33.243	46	4.638	20.243	58.120
West-mid region								
Hallands	5.454,3	50	94	205.519	122	12.675	47.144	269.338
Göteborg och Bohus	5.140,7	151	110	691.825	147	14.553	63.997	770.375
Älvsborgs	11.395,3	39	124	346.903	129	11.617	91.004	449.524
Skaraborgs	7.937,0	35	82	202.950	84	7.625	68.936	279.511
East middle region								
Stockholm	6.490,0	269	96	1.651.436	235	24.649	49.671	1.725.756
Uppsala	6.989,1	41	54	232.764	100	8.298	47.413	288.475
Söder-manlands	6.062,4	42	62	212.638	71	7.092	38.970	258.700
Öster-götlands	10.562,0	39	90	349.754	83	7.910	58.779	416.443
Örebro	8.516,7	32	65	227.008	82	7.416	41.993	276.417
Väst-manlands	6.301,7	41	46	224.743	41	3.809	32.549	261.101
North region								
Värmlands	17.586,0	13	72	209.114	123	10.618	64.279	284.011
Koppar-bergs	28.193,2	10	108	229.921	195	18.129	41.906	289.956
Gävleborgs	18.191,6	16	87	225.530	162	15.547	47.432	288.509
Väster-norrlands	21.678,2	12	82	196.389	125	11.902	49.999	258.290
Jämtlands	49.443,4	3	54	88.015	106	10.320	37.249	135.584
Väster-bottens	55.401,2	5	74	197.097	171	16.282	47.093	260.472
Norr-bottens	98.910,7	3	98	217.698	149	14.111	34.202	266.011
Sweden	410.934,2	22	1.938	7.417.685	2.756	263.031	1.156.780	8.837.496

** Statistic regarding density from1996*

7.3 Land use and real estates

The most of the area in Sweden is forests, bare rocks, high mountains, mires, agricultural or other land and only 2,7% of the area is related to built-up land, see Table 5.

Table 5. Land use in Sweden 1990 (ref. SCB 1998)

	Area (1000 km²)	**Area (1000 km²)**
Built-up and related land, totally	11	
- residential land		5,6
- commercial land		0,2
- public service and recreation		0,5
- industrial land		0,7
- transport and communication		3,2
- technical installation and waste disposal		0,1
- other		0,7
Agricultural land	35	
Forest land	243	
Mire (swamps)	49	
Bare rocks, high mountains and other land	72	
Total land area	**411**	

Of the built-up land area about the halve is used for residential land for permanent dwellings and holiday houses. About 1/3rd of the total is used for transport and communication facilities.

The statistics in Sweden is not dealing with areas of the roofs and facades of the buildings, so several assumptions and calculations must be made from the figures that are available. The available statistics includes figures of land use, real estates, number of buildings, year of completion, geographical location and heated area. There are also information about number of floors, new construction, demolition and in some respect retrofitting. On the other hand information is lacking about tilt and angles of roofs, orientation of buildings, shape of roofs, areas of the facades and areas for not heated buildings. Finally reductions for obstacles for PV mounting and shading must be obtained and limitations caused by historical and architectural values must be considered.

It is of course unrealistic that all buildings should be covered with PV modules. Changing in building envelopes are made because of several reasons, e.g. building – or material technical problems, damages in the surface of the envelope or a need for better insulation. Other reasons for renovation may be change of the use of the building or need for addition. Many building envelopes might only be renovated once during building life time and this time is depending on used materials and level of maintenance. One opportunity is to apply PV modules in a renovation situation, when some building activity anyhow is going on.

One source from the Statistics Sweden gives the number of real estates of different kind. This is not at all dealing with areas, but as there is a significant majority of single or two-dwelling houses, the biggest area potential is on all small houses, see Figure 1.

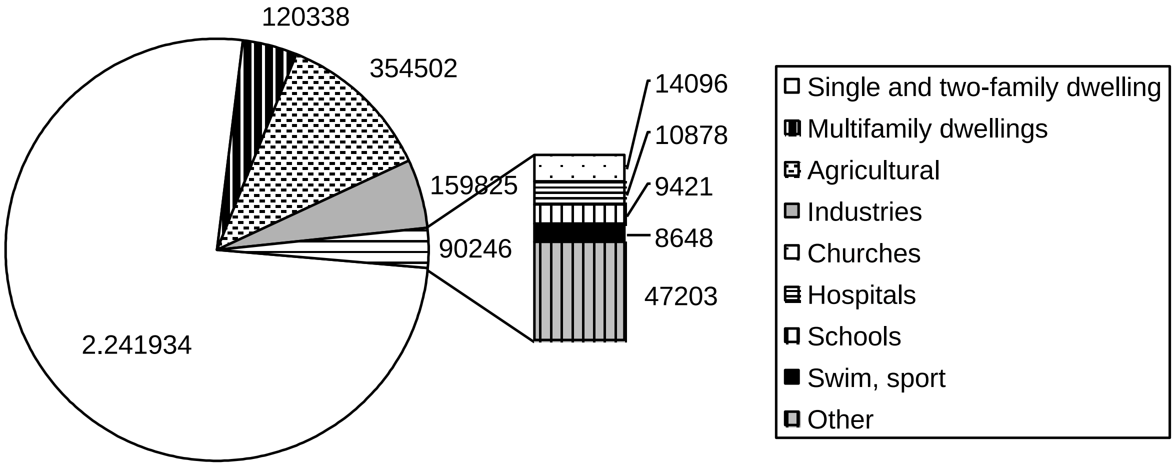

Figure 1. Number of real estates in Sweden1997(SCB 1997e).

7.4 Buildings and heated area

The majority of the Swedish 8.8 million population is living in single-or two family buildings. The figures from the latest national population and living investigation in 1990 is shown in Table 6.

Table 6. Population and households 1990. (FoB1990)

	Total number	Living in single and two-family houses	Living in multifamily
Population	8.180.620	4.907.933	3.272.687
Households	3.830.037	1.861.426	1.968.611
Vacation houses	585.654		

In this national investigation from 1990 also the number of dwellings for different completion year is presented, see Figure 2. There are about 17% (316.000) of the single and two-family dwellings in buildings constructed before 1920. During the next 40 years, up to 1960, the average number per year for the existing single and two-dwelling buildings are about 14.000/year. Then a more intensive constructing time started with an average of 29.000 dwellings per year between 1961 and 1970, with the highest figures for the next ten years, 1971-1980; 44.000/year. After this time, the building construction work was slowed done and during 1981-1990 the average was 22.000/year. During the 90´s, the speed has further decreased and in 1995 were less than 4.000 dwellings in single and two-family dwellings constructed.

The most intensive building period of multi-family dwellings was between the years 1961-1970, when almost 30% of the total existing number of dwellings in multi-family buildings was constructed (600.000 in ten years). About 32.000 dwellings per year were constructed between 1941-1960 and about the same between 1971-1980. The construction rate for multi-family buildings has also decreased and in 1995 less than 4.000 dwellings were completed.

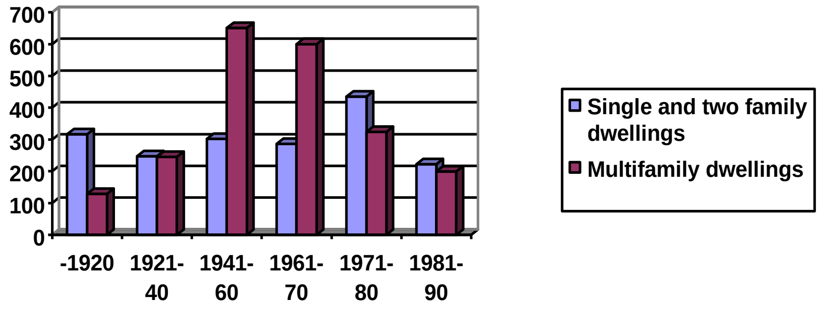

Figure 2. Number (in 1000) of dwellings with year of completion (FoB 1990).

The total number of dwellings was 1990 4.043.000, divided in 1.874.000 in one and-two family dwellings and 2.169.000 in multifamily dwellings.

There are also available statistical information regarding the heated area in buildings, separated in single and two family dwellings, multifamily dwellings and non-residential premises. This information is collected by Statistics Sweden every year in order to present data regarding use of energy. In this publications also information about year of building completion is included.

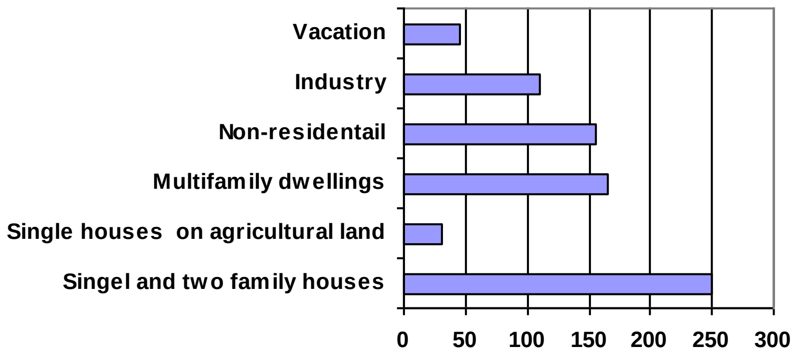

Figure 3. Heated area in different building types in Sweden 1996 (km^2), totally 757 km^2 (SCB 1997 d).

In addition to this statistical known heated area, there are also often some unheated area like garages in single-family houses or barns, machine halls and stables at the farm houses. All roofs and walls are possible to use for PV applications, but as there are not any statistical figures of the non-heated buildings, this area has to be estimated from the heated area. Often may even this non-heated buildings be more suitable for PV-mounting as they often have less windows, large areas and not any historical or architectural restrictions.

7.5 Single and two-family dwellings

The heated area in the one and two-dwellings houses is shown in *Figure 4*.

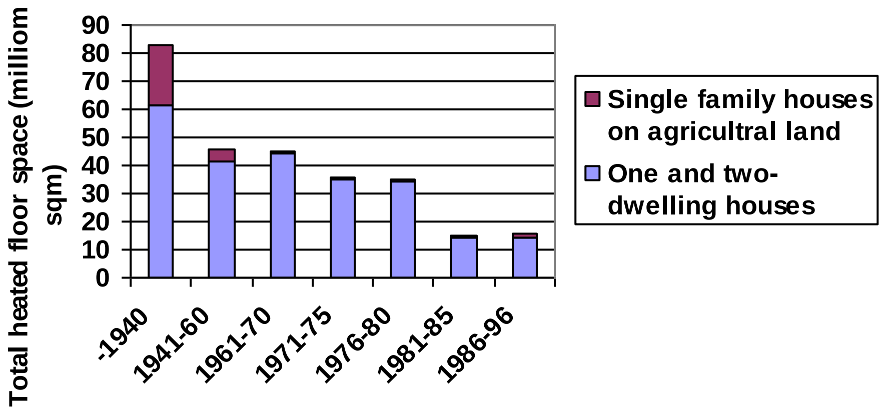

Figure 4. Total heated floor space of on and two-dwelling houses and single family houses on agricultural land and year of completion (SCB 1997 a).

Depending on year of completion, regional differences in construction and use of building material, economical reasons and other factors, the buildings characteristics changes during the time. Some examples are shown below:

One flat – 1940´s

One and a halve flat – 1940´s

The “people” villa – 1950´s

The civil service villa – 1950´s

The group constructed villa – 1960´s

The separately built villa – 1960´s

The brick villa – 1970´s

The wooden house 1970´s

Figure 5. Examples of single family buildings from different building periods.

There is a variety among the buildings in Figure 5 regarding the suitability for PV mounting. The tilt of the roof is normally steeper on houses with more than one flat, which increases the area of the roof. Although, in some buildings, e.g. the “wooden house” the roof can be separated by windows and even balconies, which creates shadows on the roof and decreases the suitable area significantly.

The suitability of the facades are very different, depending on size of windows and shadows from other buildings and surrounding vegetation. The most upper part of the facade is normally shaded by the roof. In e.g. the “brick villa” the roof-projection has a significant part outside the facade.

From the 1960´s often separate parking-garages were constructed in connection with the dwelling house. These roofs may be tilted, but are often flat. The facades are normally not equipped with windows, but as the buildings are relatively low, they are more sensitive to be shadowed, by the surroundings.

In small family houses, the roof has the best possibility for PV-applications, as the un-shadowed area is larger than for the facades, although the facades are nominally larger.

By combining the figures from the FoB 1990 with the statistical data from Statistics Sweden regarding the heated area it is possible to estimate the roof- and facade areas. The average number of stories is changed between different building period and the estimated value varies between 1,05 and 1,25.

The most common type of roof for one- and two family dwellings is the tilted roof as shown in figure 5 (gableroof), with about 85% of the total area and the average tilt of 31°.

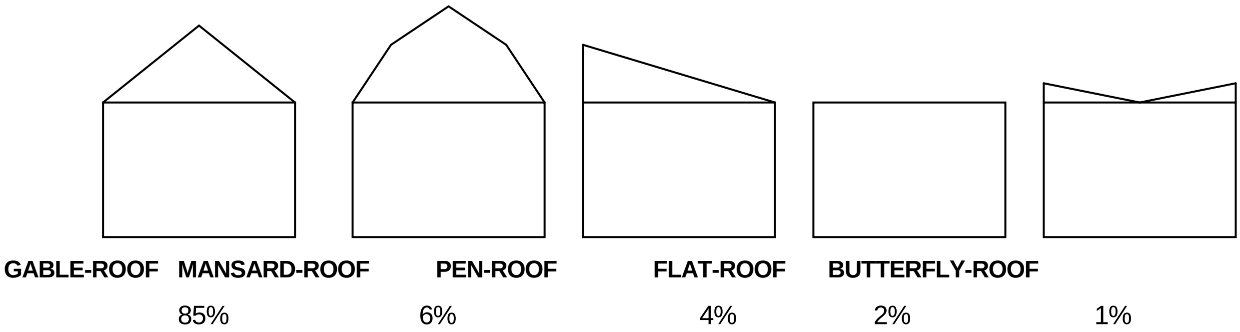

Figure 6. The most used types of roof construction in one and two-family dwellings and the percentage of the total area (VBB 1983).

In Table 14 in section 8.1, the most used roof constructions and the average tilts are described both for one-and two-family dwellings and multi-family dwellings. The average tilt of 30° is used in the area calculations. In Table 7 the results of calculation of the gross roof and facade area for the one-and two family dwellings are shown.

Table 7. Gross area of roof and facades of one-and two family dwellings.

Year of construction	**-1940**	**1941-60**	**1961-70**	**1971-80**	**1981-96**	**Totally**
Heated area one and two-family dwellings (km^2)	61,2	41,6	44	69	29	**244,8**
Heated area agricultural dwellings (km^2)	21,6	3,9	0,8	1,2	1,6	**29,1**
Number of one and two-family dwellings (1000)	563	302	286	435	289	**1.875**
Average heated area (m^2) per building	147	151	157	161	106	
Estimated number of stories	1,25	1,05	1,1	1,25	1,25	
Groundarea per building (m^2)	118	143	143	129	85	
Tilited roof area average 30° per building (m^2)	136	165	165	149	98	**(in VBB 1983 the average figure is 113 m^2/building)**
Roof-area (km^2)	77	50	47	65	28	267 km^2
Estimated roof-area of garage or other side-building (m^2 per building)	5	10	15	20	15	**23 km^2**
Total roof area (km^2)	**82**	**60**	**62**	**85**	**43**	**290 (km^2)**
Total facade area per building (m^2)	143	172	172	160	132	**(in VBB 1983 the average figure of 128 m^2/building)**
Facade area garage or other side building per (m^2 per building)	27	38	48	58	48	
Facade area (km^2)	96	63	63	95	52	**369**
Facade area (25% reduction for windows and doors) (km^2)	**72**	**47**	**47**	**71**	**39**	**277**

The total tilted gross area for one-and-two family dwellings is in Table 7 calculated to 267 km^2 with an addition for garages and other side-buildings of 23 km^2, together 290 km^2. This area includes all directions, which will be separated and evaluated when they will be linked to the irradiation. The corresponding facade area (including side-buildings) is with a reduction of 25% for doors and windows 277 km^2.

The most used material in the facade are wood. There are also facades with cladding, gas-concrete, bricks and eternit, see Table 8 (Broberg 1987).

Table 8. Percentage of material in the facades on one-and two-family dwellings for different year of construction.

Year of construction	<1930	1930-1945	1946-1960	1961-1975
Wood	60%	50%	30%	30%
Cladding	17%	20%	30%	5%
Brick	10%	15%	30%	60%
Eternit	10%	15%		
Gas-concrete			10%	5%

The material used in the roofs are brick-tiles, concrete-tiles, corrugated metal sheets and roof cardboard.

7.6 Multi-family dwellings

The total heated area in multifamily dwellings is 166 km^2, in 2.169.000 dwellings, see Figure 7. This gives an average area of the dwellings of 76 m^2. Depending on the type and mainly the depth of the building there are different potential for PV-applications. The roofs are often very suitable, but the facades are normally dominated by windows and balconies on the directions with the best irradiation.

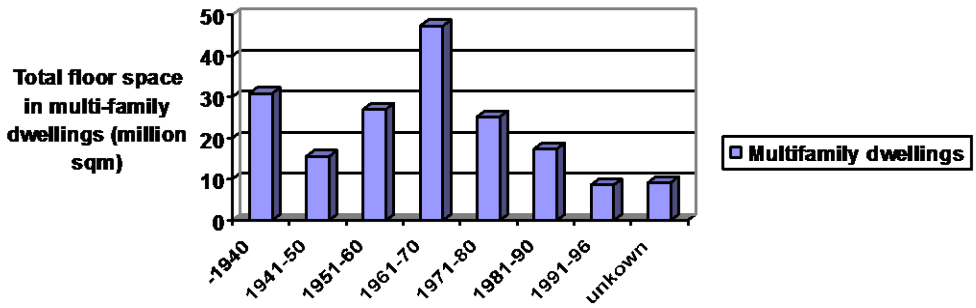

Figure 7. Total floor space in multi-family dwellings and year of completion (SCB 1997 b).

The multi-family buildings are mainly characterised by the buildings constructed between 1960-75. Almost halve (about 900.000 dwellings) of the existing multi-family dwellings were constructed during this period in the so called million-dwelling-program. It was mainly concentrated to expanding places, the big cities. The buildings constructed during this 15 years can be regarded as a rather homogenous group, regarding construction and material.

The older multi-family buildings are either a small group with multi-family villas or the buildings in the closed blocks in the center. The multi-family villas are small separated buildings with 4-6 dwellings and two-three stories. These kind of buildings were one of the most common multi-family buildings until 1930´s and 1940´s, specially in small cities. They were built together in groups or mixed up with traditional single family houses.

There are about 120.000 dwellings in these buildings and with an average of 5 dwellings per building, the total number of buildings will be about 24.000. Compared to single family buildings, the suitability for PV-mounting is better, because of the height of the buildings and the size of the roof. Normally there are nothing else, except for chimneys, on the roofs. Because of the age of those buildings, there might although be architectural and culture-historical values of these buildings, which may cause restrictions in changing of the envelope (BFR 1984).

In the heart of the cities, the buildings are normally in closed blocks, with 3-5 stories. In the bigger cities, the houses are made of bricks and in smaller localities, they are often built with wood. The wood houses may have facades with cladding or wood. In the older built blocks, there are often buildings also inside the block. More than halve of the buildings in these closed blocks are constructed before 1930 and only small part after 1946, mainly because of renewing projects in the cities. In the order of number of dwellings these closed blocks are the most common after the lamella houses, with about 240.000 dwellings. Although, among these buildings the majority is not suitable at all for PV mounting on the facades, both because of shading problems but also because of the architectural values. As the roofs normally are not visible from the streets and probably are not much shaded, there are better possibilities for adding elements, depending of the historical value of the building.

Figure 8. Three story lamella buildings with flat roofs situated with 90 ° angle (constructed during 1970´s).

The lamella houses are long multi-family buildings, often with 2-3 stair-case or more units long. The buildings are either located in parallel rows or with 90° angle. More than 35% are built in groups with more than 10 buildings. They started to be built during 1930´s, but got a domination position after 1945. They were normally built with three stories, but after 1960 and the introduction of the element building construction, they were also built higher, with about 9 stories. From 1970 the two story buildings became more common. In 1975 the number of dwellings in lamella houses was about 400.000 in buildings with maximum 3 stories and about 540.000 in building with more than 3 stories. After 1975 totally another 100.000 dwellings are constructed, the majority in lamella buildings. The roofs are very suitable for PV-mounting, with no shade from the surroundings and no historical restrictions. Many of the roofs are built flat and those built between 1961 and 1975 are most probably scheduled to be renovated, because of leakage, if they have not been renovated yet. An estimation from 1980 was that about 14% of the roofs in multifamily buildings are flat (VBB 1983).

Figure 9. Eight floor lamella building with butterfly-roof from late 1960´s.

The facade of the lamella houses may also be used for PV applications, but in some cases e.g. as seen in Figure 9, the facades may be covered with balconies and the only place for PV mounting is on the parapets.

The second most common building type is the tower-buildings. This are buildings with one central staircase and at least 3 stories, most of them higher. They started to be built in 1930´s and became more common during 1940´s. In the beginning they were not high-rise-buildings, but the number of stories increased and during 1960´s they were normally constructed with 8-10 stories.

Finally there are also some other building types like facade-corridor-buildings with facade entrance corridors (totally 30.000 dwellings), corridor houses and terrace houses. Together they include about less than 100.000 dwellings.

The situation plans and the orientations of the multi-family buildings from 1961-75 is not directly linked to the natural circumstances as it is rather more planned in order suite the tracks for the building cranes and the building technique. Of course all apartments were planned to get sufficient sun light, but there is not a predominant orientation of the buildings.

Figure 10. Eight-floor lamella building with flat roof from the late 1960´s.

The coating of the tilted roofs are often roof-cardboard, concrete tiles or sheet metal. The flat roofs normally have a water sealed coating of roof-cardboard or rubber sheet. In order to avoid that the rubber sheet should blow away, a layer of stone gravel is put upon it.

The area of the roofs are estimated in Table 9. The tilt of the roofs are supposed to be 30° for multifamily villas and closed blocks. For the rest of the buildings the calculations are not including any tilt, which makes the area a bit underestimated. The average area/flat are not exactly known for all types of buildings and the used values are shown in the table. These values are related to the construction periods. The used average flat is a bit smaller (total average 71 m^2) than the known total average value (76 m^2) which also relates to the fact that many of the very small flats have been renovated to bigger flats, since the construction time. The number of this flats have not been analyzed in more detail. The area of the facades have mostly been checked with construction drawings of the different building types. The depths of the buildings have been varied between 10 to 14 m depending on type and construction time of the buildings. The figure facade area/flat area is mainly depending on the depth of the houses, as the height of the flats has not been changing dramatically since 1960. Older buildings normally have a higher height in the apartments, which increases the facade area /flat area (BFR 1992).

Table 9. Assessment of roof and facade area of multi-family dwellings.

Type	Years	No of dwellings	No of stories	Average area/flat (m^2)	Gross roof area/flat (m^2)	Total gross roof area (km^2)	Total facade area (m^2) and (facade area /flat area)
Multi-family villas	-1940	120.000	2-3	60	28	3,3	8,7 (1,1)
Closed blocks in cities	50% before 1930	240.000	3-5	60	17	4,1	14,4 (1,0)
Lamella houses	Before 1930	32.000	4	40	9	0,3	1,2 (0,9)
Lamella houses	1931-45	106.000	3	43	14	1,5	3,6 (0,8)
Lamella houses	1946-1960	Σ 425.000 (85.000) (35.000)	Most 3 (4) (>4)	66	19 (16) (11)	8,0 (1,4) (0,4)	22,4 (0,8)
Lamella houses	1961-1975	690.000 (340.000) (170.000)	2-10 (3-4) (5-10)	78	20	13,8	32,3 (0,6) (17,2 (0,65)) (6,6 (0,5))
Tower buildings	-1975	90.000	6-8	78	10	0,9	1,5 (0,22)
Other multi-family	1961-75	110.000	2-3	80	31	3,4	6,2 (0,7)
All multi-family	1975-96	356.000	3	80	27	9,5	19,9 (0,7)
Totally	**-1996**	**2.169.000**		**76**		**44,8**	**110,2**
After reduction for windows and doors	**-1996**	**2.169.000**				**44,8**	**82,6**

For the facades a reduction for windows and doors have been done. An average estimation for this reduction is 25%, which decreases the facade area to 82,6 km^2., which is almost the doubled compared to the roof area of 44,8 km^2. A discussion of reduction of the roof area because of obstacles are made in section 8.2.

7.6.1 Material in facades and different tilted roofs

The most common used material in facades for multifamily buildings are gas-concrete and concrete, that was mainly used during the intensive building period 1961-75, but it was in use since the 1940´s. The older buildings are covered with wood or stone, with tile roofs, painted metal sheets or slate. The steep roof was natural during history because of the Swedish climate and available roof material.

For the steep roofs (roof tilt >22°) are straw or peat the oldest building materials. During middle age wood was used for the simple cottage and tiles of wood or brick for the more well-supplied buildings. Roofing tiles of brick became common after 1900 and was most used during the 1940´s and 1950´s. The use of these tiles have now decreased as the concrete tiles came into the market during the 1950´s (BFR 1991).

Different types of metal sheets have been used during the time, from copper sheets on castles and churches and steel sheets for dwellings. Sheets of iron was until 1900 the dominating roofing material for larger multifamily-buildings. From 1920 galvanized iron sheets were dominating and today metal sheets with different kind of surface treatments are used.

Roof cardboard was used before 1930´s by using tar-board that was maintained with new layers of tar. Plates with slate or eternit is not common but has been in use. After 1970 the eternit including asbestos was prohibited to use and was replaced by other material.

The low tilted roof (4-22°) became more common from 1950 and this decreased tilt put higher demands on the roofing material. Tiles, both of brick and concrete and metal sheets, was used in the same way as for the steep roofs. From 1960 the galvanized or different kind of surface treated steel sheets or aluminum sheets were used and specially for tilts lower than 5,7° roofing cardboard was used.

The first flat roofs, (tilt <4°) started to be built in 1930´s but became more common in 1950´s and 1960´s. A strong force to develop the use of flat roofs was the building industry that produced the prefabricated building elements. The roofing material was mainly different kind of card-boards (asphalt boards) but also metal sheets were used. On the flat roofs damages have occurred that has caused problem with leakage and today there is more precaution regarding construction of flat roofs.

7.6.2 Need of renovation

About halve of the number of buildings from 1961-75 has a roof with an ordinary tilt in two directions (gable roofs) or in one direction (pen roofs). These are most common in not high-rise houses. The high rise houses have normally flat roof, roofs with a rather small tilt or butterfly roofs, example see Figure 9. These roofs have a tendency to begin to leak, because of ice blocking the possibility for water to flow away, which causes damaging pressure on the roof. More than 40% of these buildings have flat or almost flat roofs.

The potential of renovating flat roofs in multifamily buildings from 1961-1975 have been investigated in 1993 (IEA Task 20, 1993). The total amount of roof area was estimated to 29.7 km^2 and about 10.8 km^2 was supposed to be renovated before 2010.

Regarding the wall area on the facades the total amount estimated in 1993 was 63.4 km^2, with about 1/3 on buildings between 1941-1960 (23.2 km^2) and 2/3 on buildings from 1961-75 (40.2 km^2). In this IEA Task 20 report also estimations regarding need of renovation until 2010 was made. The brickwalls are excluded and the potential area was 22.3 km^2, (6.2 km^2 on buildings from1941-60 and 16.1 km^2 on buildings from 1961-75).

7.7 Non-residential premises

The heated area of the non-residential premises was in 1996 152,2 km^2 (SCB 1997b and c). About 19 km^2 is included in multifamily buildings and of the rest 133 km^2 the area is used for different purposes as shown in Table 10.

Table 10. Areas of non-residential premises for different uses and construction periods in km^2 and percentages, 1996 (SCB 1997 c).

Non-residential premises (km^2)	**-1940**	**1941 -60**	**1961 -80**	**1981 -96**	**Un-known**	**Totally**	**Totally (%)**
Offices	6,2	3,8	9,4	6,2	2,0	27,6	20,8
Bank & insurance	0,2	0,2	0,7	0,1	-	1,3	1,0
Post and telephone-offices	0,2	0,2	0,5	0,5	0,2	1,6	1,2
Schools	3,5	7,5	11,9	2,2	1,2	26,4	19,9
Hospitals etc.	3,4	3,5	12,4	3,7	0,9	23,9	18,0
Shops and stores	2,4	1,1	6,4	2,4	0,4	13,2	9,9
Hotels, restaurants	2,5	0,9	1,5	1,1	0,3	6,3	4,7
Sport and swim	0,8	0,4	2,6	0,9	0,1	4,8	3,6
Churches, chapels	1,1	0,2	0,5	0,1	0,0	1,9	1,4
Theatres and cinemas	0,1	0,2	0,2	0,0	0,1	0,6	0,5
Other common premises	1,4	0,7	0,9	0,6	0,3	3,9	2,9
Other non-residential premises	1,2	2,2	3,8	1,9	6,8	16,0	12,0
Totally	**24,7**	**21,8**	**32,2**	**21,7**	**12,6**	**133,0**	**100,0**

The building intensity of these buildings is different during the time. Only the churches are mainly built before 1940, while e.g. offices including banks and insurance companies are mainly constructed after 1961. More than 30% of all non-residential premises were constructed between 1961-1975 and about 25% after 1976. There is also about 10% of the building area for which the construction period is not given in the statistics (SCB 1997 c).

As the statistics are only dealing with real estates and heated floor area, assumptions must be made to describe the roof and the facade areas. As about 70% of the heated area is offices, schools, hospitals and shops, the average floor number for non-residential premises is assumed to three, with an average height of 3 m. The flat roof area would then be about 44 km^2. This would make the total building volume to 396 km^3. According to analyses of building volumes contra facade area, which were established in the report from VBB 1983, the assumed relationship for non-residential premises is: 1 m^3 building volume corresponds to 0,112 m^2 facade area, excluding windows. This makes the total facade area to 44 km^2. This figure may be a bit rough and this should be studied in more detail.

7.8 Industry

Statistics regarding industry buildings are not very well described, but there are figures of areas on different industries and the use of areas in the real estates tax register (1992), see Table 11 .

Table 11. Building areas on industry real estates divided in activities and use 1992 (km²) (SCB 1997 c).

Industry type	Production	Office	Store	Not defined	Totally
Industry-hotel	2,4	1,0	1,7	0,1	5,2
Chemical	1,0	0,4	1,2	1,0	3,5
Food	1,8	0,6	2,1	1,5	5,9
Metal	14,4	3,0	6,5	1,3	25,1
Textile	1,1	0,2	0,8	0,0	2,2
Wood	4,1	0,5	4,7	3,6	12,9
Other manu-facturing	10,6	3,4	8,8	4,4	27,2
Petrol-stations	0,1	0,0	0,0	0,7	0,8
Repairing	2,7	0,9	1,8	0,2	5,6
Stores	1,0	1,6	12,0	0,7	15,5
Other building	1,3	0,8	2,3	0,6	5,0
Totally	**40,5**	**12,3**	**42,0**	**14,0**	**108,8**

To be able to estimate the roof and facade area from the figures in the table above, assumptions must be made regarding type and size of the buildings. A majority of the buildings are one-storey buildings and according to VBB 1983, 21% of the building volume was assumed to relate to multi-storey buildings. With an average of three storeys with four meters height and the other dimensions as defined in Table 122, the total building volume will be 760 km³. The roof and the facade areas are also calculated for the different types.

Table 12. Calculation of gross roof and facade areas of industry buildings (km²).

Type	% of volume	Height (m)	Width (m)	Length (m)	Number	Volume (Mm³)	Roof area (km²)	Facade area (km²)
A – High rise halls	54	10	30	50	27.330	410	41	44
B – Other halls	15	5	20	30	38.000	114	23	19
C – Other 1 storey buildings	2	4	15	25	10.000	15	4	3
D – Multi-storey buildings	21	12	20	30	22.220	160	13	27
E - Other	8	5	15	25	32.530	61	12	13
Totally						**760**	**94**	**106**
(VBB 1983)							(48)	(43)
Totally including 25% reduction for windows and doors							**94**	**80**

Compared to the roof and facade areas calculated in VBB 1983, it is almost doubled in the new calculation. In VBB 1983 the volume of the buildings were assumed to 250 km³ in 1975 and 400 km^3 year 2000. By using the statistical figures for areas the figure for 1992 is 760 km^3. With this way of calculating the roof area will be 94 km^2 and the facade area 106 km^2. With a 25% reduction for windows and doors the facade area will be 80 km^2.

7.9 Agricultural buildings

Totally there are in Sweden about 190 000 single-family dwellings on agricultural land (SCB 1997 a) and there are about 355 000 agricultural real estates (SCB 1997 e). To be able to calculate the building area of the farm buildings some estimations has to be done. In connection to each dwelling on agricultural land, there should be at least 1-2 farm buildings. There are probably also farm buildings on the majority of the other agricultural real estates. An estimation may be that about 250 000 buildings with an average size of: width 12 m, length 30 m, height 4 m, saddle-roof 45° tilt. A reduction factor for door, gates and windows is supposed to 25%. With these assumptions each buildings will have: 250 m^2 facade area and 510 m^2 roof area. With 250 000 buildings the total net areas will be 62 km^2 facade area and 127 km^2 roof area.

7.10 Vacancy houses

The number of dwellings for seasonal and secondary use are about 630 000 in Sweden and the average floor area is 65 m^2 in the dwelling building. Together with about 1/3rd of the dwellings, about 210 000, there are also non-residential buildings with an average area of 24 m^2 (SCB 1997 d).

The estimations regarding the dimensions of the buildings are for the dwellings: width 6,5 m, length 10 m, facade height 3,2 m and for the other buildings: width 4 m , length 6 m, facade height 3,2 m. This will be a total facade area of 106 m^2/dwelling and 63 m^2/other buildings and totally 67 + 13 = 80 km^2. By reducing the facade area with 25% for windows and doors, the net facade area will be 60 km^2.

With an overhang of the roof with 60 cm and 45° tilt, the average roof areas will be 114 m^2 and for a flat roof 86 m^2 for the dwelling. The corresponding figures for the non-residential building will be with an overhang of 30 cm: 43 m^2 for 45° tilt and 30m^2 for a flat roof. The average is between the flat and the 45° tilt and an average figure of 100 m^2 is chosen for the dwelling and 35 m^2 for the other building. Totally the roof area will be 63 + 7= 70 km^2.

8. Limitations on the roofs and the facades

8.1 Orientation and tilt

When integrating PV on buildings the optimum orientation and tilt is often not achievable, because of natural and architectural restrictions. The PV-array may have to be distributed to several differently orientated or even vaulted roofs or facade segments. As a result, irradiation is non-uniform on various parts of the PV-plant and therefore, they show different instantaneous power characteristics.

Table 13. The orientation of roofs for different kind of buildings (VBB 1983).

Building type Percentage roof areas %	NW - NE	NE - SE	SE - SW	SW - NW
One- and two famliy dwellings	26	24	26	24
Multifamily dwellings	24	26	24	26
Non-residential premises	23	27	23	27

The orientations of the roofs of the Swedish buildings are almost uniform in all directions, according to studies during 1970´s (VBB 1983), se Table 13. No new statistical data or studies are available.

The tilt of the roofs were also reported in the study from 1983 (VBB 1983). For the roofs on single-family buildings the most common tilt is around 30° and for the multi-family dwellings the tilt is 24-28°, see Table 14. Se also Figure 6, for the principal of the different roof constructions.

Table 14. The average tilt and type of roofs on different buildings (VBB 1983).

Type of roof construction	**One-and two-family dwellings**		**Multifamily dwellings**		**Non-residential premises**	
	Tilt °	Area %	Tilt °	Area %	Tilt °	Area %
Gable roof	31	85	24	67	28	61
Mansard roof	30	6	28	3	19	7
Pen roof	6	4	5	8	9	5
Flat roof	0	2	0	14	0	19
Butterfly roof	4	1	7	6	3	4
Other	0	2	0	2	0	4

For the one-and-two-family dwellings the dominating tilt is 31°, while the roofs on the multifamily dwellings are dominated by a bit lower tilt (24-28°). The multifamily buildings have also a relatively large area with flat roofs, which has been discussed in section 7.6.2.

8.2 Obstacles on roofs

Obstacles on the buildings may reduce the potential area for PV-installations in two ways. An obstacle means that the potential area will be reduced, but it also may cause shading on other parts of the building. Estimations of obstacles have been made in VBB 1983, by aerial photographs. The roofs of single family and multi-family buildings with various age have been studied with stereo-photographs. A summary of the study is shown in Table 15.

Table 15. Estimations of obstacles on roofs for different dwellings (VBB 1983).

Type of building	Roof area/ house (m^2)	Reduction (m^2)	Reduction (%)	Main reason for reduction
Condominium (1930´s)	70	7,6	11	Chimneys, shutters, dormer windows
Single-family dwellings (1940´s)	220	16,0	7	Chimneys, ventilation pipes, shutters
Single-family dwellings (1940´s)	115	6,4	6	Chimneys, ventilation pipes, shutters
Condominium (1940´s)	477	76,0	16	Chimneys, ventilation pipes, shutters
Condominium (1950´s)	707	45,0	4	Chimneys, ventilation pipes
Condominium (1950´s)	184	18,0	10	Ventilation pipes, shutters
Condominium (1950´s)	1910	180,0	9	Chimneys, ventilation pipes, shutters
Single-family house (1950´s)	493	33,9	7	Chimneys, ventilation pipes, shutters
Condominium (1950´s)	500	43,8	9	Chimneys, ventilation pipes, shutters
Condominium (1960´s)	1434	26,2	2	Design, ventilation pipes
Single-family house (1960´s)	178	33,4	19	Design, chimneys, ventilation pipes, shutters, dormer windows
Condominium (1960´s)	4320	155	4	Design, ventilation pipes
Single-family house (1960´s)	155	16,2	10	Chimneys, ventilation pipes, shutters, dormer windows
Condominium (1960´s)	2290	58	3	Design, ventilation pipes
Multi-family buildings 5-8 stories (1930´s)	821	150,0	18	Design, chimneys, ventilation pipes
Multi-family buildings 4 stories (1940´s)	3090	72	2	Chimneys
Multi-family buildings 4 stories (1940´s)	621	95	15	Chimneys
Multi-family buildings 4 stories (1940´s)	762	66,2	9	Chimneys, shutters
Multi-family buildings 4 stories (1940´s)	919	202,8	22	Chimneys, ventilation pipes, shutters
Multi-family buildings 4 stories (1950´s)	1640	171,2	10	Design, chimneys, ventilation pipes, shutters
Multi-family buildings (1950´s)	2240	1785	80	Design, chimneys, ventilation pipes, shutters
Multi-family buildings 6 stories (1950´s)	350	64	18	Design, chimneys, ventilation pipes
Multi-family buildings 5 stories (1950´s)	272	93	34	Design, chimneys, ventilation pipes, shutters
Multi-family buildings 4 stories (1950´s)	485	25	5	Chimneys, ventilation pipes
Multi-family buildings 4 stories (1950´s)	1097	138	13	Chimneys, ventilation pipes, shutters
Multi-family buildings 10 stories (1950´s)	380	136	36	Design, chimneys, ventilation pipes, shutters
Multi-family buildings 10 stories (1950´s)	372	46	12	Design, chimneys, ventilation pipes
Multi-family buildings 3 stories (1950´s)	1653	343	21	Design, chimneys, ventilation pipes

Multi-family buildings (1950´s)	1567	5	-	Ventilation pipes
Multi-family buildings 4 stories (1950´s)	2505	168	7	Chimneys, ventilation pipes, shutters
Multi-family buildings 12 stories (1950´s)	460	85	18	Design
Multi-family buildings (1950´s)	1032	203	20	Design
Multi-family buildings 3 stories (1960´s)	800	70	9	Chimneys, ventilation pipes, shutters
Multi-family buildings 5 stories (1960´s)	640	69	11	Design, chimneys, ventilation pipes, shutters
Multi-family buildings 8 stories (1960´s)	742	473	64	Design, chimneys, ventilation pipes, shutters
Multi-family buildings 6 stories (1960´s)	767	145	19	Design, ventilation pipes,
Multi-family buildings 4 stories (1960´s)	700	187	27	Design, chimneys, ventilation pipes, shutters
Multi-family buildings 6 stories (1960´s)	457	30	7	Chimneys, ventilation pipes
Multi-family buildings 2 stories (1980´s)	562	82	15	Chimneys, ventilation pipes, shutters
Multi-family buildings 3 stories (1980´s)	2211	663	30	Design, ventilation pipes, shutters
Multi-family buildings 6 stories (1980´s)	2175	248	11	Design, chimneys, ventilation pipes, shutters
Multi-family buildings 3 stories (1980´s)	1292	83	6	Chimneys, shutters
Multi-family buildings 5 stories (1980´s)	1480	427	29	Chimneys, ventilation pipes, shutters

The average reduction for obstacles in this study is for the single-family house/condominiums are 8% and for the multi-family dwellings 17%. There is an almost doubled reduction for the multifamily dwellings compared to the other dwellings, although the difference between the buildings may vary from almost zero up to 80%.

This study was made with assumptions of the size of the obstacles. The “design” - obstacle, which may be glassed areas or roof balconies, are estimated in m^2. The other obstacles (chimneys, ventilation pipes, shutters and dormer windows) were counted and depending on how the obstacles were placed, the buildings were grouped in 4 different categories.

A chimney is supposed to have the size of 0,5 m^2, but as there should be some free space around the chimney (0,5 m), the assumed area is 3 m^2. A ventilation pipe is calculated with an area of 1 m^2 , a shutter with 4 m^2 and a dormer window with 9 m^2. If the obstacles are well situated together, the building was placed in category 1 and the areas were calculated as above. The rest of the roof is then possible to use for the PV-installations. But if the obstacles are spread out over a major part of the roof, which makes it unsuitable for PV-installations, the area defined above of the obstacles are added with the double size (totally three times). For the roofs in between, the category 2 is added with an extra halve area (totally 1,5 x obstacle area) and the category 3 with one extra area. This was done in the Table 15.

As this study is a rough estimation of only a small part of the buildings, the chosen reduction figures on roofs for further calculations were chosen to 10% for single family houses and 20% for multifamily houses. The reduction factor for premises for non-residential use and industrial buildings are supposed to be the same as for multi-family houses (20%) and for the vacancy houses the reduction factor is supposed to be the same as for single family houses (10%). For the roofs of the farm houses the reduction factor is estimated to 5%, because of obstacles.

8.3 Solar collectors

As solar thermal collectors are closer to the commercial market than PV-systems, the potential area on the buildings is supposed to be used for both installations. The need of area for solar collectors is depending on the type of use, system size and solar fraction. In dwellings the type of use may be separated into:

- production and preheating of domestic hot water
- production of both domestic hot water and variations between additional heating to whole year heating.

The need of heat for domestic hot water is relatively well-known and is normally calculated to 40 kWh/m^2, year (heated area) in multifamily buildings. In single-family dwellings this figure may vary significantly depending on the behavior of the inhabitants, but may be regarded also as an average in single-family dwellings. With only a short time heat storage for a few days, the solar collector system may cover the need of heat for about 40-50% of the total need over the year. With a solar collector with a typical annual output of 400 kWh/m^2 (collector area), the need of more or less south orientated roof area, normally tilted 15-45°, will be (BFR 1998):

- 3-5 m^2 solar collector (roof area) per flat

Other calculations, which may give about the same result is:

- 1 m^2 solar collector (roof area) per person or
- 1 m^2 solar collector (roof area) per MWh heat load

A normal relation in multifamily buildings with normal tilted roofs, is that all the south facing part of roof (halve of the roof area) has to be used in 8 stories dwellings in order to preheat the domestic hot water and supply 40-50% of the yearly demand. In four stories dwellings about halve of the south-orientated roof has to be used and in two-stories dwellings about 25% of south-orientated roof is used. The average of the installed systems on multi-family dwellings are 3 m^2/flat.

In order to produce also heat to the heating system, the solar collector area increases with the solar fraction and also the storage increases to partly or totally seasonal storage. As the majority of the multifamily dwellings in Sweden are connected to a district heating network (73% of the used energy in multi-family buildings 1996), there are also opportunities of centralised systems and storage, not only just linked to one building.

In single-family buildings the normal collector size are 10 m^2/dwelling. This means that the normal system today in Sweden is a combined system with heating/preheating domestic hot water and a minor supply of heat to the building. The normal size for only domestic hot water systems are 4-5 m^2 solar collector. As the normal way of storing heat is in water, the efficiency is very dependent on the size. In order to increase the solar fraction significantly, this is most likely do be done in group systems and not for single houses. Today, there is only a small part (<1%) of single family dwellings that are connected to district heating systems.

In older multifamily dwellings there are possibilities to improve the indoor comfort, by installing mechanical ventilation. This may be done by using the facade as a solar collector and preheat the ventilation air. Depending on type of system an area of about 10 m^2 of the south facade per apartment is required to cover about 10-20% of the annual heat requirements for ventilation (BFR 1998). The roof is not used in the concept, but the whole south facing wall may be used by the solar collector.

Another possibility of using solar energy is a solar space-heating system with air collectors and a double envelope. In this case the whole south facing roof is used as a collector and the facade is a part of the distribution system. About 10 m^2 of solar collector per apartment is required to meet 10-20% of the annual heat requirements for heating (BFR 1998).

In Table 16 the need of area for solar collectors are calculated. With the assumption of an energy production of 400 kWh/m^2 solar collector and year and the use of the best south oriented and tilted roof area, the area for the domestic hot water production will be 8 km^2 and for the total heat demand (in 1996) 195 km^2 for dwellings and 265 km^2 including non-residential premises. Storage or system losses are not included.

Table 16. Area for solar collectors for production heat to domestic hot water or heat covering the total heat demand in dwellings.

	One –and two-family dwellings	**Multi-family dwellings**	**Non-residential premises**	**Totally**
Number of inhabitants	4,9 mil. inhab.	3,3 mil. inhab.		
Number of dwellings	1.874.000	2.169.000		
Total heat demand 1996	48 TWh	30 TWh	28 TWh	106 TWh
Area needed, best roof area*, for 40-50% of domestic hot water	5 km^2	3 km^2	unknown	8 km^2 (+?)
Area needed, best roof area for total heat demand**	120 km^2	75 km^2	70 km^2	265 km^2

* Best roof area is roofs orientated SE to SW with a tilt of 15-45°.

**Calculations are based on a yearly energy production from solar collectors of 400 kWh/m^2, year. No system or storage losses are included.

8.4 Shading

Shading is a very important issue when utilizing PV. Non-uniform insolation on PV-modules and shading leads to power losses of PV-generators which sometimes considerably go beyond insolation losses. Since the individual solar cells work with serial connection, there are additional losses due to mismatching at times of non-uniformal insolation. In serial parts of the circuit, the strings, the PV-element receiving the lowest insolation is mainly responsible for the current of the series connection. Especially in the case of partially shading, losses due to mismatching may increase to high scales. A 10% shading of a PV module may mean that the whole module contributes marginally to the generators power (Decker et al. 1998).

Shading is caused by neighbouring buildings or parts of the building itself like bays, dormer windows, staircases or wings. On the roof there may also be shaded parts from chimneys, antennas and aerial wires that may be responsible for the same degree of shading as e.g. streetlights. Trees and other kind of vegetation might cause severe problems with shading especially on facades or roof at one storey buildings. The maximum height in Sweden of trees are different for various species, with about 25 - 30 m for "horse chestnut", oak, birch and up to 45 m for beech and spruce. This means that trees also outside the garden of a single-family houses, may cause severe problems with shading both on facades and roofs.

Building integrated PV-modules should be placed in a suitable way to avoid shading and non-uniform insolation. With respect to the super-proportional effect of partial reduction of insolation, also smaller partial shadings have to be considered, not forgetting to estimate the growth of a possible surrounding vegetation.

There are calculation methods and models available, giving the possibility of realistic predictions of the output from the installations and for studying the effects of shading. In Sweden a tool for designing PV installations is developed with a method for describing shadings in the surroundings by a special photographic method. The tool produces the input data with the shading effects to other simulation programs (Carlsson and Cider, 1998). Also in other countries methods and tools are developed for determination of shading losses, e.g. in Germany (Niewienda et al 1996), (Quaschning and Hanitsch 1998) and Japan (Otani et al 1998).

An assessment of reduction factors because of shading on buildings are for Swiss circumstances reported in Gutschner 1995, see Table 17.

Table 17. Reduction factors for facade and roof areas because of shading (Gutschner 1995).

Type of building	**Reduction factor shading on roofs**	**Reduction factor shading on facades**
One –and two family dwellings (and vacancy buildings)	10%	30%
Multifamily dwellings	15%	40%
Non-residential premises	20%	50%
Industrial buildings	10%	30%
Agricultural buildings	10%	30%

I Sweden the majority of the buildings are situated in localities, with the three big-city areas; Stockholm, Göteborg and Malmö. There are 16 communities with more than 75.000 inhabitants and totally 7.4 million people are living in about 2.000 localities. In further 2.700 rural agglomerations about 300.000 people are living and the rest 1.2 million inhabitants are living in other rural areas, se also Table 4. Most of the buildings are situated in localities, with the highest density in the city centre, although without large areas with high rise buildings. As this type of building agglomerations are not very different to the conditions in Switzerland, the average reduction factors proposed for Switzerland (Table 17) will be used also for Sweden until closer studies have been realised.

In Switzerland further studies of reduction factors have been conducted (Gutschner 1999) and separate investigations have been done for an urban area (Zürich) and a rather rural canton (Fribourg). The reduction factors are categorised in several steps reducing the figure of the ratio of the suitable roof area/ground floor area. In the urban area the reduction factor for design elements are 33% and for shading 22% (of the already reduced area). The corresponding figures for the rural area are 16% and 20% respectively. Studies have been made for different building categories and construction periods.

8.5 Building-historical restrictions

From an architectural and historical point of view there may be objections regarding introducing PV-modules on existing building envelopes.

There are regulations in the statue of planning and buildings which restricts the changing of a building: *The change of a building should be done with care so that the characteristic of the building is considered and the building technical, historical, culture-historical, environmental and artistic values are taken care off*. This means that all buildings are included and that buildings representing all architectural styles and time-periods should be taken care off (Boverket 1995).

Sweden has a fairly new building stock with only 6 % of the dwellings in buildings before 1900. The majority of the buildings were constructed after 1945 and more than halve of the total dwellings were constructed after 1960 (Boverket 1995). The majority of the buildings regarded as building historical valuable are in the old building stock. In a culture-historical inspection from 1979 the most interesting buildings were found among dwellings built before 1920 see *Table 18* (BFR 1981).

Table 18. Percentage of building- or cultural - historical valuable building referred in the inspection 1979.

	-1920	**1921-40**	**1941-60**	**1961-75**
One family dwellings	38%	26%	16%	4%
Multifamily dwellings with more than 75% dwellings	60%	50%	-	-
Buildings with more than 25% non-residential premises	50%	60%	50%	-

The construction of a building before 1960 was mainly characterized by the local handicraft, built on the skillfulness of using different construction material, the local availability of different material and the climate.

Up to 1930 the buildings in the city were often designed with a lot of details, representing different styles. In more “simple” buildings details were often adopted, sometimes in other material imitating more exclusive e.g. stones. In the countryside more local material in facades and roofs was used and the buildings were not following the changing in styles so much.

From 1930´s the functionalism formed other types of buildings, with more plain facades without decorations. The buildings were more designed for special purposes: dwellings were situated in special areas and commercial buildings were placed together in centers. Repetition and uniformity was made to an aesthetic value. On these buildings there are available spaces for PV-installations, but depending on the actual building, it might be restrictions to make any changes because of the architectural values.

From 1960´s a major change was made in the building construction work as the industry began to produce prefabricated building elements. This was soon the dominating way of constructing buildings as it was faster and cheaper to produce a large quantities of dwellings. Among these buildings there are probably the largest potential for PV-applications in existing buildings.

Table 19. Assessment of number and area of building with cultural – historical values.

	-1940	1941-60	1961-75	Totally -1996
Number of one- and two – family dwellings	560.000	302.000	412.000	1.743.000
Number of cultural – historical valuable one – and two – family dwellings	212.000	48.000	16.000	276.000 (16%)
Number of dwellings in multifamily buildings	374.000	613.000		2.340.000
Number of cultural – historical valuable dwellings in multifamily buildings	206.000	-		206.000 (9%)
Area of non-residential premises (km^2)	24,7	21,8	40,7	133
Area of non-residential premises in historical valuable buildings (km^2)	13,6	10,9	-	24,5 (18%)

Also among older industrial buildings there are valuable buildings from a historical point of view, but no statistics are found regarding these numbers of buildings.

8.6 New construction of buildings

The rate of new construction of dwellings has during the latest years been the lowest in modern time. The bottom seems to be reached and the rate of construction are increasing, although in a very slow speed. It was foreseen by the Swedish Board of Housing and Planning that the construction of about 12.500 dwellings was going to start during 1998. During 1999 the construction of about 14.000 dwellings are planned to start and for the year 2000 the corresponding figure is 16.000. This means that from 1995 with a construction start of less than 4.000 dwellings in one-and two-family buildings and also less than 4.000 dwellings in multifamily dwellings, the rate of construction may be doubled to the year 2000. The construction of new buildings gives an opportunity to integrate PV and solar collectors in an optimal design and it is more in likely that the use of PV will come into reality in a part of the new building stock, compared to the old building stock. Although the big area potential of using PV in buildings is in the existing building stock as this area is very large.

9. Summary of net-areas

The buildings have been divided in six groups according to building use. These groups have a different statistical material to be used for assessment of the different potential areas for PV-installations. The assumptions that are made regarding the respective buildings are described under section 7 and a potential net area has been derived. In section 8 more reduction factors are described and the final potential areas will be estimated from these discussions, se Table 20 and Table 21. In these tables the area of the roofs are summarized without taking care of the calculated tilt. The differences in tilts will be accounted for in the next study, when a separation of the areas will be done according to a yield index. The used tilts in this material are: one-and two-family dwellings 30° (with a minor addition of roof area for side-buildings with a tilt of 0°), multi-family buildings 0° (a minor part with the tilt 30° and the rest with 0°), non-residential premises 0°, industrial buildings 0°, agricultural buildings 0° and vacancy buildings 22°.

Table 20. Summary of reductions for different areas.

All areas in km²	**Gross area**		**Obstacles**	**Solar collectors Roof***		**Shading**		**Building historical reductions**	
	Roof	Facade	Roof	Alt 1	Alt 2	Roof	Facade	Roof	Facade
One-and two family-dwellings	290	277	29	5	120	29	83	46	44
Multifamily -dwellings	45	83	9	3	75	7	33	4	7
Non-residential premises	44	44	9	-	70	9	22	8	8
Industry	94	80	19			9	24		
Agricultural buildings	127	62	6			13	19		
Vacancy houses	70	60	7			7	18		
Totally	670	606	79	8	265	74	199	58	59

**Calculated roof area for solar collectors are referring only to the best orientation (south-east to south-west) and the best tilt (15-45°).*

Alt 1: Estimated energy-production from solar collectors 400 kWh/m², year, covering 40-50% of the heat demand for the domestic hot water in dwellings, which means systems with only short term heat storages.

Alt 2: Energy-production from solar collectors as Alt 1 covering the whole yearly heating demand for heating and domestic hot water (losses excluded).

The result is summarised in Table 21, which shows the gross areas, reductions (except for doors and windows that are already taken away in the gross figures) and net areas for the different building types of buildings. In the net areas no reduction for thermal solar collectors has been done as these areas so far are only calculated for the optimum tilts (15-45°) and orientations (SE – SW).

Table 21. Gross and net areas of roofs and facades of different building types.

All areas in km^2	**Roof**			**Facade**		
	Gross areas	Sum of reductions*	Net areas	Gross areas	Sum of reductions*	Net areas
One-and two family-dwellings	290	104	186	277	127	150
Multifamily-dwellings	45	20	25	83	40	43
Non-residential premises	44	26	18	44	30	14
Industry	94	28	66	80	24	56
Agricultural buildings	127	19	108	62	19	43
Vacancy houses	70	14	56	60	18	42
Totally	**670**	**211**	**459**	**606**	**258**	**348**

**solar collectors not included*

These areas include all orientations and a separation will be done in the next part of this study in order to get the area-potential linked to the irradiation.

A comparison of the figures in this study, the earlier study made in Sweden 1983 (VBB 1983) and the Swiss study from 1995 (Gutschner 1995) are made in Table 22.

Table 22. Comparison between roof areas in Sweden calculated in a study from 1983 (VBB 1983), in Switzerland 1995 (Gutschner 1995) and this study.

Roof area in km^2	VBB 1983 Gross area	Switzerland 1995 gross, ground area	Switzerland 1995 gross, roof area	Switzerland 1995 net area*	This study gross area	This study net area
One-and two family dwellings	230	67-70	86-91	41-44	290	186
Multi-family dwellings	57	72-127	81-143	43-76	45	25
Non-residential premises	50	24-40	27-45	13-23	44	18
Industry	43	51-54	54-57	30-32	94	66
Agricultural buildings	54	41-68	54-89	31-51	127	108
Vacancy buildings	77	29-48**	32-53**	16-27**	70	56
Totally	511	283-407	334-479	181-260	670	459

** a ”suitability factor” is included in the reductions for Switzerland, which is not introduced for Sweden in this study*
*** refers to ”other buildings”*

Table 23. Comparison between facade areas in Sweden calculated in a study from 1983 (VBB 1983), in Switzerland 1995 (Gutschner 1995) and this study.

Facade area in km^2	VBB 1983 gross area	Switzerland 1995 gross area	Switzerland 1995 net area*	This study gross area	This study net area
One-and two family dwellings	196	73-77	17-18	277	150
Multi-family dwellings	83	132-221	36-60	83	43
Non-residential premises	50	40-67	9-15	44	14
Industry	36	56-89	22-35	80	56
Agricultural buildings	26	30-51	7-12	62	43
Vacancy buildings	61	61-101**	12-21**	60	42
Totally	452	392-564	103-160	606	348

** a ”suitability factor” is included in the reductions for Switzerland, which is not introduced for Sweden in this study*
*** refers to ”other buildings”*

The results differs from each other in the three studies and some of the differences may be explained by the reality. One point is that the VBB study calculating with the predicted building stock in the year 2000. The building rate was still rather high in 1983 and the prediction was too high. In the building stock in Switzerland it is more multifamily dwellings compared to Sweden. The population in Switzerland amount to about 7 million (1993), which is less than in Sweden (8,8 million). The potential net-roof area per capita will for Switzerland be 26-37 m^2/person (Gutschner 1995) and for Sweden this figure will be 54 m^2/person. In the EU report (EU 1996) from 1996 significantly lower values were determined (10,4 (Switzerland) respectively 12,8 (Sweden) m^2/person. The reduction factors may also be discussed and to get more realistic figures for Sweden a suitability factor will be used. This factor will take care of the competition of the use of the area for other purposes and other factors that reduces the suitability for PV use.

Finally it can also be added that except of the areas that directly is a part of the building envelope, there are more possibilities of using PV in the built environment. One application is the use of PV modules for solar shading in awning systems. In this application the need of shading is correlated to the best irradiation, which is mainly windows on south facades, but also on east and west facades. Another protection is for rain, e.g. on side-walks between buildings, transportation facilities etc. Finally there is also a need of noise protection along many of the big roads. The potential for these applications has not been included in this study, but should not be neglected.

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