DECISION SCHEME FOR THE SELECTION OF THE APPROPRIATE TECHNOLOGY USING SOLAR THERMAL AIR-CONDITIONING

Guideline Document

IEA Solar Heating and Cooling
Task 25: Solar-assisted air-conditioning of buildings

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THE IEA SOLAR HEATING AND COOLING PROGRAMME

The International Energy Agency (IEA) was formed in 1974 as an autonomous body within the Organisation for Economic Co-operation and Development (OECD). It carries out a program of energy co-operation, including joint research and development of new and improved energy technologies.

The Solar Heating and Cooling (SHC) Programme was one of the first IEA research agreements to be established. Since 1976, its members have been collaborating to develop technologies that use the energy of the sun to heat, cool, light and power buildings. The following 20 countries, as well as the European Commission are members of this agreement: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, Mexico, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, United States.

The mission of the SHC Programme is: “To facilitate an environmentally sustainable future through the greater use of solar design and technologies.”

Current Tasks of the IEA Solar Heating and Cooling Programme are:

Task 25: Solar Assisted Air Conditioning of Buildings

Task 27: Performance of Solar Facade Components

Task 28: Solar Sustainable Housing

Task 29: Solar Crop Drying

Task 31: Daylighting Buildings in the 21st Century

Task 32: Advanced Storage Concepts for Solar Thermal

Task 33: Solar Heat for Industrial Processes

Task 34: Testing and Validation of Building Energy Simulation Tools

Task 35: PV/Thermal Solar Systems

TASK 25 SOLAR ASSISTED AIR CONDITIONING OF BUILDINGS

Air-conditioning is the dominating energy consuming service in buildings in many countries. And in many regions of the world the demand for cooling and dehumidification of indoor air is growing due to increasing comfort expectations and increasing cooling loads. Conventional cooling technologies exhibit several clear disadvantages:

- Their operation creates a high energy consumption.
- They cause high electricity peak loads.
- In general they employ refrigerants which have several negative environmental impacts.

Task 25 'Solar Assisted Air Conditioning of Buildings' of the IEA Solar Heating & Cooling Programme addresses these problems. Therefore the utilization of solar energy for air-conditioning of buildings is covered by research, development and demonstration work. The main objective of the Task is to improve conditions for the market entry of solar assisted cooling systems.

The main objective of Task 25 is to improve the conditions for the market entry of solar assisted cooling systems in order to promote a reduction of primary energy consumption and electricity peak loads due to cooling.

Work in Task 25 is organized in 4 Subtasks

Subtask A: Survey of solar assisted cooling

Subtask B: Design tools and simulation programs

Subtask C: Technology, market aspects and environmental benefits

Subtask D: Solar assisted cooling demonstration projects

The current report was produced as part of the work in Subtask C. More information about TASK 25 can be found on the Task's webpage [1].

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1. Introduction

Indoor comfort depends on many factors. Most dominating out of them are indoor temperature and humidity. The indoor temperature felt by an individual of course depends on both air temperature and the temperature of surrounding wall surfaces. Indoor temperature and humidity depend on many factors, which are related to the climate of the site, the building and its construction and user depending factors. Most important climatic factors are the solar radiation, outdoor air temperature and outdoor air humidity. Building related factors are – among many others – the buildings thermal mass, building orientation, window sizes and characteristics, shading devices and their control, construction of walls and ceilings etc.. Internal loads strongly depend on internal equipment and use of artificial lighting, infiltration and ventilation gains and occupation of rooms by persons.

Goal of the presented decision scheme is to guide the decision for a certain technical solution for a given situation, defined by climatic, building and occupation related factors as described above. Finally each solution represents a technical solution to use solar thermal energy for building air-conditioning.

Details about the used technologies and the different system configurations can be found for instance in the Handbook "Solar-Assisted Air-Conditioning in Buildings – A Handbook for Planners" which has been produced in the framework of Task 25 [2].

2. Basic scheme

A basic scheme to guide the decision is shown in Figure 1.

A basic assumption in all schemes presented below is that both, temperature and humidity of indoor are to be controlled. The starting point always is a calculation of cooling loads based on the design case. Depending on the cooling loads and also according to the desire of the users/owner, either an all air system, an all water system or hybrid air/water systems are possible for extraction of heat and humidity out of the building. The basic technical decision is whether or not the hygienic air change is sufficient to cover also cooling loads (sensible + latent). This will typically be the case in rooms/buildings with a requirement of high ventilation rates, such as e.g. lecture rooms. However, a supply/return air system makes only sense in a rather tight building, since otherwise the leakages through the building shell is too high. In cases of supply/return air systems both thermally driven technologies are applicable, i.e., desiccant systems as well as thermally driven chillers. In all other cases only thermally driven chillers can be used in order to employ solar thermal energy as driving energy source.

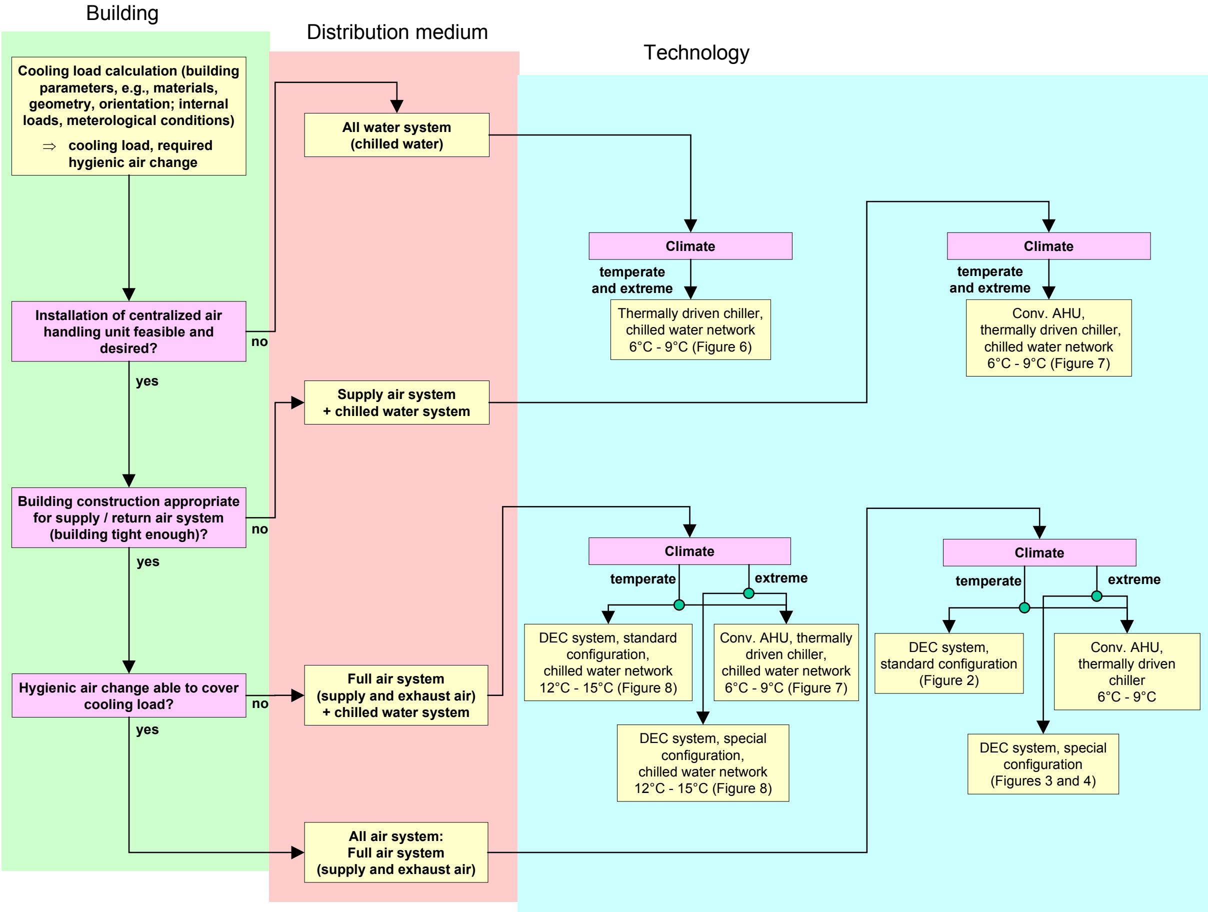

Figure 1 – Basic scheme for decision guidance

The lowest required temperature level of chilled water is determined by the question whether air dehumidification is realized by conventional technique, i.e., cooling the air below the dew point or whether air dehumidification is realized by a desiccant process. In the latter case the temperature of chilled water - if needed at all - can be higher since it has to cover only sensible loads. Application of desiccant technique in extreme climates, i.e., climatic conditions with high humidity values of the outside air, special configurations of the desiccant cycle are necessary in order to be able to employ this technology. More items of the design, which cannot be covered in this presentation, are for instance:

- Necessity of a backup system for the cold production or to allow solar autonomous operation of the solar assisted air conditioning system;
- Flexibility in comfort conditions, e.g. to allow certain deviations from the desired air states;
- Economical issues;
- Availability of water for humidification of supply air or for cooling towers;
- Comfort habits for room installations: fan coils have lowest investment cost, but allow dehumidification only when connected to a drainage system; chilled ceilings and gravity cooling systems require for high investment cost, but provide high comfort.

It is not indicated here, which type of thermally driven chiller is applied. In case of a desiccant system is required with an additionally chiller to cover peak-loads, the required chiller may be an electric driven compression chiller for economical reasons.

A basic technical scheme of a system, which contains both open desiccant cycles and closed cycle water chillers is shown in Figure 2. Also different options of back-up systems are shown in Figure 2, namely on the heat side by other heat sources (e.g. gas burner, connection to a district heating network, co-generation plant etc.) and a back-up compression chiller on the chilled water side. To provide cooling in the room several solutions are possible: a fan-coil system which is used in summer and winter, a radiative cooling system such as chilled ceilings or a ventilation system providing fresh air which is cooled and dehumidified.

Sub-systems of this complete scheme are used in the following chapters as examples of technical solutions for the different paths shown in Figure 1.

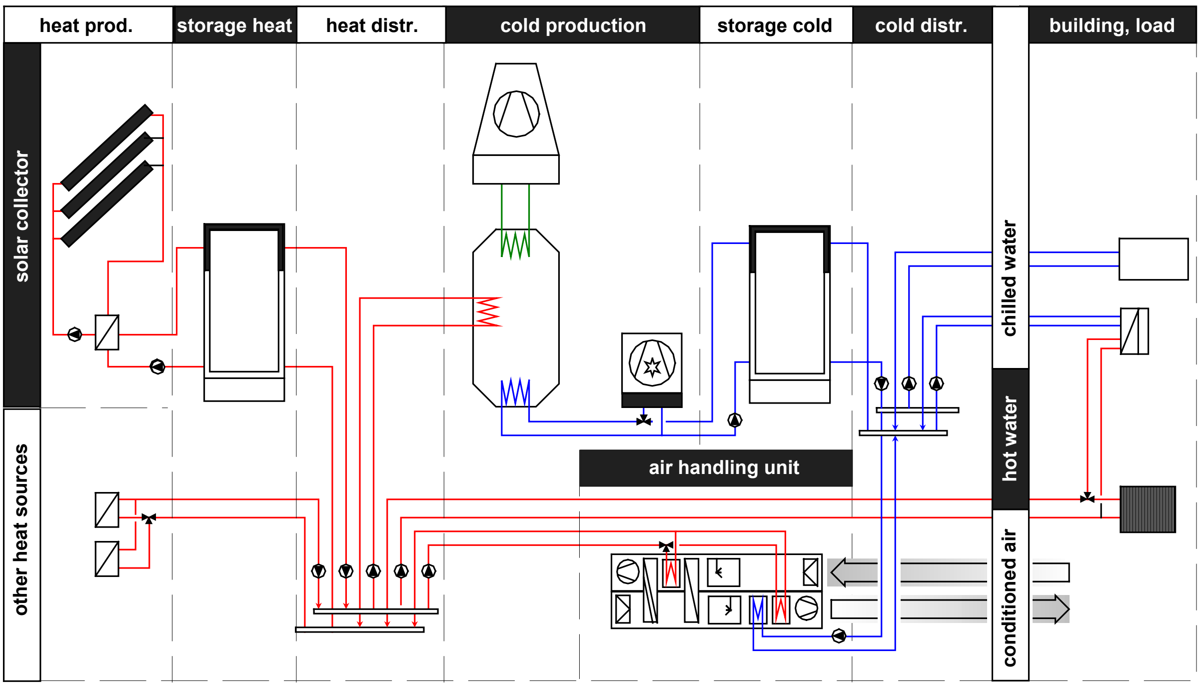

Figure 2 – Scheme of a complete system including desiccant technique and thermally driven water chiller

3. Solutions for different conditions

In the following all possible paths of the scheme shown in Figure 1 are shortly described and a technical solution is presented.

3.1. Thermally driven chiller supplying a chilled water network

In case the installation of a centralized air handling unit is not feasible or desired, the only technical solution to use solar thermal energy for building air-conditioning is to use thermally driven chiller which supplies chilled water to a chilled water network. An example might be an office building from the building stock, which has not the available space for installation of an air duct system. Independently from the climate a low temperature of the chilled water (approx. 6-9°C) is required in order to allow for air dehumidification.

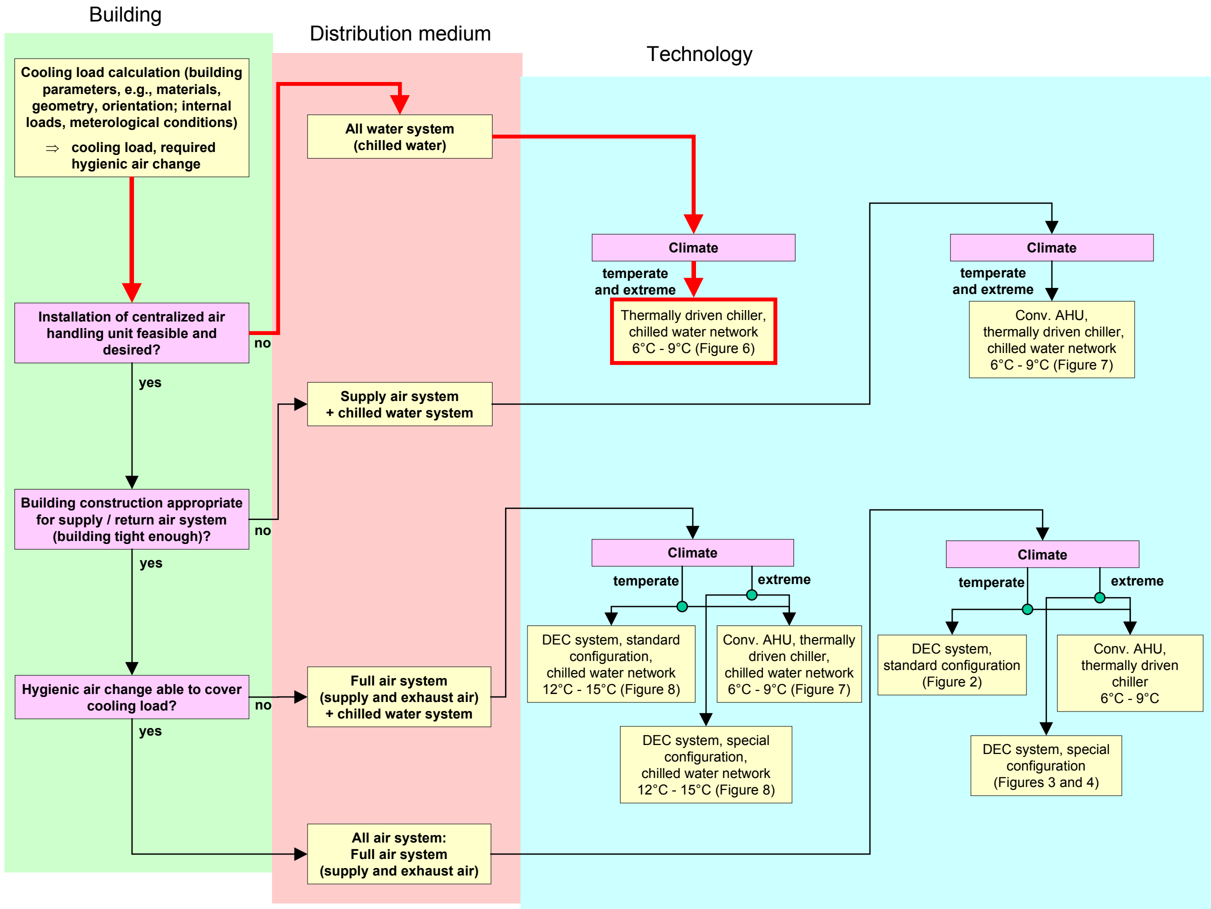

Figure 3 – Path leading to an all water system using a thermally driven chiller

A technical solution of such system is shown in Figure 4. This system uses solar collectors and other heat sources to run a thermally driven chiller. Cold water is used to supply a fan-coil system. Solar gains in winter can be used for heating using the same indoor units.

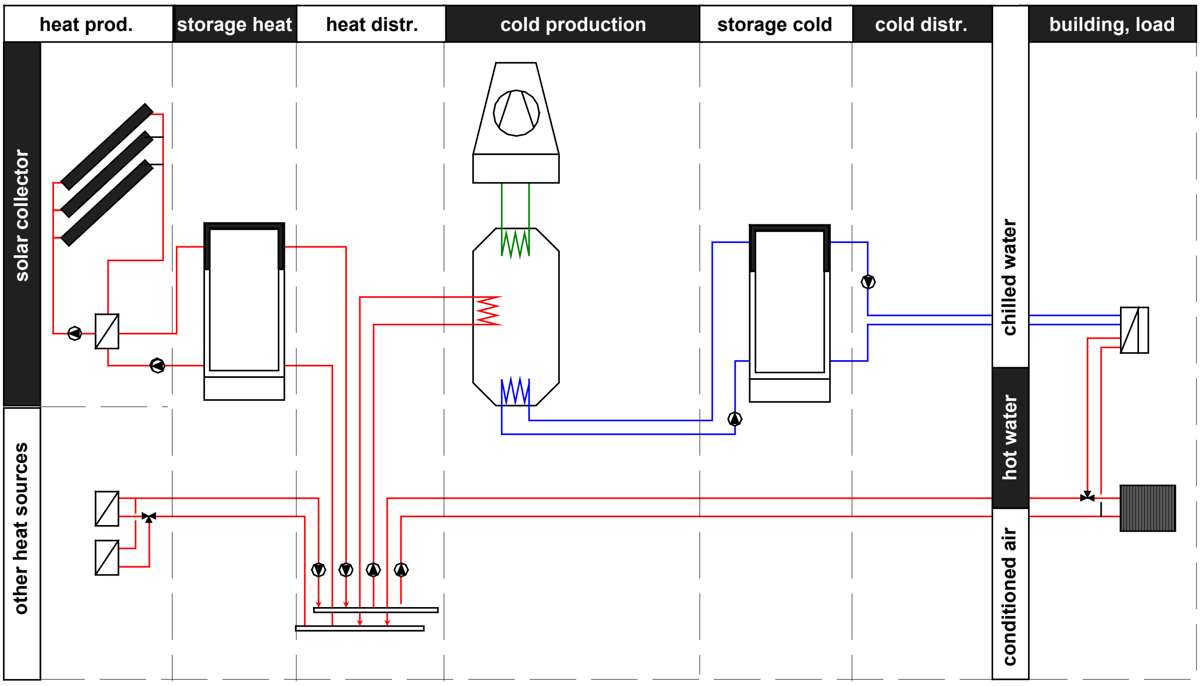

Figure 4 – Example of a technical solution for the path shown in Figure 3

3.2. Thermally driven chiller supplying a chilled water network and a supply air handling unit

In a building in which a central ventilation system shall be installed it is important to assess whether the building is tight enough that the installation of a supply and return air system is reasonable. In a sufficiently tight building no big air losses over the building shell will appear and a supply and return air system can be installed thus enabling a ventilation heat recovery system. However, in a building, which is not sufficiently tight, the installation of a supply/return air system is problematic since either outside air is sucked into the building (internal pressure lower than external) or is lost through the building shell (internal pressure higher than external). In such a case an air handling unit to provide fresh air only would be installed. Fresh air is cooled and dehumidified and sensible loads not covered by the fresh air are purged by other means. An example might be a chilled ceiling system.

The path for such a configuration is shown in Figure 5 and an example of a technical realization in Figure 6. The example shown consists of a solar collector field and other heat sources to run a thermally driven chiller. The chiller supplies chilled water to the supply air handling unit and a chilled ceiling. Dehumidification is realized in the supply air handling unit. A control valve controls the inlet temperature to the chilled ceiling in order to avoid condensation. In general it is also possible to use the chilled water return flow from the air handling unit as an inlet to the chilled ceiling, but the hydraulic scheme is more complex and therefore not shown in Figure 6.

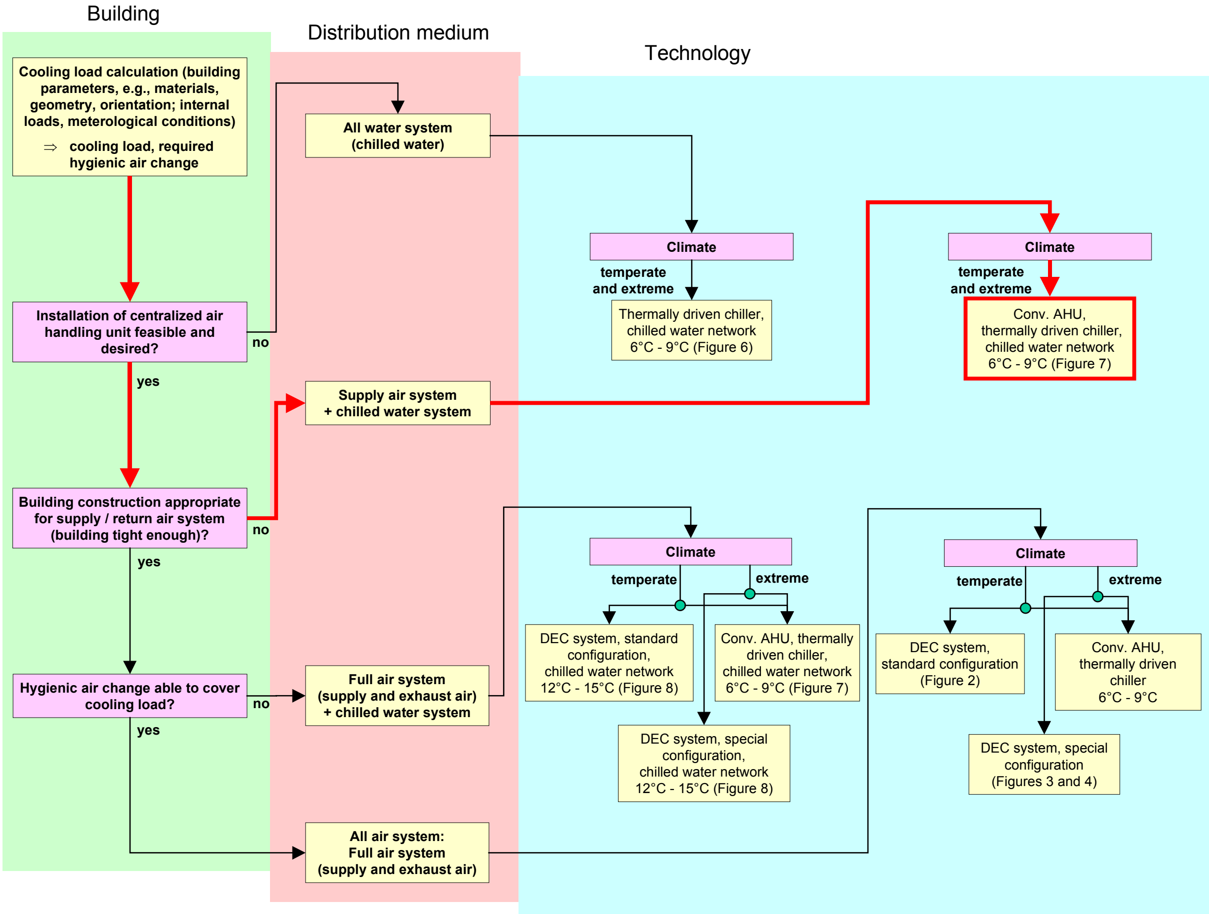

Figure 5 – Path leading to a thermally driven chiller which provides chilled water to a supply air system and a chilled water system

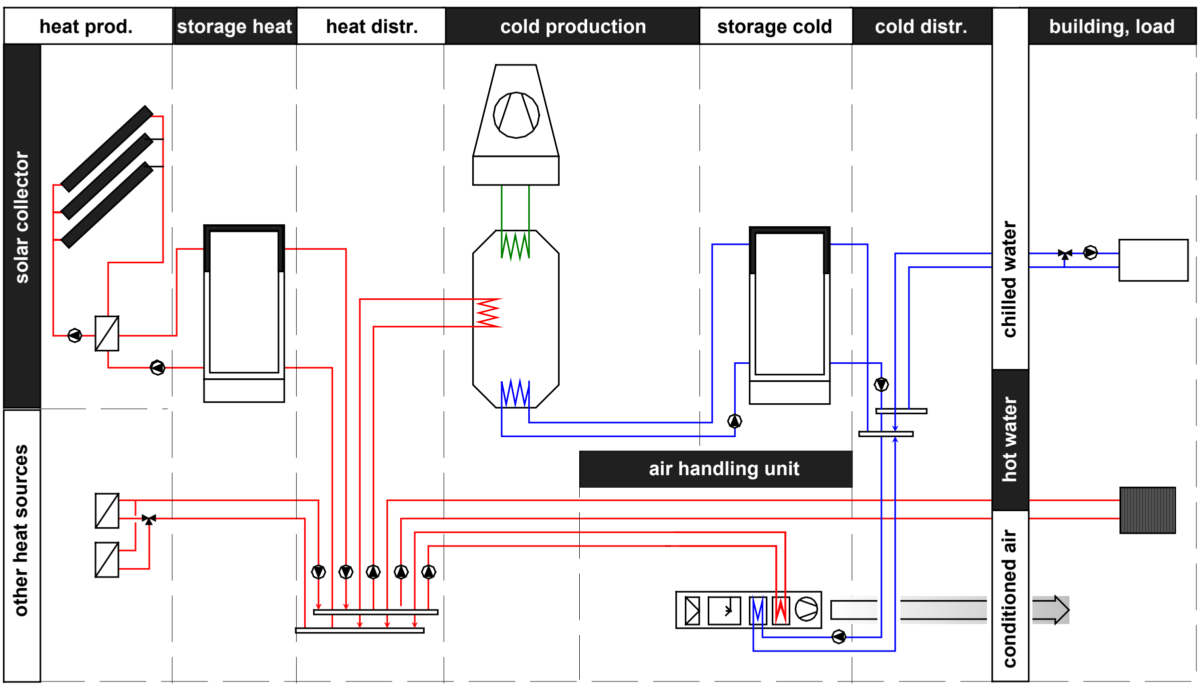

Figure 6 – Example of a technical solution for the path shown in Figure 5

3.3. Desiccant cooling system and chilled water system for temperate climate

In a tight building, which shall be equipped with a centralized ventilation system, application of a desiccant cooling system is possible. However, the exact design of the desiccant system depends on the climatic conditions: in mild conditions, i.e. a temperate climate, a standard desiccant cooling cycle will suffice to provide enough dehumidification in all cases. In a more humid climate the standard desiccant cooling cycle has to be adjusted in a way to cope with this higher humidity of outside air.

In the path shown in Figure 7 the hygienic air change is not high enough for covering all sensible loads and an additional chilled water system must be installed. Such a configuration is shown in Figure 8.

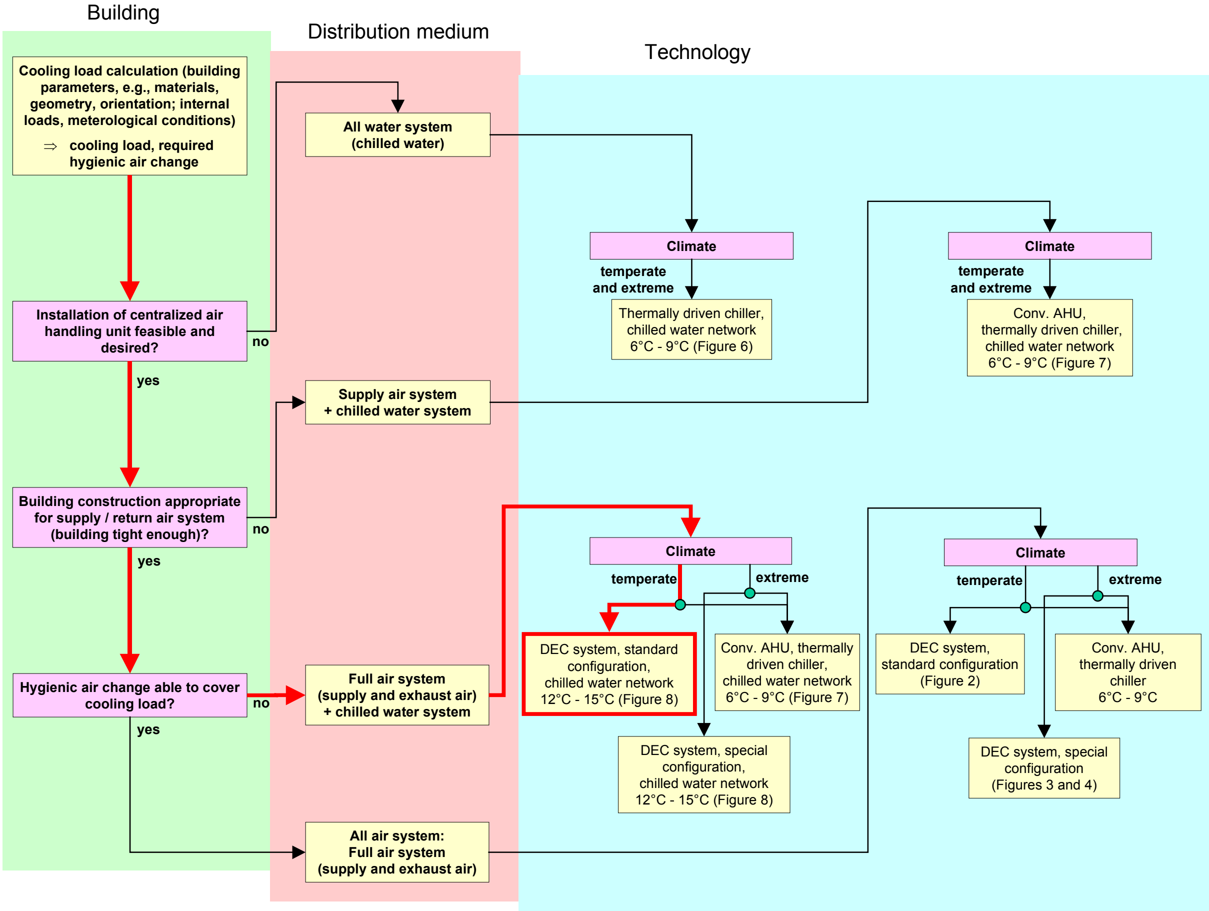

Figure 7 – Path leading to a desiccant system and a an additional chilled water system

The example shown in Figure 8 is composed of a solar collector field and other heat sources as back-up to run a desiccant cooling system. The desiccant system shown here used evaporative cooling in both supply and return air. Since the hygienic air change is not sufficient to cover cooling loads an additional compression chiller is used to operate a chilled ceiling system.

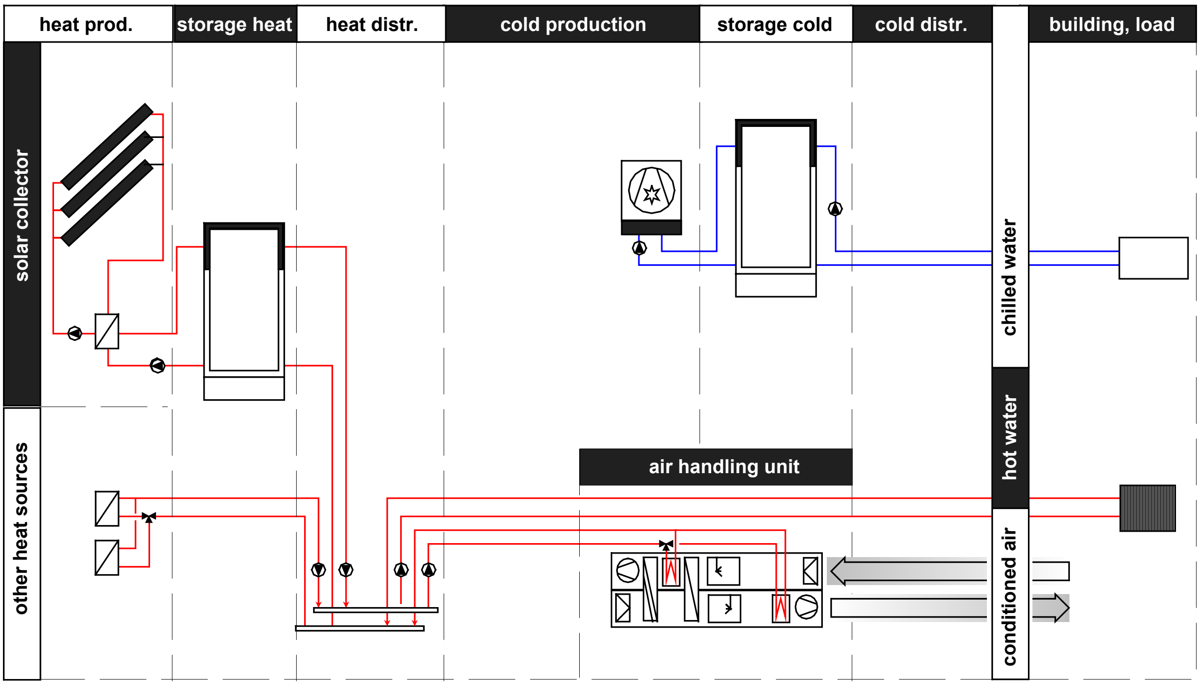

Figure 8 - Example of a technical solution for the path shown in Figure 7

3.4. Desiccant cooling system and chilled water system for extreme climate

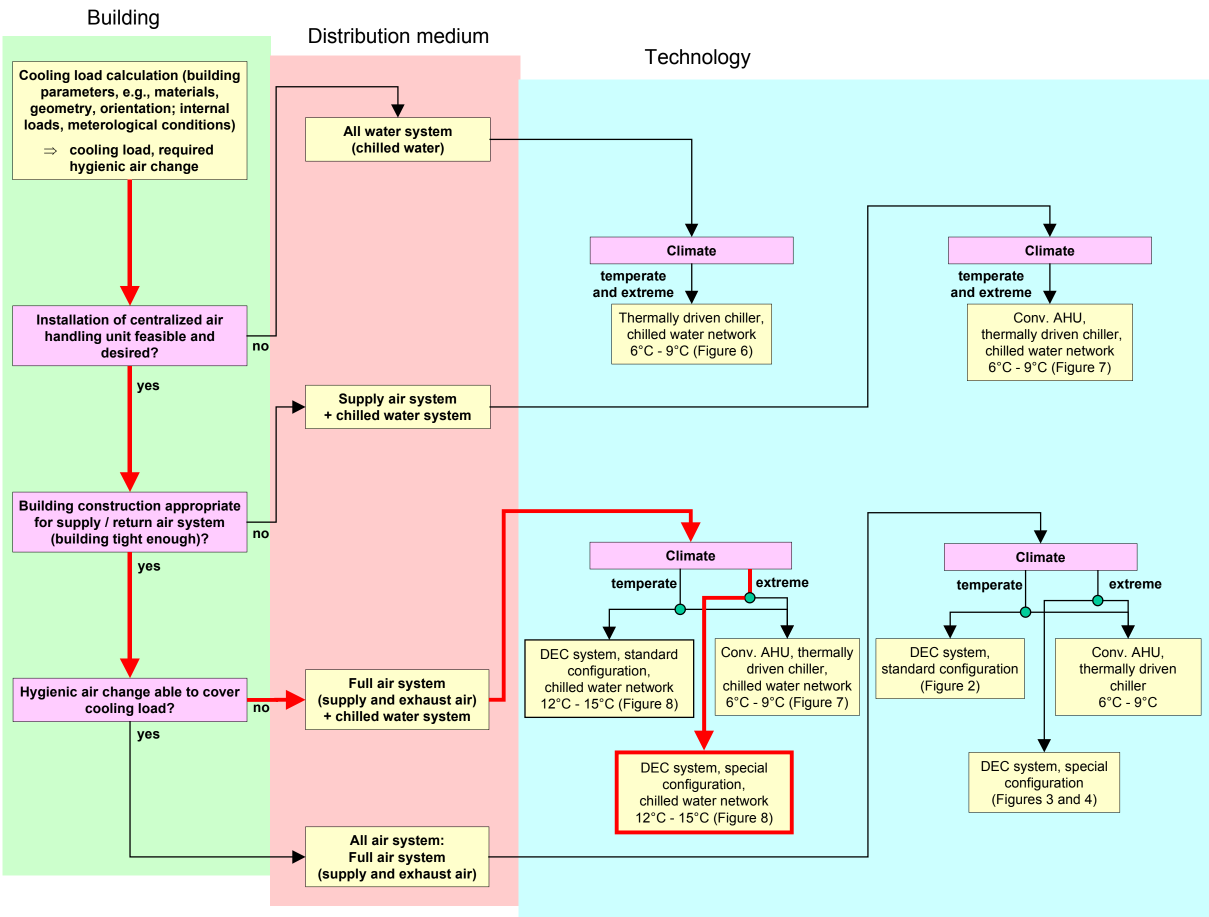

Figure 9 - Path leading to a desiccant system and a an additional chilled water system (humid climates)

In case of a climate with high humidity of outside air (denoted extreme climate) also desiccant technology might be used, but another configuration of the desiccant system is necessary in order to cope with the high humidity of outside air. A possible realization of a system, which corresponds to the path high lighted in Figure 9 is shown in Figure 10.

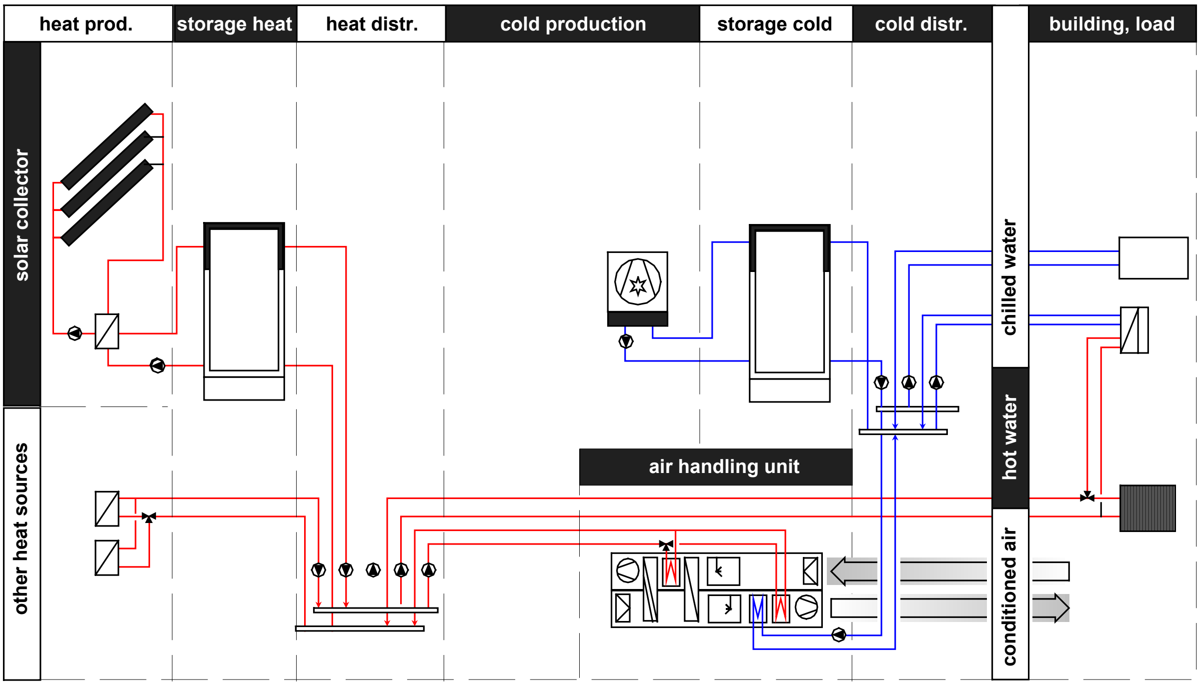

Figure 10 – Example of a technical solution for the path shown in Figure 9

3.5. Conventional air handling unit with supply/return air and additonal chilled water system

An alternative to the application of a solar operated desiccant system is to use solar thermally driven chiller and to operate a conventional supply/return air handling unit in cases of tight buildings with centralized ventilation system. If hygienic air change is not high enough to cover all sensible loads again an additional system to purge sensible loads is necessary. In this case, which is shown in Figure 11 no distinction has to be made between moderate and extreme climatic conditions, since in both cases the same air handling unit can be used. An example of such a configuration is shown in Figure 12.

The example system in Figure 12 is composed of a solar collector field and other heat sources as back-up system, which are used to operate thermally driven chiller. The chiller supplies chilled water to the air handling unit and the chilled ceiling. Dehumidification is realized in the air handling unit. The air handling unit is equipped with an evaporative cooler in the return air which in combination with the heat recovery wheel allows pre-cooling of the fresh air. A control valve controls the inlet temperature to the chilled ceiling in order to avoid condensation.

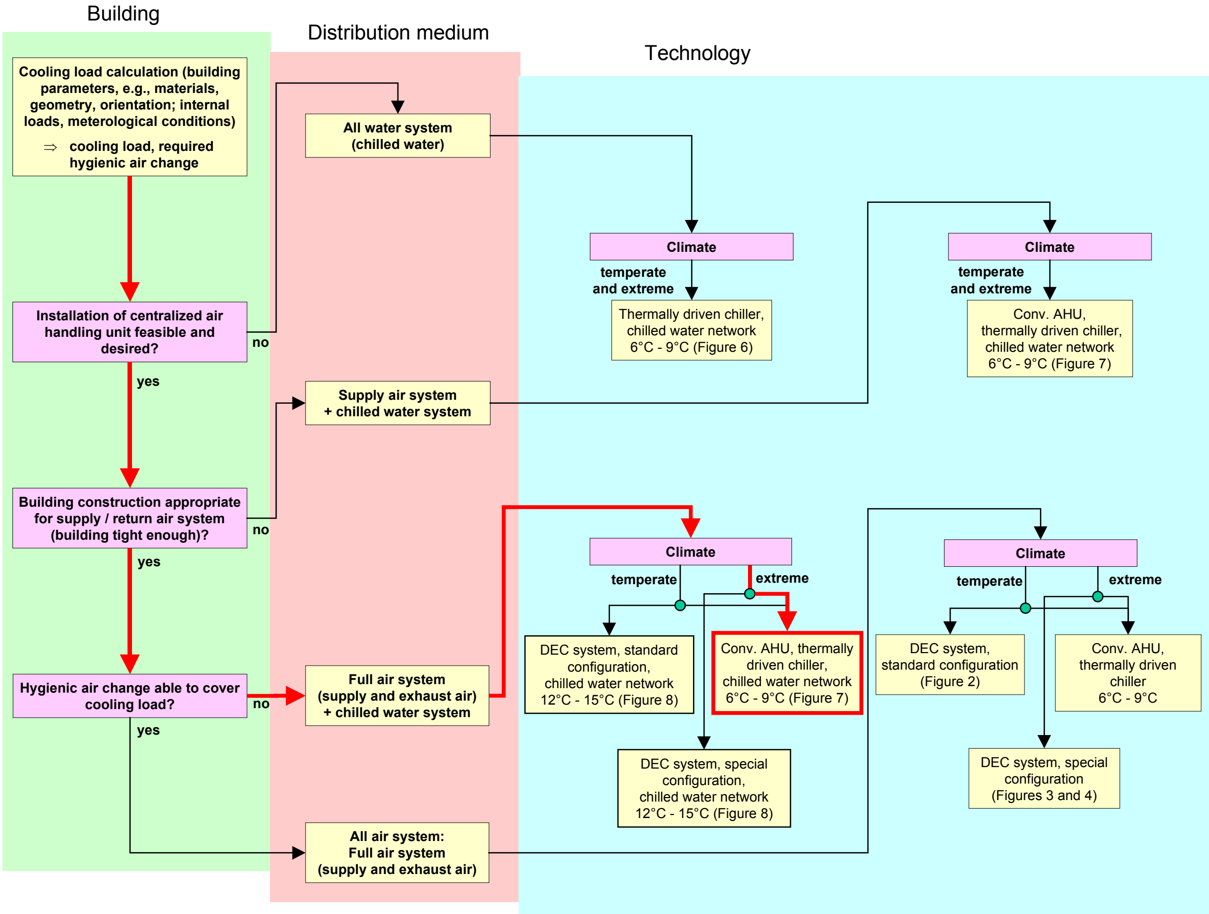

Figure 11 - Paths leading to a conventional supply/return air system and a an additional chilled water system

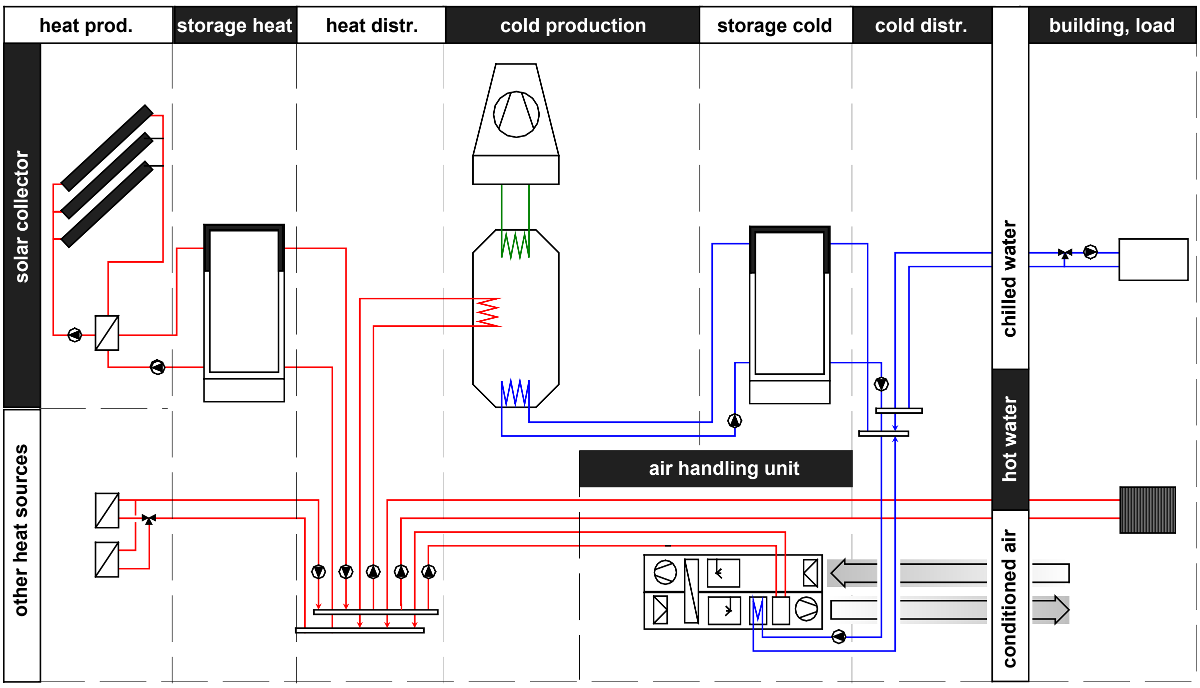

Figure 12 - Example of a technical solution for the path shown in Figure 11

3.6. Desiccant air handling unit in temperate climate

In case of a tight building with a hygienic air change rate, which is sufficient to cover the sensible loads, an all air system is possible. This might be the case in a very well designed building in which energy saving equipment is used, a highly efficient shading device is implemented, artificial lighting is minimized by using day-lighting concepts and a high thermal mass leads to reduced temperature peaks. Other means like night ventilation support the reduction of peak cooling loads. Another example of such a building is a seminar room with a high occupation rate; in such room the required fresh air amount is quite high due to the high occupation and may be high enough to purge sensible loads completely.

In the case of a temperate climate with relatively low humidity of the outside air a ventilation cycle desiccant cooling system is a possible solution to use solar thermal energy for building air-conditioning. The corresponding path in the decision scheme is high lighted in Figure 13 and a technical solution is shown in Figure 14.

The system in Figure 14 is composed of a solar collector field and other heat sources as back-up, which are used to operate a desiccant cooling system with evaporative cooling in supply and return air. No other system to provide cooling is necessary. Solar energy can be used in winter for pre-heating of air and for supplying heat to the radiator heating system.

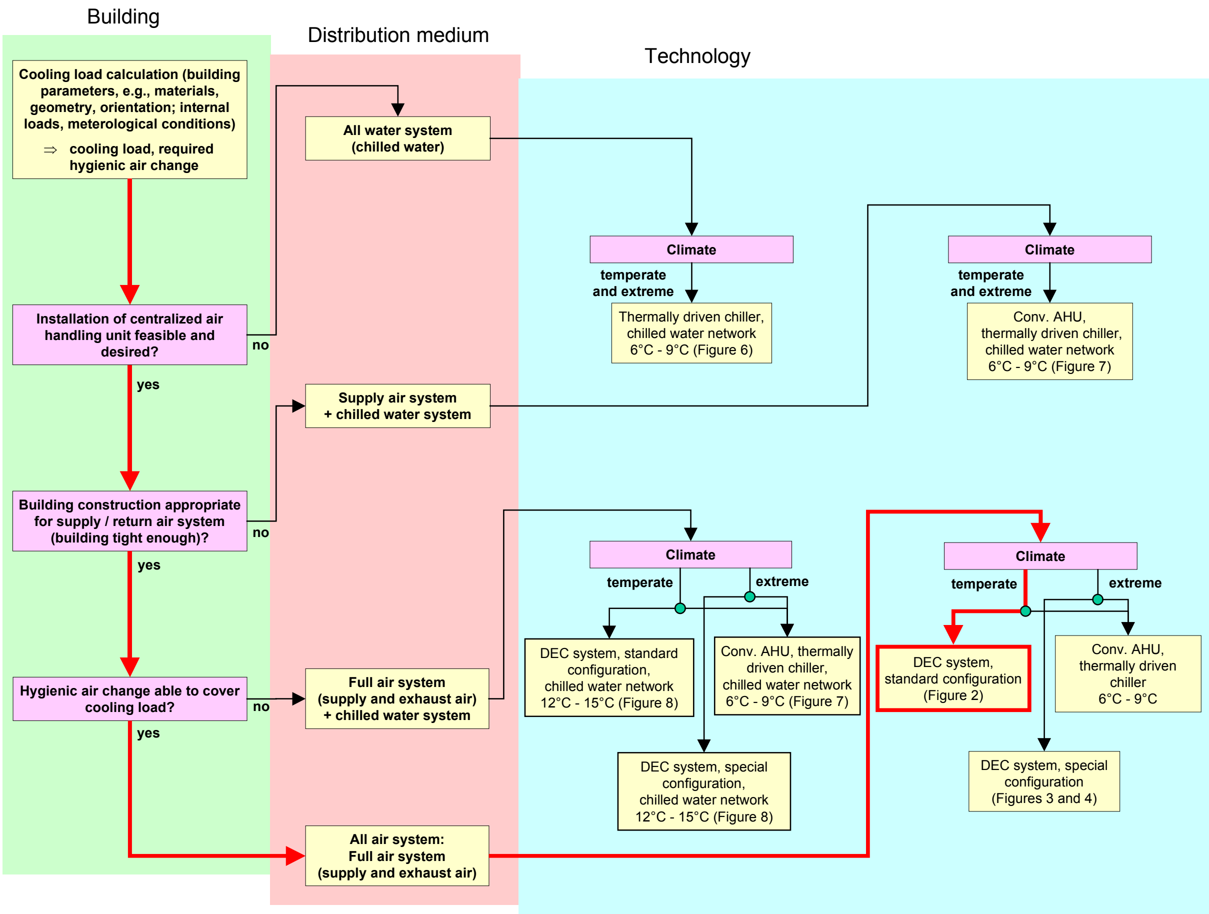

Figure 13 - Path leading to a desiccant air handling unit in an all air, full air system (moderate climate)

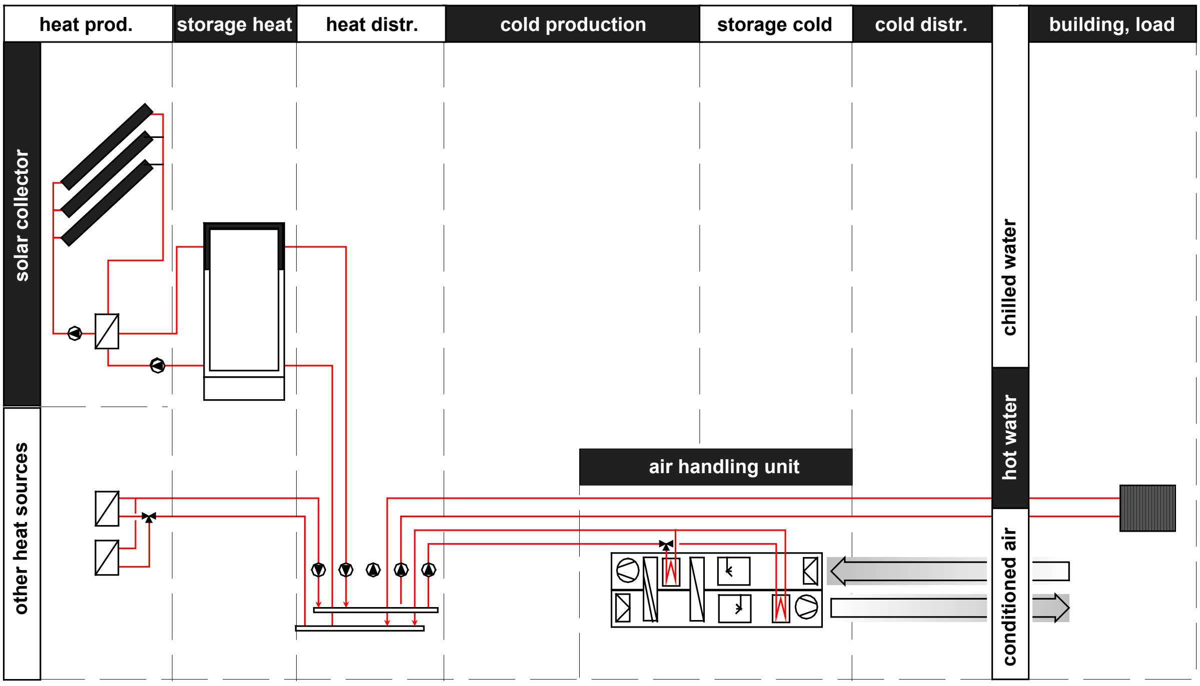

Figure 14 - Example of a technical solution for the path shown in Figure 13

3.7. Desiccant air handling unit in extreme climates

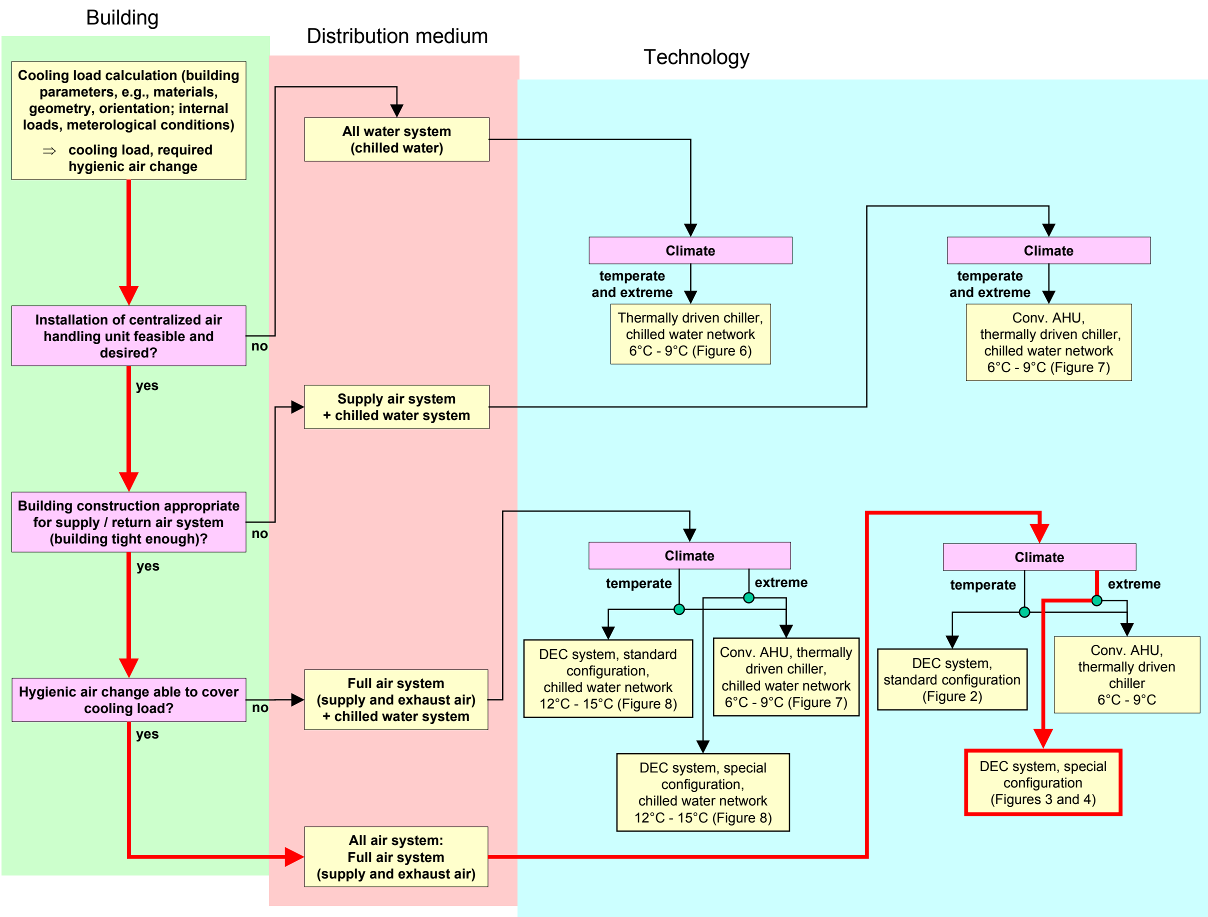

Figure 15 - Path leading to a desiccant air handling unit in an all, full air system (extreme climate)

As already outlined in section 3.4, the 'normal' desiccant cycle is not applicable under conditions of high humidity of the outside air. In such case another design of the desiccant system is required. A scheme of a system for the corresponding path in the design scheme (Figure 15) is shown in Figure 16.

The example in Figure 16 consists of a solar collector field and other heat sources as back-up to operate a desiccant cooling system, which is adapted to climates with high values of humidity of the outside air. The desiccant system shown in Figure 16 differs a little bit from the one shown in Figure 10 since two cooling coils, which are connected to the water chiller are installed on the fresh air side. Such a configuration is a promising concept in climates with very high humidity ratios of the outside air. The first cooling coil carries out a first dehumidification and cooling. Since the dehumidification starts at a high humidity level, the required chilled water temperature is relatively high (approx. 15-18°C). Final dehumidification to achieve the desired supply air humidity is realized with the sorption wheel. The second cooling coil is used for controlling the supply air temperature. More details can be found in [3].

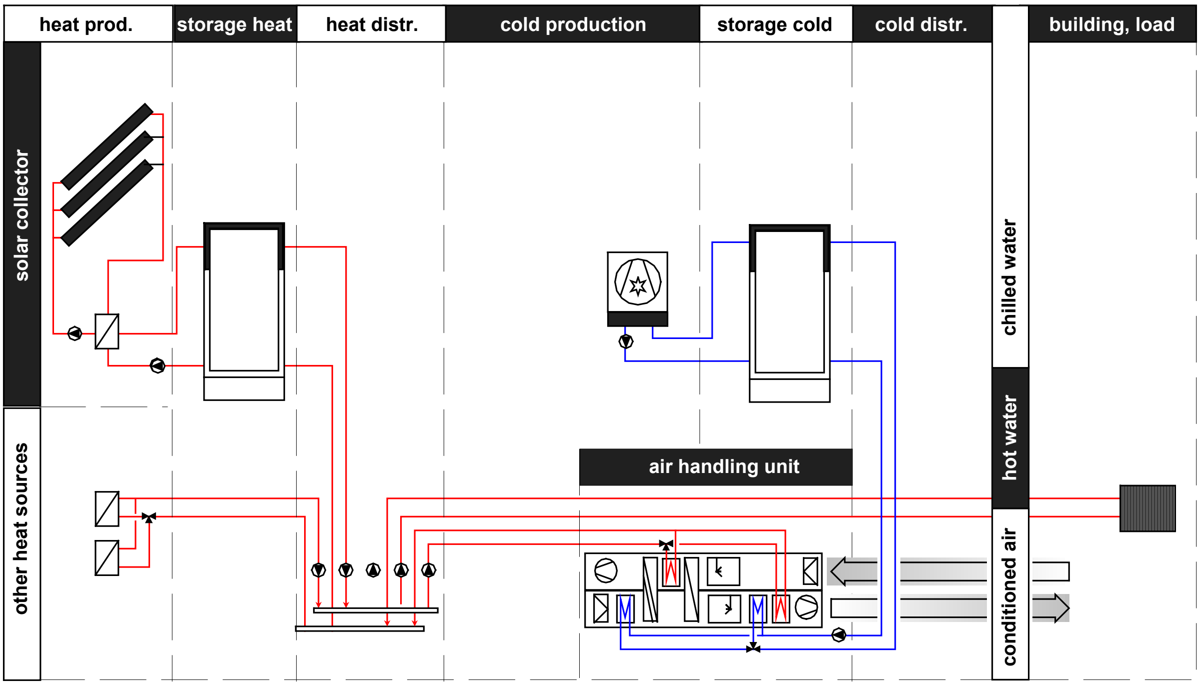

Figure 16 - Example of a technical solution for the path shown in Figure 15

3.8. All air, full air system with conventional air handling unit

An alternative to the application of a solar operated desiccant system is to use a solar thermally driven water chiller and to operate a conventional supply/return air handling unit in cases of tight buildings with centralized ventilation system. Since in the case shown in Figure 17 the hygienic are change is sufficient to cover sensible cooling loads (see description of section 3.6), no additional cooling devices in the room are necessary. A possible configuration is shown in Figure 18. No distinction has to be made for moderate and extreme climates.

The system shown in Figure 18 consists of a solar collector field and other heat sources as back-up, which are used to operate a thermally driven chiller. Cold water is used to operate the conventional air handling unit. The air handling unit is equipped with an evaporative cooler in the return air which in combination with the heat recovery wheel allows pre-cooling of the fresh air.

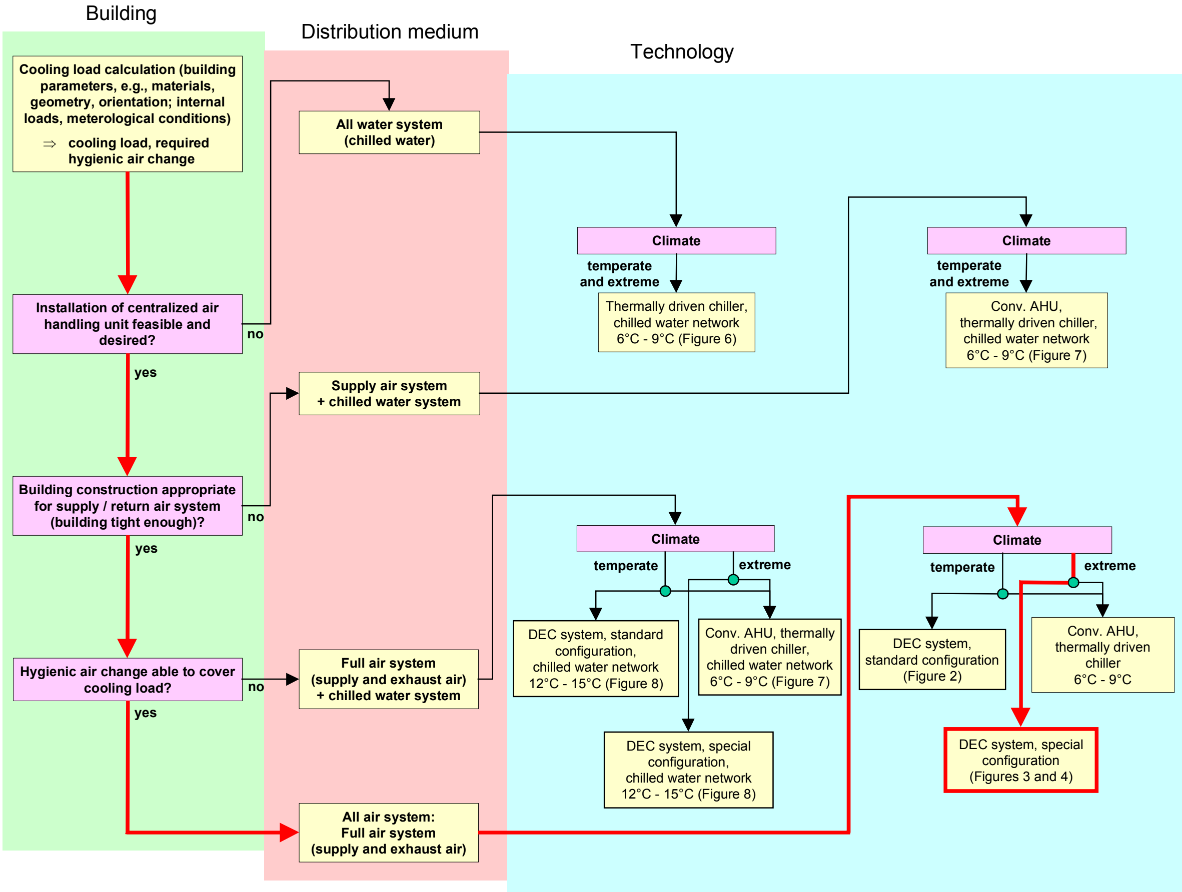

Figure 17 - Path leading to an all, full air system using a conventional air handling unit and a thermally driven chiller

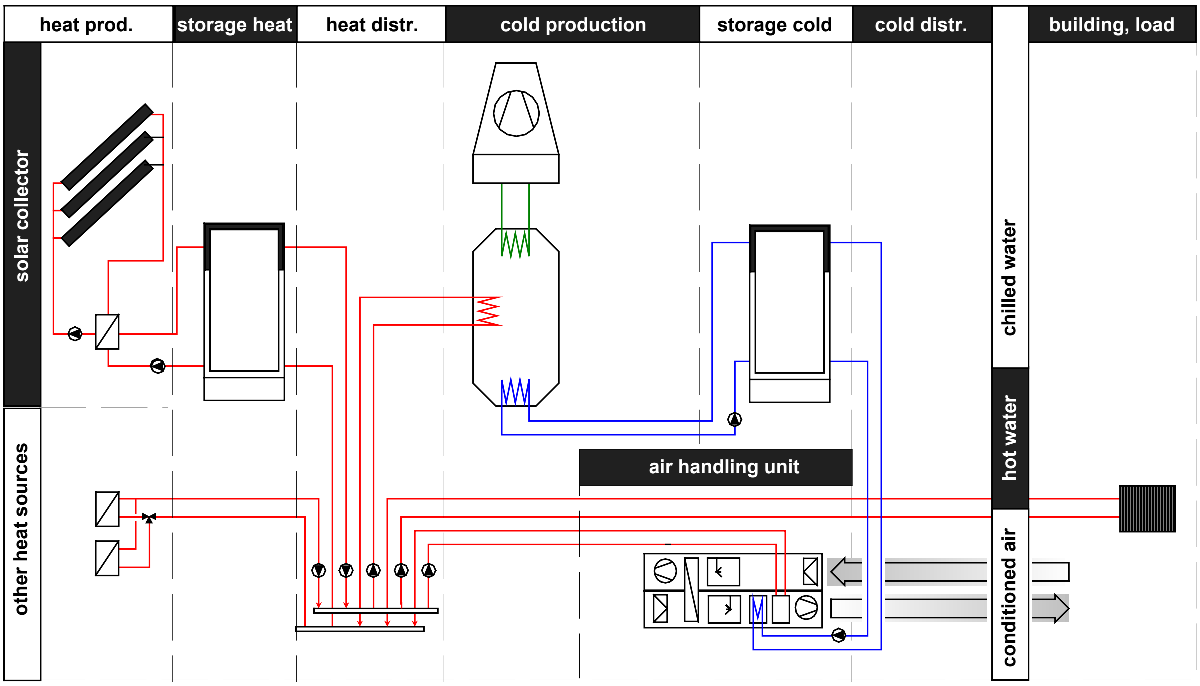

Figure 18 - Example of a technical solution for the path shown in Figure 17

4. References

[1] Solar-assisted air conditioning of buildings, IEA SHC Task 25 Internet site. www.iea-shc-task25.org

[2] Hans-Martin Henning (Editor); Solar-Assisted Air-Conditioning in Buildings – A Handbook for Planners. Springer Wien/NewYork; ISBN 3-211-00647-8

[3] Hans-Martin Henning, Tullio Pagano, Stefano Mola, Edo Wiemken, Luca Menardi: Micro tri-generation system for indoor air conditioning in the Mediterranean climate. 3rd International Conference on Heat Powered Cycles - HPC 2004 - Cooling, Heating and Power Generation Systems, Larnaca - Cyprus, October 2004