TEMPERATURE AND HUMIDITY INDEPENDENT
CONTROL (THIC) OF AIR-CONDITIONING SYSTEM
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Temperature And Humidity Independent Control (THIC) Of Air-conditioning System

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The two subsystems operate together at hot and humid outdoor climate; Only the humidity control subsystem operates at cold but humid ambient condition; Outdoor air is directly introduced into occupied spaces after energy ef? The former one is on May 27th, with ambient temperature of The measurement was divided into two parts: humidity control subsystem and temperature control subsystem.

The tested results of seven fresh air units are summarized in Table 2; the other two processors are neglected due to the different processor of the 2nd?

C 3. Performance test of the THIC system 3. Indoor thermal environment Fig. As indicated by the experiment, the occupied zone within 2 m, the temperature and humidity ratio were about 26% Both the temperature and humidity ratio increased fast along the vertical direction, which reached about 30% And the peak temperature at upper space over 7 m occurred at noon, due to the strong solar radiation and high ambient temperature. According to the test results, the THIC system applied in large space is effective on energy-saving, which only keeps the occupied zone in comfort condition and forms apparent stratification.

Moreover, the natural ventilation from the shutters contributed to remove the absorbed heat of decorations to outdoor environment. Indoor environment of the of? Temperature and humidity distribution in vertical direction of vestibule: a temperature; and b humidity ratio. Table 2 Performance of the fresh air handling units outdoor condition: Outdoor condition Supplied fresh air Stage Evaporating temperature? C Condensing temperature? C Solution parameter temperature and concentration Temperature? C, The fresh air? C and 6. So the cooling capacity Qair, calculated by energy balance equation, was The input power of compressors and solution pumps Pair inside the processor was Therefore, the performance of the fresh air unit COPair, the transport coefficient?

According to the test data of May 27th, and rated parameters of the fresh air units and fans, the calculated cooling capacity of the entire humidity control subsystem is The tested results of each device are listed in Table 4. According to the test data under the partial load condition May 27th, the calculated cooling capacity of the temperature control subsystem QCH is The former is both the moisture introduced by fresh air and released by respiration and perspiration of occupants and indoor plants, and the latter is the caused by the ventilation, heat transfer, solar radiation, heat dissipation of devices and activity of occupants, etc.

In the THIC system, processed outdoor air is used to remove the entire latent load and part of the sensible load, while cooling plant provides high temperature chilled water to remove the rest sensible load. Similar conclusion also can emerge from the test results in the very hot and humid outdoor condition.

Cooling load and power consumption in the THIC system: a cooling load proportion; and b power consumption proportion. Monthly power
consumption of the THIC system. For the conventional air-conditioning system, such as fan coil unit plus fresh air supply system or all air system, the measured average coef? Therefore, there is a remarkable energy ef?

The energy consumption in unit building area and unit net airconditioning area of the tested THIC system were However, the average energy consumption levels of THIC system. Therefore, the THIC system in this ef? Cooling capacity K. C Cooling water temperatures: C Outdoor: Discussion According to our knowledge, cooling air can be realized more easily than dehumidification of sensible load. However, the reheating process of the temperature control subsystem in present THIC system. Thus, this section will focus on how to improve the performance of the temperature control subsystem. According to the performance of each component in the temperature control subsystem shown in Table 4, three main improvements of the temperature control subsystem are recommended: 1 modifying the frequency of the chilled water pump, 2 improving the cooling tower performance by tightening the strap; and 3 improving the performance of FCUs under dry working condition.

Improve the performance of chilled water pump As indicated in Fig. It is because the variable-speed pump has operated at 50 Hz in the past that the chiller temperature difference of the inlet and outlet chilled water is only 1. C, while the designed value is 3. Therefore, the power consumption of the chilled water pump can be considerably cut down after reducing the chilled water? Improve the performance of cooling tower According to Table 4, the transport ef? Detailed performance test is then launched.

For the cooling tower, the mass? C respectively. Hence, the ef? The energy consumption of the cooling tower in the entire airconditioning system is relatively small, but it seriously in? The expected ef? At present, the cot? C and transport coef? However, the tested transport coef? Factualy, the cot? So there is a huge potential to improve the performance of dry FCU with the transport coef?

The contribution of the above three improvements to the temperature control subsystem is summarized in Table 5. Liquid desiccant fresh air units are used to supply dry fresh air to control indoor humidity, and chilled water with the temperature of C is pumped and distributed into radiant panels and dry fan coil units to control indoor temperature.

The followings are the conclusions based on the tested results: 1 The THIC system can provide a comfortable indoor environment that indoor temperatures, humidity ratios as well as CO2 concentrations are all within the comfortable ranges.

The energy consumption of the THIC system in the tested of? Thus, the expected system COP can be further increased to 4. The authors appreciate the valuable help from Mr. Qiang Bin and Mr. Yang Haibo in Shenzhen. References [1] D. Waugaman, A. Kini, C. Kettleborough, A review of desiccant cooling systems, Journal of Energy Resources Technology 111—8. Ameel, K. Gee, B. Wood, Performance predictions of alternative, low cost absorbents for open-cycle absorption solar cooling, Solar Energy 54 2 65—Ahmed, P. Gandhisan, A. Al-Farayedhi, Simulation of a hybrid liquid desiccant based air-conditioning system, Applied Thermal Engineering 17 2 — Liang, L. Zhang, L. Pei, Independent air dehumidification: Patnaik, T. Lenz, G. Yin, X. Zhang, Z. Chen, Experimental study on dehumidification. To reduce this kind of heat transfer loss caused by the significant temperature difference between the inlet fluids, using an appropriate high-temperature cooling source to precool the outdoor air is a feasible solution, which results in a cascade process and improved energy performance.

On the other hand, the handled outdoor air usually approaches the saturated state, and its temperature is too low to be supplied directly to the indoor environment, even though the humidity ratio is satisfactory for humidity control. Thus, reheating is needed to a certain extent. To avoid energy dissipation caused by the reheating process, the indoor exhaust air or the outdoor air itself could be used to reheat the handled air. The following subsection focuses on common precooling methods and reheating solutions.

Condensation dehumidification process with heat recovery module: a operating principle and b air handling process in psychrometric chart. Condensation dehumidification process using high-temperature chilled water for precooling: a operating principle and b air handling process in psychrometric chart. Condensation dehumidification outdoor air handling process with a separate heat pump. For the aforementioned outdoor air handling processes using condensation dehumidification, a common problem is that the supply air temperature is usually too low to be supplied to the indoor environment directly.

If air with such a low temperature is supplied to the conditioned space, the occupants could experience thermal discomfort. Thus, an air diffuser with good inductivity or diffusivity is required, and the air distribution should be checked carefully. However, there are some cases when the indoor temperature is too low due to the low supplied air temperature. This is because the building sensible load is related to the outdoor condition, while the indoor moisture load is mostly related to the variance of moisture sources including the number of occupants.

When the variance of occupant number does not fluctuate significantly, indicating that the indoor moisture load is steady, the required humidity ratio for indoor humidity control is therefore steady. If the condensation dehumidification method is adopted, the required supplied air state is then fixed. As a result, during the partial sensible cooling load, the supplied outdoor air temperature can sometimes become too low because of lower outdoor air temperatures or insufficient solar radiation, inevitably resulting in a decrease of the indoor temperature.

If the dehumidified air is directly supplied to the indoor environment, it may lead to overcooling in the partial load. Therefore, the dehumidified air using condensation dehumidification should be reheated to reach an appropriate temperature before being supplied to the indoor environment. Common reheating methods include electrical reheating, steam reheating, etc. However, these methods lead to additional energy dissipation and should be avoided in practice, except for certain special requirements.
Instead, reheating the supplied air after dehumidification using the indoor exhaust air or the outdoor air is a more feasible solution, since it achieves the reheating effect while reducing unnecessary energy consumption. For liquid desiccant outdoor air handling processors operating in summer, the outdoor air is dehumidified in the dehumidifier, and then the diluted solution is regenerated in the regenerator [8].

According to whether there is indoor exhaust air that can be adopted as regeneration air, a distinction can be made between two different kinds of outdoor air handling processors that use liquid desiccant. If there is sufficient indoor exhaust air, the processor with enthalpy recovery from the indoor exhaust air and the process of utilizing the indoor exhaust air for desiccant regeneration could be adopted for outdoor air dehumidification.

Alternatively, if there is not sufficient indoor exhaust air to be utilized directly, outdoor air could be adopted as the regeneration air, and a process using high-temperature chilled water to precool the outdoor air could be constructed to improve the performance of the outdoor air handling process in the THIC system. The following subsection examines the performance of these two kinds of liquid desiccant outdoor air handling processors, in which exhaust heat from the condenser is utilized to heat the desiccant coming into the regenerator, so the air handling processes are close to the iso-relative humidity line rather than the isenthalpic line.

Summer operation principle of the two-stage liquid desiccant outdoor air processor with enthalpy recovery: a operating schematic and b air handling process shown in psychrometric chart. The liquid desiccant in this outdoor air processor is divided into two parts. One part is stored in spray modules I and II in Fig. The solution heated by the condenser labeled 3 in Fig. The diluted solution and the regenerated solution are connected by solution pipes, and a plate heat exchanger labeled 7 in Fig.

It is obvious that the enthalpy recovery device can efficiently reduce the energy consumption of the outdoor air handling processor. The cooling capacity and condensation heat of the heat pump are both effectively utilized in this outdoor air processor. Two parallel compressors are utilized in the heat pump cycle to operate efficiently under the partial load condition, so that the processor can have higher energy efficiency and control accuracy at partial load.

It is worth noting that the superheating temperature is 8. The high superheating temperature is due to the slightly smaller expansion valve. The superheating temperature can be lowered by regulating the electronic expansion valve, and then COP hp can be improved further.

Moreover, the refrigerant at the expansion valve outlet is Similarly, the refrigerant at the evaporator outlet is These uncommon phenomena can probably be attributed to the unreasonable refrigerant piping layout, which results in a large pressure drop along the refrigerant pipes.

Therefore, special attention should be paid to the layout of the refrigerant piping when designing the processors. The number of elbows and tees, as well as the length of copper pipe, should be minimized to reduce the pressure drop of the refrigerant along the way. Test results of the outdoor air processor at partial load under the summer condition. Based on these test results, it can be seen that the heat pump-driven liquid desiccant outdoor air processor can effectively meet the dehumidification requirement in summer with high comprehensive energy efficiency.

Moreover, the enthalpy recovery modules are adopted in this process to recover energy from the return air. In summary, the outdoor air processor can meet the needs of running at full load and partial load with comprehensive energy efficiency up to 5. In THIC systems, the required temperature of the high-temperature cooling source in summer is significantly higher than that of conventional systems.

This offers the possibility to utilize natural cooling sources, e. If no natural cooling sources can be adopted directly for temperature control in the THIC system, a vapor compression refrigeration system can be utilized instead.

Owing to the increased evaporating temperature of the vapor compression refrigeration cycle, the operating compression ratio of chillers in THIC systems is significantly different from that in conventional systems. Thus, new requirements are proposed for system design and device development of the vapor compression refrigeration cycle for THIC systems.

In this chapter, common types of high-temperature cooling sources are examined. If no natural cooling sources are available, mechanical chillers are needed to satisfy the requirement for the high-temperature chilled water or refrigerant to buildings.

There is a significant increase in the evaporating temperature of high-temperature chillers in the THIC system compared to conventional chillers, and theoretically, the COP of these high-temperature chillers is much higher than that of conventional chillers.

Because of the increase of evaporating pressure, the compression ratio of high-temperature water chillers is much lower than that of conventional low-temperature water chillers, which results in new requirements for compressors and other components. Analyses of piston, scroll, screw, and centrifugal compressors for high-temperature chillers are summarized below.

For scroll, screw, and other fixed volume ratio compressors, overcompression or insufficient compression processes exist when the external compression ratio is not equal to the internal compression ratio. For such compressors, increasing the evaporating temperature inevitably leads to an increase in overcompression loss and a reduction of compressor efficiency.

If these kinds of compressors are used under high-temperature conditions, the actual COP values will be far lower than the theoretical values. The suction and discharge pressures of the piston compressor are equal to the evaporating and condensing pressures, respectively. As a consequence, there is no overcompression loss. To achieve efficient operation with a small compression ratio, the centrifugal compressor should adjust the inlet guide vanes and the rotation speed.

Since the refrigerant pressure difference between the inlet and the outlet of the throttle device is remarkably reduced, the throttle device of the conventional water chiller requires some regulations to satisfy the small compression ratio condition in the high-temperature water chiller. Compressor: a smaller compression ratio centrifugal and piston compressors or specially designed compressors with fixed volume ratios and a
Throttle device: greater capacity and superior regulation performance under a lower compression ratio and a lower working pressure difference. Evaporator and condenser: a greater capacity and higher heat transfer efficiency by improving the heat transfer coefficient or area to strengthen the heat transfer ability.

Oil return system: working properly under the small compression ratio condition. Refrigeration cycle of a centrifugal high-temperature water chiller developed by GREE. Test results for a conventional chiller with different chilled water temperatures.

As shown in Table 18, if the conventional water chiller is used directly to produce high-temperature chilled water, its energy performance is significantly lower than that of the specially designed high-temperature chiller.

Thanks to the improvements and optimizations mentioned previously, the performance of the newly designed centrifugal high-temperature water chiller is significantly improved. There are two subsystems in THIC system: humidity control subsystem outdoor air handling system is used to satisfy indoor requirements for outdoor air and removing indoor moisture load and temperature control subsystem indoor sensible terminals for removing indoor sensible load to control indoor temperature.

Based on the fact that indoor moisture load and outdoor air flow rate required could be regarded to be proportional to occupants in most buildings, requirements for indoor humidity control and outdoor air can be both satisfied by adjusting the humidity ratio of supplied outdoor air to a certain value and introducing the handled outdoor air to indoor space with a flow rate proportional to the number of occupants.

At the same time, there is another system used to regulate the cooling capacity of sensible terminals to effectively control indoor temperature.

With the help of the THIC idea for thermal built environment, indoor requirements for outdoor air, humidity control, and temperature control can be satisfied at the same time. In this way, natural cooling sources as well as high-temperature cooling sources with high efficiency could be used in THIC systems. If condensation dehumidification method is adopted to dehumidify outdoor air and indoor air, the temperature of the cooling source must be low enough.

In conventional system, indoor temperature and humidity are regulated at the same time. However, if the task is only to remove indoor sensible load, it is not necessary to be limited by air circulation any more. Instead, water circulation can be used to directly remove sensible heat to achieve temperature regulation, such as radiant panel for cooling in summer and heating in winter. Because heat capacity of water is much higher than that of air, the profits are not only using the same unit both in summer and winter but also a great reduction of fan power consumption for ventilation and air circulation.

Outdoor air handling processor is used to provide outdoor air with the task of maintaining indoor air quality and extracting indoor moisture load. During the most humid period, the outdoor air system is running with the lowest air flow rate. If the actual number of indoor occupants varies a lot, the indoor terminal with variable air volume should be adopted, regulating air flow rate according to the number of occupants, indoor humidity ratio, or CO2 concentration.

In this way, outdoor air flow rate can be reduced if the number of indoor occupants becomes less, resulting in less outdoor air processing power consumption as well as fan power consumption. In order to keep the balance of indoor air pressure, indoor exhaust air with a certain flow rate should be removed in most cases. In summer and winter, exhaust air state is much closer to the required supply air state than that of outdoor air, and efficient heat recovery from indoor exhaust air is necessary to save energy consumed for outdoor air handling process.

This can be realized by conventional condensation dehumidification system; however, this also brings the problem of a too low supplied air temperature. At present, outdoor air handling processor using liquid desiccant is recommended to be used to regulate supplied air humidity ratio by dehumidification in summer or humidification in winter and achieve energy recovery from exhaust air at the same time.

Combined with enthalpy recovery device, condensing dehumidifier can realize outdoor air dehumidification in summer; however, another humidifier is required if applied in winter.

Thus the outdoor air can be supplied indoor after being cooled down to realize removing extra moisture load without the need of dehumidification. The energy saving potential of THIC system can be fully realized if high-temperature cooling sources are taken advantage of. If allowed by geographical condition, cooling capacity from underground water can be used by drifting wells and recharging. The operating costs are only power consumption of water pumps.

If there are sufficient spaces to bury pipes and annual energy balance could be solved, this is an efficient method to obtain high-temperature cooling sources. However, pump power consumption used for transporting water may exceed the power consumption of chillers, and then the advantage for energy saving disappears.

Chillers can be adopted when there are no natural cooling sources or it is difficult to be used. To produce high-temperature chilled water, energy efficiency of such chillers could be higher than conventional chillers.

At present, centrifugal chiller and screw chiller specially developed for THIC system have been marketed in China, which can be used to produce high-temperature chilled water. Besides, refrigerant could be used as the high-temperature cooling source directly, with no need of secondary water loop. For example, VRF using refrigerant as the intermediate medium is a feasible solution for indoor temperature control of THIC system in small-scale buildings. Compared with conventional VRF for temperature and humidity control, this kind of VRF with an increased evaporating temperature could be more energy efficient, with a COP as high as 6.
Without the need of vapor compression refrigeration cycle, this shows up obvious energy saving effects. At present there are already indirect evaporative cooling products widely used in large-scale commercial buildings of Xinjiang, Ningxia, Inner Mongolia, and so on, achieving comfortable indoor environment and energy saving effects. High-temperature chilled water is needed to take away sensible heat from indoor to regulate indoor temperature, and corresponding terminals are needed.

The terminals are used to deal with sensible heat only, and chilled water temperature is higher than indoor dew point temperature, so there is no condensation phenomenon. Radiant cooling panel and dry FCU are commonly used.

In the last two decades, floor radiant heating has been promoted in the northern of China with fine heating effects. With the help of outdoor air handling processor, which undertakes indoor moisture load, under most circumstances, air-conditioning requirements of office buildings can be satisfied. After importing from European countries and domestically developed, capillary radiant terminal has been put forward to realize indoor temperature control in China, which is installed on the ceilings or vertical walls to realize cooling or heating with cold or hot water circulating inside.

With radiant cooling method, as panel surface temperature is lower than the surrounding air dew point temperature, there will be condensation risk on the panel surface. So, outdoor air systems are important to realize indoor air humidity control and ensure the normal operation of sensible terminals.

If displacement ventilation is used to supply dry air from below, humidity ratio in the lower space will be lower than that in the upper. Thus the possibility of condensation is higher for ceiling radiant cooling than that of floor radiant cooling. According to conventional method using forced air circulation for air-conditioning system, air is used as the medium, which exchanges heat with high-temperature chilled water and removes indoor sensible load.

The corresponding terminals include dry FCU and passive chilled beam. The former uses fans to realize forced air circulation and heat transfer, and the latter depends on the natural convection caused by the sinking of cold air around the beam.

The water temperature in the air-water heat exchanger is higher than indoor dew point temperature, and there is no condensation phenomenon. The condensation pipe or plate is no longer needed, the problem of condensation water leakage can be avoided, and environment pollution problem caused by mold breeding on the humid surface can be solved.

However, dry FCU works at dry conditions; therefore, temperature difference between water and air is significantly reduced, requiring a larger heat transfer area for a same cooling capacity. In recent years, there have been a number of large-scale office buildings and hospitals applying the THIC systems, located in the climate regions from Southern China to Northern China and from eastern coastal cities to Xinjiang and Inner Mongolia.

After operating for a few years, the new THIC air-conditioning method shows great superiorities in indoor environment control and energy conservation. Loads in the buildings include indoor load sensible cooling load through envelop, solar radiant, occupant, equipment, lighting, etc. The load calculation methods are the same with those of conventional air-conditioning system.

In this chapter, indoor load characteristic is introduced, and load splitting is discussed in different THIC systems. In THIC system, the entire indoor moisture load is removed by the humidity control subsystem. If supplied air temperature of humidity control subsystem is different from indoor air temperature, humidity control subsystem removes or brings in a part of sensible load from to the indoor environment.

According to the outdoor air handling methods analyzed in chapters 4 and 5, supplied air temperatures of different methods are different. Thus, the sensible heat taken away brought in by the humidity control subsystem will be also different. If condensation dehumidification and liquid desiccant dehumidification methods are used to handle outdoor air, supplied air temperature t S is usually lower than indoor air temperature t N, and humidity control subsystem undertakes part of indoor sensible load.

If rotary wheel is used to handle outdoor air, supplied air temperature is usually higher than indoor temperature. Temperature control subsystem has to undertake this part of sensible load caused by the temperature difference between supplied outdoor air and indoor air, as well as entire indoor sensible load. Load of major devices in temperature control subsystem and humidity control subsystem of THIC system is analyzed in the following.

In THIC system, outdoor air handling processor is the main device in humidity control subsystem, and high-temperature cooling source usually high-temperature water chiller, distribution system, and sensible terminal devices are the main devices in temperature control subsystem.

According to the plans of THIC air-conditioning systems in design stage, devices to be used for temperature and humidity control subsystems can be determined. And according to the characteristics of different devices and load calculation method mentioned above, the load of key devices can be calculated.

The main device in humidity control subsystem is outdoor air handling processor, with the major task to produce dry and clean outdoor air and supply it into the room to control indoor humidity. Outdoor air changes from outdoor state to supply air state in outdoor air handling processor, so the load of the processor is calculated by the enthalpy variance of the outdoor air.

Major devices for temperature control subsystem include high-temperature cooling source, distribution system, and sensible terminal devices. The main task of high-temperature cooling source is for extracting the sensible load, while sometimes sensible cooling is also needed in the outdoor air handling process.

Load of high-temperature cooling source is affected by different air handling methods. Taking an office building in Beijing as an example, Indoor
sensible peak load \( Q_S \), indoor moisture peak load, outdoor air peak load, and outdoor air flow rate per unit area are THIC air-conditioning system is adopted in this building.

If the outdoor air handling processor is an independent device. Loads of the outdoor air handling processor and the high-temperature cooling source are calculated by Eqs.

If precooling by high-temperature chilled water is needed in outdoor air handling process, the high-temperature cooling source has to meet the demands of indoor sensible terminals and outdoor air precooling process at the same time. Loads of outdoor air handling processor and high-temperature cooling source are closely related to the condition of outdoor air after precooling.

Then loads of outdoor air handling processor and high-temperature cooling source are calculated by Eqs. According to Appendix C, annual cooling loads of indoor sensible load, indoor moisture load, and outdoor air are As the outdoor air handling processor is the independent type, annual cooling load is 6.

And the cooling load of the high-temperature cooling source is If precooling of outdoor air is needed, under above parameters for precooling, the cooling loads of outdoor air handling processor and high-temperature cooling source cooling are 8. The common points for operating strategies between THIC system and conventional system are regulating methods of the chillers, chilled water pumps, cooling water pumps, and cooling towers and supplying the handled outdoor air from the processor to indoor space.

The present section only illustrates the differences between the operation strategies of two systems [12, 13, 14].

If outdoor temperature and humidity ratio are both lower than these of indoor condition, directly use natural ventilation to extract indoor moisture and sensible load. If outdoor temperature is higher than indoor temperature, but outdoor humidity ratio is lower than indoor, natural ventilation could be used to extract indoor moisture load, but sensible terminals are required to extract indoor sensible load and control indoor temperature.

If outdoor humidity ratio is higher than indoor, stop natural ventilation. In this condition, the passive way could not be adopted for extracting indoor moisture and sensible load any more. There are temperature control and humidity control subsystems in THIC system, regulating indoor temperature and humidity separately. Thus, the logic of the operation strategy for THIC system is easy than that of conventional system, since there is no longer coupled temperature and humidity control.

As the outdoor temperature is lower than indoor temperature but outdoor humidity ratio is higher, outdoor air dehumidification processor is required to meet the demands for outdoor air and dehumidification. In summer, condensation phenomenon should be strictly avoided. Switch on the outdoor air handling processor in advance, and the exact time should be determined according to the realities of situation. Get the dew point information with the help of indoor temperature and humidity sensors.

Then the high-temperature water chiller could be in operation. After normal operation of the THIC system, motor damper of outdoor air branch should be automatically regulated based on the monitoring data of temperature and humidity sensor, and the water valve of FCU should be automatically regulated and switched based on the monitoring data of temperature sensor for regulating water temperature.

Outdoor air processor: regulating the outdoor air handling processor based on the difference between the measured value of humidity ratio which could be calculated by the dry-bulb temperature and relative humidity and the set point. One solution is to adopt a variable air flow rate and a fixed humidity ratio of the supply air. Another solution is to adopt a variable humidity ratio and a fixed outdoor air flow rate. Indoor sensible terminals dry FCUs and radiant terminals: regulating the devices based on the difference between measured indoor temperature and the set value.

The air flow rate and the water valve of the dry FCUs could both be regulated. For radiant terminals, variable duty ratio with fixed water flow rate, variable supply water temperature with mixed water pumps, and variable water flow rate could be used to regulate indoor temperature.

Skip to main content Skip to sections. This service is more advanced with JavaScript available. Advertisement Hide. Living reference work entry First Online: 28 August Download reference work entry PDF. For these tasks, different solutions are proposed as follows: The extraction of sensible heat can be achieved by adopting various approaches; it is not limited to the direct contact method. Temperature and humidity independent control THIC air-conditioning system is proposed as an effective solution [3].

Figure 1 illustrates the operating principle of the THIC air-conditioning system, with an outdoor air handling subsystem and a relatively high-temperature cooling source subsystem that can separately regulate the indoor temperature and humidity, respectively. As indoor temperature and humidity are regulated by independent subsystems, the THIC system can satisfy the variance of the indoor heat moisture ratio.

Table 1 shows a detailed comparison of THIC systems and conventional systems. Open image in new window. Problem in conventional systems THIC air-conditioning system 1 Loss in coupled temperature and humidity handling process Avoids this kind of loss, regulates indoor temperature and humidity separately 2 Offset in cooling and heating, dehumidification and humidification Avoids offset 3 Insufficiently accommodates variance of heat moisture ratio Separate subsystems are responsible for temperature and humidity; accurate regulation 4 Indoor terminals The same terminal is adopted both for cooling and heating; radiant terminals are a feasible solution 5 High energy consumption of transportation Supplying air is only for moisture extraction; water or refrigerant is recommended as the temperature control medium 6 Influence on indoor air quality Indoor sensible terminals operate under dry conditions without condensation.

Figure 2a illustrates the operating schematic of a THIC system. The outdoor air is dehumidified to a sufficiently dry state, and then supplied to the conditioned space to extract the indoor moisture, which is quite different from the conventional system.

For the outdoor air handling processor, the high-temperature cooling source, and the indoor terminals, there are different requirements in the THIC.
system compared to conventional systems. Performances of Different Types of Radiant Panels Concrete Radiant Floors
The concept of the concrete core follows that of the heating floor, which fixes plastic or stainless steel pipes with concrete reinforcing bars into poured concrete.

**Temperature And Humidity Independent Control (THIC) Of Air-conditioning System Reviews**

According to the energy usage data recorded from the year, the energy consumption of the THIC system in the tested of? All rights reserved. Introduction In the conventional HVAC system that removes moisture by condensation, air is cooled and dehumidified?

In most cases, sensible load of building covers the majority part of the whole cooling load while the latent load moisture load takes only a small part. However, as the required cooling source temperature of dehumidification? Moreover, the ratio of sensible load to latent load varies largely due to the changes of outdoor climate, number variance of indoor occupants, indoor equipments and lighting utilization mode and so on.

Therefore, the indoor temperature and humidity, the two key parameters, can hardly be satis? In practice, the common reaction to the increased humidity is to reduce the set-point temperature and then re-condition the air after passing the cooling coil to the proper temperature, which results in a plenty of energy wastefulness [1].

To avoid the aforementioned problems, temperature and humidity independent control THIC air-conditioning system stands out as an appropriate pattern that temperature and humidity independent control THIC. Corresponding author. E-mail address: bds mail. Besides, the coil temperature for cooling in the temperature control subsystem can be considerably increased, e. C to 17? C, so that improvement on the performance of chillers or even free cooling from ambient could be obtained.

Many investigations have been carried out on the hybrid desiccant dehumidification? Many studies focusing on improving its performance with process optimization have been conducted in depth, such as Yadav [7], DryKor Ltd. Chen et al. C chilled water for an of? The performance of a hybrid system tested by Ma et al.

Besides, the speci? Zhao et al. The tested of? Description of the THIC system in an of? This system has been brought into operation in July and the basic information about the building and air-conditioning system goes as follows.

**Basis information** The 5-story of? The main function of the 1st? In the vestibule, curtain wall with ventilation shutters in the upper is applied on its north surface, as shown in Fig. The outdoor condition in Shenzhen is rather hot and humid all through the year as shown in Fig.

The building requires cooling and dehumidification? Therefore, how to handle the moisture ef? In this THIC system, the liquid desiccant fresh air handling units driven by heat pumps are employed to handle the outdoor air to remove the entire latent load and supply enough fresh air to the occupied spaces, and the high-temperature chiller that produces chilled water of C for the indoor terminal devices radiant panels and dry fan coil units is applied to control indoor temperature.

The operating principle and performance test results of the THIC system will be shown in this paper, and suggestion for performance improvement will also be included. The vestibule in the of? Annual outdoor conditions of Shenzhen: a daily highest, average and lowest temperatures; b daily average relative humidity; and c daily average humidity ratio. The right side of Fig. As the volume of the supplied fresh air is proportional to the number of people, the pollutants, CO2 and latent heat produced by human bodies can be removed by fresh air.

The schematic of the fresh air processors using liquid desiccant is illustrated in Fig. Lithium bromide LiBr aqueous solution is employed as liquid desiccant in these air processors. The total heat recovery device is used to recover the energy from indoor exhaust air return air to decrease the energy consumption in the fresh air handling process. And in the heat pump driven air handling device, the diluted solution from the dehumidification can be removed by fresh air.

To make it clear, the air-handling processes are displayed in the air psychrometric chart in Fig. In general, the COP of the liquid desiccant fresh air units total heat removed from the fresh air divided by the power consumption of the heat pumps and solution pumps can be as high as 5. Besides, as indicated in Fig. The high-temperature chiller is a Fig. Schematic of the THIC air-conditioning system.

**Liquid desiccant fresh air handling unit driven by heat pumps:**

- Schematic of air processor: a air handling process shown in the air psychrometric chart; C and C respectively, which is much higher than the conventional chiller operating at the chilled water temperature.

**Table 1 Main devices of the THIC system compared to conventional systems. Performances of Different Types of Radiant Panels Concrete Radiant Floors**

<table>
<thead>
<tr>
<th>Device</th>
<th>THIC System</th>
<th>Conventional System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating floor</td>
<td>20°C</td>
<td>40°C</td>
</tr>
<tr>
<td>Cooling tower</td>
<td>10°C</td>
<td>40°C</td>
</tr>
<tr>
<td>Chilled water pump</td>
<td>6°C</td>
<td>6°C</td>
</tr>
<tr>
<td>Humidity control subsytem</td>
<td>80%</td>
<td>70%</td>
</tr>
<tr>
<td>Efficiency</td>
<td>85%</td>
<td>75%</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>50%</td>
<td>60%</td>
</tr>
</tbody>
</table>

As for indoor terminal devices, as shown in Fig. Indoor terminal devices: a dry fan coil units; and b radiant panels.

In the previous sections, the whole THIC system layout has been introduced brie? Particularly, strait? C is pumped and distributed into radiant? The temperature control subsystem and humidity control subsystem can be operated separately according to ambient condition and indoor requirement. The two subsystems operate together at hot and humid outdoor climate.!? Only the humidity control subsystem operates at cold but humid ambient condition.

Outdoor air is directly introduced into occupied spaces after? Energy ef? The former one is on May 27th, with ambient temperature of @ measurement was divided into two parts: humidity control subsystem and temperature control subsystem.

The tested results of seven fresh air units are summarized in Table 2; the other two processors are neglected due to the difference of processor of the 2nd? C 3. Performance test of the THIC system.3.
Indoor thermal environment. As indicated by the? In the occupied zone the height within 2 m, the temperature and humidity ratio were about 26? Both the temperature and humidity ratio increased fast along the vertical direction, which reached about 30? And the peak temperature at upper space over 7 m occurred at noon, due to the strong solar radiation and high ambient temperature. According to the test results, the THIC system applied in large space is effective on energy-saving, which only keeps the occupied zone in comfort condition and forms apparent stratify?

Moreover, the natural ventilation from the shutters contributed to remove the absorbed heat of decorations to outdoor environment. Indoor environment of the of? Temperature and humidity distribution in vertical direction of vestibule: a temperature; and b humidity ratio. Table 2 Performance of the fresh air handling units outdoor condition: Outdoor condition Supplied fresh air Stage Evaporating temperature? C Condensing temperature? C Solution parameter temperature and concentration Temperature?

C, The fresh air? C and 6. So the cooling capacity...\)

According to the test data under the partial load condition May 27th, the calculated cooling capacity of the temperature control subsystem QCH is The former is both the moisture introduced by fresh air and released by respiration and perspiration of occupants and indoor plants, and the latter is the caused by the ventilation, heat transfer, solar radiation, heat dissipation of devices and activity of occupants, etc. In the THIC system, processed outdoor air is used to remove the entire latent load and part of the sensible load, while cooling plant provides high temperature chilled water to remove the rest sensible load. Similar conclusion also can emerge from the test results in the very hot and humid outdoor condition. If supplied air temperature of humidity control subsystem is different from indoor air temperature, humidity control subsystem removes or brings in a part of sensible load from to the indoor environment.

According to the outdoor air handling methods analyzed in chapters 4 and 5, supplied air temperatures of different methods are different. Thus, the sensible heat taken away brought in by the humidity control subsystem will be also different. If condensation dehumidification and liquid desiccant dehumidification methods are used to handle outdoor air, supplied air temperature tS is usually lower than indoor air temperature tN , and humidity control subsystem undertakes part of indoor sensible load.

If rotary wheel is used to handle outdoor air, supplied air temperature is usually higher than indoor temperature. Temperature control subsystem has to undertake this part of sensible load caused by the temperature difference between supplied outdoor air and indoor air, as well as entire indoor sensible load. Load of major devices in temperature control subsystem and humidity control subsystem of THIC system is analyzed in the following.

In THIC system, outdoor air handling processor is the main device in humidity control subsystem, and high-temperature cooling source usually high-temperature water chiller, distribution system, and sensible terminal devices are the main devices in temperature control subsystem.

According to the plans of THIC air-conditioning systems in design stage, devices to be used for temperature and humidity control subsystems can be determined.

And according to the characteristics of different devices and load calculation method mentioned above, the load of key devices can be calculated. The main device in humidity control subsystem is outdoor air handling processor, with the major task to produce dry and clean outdoor air and supply it into the room to control indoor humidity.

Outdoor air changes from outdoor state to supply air state in outdoor air handling processor, so the load of the processor is calculated by the entropy variance of the outdoor air. Major devices for temperature control subsystem include high-temperature cooling source, distribution system, and sensible terminal devices.

The main task of high-temperature cooling source is for extracting the sensible load, while sometimes sensible cooling is also needed in the outdoor air handling process. Load of high-temperature cooling source is affected by different air handling methods.

Taking an office building in Beijing as an example, Indoor sensible peak load Qs , indoor moisture peak load, outdoor air peak load, and outdoor air flow rate per unit area are THIC air-conditioning system is adopted in this building. If the outdoor air handling processor is an independent device e. Loads of the outdoor air handling processor and the high-temperature cooling source are calculated by Eqs. If precooing by high-temperature chilled water is needed in outdoor air handling process, the high-temperature cooling source has to meet the demands of indoor sensible terminals and outdoor air precooling process at the same time.

Loads of outdoor air handling processor and high-temperature cooling source are closely related to the condition of outdoor air after precooling. Then loads of outdoor air handling processor and high-temperature cooling source are calculated by Eqs. According to Appendix C, annual cooling loads of indoor sensible load, indoor moisture load, and outdoor air are As the outdoor air handling processor is the independent type, annual cooling load is 6.

And the cooling load of the high-temperature cooling source is If precooing of outdoor air is needed, under above parameters for precooing, the cooling loads of outdoor air handling processor and high-temperature cooling source are 8. The common points for operating strategies between THIC system and conventional system are regulating methods of the chillers, chilled water pumps, cooling water pumps, and cooling towers and supplying the handled outdoor air from the processor to indoor space.

The present section only illustrates the differences between the operation strategies of two systems [12, 13, 14]. If outdoor temperature and
humidity ratio are both lower than these of indoor condition, directly use natural ventilation to extract indoor moisture and sensible load. If outdoor temperature is higher than indoor temperature, but outdoor humidity ratio is lower than indoor, natural ventilation could be used to extract indoor moisture load, but sensible terminals are required to extract indoor sensible load and control indoor temperature. If outdoor humidity ratio is higher than indoor, stop natural ventilation. In this condition, the passive way could not be adopted for extracting indoor moisture and sensible load any more. There are temperature control and humidity control subsystems in THIC system, regulating indoor temperature and humidity separately.

Thus, the logic of the operation strategy for THIC system is easier than that of conventional system, since there is no longer coupled temperature and humidity control. As the outdoor temperature is lower than indoor temperature but outdoor humidity ratio is higher, outdoor air dehumidification processor is required to meet the demands for outdoor air dehumidification.

In summer, condensation phenomenon should be strictly avoided. Switch on the outdoor air handling processor in advance, and the exact time should be determined according to the realities of situation. Get the dew point information with the help of indoor temperature and humidity sensors. Then the high-temperature water chiller could be in operation. After normal operation of the THIC system, motor damper of outdoor air branch should be automatically regulated based on the monitoring data of temperature and humidity sensor, and the water valve of FCU should be automatically regulated and switched based on the monitoring data of temperature sensor for regulating water temperature.

Outdoor air processor: regulating the outdoor air handling processor based on the difference between the measured value of humidity ratio which could be calculated by the dry-bulb temperature and relative humidity and the set point. One solution is to adopt a variable air flow rate and a fixed humidity ratio of the supply air. Another solution is to adopt a variable humidity ratio and a fixed outdoor air flow rate. Indoor sensible terminals dry FCUs and radiant terminals: regulating the devices based on the difference between measured indoor temperature and the set value.

The air flow rate and the water valve of the dry FCUs could both be regulated. For radiant terminals, variable duty ratio with fixed water flow rate, variable supply water temperature with mixed water pumps, and variable water flow rate could be used to regulate indoor temperature.

Table 1 shows a detailed comparison of THIC systems and conventional systems. Open image in new window. Problem in conventional systems THIC air-conditioning system 1 Loss in coupled temperature and humidity handling process Avoids this kind of loss; regulates indoor temperature and humidity separately 2 Offset in cooling and heating, dehumidification and humidification Avoids offset 3 Insufficiently accommodates variance of heat moisture ratio Separate subsystems are responsible for temperature and humidity; accurate regulation 4 Indoor terminals The same terminal is adopted both for cooling and heating; radiant terminals are a feasible solution 5 High energy consumption of transportation Supplying air is only for moisture extraction; water or refrigerant is recommended as the temperature control medium 6 Influence on indoor air quality Indoor sensible terminals operate under dry conditions without condensation.

Figure 1 illustrates the operating principle of the THIC air-conditioning system, with an outdoor air handling subsystem and a relatively high-temperature cooling source subsystem that can separately regulate the indoor temperature and humidity, respectively. As indoor temperature and humidity are regulated by independent subsystems, the THIC system can satisfy the variance of the indoor heat moisture ratio.

Table 2 lists the thermal resistance and time constant of the concrete radiant floor with typical structures. Thermal resistance of the granite is around 0. For FCUs, heat exchange between the air and the water is realized through forced convection of fans. The thermal inertia problem of radiant floors is significant because of the thickness of the material. If applied in airports and railway stations, where high operation of air-conditioning systems is required, the effects of thermal storage are not obvious.

However, these problems should be taken into consideration when applied in buildings with part-time operation. Table 2 Thermal resistances and time constants of typical concrete radiant floors. The pipes connect the distributor pipe on one side and the collector pipe on the other side to form a grid structure, as shown in Fig.

Water flow velocity is slow in the pipes; it is around 0. This structure can be combined with metal panels or concrete slabs and is thus widely used in practice in retrofitting projects.

Table 3 lists the thermal resistances of plastered capillary radiant panels with typical structures, where the capillary diameter is 3.

The thermal resistance and time constant of the capillary radiant panels, which are around 0. Table 3 Thermal resistance and time constant of plastered capillary radiant panels. The sandwich structure of the flat metal radiant ceiling mainly consists of metal, such as copper, aluminum, or steel. From the cross-sectional diagram, it can be seen that the pipe is in the middle, while the insulation material and the cover plate are on the top.
and the backing strap is on the bottom, as shown in Fig.

As this type of structure includes decorative features, it is the most widely used structure. The indoor appearance after setup can be seen in Fig. 5. Thermal resistances of radiant panels with different thicknesses and intervals between neighboring pipes can be calculated.

The results indicate that, if the ratio of temperature difference between the air and the radiant panel at the end portion to that at the base portion is within 0. Table 4 lists the thermal resistance and time constant of metal panels with typical structures. The time constants of the metal panels are quite small, i. Table 4 Thermal resistance and time constant of metal aluminum panels with typical structures.

Table 5 gives the performance comparison of the five types of radiant panels described in this section. Thus, it is easy for the surface temperature distribution to be nonuniform, and the lowest surface temperature of the metal radiant panel approaches the supply chilled water temperature.

For the concrete radiant floor and the capillary radiant ceiling with plastering, the thermal resistance is mainly along the direction of the plate thickness, which helps to make the surface temperature distribution more uniform. However, the temperature difference between the surface temperature or the lowest surface temperature and the supply water temperature is relatively larger compared to the metal type. Table 5 Performance comparison between different radiant panels. Table 6 lists the operating performances of concrete radiant floors for cooling.

Due to a relatively large thermal resistance of this kind of radiant panel, the surface temperature distribution is almost uniform if there is no partially shaded area. Thus, in this table, only the variances of the surface mean temperature and the cooling capacity of the radiant panels are listed. For the same indoor environment, if the thermal resistance of the radiant floor is larger, the required mean temperature of the supply and return chilled water will be lower for the same surface temperature of the radiant panel.

For structure VII with a thermal resistance of 0. Table 6 Operating performances of concrete radiant floors with different structures for cooling. The cooling capacity of the radiant floor per unit area is significantly influenced by the operating environment i.

Table 7 lists the operating performances of the capillary radiant ceilings with plastering for cooling. It can be seen that similar conclusions can be drawn for this type of radiant panel as for the concrete radiant floors described above. For the same indoor environment, the required mean temperature of the supply and return chilled water will be lower if the thermal resistance of the radiant floor is larger for the same average surface temperature of the radiant panel.

In addition, the cooling capacity of the capillary radiant ceiling per unit area is significantly influenced by the operating environment i. Table 7 Operating performances of capillary radiant ceilings with plastering. The cooling capacity of the metal radiant panel increases with the decrease of the temperature difference between the supply and return water in the condition when the lowest surface temperature remains the same. Taking structure I of the flat metal radiant roof as an example, the cooling capacities of the radiant panels are Condensation Dehumidification Method Condensation dehumidification is widely utilized in conventional air-conditioning systems, and it can also be adopted in THIC systems.

For the THIC system, the required humidity ratio of the handled outdoor air is about 9. The above parameters of the handled outdoor air in conventional and THIC systems are listed in Table 9.

Taking the outdoor climate design parameters of Beijing dry-bulb temperature of 《The required rows of cooling coils and the water flow velocity are listed in Table 10, which shows that a four-row cooling coil is sufficient for the conventional system. Due to its lower required humidity ratio, the THIC system requires more rows of cooling coils than the conventional system, which means a six-row cooling coil is sufficient. Table 9 Supply air parameters after condensation dehumidification.

Table 10 Selected cooling coils for condensation dehumidification. By setting an appropriate indoor exhaust air system and venting the indoor exhaust air in an organized way, the heat recovery device can be implemented between the indoor exhaust air and the outdoor air, where the energy can be recovered. Figure 6 illustrates the outdoor air handling process using condensation dehumidification with the enthalpy recovery module. It can be seen that the enthalpy of the outdoor air decreases after the enthalpy recovery process from state W to W1.

Thus, the enthalpy difference required in the dehumidification process decreases, helping to reduce the energy consumption of the outdoor air handling process. The lower-temperature chilled water could be used to dehumidify the air further, as shown in Fig. 6. The high-temperature chilled water could be directly obtained from natural cooling sources such as underground water and could also be available from the high-temperature water chiller.

With the help of the precooler, the outdoor air could be cooled from the hot and humid state to the saturated state or approaching the saturated state. The major task of the precooler process is to cool the air but not to dehumidify it. i.

Low-temperature chilled water is then adopted to dehumidify the air from state W1 to state O, satisfying the humidity ratio requirement of the supplied air. Moreover, using high-temperature chilled water for precooling takes full advantage of the energy efficiency of the high-temperature cooling source. Based on the variances of the outdoor air parameters and the required supply air parameters, the air handling processor can meet the requirement of the supplied air by regulating the flow rate of the low-temperature chilled water and ensuring the use of high-temperature chilled water as much as possible.

As indicated by the results, the enthalpy difference of the precooler process is significantly higher as the outdoor temperature and humidity ratio are higher.

Thus, precooler using high-temperature chilled water could undertake the load of handling the outdoor air effectively and is a feasible approach for improving the efficiency of the outdoor air handling process. Table 11 Outdoor air enthalpy differences under typical conditions. For the outdoor
air handling process using high-temperature chilled water to precool the air in Fig. To make the air handling processor more flexible, some improvements are proposed for the condensation dehumidification outdoor air handling processes utilizing high-temperature chilled water for precooling.

Figure 8 illustrates an improved outdoor air handling process using condensation dehumidification. The air is dehumidified further by the evaporator of the separate heat pump cycle to meet the humidity ratio requirement. The condenser of the heat pump could be an air-cooled type utilizing indoor exhaust air or a water-cooled type utilizing cooling water.

For the outdoor air handling process shown in Fig. As the separately installed heat pump is responsible for dehumidification, only a single plumbing system for the high-temperature chilled water is required, resulting in a much simpler arrangement of the processors. In this figure, the straight lines and dashed lines stand for liquid desiccant and refrigerant, respectively. The top channel is for the indoor exhaust air, and the bottom channel is for the outdoor air.

The outdoor air first enters the two-stage enthalpy recovery device and then flows into the evaporator-cooled two-stage dehumidification modules numbered III and IV before being supplied into occupied spaces. The evaporator of the heat pump is adopted to further cool and dehumidify the outdoor air coming out of the enthalpy recovery device to the desired supplied temperature and humidity ratio. Because the heat pump system in the outdoor air processor utilizes two compressors working in parallel, and the solution in each stage exchanges heat with an individual evaporator condenser, the dehumidification requirement at partial load can be achieved by adjusting the on-off time of these two compressors.

The test results of the outdoor air processor shown in Fig. Table 12 Test results of the outdoor air processor under the summer design condition. The main devices are briefly introduced as follows. Indoor sensible load influenced by the supplied outdoor air, Q HS, is calculated by Eq. Figure 12 is an example if the supplied outdoor air temperature is lower than the indoor air temperature, indicating the characteristics, etc. Referring to Fig. The main devices are briefly introduced as follows. Indoor sensible load influenced by the supplied outdoor air, Q HS, is calculated by Eq. If precooling or cooling is required for outdoor air, the precooling load Q pre needs to be subtracted in calculating Q OAP by Eq.
If precooling or cooling is required for outdoor air, precooling load $Q_{\text{pre}}$ should be added to the load of high-temperature water chiller $Q_{\text{HTC}}$, as shown in Eq. In THIC system, humidity ratio of the supplied outdoor air is lower than indoor design humidity ratio, and the humidity ratio difference is the driving force to remove indoor moisture load.

Load appointment of outdoor air handling processor and high-temperature cooling source is closely related to the devices. Here the analysis of two typical conditions is given: If the outdoor air handling processor is an independent device. Based on the concept of THIC system, a new control mode is proposed for indoor thermal environment. In this control mode, priority is given to the passive approaches that natural cooling sources and waste heat are recommended to be adopted to maintain a comfortable indoor environment.

One thing to note is to check whether the air flow rate of outdoor air ventilation system is sufficient to meet the dehumidification requirements. If natural ventilation is insufficient, active humidity control system is required to meet the dehumidification requirements.

The operation modes of natural ventilation are as follows: If outdoor temperature and humidity ratio are both lower than these of indoor condition, directly use natural ventilation to extract indoor moisture and sensible load.

Taking a THIC system with the high-temperature water chiller, separate outdoor air handling processor such as outdoor air handling processor using liquid desiccant or driven by separate heat pumps and dry FCU as an example, the suggested operating order for the THIC system is as follows: Switch on the outdoor air handling processor in advance, and the exact time should be determined according to the realities of situation.

The basic concept for controlling and regulating of the entire THIC system is as follows: Outdoor air processor: regulating the outdoor air handling processor based on the difference between the measured value of humidity ratio which could be calculated by the dry-bulb temperature and relative humidity and the set point. Springer Press, Berlin Google Scholar. Meteorological Information Center of China Meteorological Administration, Tsinghua University Dedicated meteorological data sets for thermal built environment analysis in China.

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- Я что, одолжившего ей свою куртку. - Вы читаете мои мысли, Грег.