COURSEWORK II
EXAMINATION OF CONVENTIONAL PLANT CONTROL STRAGETIES

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INTRODUCTION

Control strategies of building systems are crucial to achieving ideal building performance and creating a more sustainable built environment. In this report, the control strategies of fan coil unit systems (FCUs) are investigated for an office building. The source used for examining standard published control strategies of FCUs is the BSRIA Library of System Control Strategies (AG 7/98). This report will also discuss control deficiencies and suggest energy-saving measures.

1. CONTROL REQUIREMENTS

Fan coil units provide sensible heating and cooling to surrounding zones whilst aiding the zone air distribution. A schematic for the overall air handling system of FCUs is provided in Graph 1. Outside air is handled under heating, cooling and dehumidification controls. It is induced by air handling plants which incorporate plate heat exchangers, CHW chillers and LTHW(low temperature hot water) heaters, and is then provided to FCU terminal units by supply fans. The speed of fans is determined basing on the deviation of the temperature from setpoint, and control dampers in the units adjust air flow which provides the required heating or cooling demands.

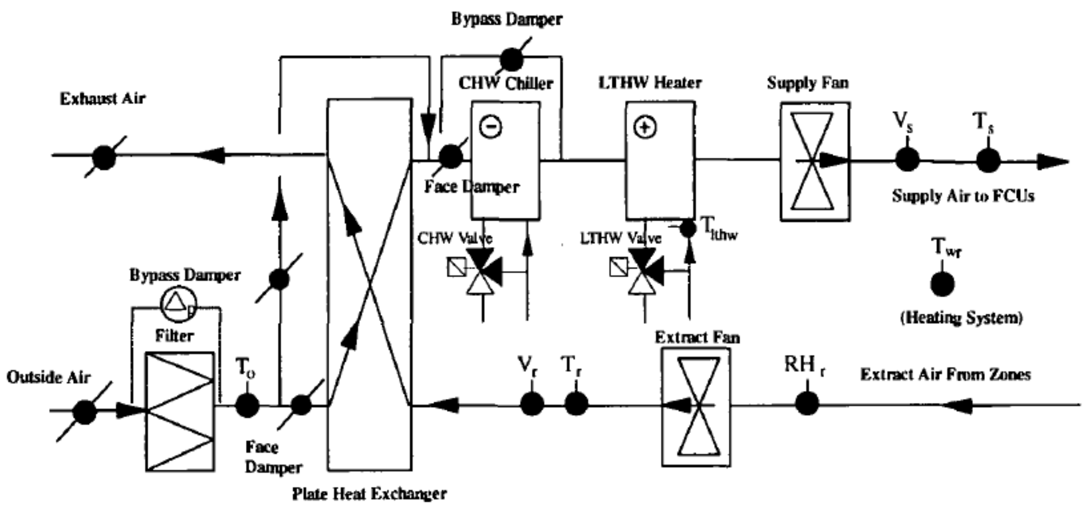
Schematics of FCU terminal units are shown in Graph 2. The two types of units, waterside controls and airside controls, represent different media through which heat is provided in the units. The work mechanism and control systems of the two types of FCUs are similar, and this report will focus on waterside control FCU units. Conditioned air is provided from the AHU plant, and is further handled in the terminal units. This report will look at the control systems of terminal FCU units.

The ultimate output of FCU systems include supply air temperature, supply air humidity, supply air flow rate, supply air quality, etc. The variables forming the outputs of FCU systems consist of both controlled inputs and uncontrolled disturbances. Controlled inputs will be discussed in the next paragraph. Uncontrolled conditions include unexpected activities in the office, blockage or air leakage in the pipework, change of outside air temperature, etc. These variables together with the U values and airtightness of the zone building fabric determine the comfort levels of the space.

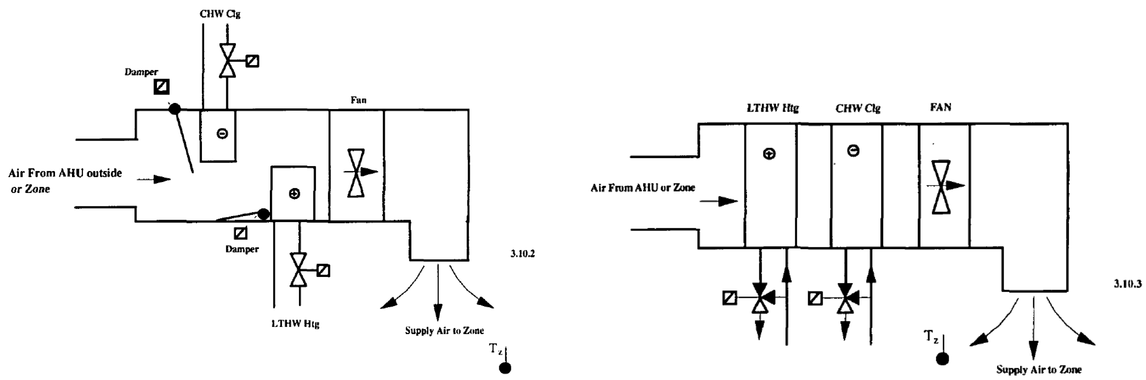
Controlled inputs of the control systems in FCU terminal units should be moderated to form the outputs. Inputs of the FCU terminal units are:

- Supply air temperature and humidity from the AHU plant. This is compared against the setpoint temperature, and positions of valves and dampers in the LTHW, CHW and fans will be adjusted accordingly. The adjustment of damper and valve positions regulates the flow rates of warm/cool water and fan speed, and thus obtains the required heating/cooling / dehumidification effect.

- Zone occupancy level. The occupancy rate of the space is sensed, and the data of predicted internal gains will be put in the control system to form a feed-forward system. Valve and damper positions will likewise be adjusted.
- Outside air temperature. This will determine the zone setpoint temperature and thus the supply air setpoint temperature.



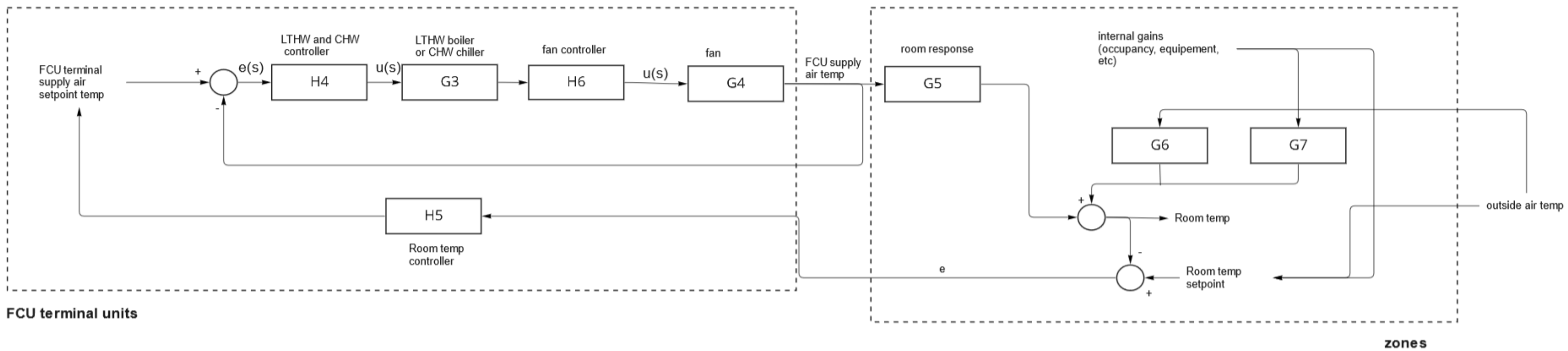
Graph 1. Schematic of the AHU plant



Graph 2. Schematic of FCU terminals: airside control and waterside control

2. BLOCK DIAGRAM

A block diagram below illustrates the flow of information in the central AHU, terminal FCU units and sensors in the zone. It shows the dependence of the controlled outputs on the various controlled inputs and uncontrolled disturbances.



Block diagram of control information flow inside the FCU system

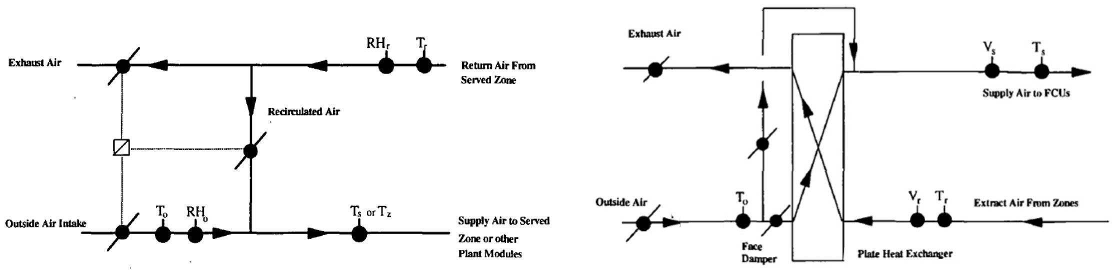
3. SENSOR REQUIREMENT AND CONTROL CRITERIA

See appendices. The schedules of required sensors to implement the control system are listed in Appendix A. The setpoints of schedules are determined by internal environmental criteria, which is also provided in the appendix B.

4. AN ADDITIONAL ENERGY-SAVING STRATEGY

Various strategies can be adopted to improve the energy performance of this system. One of them, for example, is a mixing damper system which is specified in BSRIA Library Section 3.1.2. In this system, mixing dampers modulate the proportions of fresh air and recirculated air in the mixing air, so that less energy is consumed whilst baseline fresh air requirements are satisfied.

It can be observed in Graph 4 how the systems use different mechanisms to recover heat from recirculated air. Three types of dampers are in use in both systems – outside air dampers, exhaust air dampers and recirculated air dampers. In the conventional system, outside air and recirculated is mixed in the heat exchanger, and the proportion is defined according to programmed schedules or system defaults. This means the controls of outside air damper positions and recirculated air damper positions work separately, and they need to be programmed to ensure that an appropriate amount of air is mixed.



Graph 4. Schematics of a mixing damper system (Left) and a conventional system (Right)

In the mixing damper system, however, three types of dampers work in unison and they share information with each other. In detail, the recirculation damper works in reverse operation to the outside and exhaust air dampers, which means that when more outside air comes in, less air is recirculated. Although conventional systems can also be programmed and scheduled to achieve this, a mixing damper system has this built-in mechanism which is more reliable and less demanding.

The key feature which makes mixing-damper systems more energy-saving than conventional systems is that they can more efficiently avoid energy waste when providing outside air and recirculated air at the same time. For example, when return air temperature is higher than fresh air and cooling is required, mixing recirculated air will produce unnecessary warm air and energy efficiency is maximized if we provide cooler (fresh) air. On the contrary, when return air temperature is higher than fresh air and heating is required, the most reasonable measure is increasing recirculated air and decreasing fresh air provision. The schedules and mechanisms of mixing-damper systems are listed in Table 1.

Schedule		**Measure**	**Outcome**
When served zones are occupied and normal operation starts.	When return air temp > outside air temp and cooling is required.	Dampers modulate towards the fully open position so that more outside air can enter and cooling load can be reduced. Minimum set outside air damper position is defined to ensure baseline fresh air requirement is satisfied.	The positioning of the dampers is controlled to obtain the setpoint temperature whilst ensuring minimum fresh air requirement (0.6 m3/s)is satisfied. The temperature
	When return air temp < outside air temp and cooling is required.		

	When return air temp > outside air temp and heating is required.	A minimum set outside air damper position is defined, so that only baseline outside air is supplied and heating load can be reduced. For a constant volume system like the FCU examined in this report, the position is defined during the commissioning process.	of mixed air can minimize the energy consumption of cooling/heating coils.
	When return air temp < outside air temp and heating is required.		
When dehumidification is required		Dehumidification control overrides the air damper position mentioned above, whilst minimum fresh air requirement is still satisfied.	Supply air is dehumidified whilst ensuring required fresh air is provided
After the supply fan is started.		An interlock will demonstrate that both the outside and exhaust dampers are responding to the damper open proving signal.	Full recirculation normally operates when starting up the whole system.
When the BMS signals a cooling optimum start or a night cooling operation signal		Outside air and exhaust air dampers are fully open (recirculation damper is closed)	Recirculation air dampers work in reverse operation than supply/extract air dampers. This ensures less heat is wasted in the process.
When: 1.air handling plant is not working; 2. Optimum start heating; 3. Low zone temperature conditions		The mixing damper should be in the full recirculation position (outside and exhaust air dampers are closed)	

Table 1. Operation schedules and measures of mixing damper systems.

5. CONTROL DEFICIENCIES

Transport delay between valves and sensors can cause unwanted oscillation and can even lead to instability. The primary reason for transport delay is the length of pipework connecting valves and sensors. The pipework might be unnecessarily long because of improper designs or physical difficulties that prevent the pipework from being installed in reasonable positions. To shorten transport delays, the distance of pipework should be minimized, and the positions of the pipework should be carefully designed. This means that the design of MEP systems should be integrated in early stages.

Unwanted heat gain/loss during the transport of supply air can also generate control deficiencies. Heat might be gained from the operation of CHW chillers, LTHM heaters or supply fans themselves. In these processes, heat is transferred from these facilities to air or water, and air temperatures will be more significantly influenced than water temperatures because water has higher heat capacity. To mitigate these effects, the heat emission of facilities along the heat transportation should be calculated and modelled, so that these data can be included in the BMS system when determining valve positions. This can be achieved by measuring temperatures of these facilities under operation mode and using heat transfer functions. Or this can be achieved by tracking the differences between desired temperature and monitored temperature, and thus the influence of unexpected heat gains may be modelled. Heat may also be lost due to air leakages of pipework. This can be mitigated by lagging pipes with insulation materials such as polyethylene. Air leakages can also be positioned by pressure testing and leak locating.

Control deficiencies can also be caused by a decrease of air flow rates. This can due to dirty filters and coils, which increase the resistance when air passes through. Regular cleaning and maintenance should be carried out.

REFERENCES

Martin, A.J & Banyard, C.P, 1998. *Application Guide AG 7/98 LIBRARY OF SYSTEM CONTROL STRATEGIES.*. s.l.:BSRIA.

APPENDIX A

A schedule of the required sensors to implement control strategies

Sensor		Schedule
Central plant	Outside air temperature sensor	When outside air temperature is below a setpoint of 3°C, low outside air temperature signal shall be activated, and the duty primary and secondary circuit heating & cooling pumps shall be started.
	Return air relative humidity sensor	The dehumidification demand shall be determined when the return air relative humidity is above the setpoint of 65%RH, and CHW valves shall be positioned accordingly.
	Return water temperature sensor	Low primary heating return water temperature condition signal shall be activated when the primary heating return water temperature is below a setpoint of 8°C. Primary and secondary circuit heating & cooling pumps shall be started. The signal shall remain until return water temperature rises above 35°C (condensing boilers) or 55°C (non-condensing boilers)
	Duct and atmosphere pressure sensor	When the differential pressure between the duct and atmosphere rise above 500Pa/ velocity rise above 1.0m/s, the supply air pressure / velocity shall be made and fan operation shall be proven . As a result, the supply and extract fan shall ensure a constant speed of 1.0m/s of supplied/extracted air.
	Filter pressure sensor	The BMS shall warn of a dirty filter when the differential pressure has risen above the 300Pa, or when the differential pressure has risen above pressure setpoint, which is scheduled to fan speed, being 100Pa for a IV fan speed control signal and 500Pa for a 10V fan speed control signal.
FCU terminal units	Fan supply air temperature sensor	During normal operation if the supply air temperature sensor detects temperature rising above a setpoint of 30°C or below a setpoint of 12°C, the BMS shall initiate a supply air temperature high/low alarm.
	Zone relative humidity sensor	Not specified in BSRIA Library. However, the zone RH sensor shall detect a rise of RH above 65%, when a dehumidification signal shall be sent to BMS and the cooling coil shall be working accordingly.
	Zone temperature sensor	The signal that start all heating plant shall be active when zone temperatures fall below a setpoint of 10°C and shall terminate when the zone with the lowest temperature has risen above 14°C or until the BMS signals a different operation mode. The sensor ensures that the nearest possible temperature to the zone air temperature setpoint of 19/22°C (heating/cooling) is provided by

		positioning the face and bypass dampers in response to PI control signals.
	Zone occupancy sensor	Not specified in BSRIA Library. However, on sensing a rise/decrease of occupancy, the setpoint temperature of the supply fan shall be adjusted and BMS signals shall be sent. The fan speed shall be set to be faster to mitigate a potential rise of CO2 levels.
	Fire/smoke sensor	A smoke/fire sensor shall be positioned in the return air ductwork. On sensing the smoke, the supply and extract fan shall be stopped and an alarm raised at the BMS central supervisor. The variable speed fans shall operate in response to a constant speed signal to extract 4m3/s of air when required.

APPENDIX B

Internal environment criteria that determine the setpoints of controls

Requirements	Reference
Summer room setpoint temperature should be 22-24 °C	CIBSE Guide A, Table 1.5, office space
Winter room setpoint temperature should be 21-23 °C	CIBSE Guide A, Table 1.5, office space
Supply air temperature setpoint shall be scheduled linearly to the outside air temperature, being at a maximum setpoint limit of 22°C when the outside air temperature is at or below 12°C and at a minimum setpoint limit of 14°C when the outside air temperature is above 21°C	BSRIA Library, 3.1, Specification Clause 3.14.3
Indoor humidity level should be 30% - 70%	CIBSE Guide A, Table 1.5, office space
Ventilation rate should be 10L/s per person	CIBSE Guide A, Table 1.5, office space
Indoor CO2 levels should be below 800 ppm	EN 13379:2007