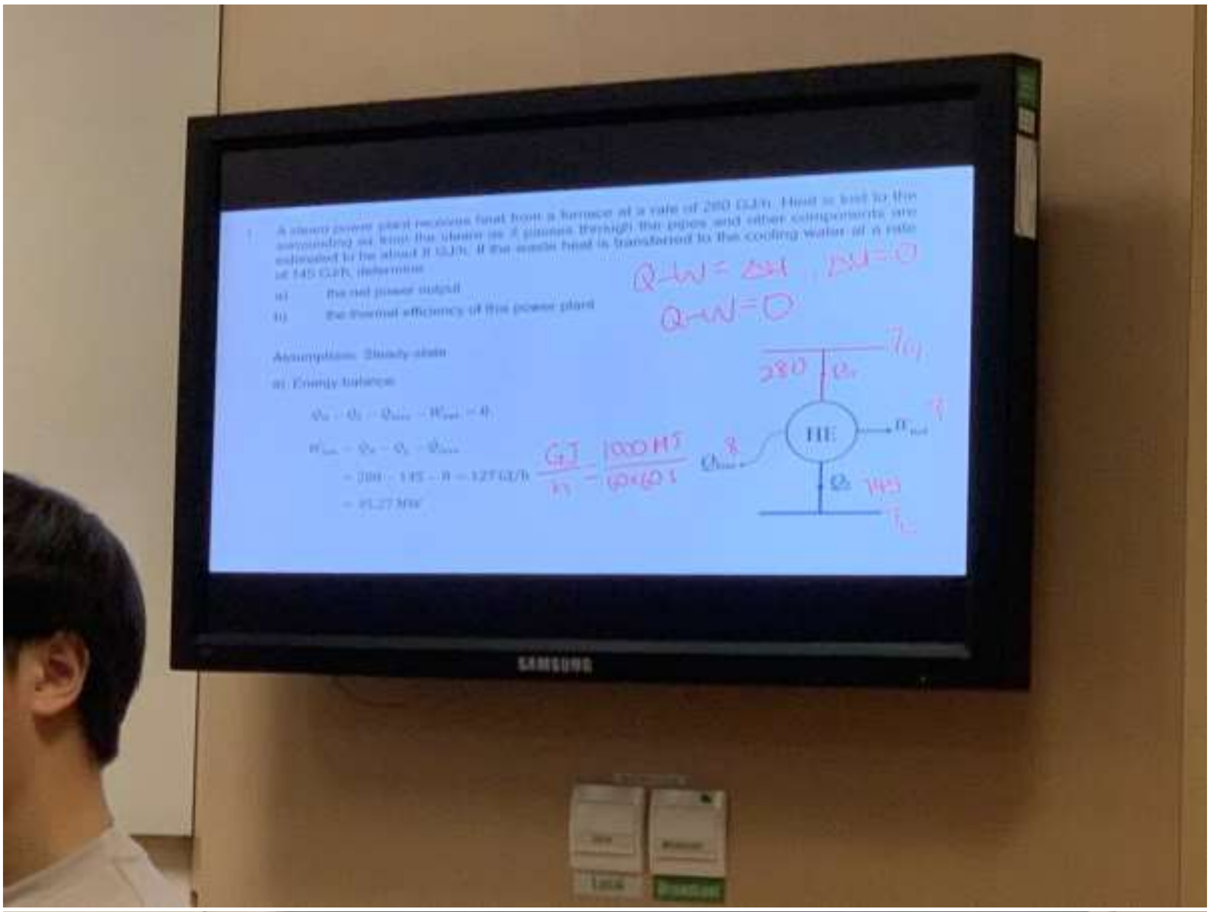
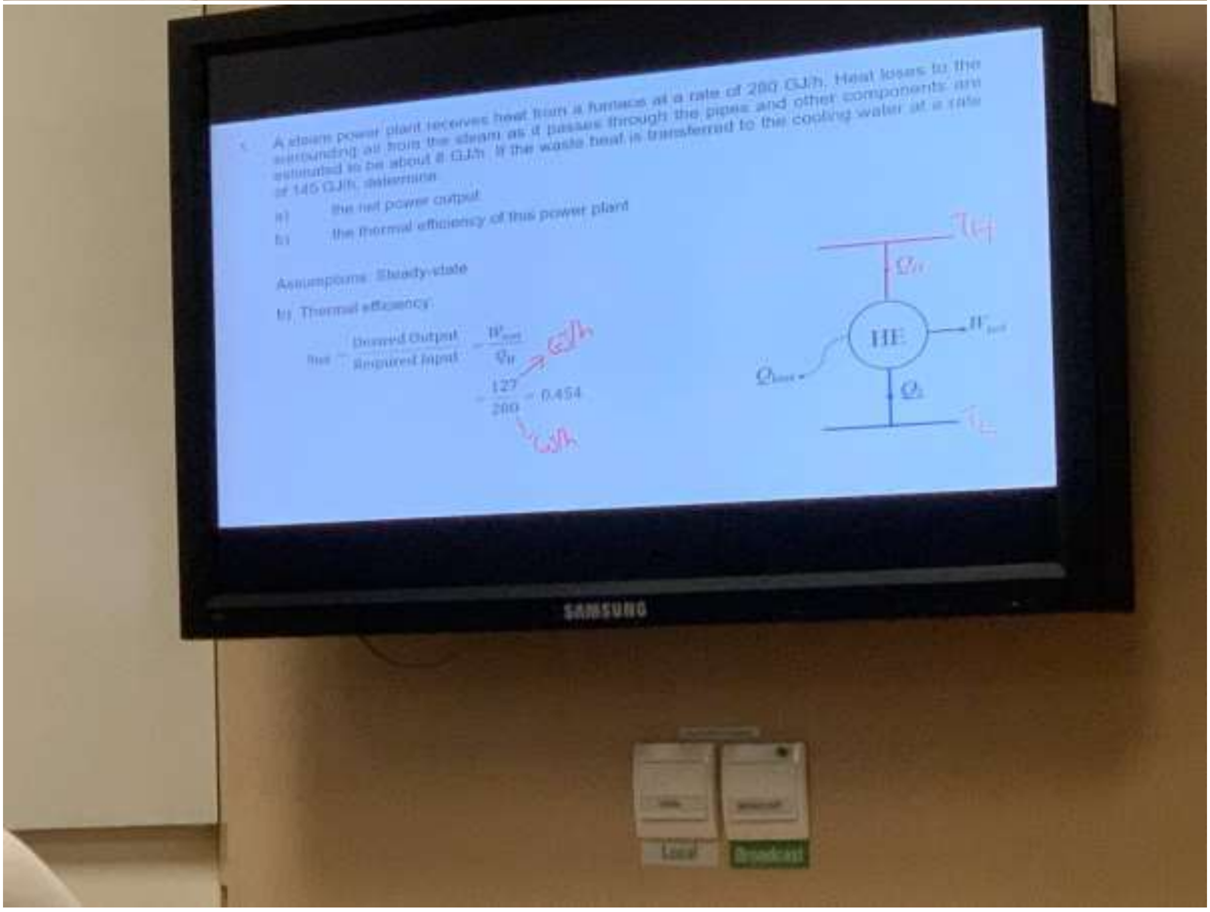
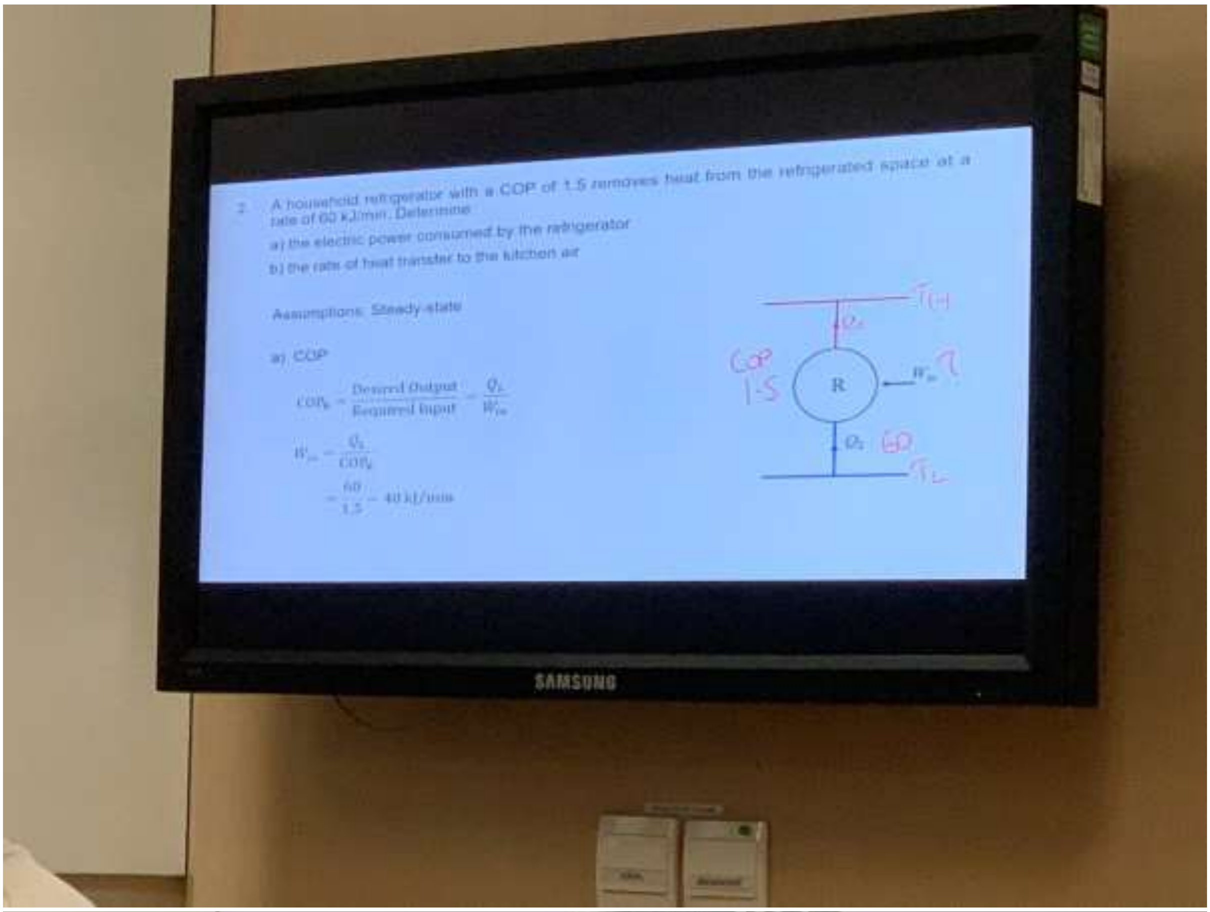
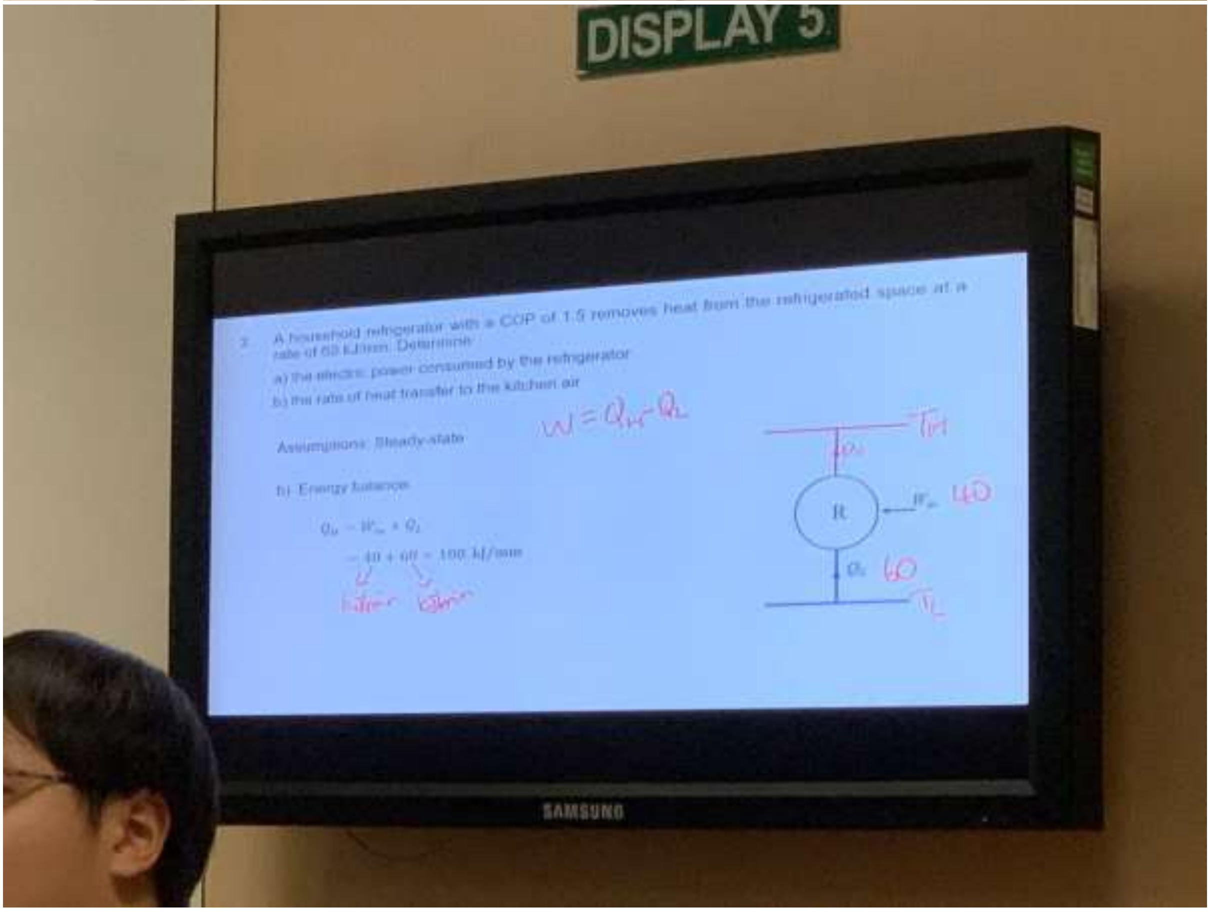
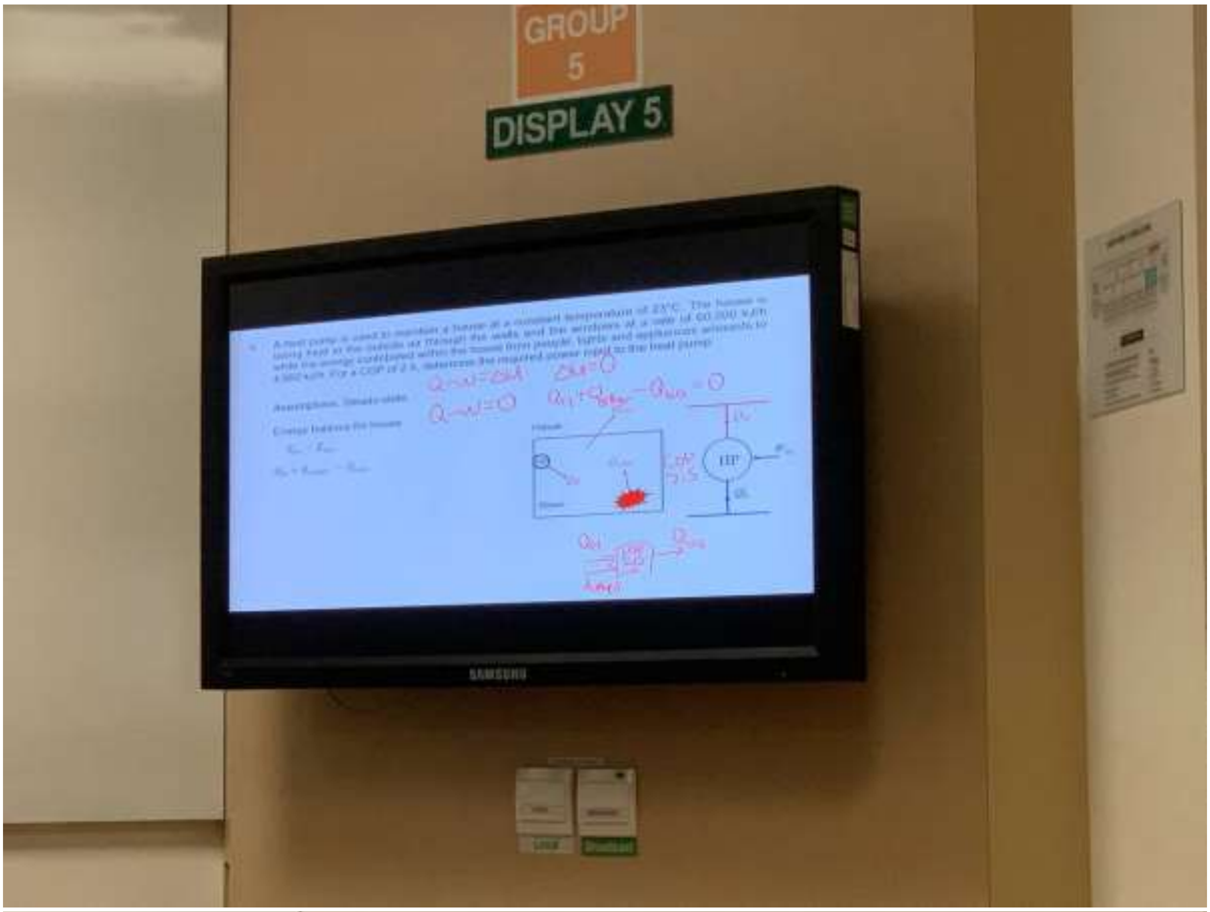
MA3010 Tutorial Answers


Q−W = ΔU , ΔU = 0
Q−W = 0
280
145
HE
GJ/h = 1000 MJ / 60×60 s
SAMSUNG


A steam power plant receives heat from a furnace at a rate of 280 GJ/h. Heat losses to the surrounding air from the steam as it passes through the pipes and other components are estimated to be about 8 GJ/h. If the waste heat is transferred to the cooling water at a rate of 145 GJ/h, determine
a) the net power output
b) the thermal efficiency of this power plant
Assumptions: Steady-state
b) Thermal efficiency
Desired Output / Required Input
127/280 = 0.454
GJ/h
HE
SAMSUNG


2. A household refrigerator with a COP of 1.5 removes heat from the refrigerated space at a rate of 60 kJ/min. Determine
a) the electric power consumed by the refrigerator
b) the rate of heat transfer to the kitchen air
Assumptions: Steady-state
a) COP
$COP_R = \frac{\text{Desired Output}}{\text{Required Input}} = \frac{Q_L}{W_{in}}$
$W_{in} = \frac{Q_L}{COP_R}$
$= \frac{60}{1.5} = 40\ kJ/min$
COP 1.5
R
T_H
T_L
W_{in} ?
Q_L 60
SAMSUNG


DISPLAY 5
2. A household refrigerator with a COP of 1.5 removes heat from the refrigerated space at a rate of 60 kJ/min. Determine
a) the electric power consumed by the refrigerator
b) the rate of heat transfer to the kitchen air
Assumptions: Steady-state
$W = Q_H - Q_L$
b) Energy balance
$Q_H = W_{in} + Q_L$
$= 40 + 60 = 100\ kJ/min$
R
T_H
T_L
W_{in} 40
Q_L 60
SAMSUNG


GROUP
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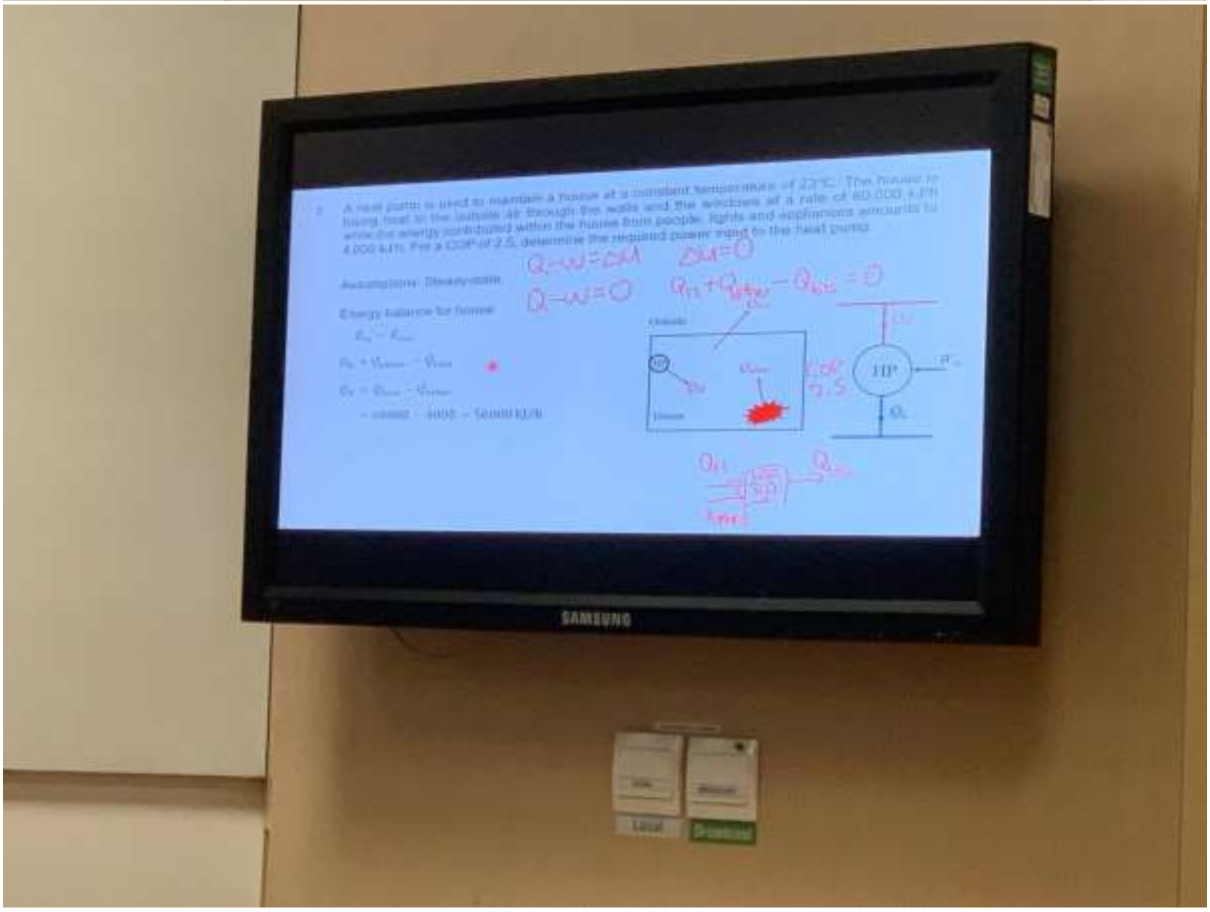
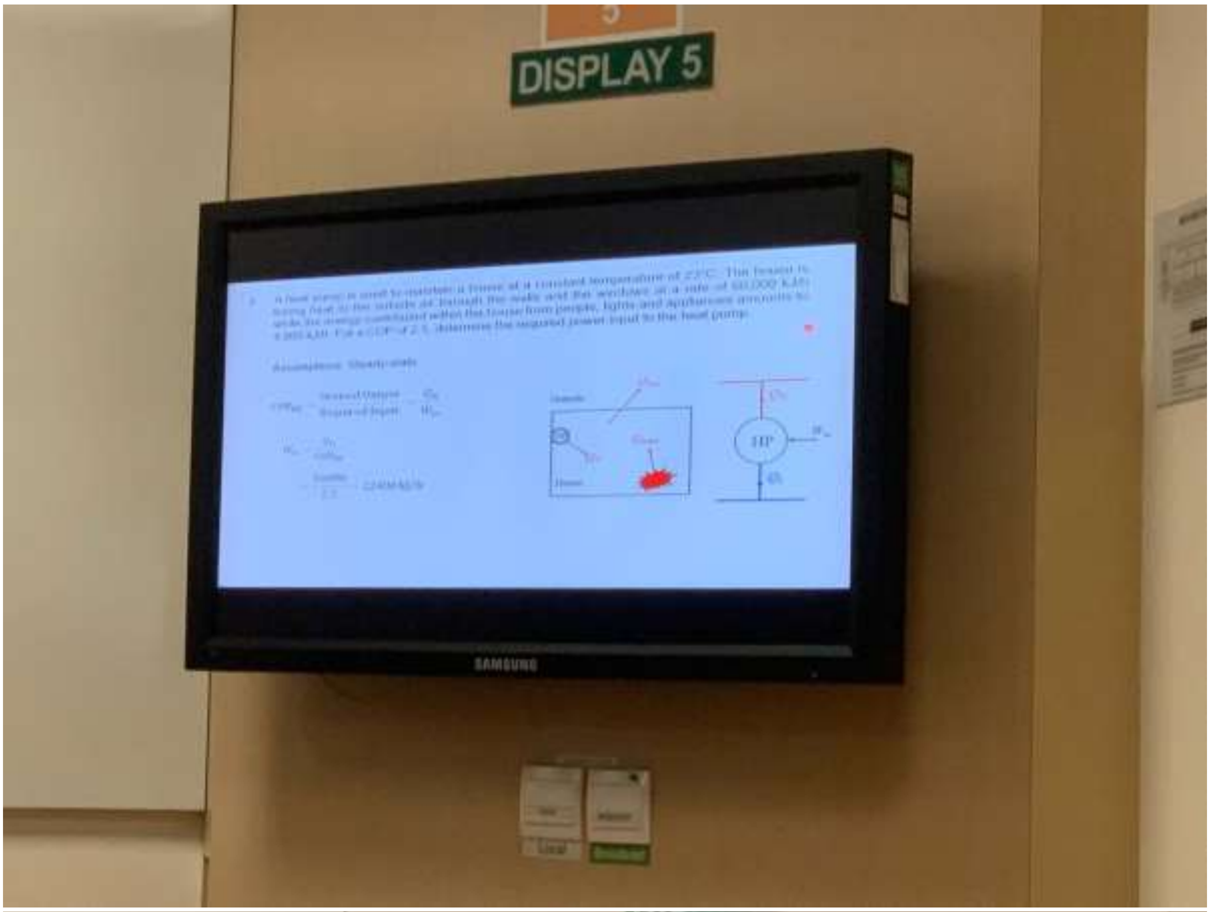
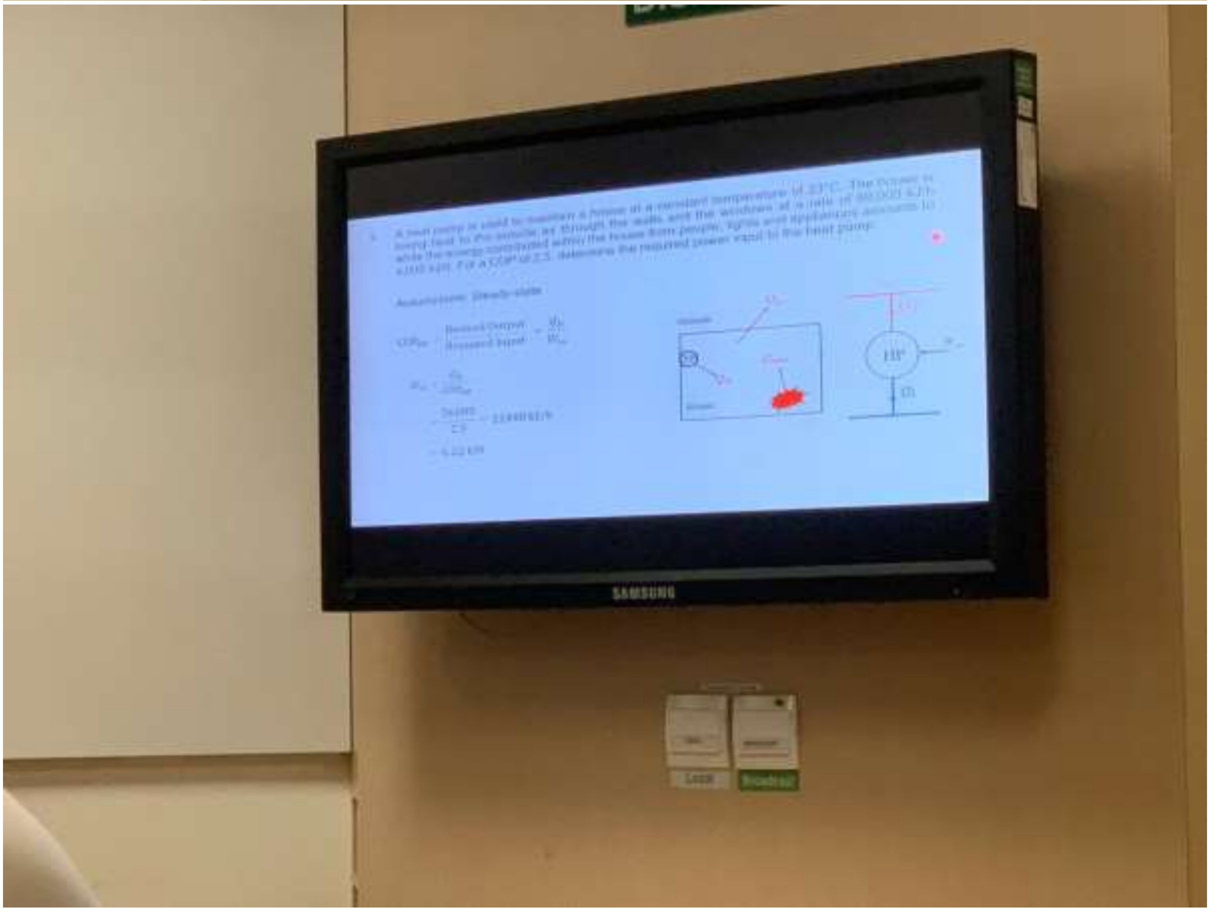
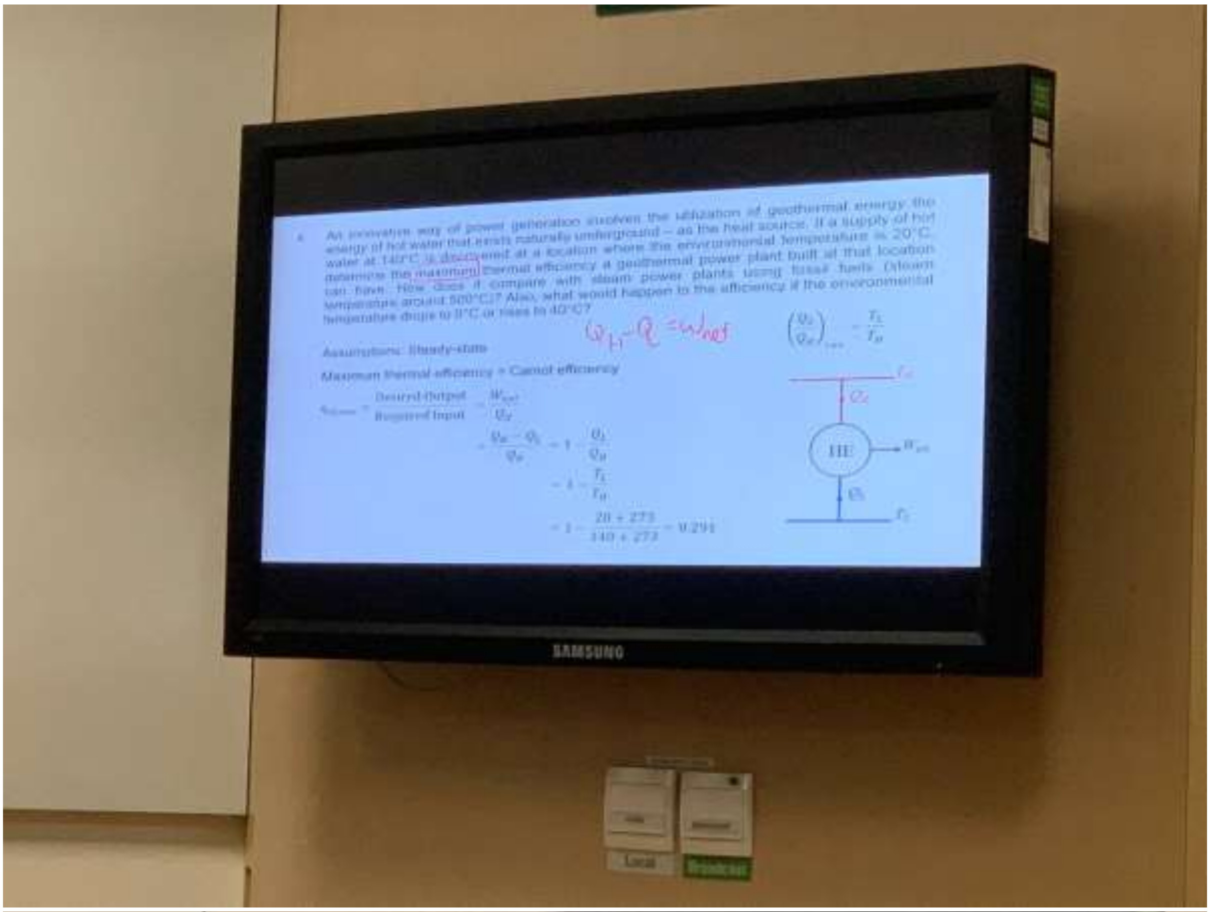
DISPLAY 5
SAMSUNG

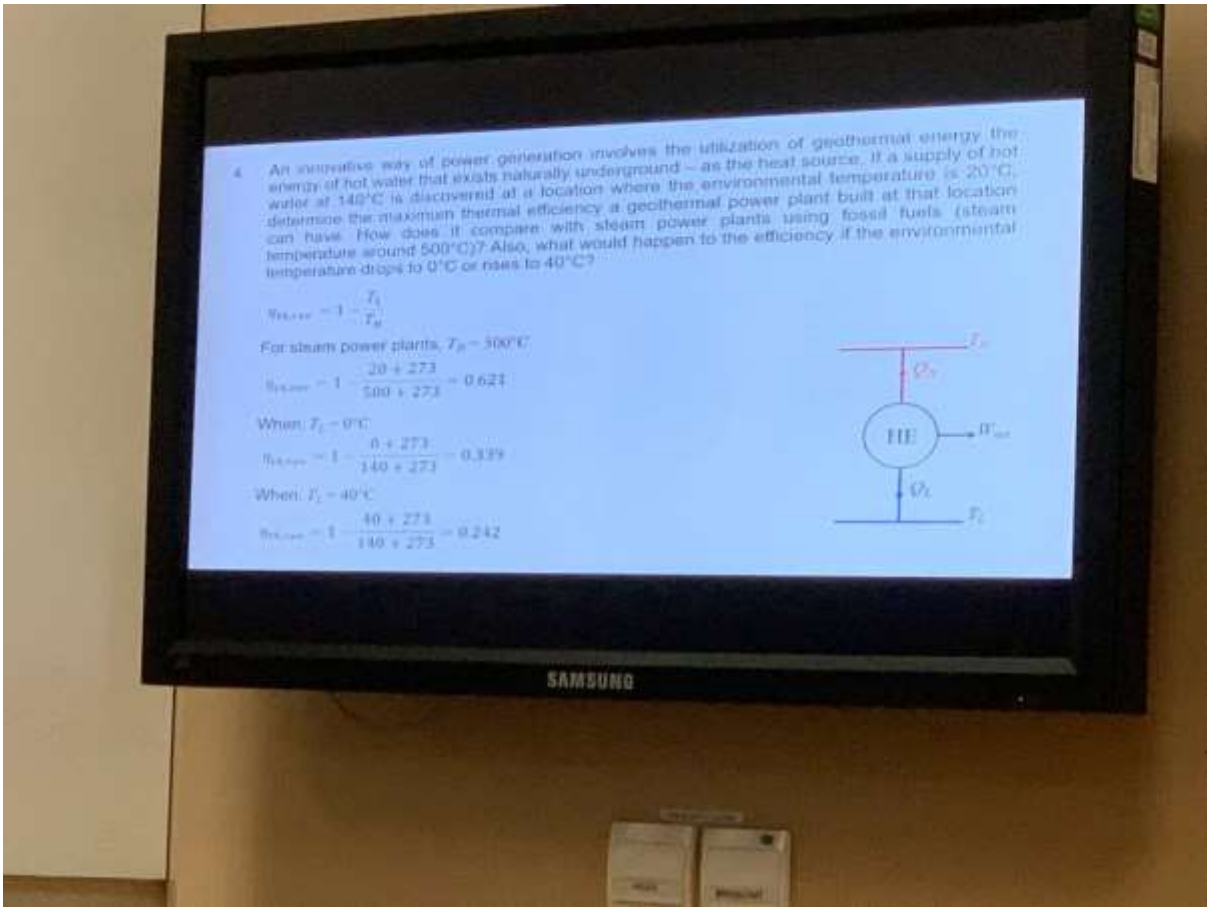

Energy balance for house
SAMSUNG


DISPLAY 5
SAMSUNG
HP

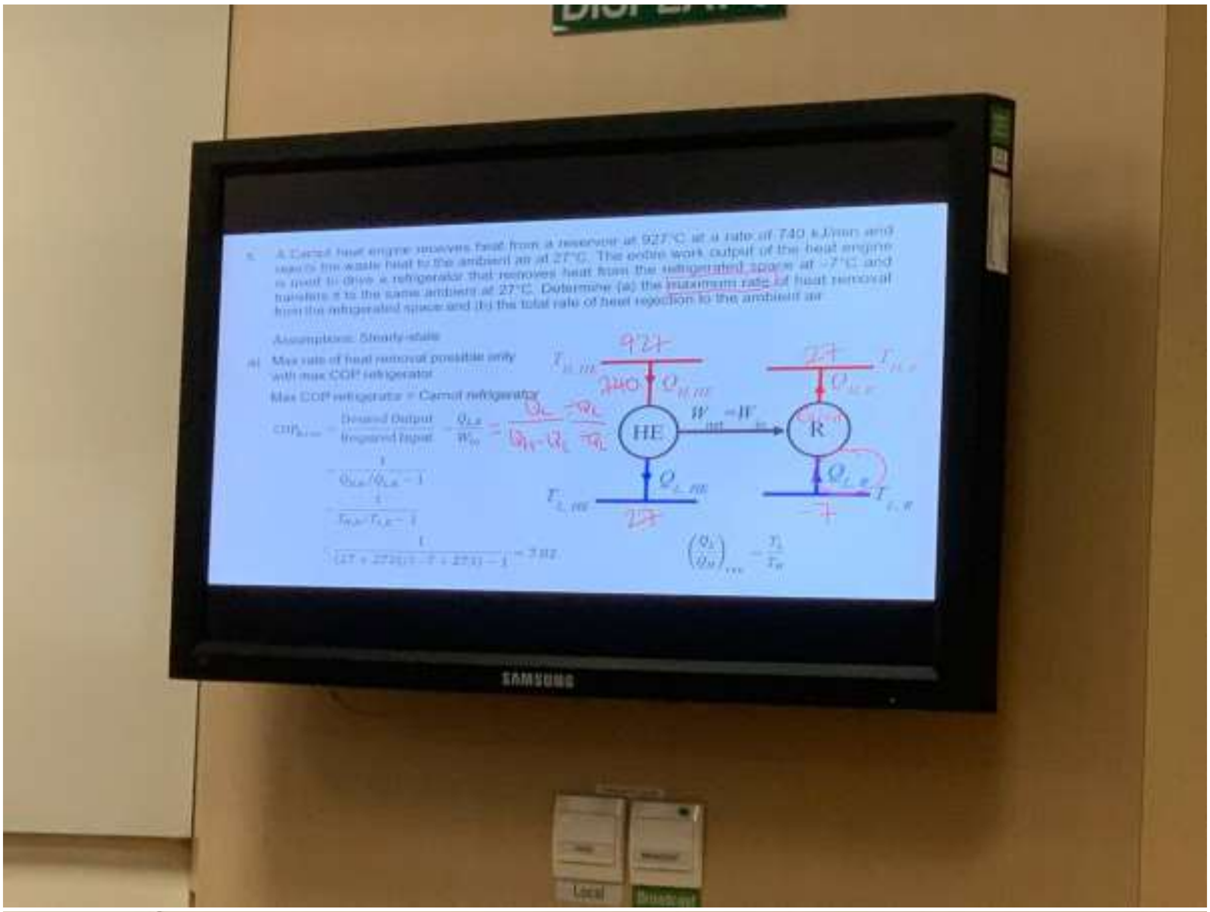

SAMSUNG
HP

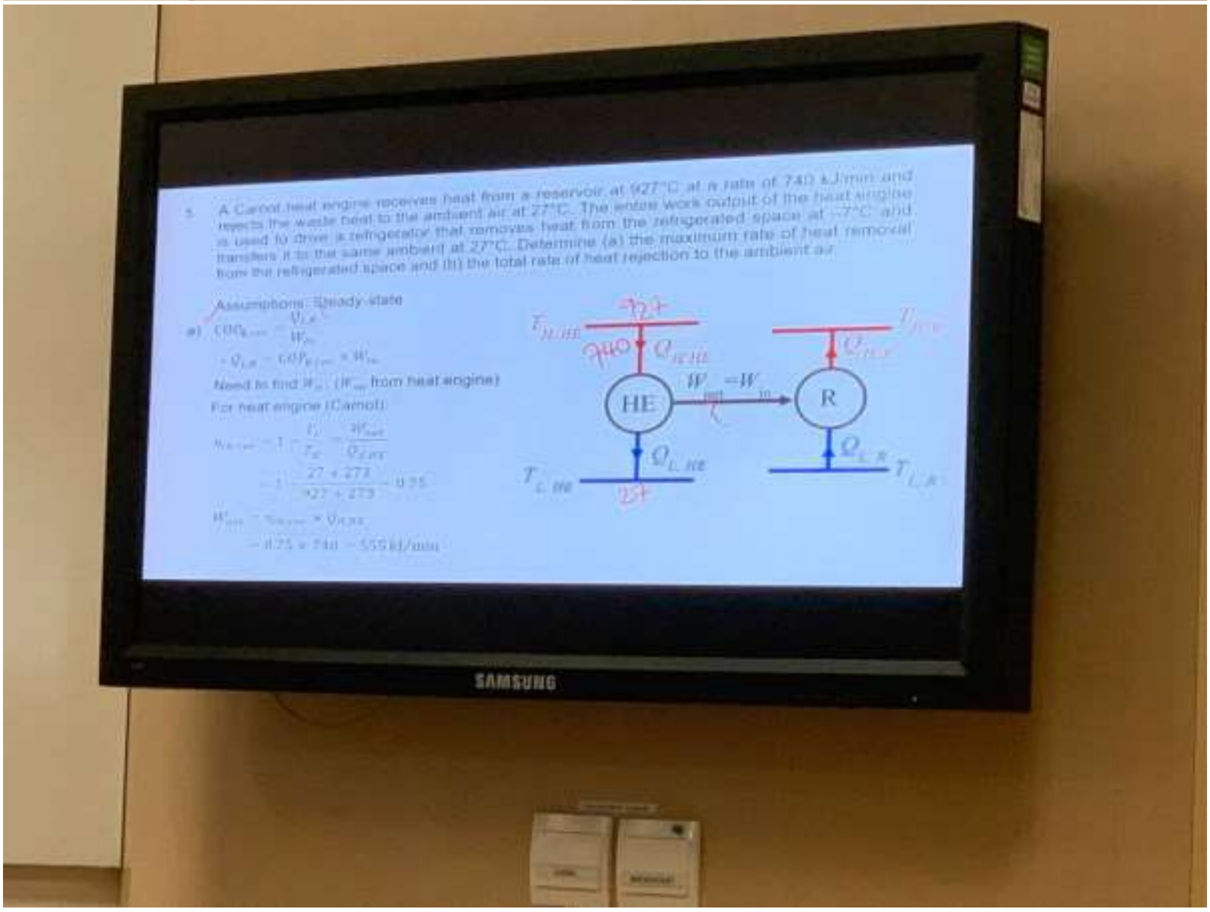


Assumptions: Steady-state
Maximum thermal efficiency = Carnot efficiency
Desired Output
Required Input
HE
20 + 273
140 + 273
0.291
SAMSUNG



An innovative way of power generation involves the utilization of geothermal energy the energy of hot water that exists naturally underground – as the heat source. If a supply of hot water at 140°C is discovered at a location where the environmental temperature is 20°C, determine the maximum thermal efficiency a geothermal power plant built at that location can have. How does it compare with steam power plants using fossil fuels (steam temperature around 500°C)? Also, what would happen to the efficiency if the environmental temperature drops to 0°C or rises to 40°C?
For steam power plants, T_H = 500°C
20 + 273
500 + 273
0.621
When: T_L = 0°C
0 + 273
140 + 273
0.339
When: T_L = 40°C
40 + 273
140 + 273
0.242
HE
SAMSUNG


A Carnot heat engine receives heat from a reservoir at 927°C at a rate of 740 kJ/min and rejects the waste heat to the ambient air at 27°C. The entire work output of the heat engine is used to drive a refrigerator that removes heat from the refrigerated space at −7°C and transfers it to the same ambient at 27°C. Determine (a) the maximum rate of heat removal from the refrigerated space and (b) the total rate of heat rejection to the ambient air
Assumptions: Steady-state
a) Max rate of heat removal possible only with max COP refrigerator
Max COP refrigerator = Carnot refrigerator
Desired Output
Required Input
HE
R
927
740
27
−7
SAMSUNG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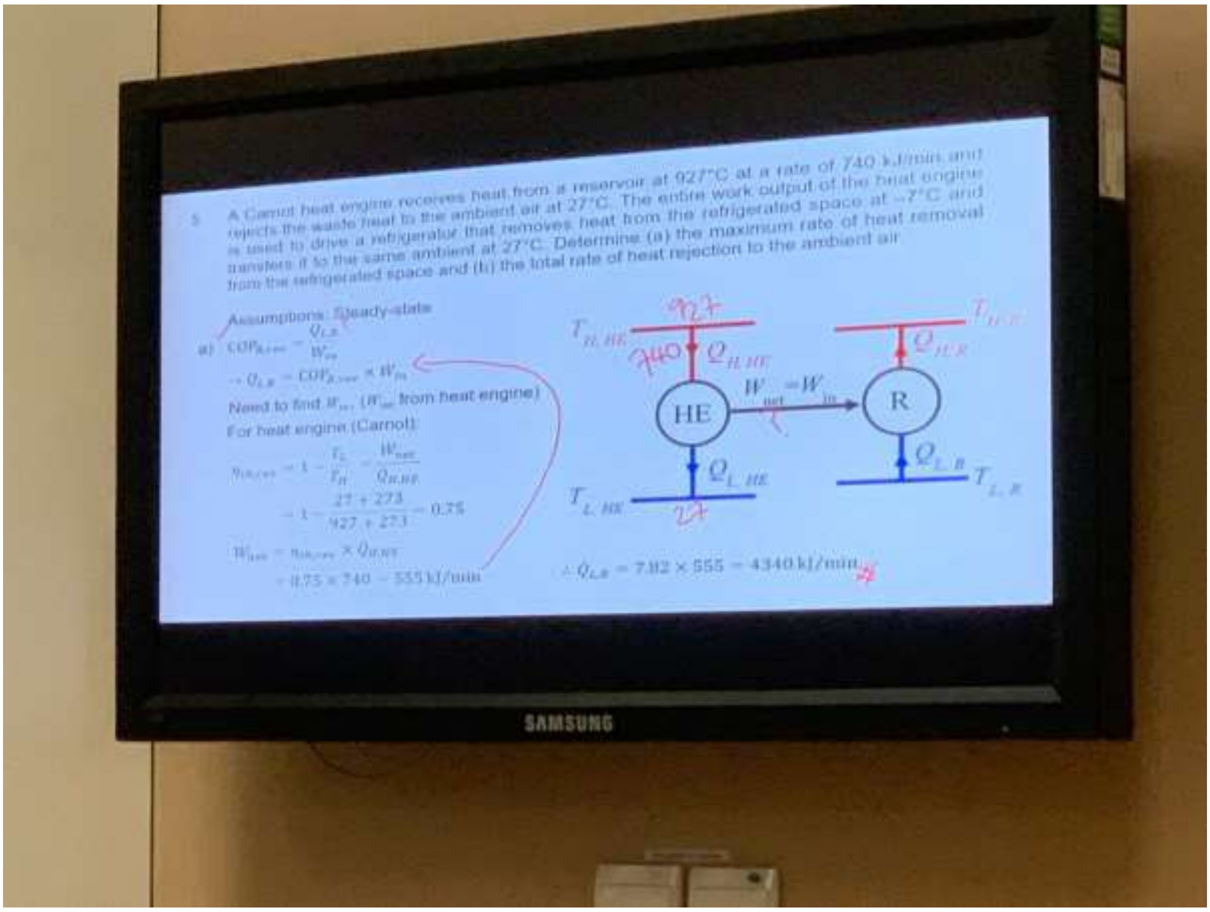
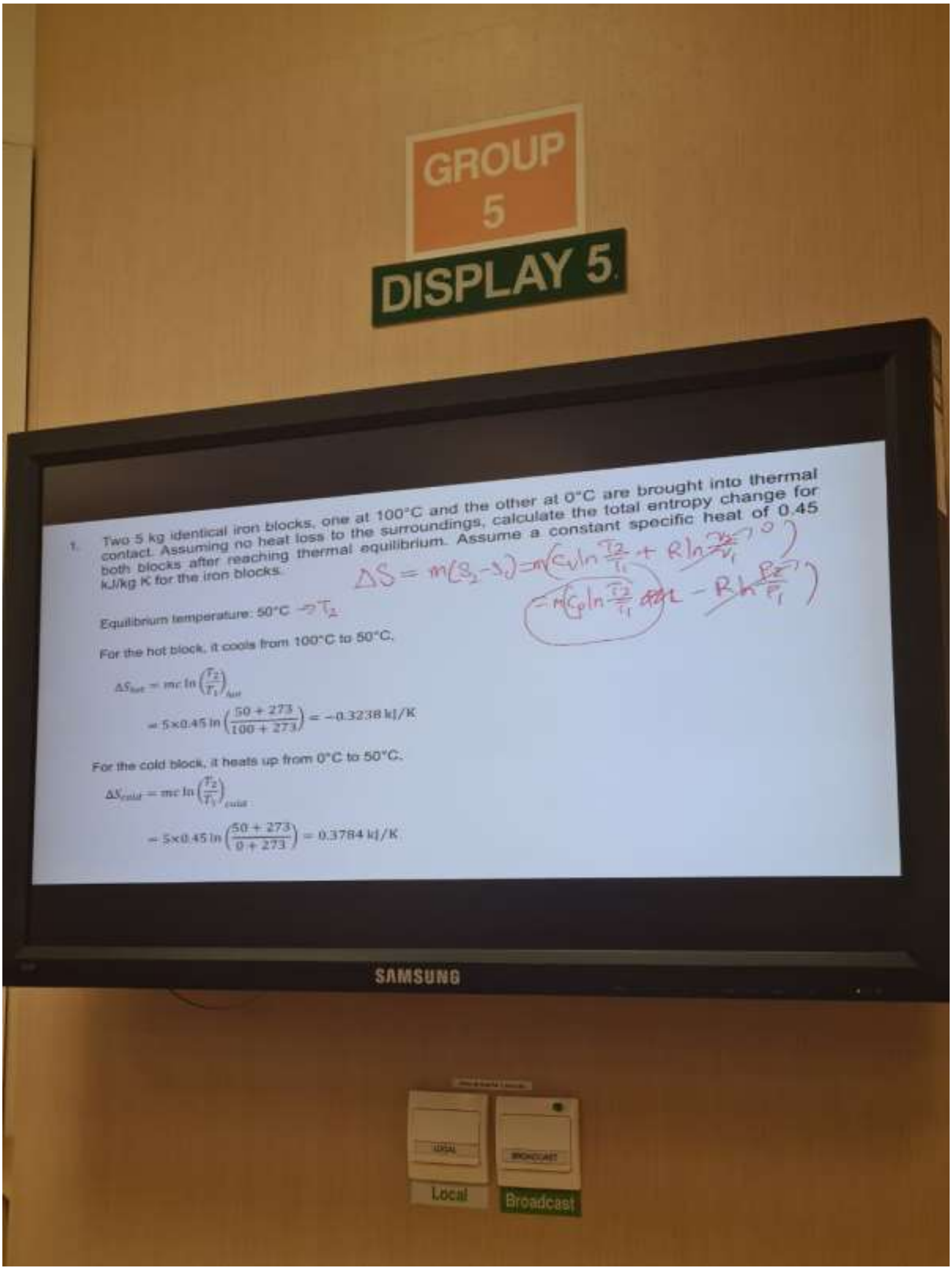
Assumptions: Steady-state
Need to find
from heat engine
For heat engine (Carnot)
27 + 273
927 + 273
HE
R
927
740
27
SAMSUNG



5 A Carnot heat engine receives heat from a reservoir at 927°C at a rate of 740 kJ/min and rejects the waste heat to the ambient air at 27°C. The entire work output of the heat engine is used to drive a refrigerator that removes heat from the refrigerated space at −7°C and transfers it to the same ambient at 27°C. Determine (a) the maximum rate of heat removal from the refrigerated space and (b) the total rate of heat rejection to the ambient air.
Assumptions: Steady-state
Need to find W_{in} (W_{net} from heat engine)
For heat engine (Carnot):
$= 1 - \frac{27 + 273}{927 + 273} = 0.75$
$= 0.75 \times 740 = 555$ kJ/min
927
740
$T_{H,HE}$
$Q_{H,HE}$
HE
$W_{net} = W_{in}$
R
$Q_{H,R}$
$Q_{L,HE}$
$Q_{L,R}$
$T_{L,HE}$
$T_{L,R}$
27
$\therefore \dot{Q}_{L,R} = 7.82 \times 555 = 4340$ kJ/min
SAMSUNG


GROUP
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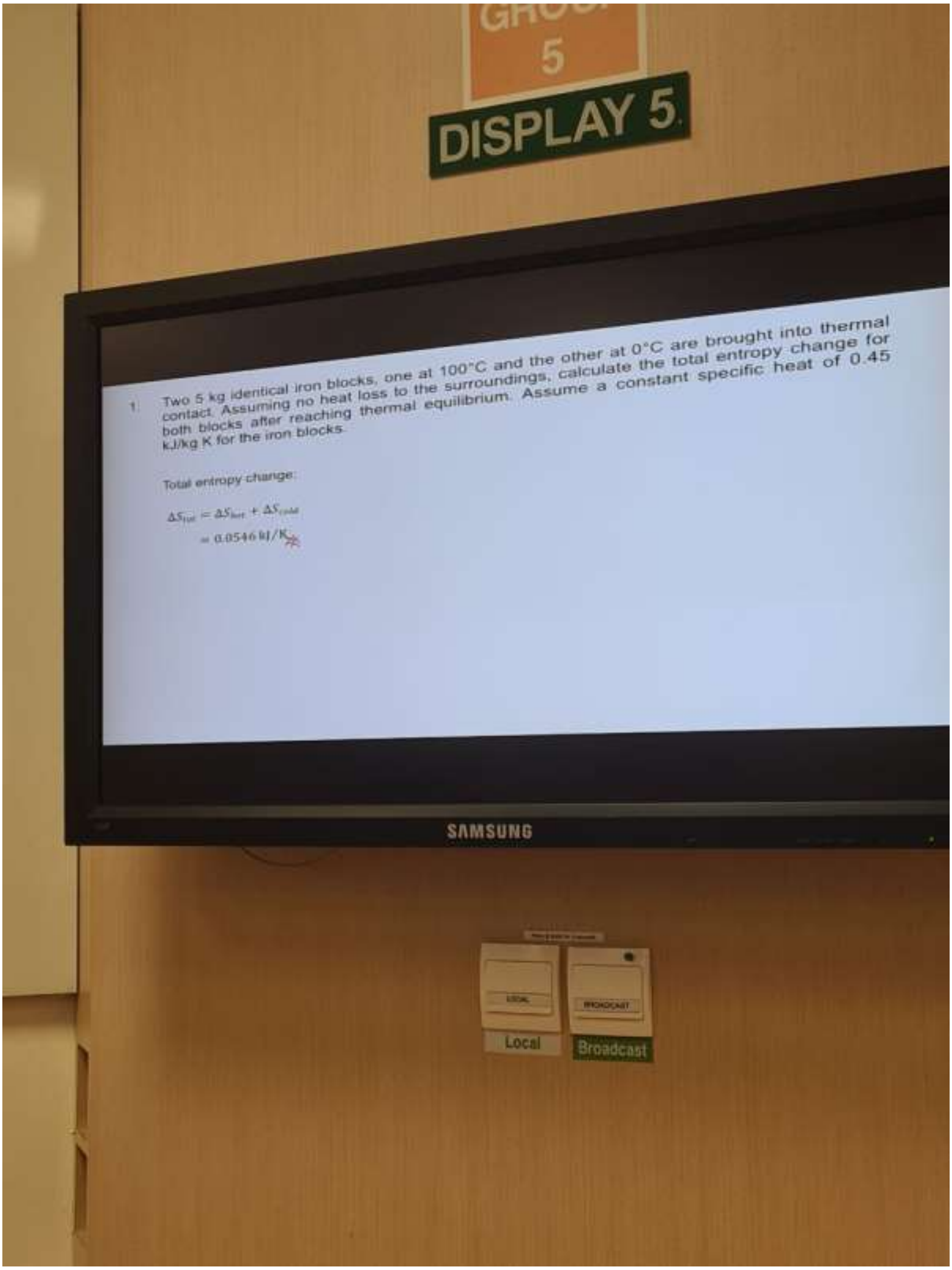
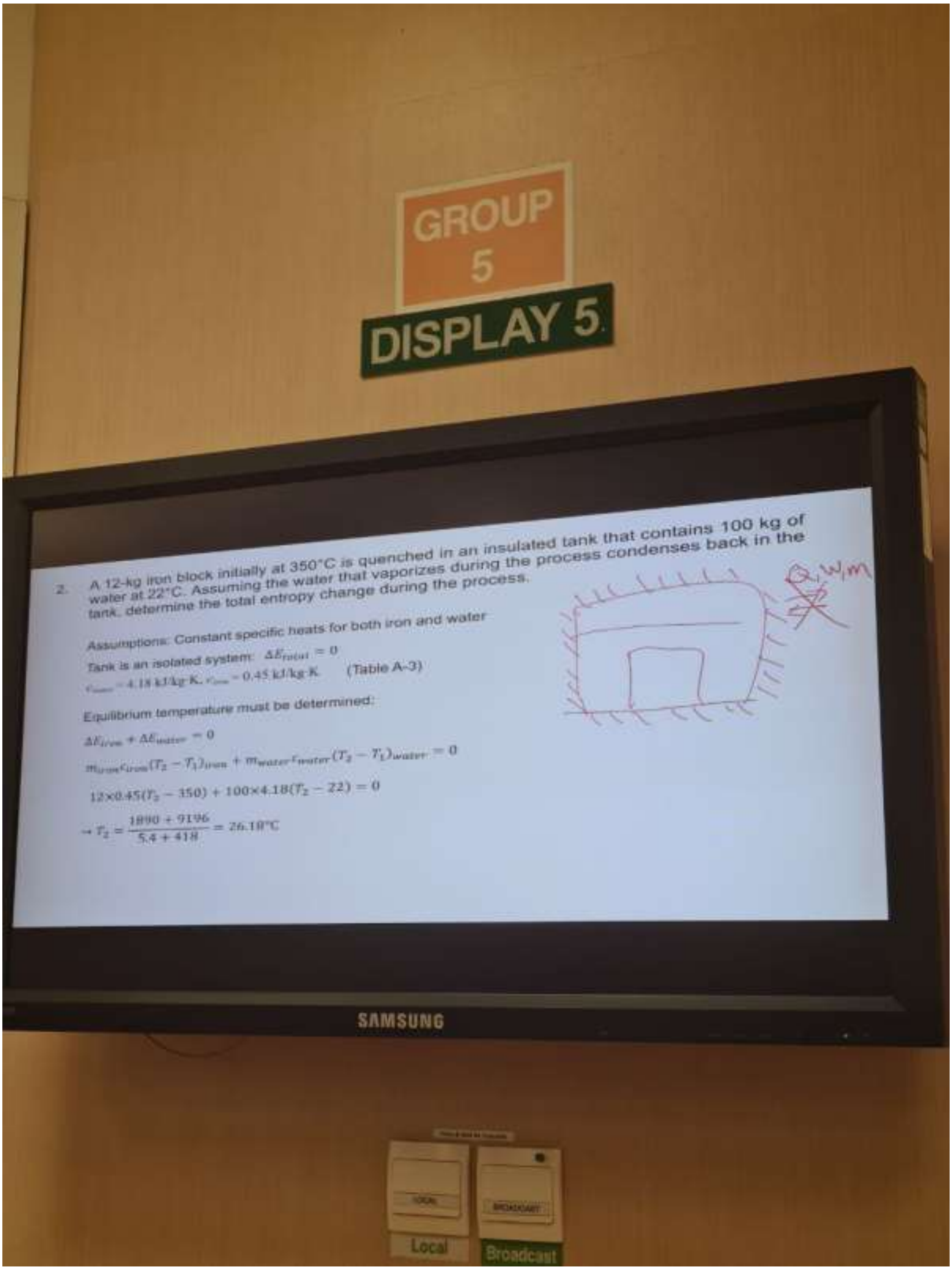
DISPLAY 5
1. Two 5 kg identical iron blocks, one at 100°C and the other at 0°C are brought into thermal contact. Assuming no heat loss to the surroundings, calculate the total entropy change for both blocks after reaching thermal equilibrium. Assume a constant specific heat of 0.45 kJ/kg K for the iron blocks.
$\Delta S = m(S_2 - S_1) = m\left(C_v \ln \frac{T_2}{T_1} + R \ln \frac{v_2}{v_1}\right)$
$= m\left(C_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}\right)$
Equilibrium temperature: 50°C → T_2
For the hot block, it cools from 100°C to 50°C.
$\Delta S_{hot} = mc \ln\left(\frac{T_2}{T_1}\right)_{hot}$
$= 5 \times 0.45 \ln\left(\frac{50+273}{100+273}\right) = -0.3238\ kJ/K$
For the cold block, it heats up from 0°C to 50°C.
$\Delta S_{cold} = mc \ln\left(\frac{T_2}{T_1}\right)_{cold}$
$= 5 \times 0.45 \ln\left(\frac{50+273}{0+273}\right) = 0.3784\ kJ/K$
SAMSUNG
Local
Broadcast


GROUP
5
DISPLAY 5
1. Two 5 kg identical iron blocks, one at 100°C and the other at 0°C are brought into thermal contact. Assuming no heat loss to the surroundings, calculate the total entropy change for both blocks after reaching thermal equilibrium. Assume a constant specific heat of 0.45 kJ/kg K for the iron blocks.
Total entropy change:
$\Delta S_{tot} = \Delta S_{hot} + \Delta S_{cold}$
$= 0.0546\ kJ/K$
SAMSUNG
Local
Broadcast


GROUP
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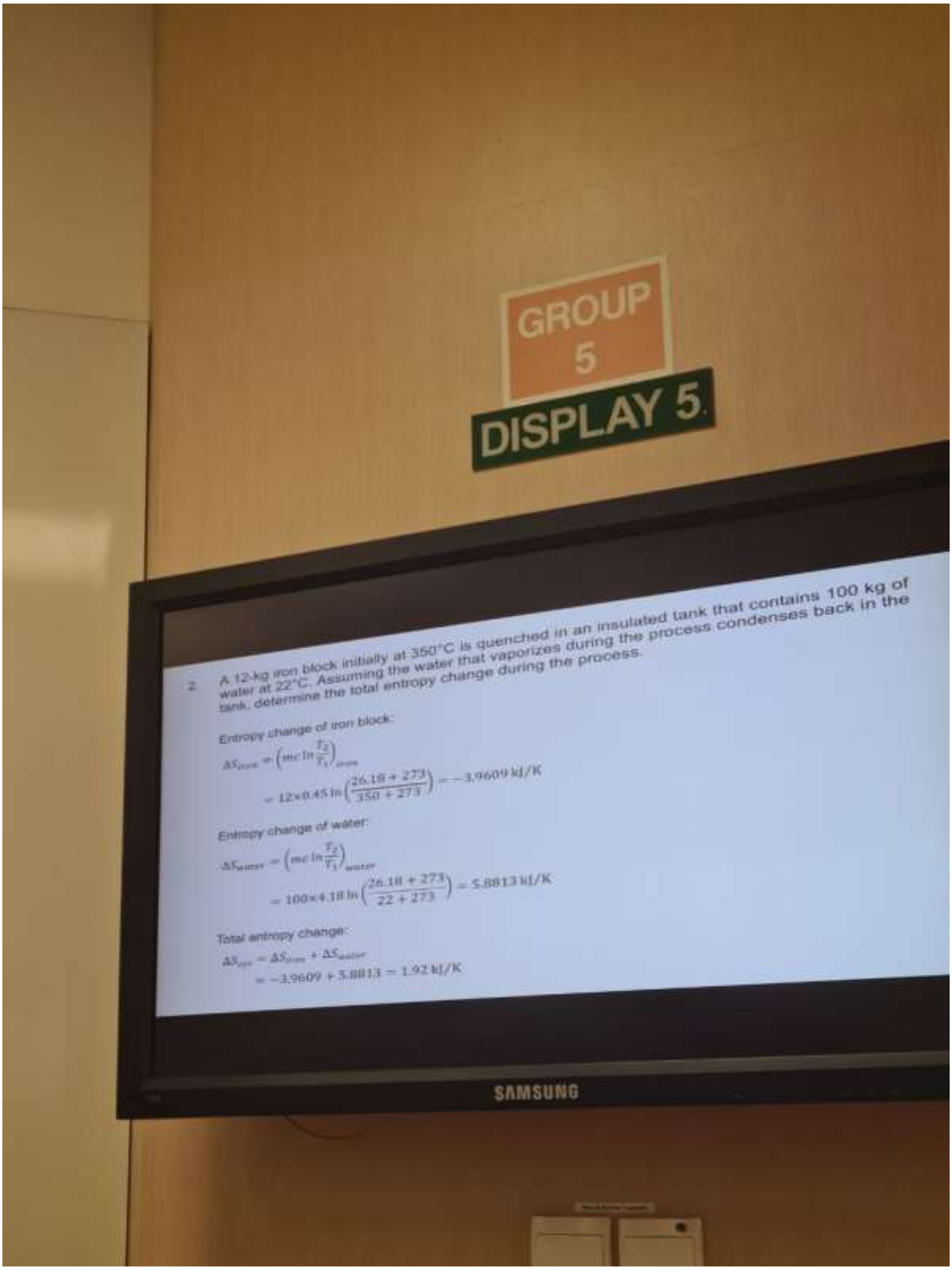
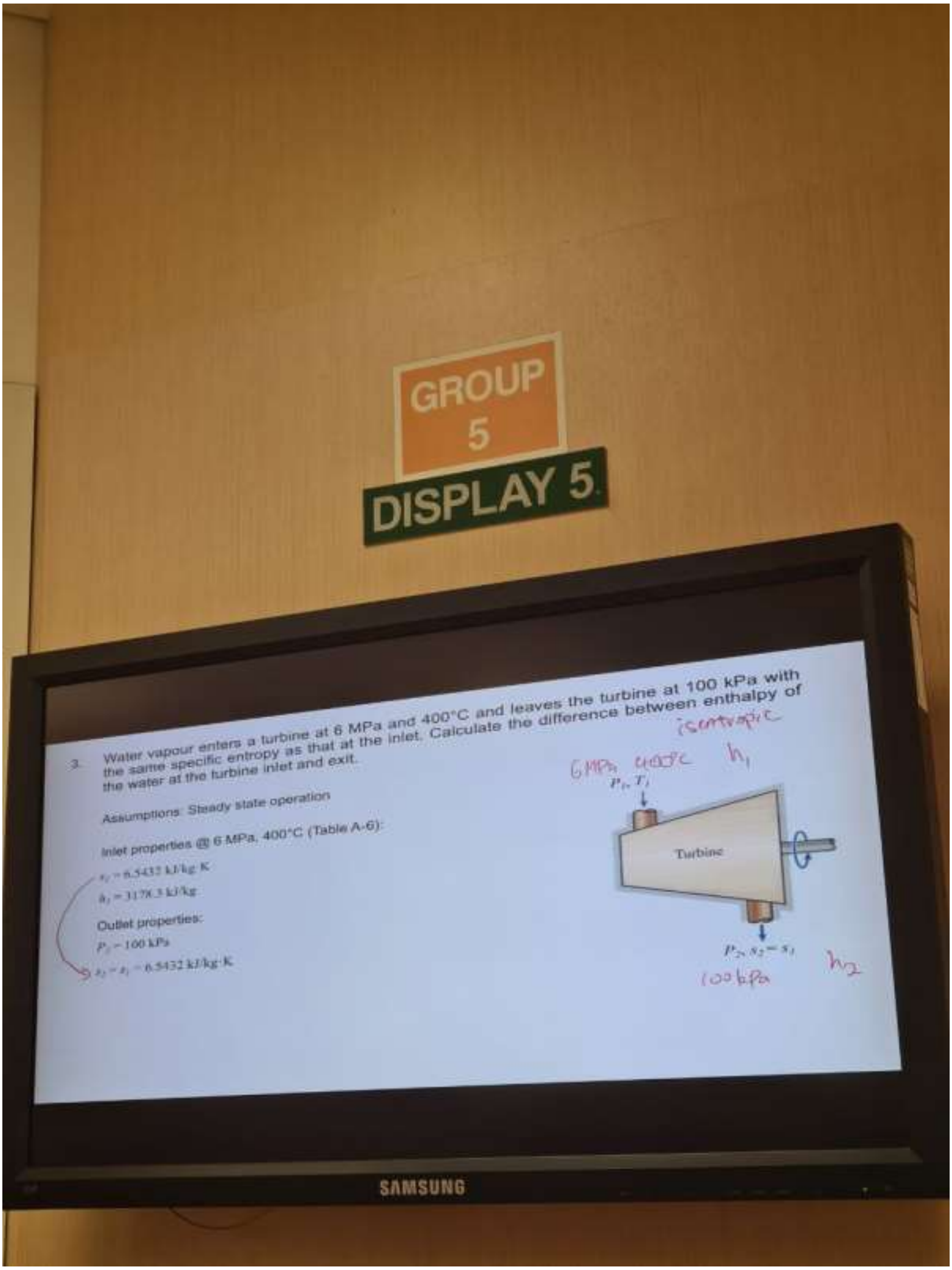
DISPLAY 5
2. A 12-kg iron block initially at 350°C is quenched in an insulated tank that contains 100 kg of water at 22°C. Assuming the water that vaporizes during the process condenses back in the tank, determine the total entropy change during the process.
Assumptions: Constant specific heats for both iron and water
Tank is an isolated system: $\Delta E_{total} = 0$
$c_{water} = 4.18$ kJ/kg·K, $c_{iron} = 0.45$ kJ/kg·K (Table A-3)
Equilibrium temperature must be determined:
$\Delta E_{iron} + \Delta E_{water} = 0$
$m_{iron}c_{iron}(T_2 - T_1)_{iron} + m_{water}c_{water}(T_2 - T_1)_{water} = 0$
$12\times0.45(T_2 - 350) + 100\times4.18(T_2 - 22) = 0$
$\rightarrow T_2 = \frac{1890 + 9196}{5.4 + 418} = 26.18°C$
Q, W, m
SAMSUNG
Local
Broadcast


GROUP
5
DISPLAY 5
2 A 12-kg iron block initially at 350°C is quenched in an insulated tank that contains 100 kg of water at 22°C. Assuming the water that vaporizes during the process condenses back in the tank, determine the total entropy change during the process.
Entropy change of iron block:
$\Delta S_{iron} = \left(mc \ln \frac{T_2}{T_1}\right)_{iron}$
$= 12 \times 0.45 \ln\left(\frac{26.18 + 273}{350 + 273}\right) = -3.9609 \text{ kJ/K}$
Entropy change of water:
$\Delta S_{water} = \left(mc \ln \frac{T_2}{T_1}\right)_{water}$
$= 100 \times 4.18 \ln\left(\frac{26.18 + 273}{22 + 273}\right) = 5.8813 \text{ kJ/K}$
Total entropy change:
$\Delta S_{gen} = \Delta S_{iron} + \Delta S_{water}$
$= -3.9609 + 5.8813 = 1.92 \text{ kJ/K}$
SAMSUNG


GROUP
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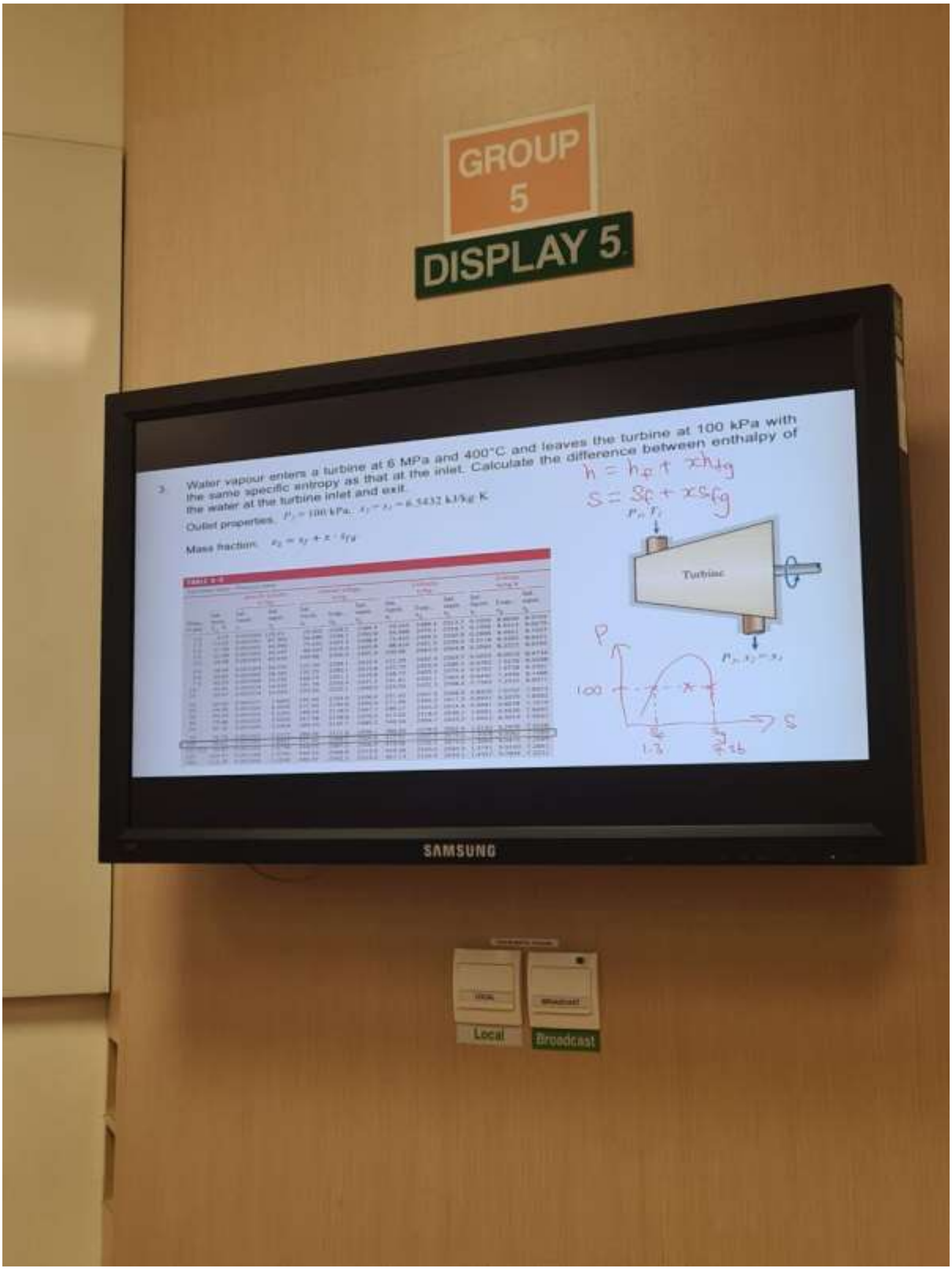
DISPLAY 5
3. Water vapour enters a turbine at 6 MPa and 400°C and leaves the turbine at 100 kPa with the same specific entropy as that at the inlet. Calculate the difference between enthalpy of the water at the turbine inlet and exit.
isentropic
Assumptions: Steady state operation
Inlet properties @ 6 MPa, 400°C (Table A-6):
$s_1 = 6.5432$ kJ/kg·K
$h_1 = 3178.3$ kJ/kg
Outlet properties:
$P_2 = 100$ kPa
$s_2 = s_1 = 6.5432$ kJ/kg·K
6 MPa 400°C h_1
P_1, T_1
Turbine
$P_2, s_2 = s_1$
100 kPa
h_2
SAMSUNG



GROUP
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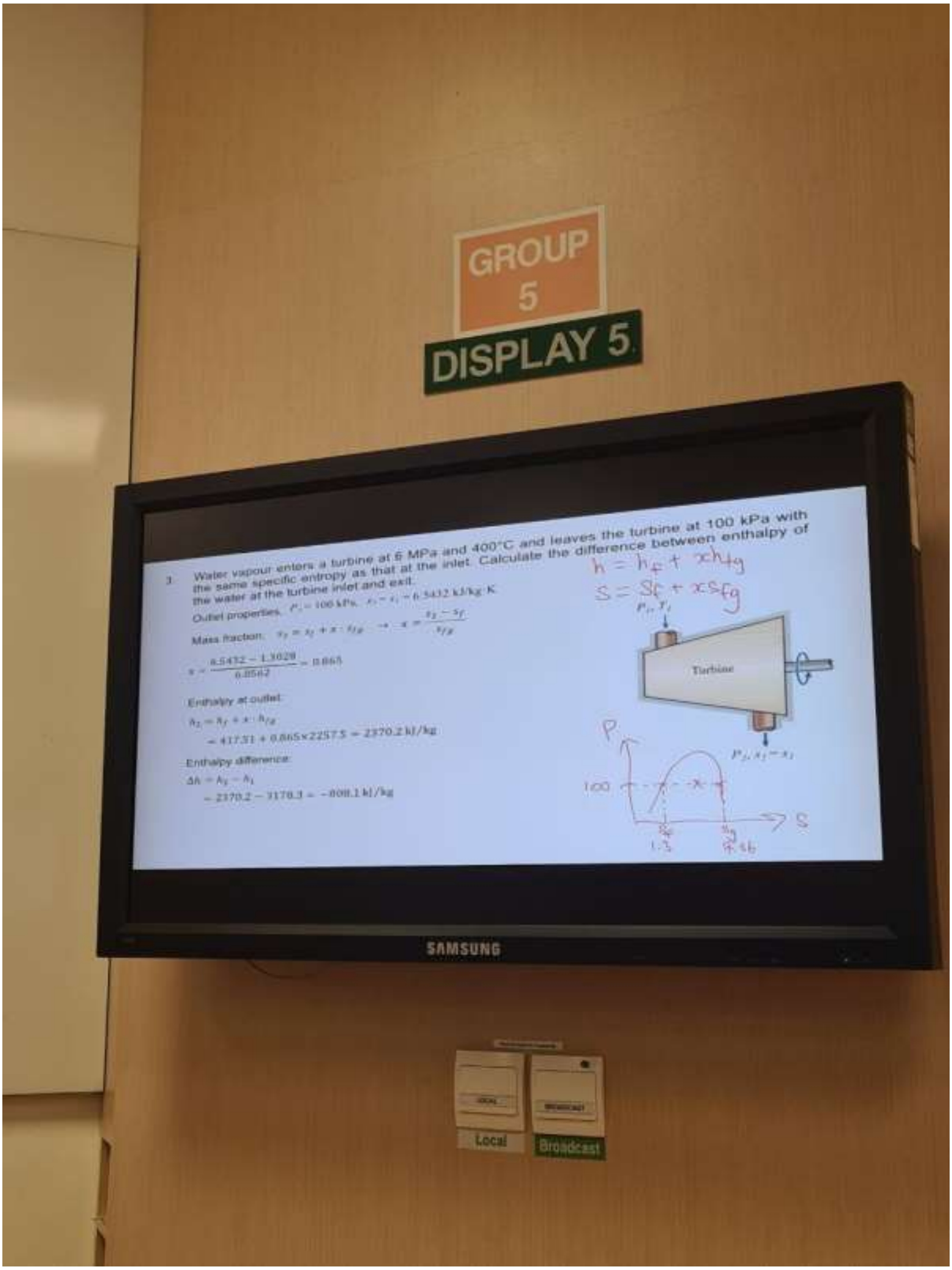
DISPLAY 5
3. Water vapour enters a turbine at 6 MPa and 400°C and leaves the turbine at 100 kPa with the same specific entropy as that at the inlet. Calculate the difference between enthalpy of the water at the turbine inlet and exit.
Outlet properties: P_2 = 100 kPa, $s_2 = s_1$ = 6.5432 kJ/kg K
Mass fraction: $s_2 = s_f + x \cdot s_{fg}$
$h = h_f + xh_{fg}$
$S = S_f + xS_{fg}$
Turbine
P
100
S
SAMSUNG
Local
Broadcast


GROUP
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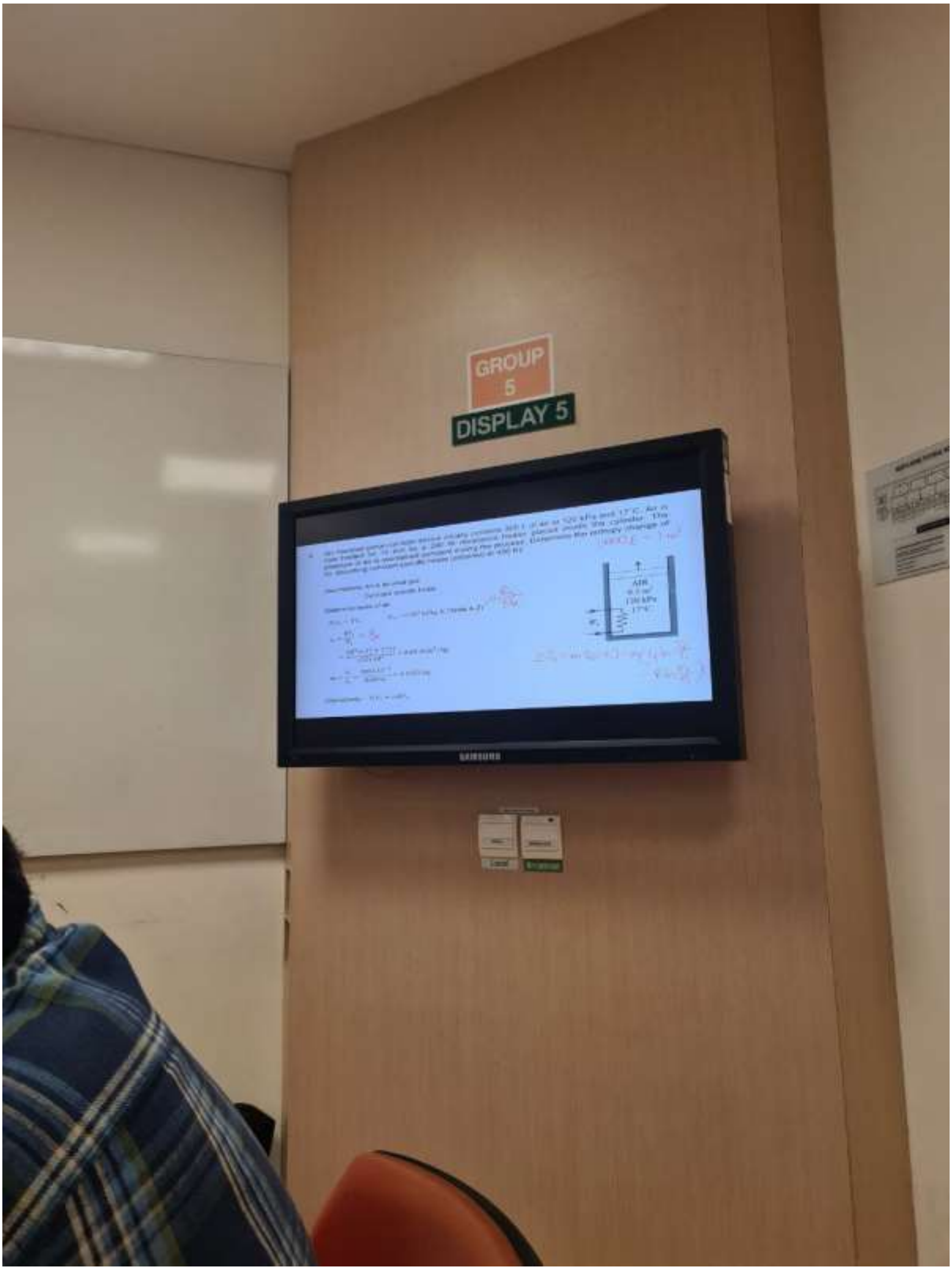
DISPLAY 5
3. Water vapour enters a turbine at 6 MPa and 400°C and leaves the turbine at 100 kPa with the same specific entropy as that at the inlet. Calculate the difference between enthalpy of the water at the turbine inlet and exit.
Mass fraction:
x = (6.5432 − 1.3028)/6.8562 = 0.865
Enthalpy at outlet:
= 417.51 + 0.865×2257.5 = 2370.2 kJ/kg
Enthalpy difference:
= 2370.2 − 3178.3 = −808.1 kJ/kg
h = hf + xhfg
S = Sf + xSfg
Turbine
P
100
S
SAMSUNG
Local
Broadcast


GROUP
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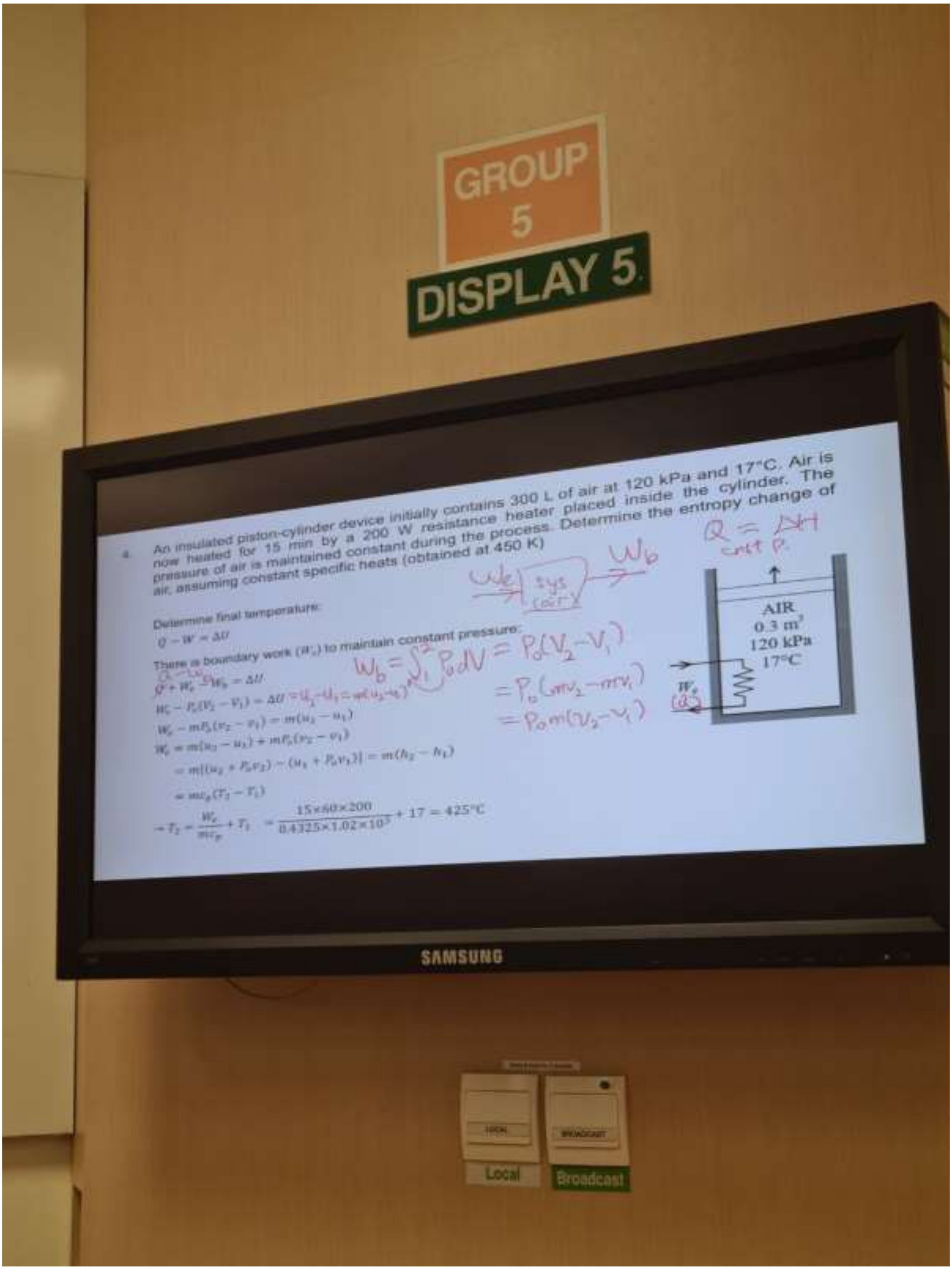
GROUP
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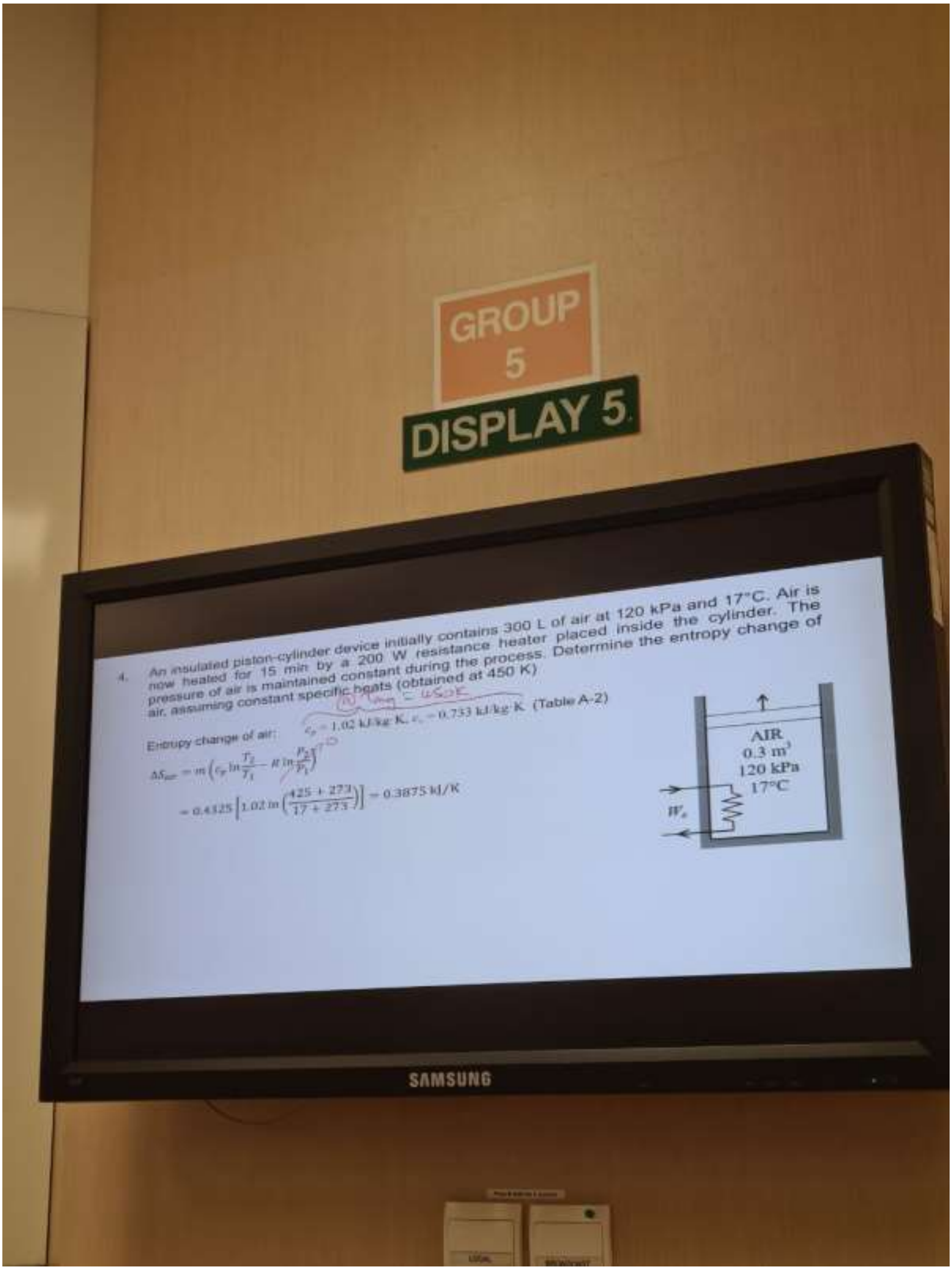
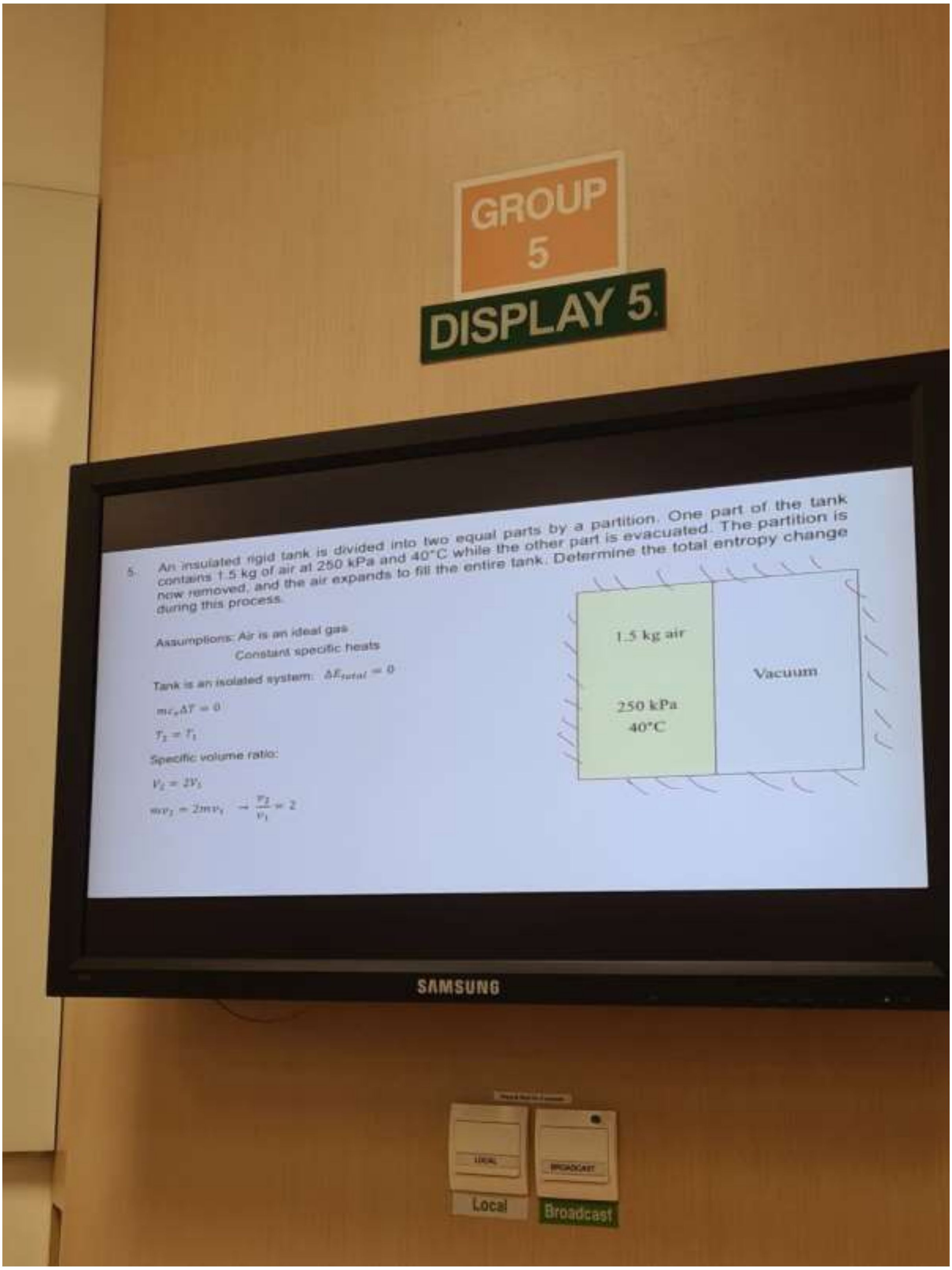
DISPLAY 5
An insulated piston-cylinder device initially contains 300 L of air at 120 kPa and 17°C. Air is now heated for 15 min by a 200 W resistance heater placed inside the cylinder. The pressure of air is maintained constant during the process. Determine the entropy change of air, assuming constant specific heats (obtained at 450 K)
Determine final temperature:
There is boundary work to maintain constant pressure:
15×60×200
+ 17 = 425°C
0.4325×1.02×10³
AIR
0.3 m³
120 kPa
17°C
SAMSUNG
Local
Broadcast



GROUP 5
DISPLAY 5
4. An insulated piston-cylinder device initially contains 300 L of air at 120 kPa and 17°C. Air is now heated for 15 min by a 200 W resistance heater placed inside the cylinder. The pressure of air is maintained constant during the process. Determine the entropy change of air, assuming constant specific heats (obtained at 450 K)
c_p = 1.02 kJ/kg·K, c_v = 0.733 kJ/kg·K (Table A-2)
Entropy change of air:
$\Delta S_{air} = m\left(c_p \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1}\right)$
$= 0.4325\left[1.02\ln\left(\frac{425+273}{17+273}\right)\right] = 0.3875$ kJ/K
AIR
0.3 m³
120 kPa
17°C
W_e
SAMSUNG


GROUP
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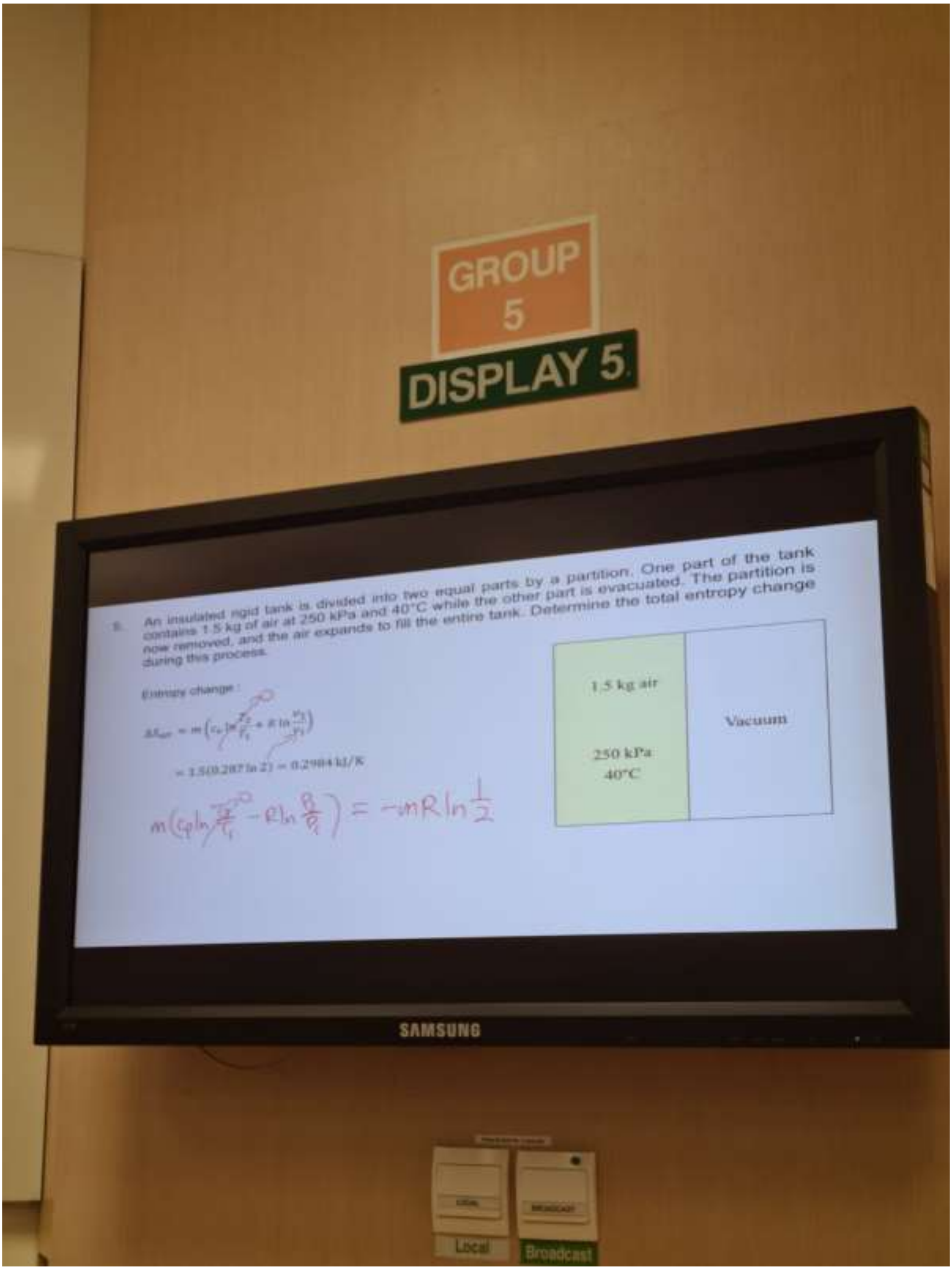
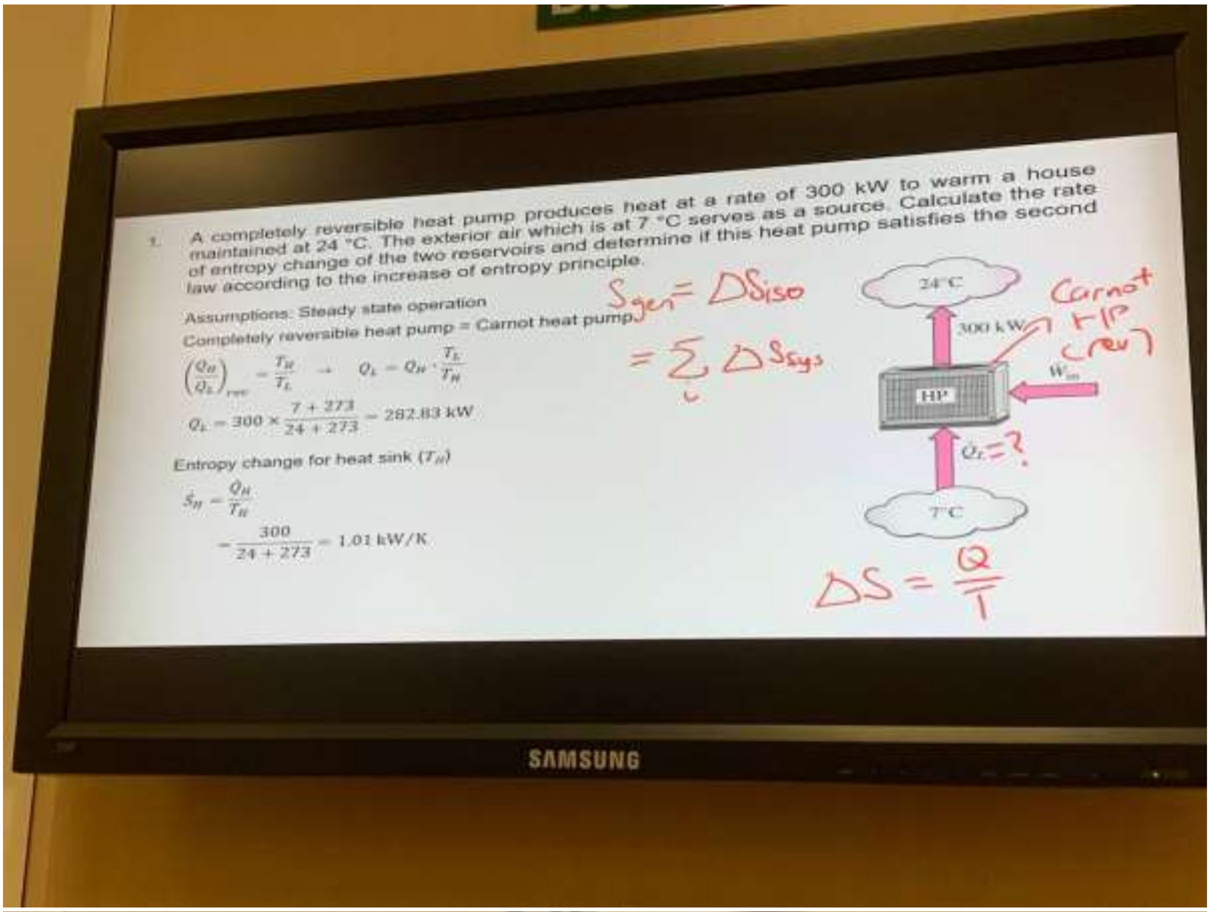
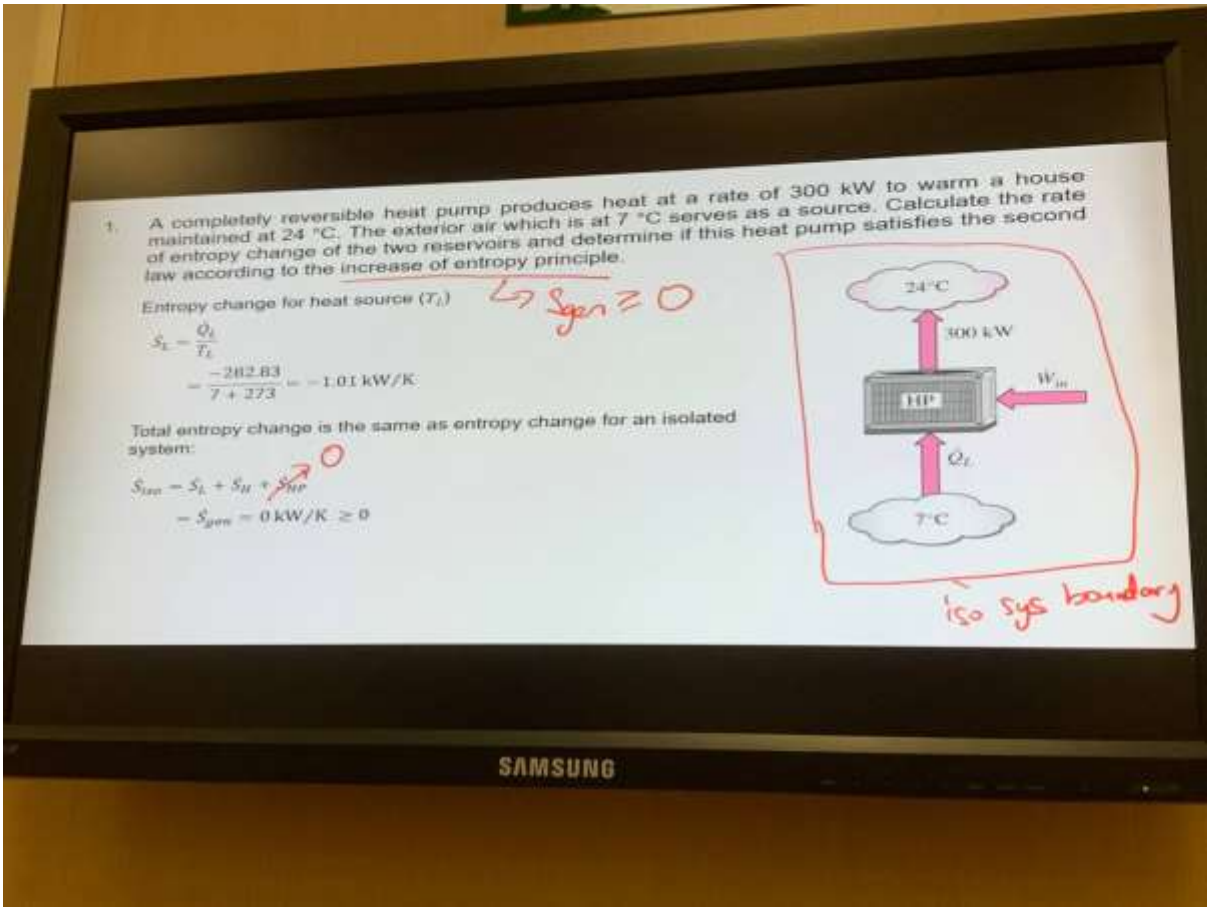
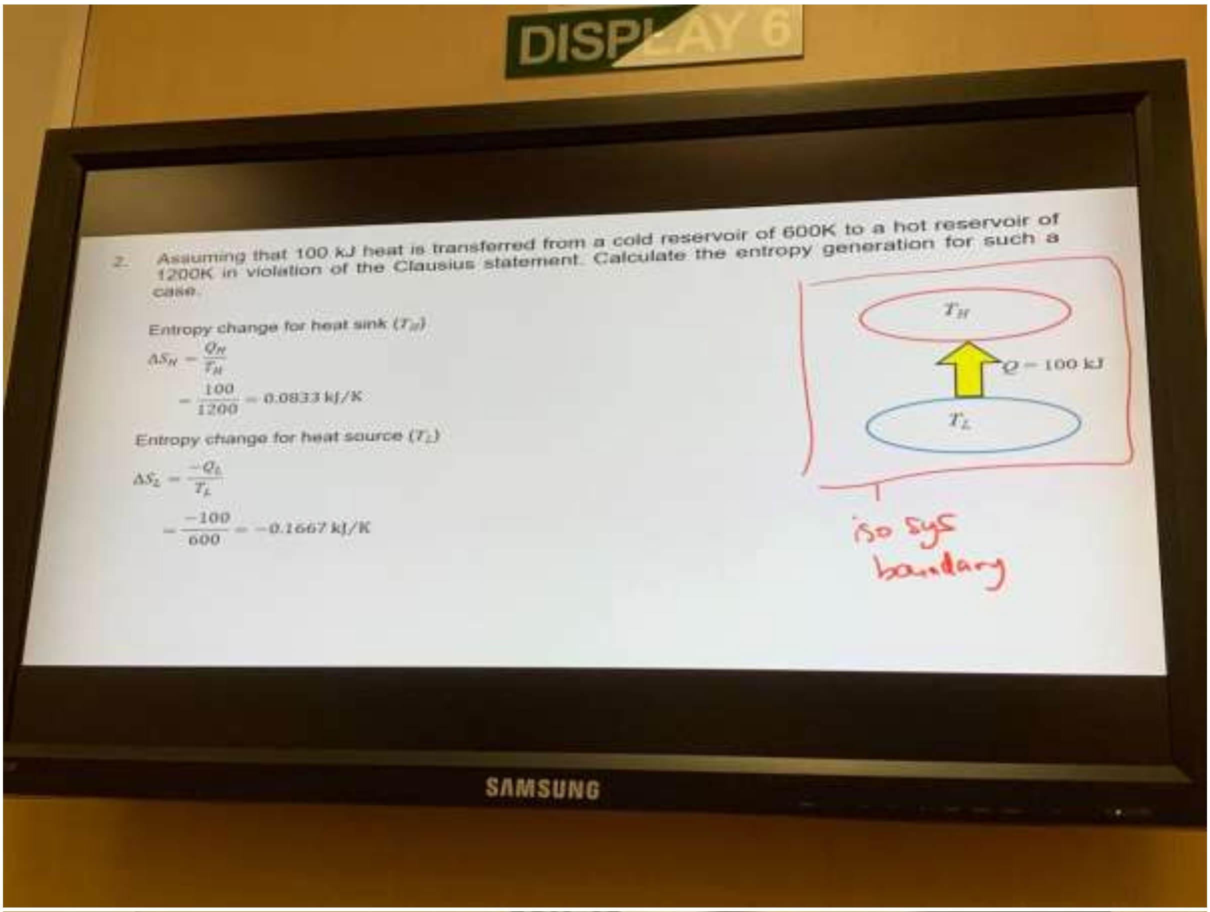
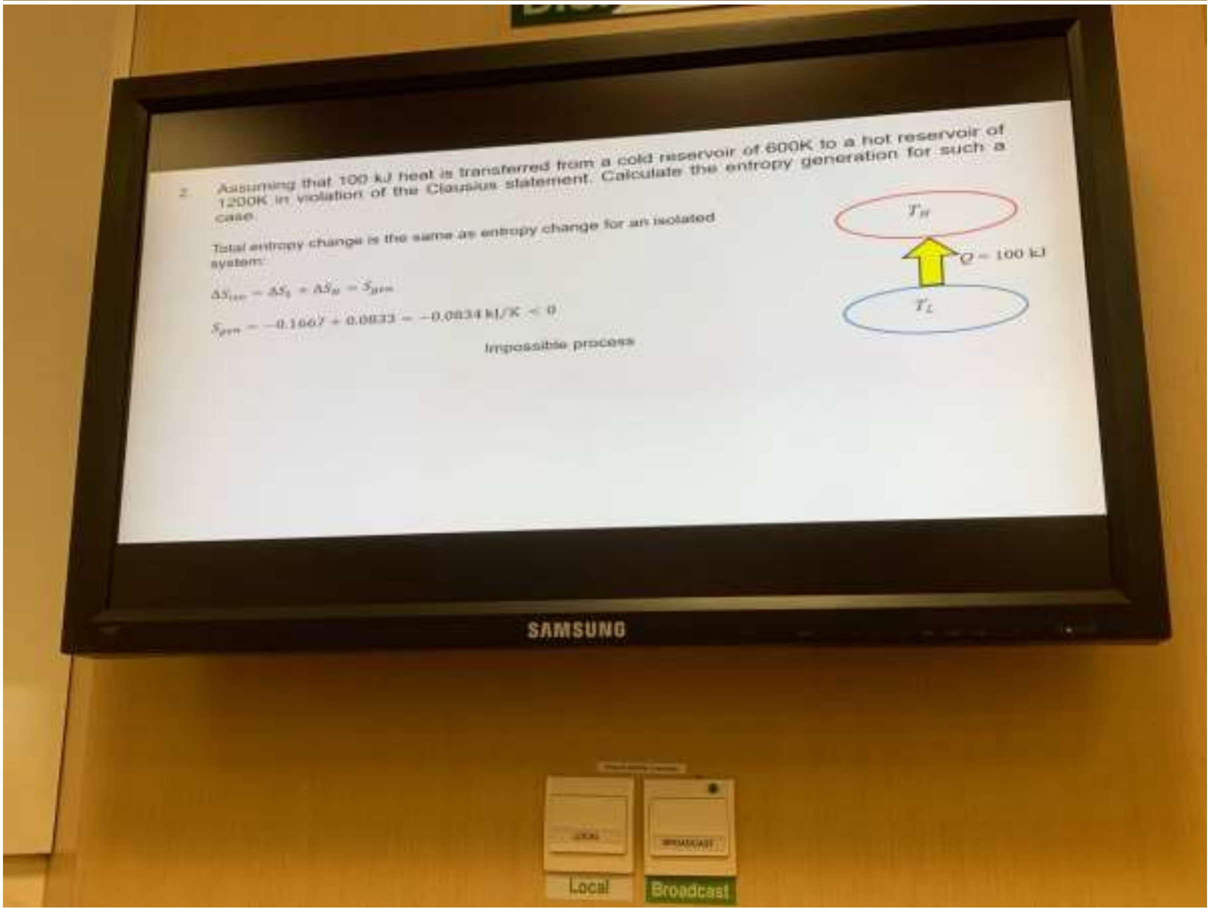
DISPLAY 5
5. An insulated rigid tank is divided into two equal parts by a partition. One part of the tank contains 1.5 kg of air at 250 kPa and 40°C while the other part is evacuated. The partition is now removed, and the air expands to fill the entire tank. Determine the total entropy change during this process.
Assumptions: Air is an ideal gas
Constant specific heats
Tank is an isolated system: $\Delta E_{total} = 0$
$mc_v \Delta T = 0$
$T_2 = T_1$
Specific volume ratio:
$V_2 = 2V_1$
$mv_2 = 2mv_1 \rightarrow \frac{v_2}{v_1} = 2$
1.5 kg air
250 kPa
40°C
Vacuum
SAMSUNG
Local
Broadcast

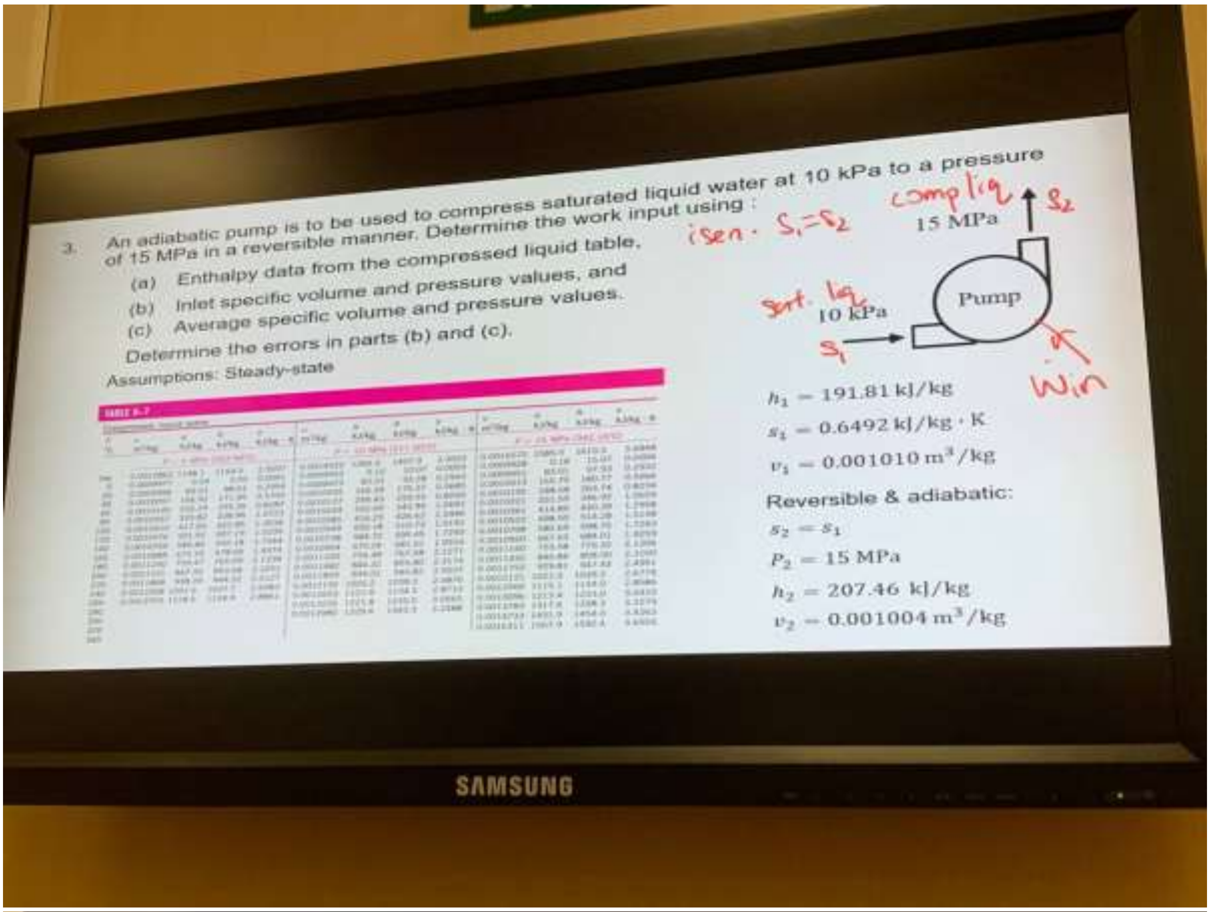

GROUP
5
DISPLAY 5
An insulated rigid tank is divided into two equal parts by a partition. One part of the tank contains 1.5 kg of air at 250 kPa and 40°C while the other part is evacuated. The partition is now removed, and the air expands to fill the entire tank. Determine the total entropy change during this process.
Entropy change :
1.5 kg air
250 kPa
40°C
Vacuum
SAMSUNG
Local
Broadcast

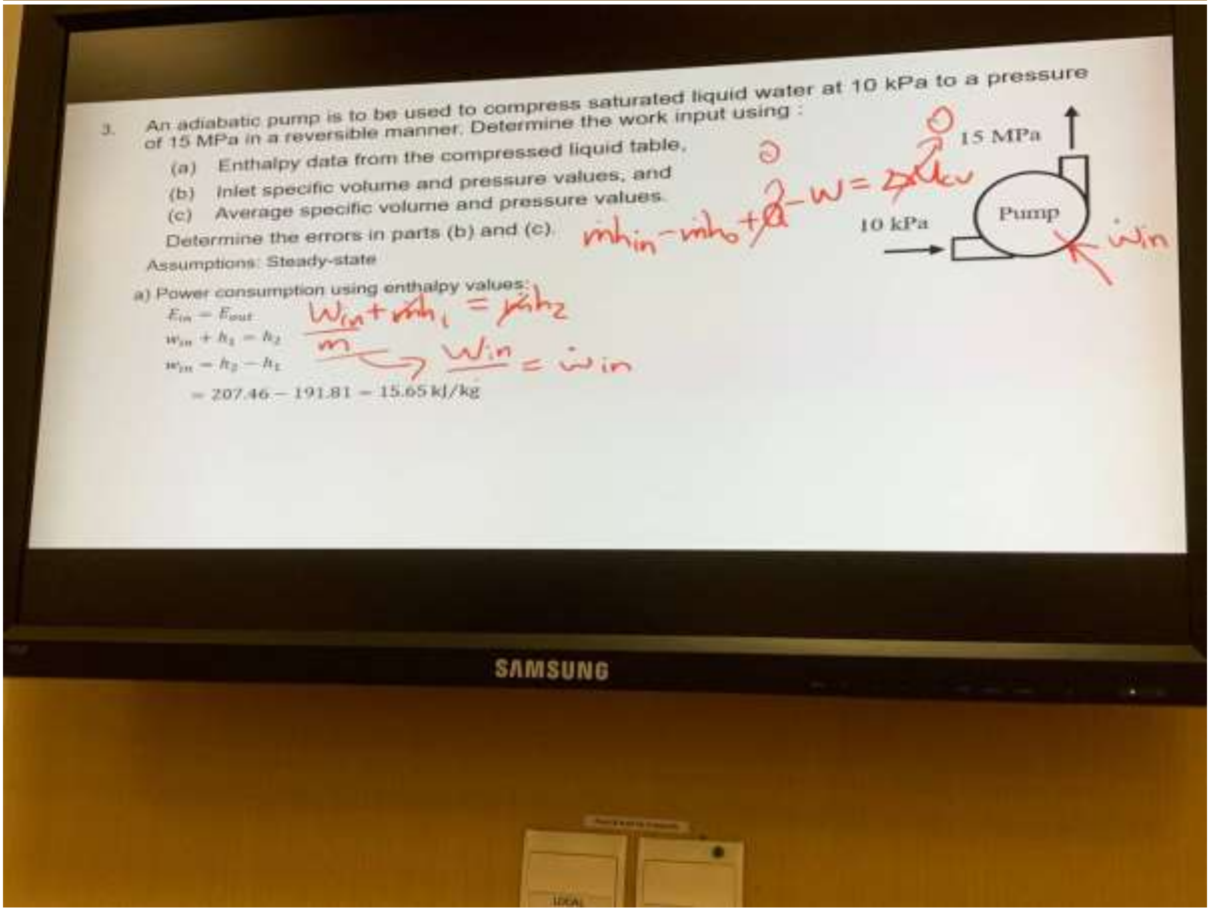

1. A completely reversible heat pump produces heat at a rate of 300 kW to warm a house maintained at 24 °C. The exterior air which is at 7 °C serves as a source. Calculate the rate of entropy change of the two reservoirs and determine if this heat pump satisfies the second law according to the increase of entropy principle.
Assumptions: Steady state operation
Completely reversible heat pump = Carnot heat pump
$\left(\frac{Q_H}{Q_L}\right)_{rev} = \frac{T_H}{T_L} \rightarrow Q_L = Q_H \cdot \frac{T_L}{T_H}$
$Q_L = 300 \times \frac{7+273}{24+273} = 282.83$ kW
Entropy change for heat sink (T_H)
$\dot{S}_H = \frac{\dot{Q}_H}{T_H}$
$= \frac{300}{24+273} = 1.01$ kW/K
24 °C
300 kW
HP
$\dot{W}_{in}$
$\dot{Q}_L = ?$
7 °C
$S_{gen} = \Delta S_{iso}$
$= \sum_i \Delta S_{sys}$
Carnot HP (rev)
$\Delta S = \frac{Q}{T}$
SAMSUNG

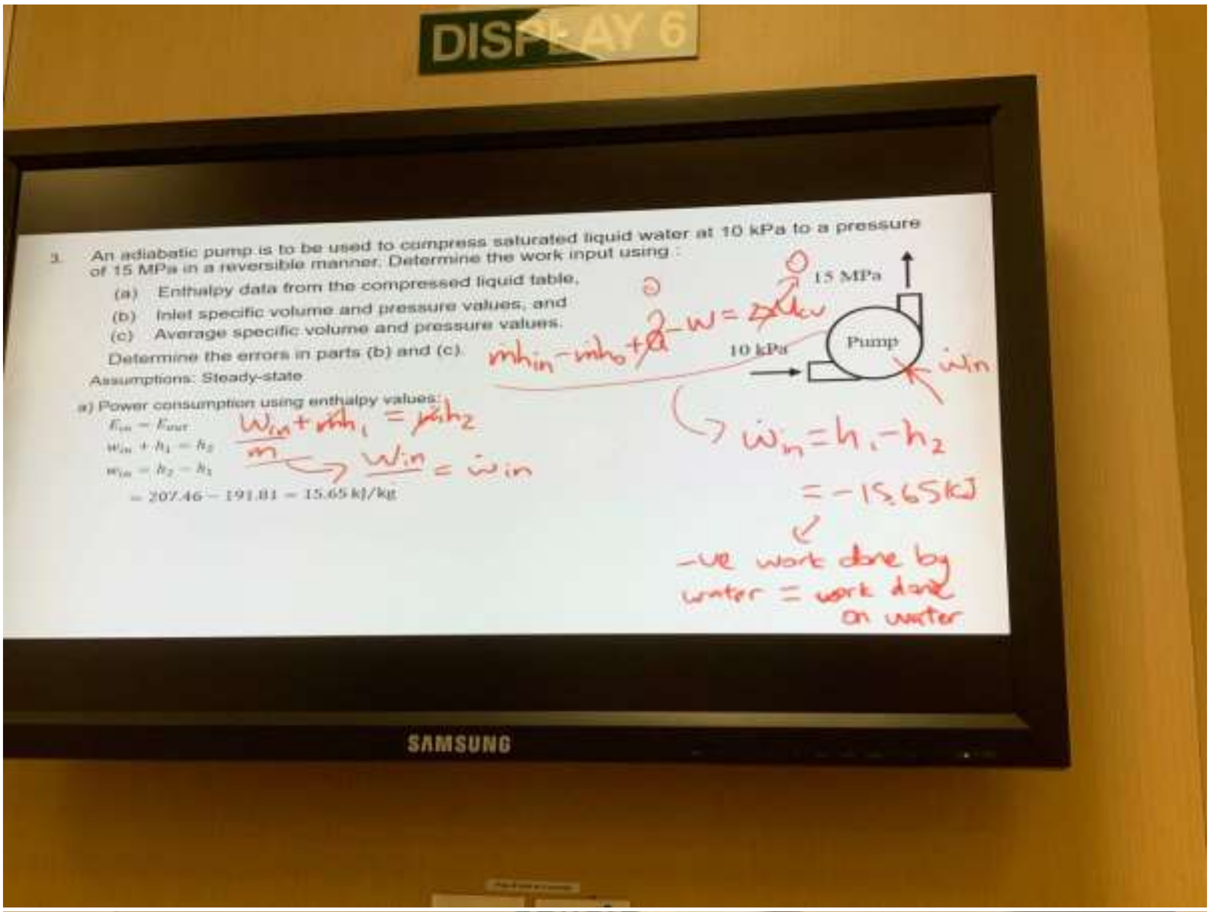

1. A completely reversible heat pump produces heat at a rate of 300 kW to warm a house maintained at 24 °C. The exterior air which is at 7 °C serves as a source. Calculate the rate of entropy change of the two reservoirs and determine if this heat pump satisfies the second law according to the increase of entropy principle.
$\hookrightarrow S_{gen} \geq 0$
Entropy change for heat source (T_L)
$\dot{S}_L = \frac{\dot{Q}_L}{T_L}$
$= \frac{-282.83}{7+273} = -1.01$ kW/K
Total entropy change is the same as entropy change for an isolated system:
$\dot{S}_{iso} = \dot{S}_L + \dot{S}_H + \dot{S}_{HP}$ 0
$= \dot{S}_{gen} = 0$ kW/K ≥ 0
24 °C
300 kW
HP
$\dot{W}_{in}$
$\dot{Q}_L$
7 °C
iso sys boundary
SAMSUNG

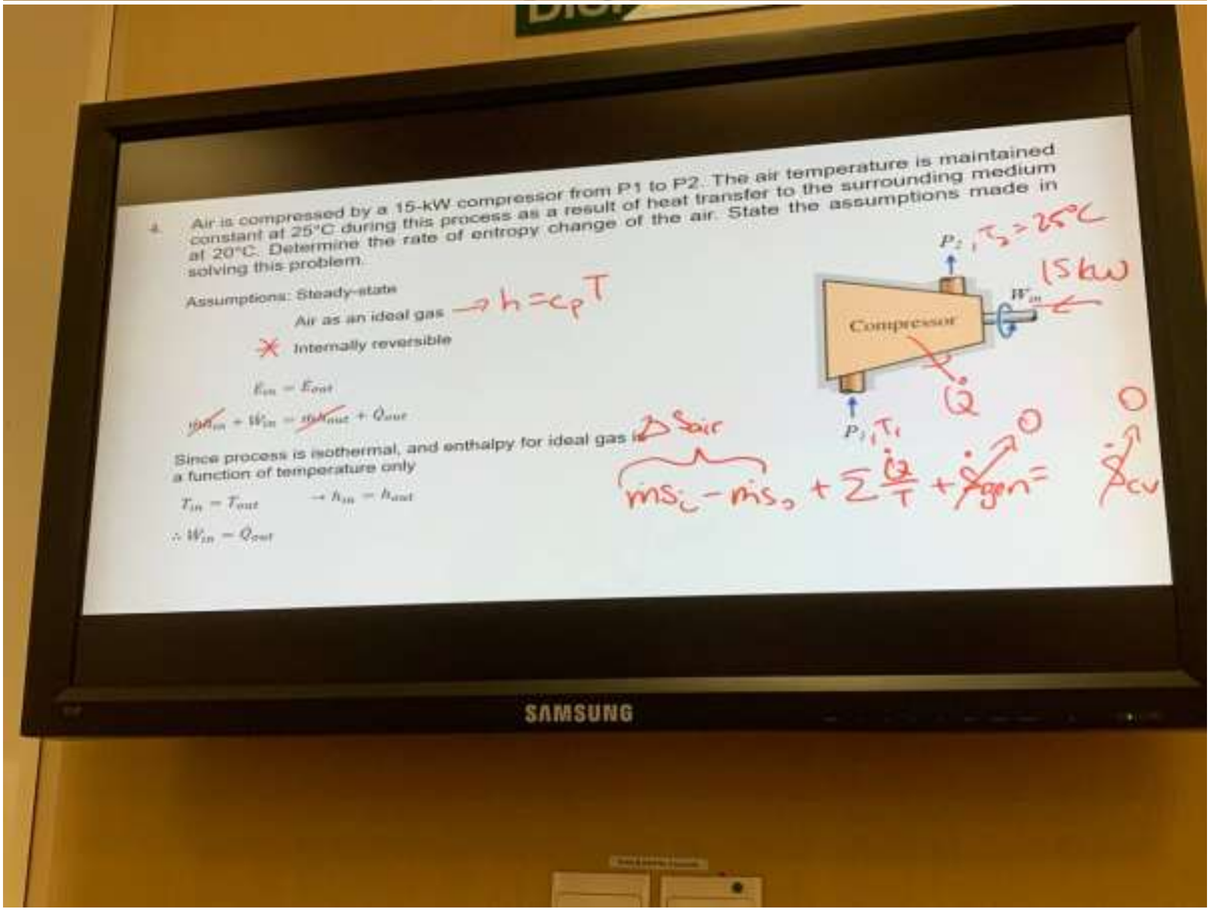

DISPLAY 6
2. Assuming that 100 kJ heat is transferred from a cold reservoir of 600K to a hot reservoir of 1200K in violation of the Clausius statement. Calculate the entropy generation for such a case.
Entropy change for heat sink (T_H)
$\Delta S_H = \frac{Q_H}{T_H}$
$= \frac{100}{1200} = 0.0833$ kJ/K
Entropy change for heat source (T_L)
$\Delta S_L = \frac{-Q_L}{T_L}$
$= \frac{-100}{600} = -0.1667$ kJ/K
T_H
$Q = 100$ kJ
T_L
iso sys boundary
SAMSUNG

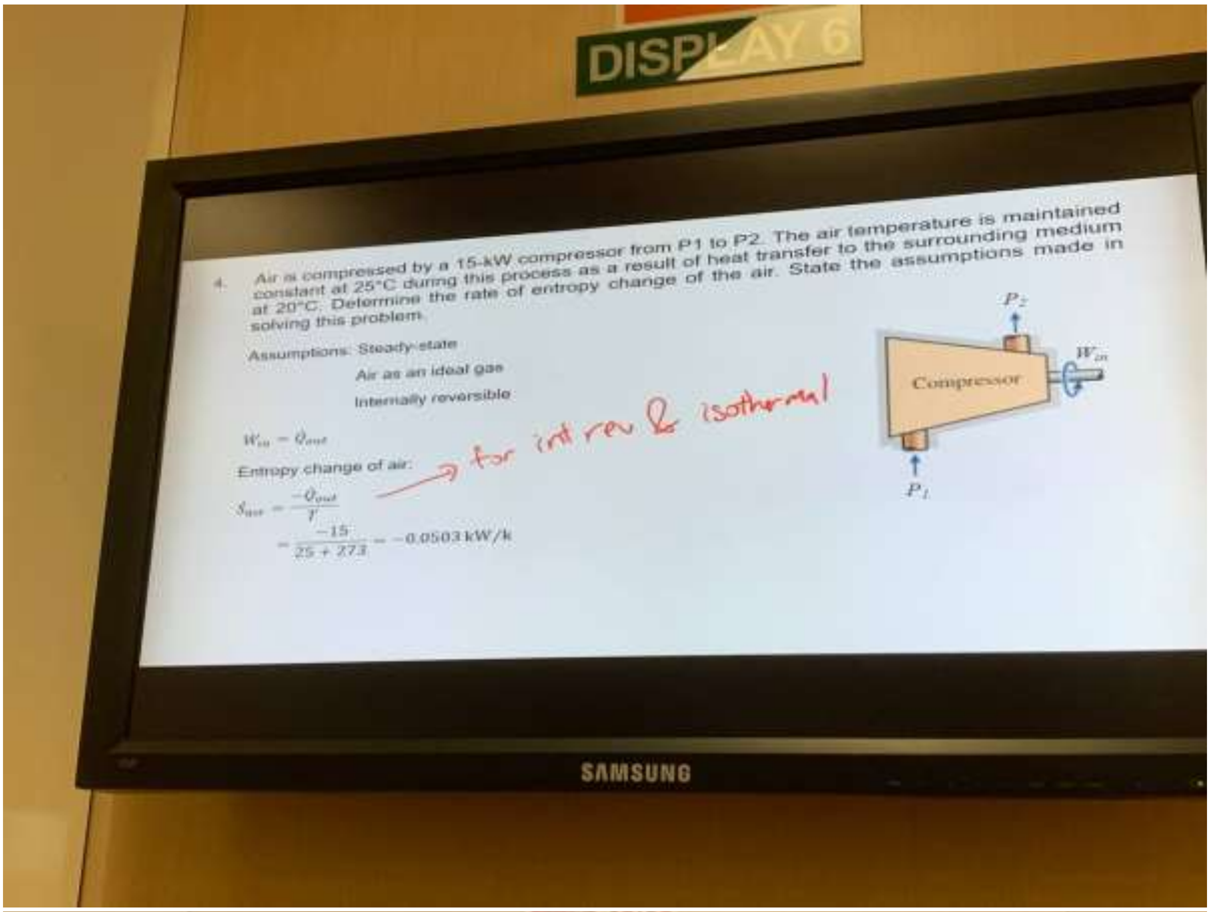

2. Assuming that 100 kJ heat is transferred from a cold reservoir of 600K to a hot reservoir of 1200K in violation of the Clausius statement. Calculate the entropy generation for such a case.
Total entropy change is the same as entropy change for an isolated system:
$\Delta S_{iso} = \Delta S_L + \Delta S_H = S_{gen}$
$S_{gen} = -0.1667 + 0.0833 = -0.0834$ kJ/K < 0
Impossible process
T_H
$Q = 100$ kJ
T_L
SAMSUNG
Local
Broadcast

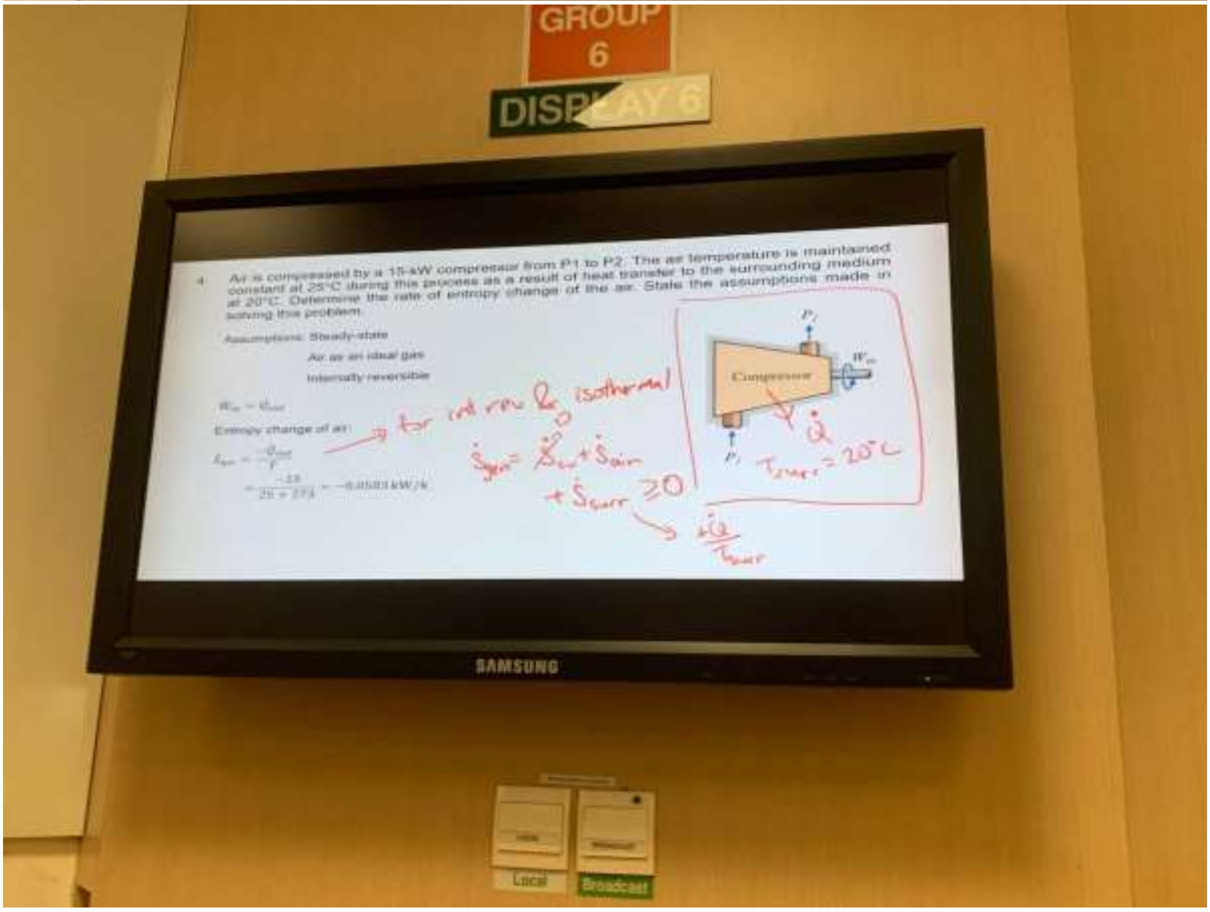

3. An adiabatic pump is to be used to compress saturated liquid water at 10 kPa to a pressure of 15 MPa in a reversible manner. Determine the work input using :
(a) Enthalpy data from the compressed liquid table,
(b) Inlet specific volume and pressure values, and
(c) Average specific volume and pressure values.
Determine the errors in parts (b) and (c).
Assumptions: Steady-state
isen. $S_1 = S_2$
comp liq
S_2
15 MPa
Pump
sat. liq
10 kPa
S_1
Win
$h_1 = 191.81$ kJ/kg
$s_1 = 0.6492$ kJ/kg · K
$v_1 = 0.001010$ m^3/kg
Reversible & adiabatic:
$s_2 = s_1$
$P_2 = 15$ MPa
$h_2 = 207.46$ kJ/kg
$v_2 = 0.001004$ m^3/kg
SAMSUNG

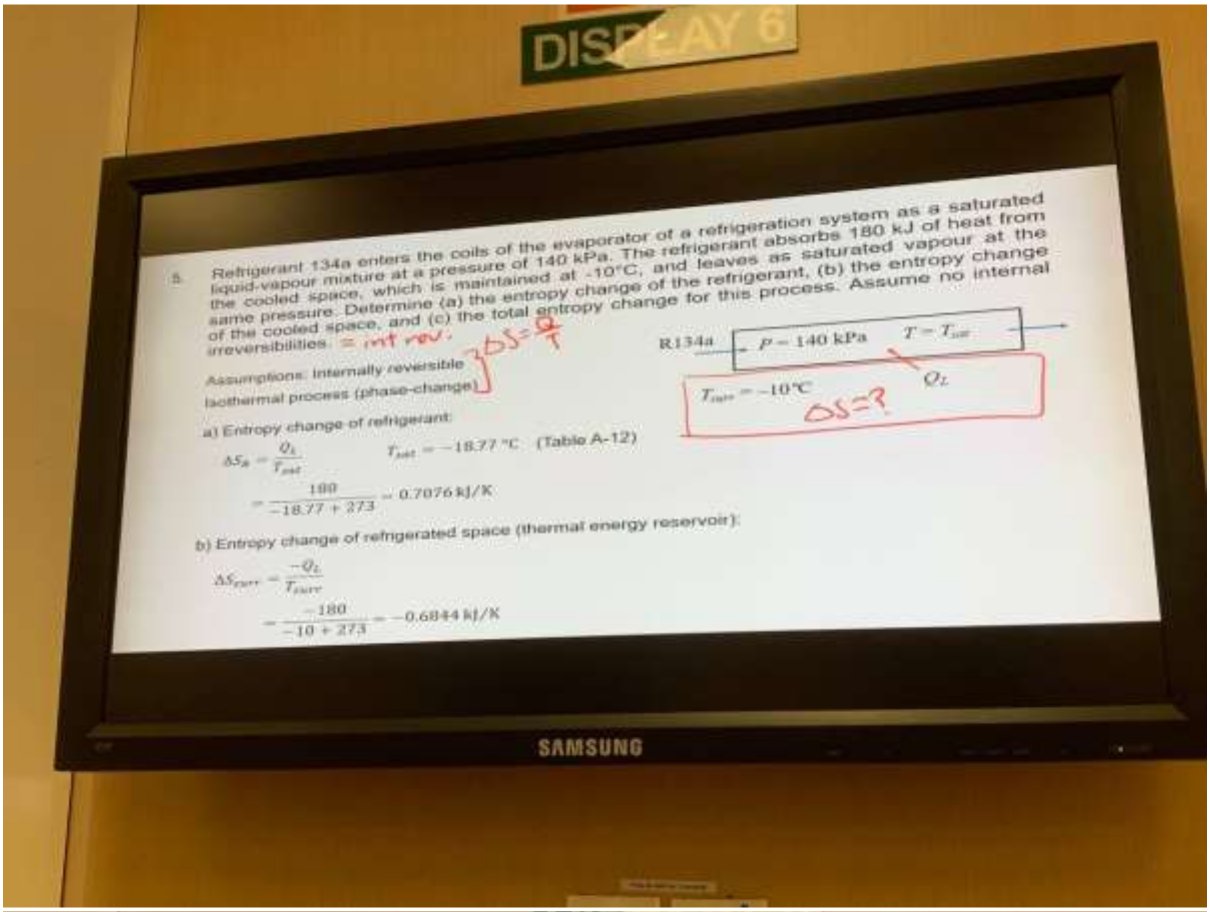

3. An adiabatic pump is to be used to compress saturated liquid water at 10 kPa to a pressure of 15 MPa in a reversible manner. Determine the work input using :
(a) Enthalpy data from the compressed liquid table,
(b) Inlet specific volume and pressure values, and
(c) Average specific volume and pressure values.
Determine the errors in parts (b) and (c).
Assumptions: Steady-state
15 MPa
Pump
10 kPa
win
$\dot{m}h_{in} - \dot{m}h_o + \dot{Q} - \dot{W} = \Delta KE$
a) Power consumption using enthalpy values:
$E_{in} = E_{out}$
$w_{in} + h_1 = h_2$
$w_{in} = h_2 - h_1$
$= 207.46 - 191.81 = 15.65$ kJ/kg
$\dot{W}_{in} + \dot{m}h_1 = \dot{m}h_2$
$\frac{\dot{W}_{in}}{\dot{m}} = \dot{w}_{in}$
SAMSUNG

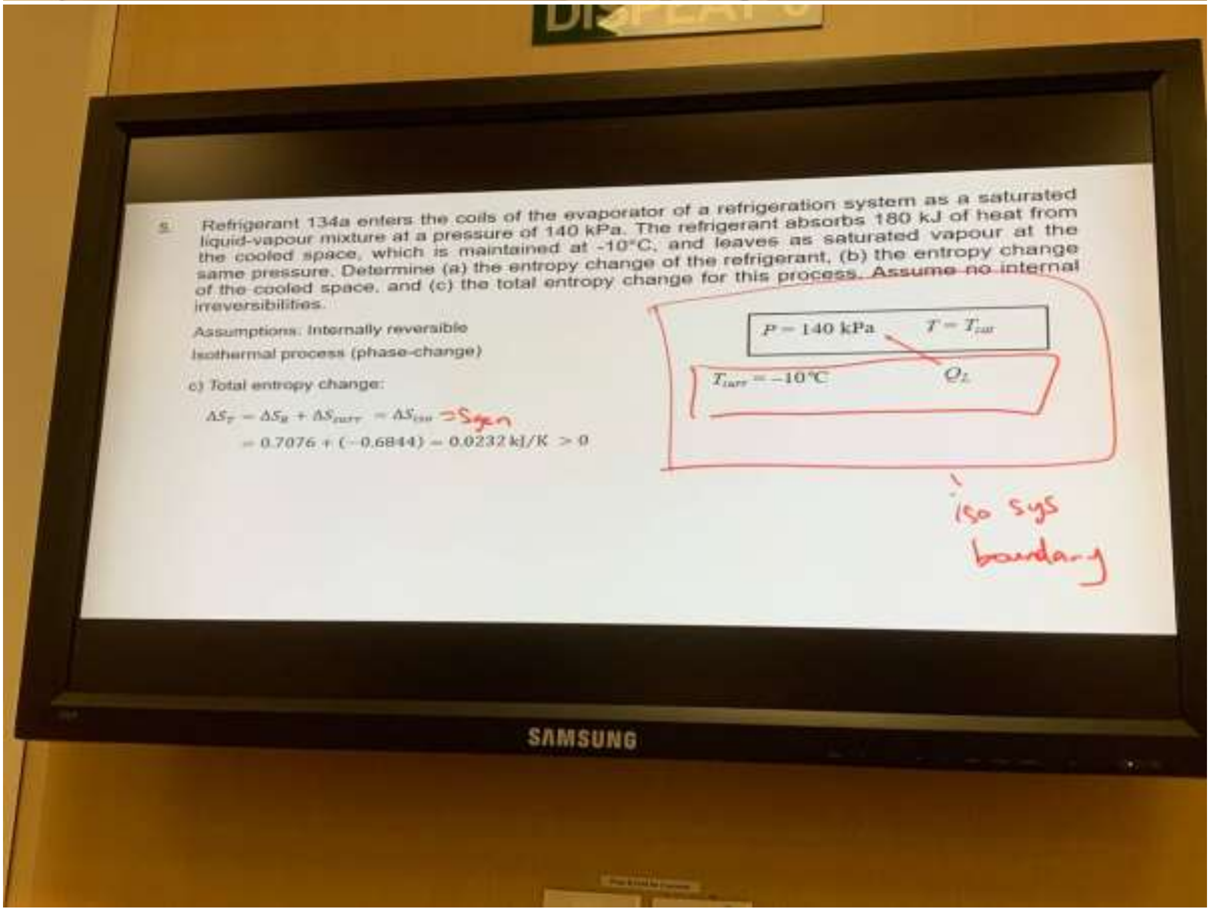

DISPLAY 6
3. An adiabatic pump is to be used to compress saturated liquid water at 10 kPa to a pressure of 15 MPa in a reversible manner. Determine the work input using :
(a) Enthalpy data from the compressed liquid table,
(b) Inlet specific volume and pressure values, and
(c) Average specific volume and pressure values.
Determine the errors in parts (b) and (c).
Assumptions: Steady-state
a) Power consumption using enthalpy values:
$E_{in} = E_{out}$
$w_{in} + h_1 = h_2$
$w_{in} = h_2 - h_1$
$= 207.46 - 191.81 = 15.65$ kJ/kg
15 MPa
10 kPa
Pump
$\dot{m}h_{in} - \dot{m}h_o + \dot{Q} - \dot{W} = \Delta E_{cv}$
$\dot{W}_{in} + \dot{m}h_1 = \dot{m}h_2$
$\dot{W}_{in} / \dot{m} = w_{in}$
$w_{in} = h_1 - h_2$
$= -15.65$ kJ
-ve work done by water = work done on water
SAMSUNG


4. Air is compressed by a 15-kW compressor from P1 to P2. The air temperature is maintained constant at 25°C during this process as a result of heat transfer to the surrounding medium at 20°C. Determine the rate of entropy change of the air. State the assumptions made in solving this problem.
Assumptions: Steady-state
Air as an ideal gas → $h = c_p T$
Internally reversible
$E_{in} = E_{out}$
$\dot{m}h_{in} + \dot{W}_{in} = \dot{m}h_{out} + \dot{Q}_{out}$
Since process is isothermal, and enthalpy for ideal gas is a function of temperature only
$T_{in} = T_{out}$ → $h_{in} = h_{out}$
$\therefore \dot{W}_{in} = \dot{Q}_{out}$
$P_2, T_2 = 25°C$
15 kW
$\dot{W}_{in}$
Compressor
$\dot{Q}$
P_1, T_1
ΔS_{air}
$\dot{m}s_i - \dot{m}s_o + \sum \frac{\dot{Q}}{T} + \dot{S}_{gen} = \dot{S}_{cv}$
SAMSUNG


DISPLAY 6
4. Air is compressed by a 15-kW compressor from P1 to P2. The air temperature is maintained constant at 25°C during this process as a result of heat transfer to the surrounding medium at 20°C. Determine the rate of entropy change of the air. State the assumptions made in solving this problem.
Assumptions: Steady-state
Air as an ideal gas
Internally reversible
$\dot{W}_{in} = \dot{Q}_{out}$
Entropy change of air:
$\dot{S}_{air} = \frac{-\dot{Q}_{out}}{T}$
$= \frac{-15}{25+273} = -0.0503\ \mathrm{kW/k}$
for int rev & isothermal
P_2
$\dot{W}_{in}$
Compressor
P_1
SAMSUNG


GROUP 6
DISPLAY 6
for int rev & isothermal
$\dot{S}_{gen} = \dot{S}_{cv} + \dot{S}_{air} + \dot{S}_{surr} \geq 0$
$\dot{Q}$
$T_{surr} = 20°C$
$\frac{\dot{Q}}{T_{surr}}$
Compressor
SAMSUNG
Local
Broadcast


DISPLAY 6
5. Refrigerant 134a enters the coils of the evaporator of a refrigeration system as a saturated liquid-vapour mixture at a pressure of 140 kPa. The refrigerant absorbs 180 kJ of heat from the cooled space, which is maintained at -10°C, and leaves as saturated vapour at the same pressure. Determine (a) the entropy change of the refrigerant, (b) the entropy change of the cooled space, and (c) the total entropy change for this process. Assume no internal irreversibilities. = int rev.
Assumptions: Internally reversible
Isothermal process (phase-change)
$\Delta S = \frac{Q}{T}$
R134a
$P = 140$ kPa
$T = T_{sat}$
$T_{surr} = -10°C$
Q_L
$\Delta S = ?$
a) Entropy change of refrigerant:
$\Delta S_R = \frac{Q_L}{T_{sat}}$
$T_{sat} = -18.77\ °C$ (Table A-12)
$= \frac{180}{-18.77 + 273} = 0.7076\ kJ/K$
b) Entropy change of refrigerated space (thermal energy reservoir):
$\Delta S_{surr} = \frac{-Q_L}{T_{surr}}$
$= \frac{-180}{-10 + 273} = -0.6844\ kJ/K$
SAMSUNG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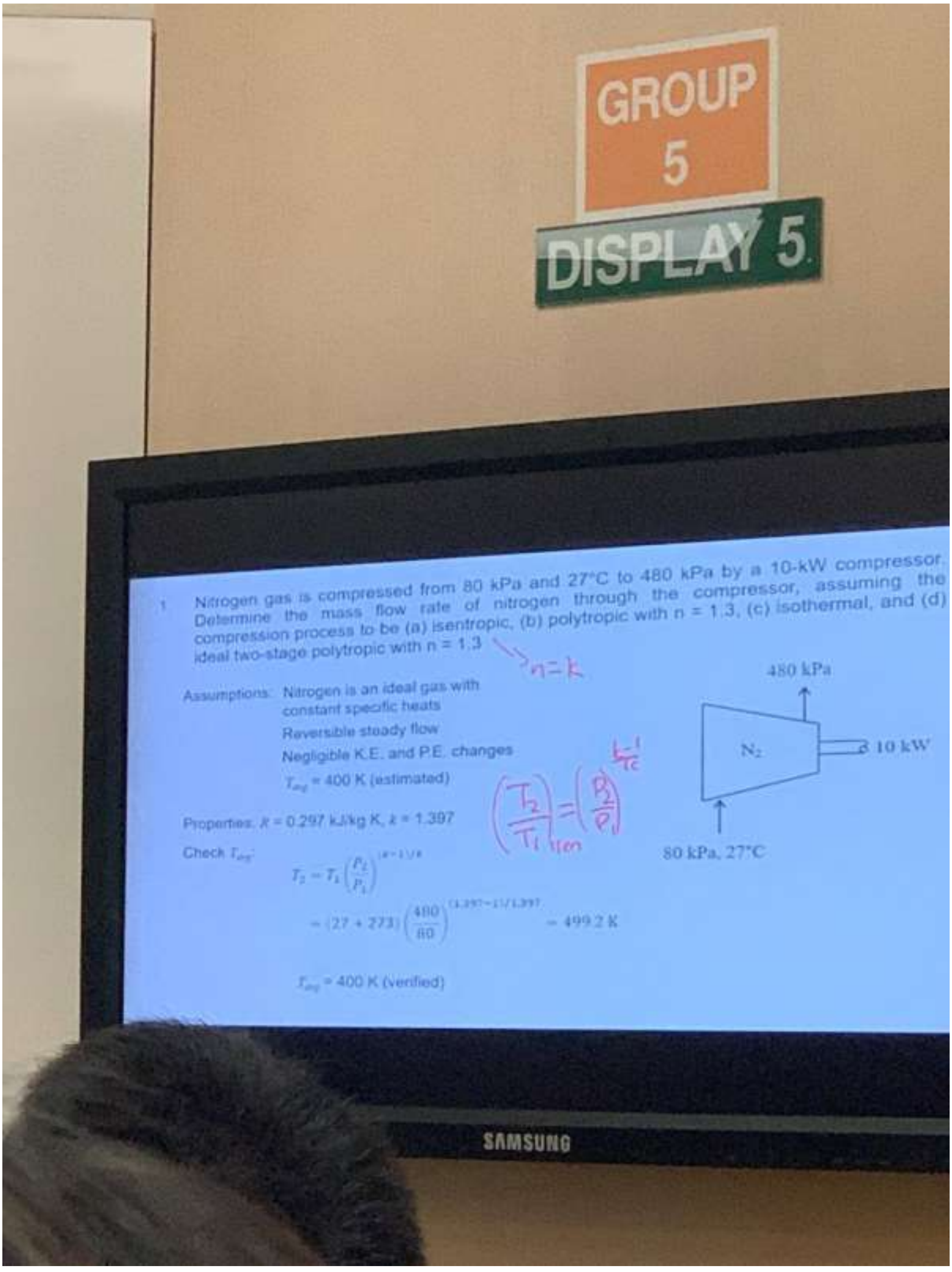
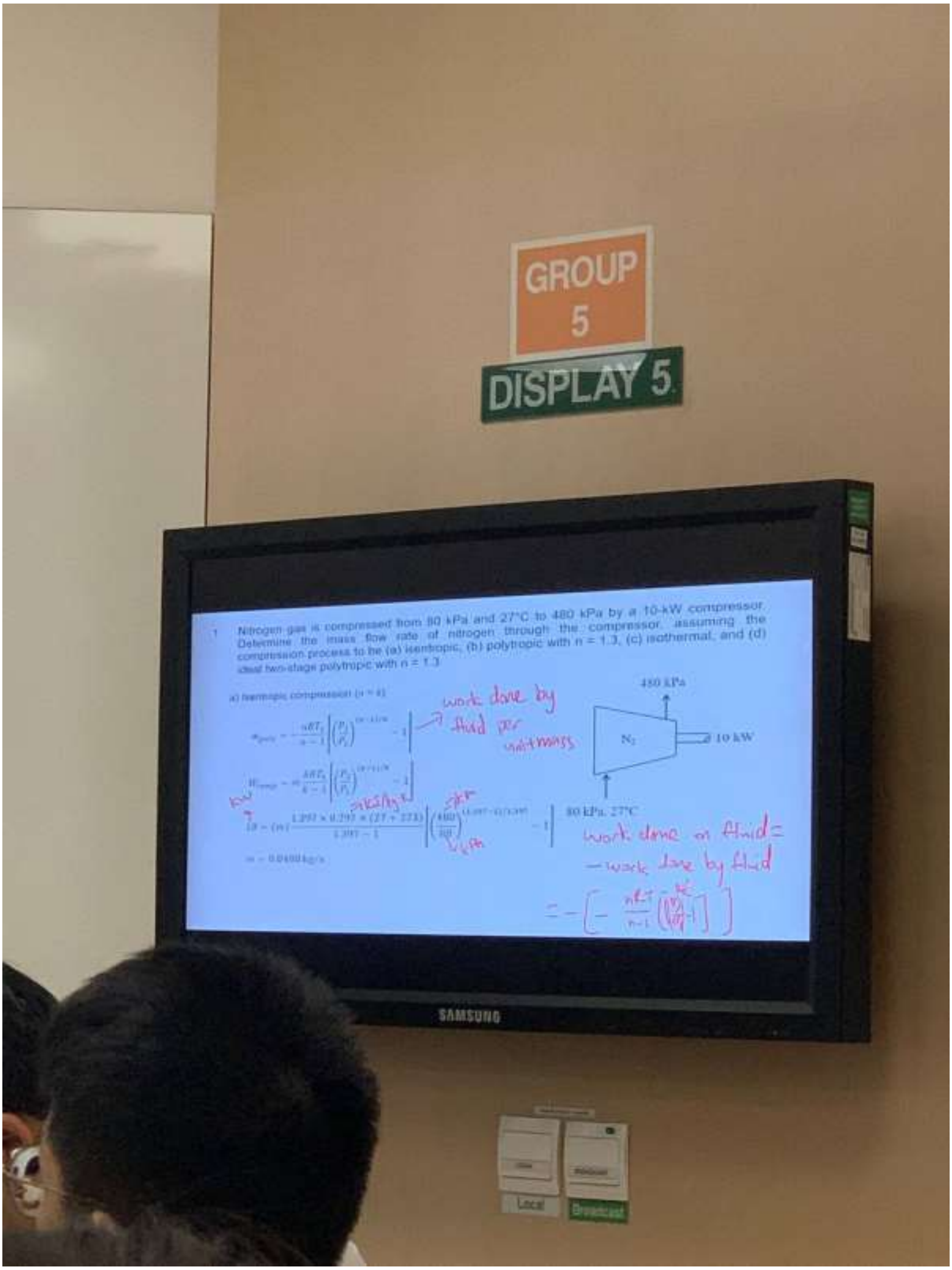
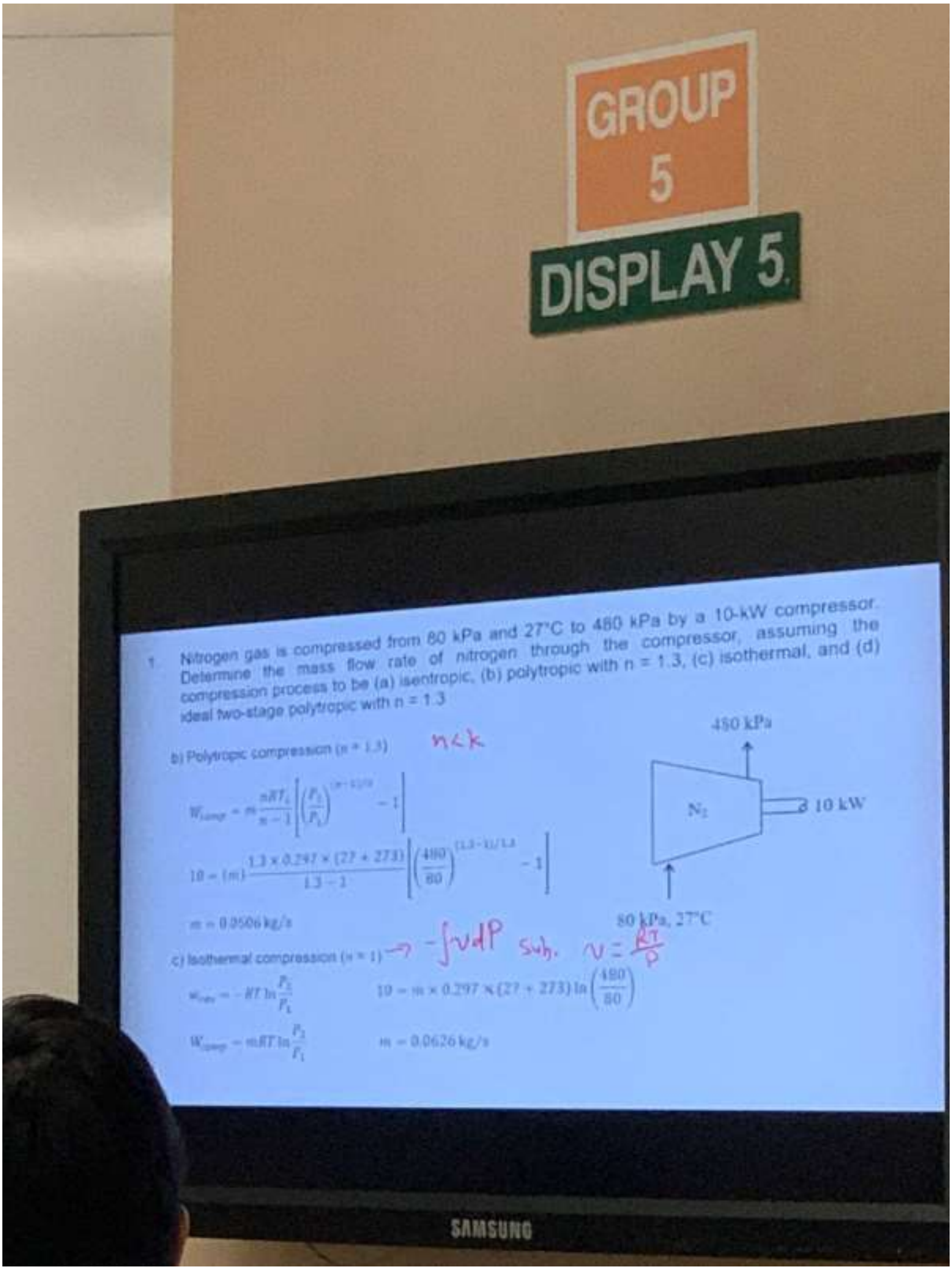
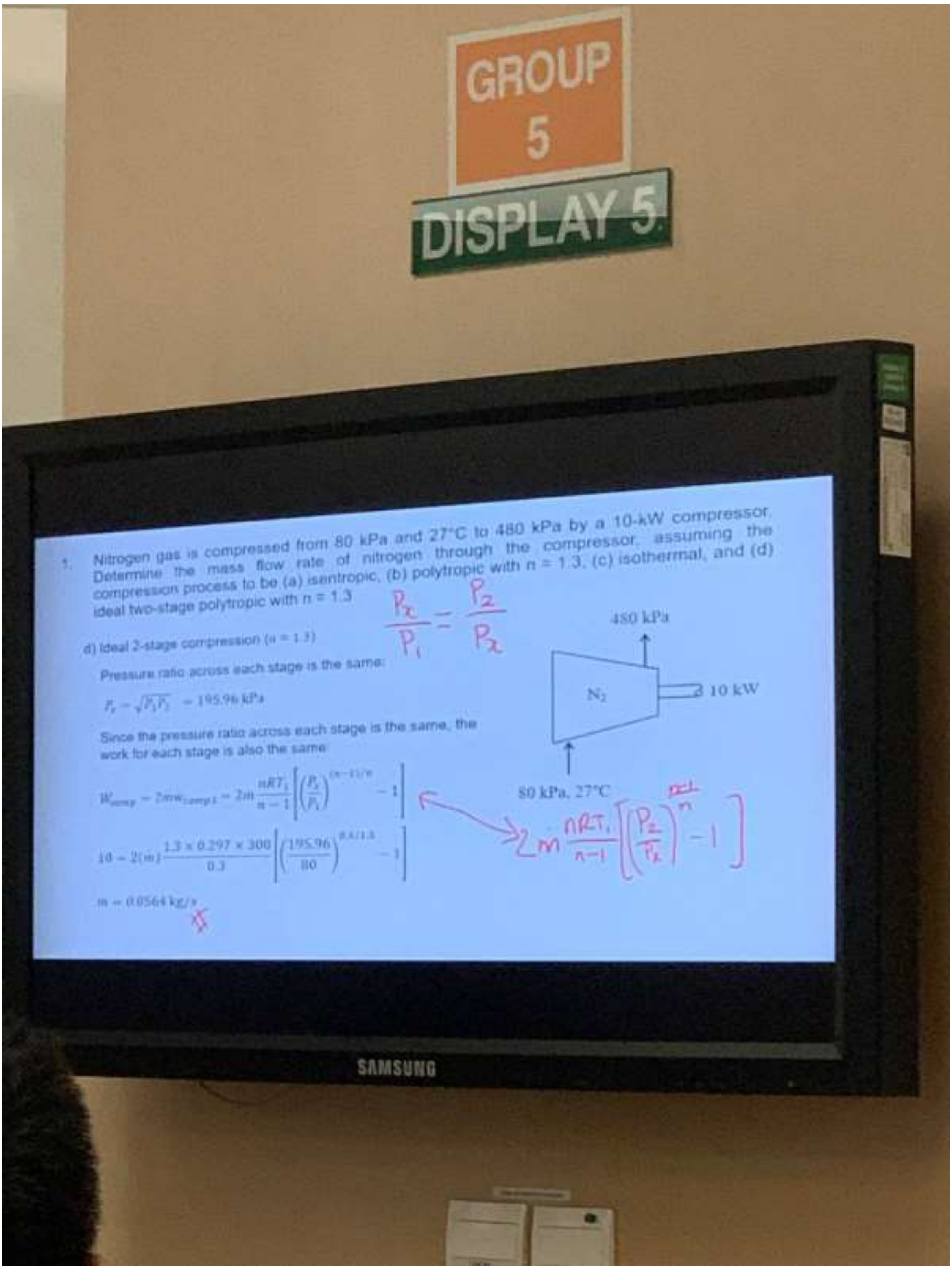
Assumptions: Internally reversible
Isothermal process (phase-change)
c) Total entropy change:
$\Delta S_T = \Delta S_R + \Delta S_{surr} = \Delta S_{iso} = S_{gen}$
$= 0.7076 + (-0.6844) = 0.0232\ kJ/K > 0$
$P = 140$ kPa
$T = T_{sat}$
$T_{surr} = -10°C$
Q_L
iso sys boundary
SAMSUNG

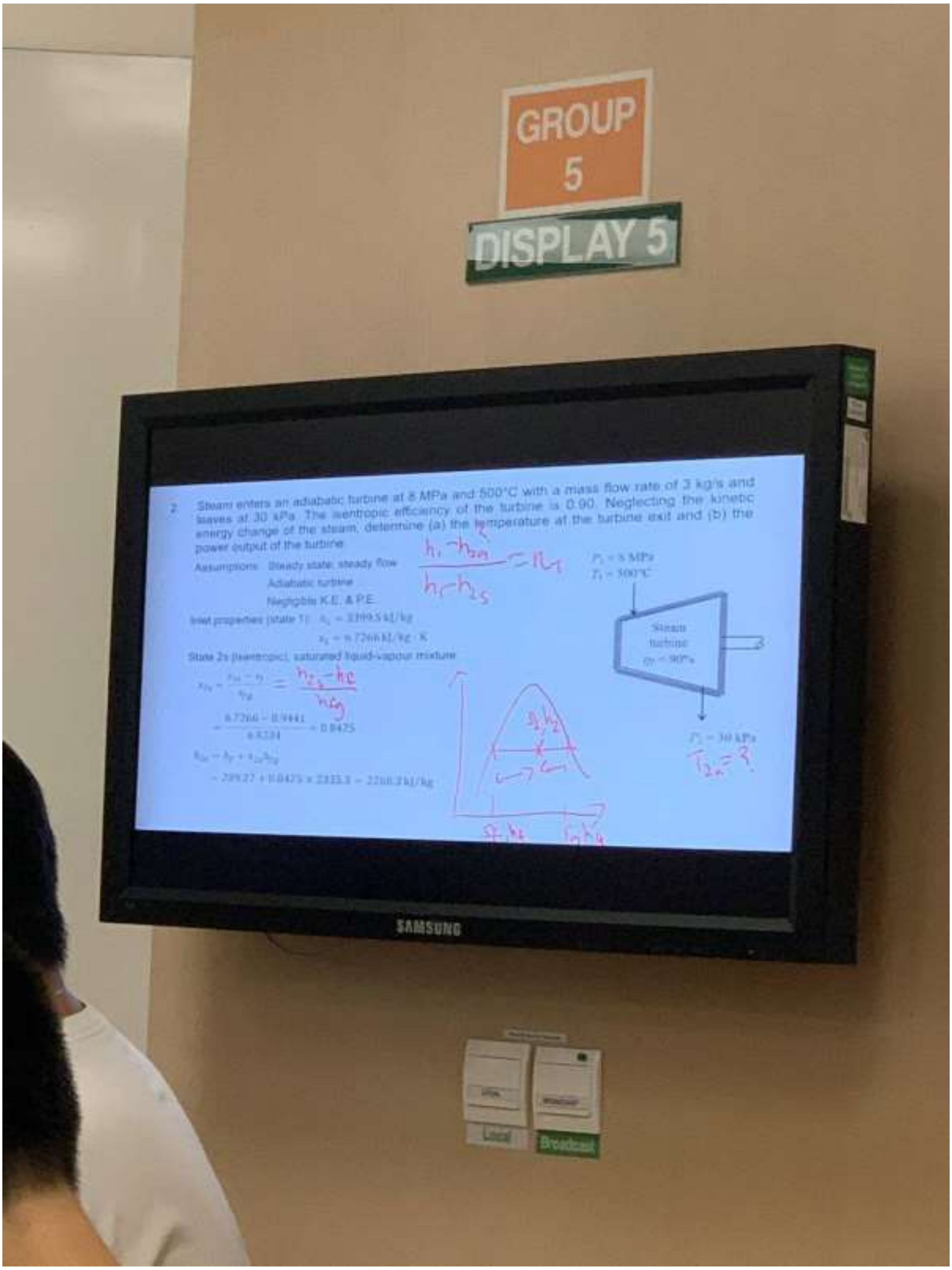

GROUP
5
DISPLAY 5
1 Nitrogen gas is compressed from 80 kPa and 27°C to 480 kPa by a 10-kW compressor. Determine the mass flow rate of nitrogen through the compressor, assuming the compression process to be (a) isentropic, (b) polytropic with n = 1.3, (c) isothermal, and (d) ideal two-stage polytropic with n = 1.3
n=k
Assumptions: Nitrogen is an ideal gas with constant specific heats
Reversible steady flow
Negligible K.E. and P.E. changes
T_avg = 400 K (estimated)
Properties: R = 0.297 kJ/kg K, k = 1.397
Check T_avg:
= 499.2 K
T_avg = 400 K (verified)
480 kPa
N2
10 kW
80 kPa, 27°C
SAMSUNG

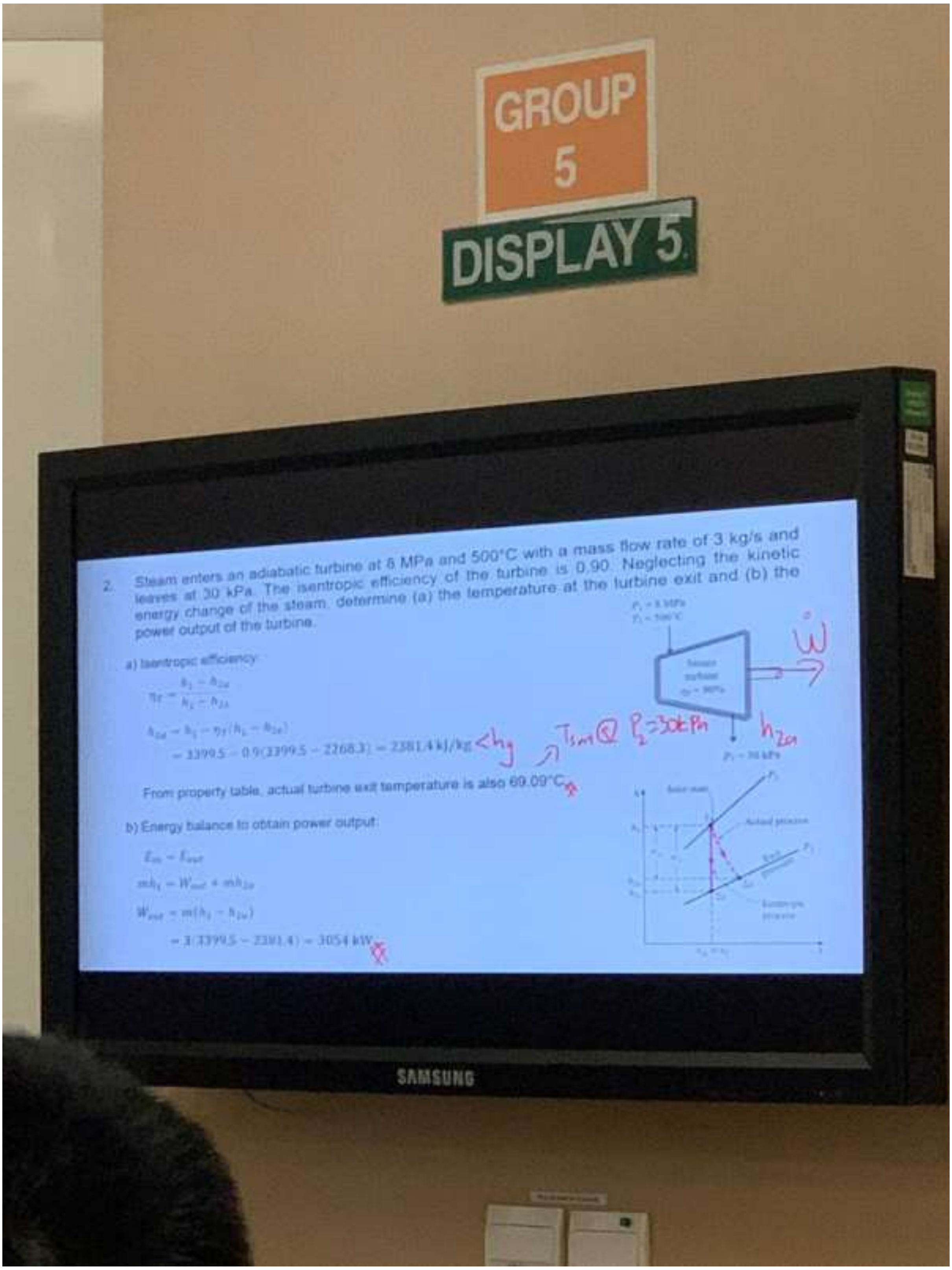

GROUP 5
DISPLAY 5
1 Nitrogen gas is compressed from 80 kPa and 27°C to 480 kPa by a 10-kW compressor. Determine the mass flow rate of nitrogen through the compressor, assuming the compression process to be (a) isentropic, (b) polytropic with n = 1.3, (c) isothermal, and (d) ideal two-stage polytropic with n = 1.3
work done by fluid per unit mass
480 kPa
N_2
10 kW
80 kPa, 27°C
work done on fluid = − work done by fluid
SAMSUNG
Local
Broadcast

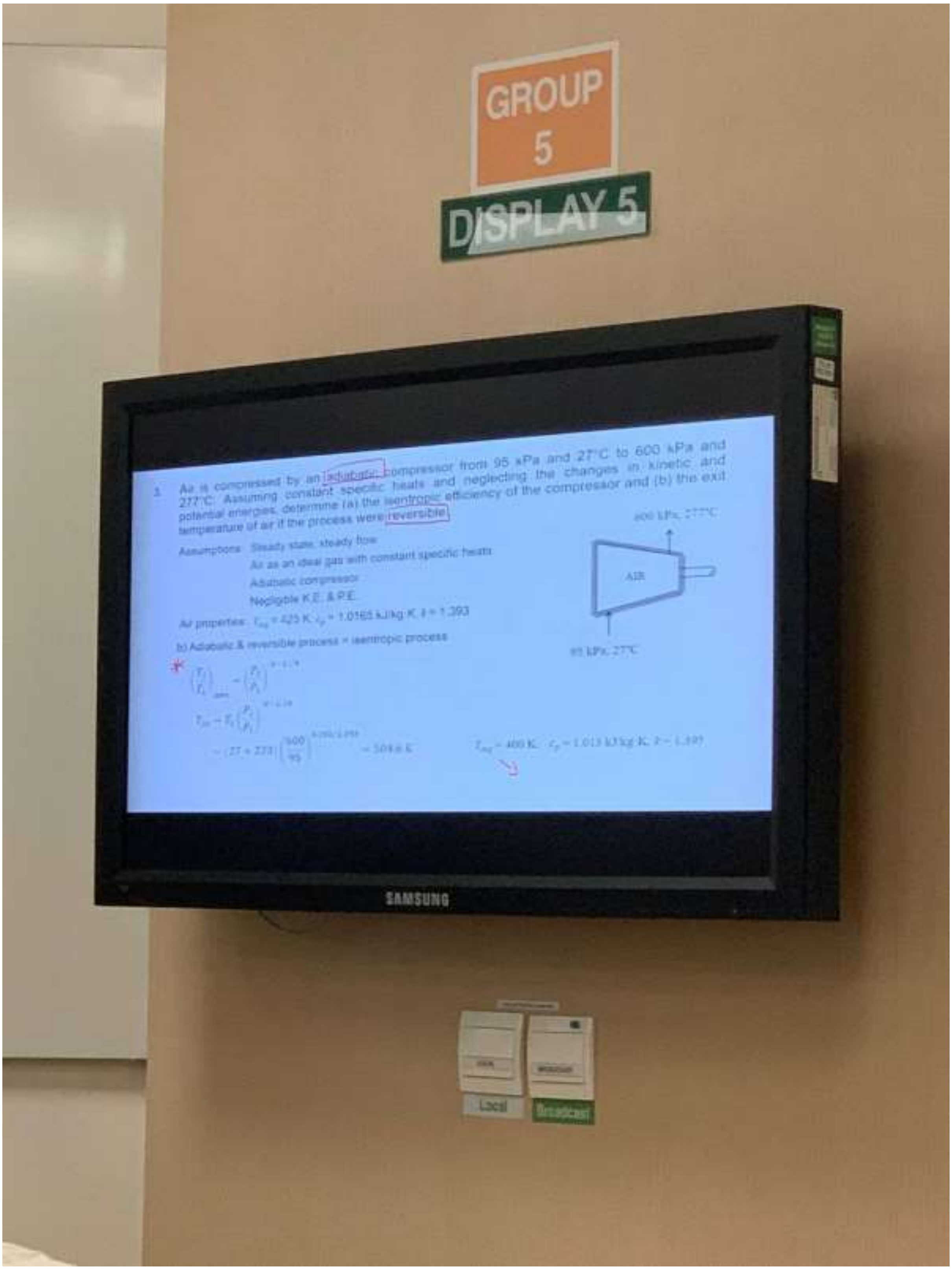

GROUP
5
DISPLAY 5
1. Nitrogen gas is compressed from 80 kPa and 27°C to 480 kPa by a 10-kW compressor. Determine the mass flow rate of nitrogen through the compressor, assuming the compression process to be (a) isentropic, (b) polytropic with n = 1.3, (c) isothermal, and (d) ideal two-stage polytropic with n = 1.3
b) Polytropic compression (n = 1.3)
$n<k$
$\dot{W}_{comp} = \dot{m}\frac{nRT_1}{n-1}\left[\left(\frac{P_2}{P_1}\right)^{(n-1)/n} - 1\right]$
$10 = (\dot{m})\frac{1.3 \times 0.297 \times (27 + 273)}{1.3 - 1}\left[\left(\frac{480}{80}\right)^{(1.3-1)/1.3} - 1\right]$
$\dot{m} = 0.0506$ kg/s
c) Isothermal compression (n = 1) $\rightarrow -\int v\,dP$ sub. $v = \frac{RT}{P}$
$w_{comp} = -RT\ln\frac{P_2}{P_1}$
$\dot{W}_{comp} = \dot{m}RT\ln\frac{P_2}{P_1}$
$10 = \dot{m} \times 0.297 \times (27 + 273)\ln\left(\frac{480}{80}\right)$
$\dot{m} = 0.0626$ kg/s
480 kPa
N_2
10 kW
80 kPa, 27°C
SAMSUNG

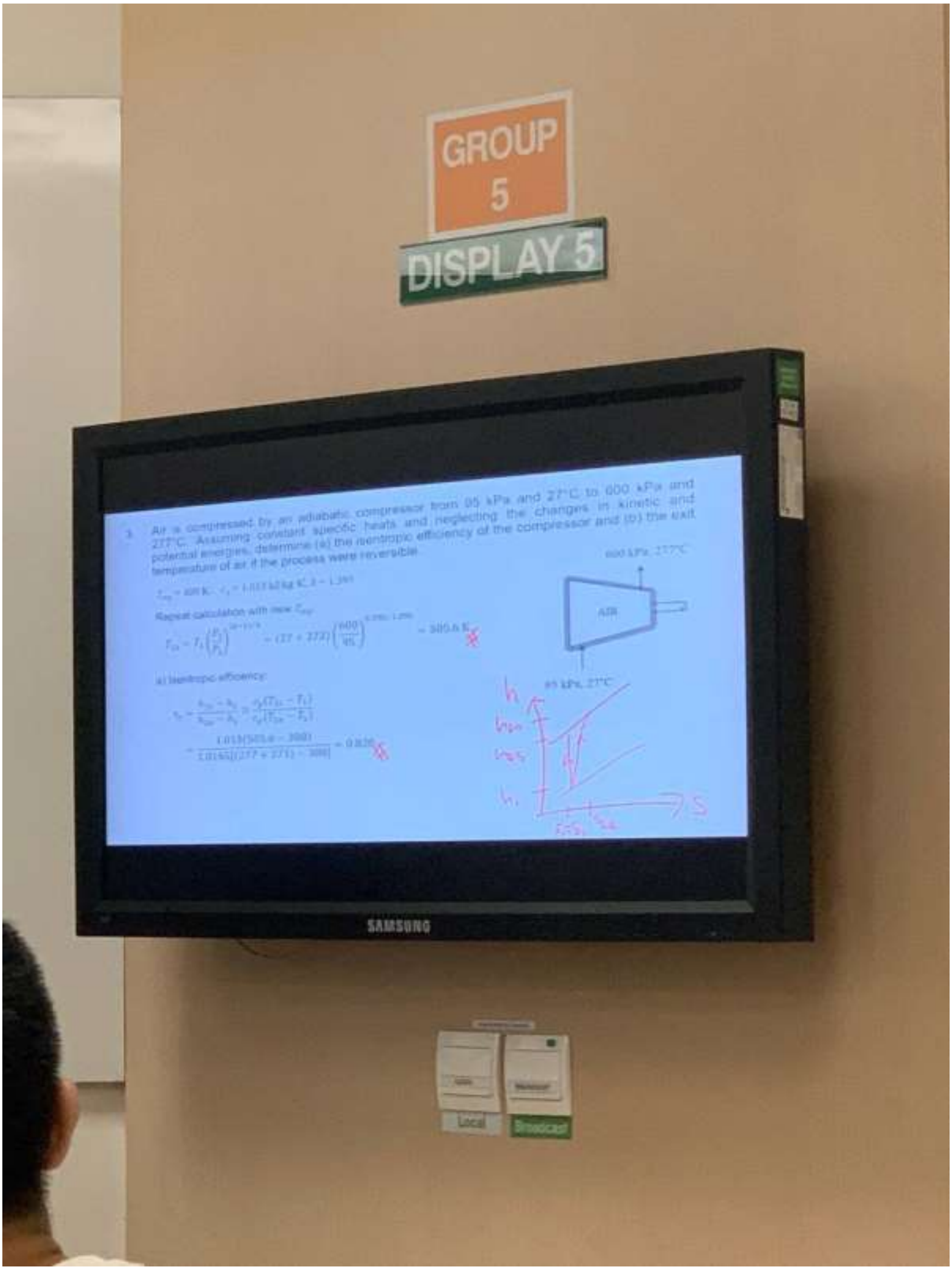


GROUP 5
DISPLAY 5
1. Nitrogen gas is compressed from 80 kPa and 27°C to 480 kPa by a 10-kW compressor. Determine the mass flow rate of nitrogen through the compressor, assuming the compression process to be (a) isentropic, (b) polytropic with n = 1.3, (c) isothermal, and (d) ideal two-stage polytropic with n = 1.3
$\frac{P_x}{P_1} = \frac{P_2}{P_x}$
d) Ideal 2-stage compression (n = 1.3)
Pressure ratio across each stage is the same:
$P_x = \sqrt{P_1 P_2} = 195.96$ kPa
Since the pressure ratio across each stage is the same, the work for each stage is also the same:
$W_{comp} = 2\dot{m}w_{comp,I} = 2\dot{m}\frac{nRT_1}{n-1}\left[\left(\frac{P_x}{P_1}\right)^{(n-1)/n} - 1\right]$
$2\dot{m}\frac{nRT_1}{n-1}\left[\left(\frac{P_2}{P_x}\right)^{\frac{n-1}{n}} - 1\right]$
$10 = 2(\dot{m})\frac{1.3 \times 0.297 \times 300}{0.3}\left[\left(\frac{195.96}{80}\right)^{0.3/1.3} - 1\right]$
$\dot{m} = 0.0564$ kg/s
480 kPa
N_2
10 kW
80 kPa, 27°C
SAMSUNG


GROUP
5
DISPLAY 5
2. Steam enters an adiabatic turbine at 8 MPa and 500°C with a mass flow rate of 3 kg/s and leaves at 30 kPa. The isentropic efficiency of the turbine is 0.90. Neglecting the kinetic energy change of the steam, determine (a) the temperature at the turbine exit and (b) the power output of the turbine.
Assumptions: Steady state; steady flow
Adiabatic turbine
Negligible K.E. & P.E.
State 2s (isentropic), saturated liquid-vapour mixture
Steam turbine
SAMSUNG
Local
Broadcast


GROUP
5
DISPLAY 5
2. Steam enters an adiabatic turbine at 8 MPa and 500°C with a mass flow rate of 3 kg/s and leaves at 30 kPa. The isentropic efficiency of the turbine is 0.90. Neglecting the kinetic energy change of the steam, determine (a) the temperature at the turbine exit and (b) the power output of the turbine.
a) Isentropic efficiency
= 3399.5 − 0.9(3399.5 − 2268.3) = 2381.4 kJ/kg
From property table, actual turbine exit temperature is also 69.09°C
b) Energy balance to obtain power output
= 3(3399.5 − 2381.4) = 3054 kW
SAMSUNG


GROUP
5
DISPLAY 5
3. Air is compressed by an adiabatic compressor from 95 kPa and 27°C to 600 kPa and 277°C. Assuming constant specific heats and neglecting the changes in kinetic and potential energies, determine (a) the isentropic efficiency of the compressor and (b) the exit temperature of air if the process were reversible.
Assumptions: Steady state, steady flow
Air as an ideal gas with constant specific heats
Adiabatic compressor
Negligible K.E. & P.E.
Air properties: T_{avg} = 425 K, c_p = 1.0165 kJ/kg.K, k = 1.393
b) Adiabatic & reversible process = isentropic process
AIR
600 kPa, 277°C
95 kPa, 27°C
SAMSUNG
Local
Broadcast


GROUP
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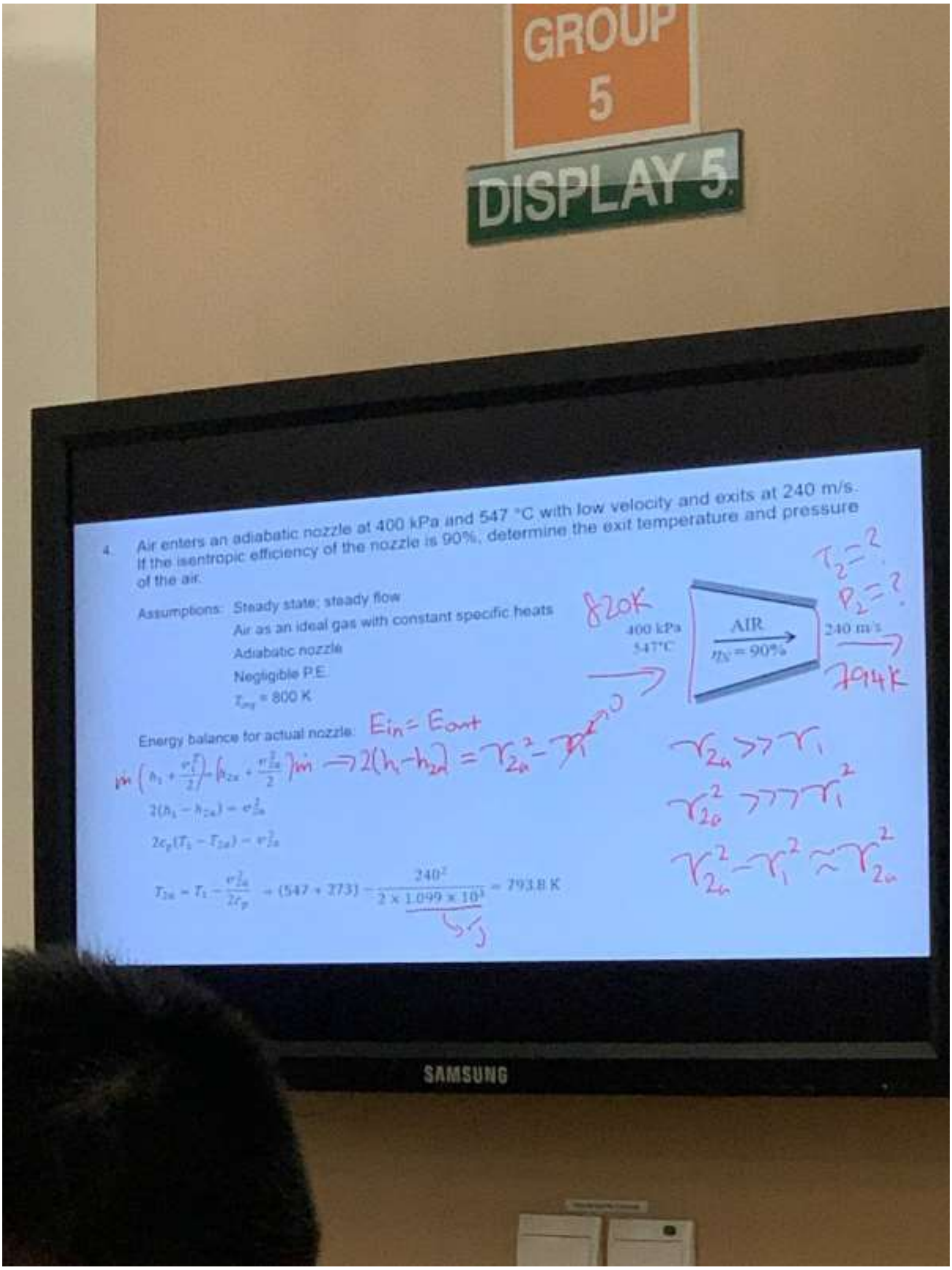
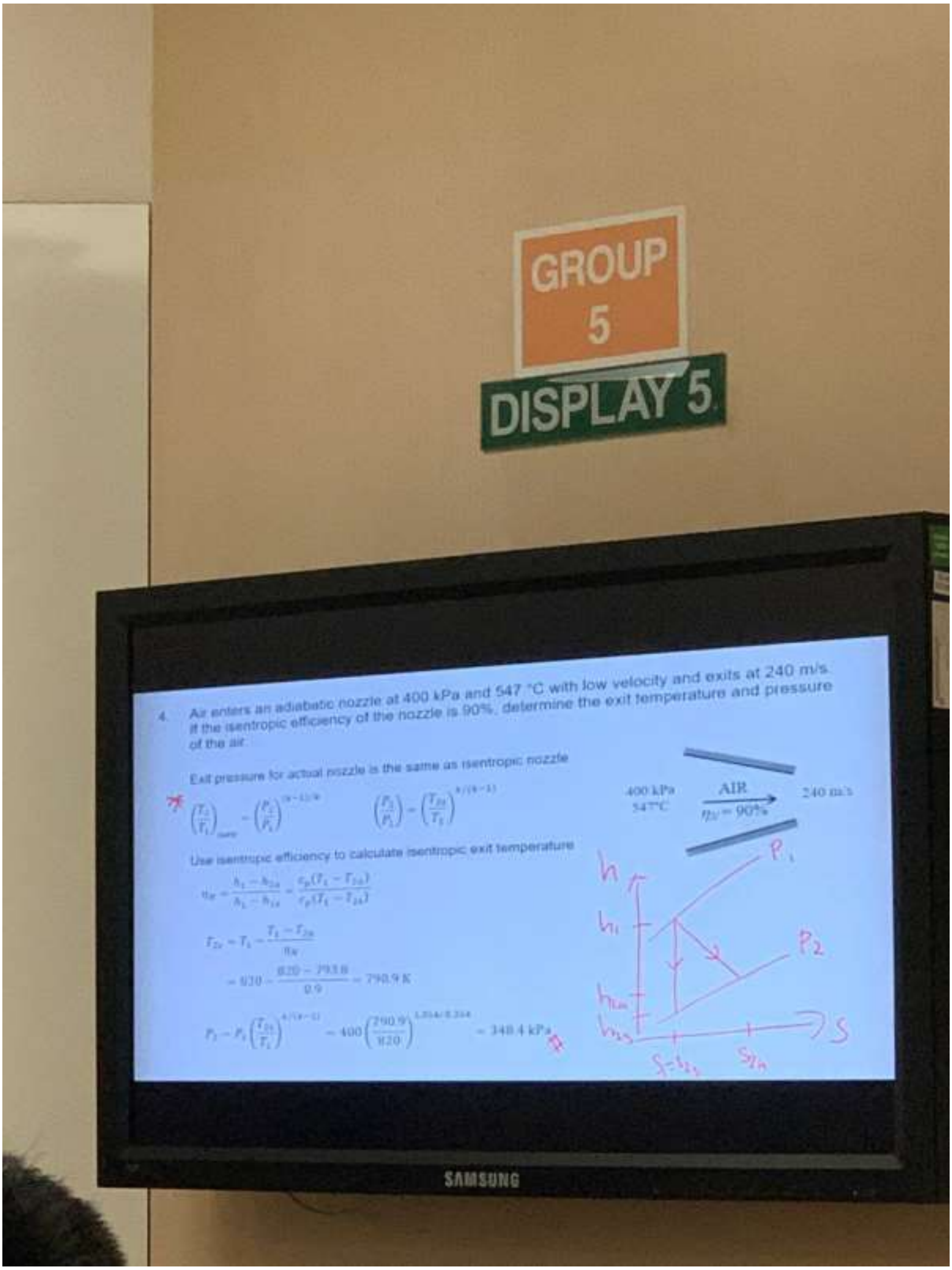
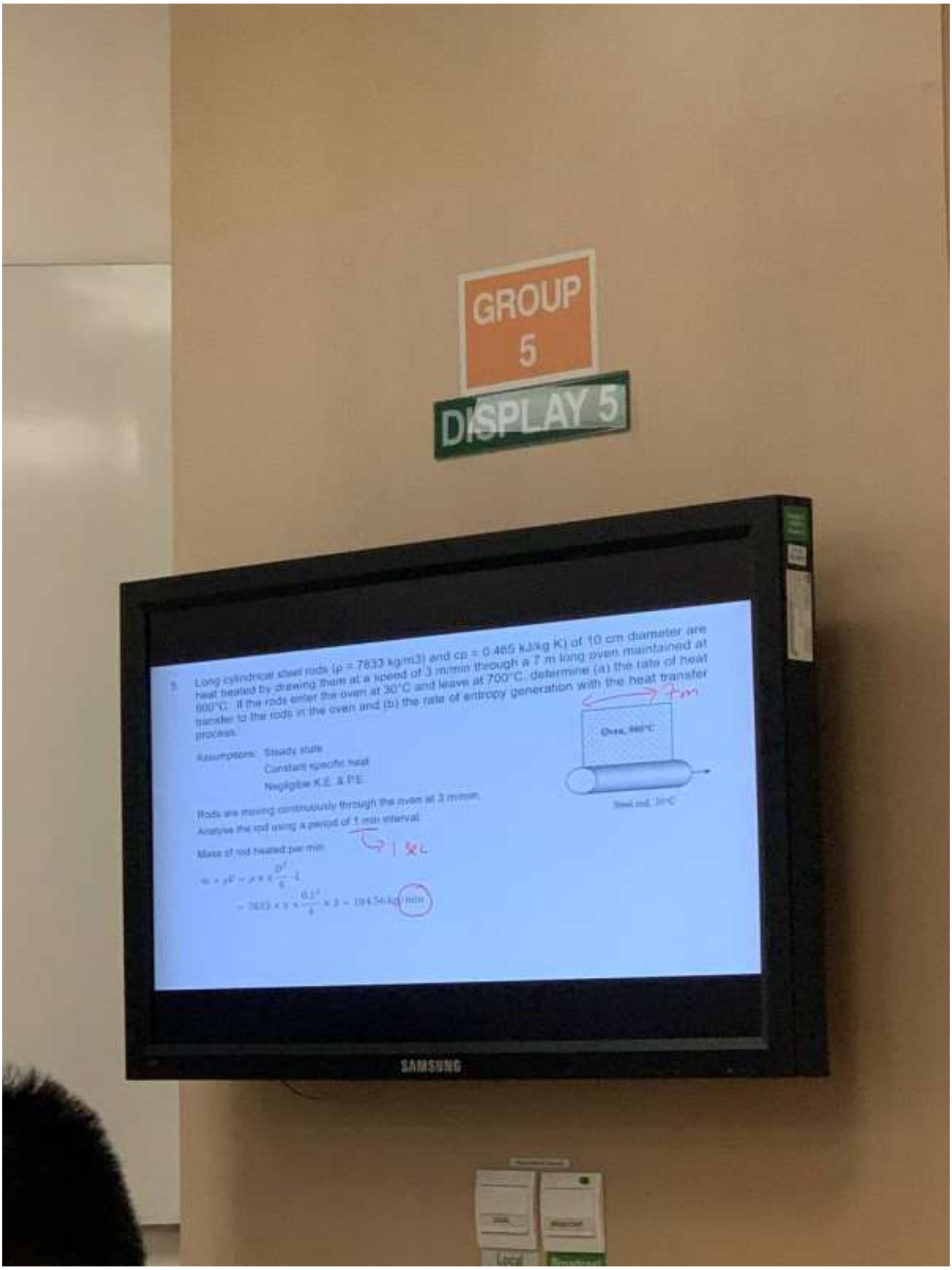
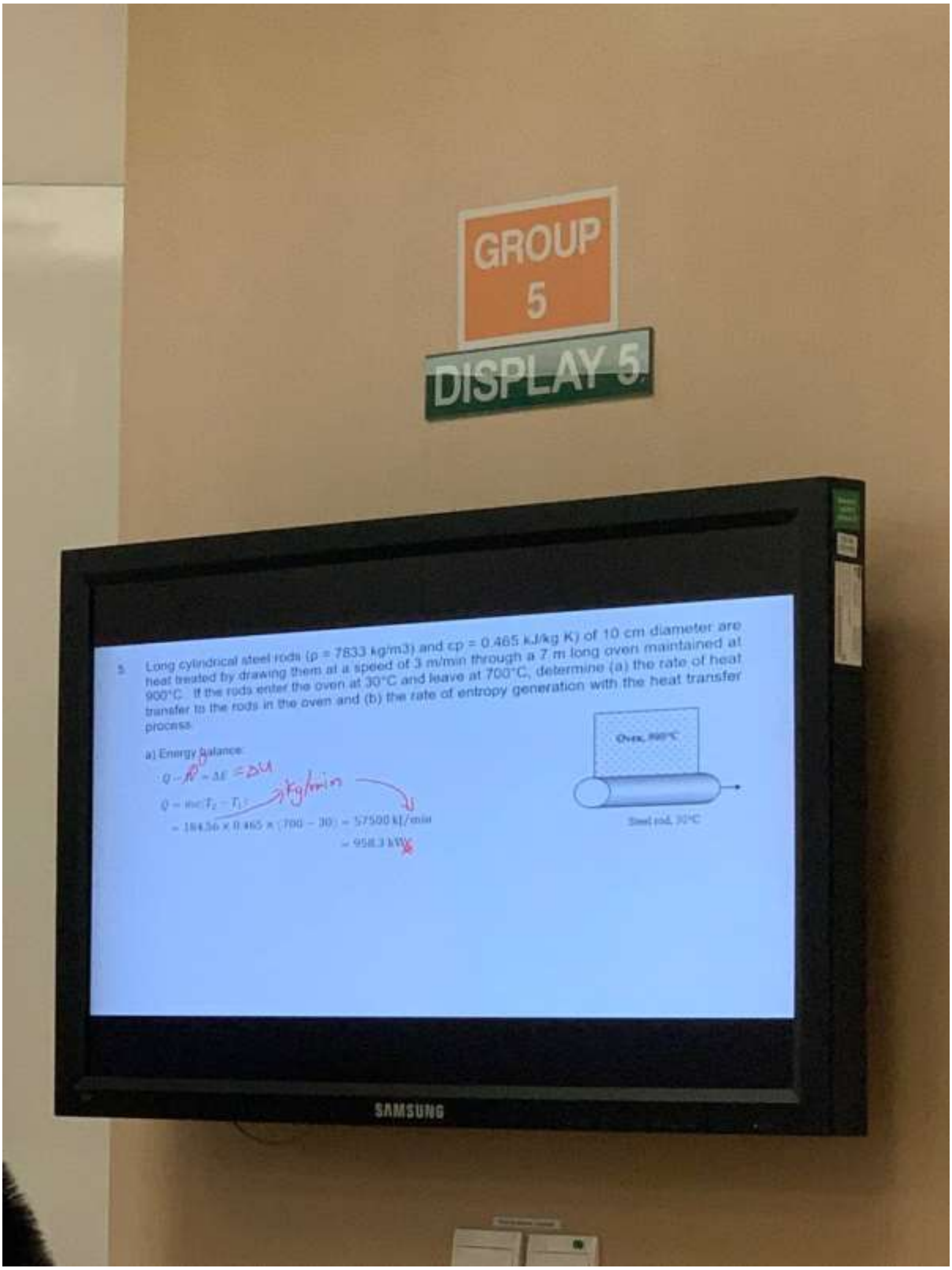
DISPLAY 5
Air is compressed by an adiabatic compressor from 95 kPa and 27°C to 600 kPa and 277°C. Assuming constant specific heats and neglecting the changes in kinetic and potential energies, determine (a) the isentropic efficiency of the compressor and (b) the exit temperature of air if the process were reversible.
600 kPa, 277°C
AIR
Repeat calculation with new
a) Isentropic efficiency
95 kPa, 27°C
h
S
SAMSUNG
Local
Broadcast

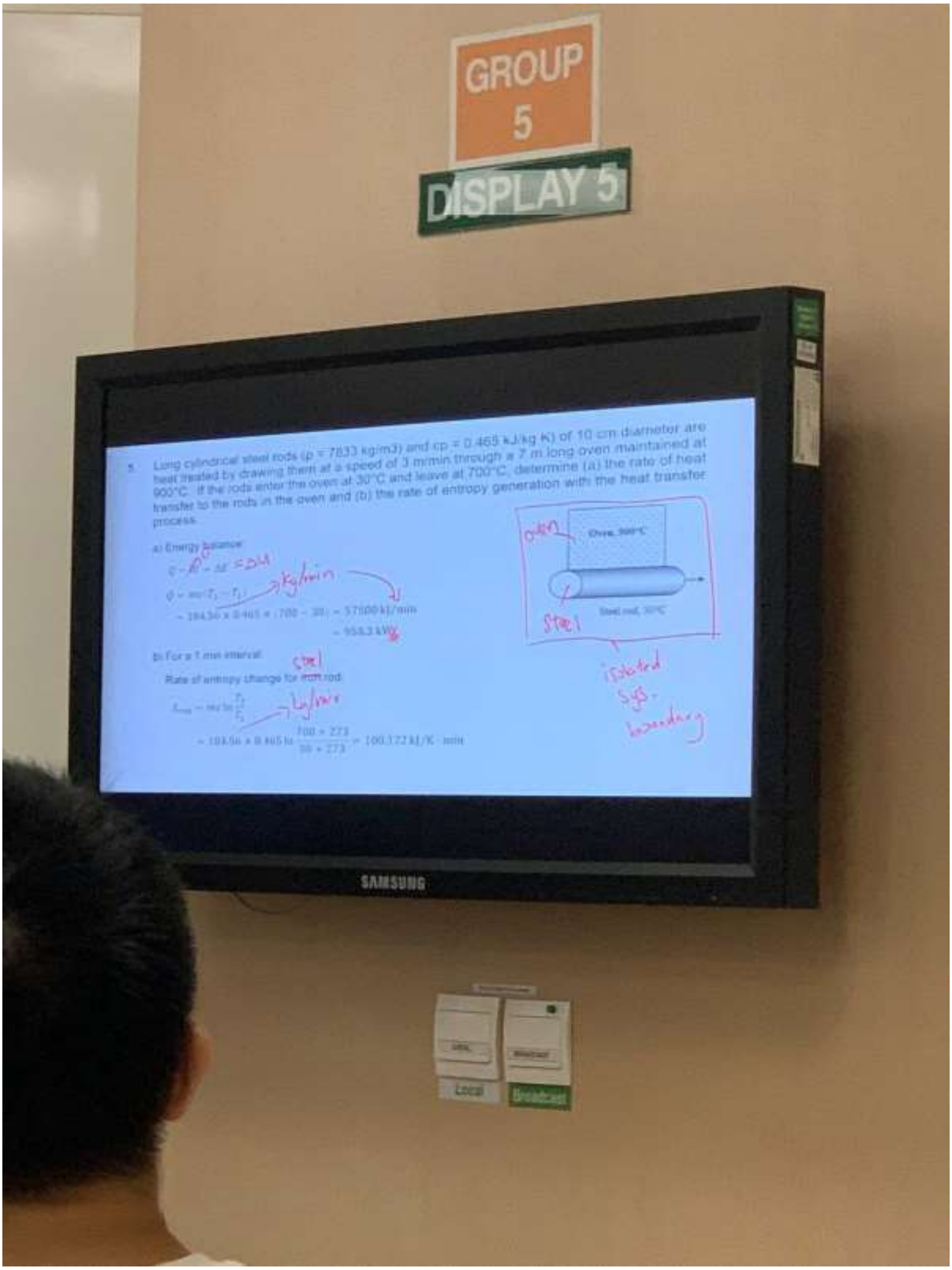

GROUP
5
DISPLAY 5
4. Air enters an adiabatic nozzle at 400 kPa and 547 °C with low velocity and exits at 240 m/s. If the isentropic efficiency of the nozzle is 90%, determine the exit temperature and pressure of the air.
Assumptions: Steady state; steady flow
Air as an ideal gas with constant specific heats
Adiabatic nozzle
Negligible P.E.
$T_{avg} = 800$ K
Energy balance for actual nozzle: $E_{in} = E_{out}$
$\dot{m}\left(h_1 + \frac{v_1^2}{2}\right) = \left(h_{2a} + \frac{v_{2a}^2}{2}\right)\dot{m} \Rightarrow 2(h_1 - h_{2a}) = v_{2a}^2 - \cancel{v_1^2}^{\,0}$
$2(h_1 - h_{2a}) = v_{2a}^2$
$2c_p(T_1 - T_{2a}) = v_{2a}^2$
$T_{2a} = T_1 - \frac{v_{2a}^2}{2c_p} = (547 + 273) - \frac{240^2}{2 \times 1.099 \times 10^3} = 793.8$ K
kJ
820K
400 kPa
547°C
AIR
$\eta_N = 90\%$
240 m/s
794K
$T_2 = ?$
$P_2 = ?$
$v_{2a} >> v_1$
$v_{2a}^2 >>> v_1^2$
$v_{2a}^2 - v_1^2 \approx v_{2a}^2$
SAMSUNG

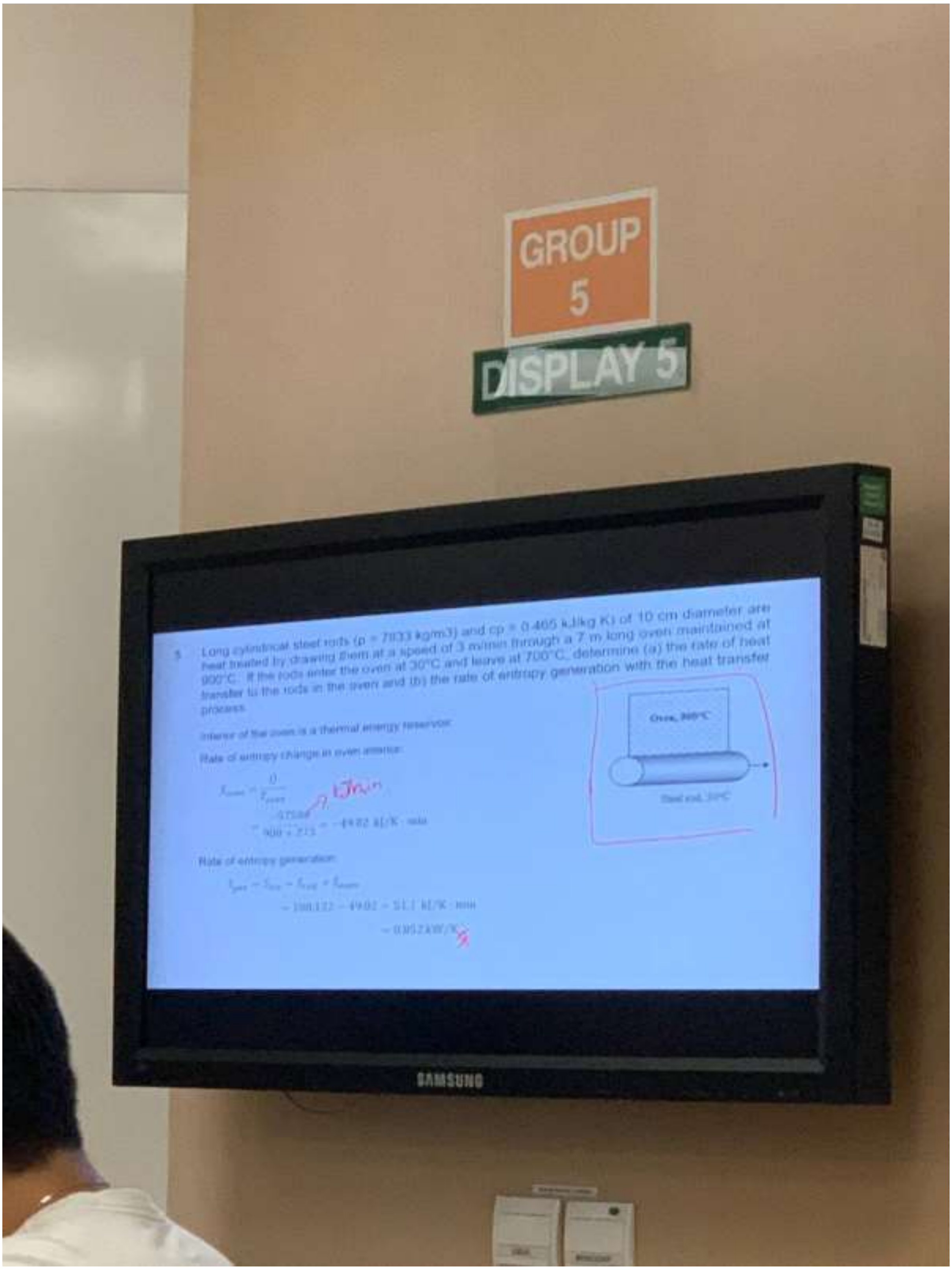


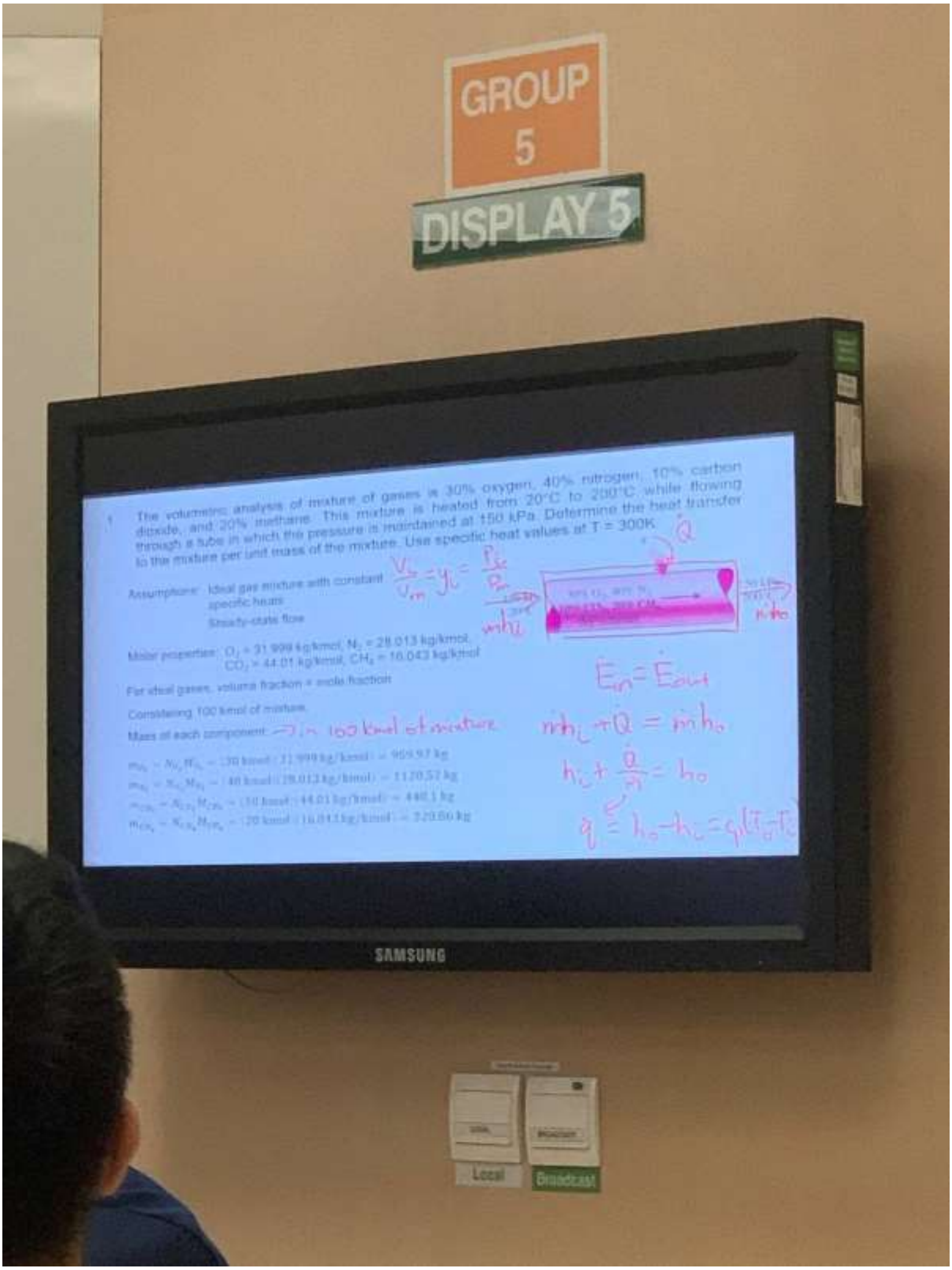
GROUP
5
DISPLAY 5
4. Air enters an adiabatic nozzle at 400 kPa and 547 °C with low velocity and exits at 240 m/s. If the isentropic efficiency of the nozzle is 90%, determine the exit temperature and pressure of the air.
Exit pressure for actual nozzle is the same as isentropic nozzle
Use isentropic efficiency to calculate isentropic exit temperature
= 790.9 K
= 348.4 kPa
400 kPa
547°C
AIR
240 m/s
P1
P2
h
h1
s
SAMSUNG

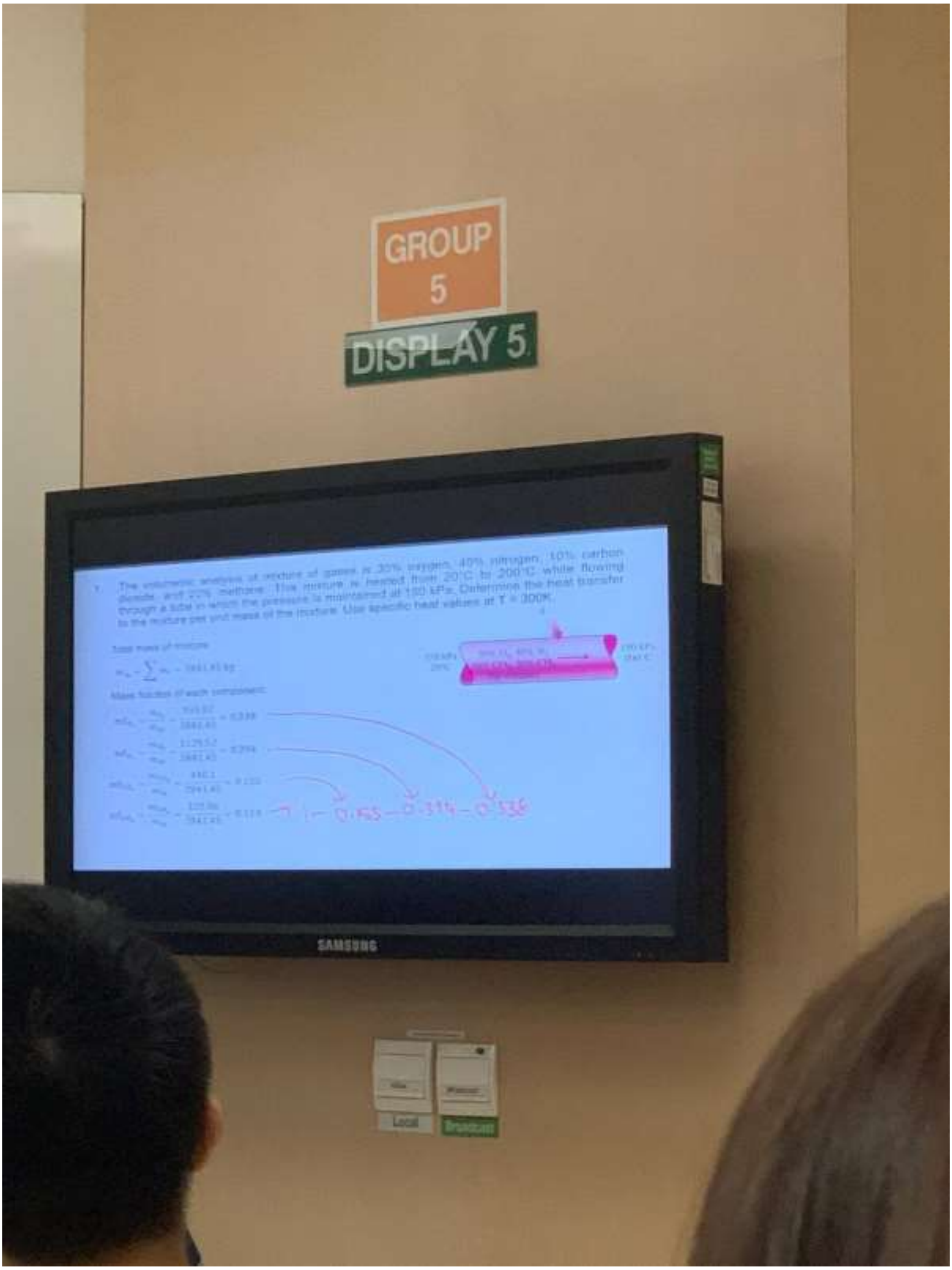

GROUP
5
DISPLAY 5
5. Long cylindrical steel rods (ρ = 7833 kg/m3) and cp = 0.465 kJ/kg K) of 10 cm diameter are heat treated by drawing them at a speed of 3 m/min through a 7 m long oven maintained at 900°C. If the rods enter the oven at 30°C and leave at 700°C, determine (a) the rate of heat transfer to the rods in the oven and (b) the rate of entropy generation with the heat transfer process.
7m
Assumptions: Steady state
Constant specific heat
Negligible K.E. & P.E.
Rods are moving continuously through the oven at 3 m/min.
Analyse the rod using a period of 1 min interval.
1 sec
Mass of rod treated per min
SAMSUNG

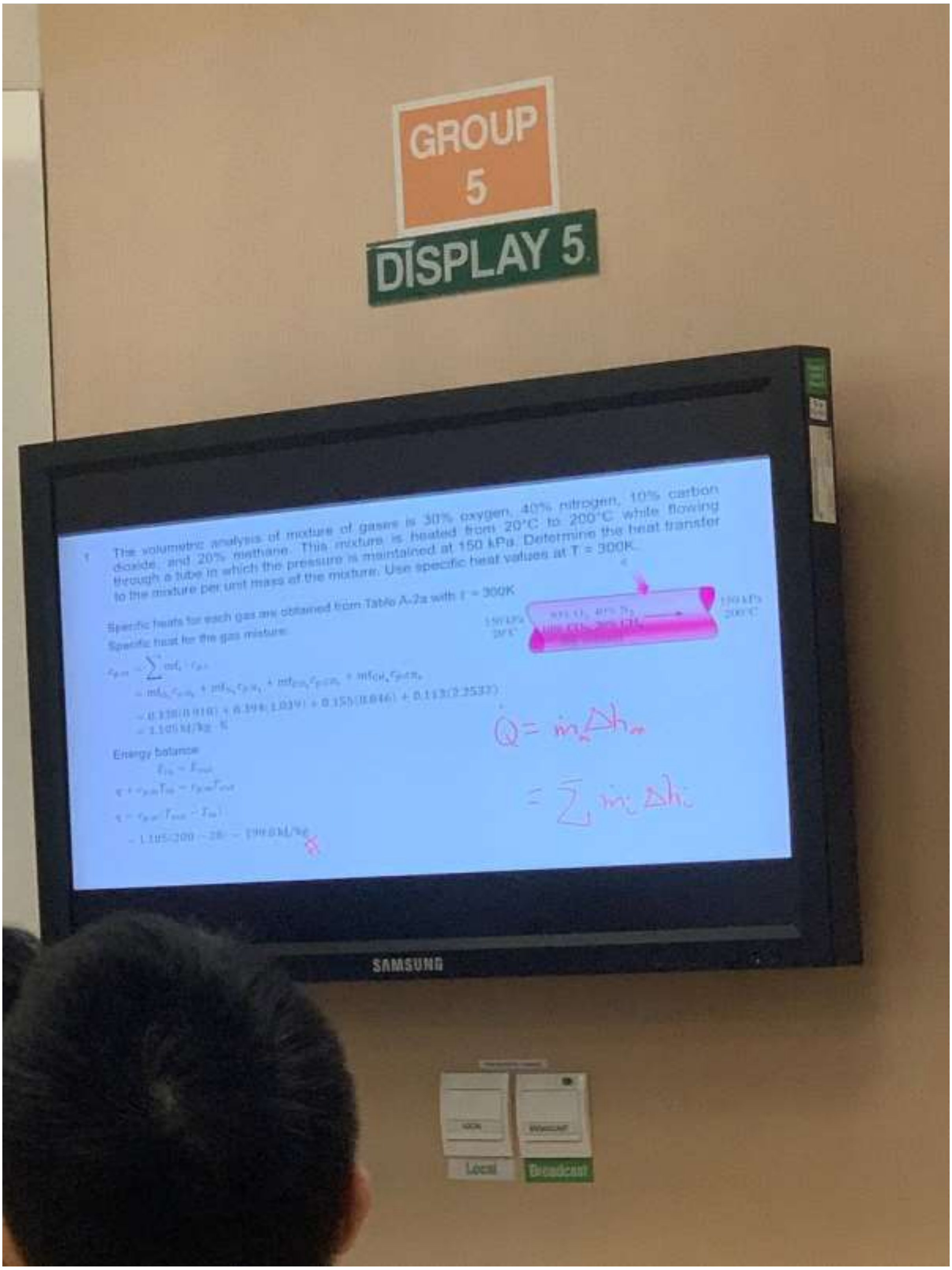

GROUP
5
DISPLAY 5
5. Long cylindrical steel rods (ρ = 7833 kg/m3) and cp = 0.465 kJ/kg K) of 10 cm diameter are heat treated by drawing them at a speed of 3 m/min through a 7 m long oven maintained at 900°C. If the rods enter the oven at 30°C and leave at 700°C, determine (a) the rate of heat transfer to the rods in the oven and (b) the rate of entropy generation with the heat transfer process.
a) Energy balance:
= ΔU
kg/min
= 57500 kJ/min
= 958.3 kW
SAMSUNG


GROUP 5
DISPLAY 5
5. Long cylindrical steel rods (ρ = 7833 kg/m3) and cp = 0.465 kJ/kg K) of 10 cm diameter are heat treated by drawing them at a speed of 3 m/min through a 7 m long oven maintained at 900°C. If the rods enter the oven at 30°C and leave at 700°C, determine (a) the rate of heat transfer to the rods in the oven and (b) the rate of entropy generation with the heat transfer process.
a) Energy balance
kg/min
= 57500 kJ/min
= 958.3 kW
b) For a 1 min interval
steel
Rate of entropy change for rod
kg/min
= 100.172 kJ/K · min
oven
steel
isolated sys. boundary
SAMSUNG
Local
Broadcast


GROUP
5
DISPLAY 5
5 Long cylindrical steel rods (ρ = 7833 kg/m3) and cp = 0.465 kJ/kg K) of 10 cm diameter are heat treated by drawing them at a speed of 3 m/min through a 7 m long oven maintained at 900°C. If the rods enter the oven at 30°C and leave at 700°C, determine (a) the rate of heat transfer to the rods in the oven and (b) the rate of entropy generation with the heat transfer process.
Interior of the oven is a thermal energy reservoir.
Rate of entropy change in oven interior:
kJ/min
= −49.82 kJ/K · min
Rate of entropy generation:
= 51.1 kJ/K · min
SAMSUNG


GROUP
5
DISPLAY 5
The volumetric analysis of mixture of gases is 30% oxygen, 40% nitrogen, 10% carbon
dioxide, and 20% methane. This mixture is heated from 20°C to 200°C while flowing
through a tube in which the pressure is maintained at 150 kPa. Determine the heat transfer
to the mixture per unit mass of the mixture. Use specific heat values at T = 300K
Assumptions: Ideal gas mixture with constant specific heats
Steady-state flow
Molar properties: O2 = 31.999 kg/kmol, N2 = 28.013 kg/kmol, CO2 = 44.01 kg/kmol, CH4 = 16.043 kg/kmol
For ideal gases, volume fraction = mole fraction
Considering 100 kmol of mixture
Mass of each component
Ein = Eout
SAMSUNG
Local
Broadcast


GROUP
5
DISPLAY 5
SAMSUNG


GROUP
5
DISPLAY 5
The volumetric analysis of mixture of gases is 30% oxygen, 40% nitrogen, 10% carbon dioxide, and 20% methane. This mixture is heated from 20°C to 200°C while flowing through a tube in which the pressure is maintained at 150 kPa. Determine the heat transfer to the mixture per unit mass of the mixture. Use specific heat values at T = 300K.
Specific heats for each gas are obtained from Table A-2a with T = 300K
Specific heat for the gas mixture
Energy balance
Q = m Δh
= Σ mᵢ Δhᵢ
SAMSUNG
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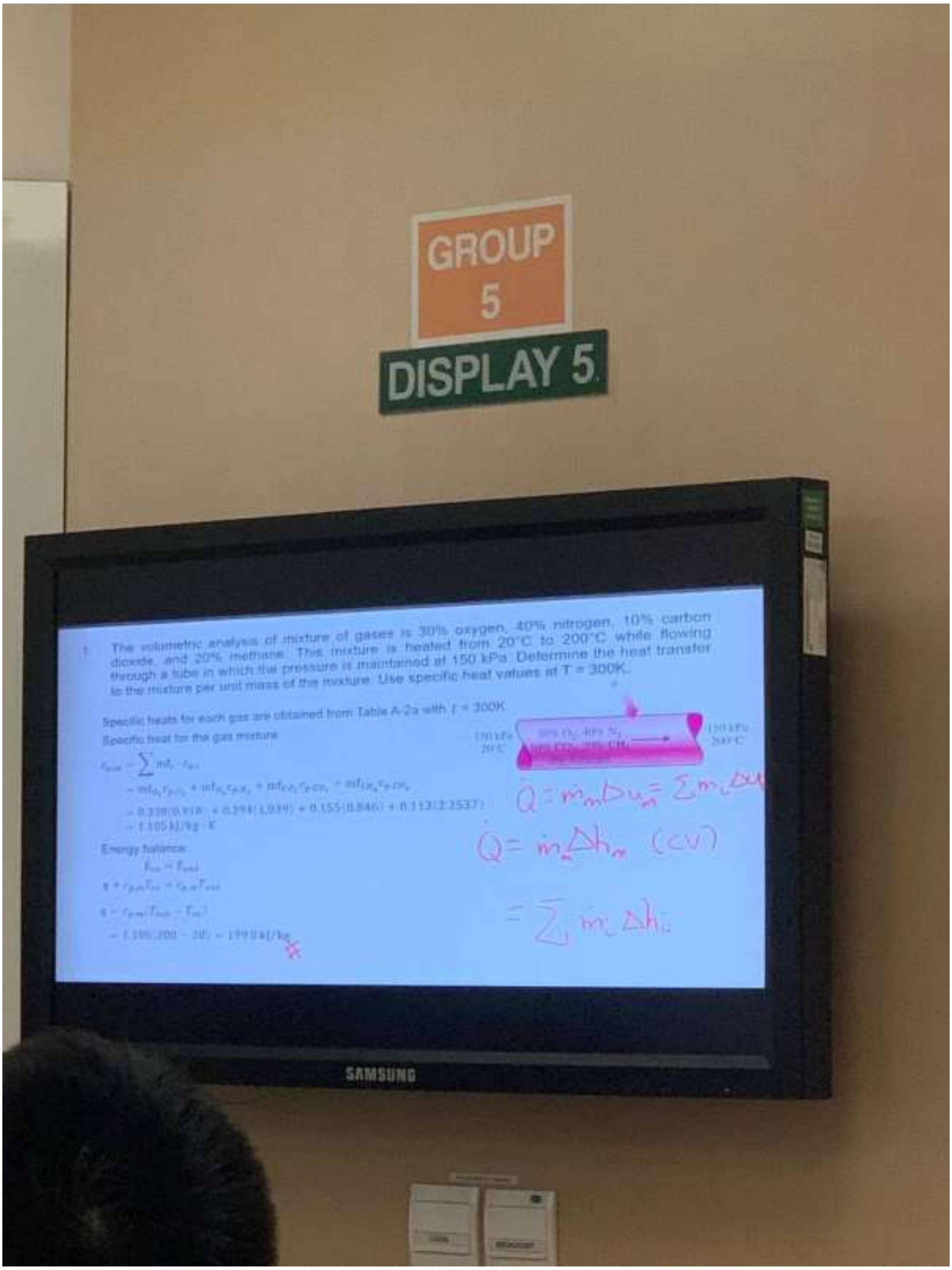
GROUP 5
DISPLAY 5
1. The volumetric analysis of mixture of gases is 30% oxygen, 40% nitrogen, 10% carbon dioxide, and 20% methane. This mixture is heated from 20°C to 200°C while flowing through a tube in which the pressure is maintained at 150 kPa. Determine the heat transfer to the mixture per unit mass of the mixture. Use specific heat values at T = 300K.
Specific heats for each gas are obtained from Table A-2a with T = 300K
Specific heat for the gas mixture
= 0.155(0.846)
Energy balance
$\dot{Q} = \dot{m}_m \Delta u_m = \sum m_i \Delta u$
$\dot{Q} = \dot{m}_m \Delta h_m$ (CV)
$= \sum \dot{m}_i \Delta h_i$
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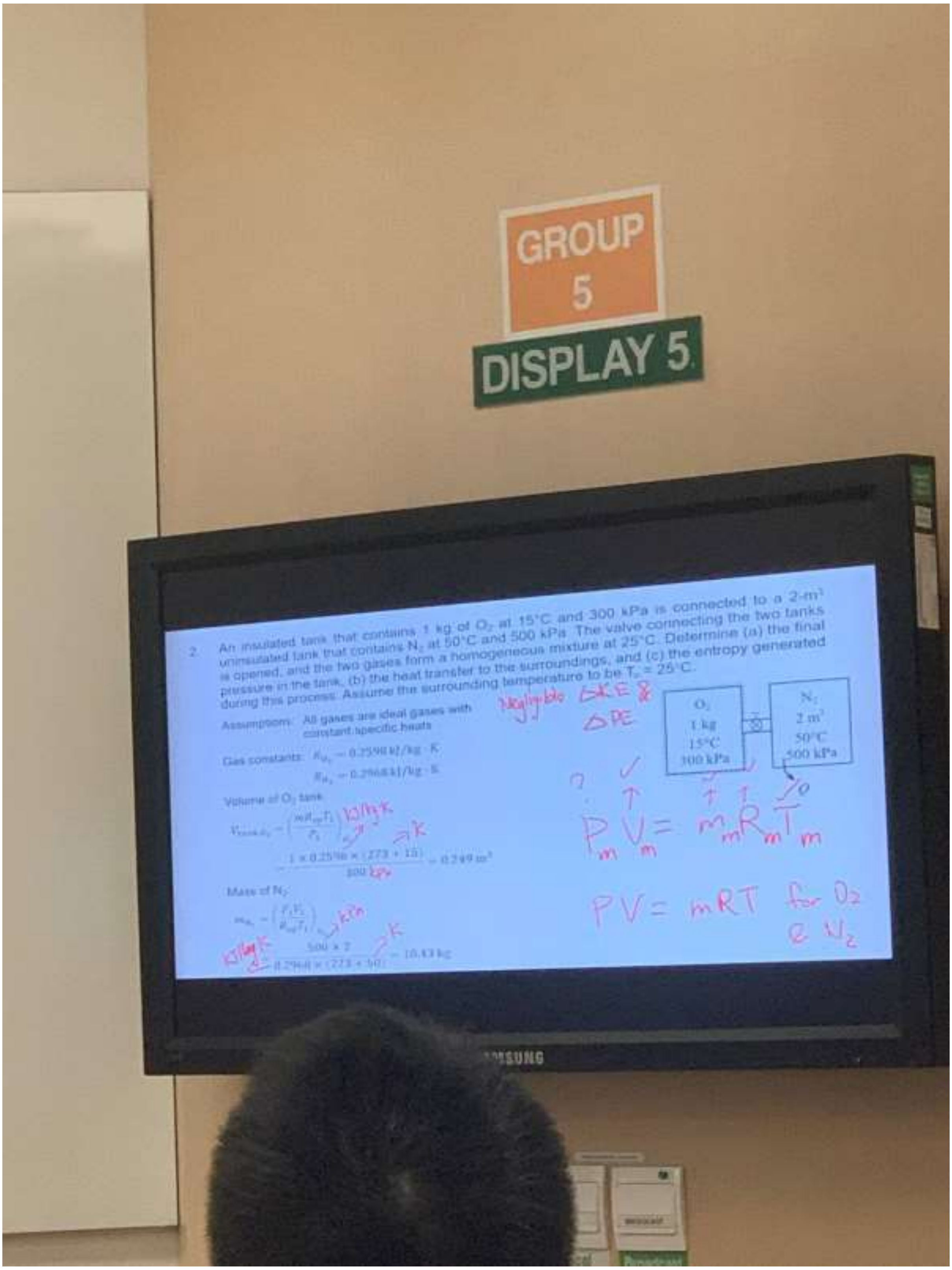
GROUP
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2. An insulated tank that contains 1 kg of O2 at 15°C and 300 kPa is connected to a 2-m3 uninsulated tank that contains N2 at 50°C and 500 kPa. The valve connecting the two tanks is opened, and the two gases form a homogeneous mixture at 25°C. Determine (a) the final pressure in the tank, (b) the heat transfer to the surroundings, and (c) the entropy generated during this process. Assume the surrounding temperature to be T0 = 25°C.
Assumptions: All gases are ideal gases with constant specific heats
Gas constants:
Volume of O2 tank
Mass of N2
Negligible ΔKE & ΔPE
O2
1 kg
15°C
300 kPa
N2
2 m3
50°C
500 kPa
PmVm = mmRmTm
PV = mRT for O2 & N2
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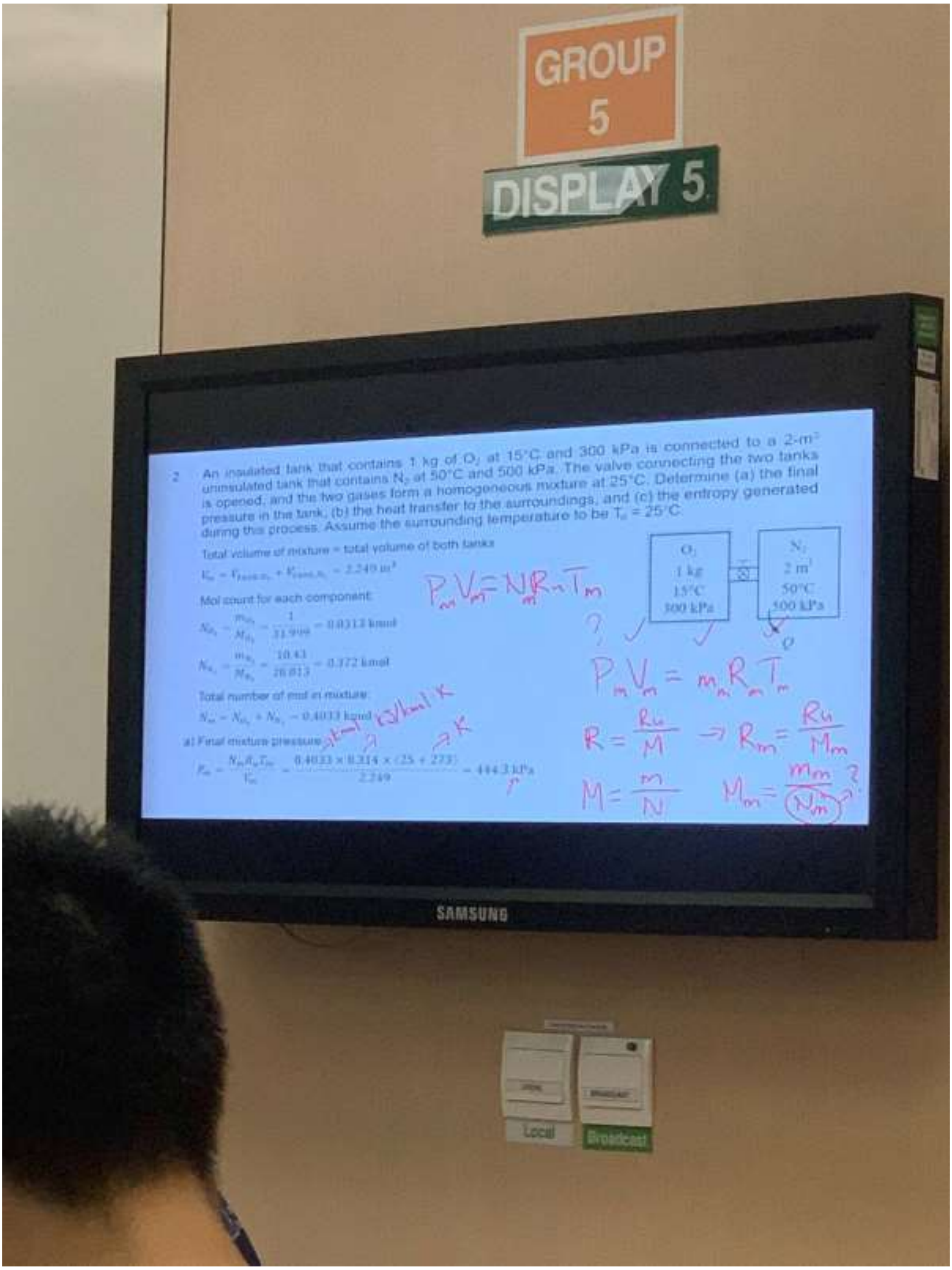

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2 An insulated tank that contains 1 kg of O_2 at 15°C and 300 kPa is connected to a 2-m³ uninsulated tank that contains N_2 at 50°C and 500 kPa. The valve connecting the two tanks is opened, and the two gases form a homogeneous mixture at 25°C. Determine (a) the final pressure in the tank, (b) the heat transfer to the surroundings, and (c) the entropy generated during this process. Assume the surrounding temperature to be T_0 = 25°C.
Total volume of mixture = total volume of both tanks
Mol count for each component
$N_{N_2} = \frac{m_{N_2}}{M_{N_2}} = \frac{10.43}{28.013} = 0.372$ kmol
Total number of mol in mixture
$N_m = N_{O_2} + N_{N_2} = 0.4033$ kmol
a) Final mixture pressure
$P_m = \frac{N_m R_u T_m}{V_m} = \frac{0.4033 \times 8.314 \times (25+273)}{2.249} = 444.3$ kPa
O_2 1 kg 15°C 300 kPa
N_2 2 m³ 50°C 500 kPa
$P_m V_m = N_m R_u T_m$
$P_m V_m = m_m R_m T_m$
$R = \frac{R_u}{M} \rightarrow R_m = \frac{R_u}{M_m}$
$M = \frac{m}{N}$
$M_m = \frac{m_m}{N_m}$?
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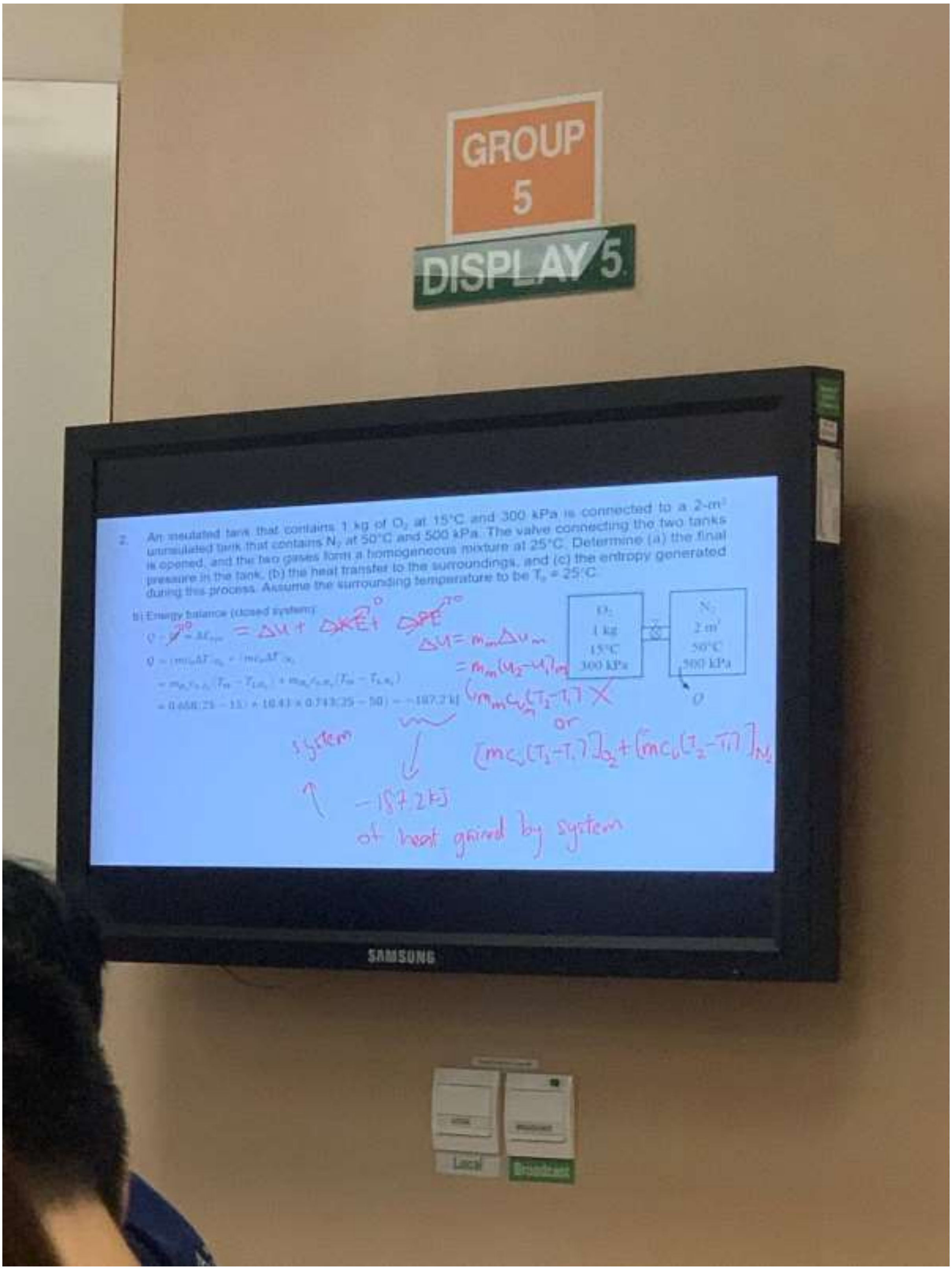
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b) Energy balance (closed system)
$= \Delta U + \Delta KE + \Delta PE$
$\Delta U = m_m \Delta u_m$
$= m_m(u_2 - u_1)_m$
$(m_m c_{v_m}(T_2 - T_1))$
or
$[mc_v(T_2 - T_1)]_{O_2} + [mc_v(T_2 - T_1)]_{N_2}$
O_2
1 kg
15°C
300 kPa
N_2
2 m³
50°C
500 kPa
Q
system
−187.2 kJ
of heat gained by system
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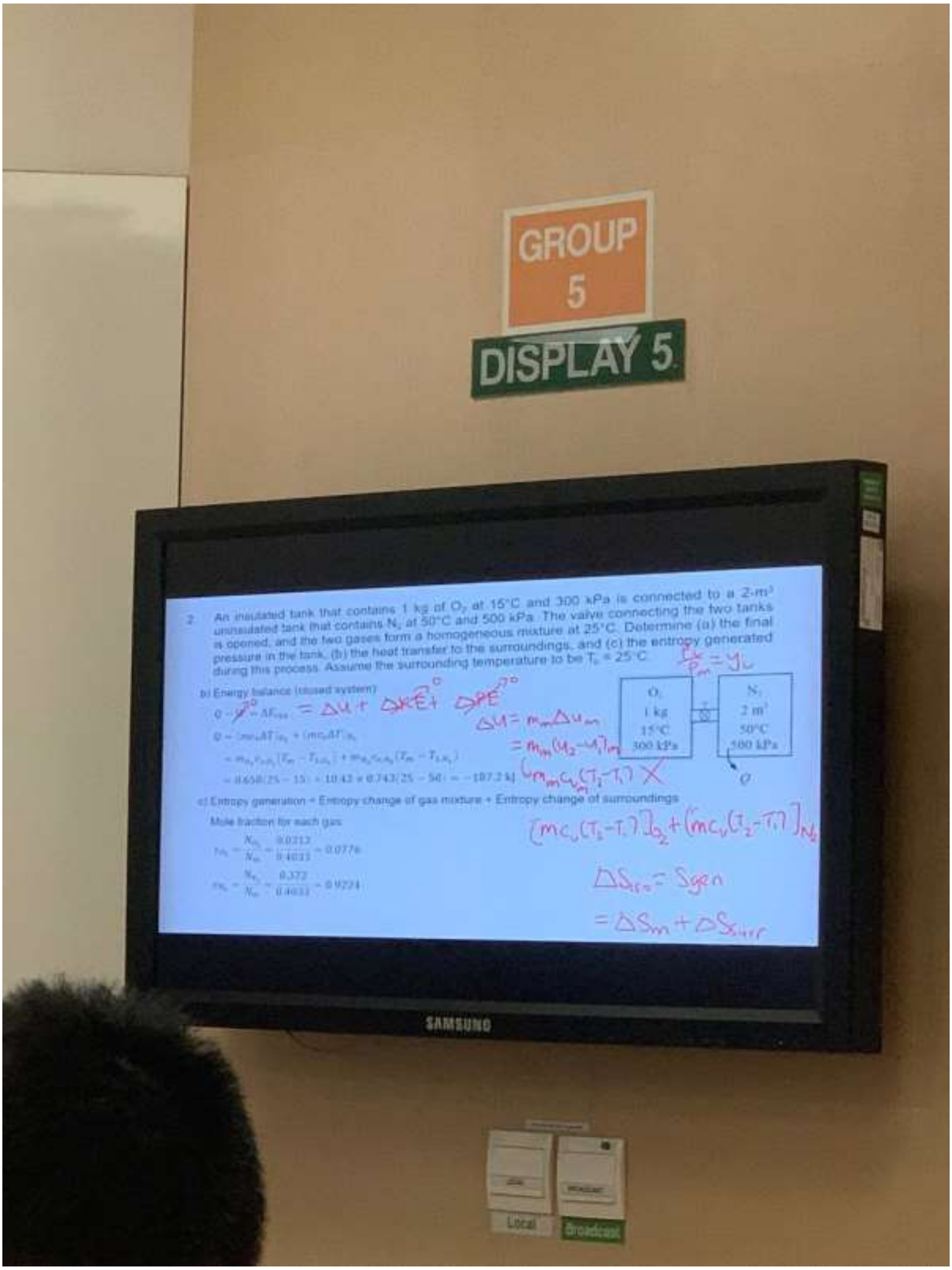
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b) Energy balance (closed system)
= ΔU + ΔKE + ΔPE
ΔU = mm Δum
= mm (u2 − u1)m
(mm cvm (T2 − T1)) X
= 0.658(25 − 15) + 10.42 × 0.743(25 − 50) = −187.2 kJ
c) Entropy generation = Entropy change of gas mixture + Entropy change of surroundings
Mole fraction for each gas
0.0313 / 0.4033 = 0.0776
0.372 / 0.4033 = 0.9224
[mcv(T2 − T1)]O2 + [mcv(T2 − T1)]N2
ΔSsys = Sgen
= ΔSm + ΔSsurr
O2
1 kg
15°C
300 kPa
N2
2 m³
50°C
500 kPa
Q
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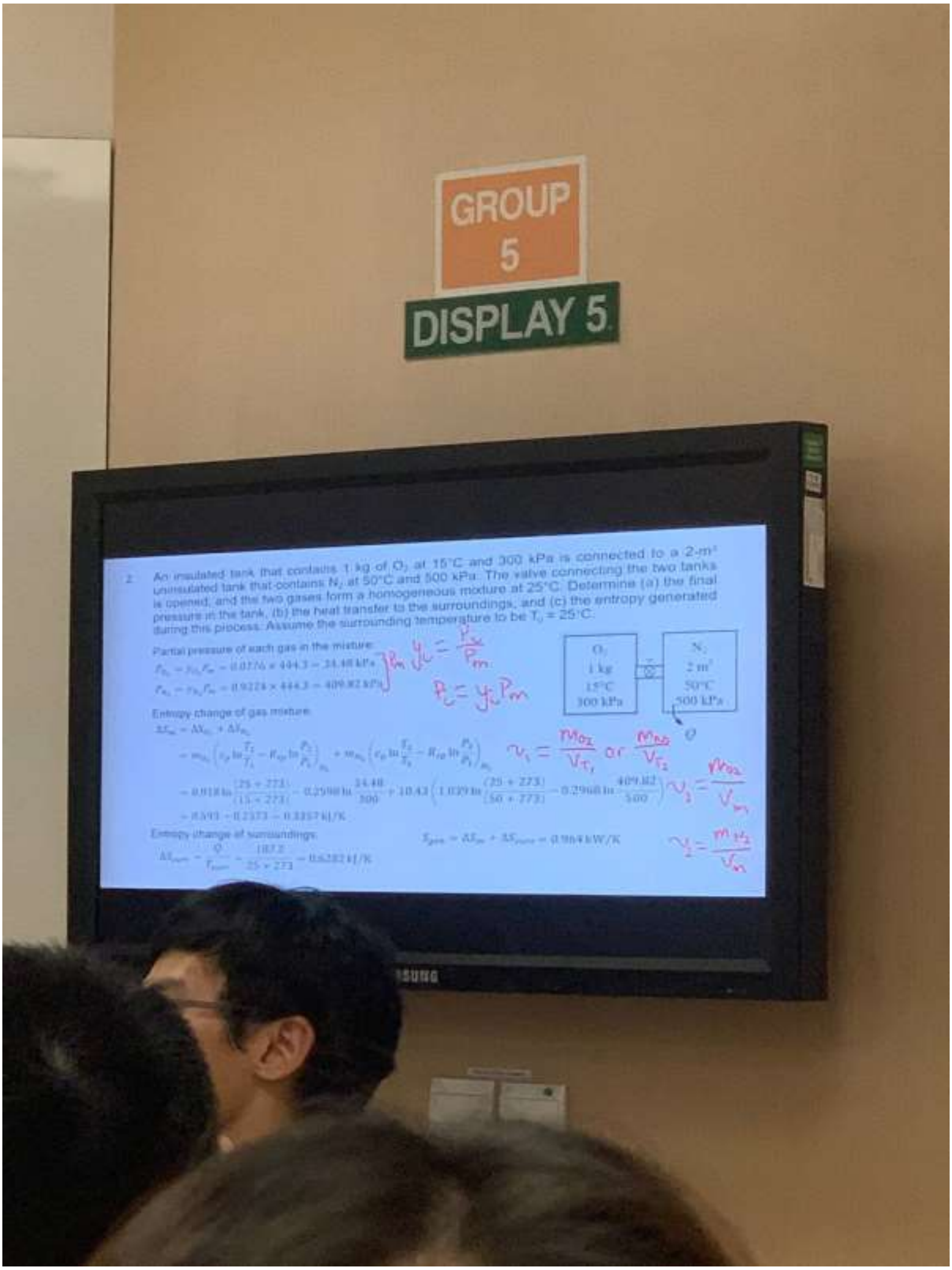

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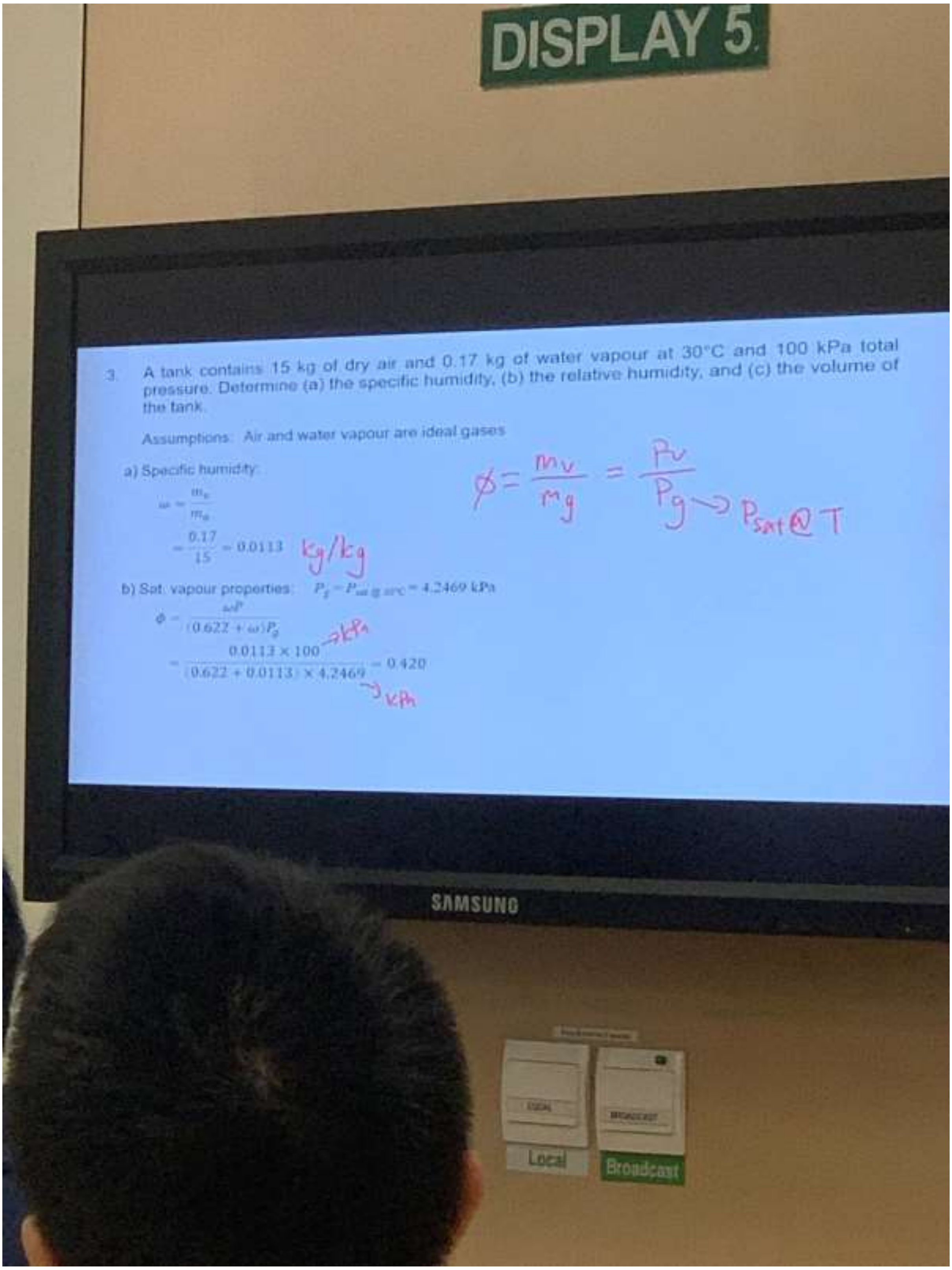
Partial pressure of each gas in the mixture:
Entropy change of gas mixture:
Entropy change of surroundings:
O2
1 kg
15°C
300 kPa
N2
2 m³
50°C
500 kPa
Q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3. A tank contains 15 kg of dry air and 0.17 kg of water vapour at 30°C and 100 kPa total pressure. Determine (a) the specific humidity, (b) the relative humidity, and (c) the volume of the tank.
Assumptions: Air and water vapour are ideal gases
a) Specific humidity:
$\omega = \frac{m_v}{m_a} = \frac{0.17}{15} = 0.0113$ kg/kg
$\phi = \frac{m_v}{m_g} = \frac{P_v}{P_g} \rightarrow P_{sat@T}$
b) Sat. vapour properties: $P_g = P_{sat@30°C} = 4.2469$ kPa
$\phi = \frac{\omega P}{(0.622 + \omega)P_g} = \frac{0.0113 \times 100}{(0.622 + 0.0113) \times 4.2469} = 0.420$
kPa
kPa
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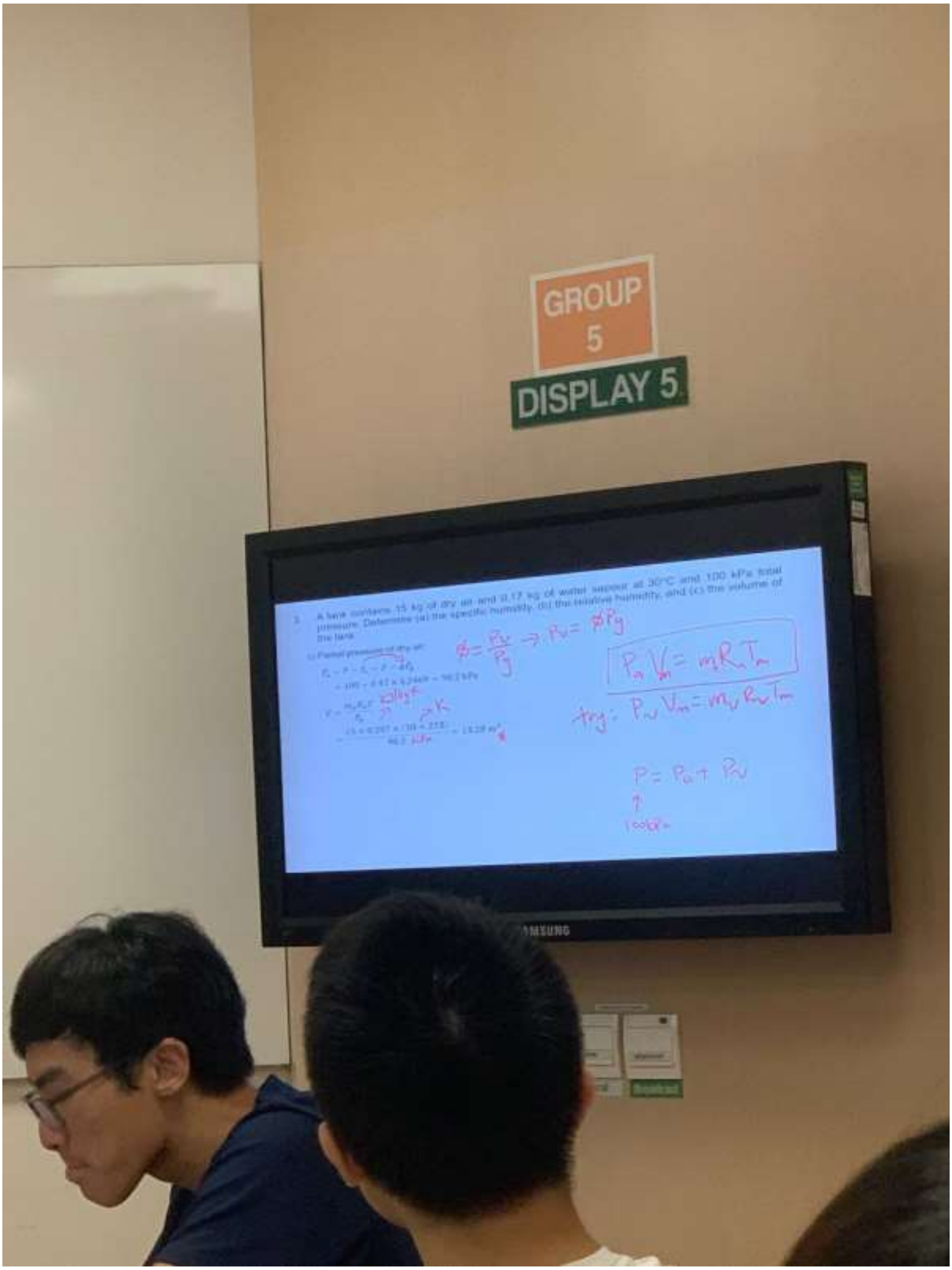
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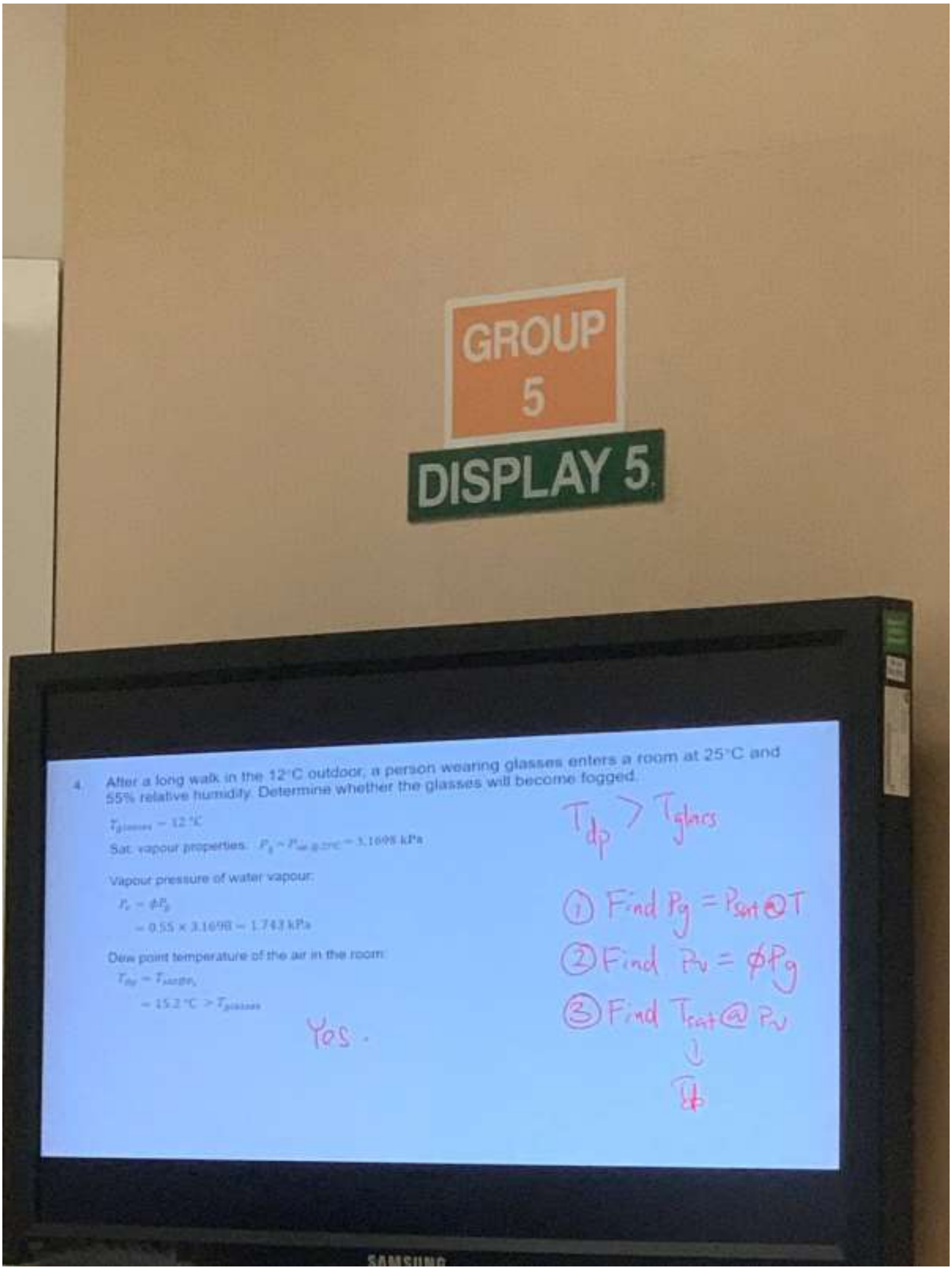
P = Pa + Pv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4. After a long walk in the 12°C outdoor, a person wearing glasses enters a room at 25°C and 55% relative humidity. Determine whether the glasses will become fogged.
Sat. vapour properties:
Vapour pressure of water vapour:
= 0.55 × 3.1698 = 1.743 kPa
Dew point temperature of the air in the room:
= 15.2 °C
Yes.
Tdp > Tglass
① Find Pg = Psat @ T
② Find Pv = ϕPg
③ Find Tsat @ Pv
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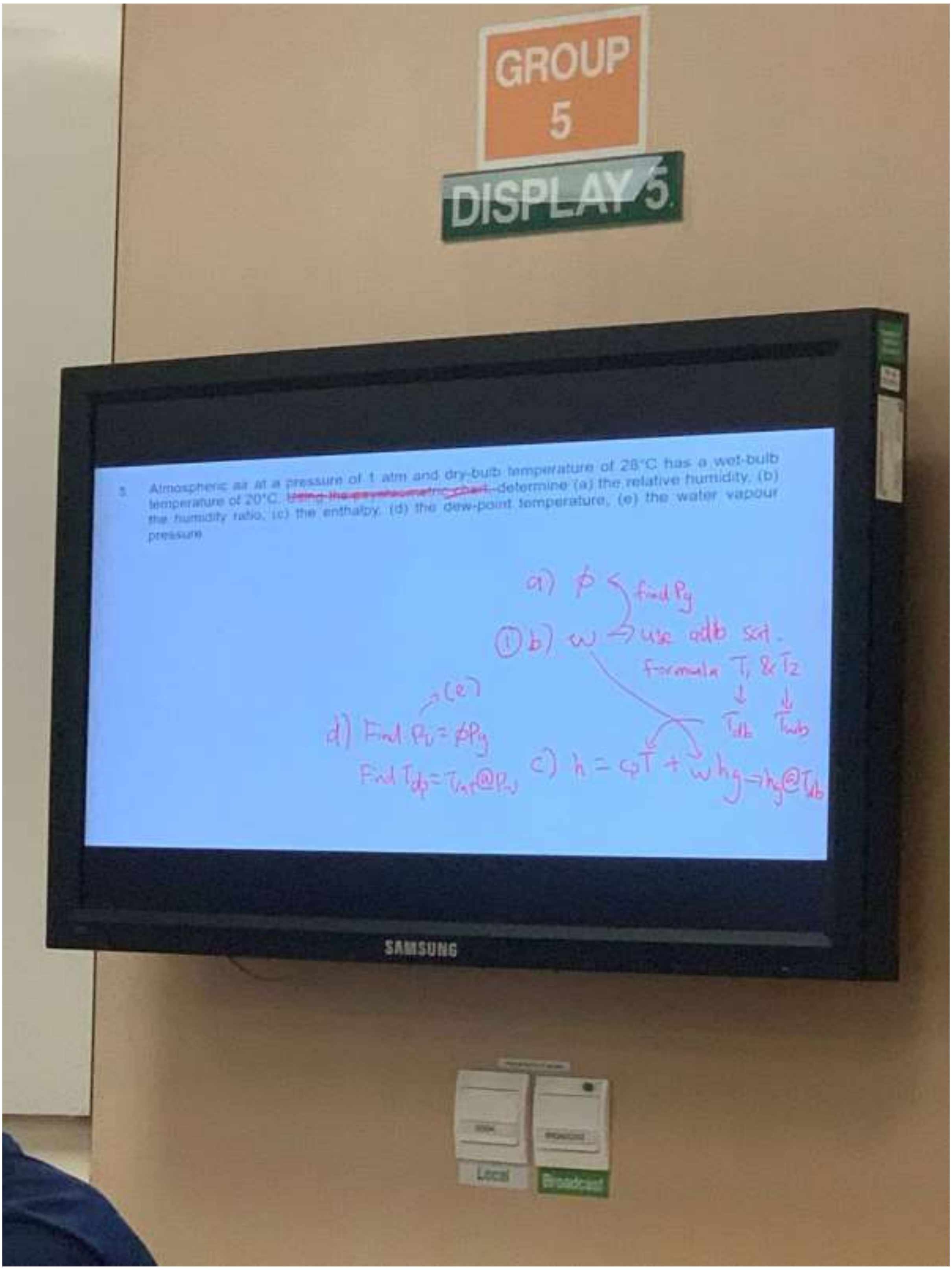
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5 Atmospheric air at a pressure of 1 atm and dry-bulb temperature of 28°C has a wet-bulb temperature of 20°C. ~~Using the psychrometric chart,~~ determine (a) the relative humidity, (b) the humidity ratio, (c) the enthalpy, (d) the dew-point temperature, (e) the water vapour pressure
a) ϕ find P_g
① b) ω use adb sat. formula T_1 & T_2
T_{db} T_{wb}
(e)
d) Find $P_v = \phi P_g$
Find $T_{dp} = T_{sat}@P_v$
c) $h = c_p T + \omega h_g$ $h_g @ T_{db}$
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